Advancing Sodium Batteries Through the DOE Office of Electricity

PRESENTED BY

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Are All Sodium Batteries The Same? Na!

Sodium batteries...
- Take advantage of globally abundant sodium...
  - 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 (Traditional ZEBRA Batteries)
      ✓ New ZEBRA Batteries (Ni-free, operate below 200°C) - PNNL
      ✓ Low Temperature (~100°C) Na-Nal Batteries - SNL

2. Sodium Ion Batteries (NaI Bs) - PNNL, ORNL

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
- NaS battery schematic from NGK Insulators.
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Molten Sodium Batteries: An Introduction

**Na-S**

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

\[ E_{cell} \approx 2.08 \text{ V at } 350^\circ \text{C} \]

**Na-NiCl₂**

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

\[ E_{cell} \approx 2.58 \text{ V at } 300^\circ \text{C} \]

<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>
<th>Suitable Ambient Temperature (°C)</th>
<th>Discharge Duration (at rated power)</th>
<th>Round Trip Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaS</td>
<td>300-400</td>
<td>4,000-4,500</td>
<td>15</td>
<td>300-350</td>
<td>-20 to +40</td>
<td>6-7 hours</td>
<td>80%</td>
</tr>
<tr>
<td>Na-NiCl₂</td>
<td>150-190</td>
<td>3,500-4,500</td>
<td>20</td>
<td>270-300</td>
<td>-20 to +60</td>
<td>2-4 hours</td>
<td>80-85%</td>
</tr>
</tbody>
</table>

- Na-S takes advantage of low cost materials, but introduces some safety concerns.
- Na-NiCl₂ is a safer chemistry, but high cost of Ni is a challenge.
Molten Sodium Battery Deployment: NaS

NGK Insulators, Ltd (Japan) has developed a successful NaS battery system with long lifetime and a strong safety record.

- Voltage: 2V
- Energy density: 367 Wh/l, 222 Wh/kg
- Power density: 36 W/kg
- C-rate: 1/6 = 0.17
- Optimal temperature range: 300 - 340°C
- Maximal temperature range: 290 - 360°C
- Life time: 4500 cycles, 15 years
- Discharge Duration: 4-6 hours

50 MW system supporting a solar array in Fukuoka, Kyusu, Japan.

Images provided courtesy of NGK Insulators, Ltd.
NGK has deployed 580 MW/4 GWh of storage in over 200 cites around the world.

Molten Sodium Battery Deployment: Na-NiCl₂ (ZEBRA)

FZSoNick (Italy, Switzerland, USA) is actively deploying ZEBRA batteries for use in

- Energy Backup (48-110V)
- Sustainable Mobility (300-700V)
- Energy Storage (48V and 620V)

FZSoNick (Na-NiCl₂) Batteries

- ~300°C operation, no cooling required
- 2-4 hour energy applications
- Operational from -20°C to +60°C
- 20 year design life (3500-4500 cycles)
- Environmentally friendly and recyclable
- “No maintenance”
Molten Sodium Battery Deployment: Na-NiCl₂ (ZEBRA)

Intended for On-Grid, Microgrid, and Off-Grid Applications

- Power Quality
- Frequency Regulation
- Load Shifting
- Peak Shaving
- Backup Power
- Renewable Resource Integration

>130 MWh of backup power and grid-storage installed globally

- **Energy Backup**
  1. Telecom
  2. Railway
  3. UPS

- **Sustainable Mobility**
  1. Light commercial vehicle
  2. Bus
  3. Mining

- **Energy Storage**
  1. Off grid application
  2. RE⁺ generator (residential/industrial)
  3. Transmission and distribution service operator

https://www.fzsonick.com
The Chilwee Group (China) recently 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-NiCl$_2$ 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.
Lowering Battery Operating Temperature to Drive Down Cost

Our Collective OE Objective: A safe, reliable, molten Na-based that eliminates costly reagents (e.g., Ni) and operates at reduced temperatures (below 200°C).

➢ Improved Lifetime
  • Reduced material degradation
  • Decreased reagent volatility
  • Fewer side reactions

➢ Lower material cost and processing
  • Seals
  • Wiring!
  • Cell body
  • Polymer components?

➢ Simplified heat management costs
  • Operation
  • Freeze-Thaw

PNNL intermediate temperature planar Na-MH battery design.

SNL design for Na-Nal low temperature (~100°C) battery

Looking Forward: Long Duration Energy Storage (LDES)

Long Duration storage is an emerging area of battery development and can mean a number of things, ranging from discharge durations greater than 10 hours to seasonal storage.

