EaglePicher™
Technologies, LLC
An CMG Company

Sodium/Beta Batteries

Presented by:

James A. DeGruson & **Dave Lucero**
Senior Engineer **Director, AES**

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Overview

EaglePicher™ Technologies, LLC
An OM Company

- Background
- Sodium-Beta Evolution
- EPT Sodium-Beta Experience
- EPT ‘s ARPA-E Contract
- Project Overview
- Design Considerations
- Summary

EaglePicher Profile

EaglePicher™ Technologies, LLC
An OM Company

Leader in Batteries, Battery Chargers & Energetic Devices for Defense, Space, Commercial, and Medical Applications

- HQ in Joplin, Missouri
- 11 Plants
  - Joplin, Missouri
  - Seneca, Missouri
  - Pittsburg, Kansas
  - Plano, Texas
  - Vancouver, B.C.
  - Rothenbach, Germany (JV)
- Expertise in >25 Chemistries
- Millions of Specialty Batteries Delivered

Headquarters - Joplin, Missouri

INTERTEK AS9100 • ISO 9001

ANAB ACCREDITED

Trusted Power ♦ Reliable Power ♦ Innovative Power

EPT Heritage

EaglePicher™ Technologies, LLC
An OM Group Company

1843 The Eagle-White Lead Company Formed in Cincinnati, OH

1874 The Picher Lead Co. Began Mining in Joplin, MO

1922 EaglePicher Initiates Research into Storage Battery Technology

1944 First Special Purpose Battery Contract Awarded to EaglePicher

1947 Bell Labs Used EaglePicher Germanium for 1st Transistor

1970 Apollo 13 Safely Returned to Earth on EaglePicher Batteries

1990 Patriot Anti-Missile System and Tomahawk Cruise Missiles Powered by EaglePicher Batteries

1997 Launched Columbia Shuttle Battery Experiment with EPT Sodium/Sulfur

2007 New State-of-the-Art Battery Facilities in Pittsburg, KS and Joplin, MO

2009 New State-of-the-Art Battery Facility in Plano, TX

2010 EaglePicher Achieves 1.4 billion cell hours in Space

2010 OM Group, Inc. purchases EaglePicher Technologies, LLC

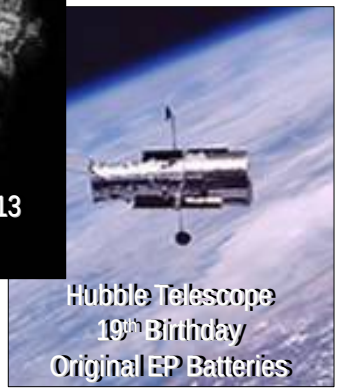
2010 EaglePicher awarded ARPA-E Sodium beta battery technology development program


EaglePicher Mine – Picher, OK


EaglePicher Ge & Ga Factory


EaglePicher Germanium at Bell Labs


EaglePicher Battery Brings Apollo 13 Home


Hubble Telescope 19th Birthday Original EP Batteries

Rich Past ♦ Bright Future

EPT Business Units

EaglePicher Technologies, LLC

Randy Moore, President

Aerospace Systems

Satellites
Aircraft
Commercial
Alternative Energy

Defense Systems

Missiles
Infantry Support

Medical Power

Implantable Devices

Sodium-Beta Evolution

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- Sodium Sulfur Batteries first developed by Ford Motor Co. in 1960's.
- Sodium Metal Halide Batteries first developed by Zeolite Battery Research Africa (ZEBRA) in 1970's.
- Present Day Players in Sodium Beta are:
  - CoorsTek
  - General Electric
  - NGK Insulator, ltd.

