

pV magazine energy **storage**⁺

November 2018

Between the lines

As big battery installations proliferate across the United States, electric vehicle charging could provide a game changing solution

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Photo: pv magazine

Stored potential

Eight years ago, when I first began writing about the solar energy industry, we were on the cusp of explosive growth. However, there were still many questions to be answered, such as which technologies and policies would play the main role.

Today we are in a similar position as regards energy storage. In the last few quarters, deployment in the United States has started to take off sharply, particularly in the behind-the-meter segment. The nation has seen a shift in policies - most notably the Federal Energy Regulatory Commission's Order 841 - which appear to be paving the way for dramatic future growth.

But questions remain. Will lithium-ion technology continue to dominate stationary storage? (pp. 26-29) Will the installation of behind-the-meter batteries pencil out after incentives expire? How will shifting rate structures including a move to time-of-use rates affect this value proposition? There is also the question of how utilities are reacting to this new technology, and how they will integrate storage into their existing plans and processes (pp. 6-9).

And there are much deeper issues here as well. Many are predicating their vision for an expanded role of energy storage on continual cost reductions, but will lithium-ion costs continue to decline, and if

so by how much? (pp. 30-32). How will material supply limitations be overcome? Will electric vehicles be able to supply grid services en masse, and what will that look like in a future of high renewable energy penetration? (pp. 14-17) Who will pay for these services, and who will get paid?

I do not think that we will answer all of these questions in any one magazine edition. However within the pages of this special edition of **pv magazine**, produced in collaboration with Strategen and Messe Düsseldorf for the Energy Storage North America trade show, we will take a hard look at these topics and more. In doing so, we attempt to shed some light on some of the thornier issues of this most critical set of technologies for the global energy transition.

I am proud that **pv magazine** was able to assemble an all-star cast to take on this task, comprised of many of the names that you have come to know through the pv magazine USA site, as well as some highly respected hired guns, and knowledgeable voices from the investment and analyst world.

And with that I want to thank you, and wish you an enjoyable read.

Christian Roselund
Americas Editor



Photo: Salt River Project

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Financial planning for large-scale storage requires some new tools, but is far from impossible. U.S. utilities are up for the challenge.

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Photo: Amber Kinetics

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Putting on the investor's glasses to find a way through the jungle of choices and opportunities in storage.



Photo: pv magazine/Eckhart K. Gouras



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Photo: Redflow



Photo: Incolith

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What will the future hold for battery technologies?

30 Limits to lithium

Lithium commodity prices are highly volatile, but a stable market requires solid forecasting. Especially when investors look 2-3 years ahead to place their bids.

The momentum behind energy storage

Janice Lin of Strategen and CESA is the co-founder of Strategen Consulting, which helped to launch Energy Storage North America. *p.v.* magazine caught up with Lin ahead of the show to get her take on this rapidly growing industry, and what ESNA has to offer.

Energy storage deployment has been growing by leaps and bounds, but quantitative measurements always mask deeper changes. Can you give us your thoughts on the status of the industry?

California had the largest energy storage procurement in history this summer- over 560 MW- and yet I think we are really just ramping up and shifting into a new pace of momentum.

The first thing that is really different this year is that storage is now part of the key priorities of foundations and NGOs. You might have seen that the World Bank just announced a billion-dollar fund to help accelerate energy storage deployment in developing and middle-market countries.

Momentum has really picked up recently due to a number of underlying trends. One is an increasing need for flexibility to cope with changes in demand and changes in supply. Grid operators have to keep the grid in balance, and that's becoming a very challenging job now with the increased penetration of intermittent, low-cost renewables.

There are also changes in the nature of demand, including the electrification of transportation. It is making the demand side of the equation more unpredictable and harder to manage. Another key driver on the solutions side is the innovation and development and expansion of storage manufacturing capability, and the resulting lower costs.

Battery storage in particular is outpacing the cost reduction forecasts, riding on the heels of the EV market. As energy dense batteries come down in cost, it expands the potential suite of applications on the grid that are now cost effective.

Another solutions driver is the huge innovation in communications, controls, and data management that has created a much better way to operate this asset that is so flexible it can be put anywhere and perform multiple functions.

As co-founder and CEO of Strategen Consulting, you helped to launch the Energy Storage North America (ESNA) trade show. With so many trade shows to choose from, why should energy storage professionals choose this show?

ESNA is the place to go to learn, but more importantly to be inspired. We strive to attract the champions that are making the market happen. Our event is very international- last year we had 27 countries represented-and it represents the entire industry ecosystem.

ESNA is also one of the few shows where you can visit deployed energy storage projects on a site tour. This year we have eight tours ranging from a huge solar plus storage installation in the Mojave Desert to a pumped hydro plant. It's so inspiring to see that the future of energy storage is now.

Finally, we are a mission-driven event. We are the only conference and expo I know of that has a fellowship program for government employees. So if you work for government and you would like to learn about storage and you can't afford to go, you can apply to our fellowship program and come as our guest.

So when people talk about energy storage, they talk primarily about lithium-ion batteries. What are some of the other promising technologies that will be on display at the show?

We will exhibit an extremely diverse range of solutions, both in our expo and in our program. We will have everything from different types of battery, to thermal storage to seasonal bulk storage solutions, as well as exploring the role of the gas sector and utilizing gas infrastructure to store green hydrogen, and hydrogen as an effective storage medium.

I myself am very excited to visit the Innovation Pavilion at ESNA, where we will have a collection of the hottest energy storage start-ups sharing their technologies and business models.

Interview with Christian Roselund



Photo: Strategen Consulting

“For this type of event, California is the place to be”

Tom Mitchell is the President of Messe Düsseldorf North America. Here, he talks about coming together with Strategen, and putting on an event that brings together players from all over the world, from up and down the energy storage value chain.

Can you talk about Messe Düsseldorf's relationship with the Energy Storage North America trade show?

Historically, we've organized events in the medical, packaging, printing, plastics, and machinery industries. A few years ago, we entered the energy storage field with the Energy Storage Europe event in Germany. We then began to look at other markets where storage is a topic of interest, and decided to pursue a United States-based conference.

And can you talk about how the Strategen/Messe Düsseldorf collaboration came about?

We became familiar with Strategen through our work in the industry. Upon our reaching out, they agreed that the energy storage industry was lacking a place where everyone could come together on a national scale. So, we decided to work together. Messe Düsseldorf brings trade show organizing expertise as well as experience from the Energy Storage Europe show, and Strategen brings its knowledge of the industry, as well as the connections needed to round up the top industry executives into one building year after year.

Among the many energy storage events, why is ESNA unique?

ESNA was among the first events that focused specifically on energy storage. Storage has started to appear at all kinds of energy-related events, but very few were solely focused on energy storage as the main topic.

California is the hot-bed of the U.S. energy storage industry. Legislation is being signed on a regular basis to continue bringing storage to the forefront of the state's energy transition. For this type of event, California is the place to be.

The show brings the entire storage value chain to one event. Manufacturers attend, but also utilities, stakeholders, system operators and the like. It is not just about showing equipment and talking about theory; this happens too, but companies meet to define business and deals actually happen.

What is the benefit of building a global storage community, and what role does the World of Energy Storage play in that?

The global reach of Messe Düsseldorf is one of the strengths that we bring to the table. We have subsidiaries in six different countries, and representatives all over the world. We've developed a global strategy: a German show for Europe, United States for North America, and events in India, China and Japan.

Exhibitors and attendees join ESNA from around the world. These companies come to learn about the U.S. market, and if they find that there is a big interest in their particular product from China, India, or elsewhere, then the World of Energy Storage provides them an opportunity to market that product on

a global scale. As the partnerships within the World of Energy Storage become stronger, opportunities for international collaboration and business development will improve and increase.

What do you see for the future of Messe Düsseldorf's involvement with energy storage?

We want to focus on the market players, and to mirror the transformation of the industry with high-quality speakers, attendees and conference content.

This year's ESNA conference has partnered with CALSTART, the nation's leading advanced transportation technologies consortium, as well as the Microgrid Global Innovation Forum. These co-located events will rally experts from the mobility and microgrid industry segments to provide a level of educational and networking opportunities that we've never before achieved. As the energy storage industry advances, we will continue to pursue strategic partnerships to ensure the quality of the ESNA event is the highest it can be.

Interview with Christian Roselund



Photo: Messe Düsseldorf

Planning for an uncertain future

Utility plans for battery storage lag well behind projections of the economic potential of storage. Yet utilities are taking on the planning challenge, which is marked by wide disagreement over the future cost of storage, the complexity of valuing storage, and the limitations of traditional planning models.

There is a major disconnect in storage planning. On the one hand, economic consultancy the Brattle Group has projected that the Federal Energy Regulatory Commission's Order 841 could spark profitable storage investments of up to 50 GW, if states unlock transmission and distribution benefits and the value of storage in reducing outages. For its part, the Energy Storage Association (ESA) has put forth a vision of 35 GW of U.S. energy storage by 2025, driven by

“evolving needs of the electric grid and market drivers that are powering rapid storage industry growth.”

But outside of a few coastal states with state-level storage targets, utilities are planning very little storage – less than three gigawatts, according to an ESA count as of last April, which is based on the integrated resource plans (IRPs) that are required of utilities in most states.

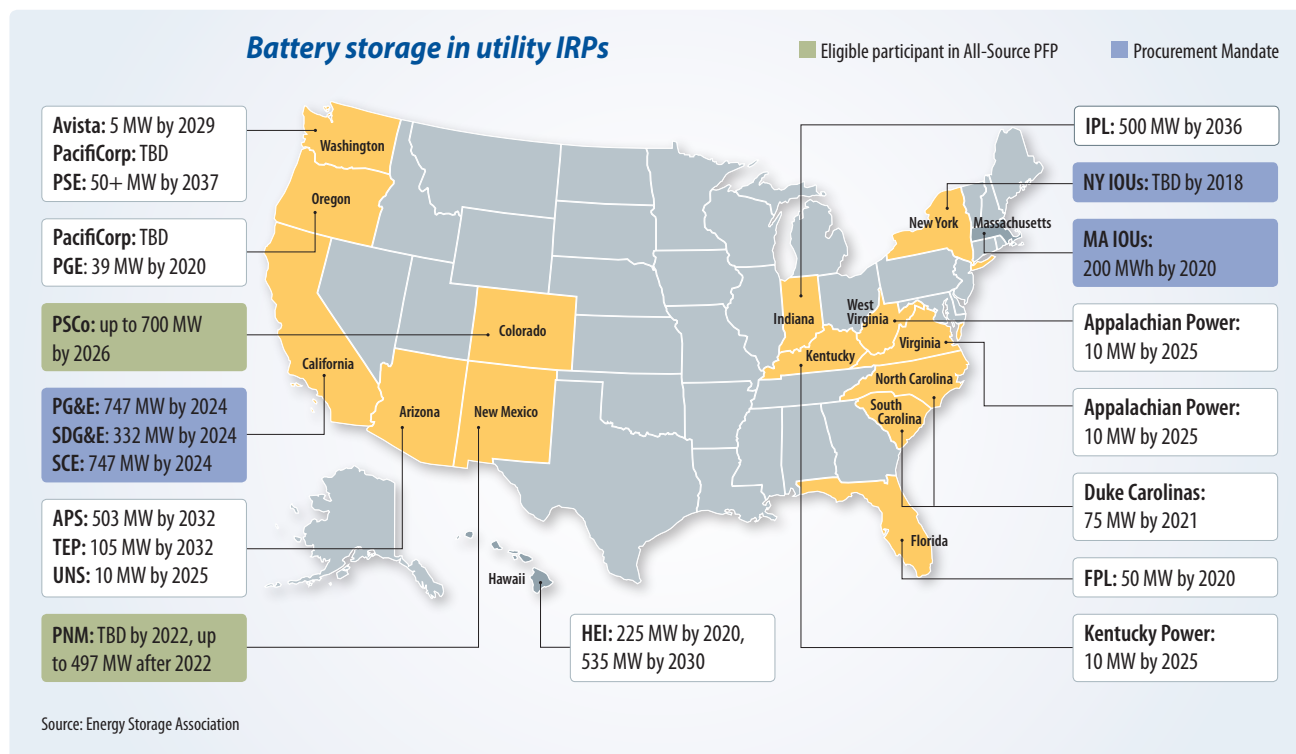
The disconnect between projections showing that high levels of storage would

