Electrical Energy Storage

"Plug-In Hybrid Electric Vehicle Battery Research and Development Activities"

Presented to
U.S. Department of Energy: PHEV Stakeholder Workshop

David Howell
Office of FreedomCAR & Vehicle Technologies

June 13, 2007

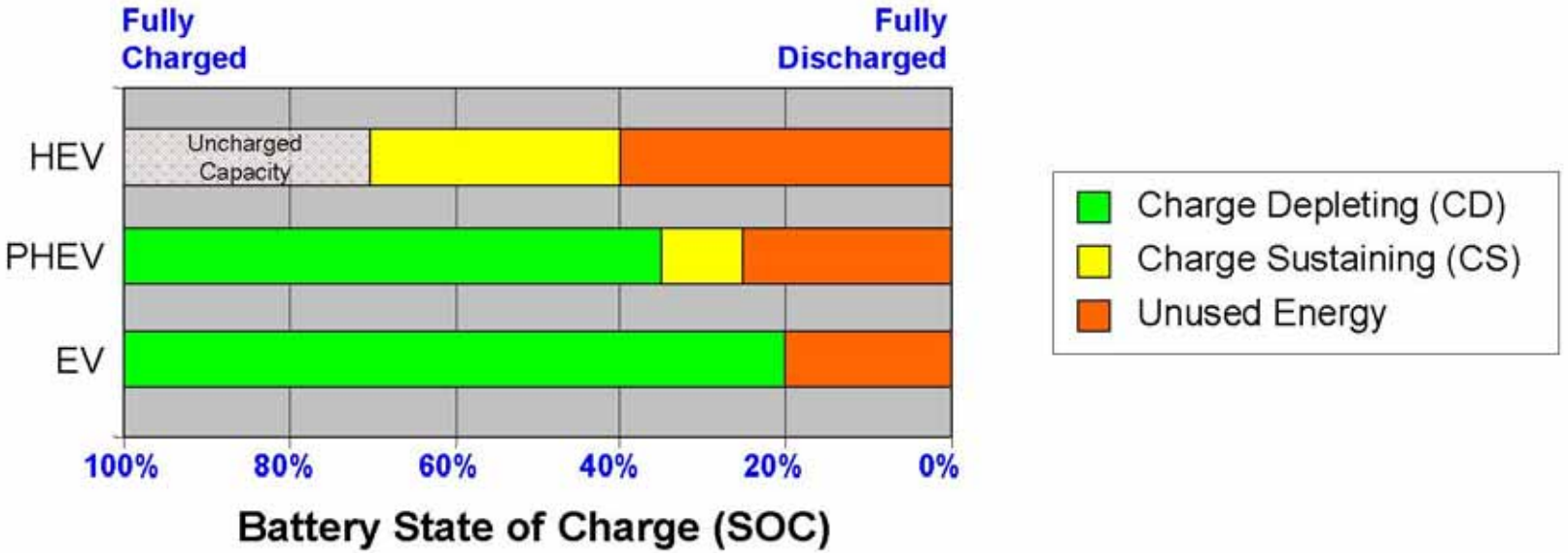
Outline

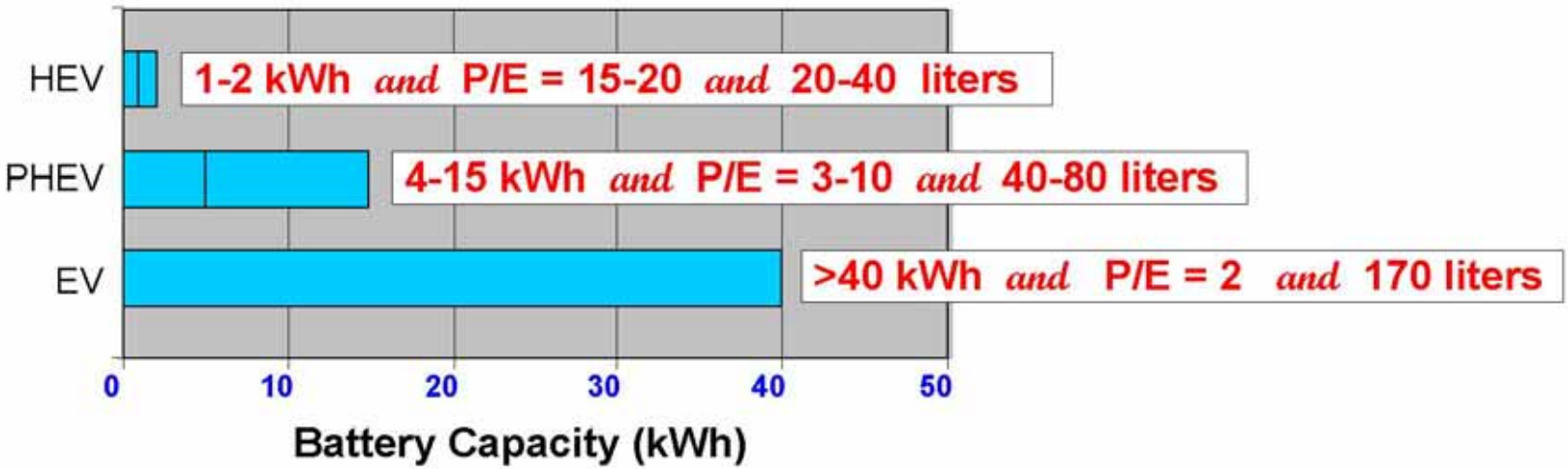
- Program Overview
  - Battery Operation and Research Goals
  - R&D Resources and Program Structure
- Battery Technology
  - Why Lithium-ion Batteries?
  - Remaining Challenges
  - Technology Development Roadmap
- PHEV R&D Activities
  - Battery Requirements
  - USABC Battery Solicitation
  - Research Directions

Charter

- Develop electrochemical energy storage technologies which support the commercialization of hybrid and electric vehicles
- Target Applications
  - Power-Assist Hybrid Electric Vehicles (HEVs)
  - Plug-in Hybrid Electric Vehicles (PHEVs)
  - Battery Electric Vehicles (EVs)

