VEHICLE TECHNOLOGIES PROGRAM

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

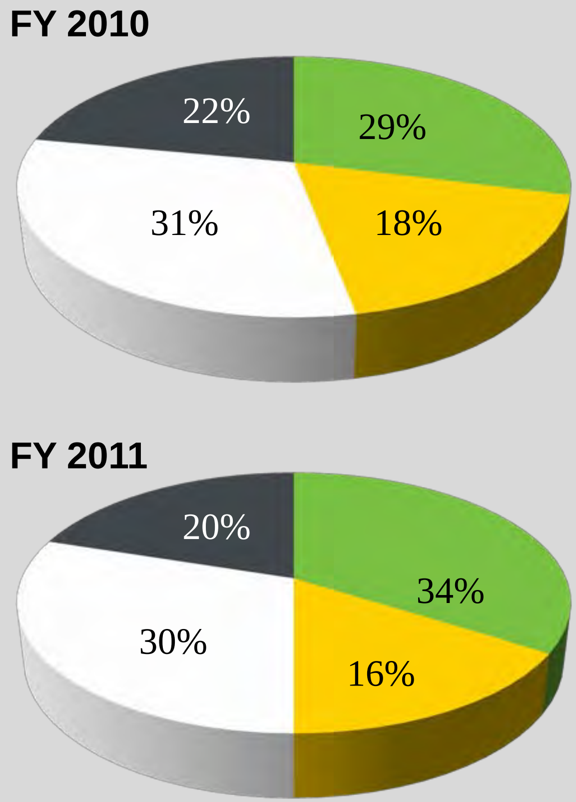
2011 Annual Merit Review and Peer Evaluation Meeting
Energy Storage R&D
May 9-13, 2011

David Howell, Team Lead
Hybrid and Electric Systems
US Department of Energy
Project ID: ES000

Energy Storage R&D

CHARTER: Advance the development of batteries/ electrochemical energy storage devices to enable a large market penetration of hybrid and electric vehicles.

Program targets focus on enabling market success (increase performance at lower cost while meeting weight, volume, and safety targets.)



Energy Storage R&D

FY	Budget ($)
2010	$76.3 M
2011	$79.4 M

2014 GOALS: Reduce production cost of a PHEV battery to $270/kWh (70%)

- ❑ **Intermediate:** By 2012, reduce the production cost of a PHEV battery to $500/kWh.

Battery R&D Activities

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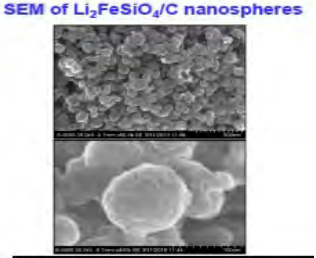
Tien Duong	Peter Faguy	Dave Howell/Brian Cunningham/ James Barnes/Chris Johnson	
Advanced Materials Research	High Energy & High Power Cell R&D	Full System Development &Testing	Commercialization

SEM of Li_2FeSiO_4/C nanospheres



Advanced Materials Research
- ❑ High energy cathodes
- ❑ Alloy, lithium anodes
- ❑ High voltage electrolytes
- ❑ Lithium metal/ Li-air

