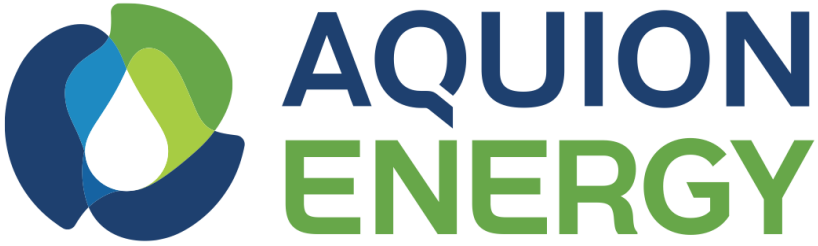


2012 Progress Report
Smart Grid Demonstration Program

Ted Wiley, Jay Whitacre

Department of Energy Peer Review
26 September, 2012

Thanks to Our Supporters

KPCB

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

USDA

CARNEGIE MELLON UNIVERSITY · PITTSBURGH PENNSYLVANIA 1900

Foundation CAPITAL

ATV
ADVANCED TECHNOLOGY VENTURES

PA
pennsylvania
DEPARTMENT OF COMMUNITY & ECONOMIC DEVELOPMENT

AQUION ENERGY

About Aquion Energy

Founded on the belief that stationary energy storage must be:

- **Safe:** Non-toxic and immune to catastrophic failure events
- **Reliable:** Long lasting and capable of operating in abusive environments
- **Affordable:** Made from abundant, simple materials via a scalable manufacturing process

This principle demands a new type of energy storage: **Aqueous Hybrid Ion Batteries**

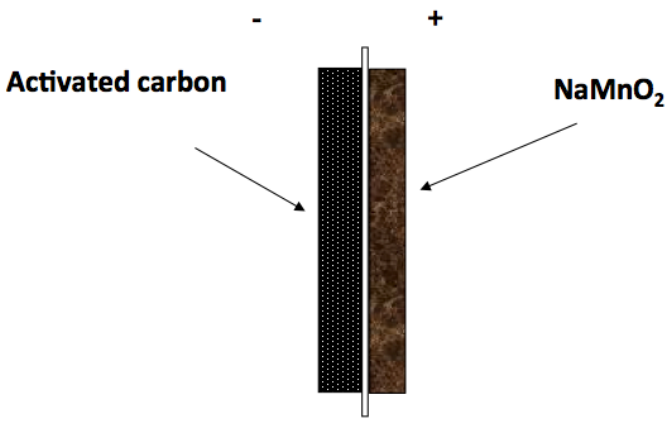
Designed for stationary, long-duration applications

- Utilities—various grid services
- Microgrids—telco, mining, commercial/residential solar, military, island, campus, etc.

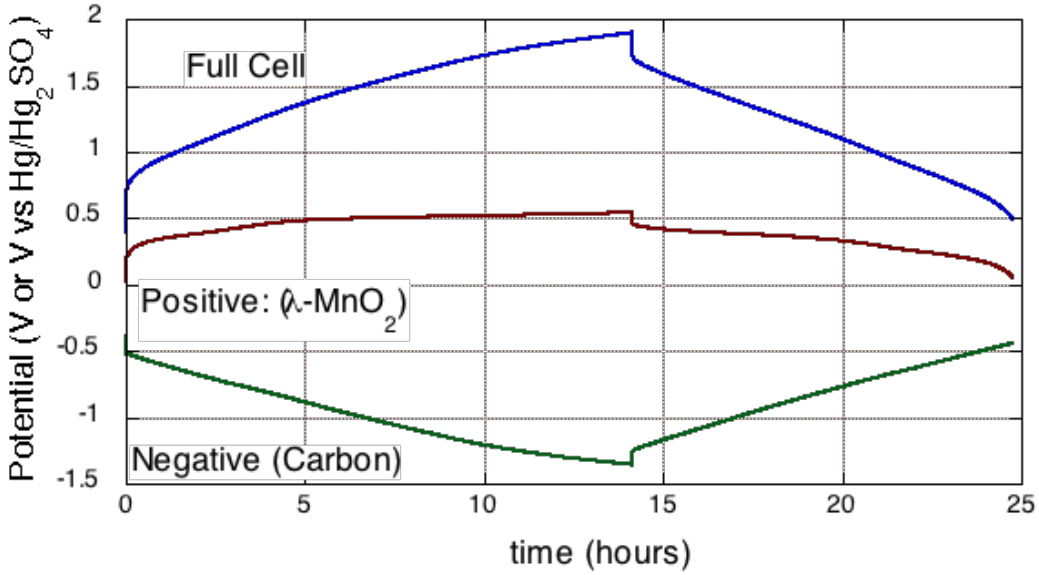
AQUION ENERGY

Aquion AHI Technology: Electrochemistry and Device

"Aqueous Hybrid Ion" chemistry:



