MSE 4950

A Sodium Ion Battery for Grid-Scale Energy Storage

Engineering low-cost, high performance, and scalable energy storage solutions.

DDP

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Executive Summary

The long-duration energy storage (LDES) market is projected to require 225–460 GW of capacity by 2060 to reach net-zero emissions in the U.S., representing a $330B investment opportunity. Our sodium-iron (III) chloride molten battery outperforms lithium-ion and flow batteries with higher energy density, longer lifespan, and lower costs. We target Engineering, Procurement, and Construction (EPC) firms developing grid-scale storage for C&I users, offering a 20% lower LCOS than competitors. Through proven chemistry, scalable design, and a $0.18/kWh price point, we aim for factory breakeven in three years, delivering a cost-effective, U.S.-manufactured LDES solution.

Market research:

The DOE published a technology commercial liftoff report that discussed the market potential of LDES, where 225-460 GW of LDES capacity is needed by 2060 to achieve net zero greenhouse gas emissions in the United States[1]. This would require an estimated $330B in cumulative capital deployed, and would require a 23% CAGR. LDES solves critical pain-points, such as:

- **Load management services:** allow large commercial and industrial companies to manage their energy supply and demand with their personal backup power supply, which can optimize their pricing and maximize reliability.
- **Firming for Power Purchase Agreements ("PPA"):** renewable energy Power Purchase Agreements enables excess energy produced by renewables to be stored such that consumers can source entirely from renewables rather than rely on fossil fuel backups.
- **Energy market participation:** LDES assets can participate in energy markets such that the supply and demand of power in a grid can be optimized by balancing uneven production and consumption of power, which varies due to weather and time of day.

Stakeholders:

The main supply-side stakeholders are material suppliers and manufacturing equipment suppliers. Key materials include our solid state electrolyte and certain firms have expertise in fabricating this at scale. Sodium metal is another key material that we need strategic suppliers for. Our manufacturing process may involve certain specialized equipment such as glove boxes for assembly of the batteries.

The main demand-side stakeholders are the following. For load management services, there are large peaking power consumers, energy service players. For firming for PPAs; commercial and industrial ("C&I") energy users with focus on decarbonizing energy supply. For energy market participation; T&D developers, independent power producers.

Competition:

Our competition can be categorized into performing inter-day storage or multi-day / week storage.

Interday storage is best accomplished by pumped hydro storage. Example companies include General Electric and Duke Energy. Their main advantage is that they are very established technology and low cost at scale ($70-170/MWh). The main disadvantage is there are limited geological sites suitable for this technology because needs elevation and large body of water

Multi-day / week storage is best accomplished by electrochemical energy storage. For aqueous electrolyte flow batteries, an example company is ESS, Inc. Their main advantage is scalable, modular, and it decouples energy capacity from power. The main disadvantages are high capital cost and operating cost due to usage of mechanical pumps that frequently break down and are expensive to repair. High material cost for non-earth abundant materials like vanadium. Another competitor is metal anode batteries, an example being Form Energy. Their main advantage is low cost of materials and being highly scalable. The main disadvantage is the moderate energy density.

Business Model:

Customers

We will serve as a cell supplier, primarily selling to Engineering, Procurement, and Construction companies (EPCs) whose end use case is firming for PPAs. EPCs are contractors responsible for delivering large infrastructure projects. They source battery modules, power electronics, and build an integrated energy product., and work with project developers to execute grid-scale energy projects.

We aim to be the leading technology supplier for EPCS' multi-day energy storage, complementing Li-ion providers and dominating the long-duration battery market. With superior lifetime, performance, and cost, we fill a critical gap. For example, Fluence is a large EPC player who has made significant initiatives to partner with innovative technologies outside of LIBs for grid-scale, like Northvolt, but they lack a partner who can do long duration energy storage.

EPCs serving C&I energy users (data centers, warehouses, manufacturing) are our ideal customers. They move faster, face fewer regulatory hurdles, and have predictable energy needs, enabling low-risk, high-certainty purchase agreements. They also have predictable energy uses that can be targeted in a bespoke manner. This allows us to secure purchase agreement contracts with less uncertainty.

Value Proposition

We seek to deliver cutting-edge battery storage technologies tailored to adapting customer needs.

- **Higher energy density**
  Our battery achieves higher energy density than lithium-ion and alternative chemistries by using pure active materials, unlike competitors (e.g., Natron Energy, Eos) that dilute with aqueous electrolytes. Our sodium metal anode (1.166 Ah/g) and iron (III) chloride cathode (0.167 Ah/g) outperform LIB cathodes like NMC or LFP (200 mAh/g) and anodes (372 mAh/g). While our voltage (~3.5V) is comparable to LIBs (~4V), our mass-based energy density is superior.
- **Longer Lifespans, Low Degradation**
  For 20+ year energy storage, longevity is critical. Unlike LIBs, which degrade due to cathode fractures, our molten electroactive materials remain stable across thousands of cycles. Competitors like Neos struggle with dendrite formation and parasitic reactions, requiring costly R&D and limiting design flexibility.
- **Lower Costs, US Supply Chain Resiliency**
  We provide **20%** lower cost per kWh, cutting CapEx for large-scale storage. More importantly, our batteries are built domestically – leveraging the abundance of sodium chloride, iron chloride, and aluminum instead of relying on foreign supply chains burdened by rare earth metal shortages.
- **Adaptability**
  Our scalable design allows independent tuning of energy and capacity to meet diverse customer needs – unlike LIBs, which require careful form factor optimization to prevent side reactions.