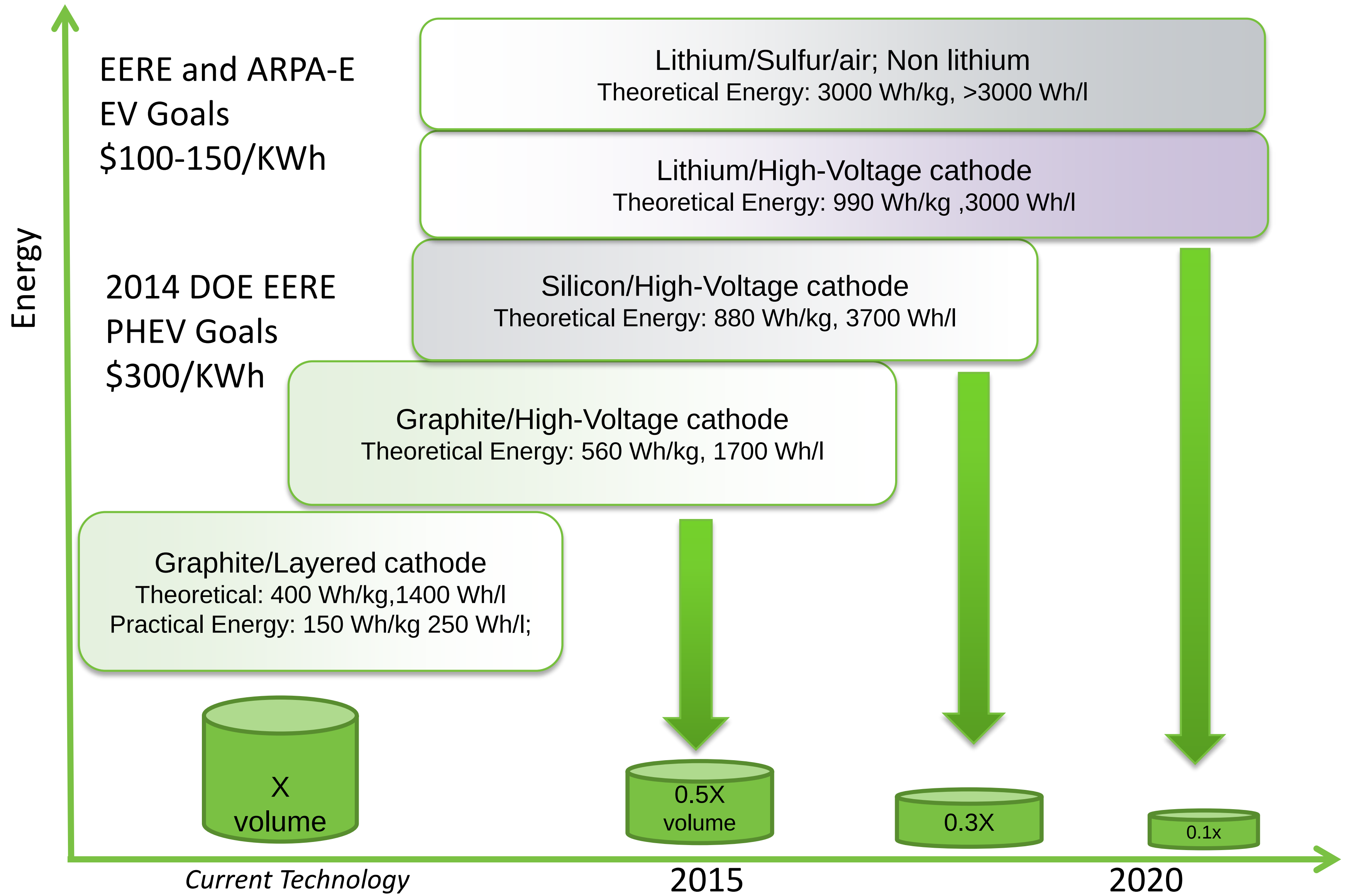
High Energy & High Power Cell R&D
- ❑ High energy couples
- ❑ High rate electrodes
- ❑ Fabrication of high E cells
- ❑ Cell diagnostics

Full System Development &Testing / Commercialization
- ❑ Electric Drive Vehicle batteries
- ❑ Testing, analysis, and design
- ❑ Cost reduction

115+ Lab, University, and Industry Projects

- ❑ Projects are competitively selected using independent experts
- ❑ Progress is tracked on a quarterly basis
- ❑ All projects are reviewed annually by a merit review committee

