Sodium-Based Batteries

PRESENTED BY
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Sodium Batteries: Diverse Technologies

Sodium batteries...

• Take advantage of globally abundant sodium...10³ more Na than Li!
  • 6th most abundant element in Earth’s crust and 4th most abundant in the oceans.
  • 5X the annual production of aluminum
• Offer potential for safe, versatile, cost-effective energy storage
  • Grid-scale and backup power
  • Portable or vehicle storage

There are a number of sodium battery technologies in development or production:

1. Molten sodium (Na) batteries
   A. Sodium Sulfur (NaS)
   B. Sodium Metal Halide (e.g., ZEBRA Batteries)

2. Sodium Ion Batteries (NaIBs)

3. Solid State Sodium Batteries (SSSBs)

4. Sodium Air Batteries (Na-O₂)
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*Sodium Image from Dnn87 at English Wikipedia. - Transferred from en.wikipedia to Commons., CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=3831512*
Molten Sodium Battery Basics

NaS and Na-NiCl₂ batteries are used today for Renewables Integration, Grid Services, Consumer Applications, and Microgrids.

- Na-S takes advantage of low cost materials, but introduces some safety concerns.
- Na-NiCl₂ is a safer, greener chemistry, but high cost of Ni is a challenge.

### Na-S

\[ xS + 2Na \leftrightarrow Na_2S_x \quad (3 \leq x \leq 5) \]

- \( E_{\text{cell}} \approx 2.08 \text{ V at } 350^\circ \text{C} \)
- 700 MW/4.9 GWh of deployed storage in over 200 cites globally

### Na-NiCl₂

\[ \text{NiCl}_2 (s) + 2\text{Na} (l) \leftrightarrow 2\text{NaCl} + \text{Ni} (s) \]

- \( E_{\text{cell}} \approx 2.58 \text{ V at } 300^\circ \text{C} \)
- Approximately 130MWh deployed storage globally

<table>
<thead>
<tr>
<th></th>
<th>Practical Energy Density (Wh/L)</th>
<th>Expected Cycle Life (cycles at 80% DOD)</th>
<th>Expected Lifetime (years)</th>
<th>Operating Temperature (°C)</th>
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<th>Discharge Duration (at rated power)</th>
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<tr>
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<td>300-400</td>
<td>4,000-4,500</td>
<td>15</td>
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<td>-20 to + 40</td>
<td>6-7 hours</td>
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<td>150-190</td>
<td>3,500-4,500</td>
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*NaS battery schematic from NGK Insulators.*
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An Na-S Flow Battery in Development

Enlighten Innovations (Canada, U.S.) has developed a long duration energy storage (LDES) flow system:

- Utilizes NaSICON solid-state separator
- Low-cost Na-S chemistry
- Decouples power and energy.
- Claim cost-competitive with Li-ion at 7+ hours of storage.

NaSICON: Nominally Na$_3$Zr$_2$PSi$_2$O$_{12}$
Further ZEBRA Battery Deployment?

Zhejiang Lvming Energy (Subsidiary of the Chilwee Group (China)) acquired GE’s Durathon technology and has announced plans to begin manufacturing these batteries as part of a more comprehensive battery manufacturing effort.

The Fraunhofer Institute for Ceramic Technologies and Systems (IKTS) in Germany has also developed their own Na-NiCl₂ battery platform (Cerenergy®) for grid-based energy storage. They advertise an effort to adapt the cell design and improve materials chemistry in these systems to reduce cost, but at present, these systems are not widely deployed.

- 100 Ah cells have now been realized for the first time, (versus 38 Ah cells typically available on the market).
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Na-Ion Batteries (NaIBs, NIBs, NiBs)

A possible alternative to Li-Ion?

Overall Discharge Reaction

$$\text{Na}_x\text{C}_6 + \text{Na}_1-x\text{MO}_2 \rightarrow \text{NaMO}_2 + \text{C}_6$$
Projected lower cost, simplified cell architectures, and improved safety are benefits of NaIBs. While NaIBs are unlikely to replace LiBs for high power (e.g., EV) applications, low-speed vehicles and stationary storage is likely to be a growing market.