be cost-effective, versus modest utility plans for storage across most of the country, reflects the difficulty in planning for storage. There are three main challenges: wide disparities in storage price forecasts; the difficulty of projecting the values of storage over time; and the shortcomings of traditional utility planning models in accounting for the uses of storage. Still, utilities and states are figuring out how to move forward in this uncertain environment.



Photo: Salt River Project

A 10 MW battery system installed close to Arizona utility Salt River Project's Pinal Central Solar Energy Center (PCSEC).



Breadth of opinion

Let's start with storage costs. Price forecasts for installed four-hour battery storage vary by a factor of two. That wide range of forecasts means that the results of any modeling effort will be hugely swayed by the selection of a price forecast.

Note that the forecasts have nearly linear slopes, suggesting that costs will fall by a certain percentage each year. That contrasts with a Bloomberg New Energy Finance assumption of an "experience curve" – where the faster the storage industry grows, the faster prices will decline – as cited by ESA in its 2016 IRP Primer.

Forecast storage costs for 2030 can vary by a factor of four. Credit Suisse stock analysts, using the results of a Nevada request for proposals released last June, calculated near-term storage capital costs bracketing the "Lazard low" cost forecast for 2021: about \$736-\$880/kW for a 4-hour battery system entering service

before 2021, given a 6% unleveraged internal rate of return. Extrapolating to 2030, Credit Suisse forecasts a four hour system at \$292/kW, or four times lower than a Brattle 2030 forecast of \$1000-\$1400/kW.

The diverging forecasts of Credit Suisse and Brattle reflect disagreement over the projected pace of decline in storage costs. ESA's current IRP primer states that "cost declines of 8-15 percent year-on-year are projected," yet the Brattle Group forecast assumed price reductions of only 5% in real terms, or 3% in nominal terms, through 2030.

If a utility uses long-run storage price forecasts that are too high, it could over-invest in traditional assets early on, and subsequently under-invest in storage, resulting in a sub-optimal outcome.

Valuing storage

After choosing a cost projection – the first minefield for analysts – lies the second challenge: valuing storage. The value of

storage for ancillary services alone could yield profitable merchant storage installations of 7 GW/20-plus GWh across the United States, according to a Brattle Group analysis, reported in an ESA presentation.

Yet Mark Becker, spokesperson for the multi-state utility American Electric Power (AEP), points out that developing price forecasts for energy and ancillary service prices at the sub-hourly level, over an extended period of time, is a key challenge of modeling. The Brattle Group study mentioned previously agrees, noting that the marginal value of storage declines as the amount of storage increases, because the need for services such as frequency regulation and local distribution capacity deferral "saturate" as storage is added.

And some values of storage require engineering analyses: valuing storage used to defer transmission investments requires a case-by-case analysis of



Photo: EDF

A battery project developed by French energy giant EDF in the state of Illinois.

planned investments, as the Brattle Group concluded in its recent study. There are also questions about whether, and how, to incorporate the value of avoided customer outages and avoided greenhouse gas emissions.

The third and final challenge is that not all utility planning models can adequately simulate the varied uses of storage at a sub-hourly basis. ESA's IRP primer recommends using models that can handle sub-hourly intervals, to "capture the flexibility of storage operations to provide both capacity and grid services." ESA highlights the commercial models PLEXOS by Energy Exemplar, SERVM by Astrapé Consulting, and RESOLVE by E3 Energy + Environmental Economics. The developers of each of these models offer various levels of support to utilities, from training to full model implementation and analysis. ESA further advises that "If sub-hourly modeling is not possible, then at minimum an hourly chronological production cost model should be used, rather than sampling from a small set of hours from each season."

"Historically," explains Frank Jakob, technology manager for energy storage for Black & Veatch, sub-hourly dynamic modeling "was not needed, as nuclear plants, coal plants, and gas plants don't

vary on their own intermittently, but renewable energy does." Black & Veatch assists utilities with the PLEXOS model, in some cases by running PLEXOS as an add-on to utility planning processes, because "utilities have traditional tools they still need to use for 90 or 80 or 70 percent of their assets, and many utilities have not made the step into the more contemporary or advanced tools," said Jakob.

A more pointed case is made in a paper published by the Institute of Electrical and Electronics Engineers (IEEE), which states: "Legacy planning, operations analytics and processes do not account for energy storage in general or [do so] sub-optimally. This slows down utility adoption and understanding."

A number of utilities and state planning agencies are using the more advanced models that ESA suggests are best. Four shared information with **pvmagazine** about their experience in meeting the challenges of storage planning: the California Public Utilities Commission (CPUC), AEP, the Sacramento Municipal Utility District (SMUD), and Public Service Company of New Mexico (PNM).

CPUC – Setting California's target

In setting out to develop a Reference System Plan, CPUC first hired E3 to run its

RESOLVE model, to identify the optimal level of storage to add to the generating mix, explained CPUC spokesperson Terrie Prosper. CPUC staff then ran the SERVM model to simulate hourly dispatch of the resulting portfolio of generators and storage, to validate the RESOLVE results.

For battery costs, E3 used Lazard's Levelized Cost of Storage 2.0 and a DNV GL study commissioned by PacifiCorp for its 2017 IRP. Challenges in modeling storage operation across California's grid, noted Prosper, include accounting for state plans to increase solar generation over time, as well as changing electric loads over time as electric vehicle use increases, counterbalanced by increased energy efficiency.

The resulting CPUC Reference System Plan includes an incremental 2,000 MW of short duration storage (about one hour at maximum output), which will augment the state's previously mandated 1,325 MW of storage.

AEP – Forecasting the energy and ancillary services values of storage

AEP, which serves over 5 million customers in 11 states, is "in the initial stages" of using the PLEXOS model to evaluate storage options in 8 states that require

IRPs, said spokesperson Mark Becker. To date, “storage has not been selected through the IRP processes as an optimal (i.e., least-cost) resource,” he said. “Typically, this is due to the high capital cost of storage, and the hourly dispatch simulation modeling that limits the ability to capture the value of additional dispatch flexibility.”

AEP has developed a methodology over the past year, said Becker, to use PLEXOS “outside of the traditional IRP process,” to model the use of flexible resources to respond to sub-hourly energy price signals.

AEP has also developed a methodology for forecasting ancillary service prices at the sub-hourly level over an extended period of time. “It is AEP’s vision,” Becker said, “to be able to include that value through various modeling methods in our traditional IRP modeling processes.”

Planning for more storage

SMUD, which serves 1.5 million customers, transitioned over a period of 16 months from a finding that storage was not cost-effective, to a target to procure 50 MW of battery storage by 2026, and then to considering up to 560 MW of battery storage by 2040.

In the earliest study, SMUD worked with EPC company Black & Veatch to use the PLEXOS model to assess its storage options in light of an increasing amount of rooftop solar coming online in its service area. The resulting report in May 2017 concluded that “energy storage is generally not cost-effective without additional revenue streams or dramatically lower costs.”

Four months later, in response to California’s first storage mandate, SMUD issued a report targeting procurement of 7 MW of battery storage by 2020, increasing to 50 MW by 2026, supported by California’s Self Generation Incentive Program and the federal tax credit for solar-related energy storage, which the report said “are creating an environment that is supportive of new business models leveraging storage technologies.”

Now SMUD has just issued a new report discussing its 2018 Integrated Resource Planning process, indicating a potential maximum battery storage contribution of 560 MW by 2040 to balance renewables.

The report adds that “future technology advancement may increase the maximum level of support battery storage could provide for local renewable inte-

gration.” SMUD will file its completed IRP report in April 2019, said spokesperson Christopher Capra.

PNM – Considering storage in an all-source request for proposals

PNM, which serves around 761,000 customers, plans to retire its two coal generating units when their coal supply contracts expire in 2022 and 2031 respectively. For its 2017 IRP, PNM worked with Astrapé to run the SERVIM model, to evaluate potential replacement options for the retired coal assets: gas units, renewables, and storage. Among the scenarios PNM considered in the IRP was a 40 percent renewable scenario; the analysis found that when renewables reach that level, “Battery storage ... can be a cost-effective replacement for flexible natural gas capacity.” PNM issued an all-source request for proposals (RFP) in late 2017 to obtain updated costs for storage and other resources. The utility is “still determining the best combination of resources” to replace its San Juan coal unit in 2022, said spokesperson Shannon Jackson. Since August 2017, New Mexico’s utility regulator has required utilities to consider storage in their resource plans.

William Driscoll



A 1 MW/ 4MWh storage system operated by utility Arizona Public Service in the town of Punkin Center.

From net metering to storage in Hawaii

The picture to the right, taken at Kahe Point in West Oahu, Hawaii, offers a stark contrast. On the grounds of the Kahe power plant of the Hawaiian Electric Company (HECO) the facility's parking lot displays shiny new hybrid electric vehicles parked next to EV charging stations. This is the future of transportation in this most populated island of Hawaii, as well as Hawaii's other islands, and for that matter in the U.S. as a whole. But looming in the backdrop is one of HECO's oldest power plants in Hawaii, an oil-fired 650 MW beast built way back in 1963. In this very scenic part of Oahu just a walk away from the Pacific coast and a string of newly built luxury hotels, the Kahe power plant seems a very dirty relic of the past.