Research Roadmap for 2015 and Beyond



Technologies Beyond Lithium-Ion

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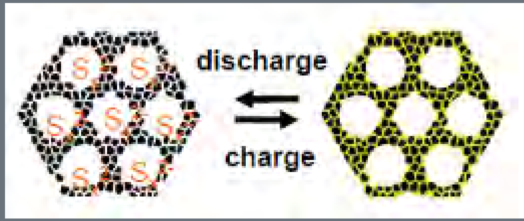
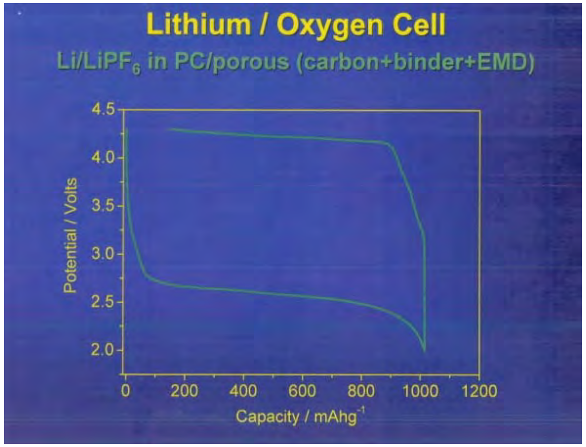
Goal	Cost Target: \$150/kWh
Participants	ANL, LBNL, ORNL, Sion Power, Planar Technologies, BNL
Issues	❑ Li metal dendrites lead to cell shorting ❑ Soluble polysulfides lead to self-discharge and poor cycling ❑ Low efficiency (<70%) – need bifunctional catalysts ❑ Poor power
Activities	❑ Develop materials that inhibit dendrite growth ❑ Enable efficient sulfur utilization (dissolve or confine polysulfides) ❑ Develop bifunctional catalysts for oxygen electrode

ORNL Mesoporous Carbon



Chemistry	Energy (system, Wh/kg)	Power (system, W/kg)	Life (cycles)	Energy Efficiency	Safety
Li metal polymer	150-200	500	~1,000	85%	Concern
Li metal/Sulfur	250-400	750	~100	85%	Concern
Li metal/Air	400-800	Poor	~10-100	<70%	Concern



Source:
Peter G. Bruce, University of St. Andrews, Scotland

AMR Session
Poster presentations (5/9–5/10)

Next Generation Lithium-Ion

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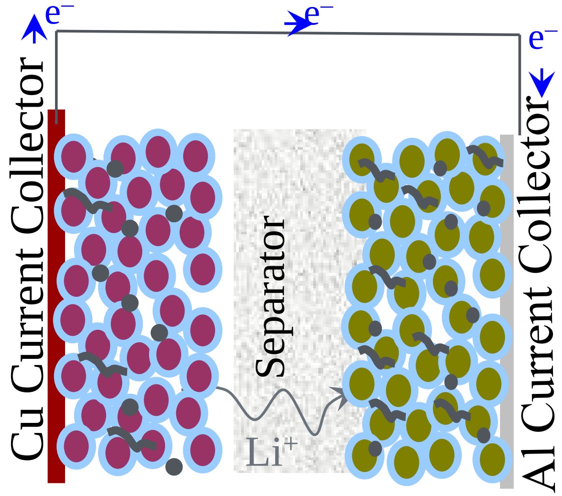
Next generation lithium-ion can increase the power and energy by 2X while decreasing cost by 70%

Anode

Today's Technology
(300 mAh/g)
- Graphite
- Hard carbon

Next Generation
(600 mAh/g)
- Intermetallics and new binders
- Nanophase metal oxides
- Conductive additives
- Tailored SEI



Electrolyte

Today's Tech (4 volt)
Liquid organic solvents & gels

Next Generation (5 volt)
- High voltage electrolytes
- Electrolytes for Li metal
- Non-flammable electrolytes

Cathode

Today's Technology
(120-160 mAh/g)
- Layered oxides
- Spinels
- Olivines

Next Generation
(300 mAh/g)
- Layered-layered oxides
- Metal phosphates
- Tailored Surfaces

Next Generation Lithium-Ion Materials

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Perform cutting-edge research on new materials, and address fundamental chemical and mechanical instabilities

