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Why the time is right to invest in non-(traditional) lithium ion grid-scale battery storage

An analysis of the U.S. battery storage market through a technological, financial, and political lens

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Executive Summary

Grid-scale battery storage is the key component that will allow the U.S. to realize the full potential of a decarbonized electricity grid. It improves reliability and efficiency while simultaneously increasing grid resilience. Through both peak shaving and elimination of expensive peak load capacity, storage keeps ratepayer prices low. However, the significant shortcomings of lithium ion batteries and the promise of other battery technologies should encourage utilities and generators to invest in diverse storage assets in order to maximize grid resilience. Technologies such as plastic polymers, vanadium redox flow batteries, and zinc hybrids deserve greater attention and have the potential to create a more dynamic grid storage market that favor the consumer.

This paper analyzes the U.S. battery storage market from a technological, financial and political perspective. It argues for greater investment in non-(traditional) lithium ion grid-scale battery storage, using three specific technologies and the work of several companies focused on each technology as case studies. Such investments are sensible from a financial as well as a sustainability perspective and the reader will learn why in the following pages.

The three perspectives (technological, financial, and political) presented in this paper have been written by different authors. The final paper is a collaborative product that aims at giving a comprehensive overview of the U.S. grid-scale battery storage market.

Technological considerations regarding grid-scale battery storage investments

BY AMANDA FORMICA

With government and corporate commitments to achieve carbon neutrality by 2050 and projections indicating that the global energy storage market will double six times by 2030, now is the best time to invest in energy storage technology. Utility companies are seeking to deploy new battery technologies that can be paired with wind and solar energy to make renewables dispatchable, flatten out clean energy supply, and eliminate the need for costly and dirty peaker plants. Lithium ion technology currently dominates the market, but it is less than ideal to meet the needs of grid storage that are looking for 4+ hours of storage time at large scale with materials that are safe, non-toxic, and plentiful. This is where solid-state plastic polymer electrolytes, zinc hybrid cathode batteries, and vanadium redox flow batteries provide promising improvements on the battery value chain. These technologies are poised for large-scale deployment to meet the needs of the energy grid and provide ideal opportunities for people looking to invest in the future of battery storage.

Importance of storage for a resilient grid

Governments and corporations around the world have made ambitious commitments to scaling up the use of renewable energy, and many of them have signed pledges to become nearly carbon neutral by 2050. At the same time, global energy demand is increasing as consumers incorporate more electronic devices into their lives and countries urbanize; moreover, energy needs to remain reliable, affordable, and resilient in the face of climate change. The opportunity that lies at the intersection of these challenges is advanced battery storage. According to Bloomberg New Energy Finance, the global energy storage market is set to double six times by 2030, to over 125 gigawatts/305 gigawatt-hours of installed capacity.[1] Currently lithium-ion battery technology has the largest share of the market due to use by major electric vehicle manufacturers. However, both the U.S. Department of Energy (DOE) and International Energy Agency (IEA) anticipate limits to the growth of li-ion batteries and a demand for other advanced battery technologies to meet the variety of needs for storage by utilities, car manufacturers, consumer electronics producers, and others.[2]

Power generators are looking at ways to partner strategically with, invest in, or acquire advanced battery technology companies. Wind and solar power are intermittent energies, with the strongest wind generation at night when demand is low, and solar generation during the day. Not only are they inconsistent, but neither supply curve can perfectly match the market demand curve. Battery storage paired with wind and solar allows for a smooth supply curve. It also enables renewables to dispatch energy, which would help put renewables first on the energy bid stack for regional system operators and guarantee a higher and more consistent revenue stream. Renewables paired with storage on the grid would also eliminate the need for peaker plants, which are expensive to maintain relative to infrequent usage and often powered by the dirtiest and most expensive forms of energy, such as coal. Adequately stored renewable power could be dispatched when demand is expected to spike and could do so at a more affordable price. Battery storage is also attractive to utility companies because of its ability to make the grid more resilient. For islands and isolated communities that would require expensive transmission lines or that are prone to major storms, storage-backed microgrids can provide secure and stable power supply for less money. All of these uses for battery storage set the stage for targeted investments in key startups.

Battery Basics

Battery storage allows electrical energy to be converted into stored energy for use later. A basic battery consists of two electrodes called an anode and cathode, two terminals comprised of different chemicals, and an electrolyte separating the terminals that allows the ions to flow between the anode and cathode and create the electrical charge.[3] The materials used in these batteries can include lithium, cadmium, nickel, zinc, sodium, vanadium, and even plastic. Most of the storage capacity currently deployed globally is in pumped hydropower; in the U.S., 94% of storage capacity is in the form of hydropower.[4] Hydropower and Compressed Air Energy Storage (CAES) technologies are both mature. CAES deserves more attention for its potential grid-scale applications, but both are limited by geography and scale. Flywheels are another type of storage technology but are not able to store energy for long periods. Given these constraints, advanced battery technologies hold the most promise for capturing the current and projected exponential growth in the storage market.

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[1] Bloomberg New Energy Finance, "Global Storage Market to Double Six Times by 2030," https://about.bnef.com/blog/global-storage-market-double-six-times-2030, (November 20, 2017).

[2] David Hart and Alfred Sarkissian, "Deployment of Grid-Scale Batteries in the United States," Office of Energy Policy and Systems Analysis, U.S. Department of Energy, https://www.energy.gov/sites/prod/files/2017/01/f34/Deployment%20of%20Grid-Scale%20Batteries%20in%20the%20United%20States.pdf, (June 2016): 28.

[3] Center for Sustainable Systems, "U.S. Grid Energy Storage Factsheet," University of Michigan, Pub. No. CSS15-17, http://css.umich.edu/sites/default/files/U.S._Grid_Energy_Storage_Factsheet_CSS15-17_e2018.pdf, (August 2018).

[4] Ibid.

Several terms are important to understand when comparing battery technologies. The rated power of a storage technology is in megawatts, while the energy storage capacity is expressed in megawatt hours.[5] Depth of discharge is the percent of energy used up and the state of charge is the percent of energy remaining in a battery.[6] It is also important to compare energy density of different batteries, or the amount of energy that can be stored in a given volume or weight. Round trip efficiency is the amount of energy that can be discharged from a battery after it has been fully charged, for example 80kWh for every 100 kWh of charge. Finally, it is important to consider the lifetime of the battery because some metals erode the battery with every cycle, meaning that it stores much less power later in its lifetime or has a short lifespan before needing replacement.