LDES may involve hybrid technologies that combine multiple storage systems (e.g., Thermal + Electrochemical) or storage combined with renewable generation (e.g., Solar + Storage).

*There are opportunities for Sodium batteries to impact “Long Duration” storage! (Stay tuned for LDES workshop later this fall!)*

**Example 1:** 18 hour NGK NaS Batteries.

- Effective solar power on microgrids requires 14-18 hours of discharge time to fully shift solar energy.
- NGK’s Na-S batteries are typically rated for 6 hours, at full output rating, but run at 1/3 rated output, they will provide electricity for 18 hours!

Example 2: Low temperature “freezable” batteries for seasonal energy shifting.

- At FY19 DOE peer review, the SNL team showed that low temperature molten salt batteries was cooled until “frozen”, and then restarted with no interruption of electrochemical cycling behavior.
- This approach could be used to store seasonal renewable energy (e.g., summer solar), then frozen until needed at a (much) later date (e.g., winter).
- The low temperature operation makes this turn-around shorter and less energy intensive.

Upcoming talk by Guoshon Li: “Perspectives and strategies of developing long duration and seasonal energy storage technologies for improving grid resiliency and reliability.”
Sodium Ion Batteries on the Horizon

While not yet commercially mature, several types of NaIBs are in development or early production.

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.

Li-Ion “Analogs” - possibly manufacturable on Li-ion production lines?
- Faradion (UK) - produced over 50kWh of prototypes with sodium-nickel layer oxide cathodes since 2011).
- HiNa (China) - Over 10,000 prototypes, currently demonstrating 100kWh prototype with anthracite anode and Co,Ni-Free layered metal oxide cathode.

“Salt-water batteries”
- Carbon-titanium phosphate composite Anode, sodium perchlorate aqueous electrolyte, manganese oxide cathode.
- Aquion - MW scale deployment before restructuring in 2017. Current status?
- BlueSky Energy (Austria) - “Greenrock” Saltwater Battery
  - 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

On to the Main Show: Presentations

<table>
<thead>
<tr>
<th>Institution</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Kentucky</td>
<td>Multi-scale characterization of the Structure and Mechanical Properties of Sodium Ion Conductors</td>
<td>Y.T. Cheng, Ryan C. Hill, Amanda Peretti, Leo Small, and Erik D. Spoerke</td>
</tr>
<tr>
<td>Pacific Northwest National Laboratory</td>
<td>Advanced Na-ion battery: Progress towards Co-free cathodes</td>
<td>Biwei Xiao, Fredrick Omenya, Hyungkyu Han, David Reed, Vincent L. Sprenkle and Xiaolin Li</td>
</tr>
<tr>
<td>Pacific Northwest National Laboratory</td>
<td>Advanced intermediate temperature sodium-metal halide (Na-MH) batteries for grid storage application</td>
<td>Miller Li, Jeff Bonnett, Evgeni Polikarpov, David Reed, Vince Sprenkle, and Guosheng Li</td>
</tr>
<tr>
<td>Pacific Northwest National Laboratory</td>
<td>Perspectives and strategies of developing long duration and seasonal energy storage technologies for improving grid resiliency and reliability</td>
<td>Miller Li, Aaron Hollas, Daiwon Choi, Xiaolin Li, David Reed, Vince Sprenkle, and Guosheng Li</td>
</tr>
<tr>
<td>Oak Ridge National Laboratory</td>
<td>Engineering Routes Towards Synthesis and Performance of Layered Oxide Cathode Materials for Sodium-ion Batteries</td>
<td>Mengya Li, Yaocai Bai, Rachid Essehli, Ruhul Amin, Ilias Belharouak, Jianlin Li, David L. Wood III</td>
</tr>
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<tr>
<td>Sandia National Laboratories</td>
<td>Development of High-Performance Low-Temperature Molten Sodium Batteries</td>
<td>Martha M. Gross, Stephen J. Percival, Amanda S. Peretti, Joshua Lamb, Erik D. Spoerke, Leo J. Small</td>
</tr>
<tr>
<td>University of Kentucky</td>
<td>Mechanical and Microstructural characterization of Montmorillonite Sodium Ion Conductors</td>
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<td>Advanced Na-ion battery: Scaling up of Na-ion battery materials and large cells</td>
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<tr>
<td>Penn State University</td>
<td>Development of sulfide based solid state electrolyte for Na-ion batteries</td>
<td>Donghai Wang</td>
</tr>
</tbody>
</table>