Sodium-Ion Battery Energy Storage Systems

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1. Introduction

This paper is about a leading technology in the manufacture of electric vehicles (EVs), and the title technology, a rapidly developing competitor. If you know anything about EVs, you've immediately guessed that the above "…leading technology…" is lithium-ion batteries, and you are correct. However, electric vehicles are not the only market that that uses these batteries, and one of them offers the first step up a ladder that may lead the new-comer to an entry-point into the EV market. Furthermore lithium-ion battery technology has some vulnerabilities, one of them very recent, very large, particularly with respect to sodium-ion batteries.

2. Lithium-Ion's Vulnerability

First of all, the EV is not the only rapidly expanding major industry that requires lithium-ion batteries, there are at least two more: Battery Energy Storage Systems (BESS) and Portable Consumer Electronic Devices (P-CEDs).

The BESS Market is expanding at every-scale, from Utility Scale BESS Arrays to Commercial & Industrial Scale BESS to Residential-Scale BESS (I own one of the latter). The core-reason for expansion is increasing dependance on renewable energy sources, specifically wind and solar (PV – ditto for my ownership). Wind and PV are intermittent, but also the most cost-effective technologies if paired with BESS. Then, PV will cover most peak-demand periods.

The P-CED Market has been expanding rapidly for at least several decades, and underpinned the rise of lithium-ion technology. However, this expansion isn't slowing down. Since it is being driven by consumers and leading-edge lithium-ion technology, although each P-CED device is small and has a small battery, each consumer (about 2-billion consumers, which is the current population of the industrialized world) is purchasing these with multiple devices per consumer, and frequent replacement purchases as technology improves. Also, because the battery is small, increases in battery-price due to rising demand has little effect on each P-CED device's price.

The net effect of these three booming markets (EVs included) is increasing price-pressure on lithium and other raw materials used in lithium-Ion batteries. There are two results as described in the following two subsections.

2.1. Environmental, Social, And Governance Challenges

Environmental, social, and governance (ESG) challenges result in price volatility:

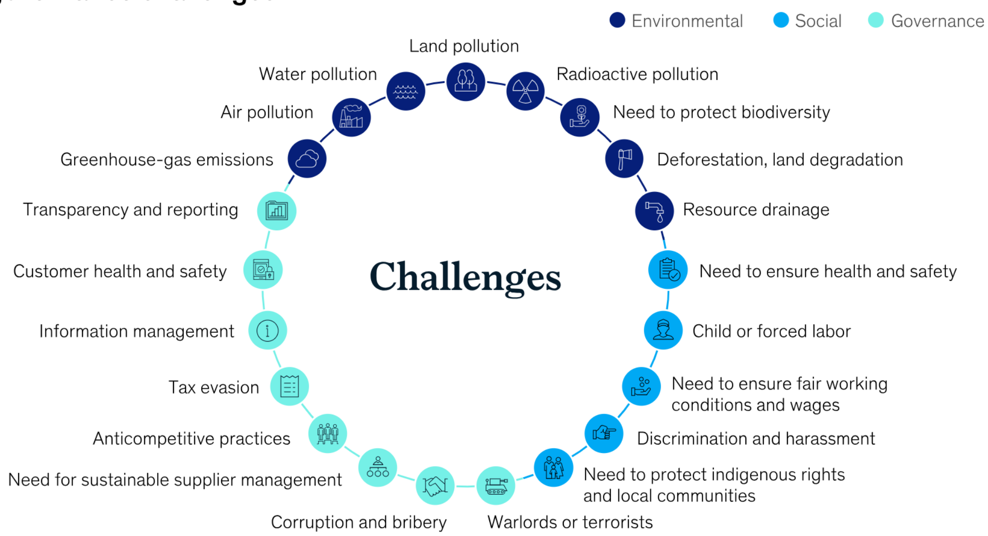
Environmental: *The extraction and refining of raw materials, as well as cell production, can have severe environmental effects, such as land degradation, biodiversity loss, creation of hazardous waste, or contamination of water, soil, and air. Unprofessional or even illegal battery disposal can cause severe toxic pollution.* [1]

[1] Jakob Fleischmann, Patrick Schaufuss, Martin Linder, Mikael Hanicke, Evan Horetsky, Dina Ibrahim, Sören Jautelat, Lukas Torscht, Alexandre van de Rijt, McKensey & Company, "Battery 2030: Resilient, sustainable, and circular," https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular

Social: *Unless strictly managed, operations across the battery value chain could have unfavorable effects on regional communities through violations of labor laws, child and forced labor, and indigenous rights, especially in emerging markets.*

Governance: *Businesses in the battery value chain may encounter conflicts of interest from companies with subpar management practices. To meet longstanding expectations for ethical businesses, companies must avoid financial situations involving corruption, bribery, funding armed conflicts, and tax evasion.*

The battery value chain continues to face numerous environmental, social, and governance challenges.



