

Emerging Stationary Battery Technologies

Erik D. Spoerke, Ph.D.

Sandia National Laboratories, Albuquerque, NM

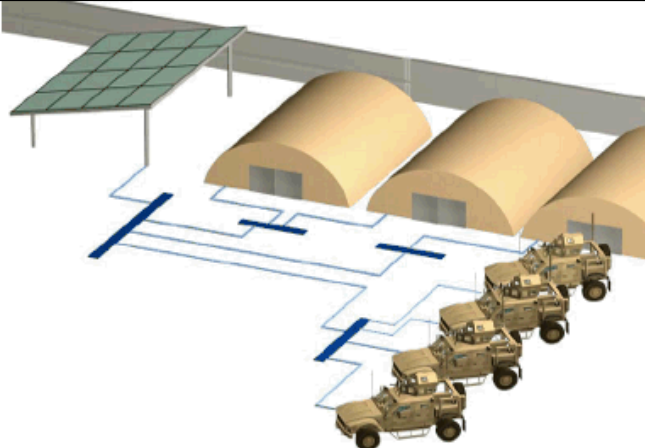
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Need for Grid-Scale Batteries

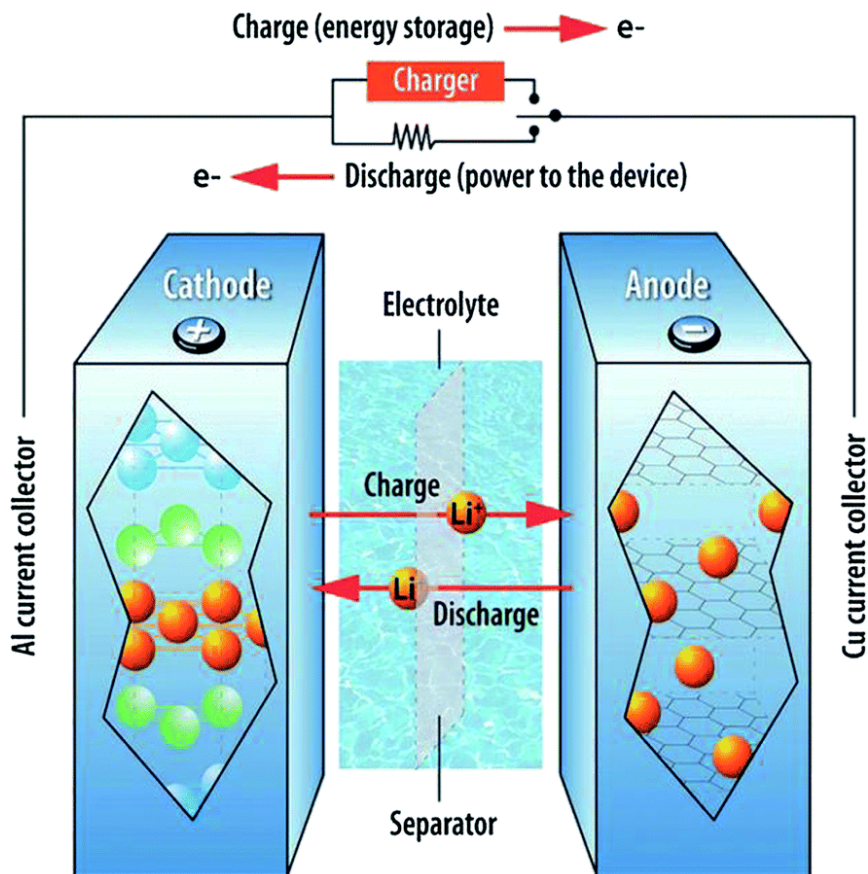


Safe, efficient grid-scale electrical energy storage is critical!

- Renewable/Remote Energy
- National Defense
- Grid Agility
- Humanitarian Efforts



Basic Battery Design



Basic elements of all (most) batteries:

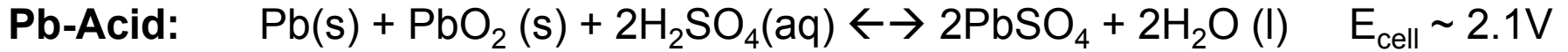
- Current collectors
- Anode
- Cathode
- Electrolyte
- Ion-conducting, electronically insulating separator (may double as electrolyte)
- External circuit

Not All Batteries are Equivalent!

