Lead-Carbon Hybrid Battery/Super capacitor

Greening Your Fleet - 2013

Elizabeth, IN
September 23, 2013

Vani Dantam

www.axionpower.com
Manufacturing and Development Facilities

- **PbC® Electrode Automation Facility**
  - (45,000 sq. ft.)

- **Battery Manufacturing Facility**
  - (75,000 sq. ft.)
Overview

- Initial System Cost
- Operating and Maintenance Costs
- Support – Incentives and Infrastructure
- Safety
- Recyclability
Transportation Applications

• Personal transportation
  ➢ Automobiles

• Freight & Mass Transportation
  ➢ Medium & Heavy Trucks (e Power Engines)
  ➢ Busses
  ➢ Locomotives
Axion PbC® Battery
Hybrid Asymmetric Energy Storage

PbC® Negative Plate
Capacitor Electrode
- Non-Faradaic
- Reversible Electrostatic Surface Charge Adsorption

PbC® Positive Plate
Battery Electrode
- Faradaic
- High Energy
- Phase Transitions

Carbon

Lead Dioxide [PbO₂]

Lead Sulfate [PbSO₄]

Electrolyte

Axion Power International 2013
**PbC® Technology**

**PbC® Battery Features**

- Ease of Integration and SOC Management
- Low-cost Platform Technology
- Fully Recyclable with end of life value
- Low to no maintenance in large strings
Advanced Lead Acid Batteries for Tomorrow’s Demanding Energy Needs

**PbC® Value Proposition**

- Optimal performance in medium to large strings with little variability
- Simpler battery management system (BMS) with built in charge equalization and stabilization
- Full Power over wide temperature range (-20°C to +50°C)
- Does not require complicated thermal management with costly liquid temperature cooling systems
- Significantly faster recharge times than Lithium ion systems (LFP & NMC chemistries) with no overcharging or thermal runaway issues
- Well established safe technology with known end of life value
- System scalability with plug and play modular design
- Abundant domestic raw materials (completely recyclable)
Updated Cycle Life Data @ room temperature for 30HT’s

Unfilled circles show current status of ongoing tests.

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Micro-hybrid Test Results: Room Temperature Comparison (26°C)

VRLA (AGM) Battery

Axion PbC® Battery

Cycling to 100,000 cycles

2x greater (~50A) [brand new]
5x greater (20A) [1 month]
10x greater (10A) [2 months]
15x greater (7A) [6 months]
20x greater (5A) [9 months]
Micro-hybrid Test Results:
Cold Temperature Comparison (-10°C)

**VRLA (AGM) Battery**

- Dynamic Charge Acceptance (A)
- Charge Time (s)

**Axion PbC® Battery**

- Dynamic Charge Acceptance (A)
- Charge Time (s)

- 13 to 8°C
- 8 to -10°C

**50x greater**
(~2A) [-10C]

**>100x greater**
(<1A) [-10C + 3days]
Data collected by Dr. Joel Anstrom
Director of Hybrid Vehicle Research Laboratory
Pennsylvania Transportation Institute
The Pennsylvania State University

12V L5 Varta AGM Lead–Acid Battery

16V Axion PbC® Battery
Capacity Summary

- The module capacity continues to exceed the rated value of 45 Ah after RPT12.
Discharge Resistance Summary

- The improvement in discharge pulse resistance seems to have slowed down, especially at 50°C.
String Variability
Module-to-Module Variation

VRLA (AGM) Battery

EQ = Equalization
BR = Battery Replacement

1/3 of VRLA string replaced in first ~100 days of testing

Axion PbC® Battery

M2M Variation 10x lower than VRLA
String Variability
Module-to-Module Variation

Battery (Voltage = 36V)

Module (Voltage = 12V)  Cell (Voltage = 2V)

VRLA (AGM) Battery

EQ = Equalization
BR = Battery Replacement

1/3 of VRLA string replaced in first ~100 days of testing

Axion PbC® Battery

CDI-Equalization applies to internal cells as well

M2M Variation 10x lower than VRLA

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Hybrid Electric Vehicle Market

Micro-hybrid stop-start is the future of the hybrid electric vehicle market

- Estimated 15-22 million vehicles by 2015 (Global Production)
- Legislation driving production increases:
  - Europe: 130 gCO2/km [42 mpg] 65% of fleet by 2010 / 100% of fleet by 2015
  - US: 205 gCO2/mi [36 mpg] 100% of fleet by 2016

