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

Update on Electrochemical Energy Storage R&D

Presented to
Hydrogen and Fuel Cell Technical Advisory Committee

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Charter and Goals

CHARTER

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

TARGET APPLICATIONS

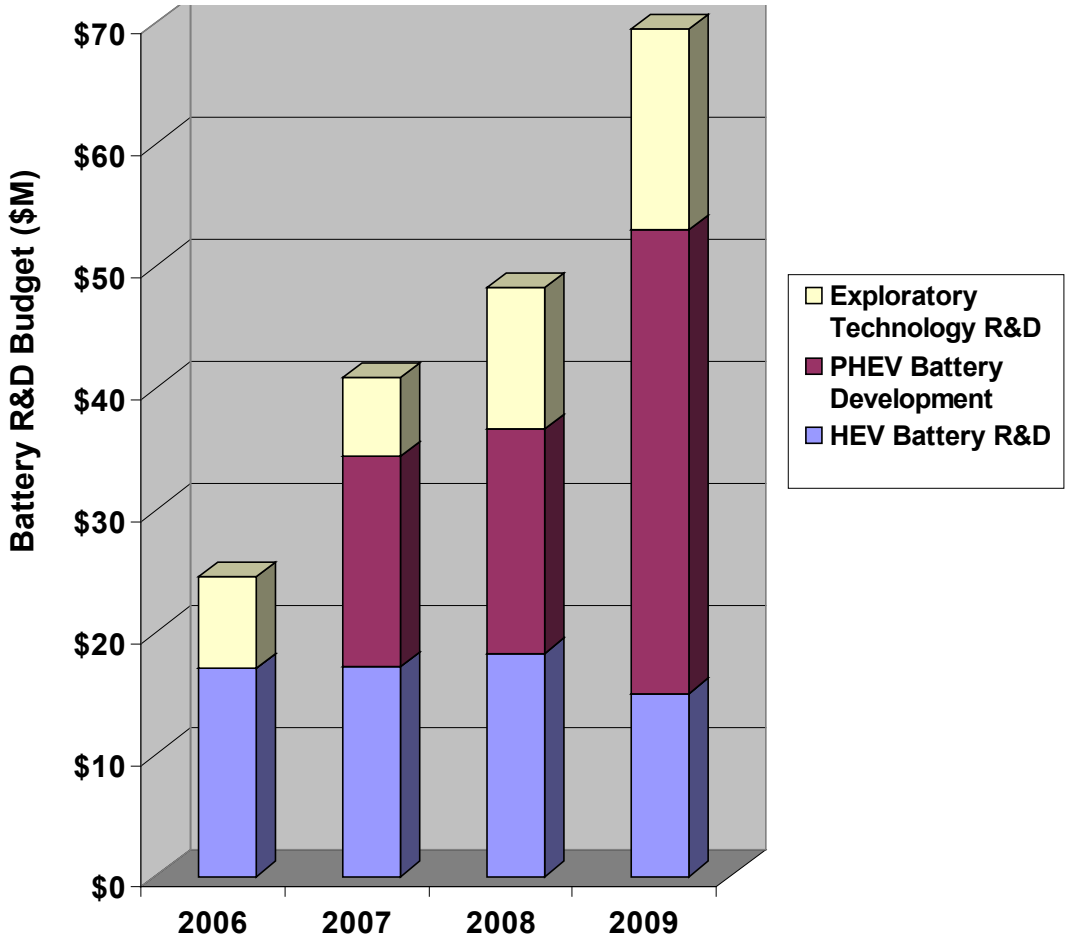
- Power-Assist Hybrid Electric Vehicles (HEVs, FCVs)
- Plug-in Hybrid Electric Vehicles (PHEVs, FCVs)
- Battery Electric Vehicles (EVs)

GOALS

- **2010 FreedomCAR Goal (Conventional HEVs):**
  - Develop a 25 kW Power-Assist HEV battery that costs $500.
- **2014 DOE PHEV Battery Goal:**
  - Develop a PHEV battery that enables a 40 mile all-electric range and costs $3,400.

Energy Storage R&D Program Budget

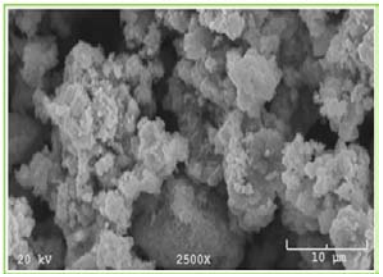
- The FY2009 budget is $69.4 million.
- The DOE battery R&D budget has tripled in the past 4 years.
- Recent budget increases have focused on PHEV battery development.
- The FY10 budget request is $78 million.