EPT's Sodium-Beta Experience

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- 1952: Molten Salt Battery Development
- 1973: Argonne National Laboratory Contract on Rechargeable Batteries for Electric Vehicles
- 1986: Air Force Contract to Develop Tubular Na/S for Satellites
- 1988: Beta" Electrolyte Development
- 1990: Planar Sodium/Sulfur*
- 1992: Sodium/Nickel Chloride
- 1997: Space Shuttle Flight Experiment
- 2010: Planar Sodium/Metal Chloride

* EPT Patent # US4894299A Cell Having Dome-Shaped Solid Ceramic Electrolyte

Columbia Shuttle Flight Cell

40 Ah Central Sodium

Columbia Shuttle Flight Battery

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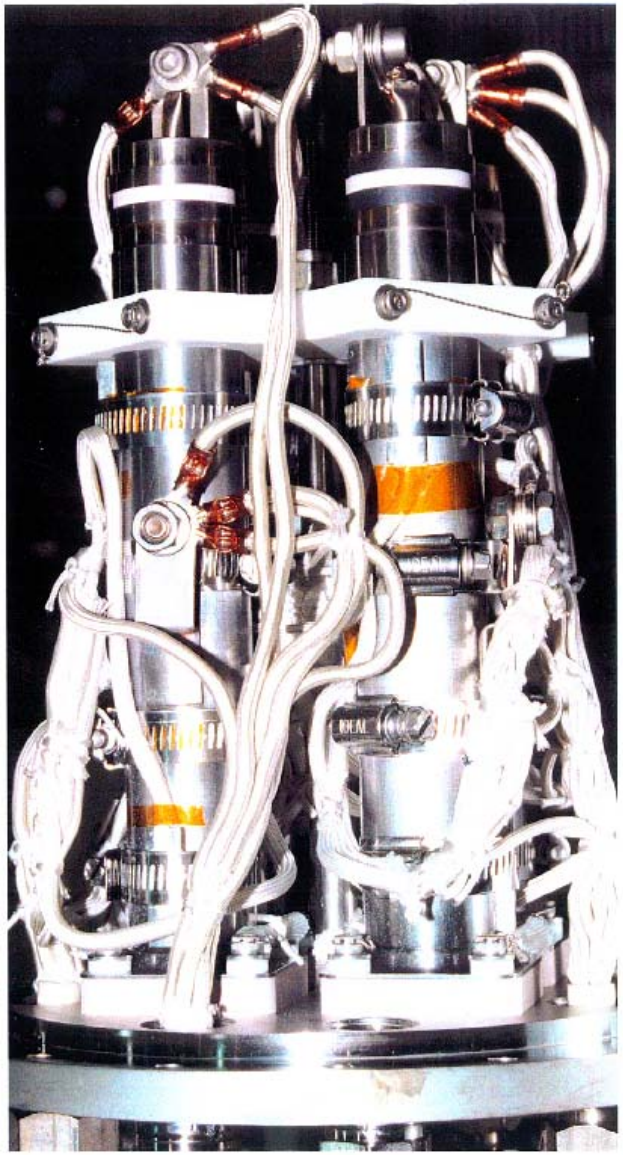