> *"Target companies will bring to market technologies that address the shortcomings of li-ion batteries by providing four to ten hours of storage potential, have a high power density and discharge rate, be safe, non-flammable, and non-toxic, rely on widely available materials that cause minimum environmental and labor concerns upstream in the supply chain, and are affordable to manufacture and transport."*

The drawbacks of lithium ion batteries

Lithium-ion (li-ion) is a powerful technology, but its major shortcomings are the following: safety, cost to maintain, energy density, and mine insecurity. While lithium ion batteries are the most popular technology on the market currently because of their use in electric vehicles, they possess inherent drawbacks that make them less than ideal investments for grid storage. Lithium ions form a flammable liquid that only functions properly within a certain temperature range; when it heats up, the liquid gives off toxic fumes. As a result, li-ion's safety concerns mean that it can be hazardous and expensive to manufacture and transport, that it does not work well under extreme weather conditions, it might not apply well to dry climates prone to forest fire hazards or that are thickly settled, and that it poses a concern for energy reliability.

The energy density of li-ion technology is 140-210 wh/kg (watt-hours per kilogram) by mass. Each time the battery is recharged and discharged it degrades slightly, meaning that it has only a certain lifetime before needing replacement. This quality drives up maintenance costs for li-ion technology and means that its capacity to store energy decreases over the life of the battery. For renewable energy grid-scale storage, reduced storage capacity over time has major financial consequences and can mean the difference between a financially viable and not viable project and the ability of a renewable with storage to compete in the market with fossil fuels on a per kWh basis. It is for the same reason that li-ion batteries cannot be left without charge for long periods, meaning it hurts the quality of the battery if they are completely recharged and then discharged.

Another drawback of li-ion batteries is that they only hold their charge for two to four hours, which is helpful for peak shaving and reduced reliance on peaker plants, which usually use the dirtiest kinds of energy and are costly to maintain. At the same time, this short storage time capacity is not ideal from a reliability standpoint. As a power generator, if you only have the financial capability of investing in one kind of storage technology to pair with your renewable energy to increase grid resilience, then you want to invest in a technology that will store energy for as many hours as possible.

Finally, any overreliance on a single technology leaves power grids equally vulnerable to that technology's supply chain. In this case, the global lithium supply is concentrated in just several countries, including China, Chile, Bolivia, and the Democratic Republic of Congo.[7] The scaling up of lithium could potentially exacerbate questionable labor practices of certain lithium mining enterprises. It could also have unintended geopolitical consequences and national security risks, as can be seen with global reliance on petroleum and the negative consequences of the 1970s oil crisis in the U.S. Although lithium ion technology has valuable uses, its risks point to market opportunities to invest in other storage technologies that improve on these weaknesses.

Considerations for Investment

Those looking to invest in new storage technologies should target investment in early stage battery storage companies that are poised for the largest growth over the next several decades, which is why it would be best to invest in companies that are looking at non-lithium-ion solutions. The best companies will be at an early stage of growth to maximize the future potential for a given investment.

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[5] Ibid.

[6] Roger Lin, "Introduction to Grid Energy Storage," NEC Energy Solutions, https://www.2018energyexchange.com/wp-content/uploads/T10S1_Lin.pdf, (August 2017): 50.

[7] David Chandler, "Will metal supplies limit battery expansion?" MIT News, http://news.mit.edu/2017/will-metal-supplies-limit-battery-expansion-1011, (October 11, 2017).

Target companies will bring to market technologies that address the shortcomings of li-ion batteries in that they provide four to ten hours of storage potential, have a high power density and discharge rate, are safe, non-flammable, and non-toxic, rely on widely available materials that cause minimum environmental and labor concerns upstream in the supply chain, and are affordable to manufacture and transport.

Solid Polymer Electrolytes

Perhaps one of the most cutting edge, but also the most promising, technologies with potential to influence the entire battery storage market by making it safer and more affordable are solid polymer electrolytes (SPEs). To date, the startup that is farthest along in bringing their product to market is Ionic Materials, but other research teams have developed similar solutions that are awaiting commercialization.[8] SPEs conduct electricity between the anode and cathode in a battery. The polymer, or in some cases gel, acts as the battery's electrolyte, taking the place of a lithium ion, other metals, or ceramic. The thin plastic sheet is stable under a wide range of temperatures, is non-flammable, and does not give off toxic fumes. SPE's durable structure means that it can be produced affordably, stored, and transported without safety issues or major concerns about damage to the product. It is lightweight also enables large quantities to be easily transported. These qualities will help to drive down cost as products scaled.

> ***"The primary risk associated with this technology, much like other battery storage technologies, is the reliance on zinc itself. Although global zinc deposits appear to be 20 times more plentiful than lithium, it is still a finite resource that could be depleted perhaps within only a few decades."***

By applying an SPE technology with lithium metal cathodes and anodes, as opposed to lithium ion, it is possible to yield five to ten times the energy density of a li-ion battery and reduce the use of lithium. At the same time, SPEs could be used with a wide range of anode and cathode materials. Its non-flammability and non-toxicity also give it a higher energy capacity when compared with other technologies.[9] Polymers do not degrade in quality with each use, enabling a longer lifetime and greater storage capacity. Since the innovation is in a battery component, rather than the entire battery structure, SPEs can be applied to any battery use, including grid-scale storage, electric vehicles, and consumer electronics.

Although SPEs are promising as potential investments, there are several risks to be aware of. They are still in the early stages and have not yet been applied to any grid storage projects or application to either front of the meter or behind the meter storage technology. The risk lies in the unknowns associated with being an early stage technology, such as exactly how effective its technology will prove at scale and how much it will ultimately lower battery costs. A potential advantage that SPEs have over other types of battery storage during commercialization is that by producing a plastic-based material they eliminate the supply chain and environmental challenges of technologies that rely on heavy metals.