Battery Operation

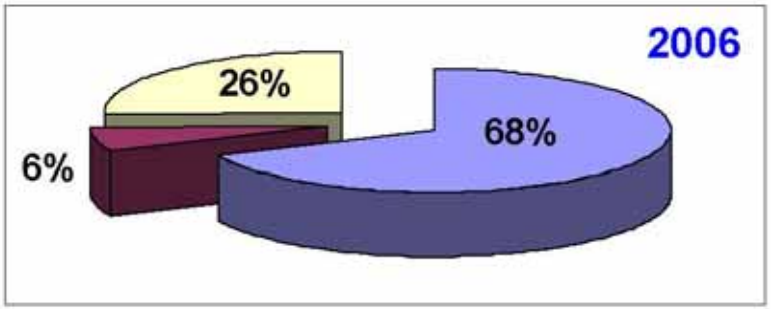




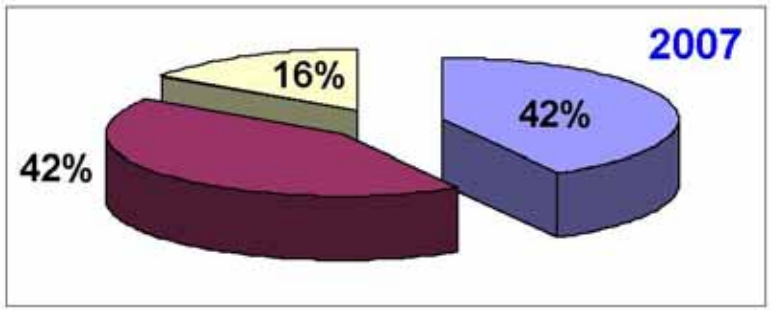
2010-2015 Research Goals

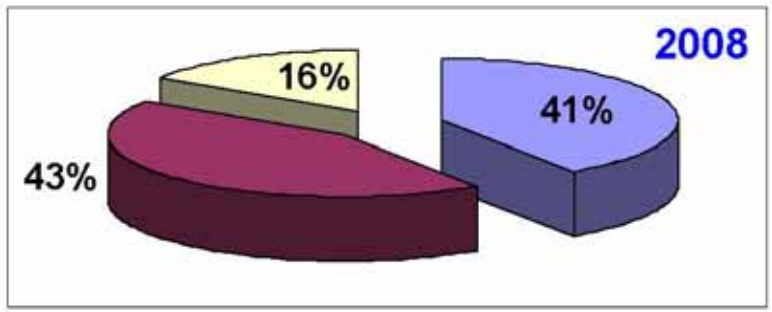
- **2010 FreedomCAR HEV Goal:** To enable reliable HEVs that are durable and affordable, the goal is:
  - Electric drivetrain energy storage with 15-year life at 300 Wh, with discharge power of 25 kW for 18 seconds, and $20/kW