McKinsey & Company

2.2. Price Peaks & Volatility

Besides the much-publicized ESG challenges, Global Battery Alliance (GBA) members have pointed out that the battery value chain confronts massive economic barriers. Historic price peaks and extreme volatility, as well as quickly changing national regulations, can massively affect the economic viability of projects. Higher battery prices also make some green applications far less attractive than they were previously, which could delay much-needed attempts to accelerate decarbonization. Although economic viability is the most urgent issue for leaders, a more complex challenge involves the industrialization and historic scale-up of the battery industry.

The Lithium-Ion Battery Market is dysfunctional because this is one technology trying to cover a broad spectrum of applications. Although there are a wide-range of lithium-ion chemistries, these have one thing in common: lithium, which is uniquely vulnerable to supply chain-issues because of the huge and rising demand by its markets plus the vulnerabilities pointed out above.

The three markets for lithium-ion batteries described above each have a different reliance on these batteries and thus have different values for this technology:

- The P-CED Market places the highest value on lithium-ion batteries light weight and high energy density, and have the lowest vulnerability to price volatility.

- The EV Market places a moderate value on lithium-ion batteries light weight and high energy density, and has differing vulnerabilities to price volatility in different EV subsegments depending on market-price content (percent of total price) of the lithium-ion batteries in each subsegment.
- The BESS Market places low value on lithium-ion batteries light weight and high energy density, but is extremely vulnerable to price volatility. Furthermore, this market would place a high value on better long-term reliability than lithium-ion batteries currently provide.

Considering of the above, the P-CED Market is first in line to get lithium-ion technology, because they are willing to pay prices beyond the ability of the others to match.

The EV Market is next in line, but perhaps not all subsegments if there is a reasonable alternative.

For most of the BESS Market there may be better alternatives, and this is probably the best entry point for sodium-ion battery technology, as we will examine in the next section.

Your author spent much time investigating whether sodium-ion batteries are likely to have a longer lifetime than lithium-ion batteries, and could not get a clear answer to this from a reputable source. In part, I would guess this is mainly because the earliest sodium-ion batteries either are not available now, or only have been available for a very short time in limited quantities. See the next-to-last paragraph in this paper.

3. BESS Market's Needs

A utility-scale or commercial-scale battery energy storage system (BESS) is a technology that enables power system operators, utilities, commercial and industrial (C&I) utility customers to store energy for later use. A BESS is an electrochemical device that charges (or collects energy) from the grid or a power plant (especially intermittent renewables) and then discharges that energy at a later time to provide electricity or other grid services when needed. Several battery chemistries are available or under investigation for grid-scale applications, including lithium-ion, lead-acid, redox flow, and molten salt (including sodium-based chemistries). Battery chemistries differ in key technical characteristics, and each battery has unique advantages and disadvantages. [2]

Author's comment: Note that I edited the above text from an NREL document to include C&I BESS in grid-scale applications and made other changes for consistency.

Residential-scale batteries are not mentioned in the above text, but these generally will use technologies similar to lower-end C&I scale. Also note that residential customers are the most price-sensitive group, but their BESS use fewer/smaller batteries. Residential scale is probably the fastest-growing segment (in percentage growth) in my home-state (California) since we started phasing out our Net Energy Metering tariff in 2023.

BESS is one of several technology options that can enhance power system flexibility and enable high levels of renewable energy integration. Studies and real-world experience have demonstrated that existing interconnected power systems can safely and reliably integrate high levels of renewable energy from variable renewable energy (VRE) sources without other energy storage capabilities, but as dispatchable fossil-fueled generators are replaced with VRE sources, more BESS will be required for reliability.

[2] NREL, "Grid-Scale Battery Storage," https://www.nrel.gov/docs/fy19osti/74426.pdf

There is no rule-of-thumb for how much battery storage is needed to integrate high levels of renewable energy. Instead, the appropriate amount of grid-scale battery storage depends on system-specific characteristics, including:

- *The current and planned mix of generation technologies*
- *Flexibility in dispatching existing generation and new renewables (like geothermal)*
- *Interconnections with neighboring power systems*
- *The hourly, daily, and seasonal profile of electricity demand, and*
- *The hourly, daily, and seasonal profile of current and planned VRE.*

Sodium-ion batteries are a promising alternative to lithium-ion batteries — currently the most widely used type of rechargeable battery. Both types of batteries use a liquid electrolyte to store and transfer electrical energy, but differ in the type of ions they use.[3]

An examination of Lithium-ion (Li-ion) and sodium-ion (Na-ion) battery components reveals that the nature of the cathode material is the main difference between the two batteries. Because the preparation cost of the cathode from raw materials is the same for both types of battery technologies, the main cost reduction for sodium-ion batteries comes from raw materials.