The writing is on the wall: Hawaii has pledged to use 100% renewables for its power generation by the year 2045. It has the most ambitious renewable energy target in the country and is also the only U.S. state to enshrine this commitment in a statute (HRS 269-92). But getting there will not be easy. According to the Hawaii State Energy Office and its

the price of petroleum. As oil prices continue to move upward in the final quarter of 2018, we can expect further pressure on the island state's electricity rates, which are already more than double the U.S. average. The silver lining to all this is that high electricity rates provide a strong incentive to deploy solar and battery storage.

position of distributed generation (DG) in Hawaii's solar PV market.

In late September, **pV magazine** had the opportunity to interview William Giese, Executive Director of the Hawaii Solar Energy Association (HSEA). Giese points to a successful net metering program (NEM), which catapulted Hawaii to the top spot among U.S. residential markets. One in three Hawaiian residents have PV on their rooftop, a much bigger percentage than California, in second place with 7%. With abundant year-round sunshine and residential power rates at a hefty \$0.37 in 2012 to 2014, the state was low hanging fruit for NEM 1.0, which provided the same high rate for PV electricity exported to the grid.

CGS and CSS replace NEM

But almost overnight in October 2015 NEM was abolished and replaced by a much less compelling subsidy regime and application process. Giese provides more details: "In January 2016 we had two options: Customer Grid-Supply (CGS) and Customer Self-Supply (CSS). The CSS process was so convoluted that the average time to get interconnected was about 8 months. Regarding CGS we went from a two-page net metering application to a 27-page CGS application. From a policy perspective, CGS and NEM are almost exactly the same. The only difference is

"One in three Hawaiian residents have PV on their rooftop, a much bigger percentage than California, in second place with 7%"

"Hawaii Energy Facts & Figures" report published this June, oil accounted for 67.3% of the state's electricity production in 2015, a staggering percentage when compared to the 0.9% figure for the U.S. as a whole. This not only puts Hawaii in a precarious position when oil prices are rising (the current situation), but also creates a serious environmental impact on this precious ecosystem in the middle of the Pacific.

Based on this dependency, Hawaii's electricity rates correlate closely with

The net metering boom

So it will come as no surprise that solar PV has thrived in Hawaii, which is blessed with abundant sunshine all year round. Driven largely by a net metering program for distributed PV, solar generated 948.6 GWh of electricity in 2016, representing 38.4% of the overall renewable energy power generation in the state that year. Wind ranks in second place with 656.7 GWh and 26.6%. Of the 948.6 GWh, only 121.8 GWh was generated by utility-scale PV, showing the pivotal



The future and the past are juxtaposed at HECO's 650 MW oil-fired power plant at Kahe Point in West Oahu.

that NEM credits you at retail and CGS credits you at 15 cents. And the other difference is that NEM has a yearly through-up for energy credits, and CGS had a monthly through-up. But other than that, there were not any bigger fundamental differences. But the process to interconnect was much more difficult."

In his presentation at this September's Solar Power International conference, Oahu-based PV and storage expert John Ogawa Borland, President of J.O.B. Technologies, recounted the aftermath of the NEM abolition: Oahu rooftop solar permits and installs went from a peak in 2012 and 2013 to a drop of 80-84% in the period to 2017. This is counterintuitive, since average rooftop PV installation costs went from \$5/W in 2012-2013 to \$3.20/W last year. But this is only the capex side. In terms of revenue, CGS is a completely different ballgame from being able to export all excess PV electricity to the grid and pocket the full retail rate,

which is double the new CGS rate of \$0.15. The clear-cut case for solar PV that NEM 1.0 had brought with it shriveled to a rather dubious CGS (or CSS) business case with multi-year payback periods.

Multi-storage demonstration

For Borland, the solution lies in so-called "nano-grid, no export, zero grid-buy" solutions, which take advantage of the low PV system costs on the market. This approach also factors in HECO's new peak time of use (TOU) rate, which begins at 5 PM when solar PV generation in Hawaii starts to fade away. While the utility's new daytime TOU rate amounts to \$0.13/kWh, the new Peak-TOU stands at \$0.35/kWh. This rate design mirrors the well-known duck curve, which exhibits a mid-day downturn when the net grid load is low due to the spike in PV generation, but ramps up rapidly when PV output declines in the late afternoon and early evening.

Such market conditions are tailor made for residential battery storage, where PV electricity can be stored to reduce demand when the Peak-TOU applies. This is where Borland's demonstration project in Oahu has its starting point. The project is divided in 4 phases and the main take-away is that energy storage can still make residential solar a compelling business case in Hawaii. Phase 1 launched in June 2016 and Phase 4 ended this summer with practically no grid-buy and a utility bill of \$218 (for the period January to July 2018) compared to \$4000 in the year (2015) before the pilot began.

Already Phase 1 involves a 10 kWh Panasonic Li-ion battery coupled with a Tabuchi Electric 5.5 kW hybrid solar inverter control system. Power is provided by a 27-panel cSi 7 KW rooftop solar PV system or (when the sun is not shining) the HECO grid, preferably not in the time window when high TOU rates apply. Permitting for this project fell



A very attractive net metering program put PV on many roofs in Hawaii. Pictured here are rooftop PV systems in West Oahu. The island of Oahu accounts for 90% of all residential PV permits in Hawaii.

under Hawaii's CSS program, preventing any export of PV electricity to the grid. With capex for the Phase 1 pilot system at \$3.91/W, the payback period amounted to 16 years, not a very compelling case for projects following the CSS path.

But this was just the beginning of Borland's quest to generate a compelling ROI for solar + storage projects in Hawaii. By adding increasing amounts of both Li-ion battery storage and solar hot water thermal storage, plus better software and a 240 Volt transformer to allow for islanding of the system, Phase 4 resulted in the savings Borland was aiming for. Instead of paying almost \$400 to the utility (the situation prior to the pilot launch), he was now paying the monthly minimum (\$17) to be connected to the grid. And instead of 16 years, the payback period for the system shrank to below 3 years.

The complete Phase 4 multi-storage solution also requires sophisticated energy management software, some behavioral changes (for example, doing

laundry during sunny periods or when batteries are sufficiently full) and a more subtle mounting of the solar PV arrays. Instead of only facing south, arrays facing east and west can broaden the PV system's generation profile to maximize self-consumption. So it is not the very straightforward NEM 1.0 solution that made Hawaii the number one PV market in the U.S.

Hawaii's utilities HEI, HECO and KIUC

While Borland recommends these grid-tied island nano-grid systems for states with ambitious renewable energy goals and the sunshine to go with it (for example, Hawaii and California), Hawaii's government probably has another approach in mind, lest its leading utility HECO be islanded itself and become a stranded asset.

Politically, HECO and its parent company HEI, which also owns the utilities serving most of Hawaii's other islands,

are already somewhat stranded with Hawaii's legislator and public utilities commission (PUC) pushing HECO to do more to embrace renewables and distributed energy resources (DERs), including battery storage. As Giese points out, HECO is also responsible for crafting the CGS and CSS permitting process, which is clearly not where it should be to turn solar and storage into driving forces to achieve Hawaii's ambitious clean energy goals.

Interestingly, the island of Kauai and its non-HEI-owned utility Kauai Island Utility Cooperative (KIUC) has been quicker to embrace solar and storage, especially when it comes to utility-scale deployments. Recent projects have included a 28 MW PV power plant coupled with a 100 MWh five-hour duration energy storage system. When the project was announced in February, KIUC's President and CEO David Bissell highlighted the benefits: "The project will provide 11 percent of Kauai's electric

generation; increasing KIUC's renewable sourced generation to close to 60 percent. At 11 cents per kWh, the pricing is well below the cost of diesel and will not only provide downward pressure on rates, but also helps us avoid the use of 3.7 million gallons of diesel each year." Another KIUC project involves a 19.3 MW PV power plant combined with 70 MWh of battery storage. In both cases KIUC teamed up with AES Distributed Energy, Inc., the Boulder-based subsidiary of The AES Corporation. AES DE will be the long-term owner and operator of these plants.

The promise of performance-based rate making

For HSEA's Executive Director William Giese the outlook for Hawaii's market is not as gloomy as 27-page CGS applications and lengthy CSS permitting pro-

cedures suggest. His optimism is based largely on a very determined regulator and legislature, who have put into statute a shift from conventional cost plus rate-making to a cutting-edge performance-based rate making. The long and short of this move is to change the way utilities do business in the state of Hawaii. The old model incentivized putting copper in the ground, especially if it was the utility's own copper, as the oil-fired plant in West Oahu. The new model puts the customer front and center and rewards utilities for implementing clean energy priorities, be it rooftop solar or storage DERs instead of costly grid build-outs. Hawaii's utilities have until 2020 to make this transition and hopefully this will kick-start the state's utilities to really support solar and storage, as well as other measures to get Hawaii's electricity completely green by 2045.

Eckhart K. Gouras

“The new model puts the customer front and center and rewards utilities for implementing clean energy priorities each year”



Utility-scale PV has not fared as well as residential PV in Hawaii. But the state's new mandate requiring performance-based rate making by 2020 is bound to change that. Utility-scale PV plus battery storage projects on the island of Kauai show the way forward.

Between the lines

Earlier this year, The Nissan Motor Company began European delivery of its extended-range electric van, the e-NV200. The updated vehicle's larger, 40 kWh battery will bring its range up to 200 km, making the all-electric van attractive for urban delivery fleets. But the feature that has technologists excited is not to be found in a simple upsizing of the battery pack. Rather, it's the built-in V2G (vehicle-to-grid) charging capability that offers a long dreamed-of solution in energy storage, achieving bi-directional energy flows between fleets of EVs and the powergrid.

Vehicle to grid capability, or to be more specific, interoperability, does indeed offer a tantalizing solution, one that's both effective and economical. If EV fleets can be used as a collective battery, not only can they smooth out peaks and valleys of demand in the power grid, they can do so as an unexpected form of moveable infrastructure, that would greatly reduce costs, and the total amount of future, fixed energy storage society would need to build. The question, however, is how close are we to a take-off point? When will global EV fleets get large enough, and charging technology sophisticated enough, to make a strong interface with the power grid?

"I don't think the broader public recognizes how many entities are ready for this change. Everyone is already quite interested," says David Schlosberg, VP of energy market operations at eMotorWerks, a Silicon Valley based provider of software-enabled charging devices.

A division of Enel, eMotorWerks recently conducted a breakthrough EV-to-grid interface project, bundling up participating EV owners on its JuiceNet charging platform and then offering to California's grid operator to "hold back" from charging those EV during times of high demand. In doing so, eMotorWerks acts as a kind of market maker to the grid. The project, which began in early 2017,

showed that by aggregating networked EVs into a single bundle, what might be called a virtual battery, eMotorWerks was able to timeshift as much as 30 MW of capacity, or as much as 70 MWh of potential demand. More enticing still, is that eMotorWerks gets discounts for being able to timeshift this demand, and passes those savings on to customers.