- Market in 2021 was estimated near $650M
- CAGR is estimated at 11.2%
- 2028 market is expected to reach $2.8B

https://www.fnfresearch.com/sodium-ion-battery-market
Several manufacturers of NaIBs are in development or early production/deployment of Li-Ion “Analogs”:

• Contemporary Amperex Technology Co. (CATL, China) - debuted initial Na-ion line in 2021, planning “basic industrial chain” in 2023.
  • Developing hybrid Li-ion, Na-ion system.

• Faradion (UK) - produced over 50kWh of prototypes with sodium-nickel layer oxide cathodes since 2011).
  • Acquired by Reliance Industries (India) with aims at Gigafabs in India in 2024.

• AGM Batteries Ltd. (AMTE Power) - Multiple battery chemistries manufactured/assembled. Targeting GW-scale production.

• HiNa Battery Technology Co. (China) - Over 10,000 prototypes, currently demonstrating 100kWh prototype with anthracite anode and Co,Ni-Free layered metal oxide cathode.

• Tiamat Energy (France - Spin-Off of CEA/CNRS) Focus on mobile and stationary products with fast charging, high cycle-life 18650 cells.
Alternative Sodium Ion Batteries on the Horizon

Prussian blue analogs (PBAs)
- Utilize ferric ferrocyanide salts as electroactive materials (mostly cathodes)
- Natron Energy is developing NaIBs with PBAs aimed at 8kW units for data server backup power.
  - With Clarios (Michigan, Li-ion facility) aiming for 600MW annually starting in 2023.
- As many as 50,000 cycles projected!
- Altris (Sweden) (Focus on sustainable materials) - Prussian White (Fully Reduced and sodiated PB) (Pilot Line underway)

“Salt-water batteries”
- Carbon-titanium phosphate composite Anode, sodium perchlorate aqueous electrolyte, manganese oxide cathode.
- BlueSky Energy (Austria) - “Greenrock” Saltwater Battery (Aquion technology through BenAn Energy))
  - 5kWh-30kWh systems for renewables, emergency power, off-grid solutions
  - 15 year lifespan, 5,000 cycles, -5°C to +50°C operation, safe and environmentally friendly


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Solid State Sodium Batteries: In Development

- Promise exists
  - High energy density
  - Abundant materials
  - Low cost

- Challenges remain
  - Low rate capabilities
  - Sodium electrode stability
  - Interface control
  - Cathode performance

**Sodium-Air Batteries: In Development**

4Na + O₂ + 2H₂O ⇌ 4NaOH \( E_0 = 3.11 \text{ V} \)

Or

2Na + O₂ ⇌ Na₂O₂ \( E_0 = 2.33 \text{ V} \)

- Theoretical energy density: 3164 Wh/kg
- Specific capacity 1166 mAh/g
- Organic, Inorganic (aqueous) electrolytes
- Solid sodium, molten sodium

**Challenges:**
- Catalyst Development
- Anode protection
- Dendrite elimination

N. Chawla, et al. *Electronics* 2019, 8(10), 1201
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   A. Sodium Sulfur (NaS)
   B. Sodium Metal Halide (Traditional ZEBRA Batteries)
      ✓ New ZEBRA Batteries (Ni-free, operate below 200°C) - PNNL, RIST
      ✓ Low Temperature (~100°C) Na-Nal Batteries - SNL

2. Sodium Ion Batteries (NaIBs)
   A. “Li-Ion Analogs” PNNL, ORNL
   B. Prussian Blue Analogs
   C. Salt-Water Batteries - ORNL