3 electrode data

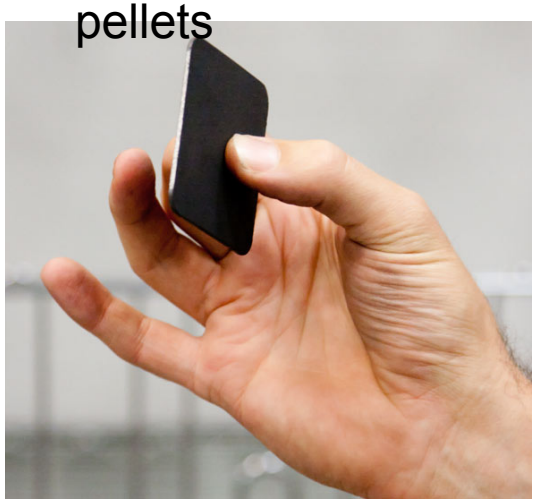


- Anode is low cost activated carbon
  - Enabling low-cost surface modification developed
  - Electrochemical Double Layer Capacitor Effect + pseudocapacitance
- Cathode is λ-MnO_2
  - Alkali ion intercalation material – very stable in neutral pH aqueous electrolyte
- Electrolyte is Na_2SO_4 in water (~1 M)
- Functional ions are Na, Li, and protons

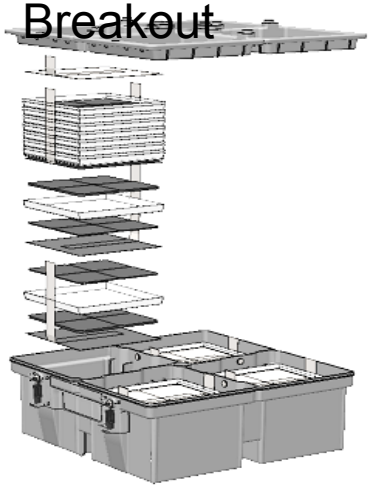
AQUION ENERGY

Aquion AHI Technology: Electrode and Device Structure

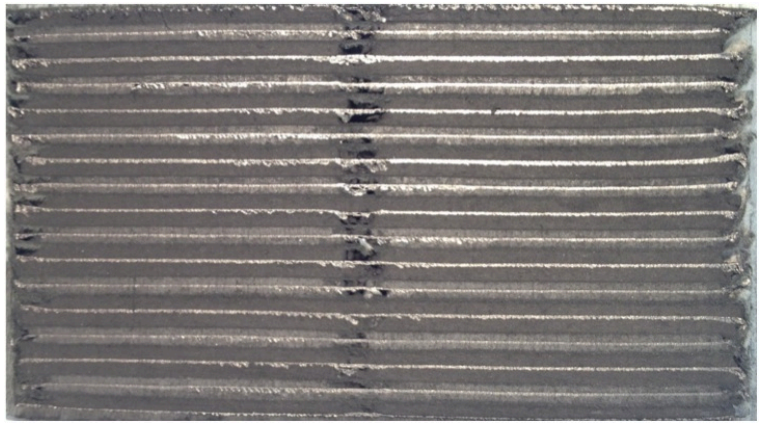
2” square pellets



Product Breakout



Electrode Stack cross section



- 1 to 4 mm thick Electrode pellets are made from a blend of active material and additives
- There are 4 pellets per electrode layer in a true prismatic electrode stack
- The electrode stacks are heat-sealed in a polypropylene package

AQUION ENERGY

Aquion's FOA36 Award: Goals and Milestones

Project Outcomes

- Successfully completed project ahead of schedule
- Proved selected materials could function in thick format electrodes
- Proved out a full pilot-scale production line
- Produced engineering prototype units showing indicative performance
- Created several functional systems, including a >10 kWh, 1000 V grid connected system
- Demonstrated key performance goals for the technology
- New materials examined at Carnegie Mellon University

AQUION ENERGY

Aquion's FOA36 Award: Performance Goals

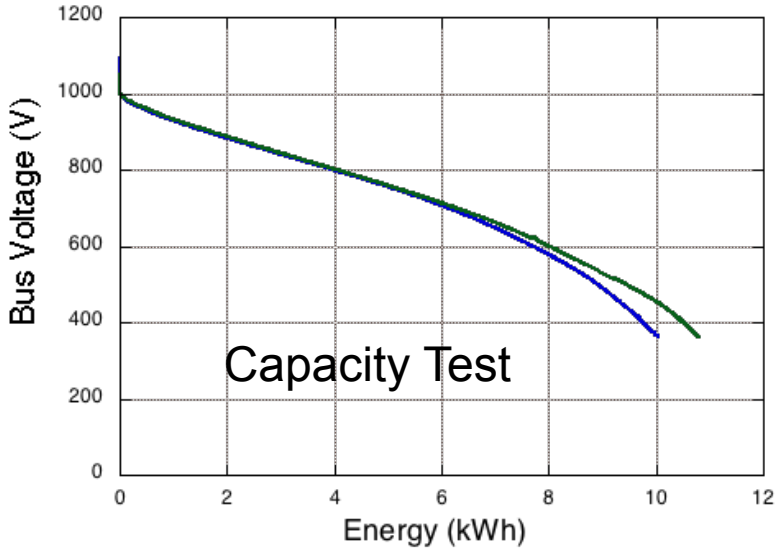
Target	Demonstrated
>5000 Cycle Life	>5000 in prototype cells, 1200 Cycles in production style cells – testing ongoing
10 years projected calendar life	No evidence to show <10 years – testing ongoing
<10% capacity degradation	Demonstrated through a variety of tests
Low capital cost	Competitive with PbA over lifetime
>10 kWh storage unit fabricated and demonstrated to be able to give/take from grid	Achieved – with a >1000 V battery pack at Aquion Energy HQ