Intellectual Property

Our proposed solution is a sodium-iron (III) chloride molten redox flowless battery. We have demonstrated a battery cell with the following cell performance characteristics: 599 mWh energy capacity, 47.12 mW power capacity, 45% mass utilization, average discharge voltage of 3.376V, average charge voltage of 3.807V. It has a $0.99 / Wh levelized cost of storage, $17.38 / Wh energy capacity cost. This represents a 17.1x reduction in cost compared to the baseline model we began with in the beginning of this project. We achieved this through innovation in cell design.

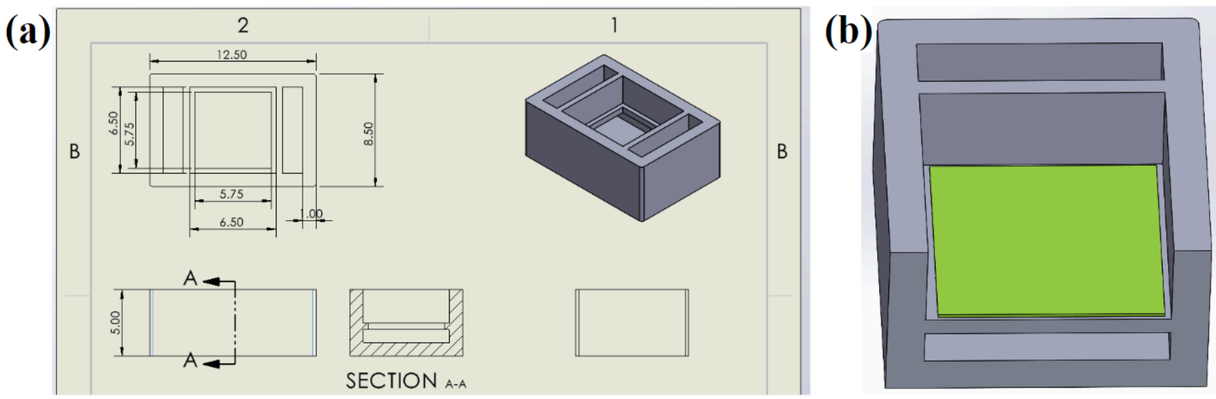

Figure 1: a) Technical drawing for our cell design and b) cross section with beta alumina plate model, made in SOLIDWORKS.

Cost Model

Our direct costs consist of material and labor costs. Material costs are calculated on a per kWh capacity basis and is $17.38 / Wh and an LCOS of $0.99 / kWh. We anticipate as we scale up the production of our batteries, the key material cost, beta alumina, will decrease in price, and we can further lower the LCOS to be more competitive, eventually reaching $0.207 / Wh.

Our labor cost is estimated to be half of the material costs and miscellaneous direct costs are 20% of the direct material costs. Therefore the total variable cost is $29.55 / Wh. We anticipate as we scale up the production of our batteries, we can introduce automation that reduces the labor cost and eventually reach $0.353 / Wh.

The upfront cost of building a 100 MWh / year capacity battery facility is estimated to be $86 M. This is based on a precedent transaction by CATL for a $4.3 billion factory that had a capacity of 50GWh / year. We scale this to our 100 MWh / year factory. On one hand, we have a much simpler manufacturing process that doesn't require specialized equipment to handle organic solvents and large space for evaporation that is limited on a per batch basis. On the other hand, CATL has high efficiencies for building factories, so we anticipate our first 100 MWh / year factory may not take advantage of possible efficiencies.

Revenue Model

We will leverage B2B contracts with EPCs. We price at a 20% discount to the leading LCOS for long duration energy storage providers. The leading zinc and vanadium flow batteries for long duration energy storage have an LCOS of $0.21 / kWh - $0.22 / kWh[2]. We target a price of $0.18 / kWh.

Assuming a lifetime capacity of 3650 kWh (2 days per cycle of a 1 kWh capacity battery for 365 days * 20 years), we charge an industry-low **$642 / kWh** battery capacity.

Contribution margin (per kWh capacity)	
Price	**$642**
Direct Materials	$207.72
Direct Labor	$103.86
Misc. Direct Cost	$41.54
Total Variable Cost	$353.12
Contribution Margin	**$289.28**
Upfront cost	$86,000,000.00
Breakeven Volume (kWh)	**297,294**

Based on the numbers above, selling 297,294 kWh capacity of batteries will allow us to breakeven for the factory. This is equivalent to 3 years of full capacity.

References:

[1] https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-LDES-vPUB.pdf
[2] https://www.pnnl.gov/projects/esgc-cost-performance/lcos-estimates