Goal

Cell component goals

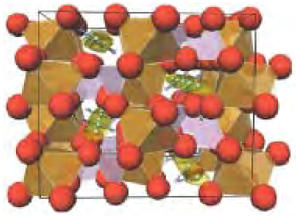
- ❑ Non-carbonaceous anodes (capacity > 500 mAh/g)
- ❑ High-capacity cathodes (capacity > 300 mAh/g).
- ❑ High-voltage cathodes (capacity >120 mAh/g)
- ❑ High-voltage electrolytes (stable up to 5V)
- ❑ Solid-polymer electrolytes with ionic conductivity 10^{-3} S/cm at room temperature

Participants

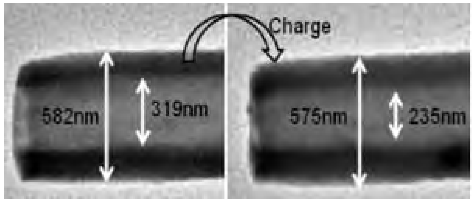
- ❑ National Labs: ANL, PNNL, NREL, LBNL
- ❑ Universities
  - University of Pittsburgh
  - State University of New York–Binghamton
  - Boston University
  - University of Texas, Austin
  - Arizona State University
  - University of California
  - North Carolina State University
  - University of Rhode Island
  - Case Western Reserve University
  - University of Utah

AMR Session
Oral presentations (5/9–5/10)

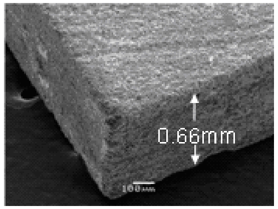
First Principles Material Discovery (Ceder) – Rational design of materials using computational tools



Size & Morphology Control Improves Performance (Cui) – Hollow Si nanotubes show greatly enhanced cycling

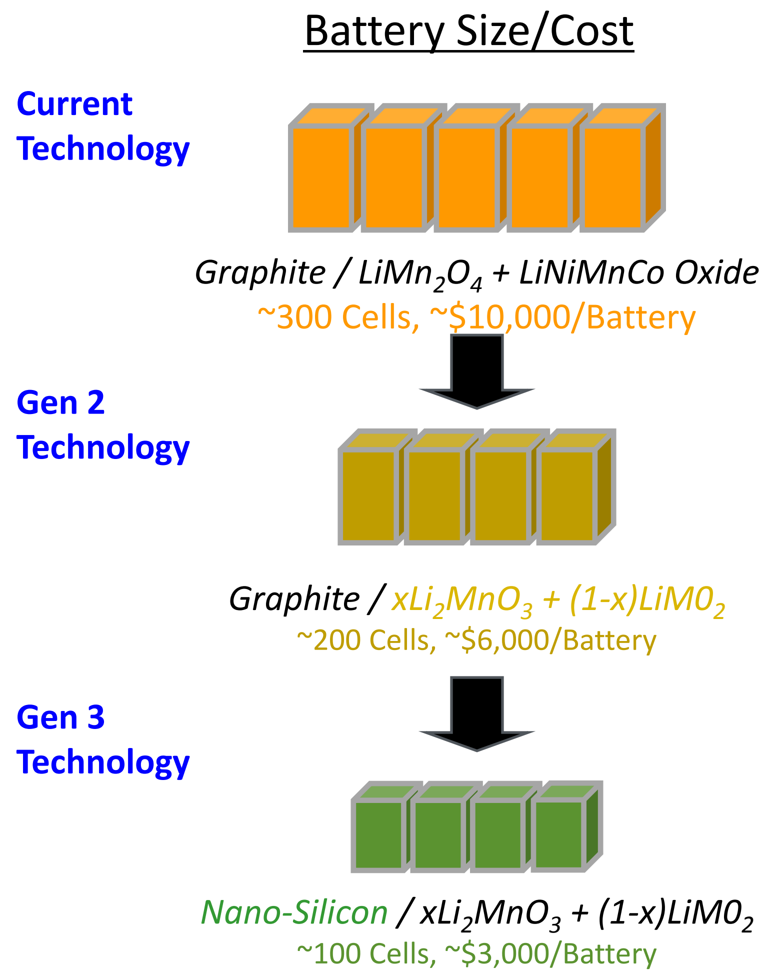


Enhanced Processing (Chiang) – 10x thicker electrodes can increase cell energy density by 20%