- **2014 PHEV Battery Goal:**
  - PHEV energy and power goals (PHEV-10 and PHEV 40) have been developed in collaboration with the Vehicles Systems & Analysis Tech Team
  - PHEV cost goal: $200-300/kWh

Battery R&D Resources

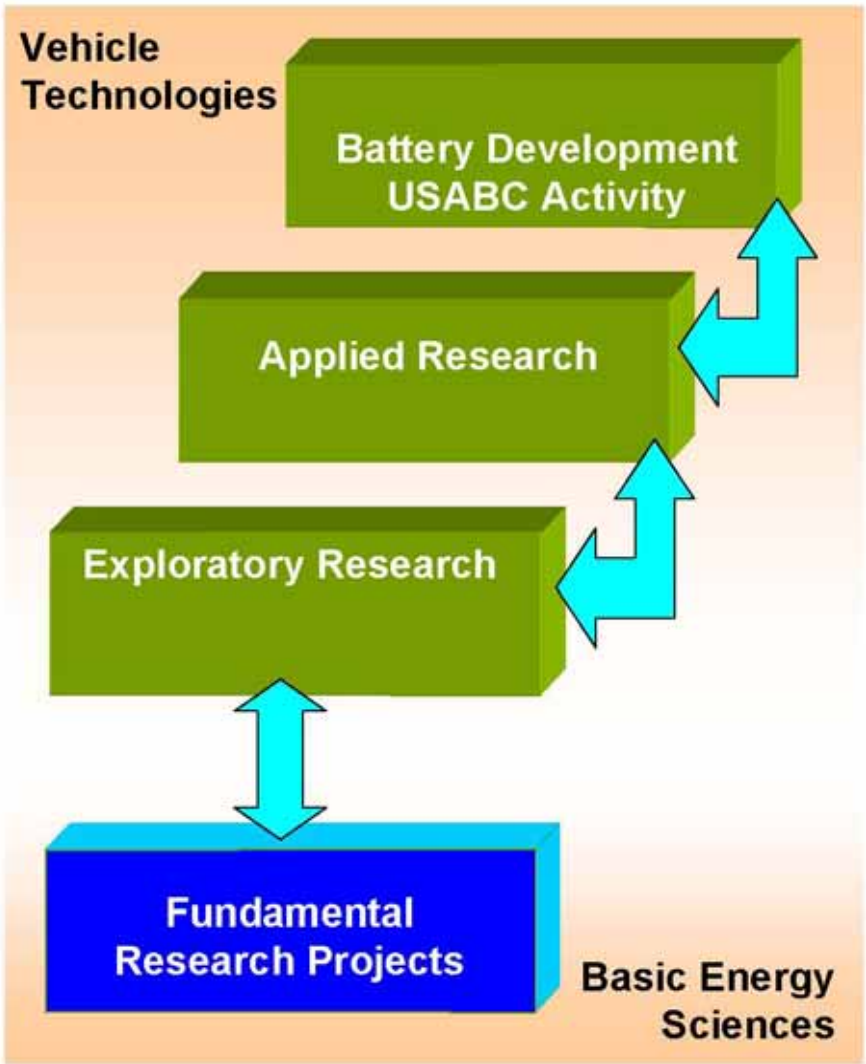


FY	Budget
2006	$24.442 Million
2007	$40.912 Million
2008*	$41.805 Million
	*Presidential request