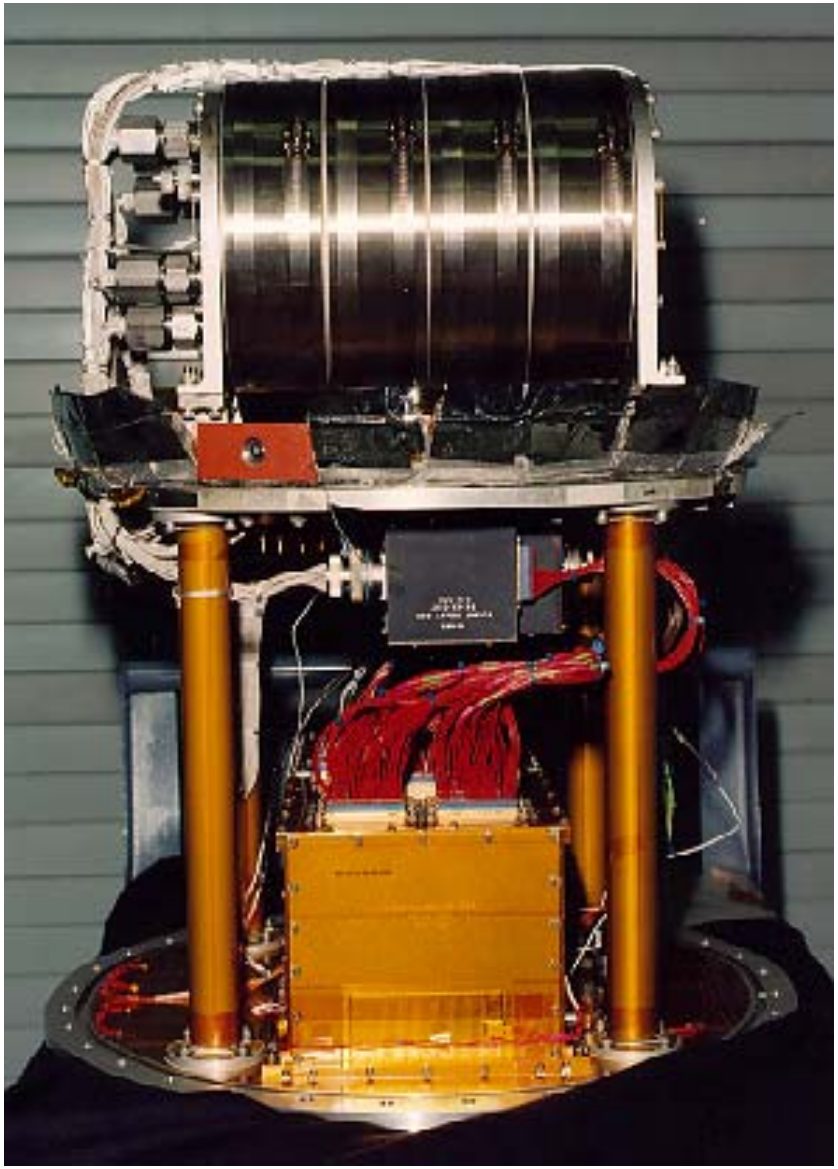

EPT's ARPA-E Contract

- Planar Na-Beta Batteries for Renewable Integration and Grid Applications
- Office of ARPA-E; US Dept. of Energy
- Contract # DE-AR0000045/001
- Effective: 1 February 2010
- 36 Month Program
- DE-FOA-0000065 Broad Funding Announcement

Sodium-Beta Team

- Team Leader: EaglePicher Technologies, LLC (EPT)
- Team Member: Pacific Northwest National Laboratories (PNNL)
- PNNL Cooperative Research and Development Agreement (CRADA) No. 301

"New Generation Na-Beta Batteries for Renewable Integration & Grid Applications"

EaglePicher Technologies, LLC
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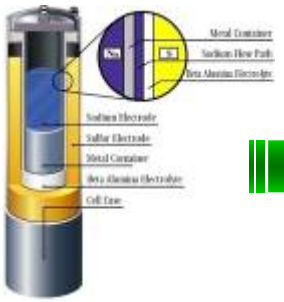
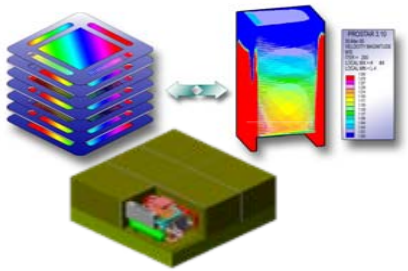
Proposed Technology vs. State of the Art





SOA **Tubular** Na-beta Design

Leverage US National Lab Tech

Proposed **Planar** Na-beta Design

- Energy Density Increase
- Cost Reduction
- Temperature Reduction
- Transformational Changes

ARPA-E Mission Area Impact

- **Renewable Energy Storage With Improved Na-beta battery reduces CO_2 emissions by 150 Million Tons/Year**
- **Improves/maintains US energy storage leadership**