Scaling up

To understand in detail how this interface works is necessary, because adoption of vehicle-to-grid technology will inevitably grow from the micro-scale testing projects currently underway. And the technological timeline to our endpoint, when a much larger, collective EV fleet is able to swing demand in large blocks, is starting to accelerate. For example, the eMotorWerks JuiceNet charging platform is not being used, not yet at least, as a battery that supplies energy to the grid. Specifically, this is not a V2G but a V1G (only one way charging from grid to vehicle) program. But the fact that V1G capability has already arrived is a tell on how close we are to a disruptive moment in the power industry. To reach this point, eMotorWerks still had to cross key technological thresholds. As Schlosberg explains, "We use information about each individual user's charging history, and combining this with predictive analytics, we let the grid operator know a day ahead what we can do."

The grid operator in this case is California Independent System Operator (CAISO), the independent entity



The 2018 Nissan e-NV200 features a 40 kWh battery. Nissan is one of a few companies that have already begun to roll out vehicle to grid technology, although so far only in certain markets, in a limited capacity.

Photo: Nissan Motor Company Ltd.

charged with making California's electricity market fair and functional, on an hour to hour basis, or really, from second to second. That a company like eMotorWerks is already active in that market is a preview of what's to come. When eMotorWerks offers CAISO a picture of the demand coming from its bundled EV fleet, the visibility offered has its own economic value. That's why, when eMotorWerks bids its ability to withhold, time-shift, or bring demand at a preferable hour, it can obtain favorable wholesale electricity rates. "We let the grid operator know what price we think is good, and if they say ok, we agree," says Schlosberg. On the customer side, he continues, each individual EV owner on the platform decides for themselves their preferable time charging window, and they can "set it and forget it." Over time, patterns develop in the small fleet that eMotorWerks serves, and that becomes its own form of intelligence. The JuiceNet platform is ready for V2G. But according to Schlosberg, "Although we are exclusively involved in reducing consumption at predictable times, we are, however, set up to put demand back into the grid. But at this time there is not yet a mechanism to get paid for it."

Compared to the gains already made in global wind and solar power generation, energy storage is very much an emerging sector. And the range of possible use cases for storage is just now coming into view. In South Australia, Tesla's deployment of a large, grid-scale battery able to provide 129 MWh of supply has largely been utilized as a frequency regulator--coming to the rescue of the larger grid to smooth over unexpected disruptions. These disruptions may last only minutes, but battery support even for that time interval has high economic value. Indeed, less than a year into operation, it's been reported the Tesla battery, which cost around \$66 million, has

already generated \$9-17 million in revenue in the first six months of operation. In the transit sector, Martha's Vineyard Transit Authority, as part of a state-wide Massachusetts Department of Energy Resources program to jump-start storage, will install a 0.5 MW/1.4 MWh battery in support of the VTA's decision to transition to electric buses. And in California, the possibility has now been raised that energy storage could be used to avoid altogether the construction of new power generation, should Pacific Gas and Electric follow through on plans to build a total of 567 MW of capacity. Such a battery would be able to grab cheap, surplus power from soaring solar during the day, putting it back onto the grid after 5PM, when demand soars.

A common theme here is that energy storage, often thought of as a dumb box, is beginning to work between the lines of the power grid. Imagine being an owner of existing natural gas generation capacity, having enjoyed years of high earnings during times of peak demand, only to discover that storage is now entering the market and taking those premiums away. Or perhaps you're a maker of natural gas turbines, like General Electric, or an engineering firm, that anticipated decades of construction ahead in power generation. Wind and solar arrays



Photo: BYD

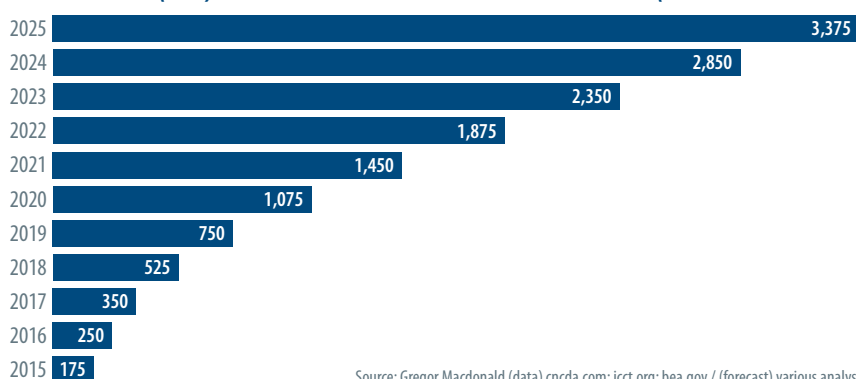
China's BYD delivered six electric buses to Martha's Vineyard in Massachusetts earlier in 2018. Now, the island's transit authority plans to install a 0.5 MW/1.4 MWh battery to support the fleet.

took the first chunk of that revenue pipeline away, and now storage threatens to take the rest. A story that eMotorWerks Schlosberg tells is that in the early days, when the company was looking for funding, their biggest hurdle was convincing investors that electric vehicles would actually happen. "A lot of investors looked at us sideways, but we had a business model that didn't require massive investments. We didn't have to build the network."

Disruptor of the disruptors

What is so disruptive about a networked battery, right at the very moment fixed-site battery storage looks to disrupt power markets, is that it's a higher order entrant, a disruptor of the disruptors, if you will. The rapid adoption of EV, made possible by the many small, individual decisions

Cumulative EV (PEV) on California roads in thousands 2015–2018 (forecast 2019–2025)



Source: Gregor Macdonald (data) cncda.com; icct.org; bea.gov / (forecast) various analysts

“A networked EV battery, in a fleet of 1.5 million vehicles, could obviate the need to build 1000 MW of fixed-site, stationary storage”

on the part of consumers, is scaling up rapidly and will soon become like a large piece of infrastructure that no government had to order, and no taxpayer had to fund.

Using examples cited so far, it's useful to lay out how these early storage projects compare to overall system demand. The Martha's Vineyard VTA battery will be a tiny, single facility focused device at 0.5 MW/1.4 MWh. The eMotorWerks networked battery is much larger, at 30 MW/70 MWh. And the Tesla Australia fixed-site grid battery is 100 MW/129 MWh. Daily demand for the entire state of California, using CAISO data for September 1, 2018, was 644,725 MWh. So at first glance, California, the world's sixth largest economy, has an energy market that dwarfs today's battery capacity. But eMotorWerks network is composed of just 6000 chargers, so far. And registered EVs in California are just now crossing the 500,000 mark, in a total passenger vehicle fleet of 25 million.

Aggregating EVs for storage

The opportunity to marshal EVs together as an increasingly powerful networked battery has enticed economists, policy makers, and researchers alike. Jeffery Greenblatt of Emerging Futures LLC in Berkeley, California is the author, along with Jonathan Coignard, Samveg Saxena, and Dai Wang of a new paper that modeled, using a simulator at the Lawrence Berkeley National Laboratory in California, how a future EV fleet in California could both positively impact the power grid, while also saving money. Clean vehicles as an enabler for a clean electricity grid (2018) simply took policy

goals already in place in California – 1.5 million EVs on the road by 2025, and 1300 MW of energy storage capacity by 2024 – and asked what kinds of impacts vehicle-to-grid charging capability might have, were it available on a widespread basis. Importantly, the paper looked equally at V1G impacts, not just V2G impacts--a timely focus given that's the first instance of grid interoperability being pursued today. Two main findings are worth highlighting. First, a large networked battery would have its greatest impact on the ramps, which are the demand declines that occur starting mid-morning, and the great increase in demand that arrives in late afternoon. While these effects would be even more impactful in a system with both V1G and V2G capabilities, it's impressive how much work a networked battery could accomplish simply by time-shifting demand in a V1G scenario. Given the pattern of electricity demand in California, that's a key finding. “Ramps are becoming more severe,” says Greenblatt. “And when I talk to grid professionals and people in the industry, this is where there's currently the most concern.”

Second, the authors found that a networked EV battery, in a fleet of 1.5 million vehicles could obviate the need to build 1000 MW of fixed-site, stationary storage. And again, that is in the V1G scenario. As the authors point out, this comes pretty close to California's current policy mandate for the state to have 1300 MW of energy storage in place by 2024. Furthermore, the value of sourcing that infrastructure through EV, rather than stationary storage, could be between \$1.45 to \$1.75 billion.

No alternative

It should be pointed out that EVs themselves already represent a substantial thermodynamic saving, captured whenever a conventional vehicle is retired or avoided. By conservative measure, a fully 100% electric vehicle reduces energy needs by 70% at the level of the vehicle, and this is enhanced further as the grid itself becomes cleaner. The Department of Energy's Argonne Lab has already noted this effect for California, which is now sourcing a full 20% of its electricity from combined wind and solar. But the spectacular success of those two renewables in California have understandably exacerbated the ramping effects, known as the duck curve. As Greenblatt further points out, “While the ramps are expected to become more severe, we are in a situation where the peak is not expected to grow very much.”

Both Greenblatt and Schlosberg agree that stationary storage will have to be built, regardless of how fast or how large the EV fleet grows. But perhaps of greatest interest is that both in the scenario modeled at Lawrence Berkeley Lab, and already put into practice at eMotorWerks, the crafting of an optimal algorithm is key to understanding how the vehicle-to-grid interface really works. The goal of this intelligent layer, which captures the chaos and variety of individual user choices and converts that complexity into predictive analytics, attempts to bring buyers and sellers of power together but in a way that serves their differing needs. EV owners would like to charge at the most convenient time, but given the right amount of incentives, might discover a willingness to expand their win-



A car is hooked up to a fast charging point at the Georgia Alternative Fueled Vehicle Roadshow in June.

dow. The grid operator meanwhile needs demand to show up when supply surges, and conversely needs as many users to lay off when demand ramps higher. Traditionally, these needs are mediated through price. But the surprising quality of today's emerging energy storage is that it has already figured out a principle of market pricing: markets take place at the margin. In other words, the pricing of the entire market can be transformed by participants at its edge.

Whether in stationary storage or virtual batteries, the killer-app feature of energy storage appears to be ability to exploit these marginal effects. Just as in stock markets, when price is ramping, lower bids at the margin can decelerate price just as higher bids or an accumulation of bids can arrest price in a falling market. Future fleets of EVs, hooked into algorithmic charging networks, will strike balances between user goals to capture competitive prices and grid goals to

de-escalate ramps. And they will do so using the power of marginal pricing. Amazingly, this will all occur while at the same time creating savings in the system, by restraining the amount of stationary storage needed across domains. That's why energy storage projects today should be taken seriously. Because energy storage, it would appear, has a market impact that well exceeds its deceptively small size.

Gregor Macdonald

AI for energy storage

Athena, a battery services software package developed by Stem – is able to think fast enough, and wide enough, to coordinate distributed batteries with the near instant changing demand requirements of the power grid. The tool's greatest strength is that it creates a “many winner” situation for businesses, utilities and Stem.

A battery alone is just hardware, and hardware alone doesn't solve the complex problems that we need to address with energy storage, according to Jeff Olson, Director of Business Development & Strategic Partnerships at storage services provider Stem Inc.