Considerations for Battery Selection

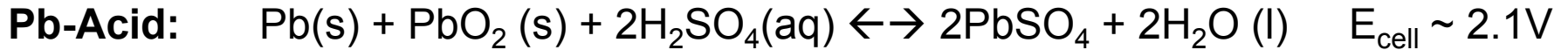
- How much energy storage is necessary?
- How quickly does that energy need to be stored/delivered?
- Does size/weight matter?
- Does the battery need to be mobile?
- Can the battery be heated?
- Will the battery be subjected to extreme temperatures or large temperature fluctuations?
- What are the consequences of battery failure or degradation?
- How much does it cost?

Challenges with Current Battery Technologies

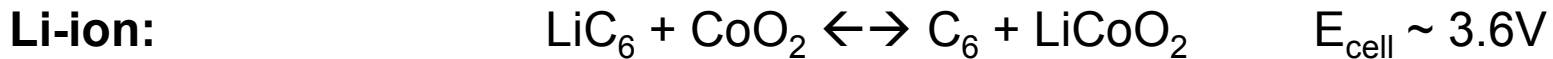


- Utilizes lead and sulfuric acid
- Overcharging (high charging voltages) produces potential explosion hazard from accumulation of hydrogen and oxygen.
- Capacity fades quickly from sulfation and grid corrosion (typically 200-300 cycles)

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- Cost (decreasing recently)
- Capacity fades relatively quickly (~500 cycles) from oxidation reactions, electrolyte degradation, cathode degradation, increased cell resistance, cell short circuits.
- Limited operational temperature range (near room temperature)
- Significant safety concerns associated with thermal runaway and flammable organic electrolytes

Safety Concerns with Li-Ion Batteries?

Galaxy Note 7



<10Wh

Laptop Computer



<100Wh

Tesla EV Battery



kWh (~6895 18650 cells)

Battery Recycling Plant



MWh (?)



This 10 kWh battery pack depicted on the side of a building likely has 5 liters of liquid electrolyte.

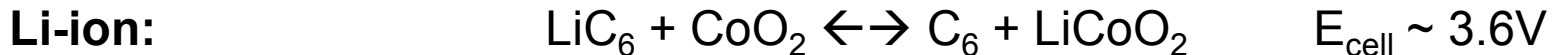
Thermal runaway and flammable organic electrolytes remain serious hazards for Li-ion batteries!

Li-ion batteries are inherently intolerant of harsh conditions.

Challenges with Current Battery Technologies



- Utilizes lead and sulfuric acid (hazardous, heavy)
- Overcharging (high charging voltages) produces potential explosion hazard from accumulation of hydrogen and oxygen
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- Cost (potentially feasible)
- Operates at elevated temperatures (270-350°C – required for molten chemistry and solid state electrolyte operation). Cell freezing can cause mechanical failure
- Corrosive, toxic chemistries
- Molten sodium and molten sulfur are highly reactive (cascading thermal runaway and fire hazard)

Notable Na-S Battery Fires

September, 2011: Fire from NGK-manufactured NAS (sodium-sulfur) batteries at the Tsukuba Plant (Joso City, Ibaraki Prefecture) of Mitsubishi Materials Corporation (Head office: Chiyoda-ku, Tokyo). Failure of single cell (out of 15,360 cells) led to short circuit and cascading thermal runaway.

February, 2010: Fire at the Oyama Plant (Oyama City) of Takaoka Electric Mfg. Co., Ltd. (Headquarters: Chuo-ku, Tokyo).

February, 2005: Fire at NGK's NAS battery plant in Komaki City. This fire broke out when a modular battery was undergoing high-voltage testing.

Putting out these fires poses significant chemical exposure and electrical risks to emergency personnel!