Zinc-Based Battery Storage

Battery technologies based on zinc and zinc compounds offer promising potential investments because they rely on non-flammable, non-toxic technologies that can be easily disposed of.[10] There are a number of companies competing in this space with variations on zinc, such as Eos Energy Storage's zinc hybrid cathode "zynth" battery, NantEnergy's zinc air battery, EnZinc's zinc sponge electrode, and ZincNyx's zinc-air flow battery. Startups in the zinc battery category have already deployed. For example, utility-scale storage projects that produce over 400 MWh of electricity annually per location, are among the first storage companies to bid in at $160 per usable kWh in 2017 and $95 per usable kWh in 2022.[11] Some zinc-based products can store three to six hours of energy, so that they are three times better suited for peak shaving and grid reliability than li-ion batteries.[12]

The primary risk associated with this technology, much like other battery storage technologies, is the reliance on zinc itself. Although global zinc deposits appear to be 20 times more plentiful than lithium, it is still a finite resource that could be depleted perhaps

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[8] Liping Yue, et al., "All solid-state polymer electrolytes for high performance lithium ion batteries," Energy Storage Materials, volume 5, https://www.sciencedirect.com/science/article/pii/S2405829716301349 (October 2016): 139–64; "Engineers design new polymer electrolyte, paving way for safer, smaller batteries and fuel cells," University of Pennsylvania, https://phys.org/news/2018-05-solid-polymer-electrolyte-paving-safer.html, (May 31, 2018).

[9] Lauren Goode, "Batteries still suck, but researchers are working on it," Wired, https://www.wired.com/story/building-a-better-battery, (May 22, 2018).

[10] Ivan Penn, "How Zinc Batteries Could Change Energy Storage," New York Times, https://www.nytimes.com/2018/09/26/business/energy-environment/zinc-battery-explain.html, (September 26, 2018).

[11] Jason Deign, "Eos grapples with scale-up challenges on route to DC cost of $95 per kWh," Energy Storage Report, http://energystoragereport.info/eos-grapples-scale-challenges/#sthash.N8vON6Vu.TEDKIX7T.dpbs, (October 31, 2017).

[12] Ibid.

within only a few decades.[13] While 7% of global zinc production is in the U.S., over half is in China and Australia, meaning that there is no major political risk today to accessing zinc, but there is a potential for one in the long term. Zinc is often mined alongside lead, cadmium, and nickel, and poses environmental threats to the areas where it is mined through toxic sulfur dioxide and cadmium vapor releases.[14] At the same time, despite its affordable cost, zinc-based battery companies face challenges. These include lack of transparency because potential customers are not able to see exactly how their technology works; there is comparatively little readily available research comparing it with the effectiveness of other battery types; and the technology has not been tested and replicated successfully around the world the same number of times as some other battery technologies. One way to mitigate this risk is through partnership with larger, more established companies.[15] While it is not clear if the leading zinc-based battery companies are doing anything to mitigate the first risk inherent to zinc mining, it is a risk shared with almost all other batteries on the market, including all lithium-based technologies.

Despite some level of risk inherent in the reliance on zinc, the risk is still less than with reliance on lithium due to its wider geographic distribution and larger global supply. The low price point offered by several zinc-based battery companies for their product deployment, combined with a number of successful grid storage deployments of this technology, means zinc-based batteries have the potential and infrastructure in place for rapid scaling in the near future.

Vanadium Redox Flow Batteries

Several startups and at least one publicly traded company are answering the battery storage challenge with vanadium redox flow batteries, which rely primarily on liquid vanadium. Some of these companies include CellCube, VRB Energy, UniEnergy Technologies, and Vionx Energy.[16] While prices are not available for all companies, CellCube is selling its storage for $200 per kWh, which provides an example for price comparison with other technologies.[17] Vanadium redox flow batteries employ liquid vanadium as the electrolyte that flows through stacked electrochemical cells.[18] These types of batteries may achieve 80% energy efficiency and store energy for up to eight hours.[19] An electrode membrane acts to diffuse charged vanadium, hydrogen ions, and water across the battery.[20] Unlike li-ion batteries, vanadium flow batteries do not degrade the anode and cathode materials with use as long as pure vanadium is used.[21] They can be fully charged and discharged, as well as left discharged for long periods, without damaging the functionality or capacity of the battery. A pump operates to replace the spent vanadium fluid in the battery with new fluid, while also recharging the spent fluid for another use. In a flow battery, energy is stored as the liquid electrolyte, rather than as the electrode material as it is in other batteries.[22]

As compared to li-ion batteries, no toxic gases, fires, or explosions are associated with vanadium redox flow batteries, and the most promising companies use exclusively non-flammable materials. The ideal temperature range for proper operation is between 10 and 40 degrees Celsius, so active cooling sub-systems are installed with the batteries to ensure proper operation. If they overheat, the batteries must be shut off temporarily until they cool down.[23] The vanadium flow battery's ability to be fully charged and discharged without damaging the machine gives it the ability to be cycled (charged and discharged) an unlimited number of times (100% depth of discharge), enabling a 20-year warranty that matches with the estimated lifetime of an average renewable energy generation asset.[24]

Vanadium is typically a component in steel and chemical manufacturing and has recovery through some waste streams.[25] Although there are small deposits of the vanadium mineral in the U.S., larger deposits are concentrated in Australia, South Africa, China, Russia, and Brazil. One potential risk with this technology involves possible future security risks and reliable access to

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[13] Ivan Penn, "How Zinc Batteries Could Change Energy Storage," New York Times, https://www.nytimes.com/2018/09/26/business/energy-environment/zinc-battery-explain.html, (September 26, 2018).

[14] Ibid.

[15] Julian Spector, "Eos finds a partner in Siemens to scale an unusual battery," Greentech Media, https://www.greentechmedia.com/articles/read/eos-finds-partner-in-siemens-on-path-to-scaling-unusual-battery#gs.NKVoC50, (January 30, 2017).

[16] Cision, "Stina announces completion of acquisition of the Gildemeister assets and resumes production of CellCube vanadium flow battery," https://www.newswire.ca/news-releases/stina-announces-completion-of-acquisition-of-the-gildemeister-assets-and-resumes-production-of-cellcube-vanadium-flow-battery-681347251.html, (May 1, 2018).

[17] Andy Colthorpe, "CellCube: 4-hours is just tip of peaking capacity iceberg," Energy Storage News, https://www.energy-storage.news/news/cellcube-4-hours-is-just-tip-of-peaking-capacity-iceberg, (August 15, 2018).

