Vehicle Technologies Program

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

Annual Merit Review
Energy Storage R&D and ARRA Overview
June 8, 2010

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US Department of Energy

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VTP Energy Storage Overview

- Charter and Goals
- R&D Program Structure and Budget
- DOE Battery R&D Landscape
- Accomplishments

Energy Storage R&D Activities

- Laboratory and University Research
- Battery Development Contracts
- Material and Processing Improvement
- Battery Cost Modeling
- Summary

Charter, Goals, and Benefits

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

Drivetrain electrification is inherently efficient and a clear pathway to low-carbon transportation. Program targets focus on enabling market success ($)

Types of Vehicles and Benefits

HEV →

Toyota Prius

50 MPG

- 1 kWh battery
- Power Rating: 80kW
- System Cost: $3000

PHEV →

Chevy Volt

100 MPGe

- 16 kWh battery
- Power Rating: 170kW
- System Cost: est. $16,000

EV →

Nissan Leaf

All Electric

- ≥ 40 kWh battery
- Power Rating: ≥ 110kW
- System Cost: est.$36,000

2010 FreedomCAR Goal (HEVs): Develop a 25kW Power-Assist HEV battery that cost $500

2014 PHEV: Battery that has a 40-mile all-electric range and cost $3,400

2009 Status: $8000-$12,000 for a PHEV 40-mile range battery

Potential Benefits

- Potential oil savings in 2030 is ~1.25 million barrels per day (Mbpd)
- Corresponding GHG emissions reduction is ~170 million metric tons of CO2 equivalent (MMTCO2e)

Team Structure

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Hybrid and Electric Systems
David Howell

VSATT

Electrochemical Energy Storage
David Howell

PEEM

Exploratory Research
Tien Duong

Applied Battery Research
Peter Faguy

Battery Development and Materials & Processing
Chris Johnson (NETL)
James Barnes

Battery Design and Optimization
Steve Goguen
Brian Cunningham

Battery Testing and Analysis
Duong/Cunningham

Funding Trends

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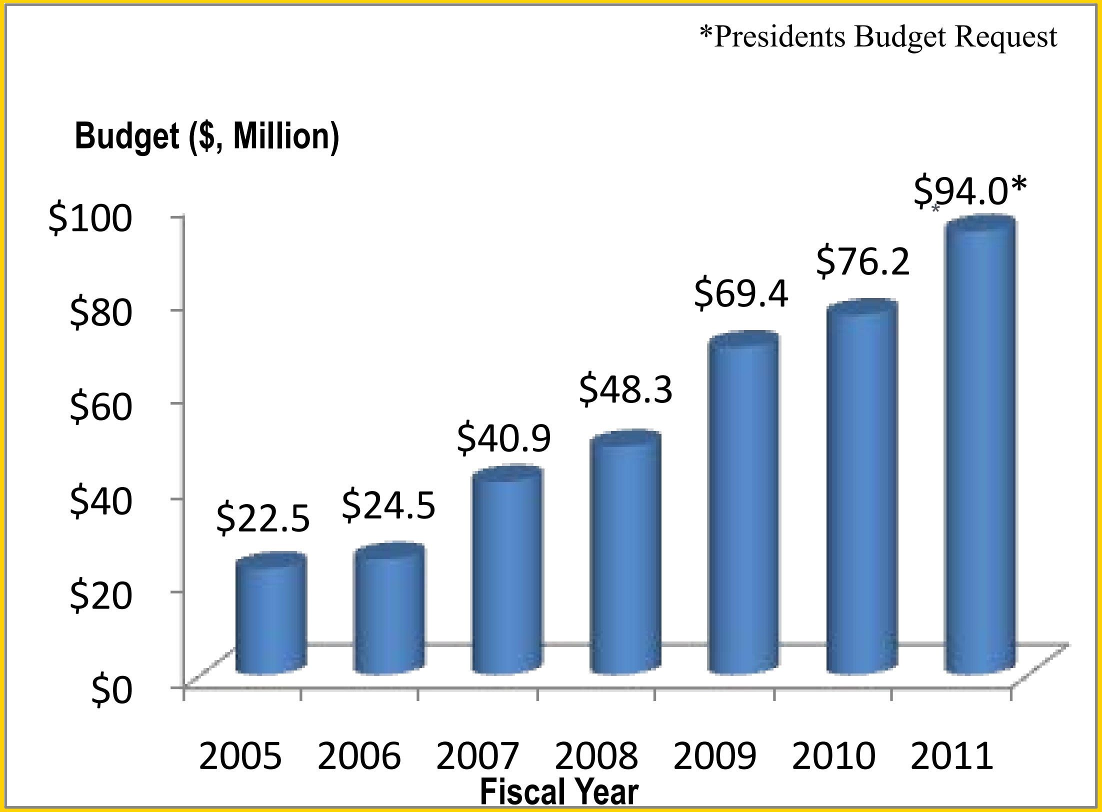
Program focus and priorities have changed over time, and the funding profile has changed accordingly.