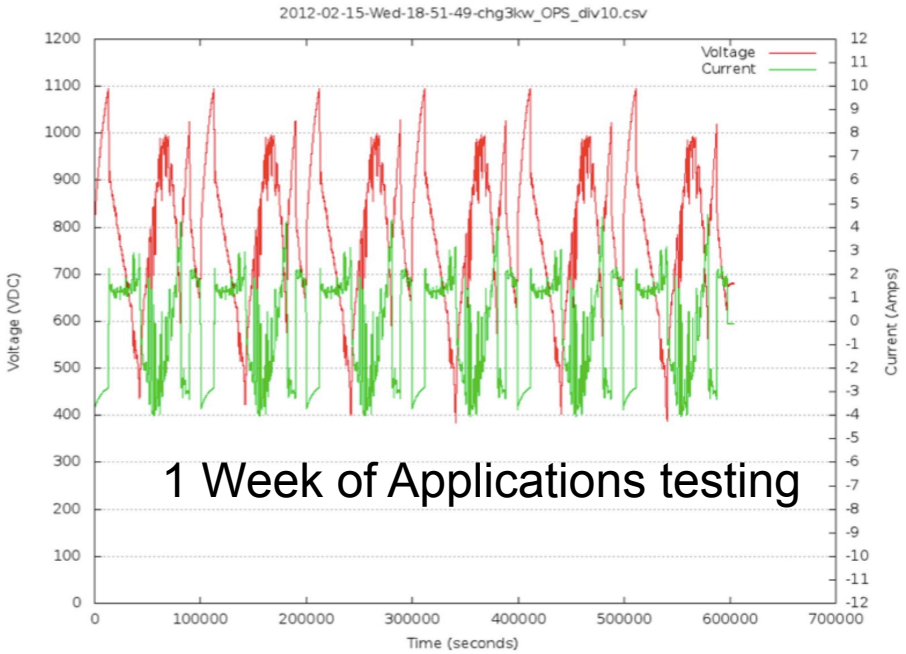
High Voltage Test System at Aquion

Pilot Line in Operation

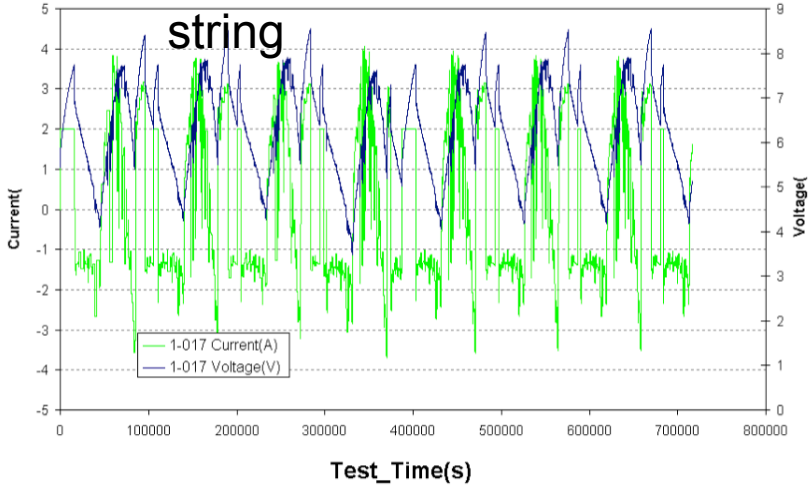
AQUION ENERGY

Deliverable Performance: >10 kWh Grid-Connected Demo



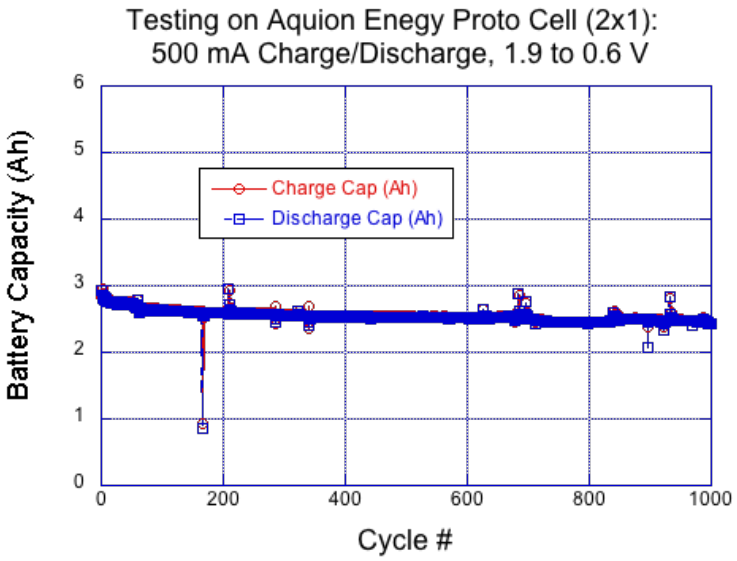


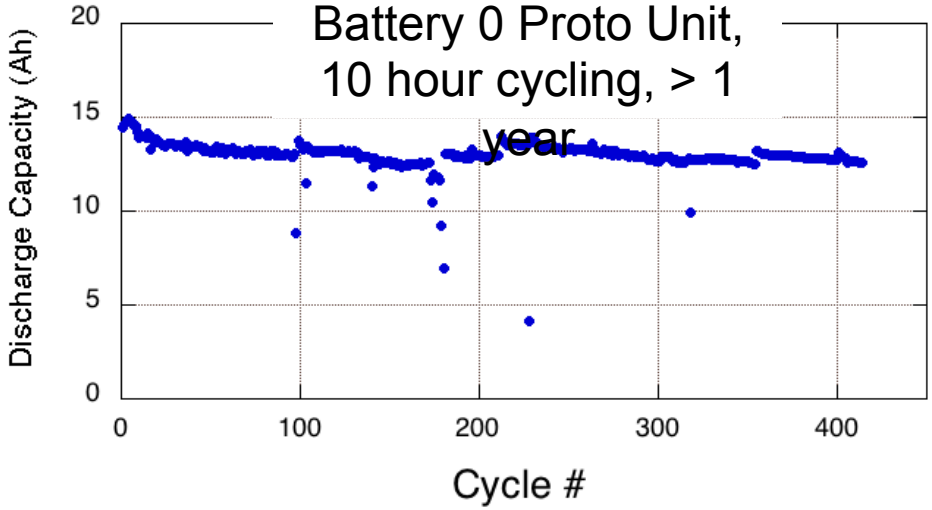
Same test on 4-Cell string



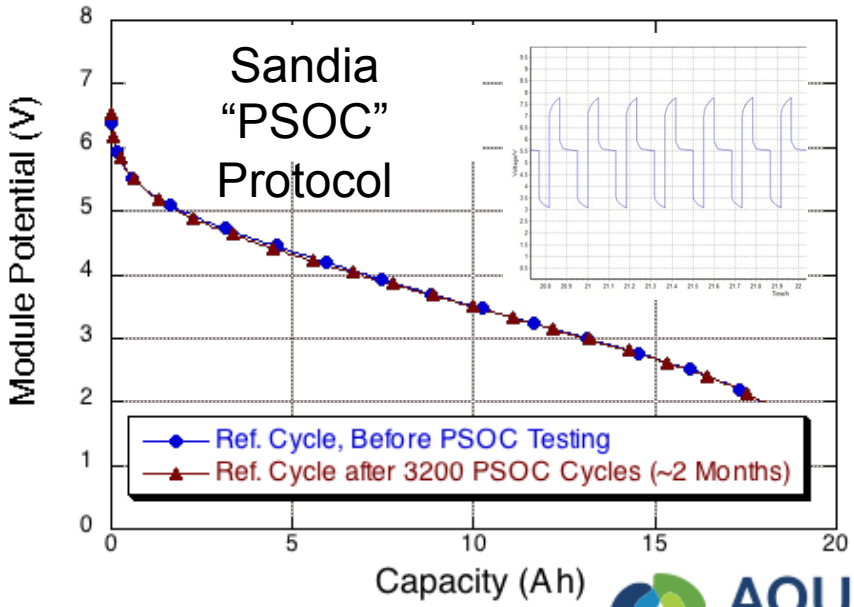