This is where we learn what Stem's Athena software really is. After input of large volumes of historical data, followed by projections of the future – weather, energy production and use, a live stream of reality is pumped in. The Past, Present and Future – integrated in inter-tangled algorithms programmed to react to the economic market signals pushed by electric utilities and local conditions.

Hive mind

This mind, able to reach across many locations at once, is the perfect tool for a utility that doesn't wish to deal with hundreds of partners – but can absolutely benefit from distributed storage. And right here is Stem – a thinking system that is quite conscious of the power grid that it sits atop, tying together local businesses and large utilities, while generating more revenue and stability for everyone involved.

As recently as this summer, Stem had 440 customers installed, and another 420 in process. Half of the systems in this pipeline are about 750 kW, with the average system around 1 MW. Hourly durations range from 1.5 to 4 hours, depending on where the system is installed.

Larsh Johnson, Stem's Chief Technology Officer, noted that in 2017, Athena was called on over 600 times to dispatch in day-ahead and real-time (five-minute) responses to the California wholesale market. These events, some of which occurred during this summer's heatwaves in Southern California, give Stem the chance to make distributed revenue for their systems when California requests demand response reactions from its customers the day before. Stem then shares this revenue with the owners of the storage systems, revenue that small business owners would not otherwise have access to.

Technically speaking, this is Stem's core competency and what customers are really paying for – leveraging the hardware to go beyond simple demand charges. For other battery installations, the main economic benefit is demand charge management. And it is this value stream that drives much of the project's economics – but if you can make more from your hardware, why wouldn't you?

The right data

Olson notes that one of the most important aspects of his work these days is educating partners – solar developers in particular – on the right questions to ask, and the right data to collect. Stem sees that almost every customer's needs are different as described by their load profiles, and adding solar power to a Stem system helps to magnify the returns.

The developer needs to collect three basic inputs – 15-minute interval data from the utility, data from solar power production, and a copy of the customer's utility bill. Once this is communi-

cated to Stem, an optimized system size will be proposed – making sure the battery and solar power are not too large to waste hardware, but big enough to meet the goals of all parties involved.

Market development has a long way to come. Right now, Hawaii and California are the main markets, while Massachusetts sales are expanding and the state has a structure in place for great growth, with Texas and Illinois seen as up and coming. The company has running hardware in all those states minus Illinois, as well as Arizona and New York.

The nature of Stem's technology is that they first need to find a market where their services will be appreciated and paid for by local utilities, then find customers within that region. Once Stem has that foothold, utilities tend to appreciate that the platform absolutely makes the grid stronger. And as Stem's network gets larger, its value to the utility increases.

For instance, in Southern California the utility contracted with Stem to go after specific substations, because it knew where the support was needed. Once these substations were found, Stem's sales team fanned out into the surrounding regions and deployed their hardware.

Johnson describes the process as follows: “As a partner of the utilities we're able to offer use of these assets, and we feel that as the utilities can observe – and feel comfortable with – the more they'll be able to trust these items on the grid with their responsiveness.”

Stem is selling intelligence. They're selling a service that makes your hardware worth more money. They're tying together layers of reality that in prior times (and in most places of reality still) were disconnected. They're waking up our power grid by combining newly cost effective energy storage with increasingly fast network connections and aggressively evolving machine learning – artificial intelligence when you're being humble – techniques.

John Weaver



Photo: Stem

Dynapower doubles down on DC

Utility-scale developers see energy storage as the Swiss army knife of the grid: a single asset able to perform many functions. As economics improve, and the penetration of renewables increases, they have moved from asking if they need storage, to asking which functions should be prioritized. And the answer to that question shapes the topology.

Dynapower is spreading its bets with its recently launched DC-DC Converter series rounding out offerings of utility scale, behind the meter and fully integrated systems. It's an interesting choice, offering design flexibility while exploiting the final years of the ITC incentive.

First some basics. When solar and storage are paired, they can be connected in four ways:

1. Operate independently, with energy storage interconnected directly with the grid
2. Have inverters for both solar and storage that are then AC-coupled
3. Use a single DC-coupled (hybrid) inverter for both solar and storage
4. Connect both solar and storage into a tight DC-coupled system

How the batteries are charged depends on the topology: in the first, they are only charged by the grid, in options two and three, they can be charged by the grid and PV, and in a tight DC-coupled system, they are only charged by PV.

DC side charging

Dynapower's DC-DC Converters are used in the fourth topology. The 250 kW, 375 kW and 500 kW DPS bi-directional DC-to-DC converters can be scaled with up to 8 units for 2 MW, 3 MW or 4 MW of energy storage respectively. All three have a 98.2% average efficiency, a 550-1500 V input voltage range (both battery and PV), and are compatible with all batteries.

The arguments for the DC-DC connector fall into three buckets: a lower initial system cost, increased design flexibility, and potentially more attractive revenues.

The lower system cost is straightforward: there are fewer components, with the elimination of separate battery inverters, AC collection systems, transformers and switching gear. And streamlined BOS is likely to trim engineering and interconnection study costs as well.

A tight DC-coupled system also offers more design flexibility. Hybrid inverters require a 1:1 DC:AC inverter loading ratio. A tight DC-coupled system can support a more natural 1.4:1 or 1.5:1 DC:AC ratio. It's the revenue argument that deserves close modeling.

Revenue streams

A tight DC-coupled system offers all the standard storage revenue streams—capacity firming, curtailment, ramp rate control—plus the all-DC topology results in lower round-trip efficiency losses, which marginally improves the economics across the board. The topology's benefits start accruing once you add the value of recapturing energy usually lost to clipping caused by the inverter loading ratio as well as low voltage energy that isn't harvested before the inverter wakes.

The topology, however, trades off two very significant revenue streams: ITC incentives versus rate arbitrage.

One of the financial arguments for the DC-DC converter is contingent on the ITC: because the battery is never charged from the grid, there's no chance of ITC clawback. While that makes it easy to claim the full ITC, most battery management systems today already can, if desired, be set to prevent AC-coupled or hybrid systems from charging from the grid. And in the future, those AC-coupled or hybrid systems can be reprogrammed as the ITC is phased out or if it is extended with different rules.

The easy-ITC comes at the cost of the ability to take advantage of rate arbitrage: a tight DC-coupled system is only charged during the day, when rates are relatively high. Other topologies offer the flexibility to store from the grid when rates are at their lowest, enabling the system owner (or the battery management system algorithms) to do the math about whether it's preferable to keep full ITC benefits or sacrifice some in order to gain arbitrage revenue. In its

2017 paper Evaluating the Technical and Economic Performance of PV Plus Storage Power Plants NREL found that, without the ITC, the loss of arbitrage revenue puts the economics of a tight DC-coupled system behind all others except for fully independent systems. With ITC, its economics outperformed others.

NREL's study captures a moment in time, looking at 2014 incentives and 2016 estimated prices. The reality is that the market is moving so quickly that any developer considering energy storage needs to model the topologies based on today's conditions and evolving incentives. What Dynapower's new offering brings is another option to consider.



LG targets a bigger slice of the energy pie

Home energy storage has a new entrant: LG Electronics USA's LG Solar division. Revealed at Solar Power International in September, LG announced two mid-sized residential offerings: a 5 kW AC-coupled system which is designed as an add-on to existing solar but could also be used with LG's NeON AC modules, and a 7.6 kW DC-coupled system that provides a single inverter for solar and storage in new installs. The transformerless power conversion systems have 97.5% CEC efficiency, are designed for indoor or outdoor installation, and carry a 10-year warranty. Both units can be paired with up to two 9.8 kWh LG Chem RESU 10H batteries for a total 19.6 kWh capacity if needed. Each battery unit weighs in at 214 lbs, making them easier to handle than the 276 lb, 13.5kWh Tesla Powerwall.

LG's move is reflective of an industry-wide trend to develop integrated systems. Inverter companies have led the way, with SolarEdge and SMA offering solar, storage, and even EV-charging systems. Module manufacturers are particularly hungry to find ways to add to their razor-thin margins and LG is the first to go beyond simply offering smart PV with module-level power electronics. LG's heritage in consumer electronics gives it an advantage over most other module manufacturers.

Its solution, while complete, isn't sleek. By providing separate components for the Power Conversion System (PCS), Auto Transfer Switch (ATS), and batteries, LG is leveraging the volume manufacturing of the RESU battery unit, but doesn't offer the simple single-component feel of competitors such as Sonnen. Still, given LG's breadth of consumer product lines, their bundled approach is one way to step ahead of other leading module manufacturers.



Photo: LG

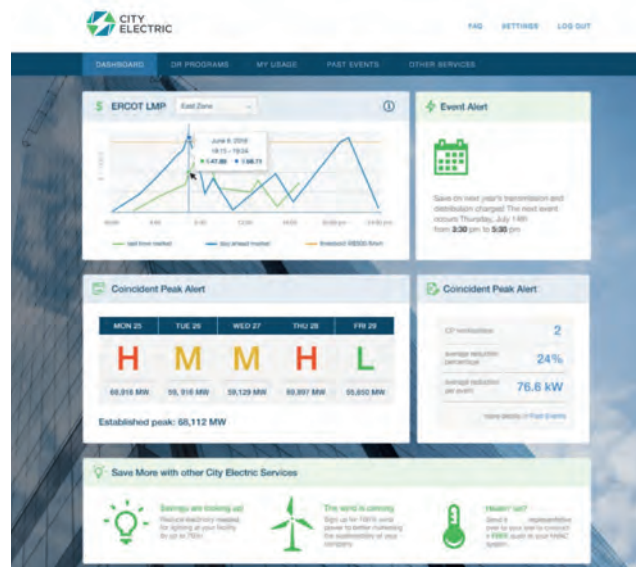


Photo: Autogrid

Autogrid: More, batteries, more use cases

As residential storage expands, more solutions are coming on to the market, looking to capture the full value of distributed energy storage. Aggregating residential assets together to provide ancillary services to the grid is one of the trickier slices of the energy storage value stack to capture, and one that will require a comprehensive energy management system.

AutoGrid was recently chosen by residential installer Swell Energy to aggregate its 35 MWh pipeline of distributed batteries in California. The partnership draws on AutoGrid Flex's flexible management platform, and AutoGrid Engage's customer-experience interface, and highlights the advantages of AutoGrid's expansive vision.

Flex is marketed as the "first truly integrated flexibility management suite" and provides a serious challenge to market entrants that have previously focused on managing a single asset, such as energy storage. It can manage distributed energy resources and demand response assets, residential, commercial and utility-scale customers, and offers capacity, energy and ancillary services for wholesale, transmission & distribution and behind the meter value streams.

Swell's partnership shows it can meet narrow needs, but AutoGrid Flex's true value will be seen as larger players implement it in scenarios where energy storage is simply one part of a more complicated story.

The Engage package, which comes in both commercial and residential flavors, offers a single-point of insight into disparate solar, storage, and other distributed energy assets. Its ability to be white-labeled makes it an easy product to build customer preference with, especially with AB testing potential that enables utilities to refine their customer messaging.