Na-S Batteries are still vulnerable to thermal runaway and cascading failure, particularly under non-ideal conditions.

Although engineering solutions to these challenges are possible, they are expensive!

Despite the challenges, Na-S battery deployment continues to expand:

- 190 sites in Japan, more than 270MW installed
- More than 20MW installed in U.S.

Current Battery Research

We aim to develop and improve energy storage technologies that effectively store and delivery electricity, while optimizing cost, safety, and cycle life.

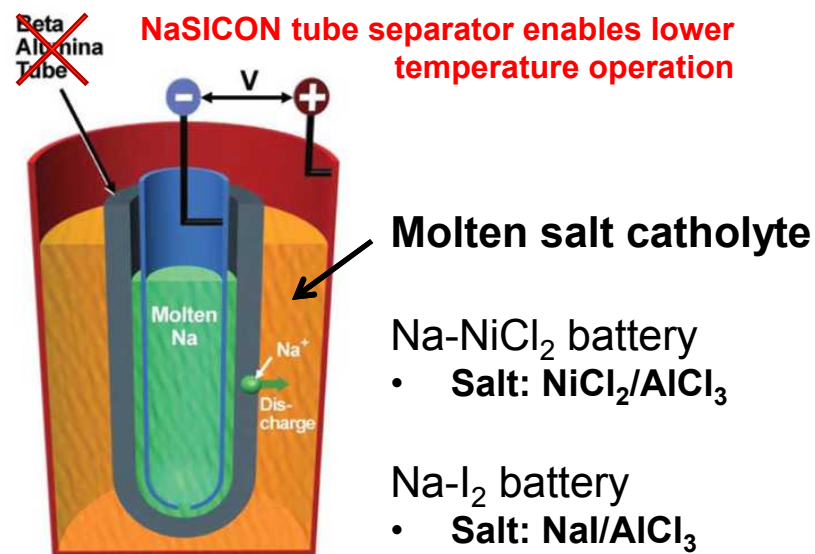


Work at Sandia National Laboratories is supported by Dr. Imre Gyuk through the Department of Energy Office of Electricity Delivery and Energy Reliability.

Na-Based Batteries

Our Goal: to develop low cost ($\leq \$100/\text{kWh}$), intermediate temperature ($\leq 200^\circ\text{C}$), long-lifetime, safe, nonflammable Na-based alternatives to Na-S, Pb-acid, and Li-ion batteries.

- Na-chemistry utilizes abundant Na-supply
- Intermediate temperature enabled by highly conductive NaSICON (Sodium Super Ion CONductor) ceramic separator.
 - ✓ High Na-conductivity ($>10^{-3} \text{ S/cm}$ at 25°C)
 - ✓ Scalable production (Ceramatec, Coorstek)



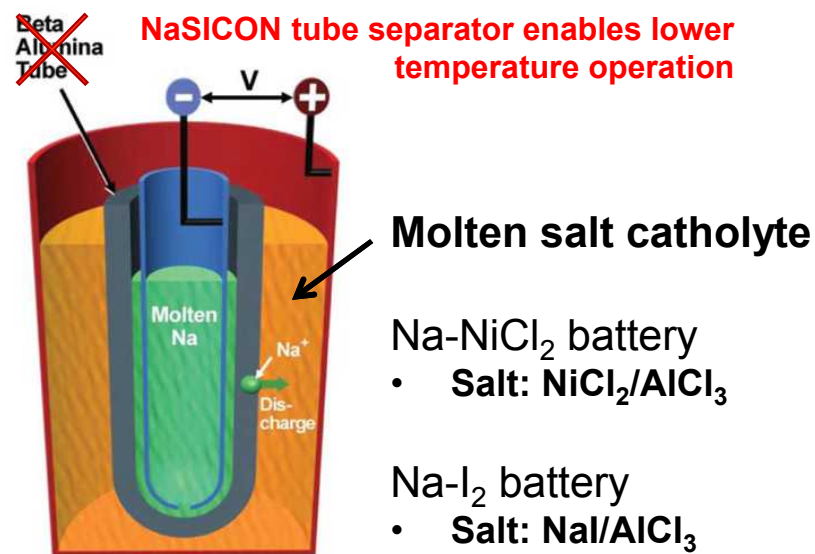
Sodium-nickel chloride (195°C , $E_{\text{cell}} \sim 2.6\text{V}$):
 $\text{Na} + \frac{1}{2} \text{NiCl}_2 \leftrightarrow \text{Na}^+ + \text{Cl}^- + \text{Ni(s)}$