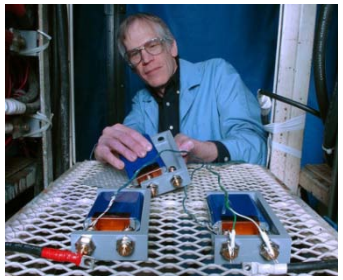


R&D Program Activities

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, Li anodes
- High V electrolytes
- Li air couples

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

- HEV systems
- 10 and 40 mile PHEV systems
- Advanced lead acid
- Ultracapacitors

USABC Activity Focus

- Develop full battery systems through competitive subcontracts
  - All subcontracts are at least 50% cost-shared
- USABC deliverables tested and analyzed against performance targets using standardized test procedures
  - Performance testing at ANL and INL
  - Abuse testing at SNL
  - Thermal analysis and design support at NREL
  - Battery modeling/simulation support at ANL and NREL

Battery Performance Targets and Test Protocols

- **Battery Performance Targets are determined through;**
  - Establishing electric drive vehicle performance requirements (OEMs)
  - Battery Performance Modeling and Simulation (ANL/NREL)
  - Hardware-In-the-Loop Testing (ANL—supported by VSATT)
- **Develop Battery Testing Protocols**
  - Develop battery performance and cycle life test protocols based on different EDV architectures (ANL/INL)
- **Contract Deliverables tested according to established Performance and Abuse Testing procedures (ANL/INL/SNL)**
- **Complete list of Test Procedures posted at www.uscar.org**

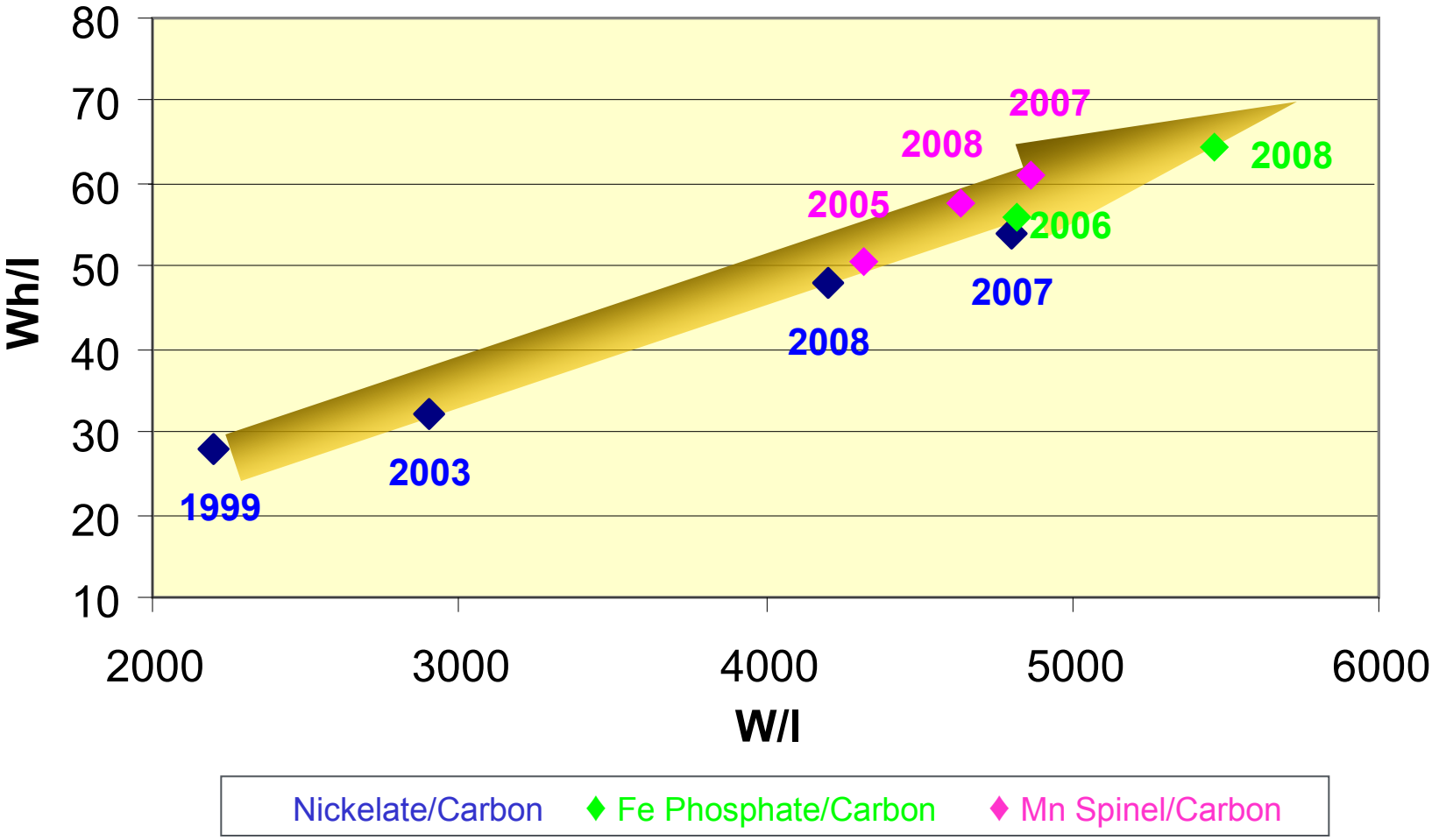
Progress Since Last Review for High Power Batteries (HEV)