By 2014, a PHEV battery that can deliver a 40-mile all-electric range and costs $3,400

Goal	Develop advanced cell chemistries using next-generation materials ❑ 200 Wh/kg, 400 Wh/L cell goal ❑ 5,000 cycles, 10+ year life ❑ $300/kWh at the pack level
Participants	❑ **National labs:** ANL, BNL, INL, LBNL, ORNL, SNL, ARL, JPL ❑ Industry Partners
Issues	❑ Cycleability ❑ Rate (power) ❑ High-voltage stability ❑ Electrode and cell fabrication
Activities	❑ Advanced Cell Chemistries ❑ Calendar and cycle life studies ❑ Abuse tolerance studies



AMR Session
Poster presentations (5/9)

Battery Testing, Analysis, & Design

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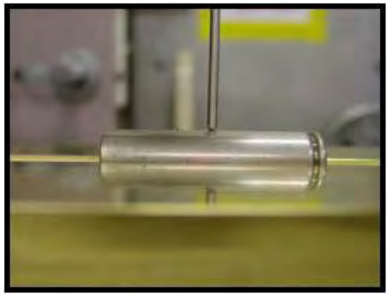
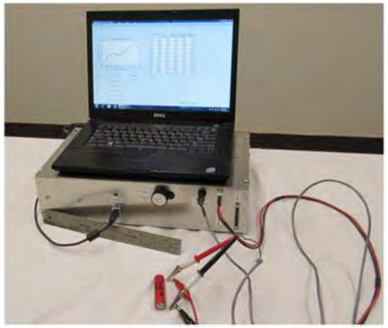
By 2014, a PHEV battery that can deliver a 40-mile all-electric range and costs $3,400

Participants	INL, ANL, NREL, SNL
Activities	❑ Develop and maintain battery testing procedures and methodologies ❑ Provide high-fidelity battery performance testing and analysis ❑ Develop methodologies that estimate battery state-of-health and remaining life ❑ Abuse testing for USABC prototype cells and modules ❑ Develop mechanism to mitigate failures ❑ Perform and evaluate the characteristics of thermal management systems for USABC deliverables ❑ Design Computer Aided and Design (CAD) tools to reduce waste and improve manufacturing efficiency
Progress/ Highlights	❑ Idaho National Laboratory collaborated with the University of Montana and Qualtech Systems, Inc. to develop an inexpensive and rapid technique of measuring battery impedance.



Test setup for the blunt rod test on an 18650 cell



Hardware for *in situ* Impedance Measurement

AMR Session
Poster presentations (5/10)

Advanced Materials and Processing

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Participants

3M, Angstrom Materials, North Carolina State University and ALE, Inc., FMC, Sion Power, TIAX, EnerDel, BASF, A123Systems

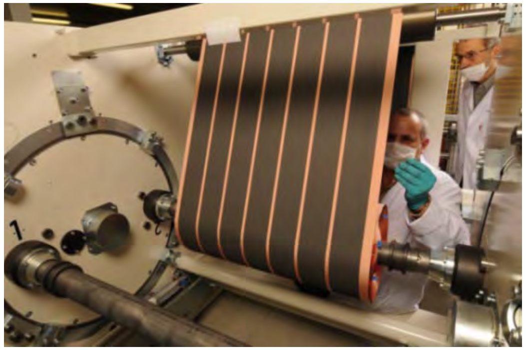
Activities

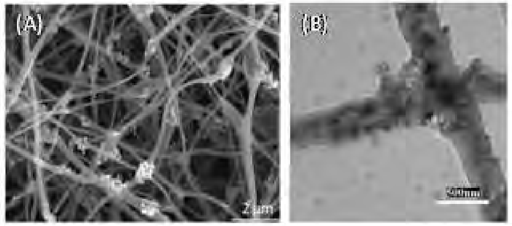
FY2009 FOA

- Nine (9) Materials and Processing Awards
- Focus on advanced materials development, safety, and manufacturing process improvement (DOE cost-share: $17.8 M)