Sodium-iodine ($120\text{-}150^\circ\text{C}$, $E_{\text{cell}} \sim 3.25\text{V}$):
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 - ✓ Lower cost
 - ✓ Increased reliability and lifetime
 - ✓ Improved capacity retention (limitation of Li-ion and Pb-acid)



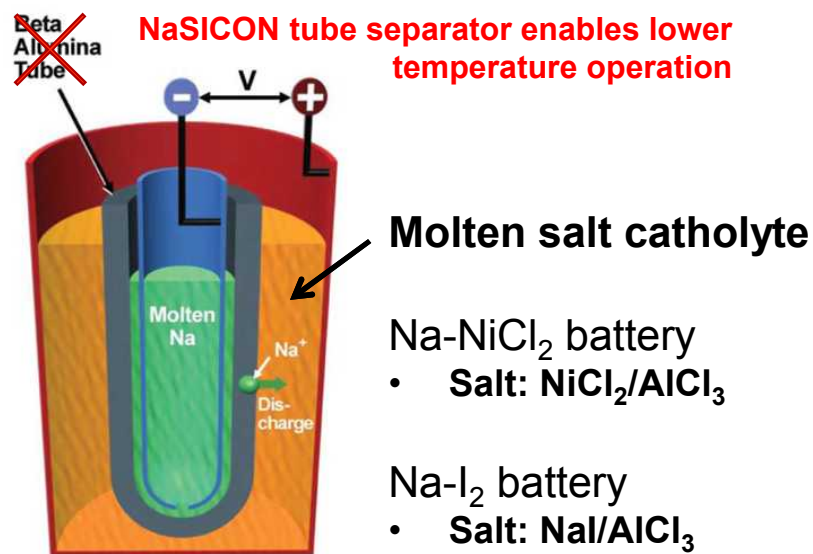
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 - ✓ Improved capacity retention (limitation of Li-ion and Pb-acid)
- Safety-by-design in all-inorganic system
 - ✓ No cascading thermal runaway
 - ✓ No flammable gas generation
 - ✓ Separator failure and electrode cross-over produces inert Al metal and NaCl.



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Pre-Commercial Na-NiCl₂ systems

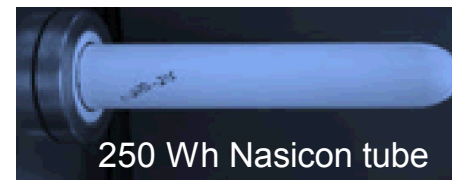
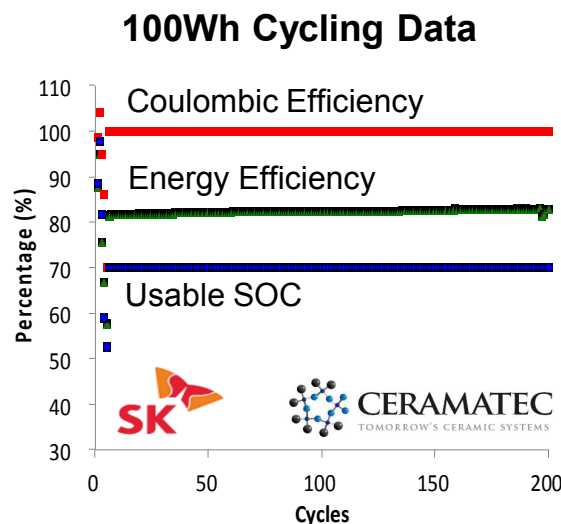
Recently demonstrated high performance cycling in precommercial prototypes at 195°C at 53mA/cm² and C/7 rate (w/ Ceramatec, Inc. and SK Innovation):