[18] Ibid.

[19] Ibid.

[20] Energy Storage Association, "Vanadium Redox Flow Batteries," http://energystorage.org/energy-storage/technologies/vanadium-redox-vrb-flow-batteries.

[21] Ibid.

[22] Energy Storage Association, "Flow Batteries," http://energystorage.org/energy-storage/storage-technology-comparisons/flow-batteries.

[23] Energy Storage Association, "Vanadium Redox Flow Batteries," http://energystorage.org/energy-storage/technologies/vanadium-redox-vrb-flow-batteries.

[24] Ibid.

[25] Ibid.

vanadium in the long term, particularly in China and Russia. As companies attempt to scale production it might prove more difficult for companies relying on vanadium to monitor the labor practices and working conditions of the mines where they source their metals. The fact that vanadium flow batteries incorporate more moving parts than li-ion batteries means that they can be prone to higher cost for repairs in the event of a malfunction.[26] This is particularly true for the pump that is required to pump out the discharged and recharged vanadium liquid and is key to the battery's functionality. Vanadium-based batteries can also be difficult to make cost competitive when compared with other technologies, though some companies are looking to prove that tendency wrong.

The primary advantage of the redox flow battery, when compared with other battery types, is its eight-hour discharge time. This discharge time, paired with the use of inflammable materials, 100% depth of discharge ability, low maintenance costs, and megawatt level scalability, drive down its long-term costs and make it ideal for grid storage applications.[27] Eight-hour storage time means that it has the potential to be scaled for use with intermittent power generation like wind and solar and allow it to become dispatchable energy. It can help to deploy solar energy from the daytime for evening peaks and wind energy from the night for morning peaks in residential and commercial use, allowing for the levelized cost of energy to be reduced for renewables because they would increase in dispatchability. This technology can also play an important role in smoothing out the inconsistent supply of electricity from renewables and can help with peak shaving by storing up electricity during low use times and deploying it during peak usage by the grid.

Summary of technological arguments for grid-scale battery storage investments

Utility companies, governments, and corporate stakeholders are eager to take part in the low carbon economic transition, but they need technological options that will make it easy and affordable to do so. Advanced battery storage companies that can offer a reasonable cost and stable long-term investment, allow for renewables to become dispatchable, and provide reliable technology that offers over four hours of storage face exponential market demand for their products. Plastic polymer electrolytes, vanadium redox flow batteries, and zinc-based batteries all offer emerging technological solutions that can address the unique challenges of grid-scale electricity generators, address many of the drawbacks of lithium ion batteries, promise to break the $100 a kWh cost barrier, and are poised for takeoff. ▪

Financial considerations regarding grid-scale battery storage investments

BY MICHAEL SEMERARO

The rise of renewable energy generation, new regulations, and falling battery prices will result in an increased demand for battery energy storage. Lithium-ion batteries, the prevailing battery technology, have already fallen in price per kWh from approximately $1,000/kWh in 2010 to $209/kWh in 2017 and could fall another 67% in price by 2030 to $70/kWh.[28] Additionally, other battery technologies, which are cheaper and more suitable to grid-scale energy storage, are expected to see their capital costs decline at a rate faster than lithium-ion over the next 5 years. While capital costs for batteries based on lithium-ion technology could decline by 28% over the next 5 years, vanadium flow batteries might decline by 38%, and zinc bromide flow batteries are expected to decline by 45%.[29] Due to its size, the overall global market for batteries will have an impact on the economics of the energy storage battery market.

With the reduction in battery costs, the levelized cost of storage (LCOS) for the energy storage systems will open the market to new investment opportunities. According to Bloomberg New Energy Finance, 1,291 GWs of battery storage capacity are likely to become available globally between 2018 and 2050. This increase in capacity will require over $620 billion in investments through 2040 and result in total energy storage capacity growing to 7% of total installed generating capacity globally.[30] Of the new capacity installed by 2050: 60% of the storage installed will be used within the grid itself, and 40% of the batteries will be installed behind-the-meter.[31]

All these developments create a very favorable market for the future of battery energy storage systems. While the market for stationary

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[26] International Renewable Energy Association, "Electricity Storage and Renewables: Costs and Markets to 2030," http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Oct/IRENA_Electricity_Storage_Costs_2017.pdf, (October 2017): 87.

[27] Andy Colthorpe, "Long Time Coming: Part 1," Energy Storage News, https://www.energy-storage.news/blogs/long-time-coming, (June 14, 2018).

[28] Bloomberg, "Batteries & their impact on the electricity sector," https://bnef.turtl.co/story/neo2018, (November 2018).

[29] Lazard, "Lazard's Levelized Cost of Storage Analysis - Version 4.0," https://www.lazard.com/media/450774/lazards-levelized-cost-of-storage-version-40-vfinal.pdf, (November 2018).

[30] Mark Scott, "Battery Energy Storage Is a $620 Billion Opportunity As Costs Continue To Crash," Forbes, https://www.forbes.com/sites/mikescott/2018/11/09/battery-energy-storage-is-a-1-trillion-opportunity-as-costs-continue-to-crash, (November 9, 2018).

[31] Bloomberg, "Batteries & their impact on the electricity sector," https://bnef.turtl.co/story/neo2018, (November 2018).

battery energy storage systems is projected to increase rapidly over the next two decades, the market for batteries will be dominated by the demand from electric vehicles (EVs). Bloomberg projects that by 2025, the annual demand for batteries for EVs will be 408 GWh and that demand will grow to 1,293 GWh annually by 2030. This compares with a demand of 65 GWh in 2025 and 200 GWh in 2030 for stationary storage.[32] The demand from EVs will result in higher costs for raw materials, particularly those used with the lithium-ion battery chemistries. The increase in demand, and the specialized nature of the batteries demanded by EVs, as opposed to stationary storage batteries which do not have as significant restrictions on energy density, weight or size, opens the opportunity for new battery manufactures to enter the market to supply batteries which meet the market needs.