Eos Energy Storage: Grid, meet Zinc

There are reasons to look beyond standard lithium-ion batteries. Concerns about both supply chain and safety mean that it makes sense to stay on top of alternate battery chemistries. While some utility-scale energy storage companies are leaving cobalt-based lithium-ion batteries behind in favor of the safer, but less energy dense, lithium ferrous phosphate, others are exploring alternate chemistries including vanadium and zinc. Eos Energy Storage turned to zinc for its low cost, safety, and high depth of discharge.

Eos's Aurora utility-scale energy storage system is based on a zinc hybrid cathode that they call Znyth. The Gen 2 Eos system is scalable, with modular, plug and play components. Its basic building block is a 100kW unit with a 4-hour discharge time, configured into a 1MW 4MWh DC battery system. The units have a projected 5,000 cycle, 5-year life, which is low by lithium standards but reasonable given the price is closer to affordable but short-lived lead-acid. Unless HVAC is added, the Aurora is a fine weather friend, with a narrow 10-45°C (50-113°F) operating range. And any cost-benefit analysis of the "ultra-low cost" solution has to take into account its 75% round trip efficiency, and short one-year warranty.

While still relatively new to the market, Eos recently secured a partner, Holtec International, that brings not only funding but also manufacturing expertise in order to help them implement their distributed manufacturing strategy. For utility-scale installations where energy density is low on the wish list, it's a product worth exploring.

Photo: Eos Energy Storage



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Refreshing blend or toxic technology cocktail?

Battery storage is racing even faster than the PV market did a few years ago. Costs are plummeting, and new production lines are popping up all around the world. Smart people with smart ideas are leveraging venture capital and research funds. M&A activity is also accelerating with a new range of investors taking interest. But the technology battle is far from over, says Ragna Haupt-Schmidt, Partner at Energy Consultancy Everoze.

Revolutions in lithium-ion (Li-ion) chemistries and ground-breaking flow batteries are fighting head-to-head with hydrogen-based systems for corporate investment. Everyone is trying to disrupt the market with myriad applications from high energy to high power, from long duration to frequency control, displacing diesel gensets or gas peakers. This article assesses technical developments and changing business models from a wider investor community perspective, including battery tech

This is on top of the increasing number of undisclosed M&A deals, and of course the research funds made available to new innovative ideas.

Typical investors in this area so far have been VC arms of large energy firms, such as Shell Ventures, or Asian technology conglomerates, such as Samsung. However, there is now a sudden surge of new investor groups. Financial investors are increasing their presence on the global battery playing field. For example; this year a total of \$80 million was

The battery storage industry is not only following a similar path to solar PV, it is also closely linked to it. Large renewable energy IPPs develop or buy utility-scale PV + storage projects displacing diesel gensets around the world. Some solar players are even screening investment opportunities in companies for the sole purpose of securing their own growing battery supply needs.

So, what are the key questions that these new types of investors ask at the beginning of a project or even for a corporate Due Diligence (DD)?

“The industry is clearly going through a growing-up phase similar to that which solar PV underwent”

investors and new entrant solar system integrators. Taking the role of infrastructure-drinks-mixer, we ask: will combining battery storage and PV emerge as a refreshing investment blend, or a toxic technology cocktail?

Surge in new investor types

The stats paint a clear picture. There is plenty of money around. Venture capital funding for battery storage related investments amounted to \$539 million in the first half of 2018, according to Mercom. This is a 12% increase from 2017, but scattered over ever more deals, 29 in total.

invested in the battery software services company Stem by the Ontario Teachers' Pension Plan and Singapore investment company Temasek.

Both of these institutional investors have previously invested in solar PV assets. The solar arm of Banpu, a leading Thai coal player, has taken a stake in New Resources Technology, a Singaporean energy storage systems start-up. The industry is clearly going through a growing-up phase similar to that which solar PV underwent. Even project finance is reluctantly, but increasingly pouring into battery projects.

Is lithium-ion a safe bet?

Yes and no. Li-ion is still the dominant chemistry sold on the market with plummeting costs. Most commentators are comfortable with the strong demand predictions for many years to come. So, for project investors Li-ion batteries seem to be the best bet today.

However, VC investments in the first half of 2018 also covered many other chemistries and storage technologies. Investors seeking a stake in a company need to look deeper. On the one side there are battery technologies, that include various chemistries such as Li-ion (nickel-manganese-cobalt, silicon anodes etc), sodium-sulphur and flow batteries. Then there are fuel cell technologies which involve hydrogen or methanol. Finally, other technologies such as thermal, compressed air energy storage (CAES), liquid air or flywheels can also fulfill storage needs.

Photo: Amber Kinetics



While Li-ion will remain the dominant technology for energy storage in the coming years, other technologies, including flywheels can also fulfill large-scale storage needs.

The competition is far from over. Ground-breaking research results are being announced on a seemingly weekly basis, claiming drastic cost reductions or increasing lifecycles. But what about sustainability and health considerations? Li-ion batteries have well-publicized issues related to current recycling and mining practices. It is not yet economically viable to recover lithium from old batteries; the cost of mined lithium is lower. And the recycling processes vary depending on the different battery types.

What if Li-ion follows a similar path to silicon in PV?

Crystalline silicon (c-Si) has been considered an intermediate technology from early on, soon to be replaced by thin film or other new breakthrough developments. These expectations have in reality been confounded, and c-Si continues to endure. In energy storage, Li-ion has benefitted from technology improve-

ments and scale effects, thanks largely to investments from the automotive sector. This has left limited market share for competing technologies to date. Whilst Li-ion is the go-to product for now, if its supply chain fails to address sustainability concerns or the cost curve stalls, there is potential for disruptive technologies to make a much bigger dent in its dominant market share.

What if a new innovation claims to halve battery costs?

The key question is by when can cost reduction of a new technology be achieved. It is hard to beat Li-ion's ongoing cost reductions. Despite current overcapacity, recent announcements by leading supply chain players such as BYD, CATL or LG Chem show that new production lines of Li-ion based batteries are being set up and existing lines are being expanded all over the world. Li-ion prices have plummeted to less than

one third over the last six years, and they are expected to drop a further two thirds to as little as \$73/kWh in 2030, as per the latest BNEF 2017 predictions. Investors need to be wary of declarations claiming that the new technology is able to compete with Tesla and ready to disrupt the market.

Should investors look for a 'Swiss army knife', or one application?

The answer here is rather complex. When solar project sponsors approach this question, their natural instinct is to look for a battery – a solution which can cope best with the generation pattern of the sun, store energy for many hours during the day and discharge overnight. Sizing a battery to match this peak requirement to date has meant paying a hefty sum for extra capacity which is rarely used. Hence the main usage for batteries in grid connected environments has been for frequency response or ancillary ser-



Photo: Tesla

Tesla's battery factory in Nevada, USA. Announcements from major battery players show new production lines of Li-ion based batteries are being set up all over the world. Li-ion prices have plummeted to less than one third over the last six years.

vices rather than for arbitrage purposes. The benefits of co-locating with a renewable energy plant have mainly come from savings on development, balance of plant and grid connection costs.

But this duck curve effect of solar is one of the key drivers for further market development of storage. Longer duration batteries (4hrs+) will reach commercialization in the next couple of years, even 8hrs+ are not ruled out. With longer durations, storage can even take on peaker roles, so grid operators can maintain gas resources for those prolonged peaks that batteries would not meet. The recent Pacific Gas & Electric Corp tender in California for four gas peaker replacement projects using battery technology is paving the way for this trend which will surely follow in other jurisdictions.

Over the next five years, market requirements will continue to lean towards the high power applications, with grid operators pushing the markets towards providing short duration, fast response times and ramp-up rates. However, in the mid-term a market swing from power towards energy can be expected. More mature grid markets for battery storage, for example the UK or the US, have tended to be kickstarted by ancillary services, such as frequency

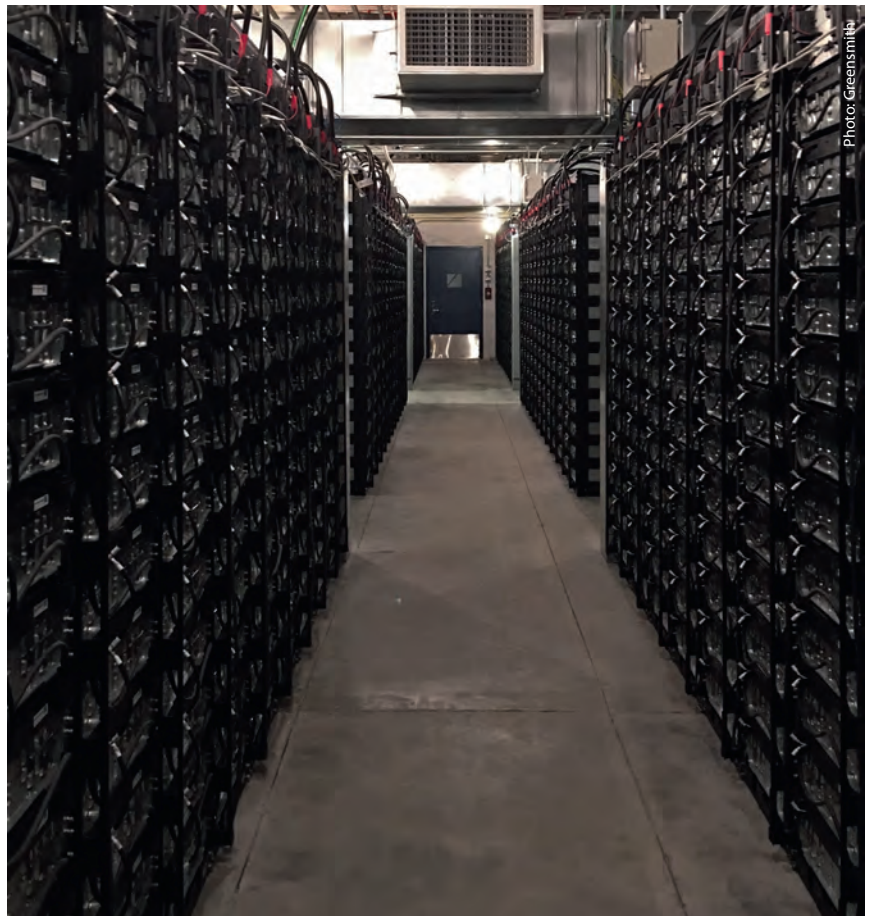


Photo: Greensmith

California utility Pacific Gas & Electric Corp's tender to replace four gas peakers with battery technology has paved the way for a trend of longer duration batteries taking on the role of peakers.

control, but are already transitioning towards capacity services, arbitrage or similar.

For investors wishing to acquire a stake in an innovative battery company, it is important to assess the clarity of vision of the new product. Selling into a wide range of markets or even trying to take on the niches that the big corporates already fill could be a risky approach.

