ON BATTERY GRAILS

How Na-ion can move from Holy to Good Enough Red Solo

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Sam Jaffe’s Golden Rules for Battery Investing

- Assuming safety is mostly solved, cost is by far the most important factor.
- Evaluate a technology at scaled manufacturing, not current state of costs.
- Never invest in a new battery architecture.
- Never invest in a “wouldn’t-it-be-nice so now look at my spreadsheet or powerpoint” technology—only real people with real data.

The problem with batteries today

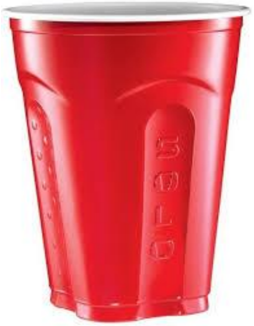
- **Battery pricing is still too expensive to allow all use cases:** even at \$53-\$85/kWh (LFP pricing today), more than half of use cases for batteries are not profitable
- **Commodity risk remains:** Li, Ni, Co, graphite, phosphates and Al are all close to ten-year lows. When they rise, battery pricing will go up again.
- **Margin compaction:** Gross margins throughout the supply chain today in China are at near zero. When commodity scarcity returns, they will too.
- **Intra-continentalization of supply chain:** The entire LFP supply chain is still today in China. Only baby steps have been taken to start it in the U.S. and Europe.
- **System cost of LFP is understated:** Due to voltage cliff and temperature tolerance issues, LFP has an additional 20% hit on energy density on a system level. Its manageable, but it reduces range (automotive) and efficiency (stationary) further.

Battery technology development is not over: If you think the world will be using LFP/graphite prismatic cells forever, you should not invest in battery development. If you think there's a disruptive technology on the horizon, now is the best time to invest.

The good-enough battery

Target Specifications:

- $25/kWh or less (price, not cost)
- 180 Wh/KG or greater (pack level, not cell level) to reach 400-mile-range car
- High thermal tolerance (not flammable even better, but not required)



To achieve that, the following would be required:

- An anode-free metal-anode design
- Dry coating of cathode
- Low-cost current collectors
- Zero or low-pressure requirement
- Better intra-cell thermal management

The best hypothetical battery is: safe (exceedingly low chance of fire), low-cost ($25/kWh cell price), long-lived (1200+ cycles), and efficient (95% RTE)

The problem with Li metal anode/solid state

- Electrolyte thickness (6 micron is ideal, nobody has shown less than 30 micron yet)
- Hermetic conformality (have to touch, can't not-touch) between electrolyte and anode is required, not nice-to-have
- In most cases, expensive and hard-to-handle Li foil is required on the anode (not Quantumscape)
- For zero-anode approach, overlithiation on the cathode can be very expensive
- Too much pressure is required
- Electrolyte is too expensive
- Poor plating/deplating dynamics cause breakoff and segregation of metal anode material, lowering coulombic efficiency faster

Lithium metal anode batteries are: Too expensive, require too much pressure, don't experience sufficient cycle life (much of that is due to the nature of lithium metal)

The problem with Na ion

- No supply chain buildout yet for input chemicals
- Hard carbon anodes are awful
- Most prospective cathodes are very low specific capacity (probably oxides will win in the end)
- Lithium is crazy cheap (LCE is $10/KG vs. $82 in 2022)
- Entire value proposition of current Na ion batteries is as a hedge against lithium commodity price risk—that's not a feasible business proposition

Sodium ion batteries are: Not much cheaper than Li ion yet, show poor life cycle and are extremely low energy density.

0.69

1200

25

30

22

0.69 HV

Vickers Hardness of sodium

Sodium is the softest of the abundant metals, which aids in the uniform distribution of nucleation spots for deposited metal. This leads to a consistent and monolithic layer of metal on the current collector.

Sodium is the ideal metal for battery anodes from a deposition mechanics perspective.

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1800 cycles

Cycle life to 80% capacity loss

A committed engineering program can expand cycle life to 1800 cycles with milestones of reducing separator/electrolyte thickness, optimizing current collector assembly and establishing electrolyte manufacturing process will improve CCD and cycle life to Li-ion norms.

The Na-metal-anode battery has the promise of meeting or exceeding conventional Li ion battery safety and performance specs at half the cost.

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$25 /kWh

Sale price of Ampa Rei battery at scale

No primary input for an Na-metal-anode battery costs more than $2/KG. At 200 Wh/KG, multiplying all material by 5 brings unshipped, unprocessed BOM to <$10. Processing, shipping and taxes bring it to $15. Depreciation of machinery brings it to $18.

At a CoGS + depreciation of $18/kWh, a battery manufacturer sell at $25/kWh and make a gross margin of 28% (compared to 0-16% today). This translates to a pack cost of $50/kWh.

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$30m/GWH

Capex to build a factory

An anode-free, dry coated battery factory would cost $30 million/GWH of annual capacity, compared to historical norm of $150 million/GWH and current bleeding edge of conventional Li ion of $30 million.

At $30 million capex per GWH, building a large battery factory is a much simpler decision than it currently is.

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22 TWH

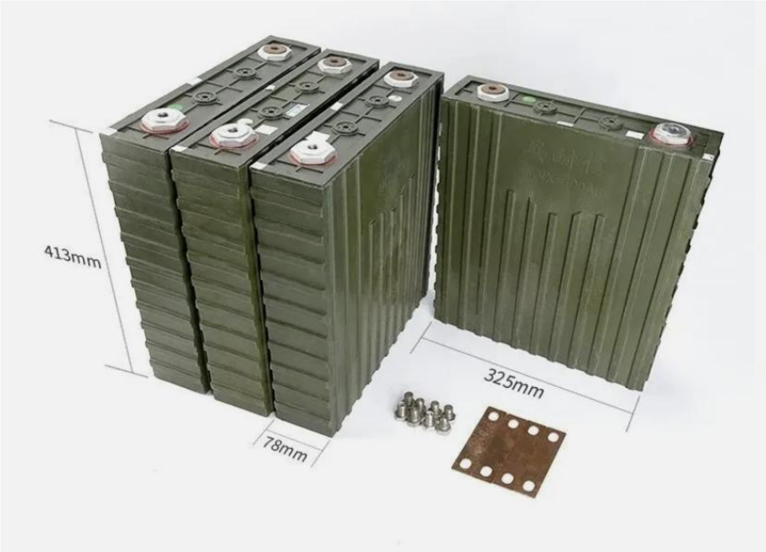
Market opportunity of battery industry

The world today produces 1.4 TWH of Li ion batteries. This is expected to grow to 3 TWH by 2034. If battery system pricing drops to $50/kWh, global demand could increase 7X as all use cases become profitable.

One knob turns the market demand knob for batteries: battery price. At $50/kWh system price, the market for batteries could increase 7X.

Breaching the 1 kAh threshold

- The highest capacity today is a 500 Ah LFP cell, which requires a gentle duty cycle to avoid heat mismanagement
- Getting to 1 kAh (approximately a 3.2 kWh cell) saves significant costs on the pack level and is an ideal base unit for a 120 kWh+ vehicle battery pack. But thermal issues prevent that battery size from happening.
- Introducing an intra-cell heat exchanger, either separately or as part of the current collector, could reduce thermal extremes in the cell and enable a larger battery size.



500 Ah, 1.6 kWh LFP cell available from China today (Ebay)

Thank you

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