100 Wh Na-NiCl₂ unit cell:

- operational for 4+ months.
- 500+ cycles (70% DOD)
- coulombic efficiency ~100%
- energy efficiency 81.5 %

250 Wh Na-NiCl₂ unit cell:

- operational for 3+ months
- 110 cycles (70% DOD)
- coulombic efficiency ~100%
- energy efficiency 80 %



100 Wh, Na-battery prototype →



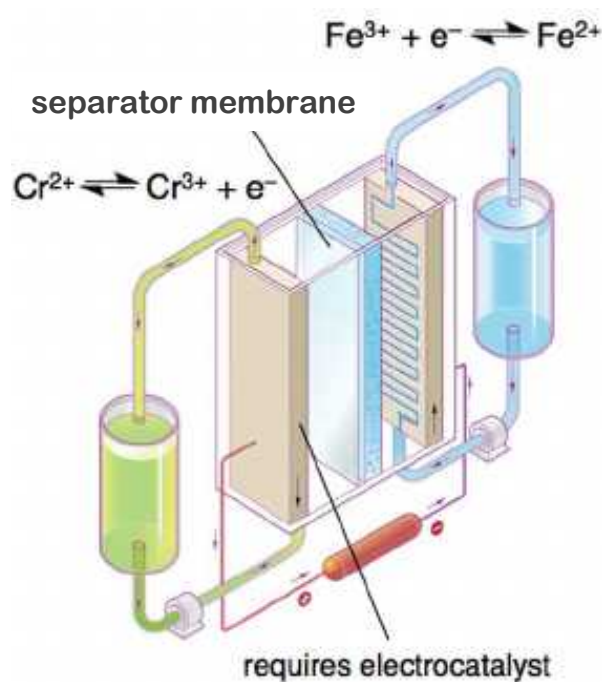
Proposed 10 kWh Na module:
40x250Wh Ceramatec cells

Ongoing efforts targeting for large scale (10kWh), intermediate temperature demonstrations (w/ Ceramatec: 180 Wh/l, \$150/kWh, 2.6V, 40 cells).

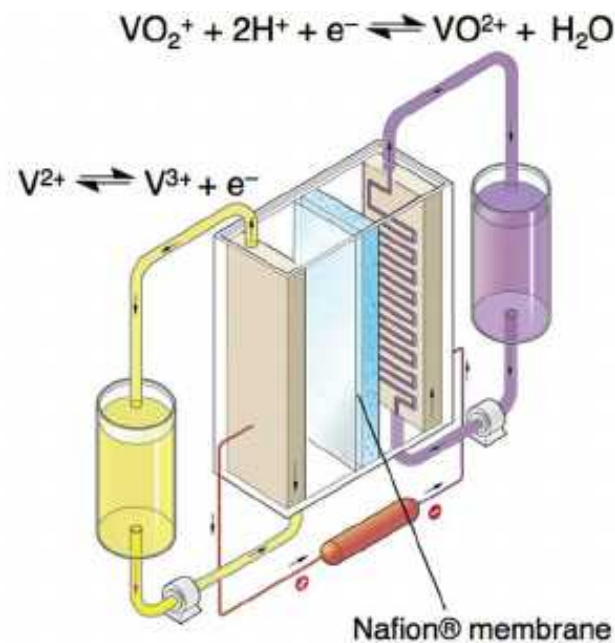
We are currently seeking industry partners to advance large-scale demonstrations and drive commercialization of these batteries.