Year	Focus/Priority
1992 – 1998	EV focus (NiMH, Lead Acid)
1995 – 2006	HEV focus (NiMH, Li-Ion)
2007 – Present	PHEVs (Li-ion)

Energy Storage R&D Budget



DOE Battery R&D Landscape

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Legend
- Blue- Advanced R&D,D
- Red- Commercialization
- Yellow- Early Stage R&D

Advanced Battery Manufacturing

ARRA

First Generation Lithium-Ion Batteries and Material Supply

Applied Research and Technology Development

Vehicle Technologies Program

Next Generation, High Energy Lithium-Ion Double Layer and Asymmetric Ultracapacitor

Lithium-Air

Lithium-Sulfur

Lithium-Alloy

Transformational Research

ARPA-e

- -Lithium-Sulfur
- -Lithium-Air
- -Lithium Metal
- -Lithium Polymer

Basic Research

Basic Energy Science

Basic Electrochemical Materials Research and Phenomena

2010 ● 2011 ● 2012 ● 2013 ● 2014 ● 2015 ● 2020 ● 2025

Vehicle Technology Battery R&D Activities

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The energy storage effort is engaged in a wide range of topics, from fundamental materials work through battery development and testing

Advanced Materials Research → **High Energy & High Power Cell R&D** → **Full System Development And Testing** → **Commercialization**

- High energy cathodes
- Alloy, Lithium anodes
- High voltage electrolytes
- Lithium air couples

- High rate electrodes
- High energy couples
- Fabrication of high E cells
- Ultracapacitor carbons

- Hybrid Electric Vehicle (HEV) systems
- 10 and 40 mile Plug-in HEV systems
- Advanced lead acid
- Ultracapacitors