Transition Strategy

Proof of Concept | Commercialization

PNNL Research and Development

Tech Transfer & IP

EaglePicher R&D and Production

3 Yr

One Team: Concept Thru Production

No Tech Transfer Lag

No IP Transfer Lag

EaglePicher Full Scale Development

2 Yr

EaglePicher Establish Large Scale Production

2 Yr

Program Summary

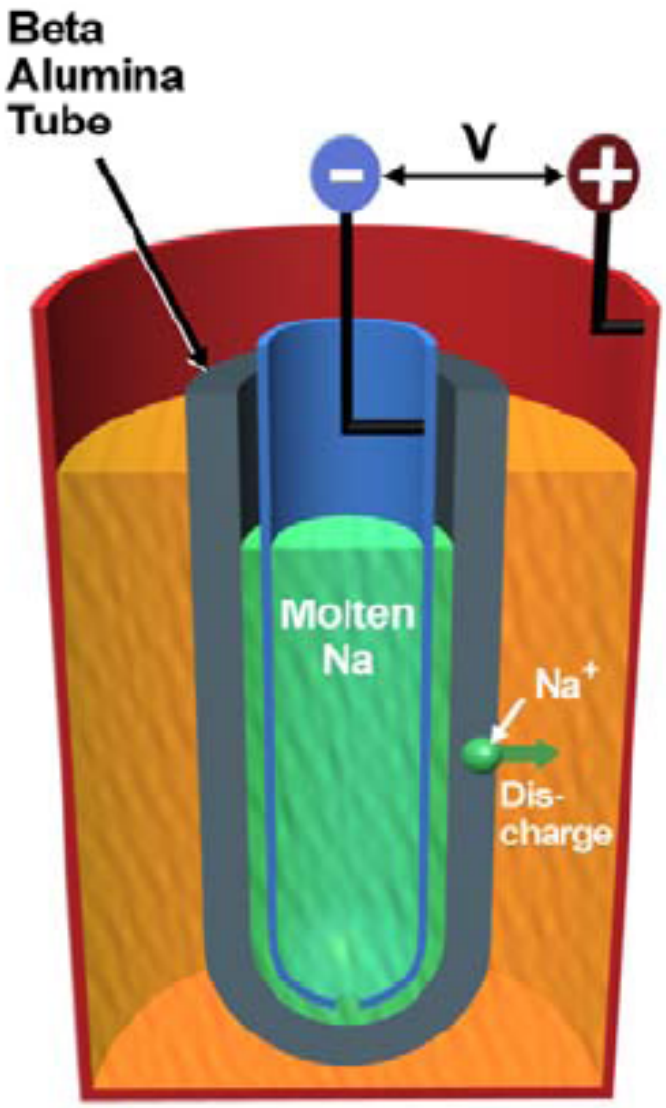
Period of performance:
36 months

ARPA-E funds:	**$7.2M**
Cost-share:	**$1.8M**
Total budget:	**$9.0M**

Annual Schedule Milestones

- Improved Na-beta cell demonstration & initial system model complete
- PNNL electrolyte & seal technology transfer complete & demonstration of multi-cell battery
- 5kW-20kWh battery model demonstration & system model complete

Tubular Construction



Sodium-sulfur battery (NBB)

Positive electrode:

$$S_x^{-2} + 2Na^+ \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} Na_2S_x$$

Negative electrode:

$$2Na^+ + 2e^- \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} 2Na$$

Sodium-$NiCl_2$ battery (ZEBRA)

Positive electrode:

$$2NaCl + Ni - 2e^- \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} 2Na^+ + NiCl_2$$

Negative

$$2Na^+ + 2e^- \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} 2Na$$

Metal Chloride Attributes

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- 2.35 to 2.58 Open-Circuit Voltage
- Built in Discharged State
- Operating Temperature (>300°C)
- Failure Mechanisms Benign
- Fails in Shorted Condition
- Energy Density: 120 Wh/kg
- Power Density: 170 W/kg

Metal Chloride Targets

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- Charge/Discharge Rate: 1C
- Low Operating Temperature (< 280°C)
- Cycle Life: >5,000@80% DOD
- Calendar Life: >10 Years
- 90% Round Trip Efficiency
- Energy Density: 200 Wh/kg
- Power Density: 300 W/kg

Project Overview

- Planar Configuration Development
- Initial Component & System Development
  - BASE
  - Seal
  - Cathode
- Component Scale-up & Technology Transfer
- Technology Demonstration
  - Deliver 5 kW/10 kWhr Module