Redox Flow Batteries

Redox flow batteries utilize dissolved redox-active species that are flowed through electrochemical cells. Anolytes and catholytes are separated by ion-conducting, but electronically-insulating, membranes. Critically, *energy and power are separated in this design.*



Open Circuit Potential (OCP) 1.2 V



Open Circuit Potential (OCP) 1.3 V

Promising large-scale storage candidate

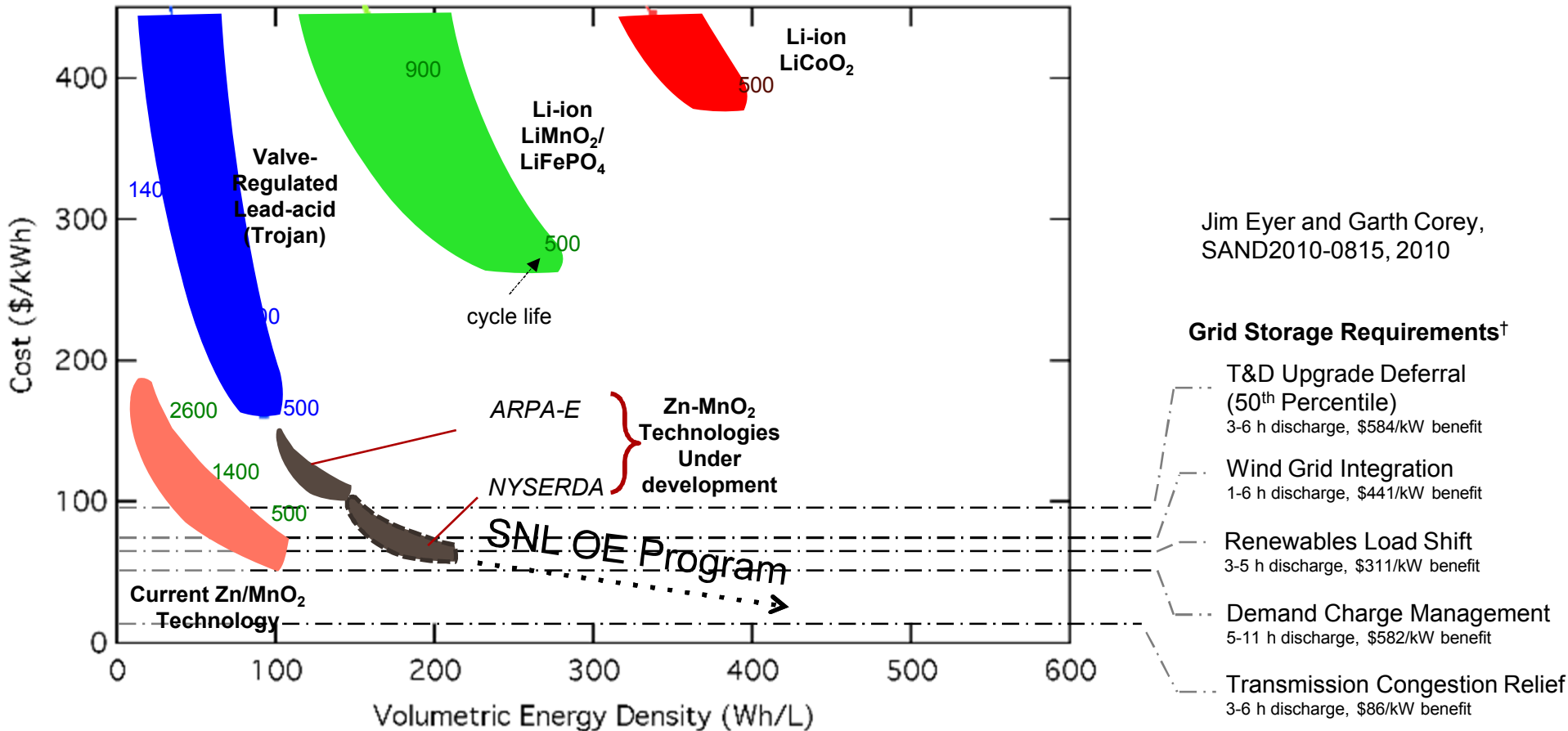
- Low cost: traditional primary batteries @ \$18/kWh
- Long shelf life, lowest cost of materials, lowest manufacturing expenses, established supply chain
- Can be scaled to large form factors
- Limited thermal management required compared to Pb or Li
- Safer, environmentally friendly (EPA certified for landfill disposal, non flammable)