What about the impact from big data, AI and V2G?

Are they supportive of the industry or slowing it down? The unfolding energy transition is not only impacted by evolving storage solutions and applications, but also the infrastructure needs they entail. Technology-led mega-trends such as smart cities, EV-networks, co-location with renewables and vehicle to grid (V2G) solutions will determine how much of our current infrastructure will be obsolete ten years from now. Unlike before, where developments of the different industries were separate, today everything in the flexibility space is connected and influences each other.

The complexity of future systems and the objective of achieving overlapping yet different applications within one asset can have the effect of paralyzing regulatory reform and the development of new laws.

On the plus side, developments on the software side are clearly breaking new ground, with big data analytics and machine learning algorithms being put to work on energy production data for large PV plants, allowing for ever more accurate revenue predictions or health assessments. Artificial Intelligence (AI) is, for example, allowing U.S. company Stem to build AI-powered distributed energy storage networks in a more efficient and cost-saving way.

What about my PV-storage investment case right now?

There is no simple answer, and detailed assessment of each individual case is required. In the end, the PV-battery game is all about revenues and their timing. The real uncertainty for investors lies in achieving a reliable revenue stream in the near term with the carrot of sky-rocketing upside in the mid-term future.

While solar revenues for renewables projects with government guaranteed tariffs or PPAs are rather safe, the crys-



Israel headquartered SolarEdge's recent acquisition of Li-ion battery cell manufacturer Kokam is one example of an established solar player eyeing up investments in storage to meet their own growing need for batteries.

tal ball gazing required to predict stacked battery revenues and future power curves is still something infrastructure investors are getting used to.

In the case of corporate investment, the analysis goes even deeper. A highly patented product is not sufficient for the success of an overall venture. A plausible business plan detailing market, competitor analysis, technology, patents, costs, commercialization as well as team capability are the minimum required information to weigh risks against potential returns. While investing in the final stages of a new product development or building up a service provider appear highly challenging, these investments still bear lower risks than setting up a manufacturing plant or even capitalizing a new luxury resort solely running on PV and storage. The sooner the revenues, the lower the risk, but also the lower the return. Return requirements for less risky PV-battery projects might range in the higher single digits to lower teens. A corporate invest can stretch far beyond 15%, albeit on a shorter investment horizon.

The range of PV-battery investment opportunities is almost bewildering, as are the risks and the level of commitment required. The current enthusiasm of PV-storage players is leading to innovative business models and financial solutions.

This might just fill the regulatory void left by governments around the world who are struggling to keep up with the pace of technological change. But whether you work in government or industry, finding the right blend of solutions in this complex and uncertain landscape is no easy task. A skilled drinks mixer is needed, blending quality ingredients with care to deliver a refreshing tonic for thirsty investors.

Ragna Schmidt-Haupt



About the Author

Ragna Schmidt-Haupt is a partner of Everoze, a technical and commercial energy consultancy specializing in renewables, storage and flexibility. With ~15 years of experience Ragna has gained a strong background in finance and strategy consulting across renewables technologies, with an emphasis on Solar PV. She has worked across a wide range of international markets, including a significant stint based in Singapore, leading a team of technical and strategy consultants focused on mobilizing investment in Asian markets.

Lithium-ion versus flow batteries, versus the future

As the energy storage industry begins to see meaningful growth in markets around the world, all eyes are on lithium-ion technology. But developers and utilities are investigating other battery concepts. Flow batteries are seen by some as having particularly strong advantages over lithium-ion, and several large-scale batteries are already being built using this technology.

On November 30, 2017, around 4:30 PM local time, Tesla’s 100 MW / 129 MWh battery – the world’s largest running chemical battery – at the Hornsdale Power Reserve in South Australia breathed its first life into the power grid. The lithium-ion battery, which had been delivered within its “100 days or free” timeline bet by Elon Musk on Twitter, delivered 70 MW of its electricity upon demand just as pricing started to bump up in the days before the Australian summer started.

The massive size of our global power grid means that there are going to be tens of trillions of dollars in construction contracts signed specifically for energy storage, and there will be millions of people involved in this global project. So sign right up!

There is an issue though – we’re not yet sure what we are going to build, and this is partially because we are at the most cutting, bleeding and leading edges there are.

The stupendous – amazing – explosion of a battery built in Australia – covers exactly 17 seconds of electricity usage in the country. That’s about two hundredths of a percent of the day’s electricity needs, assuming Tesla would even allow this battery to run a single 100% depth of discharge cycle per day. And further cementing the enormity of the coming change – Australia, in all its enormity, represents 0.3% of the world’s population.

Maybe what we’re saying is that we’ve got a while to go before we really know who the competitors are going to be in this space, but there are some early players worthy of consideration.

The case for lithium-ion

Because of lithium-ion batteries, our laptops and smartphones have respectable lives. And electric cars with long distance capacities – 200 miles seems to be the value that gets headlines these days – coming from many manufacturers. In the United States we’re seeing energy

storage just start to break through the soil consistently.

The most recent quarter saw an even spread across the three main market segments, and continued broader market growth. And of course, deployment volumes of the past three quarters still stand in the shadows of the period Q4 2016 – Q1 2017, when battery facilities were deployed to replace a natural gas storage field in California that had suffered a leak leading to its closure, and the Governor declaring a State of Emergency.

For many observant professionals, it was this deployment that represented a real coming of age. We’d all known the industry could deliver storage in mass produced factory assembled packages – but no one had ever bought enough to test it. Tesla’s portion of the installation, 20 MW/80 MWh, went from announcement in September 2016 to deployed in January 2017. Meaning the Australia battery wasn’t that much a risk for Elon Musk, as there had already been a test run.

| Energy Storage Contracts resulting from PG&E’s Local Sub Area Request for Offers Per Resolution E4909 | | | | | | |
|---|-----------------------|--------------|--------------|----------------------------|-----------|--------------------------|
| Counterparty (Project Name) | Storage Technology | On-Line Date | Term (Years) | Discharge Duration (Hours) | Size (MW) | Local Sub-Area |
| Dynegy Marketing and Trade, LLC (Vistra Moss Landing Energy Storage) | Lithium Ion Batteries | 12/01/2020 | 20 | 4 | 300 | South Bay – Moss Landing |
| Hummingbird Energy Storage, LLC (Hummingbird Energy Storage) | Lithium Ion Batteries | 12/01/2020 | 15 | 4 | 75 | South Bay – Moss Landing |
| Micronoc Inc. (mNOC AERS Energy Storage) | Lithium Ion Batteries | 10/01/2019 | 10 | 4 | 10 | South Bay – Moss Landing |
| Tesla Inc. (Moss Landing Energy Storage) | Lithium Ion Batteries | 21/31/2020 | 20 | 6 | 182.5 | South Bay – Moss Landing |

Source: Pacific Gas and Electric



Unienergy Technologies' containerized 2 MW / 8 MWh Vanadium Flow Battery being installed in Snohomish County, Washington State, USA.

Regarding the Australia battery, more important than it being cool or fast to deploy, is that the unit has shown to be immensely profitable for its owner. Recent quarterly filings show installation costs around \$66 million, with the installation having made approximately \$17 million in its first six months on the grid. Lithium-ion is orders of magnitude faster at some of the work being done by lumbering, steam powered, fossil plants – and its ability to extract revenue from these is enough evidence to rest one's case on.

Complementing those being deployed today are future projects being signed by electric utilities trying to deploy before the United States' 30% solar+storage tax credit drops to 10% in 2022. Warren

Buffett's utilities in Nevada tentatively agreed to 100 MW / 400 MWh worth of storage attached to multiple solar fields. The City of Los Angeles, along with Fluence Energy, has signed an agreement for a standalone 100 MW / 400 MWh project.

And, most recently, we saw California utility Pacific Gas & Electric sign on the dotted line to deploy 567 MW / 2.6 GWh of storage in four projects. This proposal includes one of the world's largest planned chemical batteries at 300 MW / 1.2 GWh, and a uniquely sized six-hour lithium-ion battery at 182.5 MW / 1.1 GWh.

These power grid battery numbers are awesome as they grow, but the 17 seconds in Australia reminds us their numbers are still small. However, there is a

dark horse in this growth of energy storage by lithium-ion game – the vehicle to grid (V2G) connection.

While there are many that doubt car owners will be interested in sacrificing their battery lifetimes for the power grid, recent field data has suggested a leading manufacturer's car batteries have the potential to lead a 500,000 mile existence before falling to 80% of their original capacity. How many car owners keep a car for that many miles? How many would sacrifice enough battery to get to 250,000 miles in their car if the power company paid them when they were parked for the rest? Imagine free fuel in exchange for capacity utilization.

The current U.S. passenger vehicle fleet is near 260 million units. If this fleet were



Australian manufacturer Redflow's Z Cell is a zinc bromine flow battery, and the first flow battery to be launched for residential purposes.

100% electrified with 100 kWh batteries that'd be 26 TWh of available capacity – just under 2.5 days worth of U.S. electricity needs stored in our cars.

2.5 days of electricity stored is a considerable tool to wield – in fact, it's five times more than enough to get the United States to 80% solar+wind power, with not much more than our current power grid, according to research presented by scientists at the University of California, Irvine; the California Institute of Technology; and the Carnegie Institution for Science in their paper titled, 'Geophysical constraints on the reliability of solar and wind power in the United States'.

It is without a doubt that lithium-ion has gained first mover status that is compounded by its use in multiple industries. And while some might lament the technological lock-in that might occur due to significant focus on this specific energy storage technique, who cares if said lock-in leads to a lithium ion price collapse anywhere akin to that of solar panels – bring it on!

And in this corner ...

At 200 MW/800 MWh, the vanadium flow battery project being built across the city of Dalian, China by Rongke Power and its technology development partner UniEnergy Technologies (UET), is the largest battery storage project under construction anywhere in the world. The battery is part of a push from the China National Development and Reform Commission to develop multiple types (including lithium-ion) of energy storage. This particular project is actually made up of 10 units dispersed around the city, each with a capacity of 20 MW/80 MWh. It's estimated it will be able to shave 8% off of the peak electricity usage when fully deployed in 2020.

UET's vanadium reduction-oxidation (redox) flow battery was developed with funding from the US Department of Energy (DOE) at the Pacific Northwest National Laboratory. The main reason utilities want to install flow batteries is they might just have an unlimited lifetime, even when using 100% of the battery

every single day, with a couple of regular component replacements.

The degradation that slowly makes your cell phone battery hold less charge doesn't exist in a flow battery. And if a battery can last for many decades, with repeatable predictable operations and maintenance costs and practices, then we see the product's 'levelized cost of storage per cycle' head toward cheap, cheap prices.

For instance, using a simplified calculation, a 1 MWh battery that costs \$1,000/kWh to install, and is 100% cycled every single day – will need to charge \$0.14/kWh to break even after 20 years. However, if the same battery is run five more years – that cost can drop 20% to around \$0.11/kWh. A 30-year lifetime gets the price to \$0.09/kWh, and at 40 years, 14,600 cycles, the price sneaks to \$0.068/kWh. A full 50% lower than a comparably priced 20 year lithium-ion battery.