Battery Manufacturers Overview

The current demand from EVs has been the primary driver of investment in the battery-manufacturing sector thus far. Global manufacturing capacity for lithium-ion batteries to supply new EV vehicles will likely triple from 116 GWh to 351 GWh by 2021.[33] This investment surge includes many high-profile battery corporations including Panasonic, LG Chem, CATL and SK Innovation. While the overall investment has received a positive outlook, there are recognized risks to the massive expansion in manufacturing capacity.[34] The majority of the announced plants in development are for lithium-ion batteries, which require a complex supply chain to acquire the raw materials and key components needed for battery manufacturing. Without investment in the components, the manufactures will not be able to obtain the materials necessary to expand capacity. Additionally, many of the raw materials are already scarce and the increase in manufacturing capacity could drive the costs of lithium and cobalt, which have already tripled over the last three years, to increase further, raising overall battery costs.[35]

> ***"While the overall battery manufacturing market has its challenges, several companies and technologies can take advantage of the demand for energy storage."***

Economics of a Battery Manufacturing Plant

The potential return of investing in a battery manufacturing plant is rather risky; Panasonic invested $1.9 billion in its Gigafactory for Tesla in Nevada and as of November 2018, they had yet to turn a profit.[36] Since the initial capital costs of the plant are fixed and relatively high, battery manufacturing has a high barrier to entry. As more manufacturers enter the market, the prices, and consequently revenue, per battery pack will decline due to efficiency and increased competition. This will result in new entrants having to wait longer to achieve a return on their investment. Clearly, there is a significant advantage to being an early market entrant, and success in the battery manufacturing market is reliant on the ability to remain cost competitive as overall battery prices decline, which will be challenging if new technologies drive prices lower or make prior investments obsolete.

Battery Market Investing Strategy

While the overall battery manufacturing market has its challenges, several companies and technologies can take advantage of the demand for energy storage. Ionic Materials' solid polymer has the potential to provide a solid electrolyte for batteries, which will work with a variety of chemistries.[37] The battery material is also non-flammable and has a higher energy density than the existing liquid electrolytes. The solid-state nature of Ionic's electrolyte opens the possibility to revolutionize the battery manufacturing techniques, reducing costs due to manufacturing efficiencies, which cannot be achieved with liquid electrolyte batteries. The technology caught the attention of the U.S. government, which awarded Ionic Materials a $3 million ARPA-E grant in November 2018 to develop their solid polymer to utilize an aluminum-alkaline chemistry.[38]

Another firm, Eos Energy Storage, utilizes a zinc hybrid cathode, streamlined manufacturing techniques, and a utility scale storage solution at a low cost. Their main product, the Eos Aurora, is a 1 MW, 4 MWh system which is guaranteed by the company to operate

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[32] Claire Curry, "Lithium-ion Battery Costs and Market," Bloomberg, https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf, (July 5, 2017).

[33] Tobias Nystedt, "Battery Energy Storage Topic Primer," Bloomberg, (August 23, 2018).

[34] Claire Curry, "Lithium-ion Battery Costs and Market," Bloomberg, https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf, (July 5, 2017).

[35] Tobias Nystedt, "Battery Energy Storage Topic Primer," Bloomberg, (August 23, 2018).

[36] Pavel Alpeyev, "Panasonic Says Gigafactory Profit in Sight as Tesla Ramps Output," Bloomberg, https://www.bloomberg.com/news/articles/2018-11-01/panasonic-says-gigafactory-profit-in-sight-as-tesla-ramps-output, (November 1, 2018).

[37] Henry Sanderson, "Electric cars: the race to replace cobalt," Financial Times, https://www.ft.com/content/3b72645a-91cc-11e8-bb8f-a6a2f7bca546, (August 20, 2018).

[38] U.S. Department of Energy, "ARPA-E Open 2018 Project Descriptions," https://arpa-e.energy.gov/sites/default/files/documents/files/OPEN_2018_Project_Descriptions_FINAL.pdf, (November, 2018): 8.

for 20 years without significant maintenance. The system costs $160 per kWh with the price for the next generation at $95 per kWh for delivery in 2022.[39] At such a price, zinc hybrid cathode batteries will be at a cost level below the industry average as projected by Bloomberg.

A final technology, vanadium flow batteries, have the advantage of offering the market long duration solutions at a large scale. Vanadium is also advantageous as the battery technology is projected decline in cost faster than lithium-ion based batteries, offering a cheaper alternative which doesn't degrade and provides a long-term, 4–8-hour supply of energy, advantageous for use in electrical grids. One company has installed over 130 vanadium flow battery systems globally, totaling 4.3 MW with an energy capacity of 19.9 MWh.[40] Vanadium flow batteries are targeted at customers who need large energy storage systems. These systems can provide clients with the ability to supplement their generation capabilities to improve grid stability, manage peaking capacity or maximize renewable generation.

Summary of financial arguments for grid-scale battery storage investments

The demand for energy storage systems is growing at an incredible rate. Companies are racing to construct new manufacturing facilities to meet the projected future demand while new entrants are working to commercialize technologies, which could revolutionize the industry. With the potential to have over $620 billion dollars invested into the market globally by 2040, there are many opportunities to invest within the industry. As the world looks toward the future of energy, the demand for battery energy storage will continue to grow. New battery technologies like the solid polymer of Ionic Materials have the potential to change how batteries are made, revolutionizing the manufacturing process. Meanwhile other battery chemistries, like zinc hybrid cathode and vanadium, have proven to be highly useful in certain circumstances and are in demand. ▪

Political considerations for grid-scale battery storage investments

BY MARA MENZ

Grid-scale energy storage is the key element for the U.S. grid transition into a renewable future with low electricity prices, fair distribution, and less power outages. Even though the U.S. administration opted out of the Paris Agreement to an 80% reduction in greenhouse gas emissions, the target is still relevant. Many states have instituted renewable portfolio standards (RPS) as a way to enhance the speed of the energy transition.[41] Grid-scale energy storage has the potential to make this transition easier, quicker, and cheaper. It enables the balancing of supply and demand in the electricity market. By smoothing the load curve, battery storage avoids costly investments in peak generation and transmission lines. It makes the grid more reliable while at the same time keeping it resilient.[42] The time is right to invest in mid-stage grid storage battery producers that present alternatives to traditional lithium-ion technology:

1. Grid-scale energy storage is the key component to a renewable energy transition as it is the only means to transform renewable energy sources into baseload and thus enable a reliable renewable grid;
2. Grid-scale energy storage gained in salience and many regulatory adjustments did or are about to levelize the market. Investments in the current stage are promising;
3. Grid-scale storage that differs from traditional lithium-ion technologies opens up the market, lowers electricity prices for consumers, and offers investors early stage advantages.