3. Solid State Sodium Batteries (SSSBs)

4. Sodium Air Batteries (Na-O_2)
<table>
<thead>
<tr>
<th>Institution</th>
<th>Title</th>
<th>Presenting Author</th>
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<tbody>
<tr>
<td>Sandia National Laboratories</td>
<td><strong>Experimental and Modeling Studies of Metal Halide Catholyte and Cathode Materials to Enable Low-Temperature Molten Sodium Batteries</strong></td>
<td>Adam Maraschky (Erik Spoerke)</td>
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<tr>
<td>University of Kentucky/Sandia National Laboratories</td>
<td><strong>Sodium Penetration through Solid State NaSICON Electrolytes under High Current</strong></td>
<td>Ryan Hill and Y-T Cheng</td>
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<tr>
<td>Sandia National Laboratories</td>
<td><strong>Al-Fe Based Molten Salts for Long Duration Energy Storage</strong></td>
<td>Stephen Percival</td>
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<tr>
<td>RIST/PNNL</td>
<td><strong>Interfacial Resistance Reduction via Enhanced Na(l) Wetting in Na β&quot;-Al2O3 Batteries at Lower Temperatures</strong></td>
<td>Choongmo Yang</td>
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<td>RIST/PNNL</td>
<td><strong>Nickel-Ferronickel Composite as a Cathode Material for Low Cost Sodium-Metal Chloride (Na-MCl2) Batteries</strong></td>
<td>Keeyoung Jung</td>
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<tr>
<td>Penn State University</td>
<td><strong>Stable All-Solid-State Sodium-Sulfur Batteries for Low-Temperature Operation Enabled by Sodium Alloy Anode and Confined Sulfur Cathode</strong></td>
<td>Li-Ji Jhang</td>
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On to the Main Show: Presentations

Session 4: Sodium Batteries

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<thead>
<tr>
<th>Time</th>
<th>Presentation</th>
<th>Presenter</th>
<th>Organization</th>
<th>Presentation #</th>
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</thead>
<tbody>
<tr>
<td>8:50 – 8:57am</td>
<td>Sodium-Based Batteries</td>
<td>Erik Sporke (Session Lead)</td>
<td>Sandia National Laboratories</td>
<td>400</td>
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<tr>
<td>8:57 – 9:12am</td>
<td>Low Temperature Molten Sodium Batteries (presented by Erik Sporke)</td>
<td>Leo Small</td>
<td>Sandia National Laboratories</td>
<td>401</td>
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<tr>
<td>9:12 – 9:25am</td>
<td>Intermediate Temperature Sodium Battery Technologies</td>
<td>Guosheng Li</td>
<td>Pacific Northwest National Laboratory</td>
<td>402</td>
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<tr>
<td>9:25 – 9:35am</td>
<td>Polymer-Sealed Planar Na:NaCl₂ Batteries at 180°C</td>
<td>Keeyoung Jung</td>
<td>Research Institute of Industrial Science and Technology (RIST)</td>
<td>403</td>
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<tr>
<td>9:35 – 9:50am</td>
<td>Sodium based Solid Electrolytes and Na-Metal</td>
<td>David Mitlin</td>
<td>University of Texas at Austin</td>
<td>404</td>
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<tr>
<td>9:50 – 10:05am</td>
<td>Sodium Battery Research at ORNL</td>
<td>Mengya Li</td>
<td>Oak Ridge National Laboratory</td>
<td>405</td>
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<td>10:05 – 10:20am</td>
<td>Sodium Ion Battery Development</td>
<td>Xiaolin Li</td>
<td>Pacific Northwest National Laboratory</td>
<td>406</td>
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<td>10:20 – 10:35am</td>
<td>Q&amp;A</td>
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Backup Slide: Commercial Molten Sodium Battery Deployments

NGK Insulators Sodium-Sulfur (NAS) batteries:

- Deployed 700 MW/4.9 GWh of storage in over 250 sites around the world.
- World's first commercialized battery system capable of megawatt-level electric power storage.
  - Up to 210 MW/1.5GWh in TEPCO Area, Japan
- Strong record of safety and reliability
  - Systems demonstrated operation for >10 years!
- Renewables Integration and Power Plants
  - Peaker Plant Replacement
- Grid Solutions (Ancillary Services, Investment Deferral)
- Long-Duration Storage Applications
- Consumers (Industrial, Commercial & Residential)
- Microgrids (Including Islands, Remote Grids)

FZSoNick ZEBRA (Na-NiCl₂) batteries:

- Energy Backup (48-110V)
- Sustainable Mobility (300-700V)
- Energy Storage (48V and 620V)
- Approximately 130MWh deployed storage
- Energy Storage Systems
  - Renewables Integration
  - Microgrids
  - Grid Services (e.g., grid balancing, voltage regulation)
- Backup storage capacity (e.g., telecommunications)
- Environmentally friendly and *recyclable*
- “No maintenance”

https://www.fzsonick.com