FreedomCAR Energy Storage Goal Characteristics (Units)	2010 Goal (End of life)	2007 NAS Review	Current Status
Discharge Power (kW)	**25** (10 sec)	25	25+
Available Energy (Wh)	**300**	**300**	**300**
Calendar Life (years)	**15**	10 - 15	12 - 15
Estimated Cost at 100,000 units/year	**500**	750 - 900	>936
Regen Pulse (kW)	20 (10 sec)	20	20+
Cycle Life profiles, (cycles)	300k	300k+	300k+
Maximum System Weight, (kg)	40	25	25
Maximum System Volume, (liter)	32	20	20
Cold cranking power, (kW at -30 C)	5 for 2 sec	3 - 5	3.2 – 5.1
Operating Temperature Range, (C)	-30 to +52	-10 - +40	-10 to +40

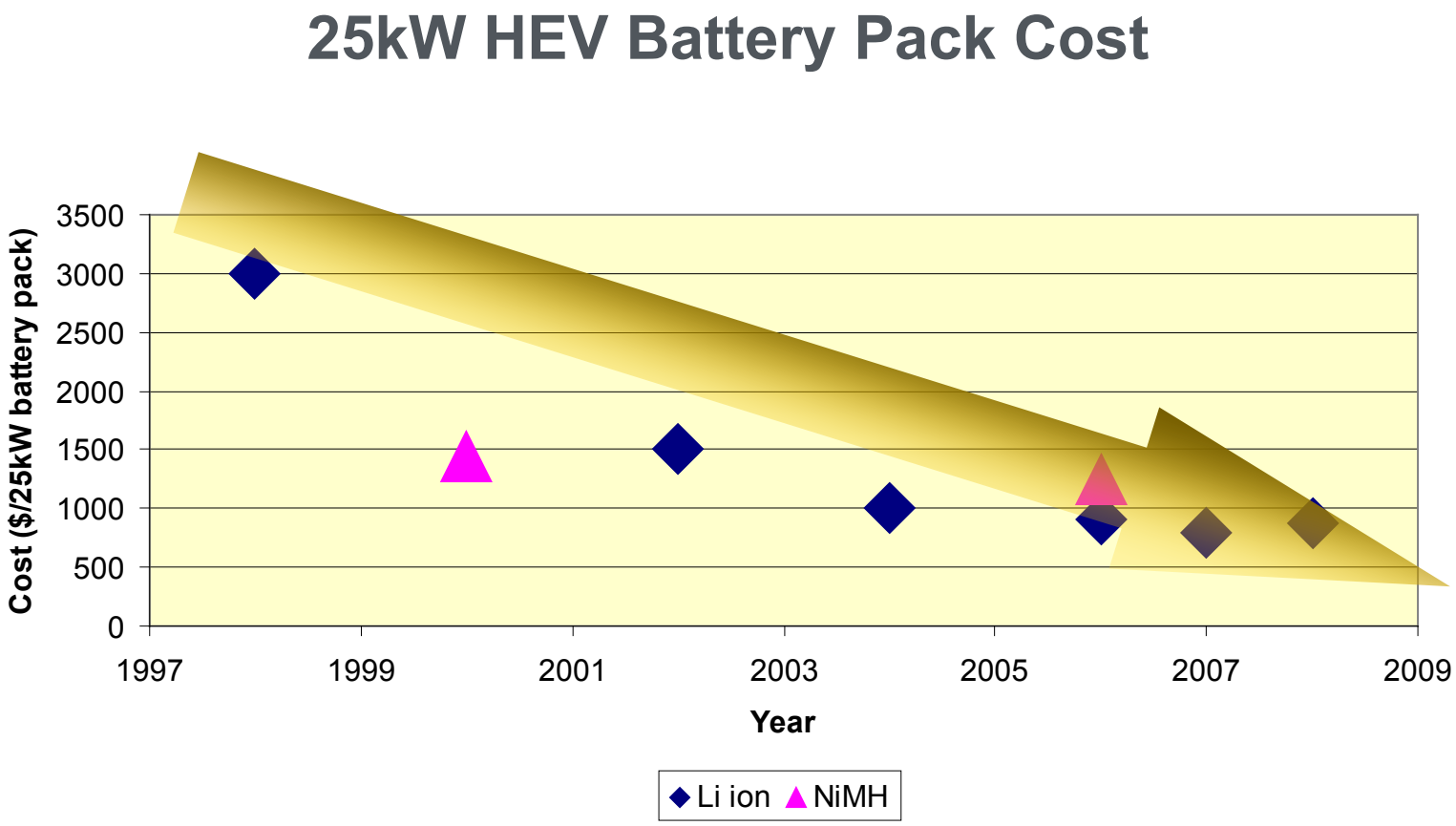
Overall Progress in DOE/USABC HEV Programs