The benefits grid-scale energy storage has to offer

The potential of grid-scale energy storage for a renewable energy transition is manifold. The following is an iteration of the most important benefits.

Increased grid reliability and reduced infrastructure costs

The U.S. power grid relies almost entirely on large, centralized power plants. These plants have limited ability to adapt to changing needs. Hence, the energy network must address the predictable and infrequent peaks in demand. This system design is vulnerable to disruptions and ineffective at adapting to changes in network

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[39] Eos Energy Storage, "Eos Energy Storage Now Taking Orders at $95/kWh for the Eos Aurora DC Battery System," https://www.businesswire.com/news/home/20170418005284/en/Eos-Energy-Storage-Orders-95kWh-Eos-Aurora%C2%AE, (April 18, 2017).

[40] CellCube Energy Storage Systems, "Investor Presentation," https://www.wallstreetreporter.com/wp-content/uploads/2018/10/cellcube-presentation.pdf, (July, 2018)

[41] National Conference of State Legislatures, "State Renewable Portfolio Standards and Goals," http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx, (July 20, 2018).

[42] David M. Hart, William Bonvillain, and Nathaniel Austin, "Energy Storage for the Grid: Policy Options for Sustaining Innovation," MIT Initiative Working Paper, http://energy.mit.edu/publication/energy-storage-for-the-grid, (April 2018): 4.

conditions. Essentially, consumers have to pay for an overbuilt system burdened with underutilized assets. Furthermore, the current trend towards electrification brings about increasing load that poses reliability challenges for the system at peak demand times. System disruptions yield massive costs for the public.[43] Grid-scale energy storage is able to instantly adapt to changing network conditions, smooth out load curves and ensure system capacity in different locations.[44] Hence, investments in grid storage make the grid more reliable, increase efficiency, and reduce the need for costly peak demand plants or transmission lines. Low energy prices are an important aspect for voters, thus policy makers should be motivated to enable more favorable policy adaptions for grid-scale energy storage.

> *"System disruptions yield massive costs for the public. Grid-scale energy storage is able to instantly adapt to changing network conditions, smooth out load curves and ensure system capacity in different locations."*

Increased grid efficiency and empowering of renewables

To date, 29 states have adopted renewable portfolio standards, while 8 states set renewable energy goals.[45] However, due to the limited ability of the grid to store energy, tens of thousands of megawatt-hours of renewable energy are lost. If one looks at the load duck curve, one becomes instantaneously aware, that storage is the best means to avoid wasting this much emission-free energy. Storage supply is especially valuable at peak times and thereby significantly increases the efficiency of the grid. Currently, the top 10% of demand can account for more than 40% of the total system costs. The deployment of grid-scale storage can reduce these metrics considerably.[46] In addition, the Energy Storage Association assesses that 35 GW storage deployment in the U.S. grid could save 3,666,200 mt-Co2 (metric tons of carbon dioxide equivalent) in emissions by 2025.[47] Hence, in order to implement the renewable portfolio standards and to make renewables economically compatible with traditional energy sources, it is indispensable to make regulatory adaptions that levelize the market for grid storage deployment.

A decentralized grid with new technologies: a security asset

With the fostering of renewables, more plants will come online that generate loads of around 150 MW.[48] Thus, storage enables a decentralization of the grid, especially if one considers not only the potential of grid-scale storage but also the battery capacity of EVs and home storage. This reduces the need for major infrastructure investments in energy-generating plants and transmission lines. In addition, with terrorist and warfare attacks increasingly happening nowadays through technological means, a decentralized grid presents a security asset. It is far more resilient against cyber-attacks and other threats than a centralized grid. In addition, it strengthens resiliency towards environmental catastrophes, which are an increased threat due to climate change.[49] Thus it is highly relevant from a security perspective to foster investments into grid-storage. If one looks at the cumulative value of lost load (VOLL) in case of power outages, which is rapidly growing for residential and industrial customers, one realizes that such costs are not bearable for the public in the long run. Politicians are certainly motivated to reduce these risks by enabling energy storage investments.

Political Adaptions for levelized competition of grid-scale storage

Policy makers increasingly recognize the potential of grid-scale battery storage and understand that there must be regulatory changes to promote this technology. Changes are needed to overcome the three main challenges grid-scale energy storage is facing in today's electricity market: 1) flexibility services that are offered by grid-scale storage call for a competitive wholesale market structure; the current market structure hampers levelized competition; 2) rigid energy network regulations are not suitable for storage services, which tend to avoid the use of regulated networks;[50] 3) storage building is dependent on policy incentives which should be increased.[51] These challenges have been gradually addressed through regulatory adaptions by the Federal Energy

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[43] Energy Storage Association, "35x25: A Vision for Energy Storage," http://energystorage.org/vision2025, (November 2017): 6.

[44] Ibid.: 8

[45] National Conference of State Legislatures, "State Renewable Portfolio Standards and Goals," http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx, (July 20, 2018).

[46] Energy Storage Association, "35x25: A Vision for Energy Storage," http://energystorage.org/vision2025, (November 2017): 7–8.

[47] Ibid.: 15.

[48] U.S. Energy Information Administration, "Cost and Performance Characteristics of New Generating Technologies," Annual Energy Outlook 2019, (2019): 2.

[49] Energy Storage Association, "35x25: A Vision for Energy Storage," http://energystorage.org/vision2025, (November 2017): 14.

[50] Miguel Vazquez and Matteo Di Castelnuovo, "Policy and Regulation for Energy Storage Systems," Working Paper Series: ISSN 1973-0381, ftp://ftp.unibocconi.it/pub/RePEc/bcu/papers/iefewp106.pdf, (June 2018): 1.

[51] Energy Storage Association, "State Policies to fully charge advanced energy storage: The Menu of Options," http://energystorage.org/statepolicymenu, (July 2017).

Regulatory Commission (FERC) and at the state level. More policy adaptions for grid-scale storage can be expected in the future.