AQUION ENERGY

Performance Overview – Cycle Stability



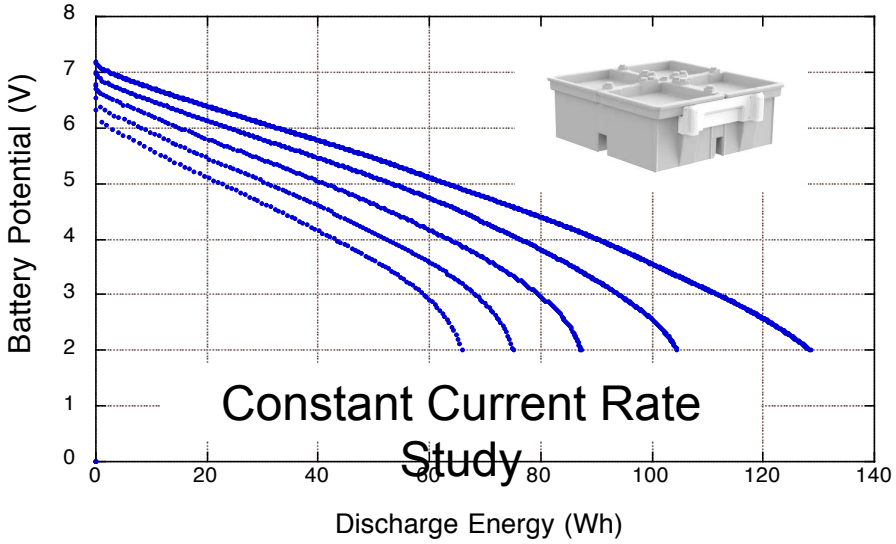


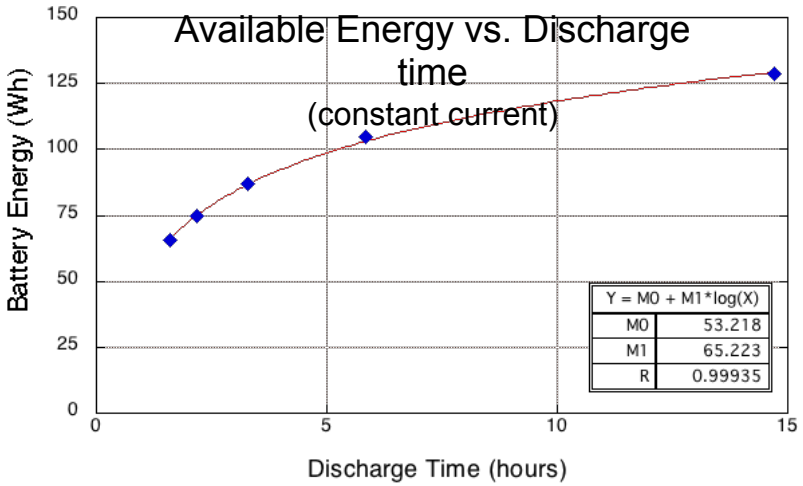
- >1000 cycles demonstrated on production electrodes in 1/8th size cell fixture
- >1 Year, 400 deep cycles on full size “battery 0” ubit
- Approaching 20,000 PSOC cycles on set of Battery 0 units with minimal loss in function