Energy and Power Density of USABC HEV Technologies

3 Sample Data Sets

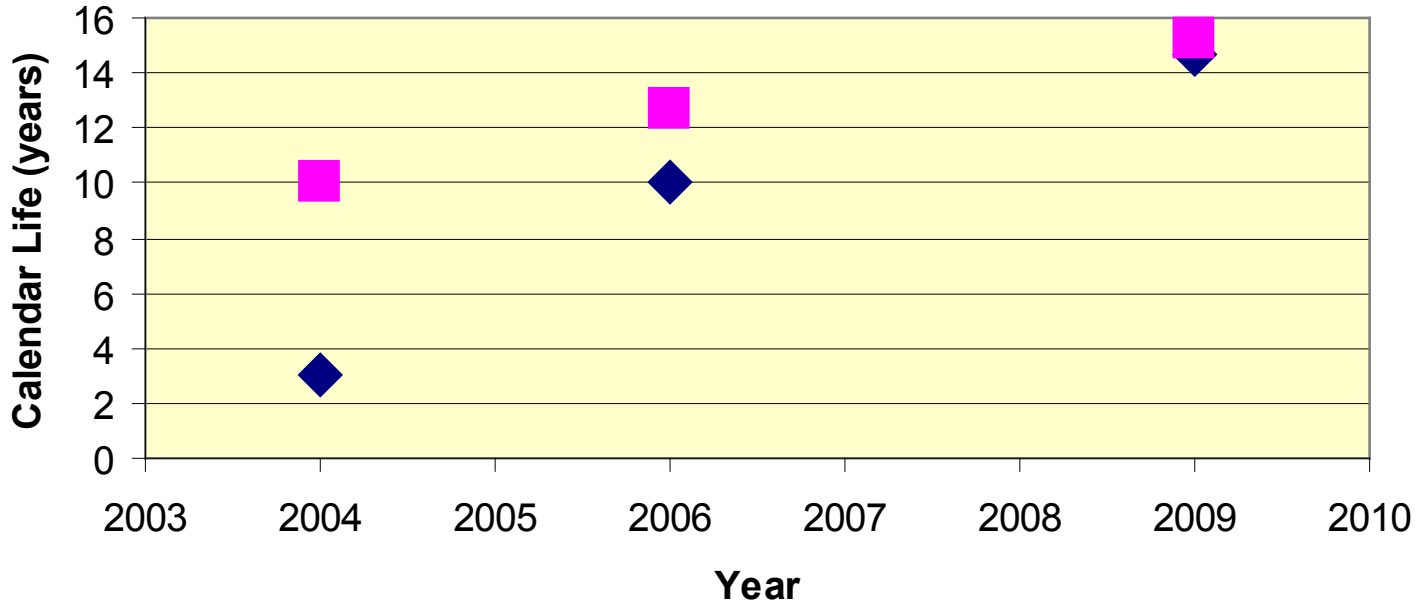


Overall Progress in DOE/USABC HEV Programs



Overall Progress in DOE/USABC HEV Programs

Calendar Life -- Two Sample Data Sets



Comparison of Li-ion Couples

Couple	Nickelate/ Carbon	Mn spinel/ Carbon	Fe Phosphate/ Carbon	Mn spinel/ LTO
Life	+			–
Power		+		+
Energy	+			–
Abuse tolerance (materials level)	–		+	+

- **Most HEV performance targets met by Li-ion batteries developed with DOE support.**
  - However, each chemistry has technical issues ranging from fundamental material properties to high manufacturing cost
  - Mature Li-ion chemistries have demonstrated more than 300,000 cycles and 10-year life (through accelerated aging)
  - R&D focus remains on cost reduction, improved abuse tolerance and the development of alternative technologies such as ultracapacitors.