Challenge: Re-chargeability = Battery Lifetime & Cost



Future of Zn-MnO₂ Batteries

Opportunity exists to increase capacity and decrease costs



Jim Eyer and Garth Corey,
SAND2010-0815, 2010

Toward Low Cost/High Volumetric Energy Storage

Rechargeable Alkaline Zn-MnO₂ Batteries

Promising large-scale storage candidate

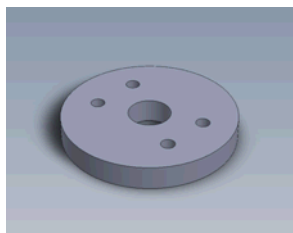
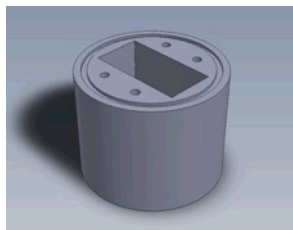
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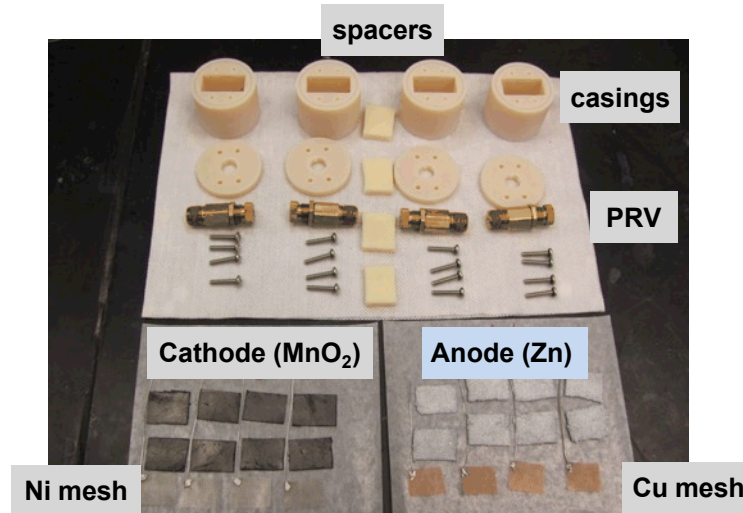


3D Printed Fabrication of Batteries

Solid Works design
3D Printing of PP casing



Planar electrodes w/Teflon binder/additives



Zn/MnO₂ alkaline
test prototypes

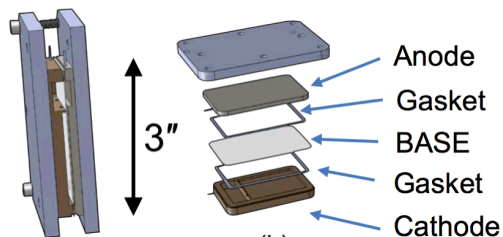


*Casing allows for
~ 100-500 mAh
prototype batteries*

Pacific Northwest National Laboratory



- Intermediate temperature Na-Halide batteries



- Flow Batteries
 - Organic Redox Systems
 - Mixed Acid Redox Flow



Dr. Vincent Sprenkle

Technical Group Manager, Electrochemical Materials and Systems Group

Email: vincent.sprenkle@pnnl.gov

Oak Ridge National Laboratory



- Emphasis on component research for redox flow batteries
 - Membranes
 - Electrodes
 - Cell Design



Dr. Mark A. Buckner

Power and Energy Systems Program Manager, Energy Storage

Email: bucknerma@ornl.gov

Take Home Messages

- ✓ Grid scale energy storage will continue to be a critical national priority, important for both civilian and defense-based utilities.
- ✓ Specific performance requirements are important in determining what types of batteries will be best suited to an application – not all batteries are the same!
- ✓ There remains a need for *safe, low-cost*, large scale energy storage technologies with *reliable, long-term* performance.
 - ✓ Na-based batteries
 - ✓ Redox flow batteries
 - ✓ Rechargeable alkaline batteries



- ✓ Research across the DOE National Laboratory complex is aimed at meeting the challenge to create truly enabling next generation energy storage technologies.

Thank you!



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Contact: Erik D. Spoerke, Ph.D.
edspoer@sandia.gov