Configuration

- Planar Electrodes
- Series Connected
- Thermal Conductive Fins
- Electrically Isolated
- Electrically Balanced
- Adjacent Battery Management System

Cell Design Approach

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- Metal Chloride Cathode
- BASE
- Configuration
- Active Temperature Control
- Series Connection for Modular Concept
- High Energy Density
- Low Cost Materials
- Extended Cycle Life

- Ultra-Thin
- Sealed in Cell Case
- Sodium Conductivity
- Strength Enhanced
- Process Manufacturing
- Geometry
- Cost

High Power Density

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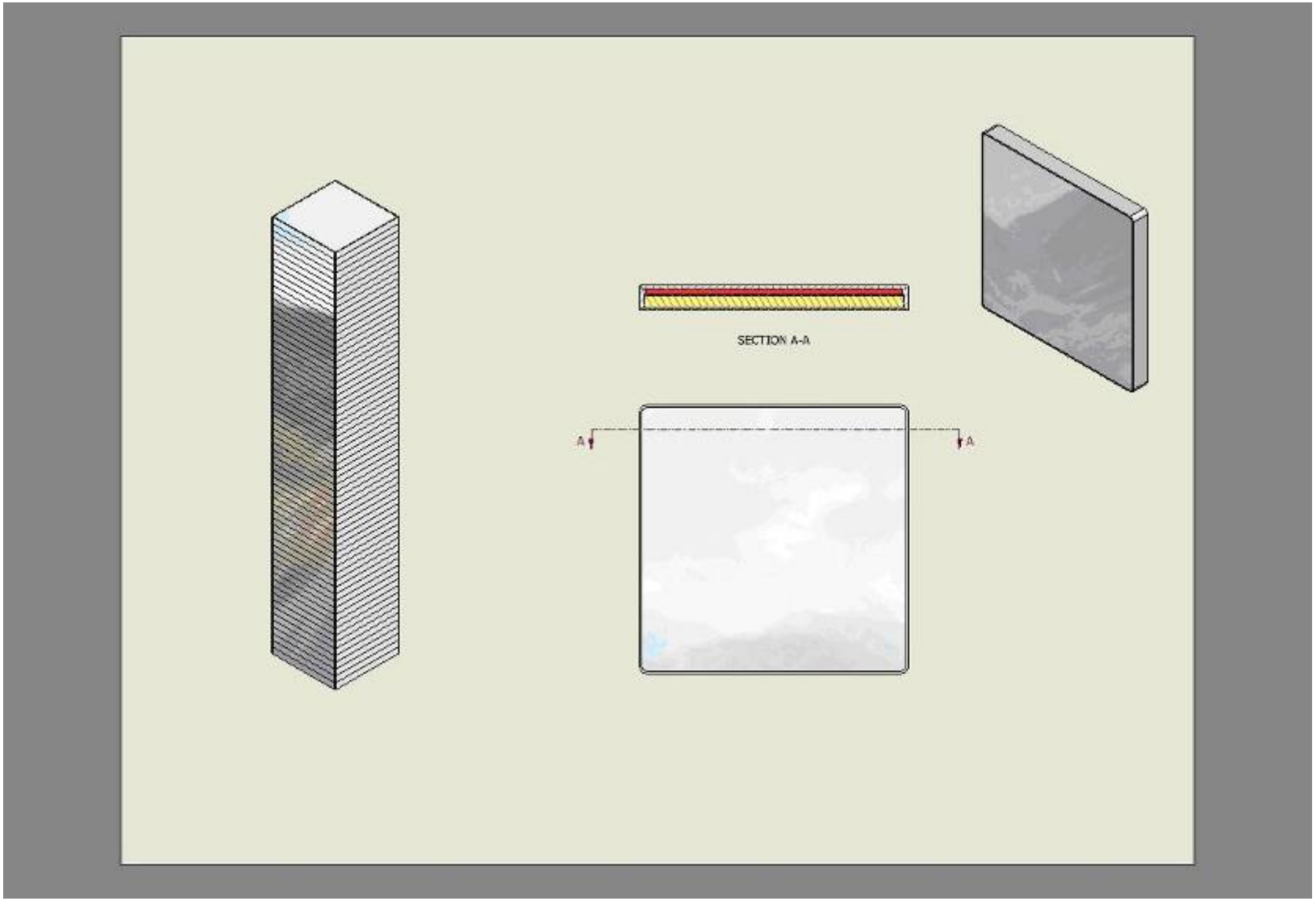
- 300 W/kg Projected @ 250°C
  - Thin Electrolyte
  - Sodium Conducting Liquid Phase
  - Improved Solid Phase Cathode
  - Minimal Cathode Thickness
  - Improved Anode Contact