Changing the unilateral grid design

The electric system was designed before cost-effective energy storage was available. The traditional electric industry is one-dimensional: electricity flows from generators over utilities to loads. Money flows in the opposite direction, from loads to generators. However, battery storage alters that system by adding a two-dimensional element. This means that batteries can act as consumers in low load times and buy energy from the grid. In high load times, batteries can take on the role of a generator and sell stored electricity to the grid.[52] Thus, grid-scale battery storage adds flexibility to the grid and reduces transmission urgencies by smoothing production and consumption.[53] However, existing FERC and state regulations exclude energy storage as an investment option, in comparison to traditional investments in transmission, generation, demand management, and distribution.[54] In order to account for the different functions provided by storage, changes should be made to enable system planning models that accurately incorporate the value of storage for the grid. Such models should account for the precise location of storage, streamline interconnection standards, and adapt rate design to reflect cost and value of energy storage (e.g., include time-of-use rates or apply net metering standards).[55] Recent FERC orders (Order 890[56] in 2007, Order 755[57] in 2011,[58] and Order 841[59] in 2016) have addressed these issues and adapted the wholesale market design in ways that allow for a more levelized market position of grid storage. PJM, which operates a wholesale market in the mid-Atlantic region, offers a system where independent power producers play the dominant role. It also created a similar market for ancillary services. In this market, renewable integration and frequency regulation are incentivized by regulators (based on FERC Order 755) and drive the deployment of grid-scale batteries.[60]

Adapting regulated networks for storage capacity

A related challenge is presented by the strongly regulated electricity networks currently operating in the U.S.[61] For example, certain markets call for a technological-governor (which ramps plants up and down according to load). An energy storage system provides a digital response to grid commands. It does not need physical devices to slow it down or speed it up. In addition, most utilities assess their assets in three categories: generation, transmission and distribution (T&D) infrastructure, and load. Grid storage, however, can provide services in all three categories and becomes generally under-valued in this siloed approach. This hampers innovative ownership and new business models. Furthermore, in some markets, utilities cannot own generation assets, what presents an undue restriction for energy storage systems (which count as generators). In addition, traditional integrated resource plans merely capture three inputs: forecasted demand, the capital cost of available technologies, and the technologies operating profiles, to calculate economic long-term options for system capacity.

All of these restrictions present obstacles for the investment and fair competition of energy storage in the market. Advanced energy storage provides flexibility services in peak times, as well as ancillary grid services in off-peak times. Thus, in order to capture the various services storage offers, system planners should rely on net cost of capacity on a more granular sub-hourly basis: *Net cost of capacity = Total installed cost-total operational benefits.*[62] As the market players are increasingly impacted by these problems, FERC and states try to adapt their regulation standards to level competition for storage in the grid. For example, New York is about to reform its utility business model regulations in order to account for flexibility and ancillary services by grid-scale energy storage. Texas is currently changing its regulations for transmission and distribution service providers, what allows for more levelized competition of grid-scale storage.[63]

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[52] John Martin P. Eng, "Grid Energy Storage: Policies," IEEE Northern Canada Section PES/IAS Chapter Seminar, http://sites.ieee.org/sas-pesias/files/2017/12/IEEE-Chapters-Presentation-Grid-Energy-Storage-Policies-2017-11-20-Handouts.pdf, (November 20, 2017).

[53] Miguel Vazquez and Matteo Di Castelnuovo, "Policy and Regulation for Energy Storage Systems," Working Paper Series: ISSN 1973-0381, ftp://ftp.unibocconi.it/pub/RePEc/bcu/papers/iefewp106.pdf, (June 2018): 1.

[54] Energy Storage Association, "State Policies to fully charge advanced energy storage: The Menu of Options," http://energystorage.org/statepolicymenu, (July 2017).

[55] Energy Storage Association, "35x25: A Vision for Energy Storage," http://energystorage.org/vision2025, (November 2017): 26–27.

[56] Order 890 obliges grid operators to modify their market rules and tariffs so non-generating resources can fully participate in ancillary services markets (unfavorable compensation model stayed in place).

[57] Order 755 requires grid operators to compensate frequency regulation providers for the speed and accuracy of their performance.

[58] Hunter Ellis, "The Emerging Regulatory and Policy Landscape for Grid-Scale Electric Energy Storage," Stanford Energy Club, https://energyclub.stanford.edu/the-emerging-regulatory-and-policy-landscape-for-grid-scale-electric-energy-storage-ellis, (June 5, 2013).

[59] Order 841 requires RTOs and ISOs to facilitate participation of energy storage applications in their markets by establishing a minimum size requirement for such resources.

[60] David Hart and Alfred Sarkissian, "Deployment of Grid-Scale Batteries in the United States," U.S. Department of Energy, https://energy.gov/epsa/downloads/deployment-grid-scale-batteries-united-states, (June 2016): 22.

[61] Miguel Vazquez and Matteo Di Castelnuovo, "Policy and Regulation for Energy Storage Systems," Working Paper Series: ISSN 1973-0381, ftp://ftp.unibocconi.it/pub/RePEc/bcu/papers/iefewp106.pdf, (June 2018): 5.

[62] Energy Storage Association, "35x25: A Vision for Energy Storage," http://energystorage.org/vision2025, (November 2017): 26–28.

[63] David Hart and Alfred Sarkissian, "Deployment of Grid-Scale Batteries in the United States," U.S. Department of Energy, https://energy.gov/epsa/downloads/deployment-grid-scale-batteries-united-states, (June 2016): 28.

Launching Incentives to increase investments in energy storage

In order to increase investments in energy storage systems, states should improve incentive systems for grid storage to provide varied competitive services. More and more states are creating such incentives and serve as models for other states. California has established storage procurement targets, which set minimum requirements for utilities to adopt storage systems; Oregon and Massachusetts are in the process of adopting similar targets. Procurement targets serve to clarify long-term objectives for the storage industry to invest, spur action from utilities, and provide operational experience for grid stakeholders. Other important means to foster energy storage investments are incentives, subsidies, and rebate programs. Many states implemented incentives for peak load reduction, renewables, and energy efficiency for which energy storage systems may qualify. Such incentives lower the costs of storage projects and thereby hasten adoption and accelerate market growth. Furthermore, they lower system costs for all consumers. In addition, over 29 states have adopted Renewable Portfolio Standards (RPS), which pave the way towards considering energy storage competitively alongside other energy solutions.[64]

> ***"Battery storage combines longer duration times with little geographic restrictions, which promises to add flexibility to the grid and release congestion. However, grid-scale battery storage amounts to less than 3% of U.S. storage capacity."***

Why investments in non-traditional lithium-ion battery technology should be made

The grid-scale battery market is on the rise but mainly dominated by lithium-ion technology. This has implications for prices, market design, and research and development. This paper argues that investments into non-(traditional) lithium-ion grid-scale battery storage should be made and the following will justify why.