Angstron Materials

NC State & ALE Inc





Typical SEM and TEM Images – Si/C Nanofibers

FY2011 FOA (Targets)

- Improved power and energy densities
- Improved affordability of cost
- Improved battery designs – safer, more reliable, and longer-lasting

AMR Session
Poster presentations (5/10)

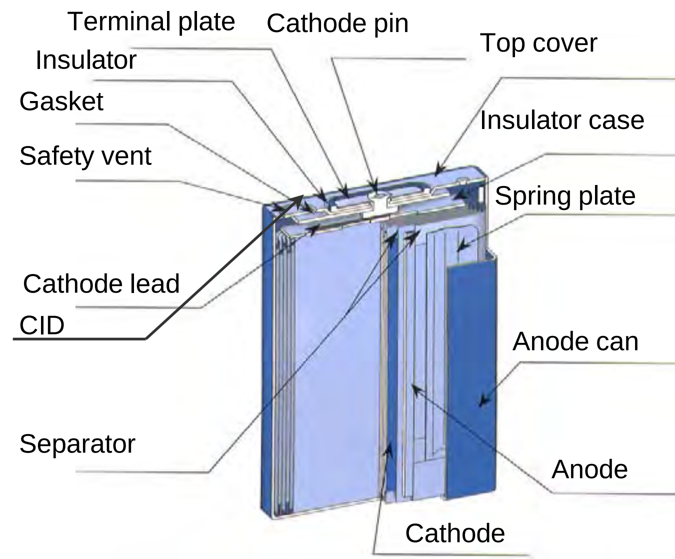
Advanced Battery Development (USABC Activity)

Battery Cell /Pack Development

- ❑ Material Specifications and Synthesis
- ❑ Electrode Formulation and Coating
- ❑ Electrode & Cell Design/Fabrication
- ❑ Module & Pack Design/Fabrication

- ❑ Battery Control & Safety Devices
- ❑ Detailed Cost Modeling
- ❑ Standardized Performance Targets
- ❑ Standardized Test Procedures

Target	Company	Technology
PHEV	A123Systems	Nano Iron Phosphates
	JCI-SAFT	Nickel, Manganese, Cobalt
	3M	Li Ni-Co-Mn Oxides
EV	Envia Systems	High Energy Cathode
	Cobasys	High Capacity NMC/LMO Cell
	EnerDel	NMC/Graphite – Very High Capacity Cell
	Quallion	High Energy and High Power Cells
	Leyden Energy	Li-Imide Salt & Graphite Current Collector
HEV	Maxwell	Asymmetric Ultracapacitor
	A123Systems	Nano Iron Phosphates
Materials	Entek	Low Cost, High Melt Integrity Separators
	Celgard	Low Cost, High Melt Integrity Separators



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DOE-funded technologies move to commercial applications

Several technologies, supported by VTP, have moved into commercial applications.

- ❑ 1990s Nickel Metal Hydride
  - **Cobasys** NiMH technology: Every HEV sold uses intellectual property developed in the DOE battery program. The US Treasury received royalty fees.

- ❑ 1998 High-Power Lithium-ion (HEVs)
  - **Johnson Controls Saft (JCS)** nickelate technology: BMW, Mercedes and Azure Dynamics/Ford Transit Connect

- ❑ 2004 High-Energy Lithium-ion (EVs)
  - **A123Systems** nano iorn phosphate technology: Fisker, BAE, Hymotion, Prius, Navistar
  - **CPI/LG Chem** manganese technology: GM Volt extended range PHEV, Ford Focus EV

American Recovery and Reinvestment Act

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Goal ($1.5B ARRA)

Accelerate the development of U.S. manufacturing capacity for batteries and electric drive components and the deployment of electric drive vehicles.