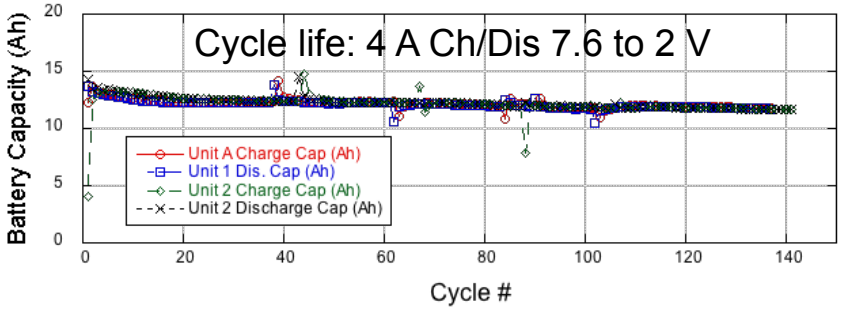


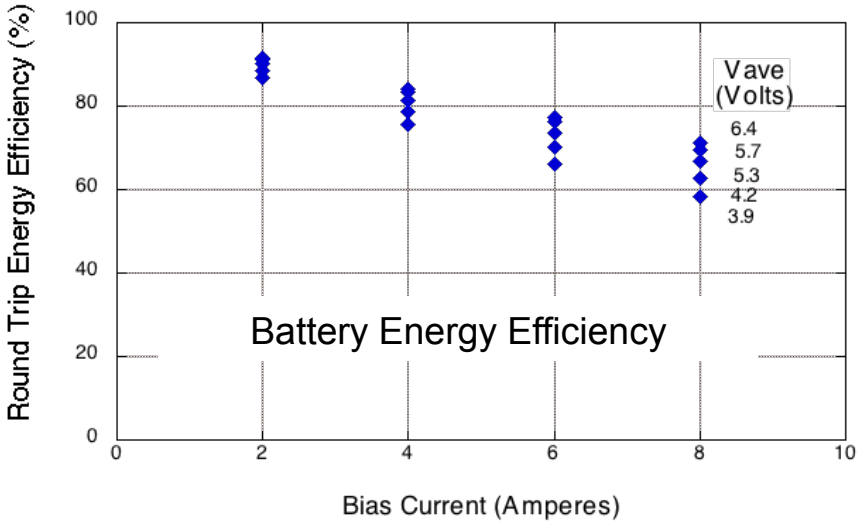
AQUION ENERGY

Pre-Production “Alpha” Unit Performance









- Units are ~7.6 V at full state of charge
- Give ~130 Wh at >15 hour discharge rates
- Efficiencies range from the low 90’s to 60%, depending on state of charge and current/power load
- Cycle life data consistent with prototypes