Grid-scale battery storage incorporates features that other storage items lack

The grid-scale storage market is dominated by four technologies: battery storage, pumped hydroelectric storage, flywheel energy storage, and compressed air storage. Pumped hydro and compressed air are large-scale technologies which are, however, geographically limited. Flywheel storage, on the other hand, is only able to store energy for very short durations of time. Battery storage combines longer duration times with little geographic restrictions, which promises to add flexibility to the grid and release congestion. However, grid-scale battery storage amounts to less than 3% of U.S. storage capacity.[65] Thus, investments in battery storage are crucial to realize the energy transition whilst upholding a reliable grid.

Counter threat of political and technological lock-in of Lithium-ion batteries

As mentioned, the grid-scale battery storage market today is focused around lithium-ion batteries. This technology accounts for more than 90% of the global and domestic market. Lithium-ion batteries are relatively mature compared to battery alternatives and benefit from large-scale use in electronics and electric vehicles. This situation presents the risk of regulatory technology lock-in. That is, lithium-ion batteries could drive out alternatives that would perform the same function because regulation becomes adapted to the specific characteristics of lithium-ion batteries. Regulatory technology lock-in should be avoided since it hampers innovation.[66] Although energy efficiency and lifetime of lithium-ion batteries is high, they are expensive and have a comparatively low energy density.[67] These are features that make them attractive for transportation applications, but not ideal for the grid. Lock-in makes it difficult for producers of alternative storage technologies to survive and scale up.

Public policy makers should take action to grow the grid-scale energy storage market, create niches within the market for a range of technologies, and ensure that R&D continues in order to mitigate this technology lock-in.[68] But policy makers are reliant on other actors to foster innovation in non-lithium grid storage as well. This is why this paper calls for investments into non-(traditional) lithium-ion battery technology.

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[64] Energy Storage Association, "35x25: A Vision for Energy Storage," http://energystorage.org/vision2025, (November 2017): 24–25.

[65] Center for Sustainable Systems, "U.S. Grid Energy Storage Factsheet," University of Michigan, Pub. No. CSS15-17, http://css.umich.edu/sites/default/files/U.S._Grid_Energy_Storage_Factsheet_CSS15-17_e2018.pdf, (August 2018).

[66] David M. Hart, William Bonvillain, and Nathaniel Austin, "Energy Storage for the Grid: Policy Options for Sustaining Innovation," MIT Initiative Working Paper, http://energy.mit.edu/publication/energy-storage-for-the-grid, (April 2018): 3.

[67] Sonnen, "Stromspeicher – Flexibilität für die Energiewende," https://sonnen.de/wissen/stromspeicher, (2018).

[68] David M. Hart, William Bonvillain, and Nathaniel Austin, "Energy Storage for the Grid: Policy Options for Sustaining Innovation," MIT Initiative Working Paper, http://energy.mit.edu/publication/energy-storage-for-the-grid, (April 2018): 3.

Alternatives to lithium-ion are cheaper, safer and more sustainable

The average price for technologies discussed in this paper are considerably lower priced than lithium-ion batteries (around $260/kWh), with zinc-hybrid batteries at $160/kWh,[69] plastic polymer solid state batteries assessed to lower cell costs to below $100/kWh,[70] and vanadium redox flow batteries still costly, but below $200/kWh.[71] In addition, all three technologies proclaim to be safer than lithium-ion batteries. For example, solid state batteries are much less flammable than liquid batteries. Use of vanadium salts creates non-flammable and non-explosive batteries.[72] Zinc-based batteries are especially robust for outdoor deployment and promises non-flammability.[73] Thus by investing in these technologies, the grid becomes safer and more reliable. In addition, a diversification of the market away from lithium-ion batteries counters lithium resource depletion and reduces U.S. dependency on lithium imports.[74] Investments into non-(traditional) lithium-ion battery technologies contribute to more sustainable supply chains.

Summary of political arguments for grid-scale battery storage investments

The Energy Storage Association claims "A more resilient, efficient, sustainable and affordable electric system benefits everyone that interacts with it."[75] The assessment presented by this paper proves that an investment in battery storage contributes to all of these aims. The current political climate is favorable for investments into grid-scale energy storage, since regulatory adaptions create paths towards levelized competition of energy storage. Investments into non (traditional) lithium ion grid-scale battery storage stimulate the market and pave the way for a renewable, affordable, and reliable energy future. ▪

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[69] Eos, "Eos Energy Storage," https://eosenergystorage.com/#welcome, (2018).

[70] Brian Wang, "Ionic materials could achieve 50% higher energy density while costing less than $100 per kwh," Next Big Future, https://www.nextbigfuture.com/2018/07/ionic-materials-could-achieve-50-higher-energy-density-while-costing-less-than-100-per-kwh.html, (July 16, 2018).

[71] Andy Colthorpe, "Cellcube: 4-hours is just 'tip of peaking capacity iceberg,'" Energy Storage News: https://www.energy-storage.news/news/cellcube-4-hours-is-just-tip-of-peaking-capacity-iceberg, (August 15, 2018).

[72] Cellcube, "About Us," https://www.cellcubeenergystorage.com, (retrieved November 23, 2018).

[73] Eos, "Eos Energy Storage," https://eosenergystorage.com/#welcome, (retrieved November 23, 2018).

[74] Jens F. Peters and Marcel Weil, "A Critical Assessment of the Resource Depletion Potential of Current and Future Lithium-Ion Batteries," Resources 5, no. 4, https://doi.org/10.3390/resources5040046, (2016): 1.

[75] Energy Storage Association, "35x25: A Vision for Energy Storage," http://energystorage.org/vision2025, (November 2017): 31.

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