Consider the following: Sodium is more than 500 times more abundant than lithium. However, there are major attempts to increase the supply of lithium, especially in the US. See the earlier paper summarized and linked below.

Domestic Lithium: *Currently Electric Vehicles (EVs) are ramping up production very rapidly. Ditto Battery Energy Storage Systems (BESS), mostly used in conjunction with renewable energy production from Wind and Solar-Power. The primary chemistries used in conjunction with the batteries in both of the products is Lithium-Ion (Li-Ion) Batteries. Although other non-lithium chemistries have been proposed, Li-Ion is the state-of-the-art presently.*

Although there are several viable types of Li-Ion batteries, each requiring different other elements in their cathode chemistries, all of these require lithium. The primary questions about these product's supply chain are: (1) can we ramp up the Lithium supply rapidly enough, and (2) can we source these domestically (from the U.S.)?

https://energycentral.com/c/cp/domestic-lithium

For now, and the immediate future, converting from lithium to sodium for at least some of the BESS Market would relieve the pressure on lithium supply. The following additional text is from one of my most trusted sources.

Sodium-based batteries are not new, but technical shortcomings have previously kept them from taking on lithium. Earlier sodium-ion batteries wore out quickly, and they still had a lower energy density than lithium-ion, says Shirley Meng, a battery researcher at the University of Chicago and Argonne National Laboratory.[4]

[3] Sanket Chipade, GEP, "Sodium-ion vs. Lithium-ion Battery: Which is a Better Alternative?" https://www.gep.com/blog/strategy/lithium-ion-vs-sodium-ion-battery

[4] By Casey Crownhart, MIT Technology Review, "This abundant material could unlock cheaper batteries for EVs," May 9, 2023, https://www.technologyreview.com/2023/05/09/1072738/this-abundant-material-could-unlock-cheaper-batteries-for-evs/

That means in order to store the same amount of energy, a sodium-based battery would previously need to be bigger and heavier than the equivalent lithium-based one. For EVs, that means a shorter range for a battery the same size…

A somewhat easier market for sodium-ion batteries might be stationary storage installations, like those used to provide backup power for a home or business or on the electrical grid. Some companies, like US-based Natron,[5] are developing the chemistry specifically for stationary applications, where size and weight aren't as critical as they are in a moving car.

Sodium-ion batteries have been in development for over half a century, and their performance has improved consistently, with especially steep gains over the past decade, Meng says. Battery researchers have worked out earlier issues with lifetime, partly by finding more compatible electrolytes (the liquid that helps ferry charge around in a battery) for the electrode materials used in sodium-ion cells. Researchers have also developed better electrode materials to boost the batteries' energy density.

But the real reason for sodium-ion's sudden surge in popularity is that lithium mines and processing facilities are straining to meet skyrocketing demand for EV batteries.

The world isn't going to run out of any materials needed for EVs or renewable energy infrastructure anytime soon. Estimated reserves suggest that Earth's crust has plenty of lithium for billions of EVs. But adding the infrastructure to pull lithium and other materials out of the ground and process it for use in batteries is proving to be a challenge. It can take the better part of a decade in most parts of the world to get a new mine built.

Final author's comment: Thus, this is really a question of timing and market strategy. Sodium-ion batteries are probably currently the best fit for BESS applications. However, currently only one company, Natron Energy Inc. has started limited production of these batteries in the US.[6]

Note the article linked in the reference below uses the words "…longer lifecycle…" Lithium-ion batteries have some interesting "lifecycle" limitations that I'm not going into here, but I expect the two battery technologies (including sodium-ion) have comparable cycle-lifetimes, assuming both are manufactured and then promptly put in service, and operated (more or less) continually until their capacity starts to degrade significantly.

The first step into the EV Market after the sodium-ion battery is established in the BESS Market is likely to be on the physically larger end of the market (read: large trucks). This would include both primary traction batteries in some limited-range truck markets, and auxiliary batteries for hydrogen-fueled long-distance transports. There are some other niches that might be attractive, but these large truck markets are rapidly-developing, fueled (pun intended) by my state's recent Air Resources Board's approval of rules that set goals to, starting in 2036, allow no new fossil-fueled medium-duty and heavy-duty trucks to be sold in California.

[5] https://natron.energy/

[6] C.C. Weiss, New Atlas, "Lithium-free sodium batteries exit the lab and enter US production," May 02, 2024, https://newatlas.com/energy/natron-sodium-ion-battery-production-startt/