Lab and University Focus

Industry Focus

Applied and Exploratory Research

Modeling
5 Projects

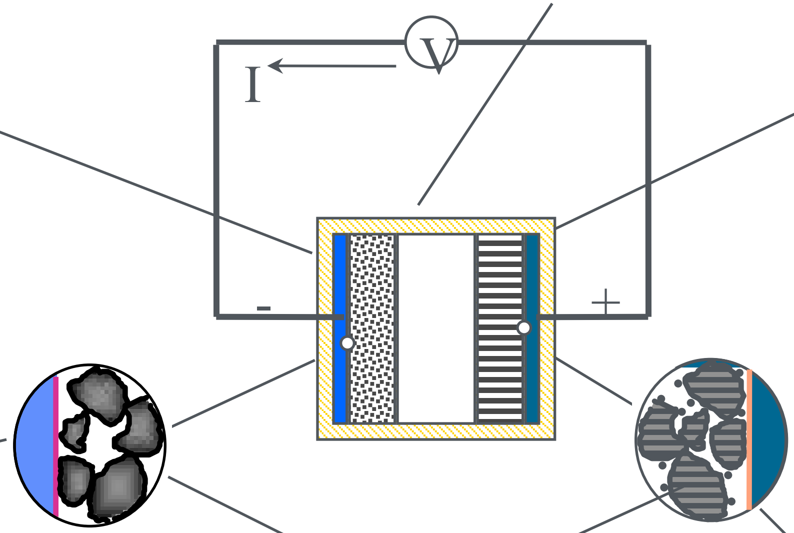
LBNL, ANL, NREL, INL,
U of Michigan

Cell analysis and Construction
10 Projects

Lawerance
BerkleyBNL, ANL,
SNL, Hydro-Quebec

Electrolytes
12 Projects

LBNL, ANL, ARL, JPL,
BYU, CWRU, NCSU,
UC Berkeley, U of Rhode Island, U of Utah



Advanced Anodes
11 Projects

ANL, PNNL, ORNL
SUNY Binghamton
U of Pittsburgh

Diagnostics
6 Projects

LBNL, BNL, ANL
SUNY Stony Brook,
MIT

Advanced Cathodes
15 Projects

ANL, PNNL, LBNL
UT Austin, SUNY Binghamton

Materials & Processing Improvement

DOE/NETL has selected ten companies to focus on advanced materials development, safety, and manufacturing process improvement

3M	Advanced high-energy anode materials
Angstron Materials	Hybrid Nano Carbon Fiber/ Graphene Platelet-Based High-capacity Anodes
NC State & ALE Inc	High-Energy Nanofiber Anode Materials
FMC	Stabilized Lithium metal powder
Sion Power	Develop and improve Lithium sulfur cells for electric vehicle applications

TIAX	Internal short diagnostics & mitigation technologies
EnerDel Lithium Power Systems	Develop technologies to mitigate abuse tolerance
BASF The Chemical Company	High volume, low cost, manufacturing techniques for cathode materials
A123 Systems	Develop advanced, low cost electrode manufacturing technology

DOE cost-share: $17.8 million (cost-shared by industry)

Materials and Processing Improvement

VTP collaborated with the DOE Industrial Technologies Program to fund Advanced Battery Processing Technology Development

A123 SYSTEMS	Domestic supply chain for and processing methods of anodes ($1.5M total effort).
Johnson Controls	Substantial improvement of electrode processing quality control ($762k total effort).
DOW KOKAM	Processing and characterization of novel cathode materials ($870k total effort).
PLANAR Energy Devices	Scalable and cost-effective processing for all solid-state LIBs ($1M total effort).
POROUS POWER TECHNOLOGIES	Improved separator and unique method of production ($1.7M total effort).

DOE/USABC PHEV Developers

DOE Cost Share: $12.5 M per year (cost-shared by industry)

A123 Systems	Develop batteries using nanophase iron-phosphate
Johnson Controls / SAFT	Develop batteries using a nickelate/ layered chemistry
cpi compact power, inc / LG Chem	Develop batteries using manganese spinel chemistry
EnerDel Lithium Power Systems	Develop cells using nanophase lithium titanate and a high voltage spinel cathode material
3M	Develop and screen Nickel-Manganese -Cobalt cathode materials
CELGARD	Develop low-cost separators with high temperature melt integrity
ENTEK International	Develop low-cost separators with high temperature melt integrity

USABC Request For Proposals Topics

- Advanced High-Performance Batteries for **Electric Vehicles**
- Advanced Energy Storage Systems for high Power, Lower Energy **Power Assist Hybrids**
- Advanced High-Performance Batteries for **Plug-in Hybrid Electric Vehicles**
- Technology Assessment - Electric Vehicle Applications

Industry Focus
PHEV Battery Targets & Challenges

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Battery Attribute	Current Status	Goals	
		2012	2014
Available Energy	3.4 kWh	3.4 kWh (10 mile)	11.6 kWh (40 mile)
Cost	$700-$950 Per kWh	$500/kWh	$300/kWh
Cycle Life (EV Cycles)	$2{,}500^{+}$	5,000	3000-5000
Cycle Life (HEV Cycles)	300,000	300,000	200,00-300,000
Calendar Life	6-12 years	10^{+} years	10^{+} years
System Weight	60-80 kg	60 kg	120 kg
System Volume	50+ liters	40 liters	80 liters