The world's largest single axis tracker manufacturer – and aspiring solar power plant developer – Nextracker, has also

heard the call of the flow battery and is installing them. The NX Flow is a 10 kW-AC / 40 kW-DC vanadium flow battery.

The batteries are delivered ‘wet’ – meaning you plug them in and they run, since they were assembled in a factory. These batteries sit at the end of a 30 kW-DC, 1,000-V string of solar modules, allowing for pure and efficient DC-coupled battery charging.

Nextracker Chief Technology Officer Alex Au said, “During our evaluations of more than 40 storage alternatives, we looked at many variations on lithium-ion to flywheel to flow, as well as a host of software providers. We set our targets aggressively high by looking for a solution that was free of limitations prevalent with many technologies. Limitations characterized by mindsets like “can you use it and how much are you allowed to use it” and quantifying “are you using it in such a way that you’re keeping the product stable, so that it can be used for a long time.””

And if you give Nextracker just a moment, they’re going to tell you that with the NX Flow, what we’re really seeing are the building blocks of the world’s future solar power plants. Au says it’s time that the solar industry started to think about delivering stable, dispatchable solar powered power plants – not just solar farms – to the power grid. Not a bad start for flow batteries...

Residential flow battery

In Australia meanwhile, residential customers pay some of the highest electricity rates on the planet. It’s no surprise that the first flow battery for regular people would be launched there.

The Z Cell, by Redflow, is a 48-V DC, 10 kWh capacity zinc-bromine flow battery delivered in a quiet suburban garage with appropriate white plastic case. The unit charges at a consistent rate of 50 amps, and discharges at a standard 75 amps – but can jump to 125 when needed.

While the Redflow hardware ‘only’ comes with a ten year warranty, it is while having the unit used 100% every single day, for ten years straight. And we don’t know anything yet, but at year ten it is very probable that refresh of key hard-

ware will extend the life because this type of hardware has it in their DNA.

And if our homes are expected to last fifty years and longer – why shouldn’t our power systems? SunPower, arguably the manufacturer of the world’s highest quality consumer level solar panel, projects that 99% of their solar panels will be above 70% of original output after 40 years.

To the future

And it might just be that neither flow nor lithium-ion can meet our longest energy storage demands. The U.S. government’s Advanced Research Projects Agency-Energy (ARPA-E) has recently chosen ten projects as part of its duration addi-

“It is without a doubt that lithium-ion has gained first mover status that is compounded by its use in multiple industries”

tion to electricity storage program, which aims to develop energy storage systems that provide power to the electric grid for durations of 10 to approximately 100 hours – at \$0.05/kWh. The program suggested it would consider some opportunities that will offer energy storage systems that don’t provide frequency services and cycle only 10 times in a year. The ten programs were chosen in September of 2018. Two were flow batteries, one a fuel cell and seven thermal systems using heat exchanges.

We’re participants in an industry, at its advent, that will take a decade or more to scale before we start using words like mature, has innumerable advances and failures ahead of it, and will be the bedrock upon which a global society based upon energy collected from wind and solar drive everything an advancing species will dream up.

Let’s not get ahead of ourselves though and declare any winner, let’s deploy some projects and get things going for the next generation.

John Weaver

Limits to lithium

Lithium-ion prices are jolting upwards; it's time to take second generation storage solution seriously. Craig Irwin of ROTH Capital Partners says his company has been a long-term skeptic on both the lithium-ion battery cost curves shared by major OEMs and price forecasts presented by industry consultants.

Lithium mining operations close to the town of Silver Peak, in the Nevada desert. Commodity cost increases to lithium could mean Li-ion cell prices increase 5-15% in 2019.

Photo: Doc Seals

Public enthusiasm for lithium-ion storage solutions that should lift growth rates and enable high-level penetration for renewables has helped drive robust activity, but this technology is not without complicating factors. We understand lithium-ion cell prices are slated to increase around 5%-15% in 2019, as commodity cost increases roll through.

The seismic importance here cannot be underestimated. Utility scale project developers have been bidding PV projects two to three years ahead, anticipating the continued cost down of PV. They have been right and rewarded handsomely. These project owners and developers are now counting on continued battery cost reductions that may not materialize, or at least not on the desired timeline, to make many storage projects viable.

We are long-term supporters of the energy storage industry; and are concerned that overly optimistic cost-out forecasts for batteries could wreak havoc on future energy storage market development. Similar weak quality logic was used a decade ago to push investments in battery production for EVs, and yes these projects may have been disappointing, but the outcome was positive, as lithium was always the only clearly viable solution. We see today's market distortion differently, as overemphasis on lithium technology has pulled appropriate investment away from other battery technologies that could outperform on both installed and leveled cost metrics.

Positive sentiment vs reality

Twenty years on Wall Street, almost entirely in CleanTech, has taught me how during periods of market enthusiasm, estimates will be pro-cyclical, tracking largely with sentiment. Positive sentiment for lithium storage is undeniable, and we too are bullish (small "b"). Where things break down, is when discussion of market pricing and volumes separates from reality. We can't fault OEMs for wanting to share a competitive outlook when a neighbor suggests an overly optimistic view on how prices are heading lower, but only a few iterations can start a much wider game of liar's poker.

We closely follow the Japanese Ministry of Trade and Industry (METI) for

quality data on lithium battery cell volume and price trends (see graph below). METI data often diverges widely from pricing estimates shown by analysts and consultants. This data shows consumer lithium battery pricing as sometimes volatile, yet mostly flat for the past three years, after the prior five years of moderate cost reductions.

Looking at METI's data series for automotive also shows some impressive medium-term price improvement, as expected, but more recently prices seem to be increasing. This differs greatly from the conventional wisdom where many believe costs are dropping by over 20% a year and expect significant cost reductions to continue to the horizon.

Cost optimization through technology

The big opportunities for lower prices in lithium ion batteries come from silicon anode technology, and solvent-free manufacturing. We expect silicon anodes to reach commercial scale in consumer applications first, where there is less sensitivity to higher initial prices, as these cells will likely come at a higher cost. After a sustained period of years on the market we expect silicon anode cells to have superior economics, primarily for squeezing more juice into the box. Time will tell.

Everyone check your watches in five years? Solvent-free manufacturing for battery electrodes has the potential to reduce capital costs by over 50% for a lithium cell production facility, but experi-



Lithium batteries at end of life. Developers are now counting on continued battery cost reductions that may not materialize, or at least not on the desired timeline, to make many storage projects viable.

ence here points to major challenges. This has been tried at Electrovaya, Gore, Johnson Controls, Maxwell Technologies and others, with Maxwell's simpler carbon UCap electrodes currently the only commercial dry extruded product. Customers point to batch-to-batch, and even intra-batch variance in electrode thickness as a major problem for reliable cell assembly.

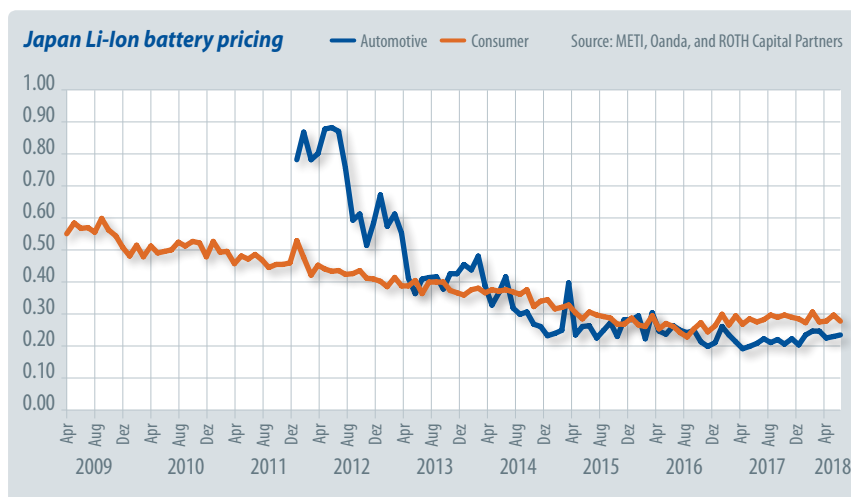




Photo: Innolith

Germany's Innolith recently announced plans to begin production of an Li-ion battery using an inorganic electrolyte. Roth Capital's Craig Irwin states that alternative Li-ion concepts and other battery technologies, 'deserve a much closer look'.

Alternatives to Li-ion

We believe second generation battery technologies are an equally credible solution that merits greater investment than has been garnered in the past couple years. Comparisons against hard data like that available from METI, instead of wishful thinking on the part of the most aggressive competitors or echoes here in analyst forecasts, shows a cost gap today for many proposed solutions that is much smaller than perceived.

In our view, the full portfolio of technologies – zinc bromide flow, vanadium flow, metal air secondary, advanced lead

acid, low cobalt lithium ion, solid state lithium ion, lithium sulfur, and others – all deserve a much closer look. We are not saying second generation technology is a certainty, but manufacturing a flow battery for example, is a lot like making a washing machine, so cost/volume forecasts are something where we think engineers can have reasonable comfort.

The failure of second-generation PV was largely due to the absence of continued venture capital investment following the bankruptcy of Solyndra. Second generation biofuels flopped as many companies came public too early, and there

was no sustained development cycle. For energy storage markets to work, we need reasonable expectations for the lithium battery price outlook, fair comparisons between technologies, and sustained development cycle for a portfolio of technologies and solutions.

Craig Irwin, ROTH Capital Partners



Photo: ROTH Capital

About the Author

Craig Irwin is a Managing Director, Senior Research Analyst leading ROTH's Cleantech coverage in biofuels, advanced lighting, and the companies providing products and services that enable the Utility of The Future, including batteries and electric vehicles. Prior to joining ROTH Capital Partners, Mr. Irwin covered Cleantech companies at Wedbush, Merriman Curhan Ford, and First Albany, where his equity research experience in the sector reaches back to 2001.

ROTH research disclosures

- Within the last twelve months, ROTH has received compensation for investment banking services from Maxwell Technologies, Inc.
- ROTH makes a market in shares of Maxwell Technologies, Inc. and as such, buys and sells from customers on a principal basis.
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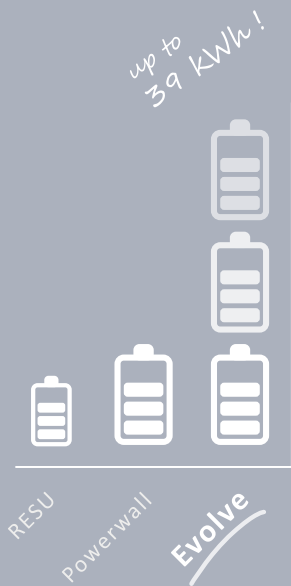


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Evolve
Home energy storage



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