Participants (20 Companies)

A123 Systems, JCI, SAFT, CPI-LG, General Motors, Dow-Kokam, Exide, East Penn, BASF, Toda, Celgard, ENTEK, EnerG2, Pyrotek, Future Fuel, Novolyte, Honeywell, Chemetall Foote, H&T Waterbury, TOXCO

Activities (20 facilities)

Material Supply
- ❑ Lithium Supply

Cell Components
- ❑ Cathode Production
- ❑ Anode Production
- ❑ Electrolyte Production
- ❑ Separator Production
- ❑ Other Components

Cell Fabrication
- ❑ Iron Phosphate
- ❑ Nickel Cobalt Metal
- ❑ Manganese Spinel

Pack Assembly
- ❑ Iron Phosphate
- ❑ Nickel Cobalt Metal
- ❑ Manganese Spinel
- ❑ Advanced Lead Acid Batteries

Recycling
- ❑ Lithium-Ion

Progress/ Highlights

- ❑ All projects were under way in 2010
- ❑ Production has begun at several facilities
  - Battery pack assembly at General Motors facility in Brownstown, MI
  - Cell and pack assembly at A123Systems in Livonia, MI
  - Battery pack assembly at Johnson Controls Saft in Holland, MI
  - Separator material production at Celgard LLC in Charlotte, NC

Saft America lithium-ion battery plant groundbreaking in Jacksonville, FL

Toda America, Inc. Battle Creek Facility

A123Systems, Livonia Facility

AMR Session
Poster presentations (5/10–5/11)

Outlook for Battery Cost and EV Production Capacity

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On Track to Meet Administration's Goal of 1 Million EVs by 2015

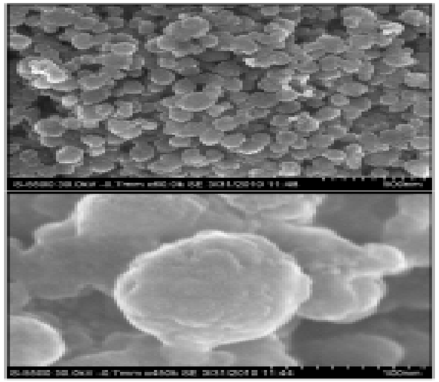
Year	Battery Cost ($ per kWh)	Battery Production Capacity (10 kWh packs) ARRA	Battery Production Capacity (10 kWh packs) ATVM	Vehicle Production (announced, cumulative)
2008–2009	$1,000-$1,200	0	0	0
2010–2011	$700-$950	50,000		45,600
2012	Goal = $500	150,000	144,000	223,200
2013				486,200
2014	Goal = $300			854,200
2015		500,000	488,000	1,222,200

~10M kWh per year production capacity in 2015

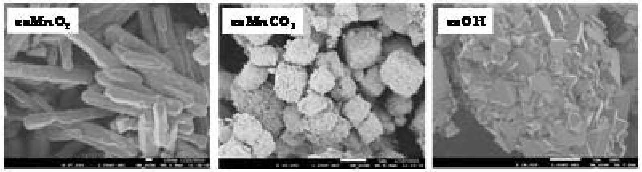
>8M kWh per year capacity demand in 2015

Summary

- Track record of success
  - DOE R&D has brought NiMH and Li-ion batteries into the automotive market
- Clear pathway to meet 2015 goals
  - On track to meet cost and performance targets
- Technologies in the pipeline to go beyond 2015
  - Research program focused on Li metal systems
  - Closely coordinated with ARPA-E and the Office of Science



SEM of Li_2FeSiO_4/C nanospheres



SEM pictures of $LiNi_{0.5}Mn_{1.5}O_4$ made from MnO_2, $MnCO_3$ and hydroxide precursors