Cell Configuration



Battery Design

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- Modular Concept: 120 Volts
  - 64 Cells in Series (Expandable to Higher Voltage)
  - Cell Individually Sealed
  - Cell Replacement Possible
- Parallel Modules
  - Each Module 20 kWh
  - Number Tailored to Application
  - Modules Contained in Insulated Container
  - Battery Management System External

Battery Attributes

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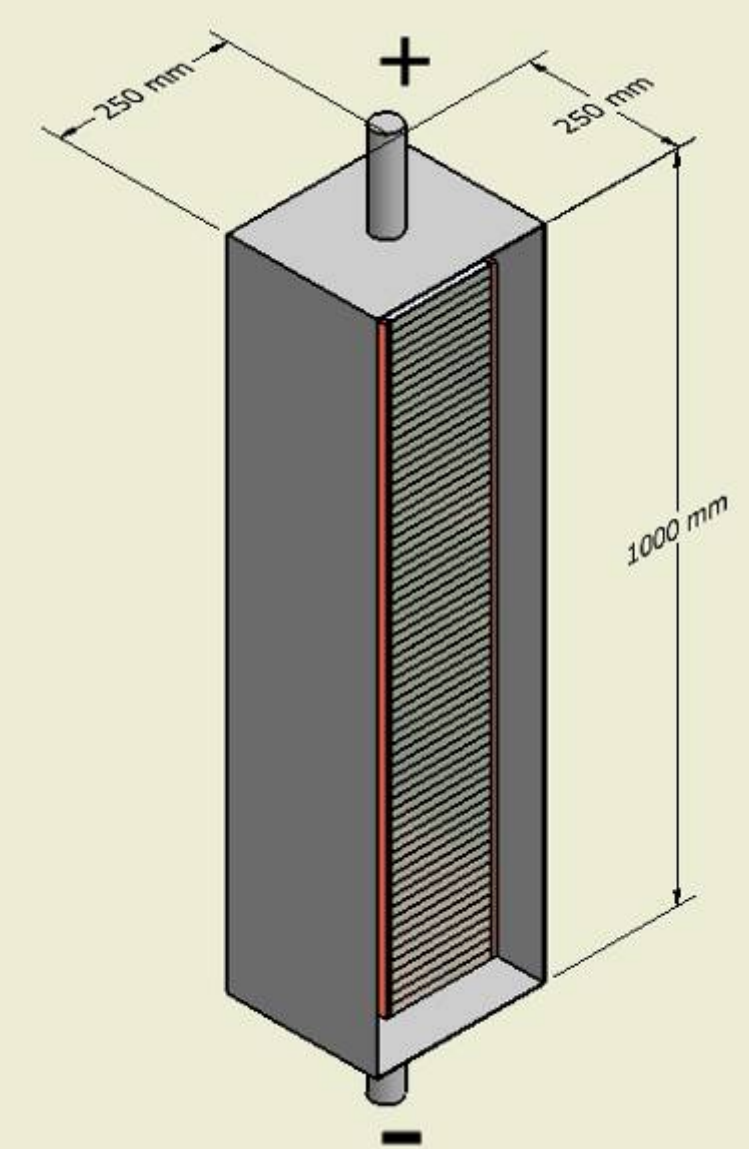
- Safety
- No Maintenance
- Low Cost
- Zero Emissions
- Recyclable
- Minimal DOT Regulations