Notable Accomplishments of USABC Battery Development Partners

- Johnson Controls-Saft (JCS)
  - Will supply lithium-ion batteries to BMW and to Mercedes for their Hybrids to be introduced in October 2009.
- 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

PHEV Battery Status and Challenges

Battery Attribute	Goals		Current Status (10-mile)	Notes
	2012	2014		
Available Energy	3.4 kWh (10 mile)	11.6 kWh (40 mile)	3.4 kWh	
Cost	$1700	$3400	$3400 (10-mile)	@ 100,000 batteries /year
Cycle life (EV Cycles)	5,000	3000-5000	1,700-2,000	For mature technologies
Cycle life (HEV Cycles)	300,000	300,000	300,000	At low states of charge?
Calendar Life	10^+ years	10^+ years	3^+ years	Life prediction is difficult
System Weight	60 kg	120 kg	80-120 kg	
System Volume	40 liters	80 liters	50-70 liters	

Key challenges: (1) Reducing cost, (2) Extending life (while operating in 2 discharge modes), and (3) Weight & volume.

DOE/USABC PHEV Battery Developers

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.

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

Research Directions

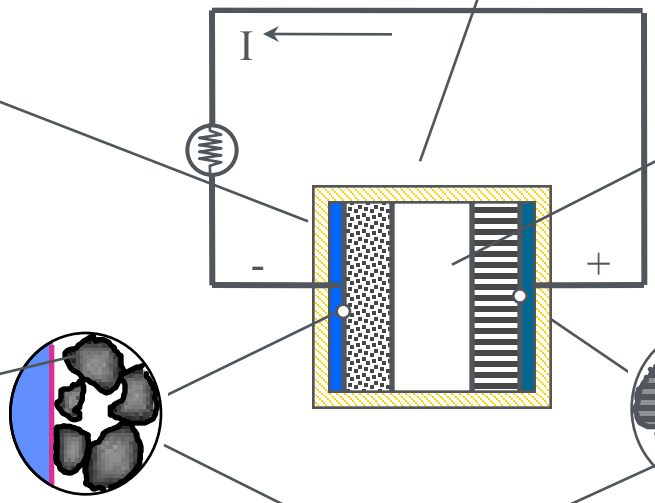
- In the long-term, new lithium battery chemistries with significantly higher energy densities need to be developed to enable PHEVs with a longer charge depleting range
  - High capacity positive electrode materials
  - Electrolytes stable at 5 volts
  - Alloy electrodes
- New materials with increased energy density mean
  - Less active material
  - Fewer cells
  - Less cell & module hardware
  - Reduced weight and volume

COST REDUCTION

Applied and Exploratory Research

Modeling
6 Projects
LBNL, ANL, NREL, INL,
U of Michigan

Cell analysis
7 Projects
LBNL, ANL,
SNL, Hydro-Quebec



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

Advanced anodes
8 Projects
ANL, PNNL, ORNL
SUNY Binghamton
U of Pittsburgh

Diagnostics
7 Projects
LBNL, BNL, ANL
SUNY Stony Brook, MIT

Advanced Cathodes
11 Projects
ANL, PNNL, LBNL
UT Austin, SUNY
Binghamton

50 projects, 10 Federal Laboratories, 12 Universities, $23.5 million

Notable Accomplishments/ Commercialization Activities

Toda

BASF

Hydro Québec

Phostech Lithium

ActaCell

SEEO

EnerDel Lithium Power Systems

- **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

Material Supplier and Manufacturing 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 Li metal powder
Sion Power	Develop and improve lithium sulfur cells for EV applications

TIAX	Internal short diagnostics & mitigation technologies
MaxPower INC.	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)

Summary

- R&D is focused on breakthroughs in critical enabling technology for HEV, PHEV, and EVs.
- Most HEV performance targets met by Li-ion batteries developed with FreedomCAR support.
  - Commercial introduction of lithium ion batteries has begun.
- Emphasis is evolving from high-power HEV systems to high-energy PHEV and EV systems.
  - Key challenges: (1) Reducing cost, (2) Extending life, (3) Weight & Volume, and (4) Abuse Tolerance.
  - A broad R&D portfolio has been developed ranging from battery development to exploratory (transformative & revolutionary) ideas to develop innovative solutions to address these issues