Key Challenges

- Weight and volume for the PHEV-40
- Extending life (while operating in 2 discharge modes)
- Reducing cost

Battery Cost Models

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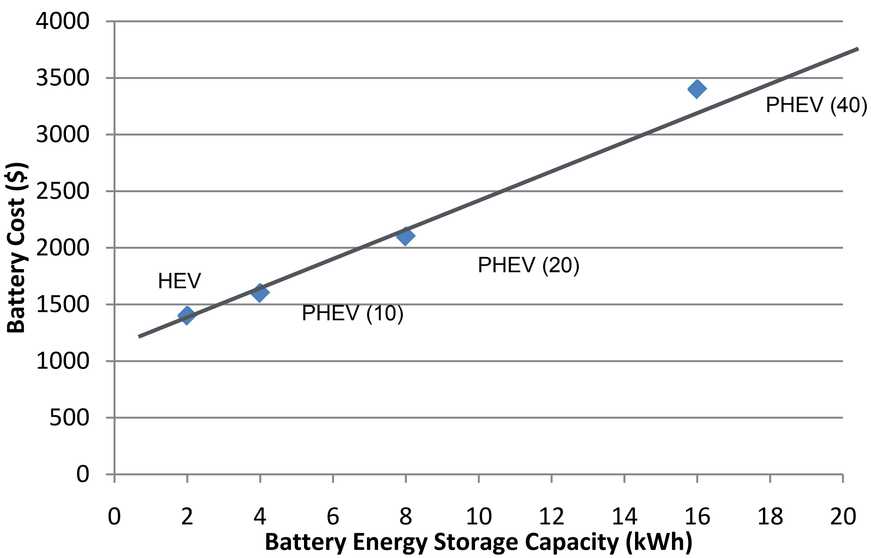
Objectives of Battery Cost Modeling

- Provide a common basis for calculating battery costs
- Provide checks and balances on reported battery costs
- Gain insight into the main cost drivers
- Provide realistic indication of future cost reductions possible



USABC model –

- Detailed hardware-oriented model for use by DOE/USABC battery developers to cost out specific battery designs with validated cell performance

Argonne model –

- Optimized battery design for application
- Small vs. large cell size
- Effect of cell impedance and power on cost
- Effect of cell chemistry
- Effect of manufacturing production scale

TIAX model –

- Assess the cost implications of different battery chemistries for a frozen design
- Identify factors with significant impact on cell pack costs (e.g., cell chemistry, active materials costs, electrode design, labor rates, processing speeds)
- Identify potential cost reduction opportunities related to materials, cell deign and manufacturing

Key Results

- Current high volume PHEV lithium-ion battery cost estimates are $700 -$950 /kWh.
  - Cost ($/kWh) should be determined on “useable” rather than “total” capacity of a battery pack
  - ANL & TIAX models project that lithium-ion battery costs of $300/kWh of useable energy are plausible.

- Material Technology Impacts Cost
  - Cathode materials cost is important, but not an over-riding factor for shorter range PHEVs Cathode & anode active materials represent less than 15% of total battery pack cost.
  - In contrast, for longer range PHEV’s and EVs, materials with higher specific energy and energy density have a direct impact on the battery pack cost, weight, and volume.
  - Useable State-of-Charge Range has direct impact on cost for a given technology
  - Capacity fade can dramatically influence total cost of the battery pack

- Manufacturing scale matters
  - Increasing production rate from 10,000 to 100,000 batteries/year reduces cost by ~30-40% (Gioia 2009, Nelson 2009)
  - For example, consumer cells are estimated to cost about $250/kWh.