AQUION ENERGY

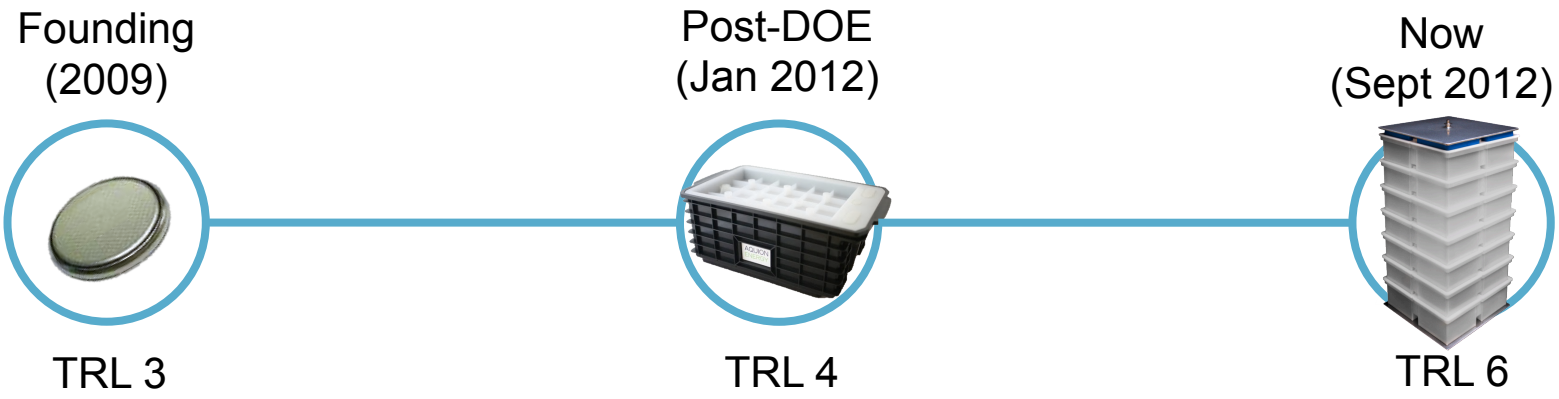
Basic Research at Carnegie Mellon

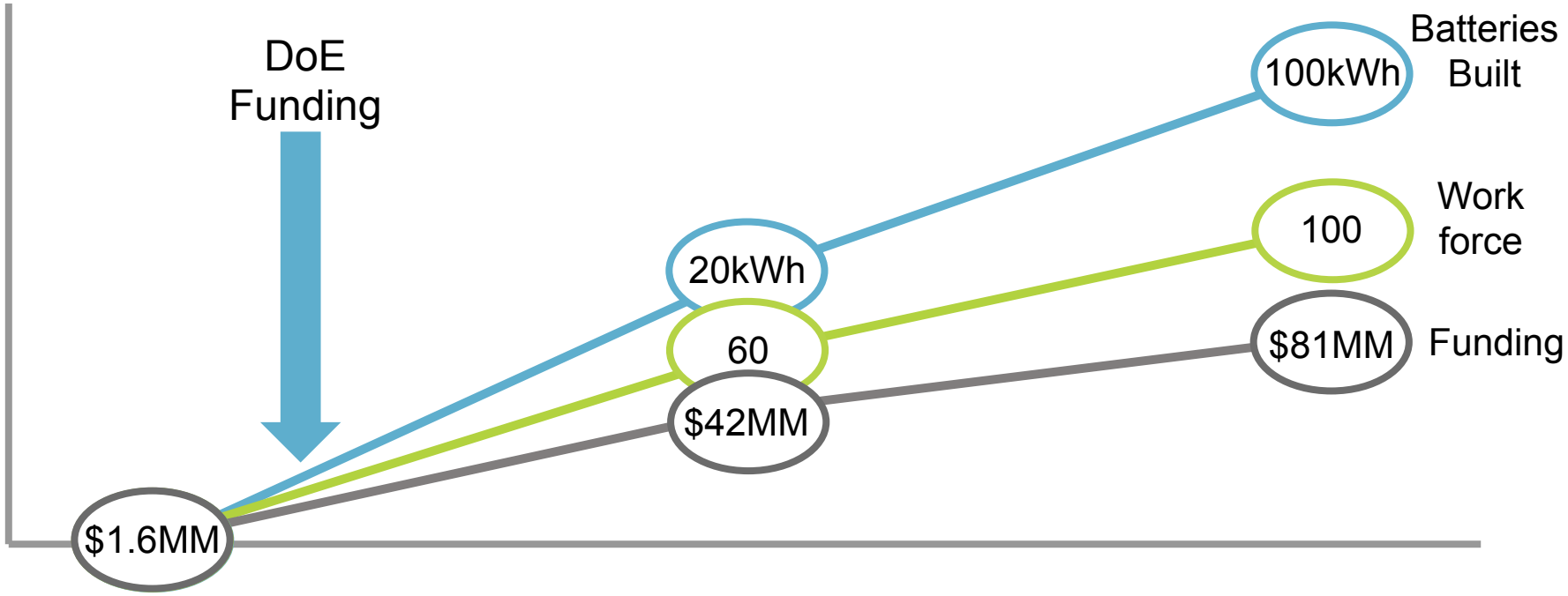
Carnegie Mellon

- Funding has supported (in part) 1 Postdoctoral Scholar and two graduate students
- 2 Key projects:
  - Understanding carbon/electrolyte interactions for neutral pH energy storage devices
  - Low cost manufacturing of next generation anode materials
- Papers/Dissertations Published:
  - Wei Wu, Alex Mohamed, J.F. Whitacre, “Microwave Synthesized NaTi2(PO4)3 Anode Material for Aqueous Electrolyte Batteries: Process Routes and Performance in a Dual Intercalation Sodium-Ion Battery”, Submitted, Journal of Electrochemical Society (2012)
  - J.F. Whitacre, A. Mohammad, S. Snehbag, T. Wiley, E. Weber, D. Blackwood, E. Lynch-Bell, J. Matusky, D. Humphreys, “Large-Format Asymmetric Sodium-Ion Functional Energy Storage Devices for Stationary Applications”, Journal of Power Sources (2012), 213, 255-264, (2012)
  - S. Chun, J.F. Whitacre, “Relating Electrolyte Acidity and Hydrogen Uptake in Mesoporous Activated Carbons”, Submitted, Electrochemistry Communications, (2012)