“Of the 70.9 million passenger vehicles sold worldwide in 2020, only 7.3% will be advanced vehicles – plug-ins and all electric”
- J.D. Power and Associates November 2010

Remainder will be a different hybrid stop-start chemistry

Axion Power International 2013
Hybrid Electric Vehicle Market

Pike Research

Annual SSV/HEV Sales, World Markets: 2011-2017

(Source: Pike Research)
Standardized DCA Testing
Dynamic Micro-Hybrid Test (DMHT)

DKE Test EN-50342-6
[Deutsche Elektrotechnische Kommission]
(German Electrotechnology Commission)
Co-developed by Axion Technologies and BMW

Initial Counter Setting
N=50

Counter Increment
Every cycle:
If Volts > SP → N = N-1
If Volts < SP → N = N+1

Dynamic Charge Step
100 A maximum
Ah returned =
3600 As + 4.0 As x N
(initial Ah = 1.055 Ah)

DCA: Dynamic Charge Acceptance
Current at end of step

Charge Time
Time required to maintain SOC

Off-line REST
Every 500 cycles
rest battery at open circuit for 6 hours

Axion Power International 2013
Comprehensive, Proprietary Technology

Integration Delivers a System that is Greater than the Sum of its Parts

With Deep Intellectual Property and Patent Pending Protection Throughout

Diesel Gen-Set
• Small, efficient unit
• Active AC power Management
• Ability to provide an external power source while not moving

Power Electronics
• Unique integration of AC and DC power
• Power management / distribution software
• Active AC power Management
• Fully programmable driving experience

Shifting and Control Unit
• 5 speed automatic transmission
• Dynamic braking
• Electronic jake brake
• Cruise Control

Battery and Management Systems
• Axion PbC® battery Technology
• Rapid charge / discharge
• Axion Power BMS unit
• Extended life cycle
• Battery SOC active computer management
• Active temp. control

Electric Motor
• AC induction motor
• Full torque from 0 to base rpm
• AC Vector controller
• Thermal overload protection
• High efficiency design
• Rugged construction for maximum durability
Driving the world forward

The epower Advantage

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Axion Power International 2013
Driving the world forward

epower tested mpg and projected future mpg / course 1% to 3% grades 59 average mph

- 25,000 GVW
- 35,000 GVW
- 45,000 GVW
- 55,000 GVW
- 65,000 GVW
- 75,000 GVW

Tested
Future

Axion Power International 2013
ePower tested mpg and projected future mpg / course 1% to 3 % grades 55 average mph

- 25,000 GVW
- 35,000 GVW
- 45,000 GVW
- 55,000 GVW
- 65,000 GVW
- 75,000 GVW

 Tested
 Future
Comparison made to data contained in a 2012 NREL / CCR on road test report

0 to 60 mph in seconds @ 35,000 lb GVW

- Eaton Hybrid
- Conventional
- ePower Hybrid

Time
NREL / CCR tests were conducted using an Eaton hybrid (costing over $250K) and conventional tractor. The conventional test vehicle was a 2009 Freightliner M2 106 at a test weight of 33,840 lbs, the hybrid test vehicle was a 2010 Kenworth T370 at a test weight of 34,300 lbs, with an Eaton hybrid electric system. NREL / CCR testing conducted on a relatively flat course. ePower test course contained measured grade changes ranging from -1% to + 2 % in elevation.

**WVU / CILCC / Combined City Course MPG Comparison**

- **Eaton Hybrid**
- **Conventional**
- **ePower Hybrid**

(avg. mpg)
Testing configuration at 34,940 lb GVW with removable fuel tank for weighing per SAE J1321.
Testing configuration at 34,940 lb GVW with removable fuel tank for weighing per SAE J1321.
Axion Batteries are ideal for Stop – Start applications in automobiles

Axion batteries have been successfully used to build a class 8 hybrid truck with demonstrated fuel economy gains of 30 to 50%

First Norfolk – Southern Locomotive with Axion Batteries will go into operation in 4th quarter this year. Projections show that a single locomotive will save tens of thousands of gallons of diesel/yr in Crescent Corridor (From Roanoke, VA to New Orleans, LA) and significant reductions in emissions.
Thank You

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