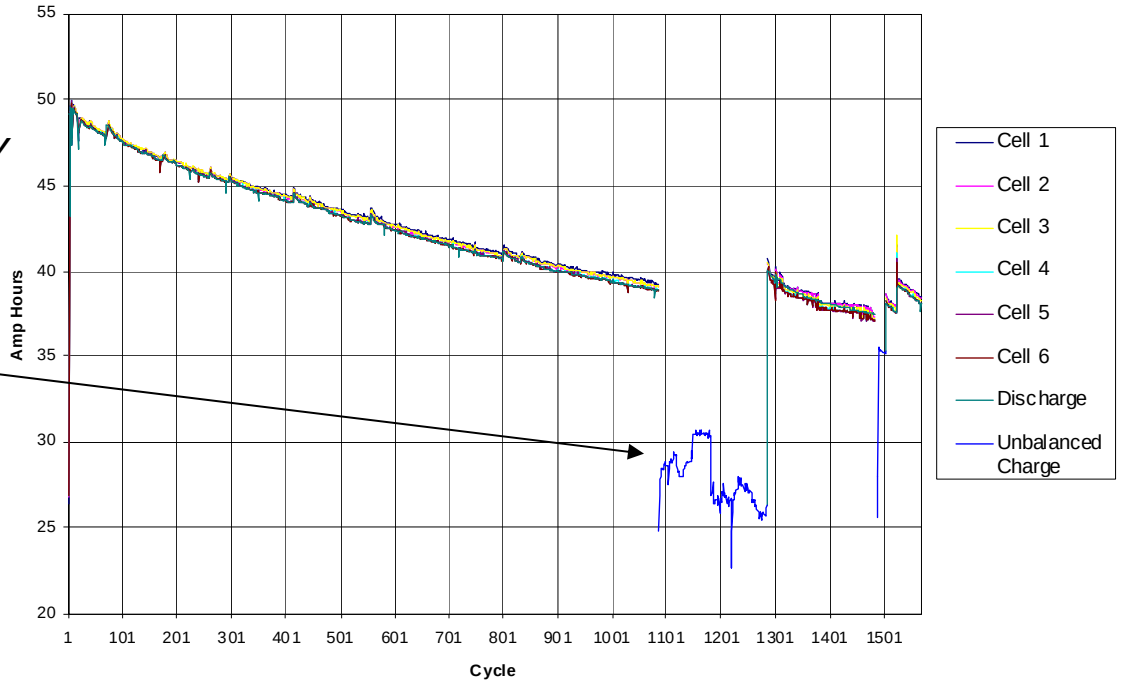
Battery Module Configuration



EPT's Battery Management

- All rechargeable battery systems have "sweet spots" of operation that maximize cycle life and capacity
- EaglePicher's active battery management system continuously monitors and regulates each battery system in order to get the most out of them
- This technology is being applied to the sodium beta battery chemistry

Actual data from Lithium Ion cells that demonstrates the effectiveness EaglePicher's Battery Management System (BMS) on long term capacity



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Battery Management System (BMS)

- EaglePicher's BMS technology has been successfully demonstrated through multiple space, defense and aerospace applications - 1.4 billion cell hours in space without mission failure gives testimonial to the integrity of these robust systems.
- BMS features include:
  - Over and under voltage sensing
  - High and low temperature sensing
  - Over current and short circuit protection
  - Equalization time limit
  - State-of-Charge, State-of-Health

- In addition, the BMS control algorithms will monitor and provide:
  - Battery cycle cost and estimated life
  - Overall Storage System power costs and efficiencies
  - Utility definable metrics to help optimize Battery Storage System reliability

Temperature Control

- Thermally Balanced
- Heating/Cooling Paths
- Thermal End Buffers
- Thermally Isolated Connectors
- Insulated Enclosure
- BMS Controlled

Project Summary

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- Domestic Supply
- Energy Dense Storage
- Improved Power/Energy Ratio over Tubular
- Moderate Initial Cost
- Long Installed Life (low life cycle cost)
- Site Independent Use
- Near Term Availability

Acknowledgements

- EaglePicher Technologies wish to recognize the following team members from Pacific Northwest National Laboratories:
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  - Dr. John Lemmon

Work is being accomplished under

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