  - “Electrochemical Capacitors: The Evolution and Control of Physicochemical Properties during Processing” Ph.D. Dissertation, Sangeun Chun, Carnegie Mellon, 2011
  - S. Chun, J.F. Whitacre, “The evolution of electrochemical functionality of carbons derived from glucose during pyrolysis and activation,” Electrochemica Acta, 60 pg 392-400, (2012)
  - S. Chun, Yusuf N. Picard, Jay Whtiacre, "Relating Precursor Pyrolysis Conditions and Aqueous Electrolyte Capacitive Energy Storage Properties for Activated Carbons Derived from Anhydrous Glucose-d", Journal of the Electrochemical Society, 158 (2), A83, (2011).
- Key findings:
  - Relationship between electrolyte species and functionality for different carbon morphologies explained
  - Carbon’s ability to locally store hydrogen and derive current later is maximized in intermediate pH solutions
  - Very rapid microwave synthesis processes can be used to create $NaTi_2(PO_4)_3$ which performs well as an anode material in an AHI environment

AQUION ENERGY

Aquion Over Time: Product, Employment, Funding





AQUION ENERGY

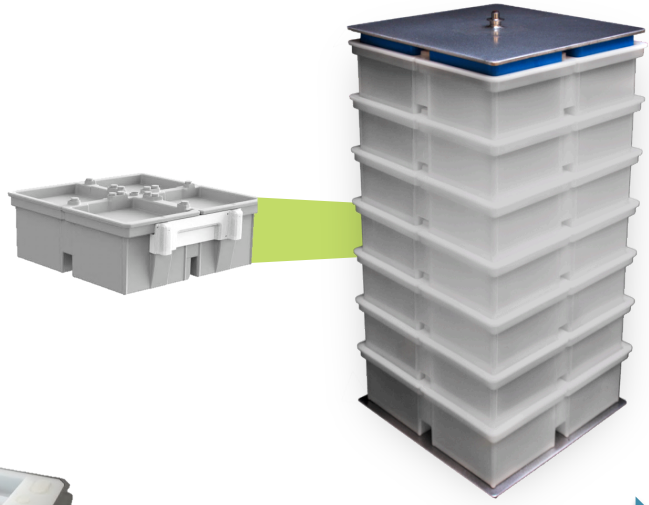
Product Progression: Coin Cells to Stacks