Energy Storage Recovery Act Funding

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$1.5 Billion for Advanced Battery Manufacturing for Electric Drive Vehicles
“Commercial Ready Technologies”

Material Supply ($28.43 M)

Lithium Supply
- Chemetall Foote

Cell Components ($259 M)

Cathode Prod.
- A123
- BASF
- Toda

Anode Prod.
- EnerG2
- Pyrotek
- FutureFuel

Electrolyte Prod.
- Novolyte
- Honeywell

Separator Prod.
- Celgard
- ENTEK/JCI

Other Component
- H&T Waterbury

Cell Fabrication ($735 M)

Iron Phosphate
- A123

Nickel Cobalt Metal
- JCI
- SAFT
- EnerDel

Manganese Spinel
- CPI-LG
- DOW-Kokam

Pack Assembly ($462 M)

Iron Phosphate
- A123

Nickel Cobalt Metal
- JCI
- SAFT
- EnerDel

Manganese Spinel
- GM
- DOW-Kokam

Advanced Lead Acid Batteries
- Exide
- East Penn

Recycling ($9.55 M)

Lithium Ion
- TOXCO

Recovery Act Awards – National Laboratory Facilities

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Advanced Battery Prototype Fabrication and Testing Facilities

Laboratory	DOE Grant	Facility Description
Argonne National Laboratory	$8.8 M	-Battery Prototype Cell Fabrication Facility -Materials Production Scale-up Facility -Post-test Analysis Facility
INL Idaho National Laboratory	$5.0 M	High-energy Battery Test Facility
Sandia National Laboratories	$4.2 M	Battery Abuse Testing Laboratory
NREL	$2.0 M	Battery Design and Thermal Testing Facility

Accomplishments of Battery Development Partners

- Most HEV performance requirements have been met by Li-ion batteries developed with DOE support.
- Significant progress has been achieved toward reducing the cost and increasing the performance of PHEV Batteries.

Johnson Controls-Saft (JCS)

- Supplying lithium-ion batteries to BMW and to Mercedes for their Hybrids.

A123Systems

- Selling a 5kWh battery for Hymotion's Prius conversion.
- Partnering with Chrysler on EV battery development.

Compact Power/LG Chem

- Will supply GM Volt PHEV battery

JCS high-power lithium-ion battery pack

A123 Systems high-power lithium-ion cell

CPI/LG lithium-ion battery pack for GM Volt

Commercialization Activities and Notable Accomplishments

- **Composite high energy cathodes**
  - licensed to Toda and and to BASF
  - developed by Dr. Thackeray of ANL
- **Conductive, electroactive polymers**
  - licensed to Hydro Quebec, world's leading supplier of this material.
  - developed by Prof. Goodenough at Univ Texas
- **Hydrothermal synthesis technique for $LiFePO_4$**
  - licensed to Phostech, for production
  - developed by Dr. Whittingham at SUNY
- **Conductive polymer coatings and a new $LiFePO_4$ fabrication method**
  - used by Actacell Inc fabricate high power Li ion cells
  - developed by Prof. Manthiram at Univ Texas
- **Polymer electrolytes for Li metal rechargeable batteries**
  - Seeo Inc a start-up of Prof. Balsara (LBNL) will commercialize material
  - 2008 R&D100 award
- **Nano-phase Li titanate oxide (LTO)/Manganese spinel chemistry**
  - licensed to EnerDel
  - developed by Dr. Khalil Amine at ANL, 2008 R&D100 award

Summary

- The American Reinvestment and Recovery Act provides significant funding to address the lack of domestic battery manufacturing.
- Significant progress has been made toward developing commercially viable PHEV batteries.
- Focus is on developing next generation lithium-ion batteries for longer range PHEVs and EVs.
- ARPA-E and BES contributing significant funding for novel and transformational battery technologies.

Thank you

Monday, June 7 - Poster Session: ARRA Grants, BES and Exploratory Research
Atrium (lower level), 6:30-8:30 PM

Tuesday, June 8 -Presentations: AM/PM Industry Development Contracts
Poster Session : BES and Exploratory Research
Atrium (lower level), 6:30-8:30 PM

Wednesday and Thursday, June 9-10 - Presentations: Applied Battery Research

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