2009

Coin Cell:
Demonstrated
Functional
Material
~4 mWh

2011

Engineering
Prototype:
Demonstrated
Manufacturability
~35 Wh



May 2012

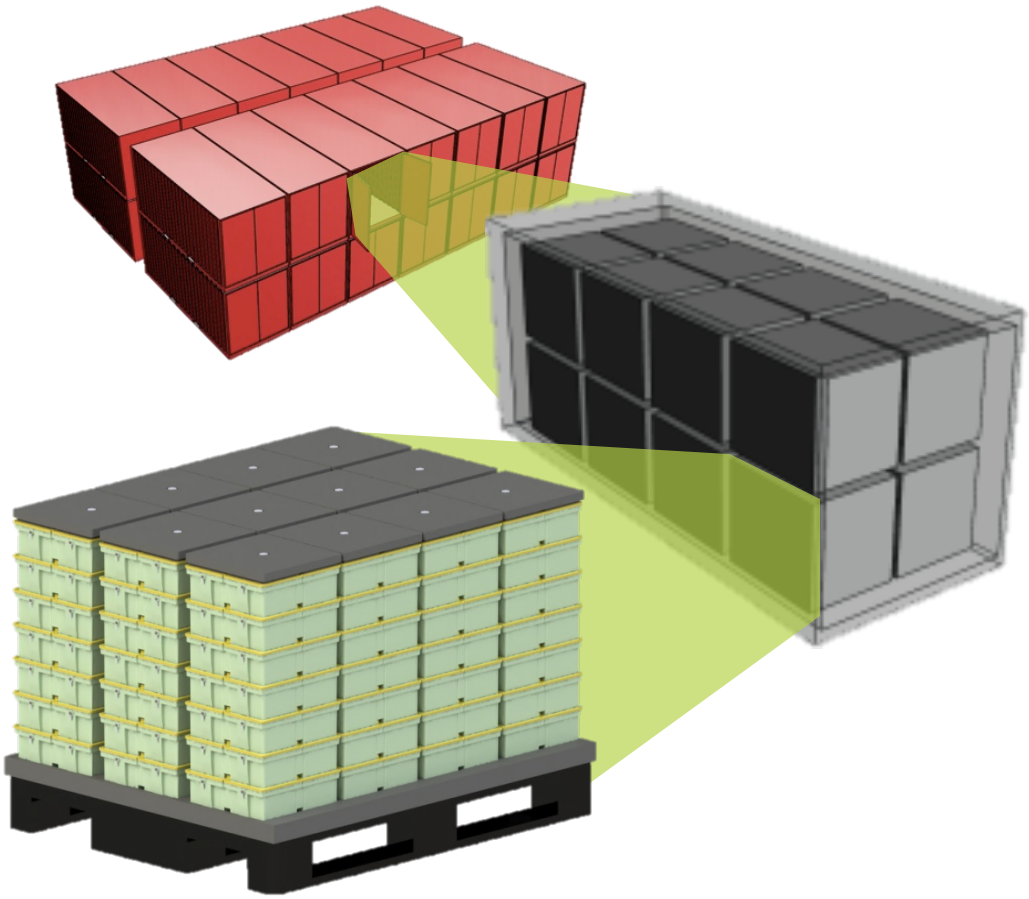
Beta Product:
Initial Sales
~1 kWh (stack)
~140 Wh (battery)
** 7 battery stack (48V) will be base unit of delivery*

AQUION ENERGY

Product Progression: Future Plans

Current beta product

TRL 6



Planned modules and containers

TRL 7

AQUION ENERGY

Manufacturing Progression

Lab Assembly

Hand assembled cells, 1 cell per hour, to quantify advancements

2009

Manual Pilot

Hand assembled assembly line on pilot dial table

2011

Automated Pilot

Semi-automated manufacturing on dial table

May 2012

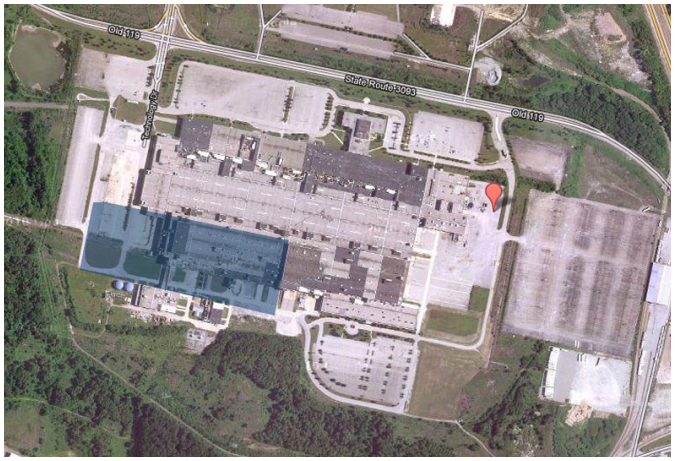
AQUION ENERGY

Manufacturing Progression: Future Plans

Current Operations

Pilot facility in Pittsburgh, PA
~30,000 sf

Planned 2013 Operations



Full Scale Manufacturing in Westmoreland PA
~300,000 sf

AQUION ENERGY

AHI Battery Deployments

Development Systems

- Collaborate with PCE Developers

Grid Tied Demos

- Wind & Solar Support; Demand Management
- 5-15kWh systems
- Sited at PGH

Off Grid Grid Demos

- Residential and Portable Solar
- 2-5kWh systems
- CA, ME, FL, PA, Africa and Australia

AQUION ENERGY

AHI Battery Deployments: Future Plans

Reference Systems at Aquion Headquarters

Large Demos and First Commercial Deployments

Summary of Accomplishments Enabled by FOA 36

- Grew from one full time employee to over 100
- Raised over $81M in Equity and Debt
- Produced 1000's of battery units for preliminary testing
- Deployed AHI energy storage systems globally
- Scaled production from lab to pilot scale
- Designed and deploying commercial scale manufacturing facility in PA
- Designed built and tested DoE final Deliverable for project: > 10kWh high voltage energy storage system able to perform grid operations

AQUION ENERGY