Program Structure



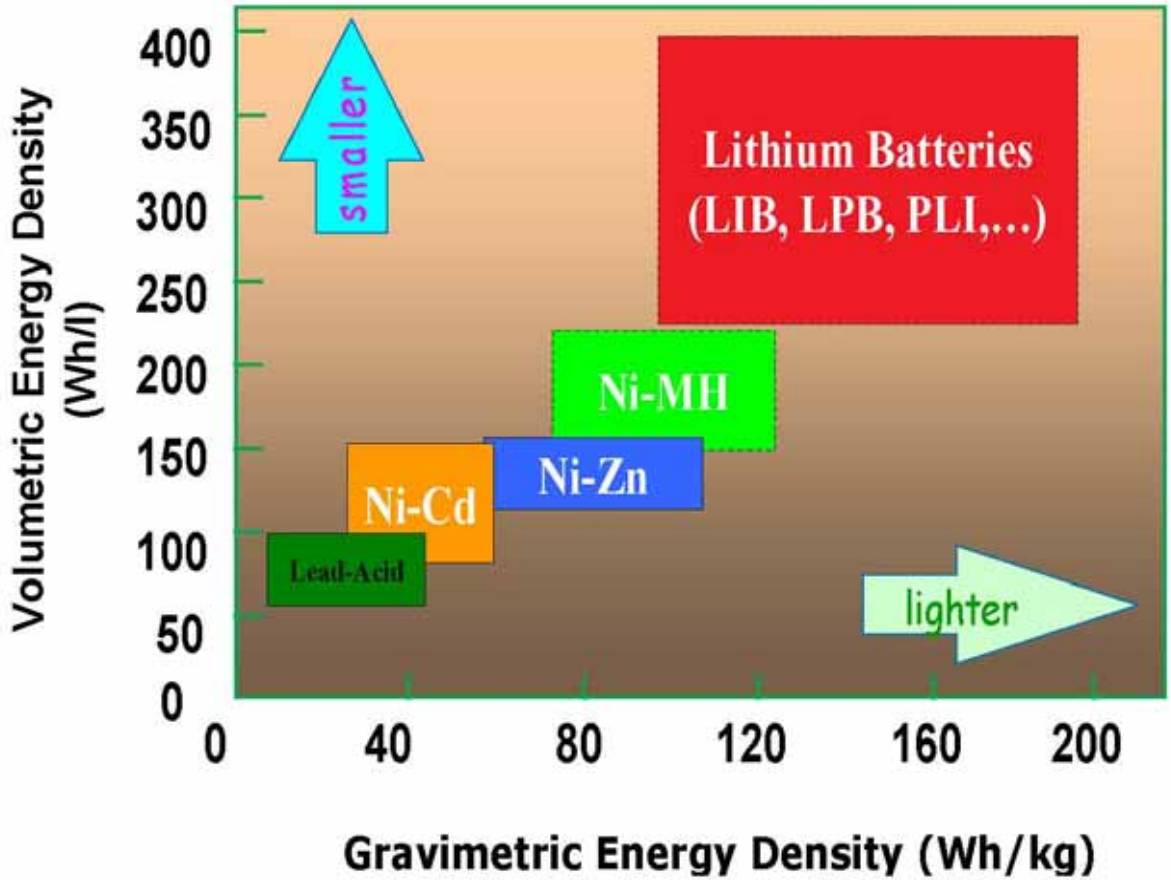
Develop full battery systems through competitive subcontracts with the USABC. (Industry)

Investigations on cell behavior to understand and overcome performance barriers of Li-ion battery technology. (DOE National Laboratories)

Novel materials development (cathode, anode, electrolyte) that promise increased power and energy. (DOE National Labs and Universities)

Why Lithium-ion?

- Lithium-ion has higher volumetric and gravimetric energy densities than competing battery technologies, enabling smaller and lighter battery packs.
- Lithium-ion also promises reduced cost, increased performance, and longer life.



Lithium-ion is viewed as the most viable PHEV battery chemistry

Remaining Challenges for HEV Lithium-ion Batteries

Power Assist Hybrids

- Cost: Current estimated cost of lithium-ion batteries for HEVs is about 1.5 to 2 times the FreedomCAR target.
- Abuse Tolerance: Existing lithium-ion batteries are intolerant to overcharge, crush, and high temperature exposure.
- Calendar Life: Accelerated life testing on multiple lithium-ion electro-chemistries has demonstrated an 8-15 year calendar life, but getting accurate life prediction is very challenging.
- Low Temperature Performance: Reduction in discharge power is an issue and lithium plating during regenerative braking may reduce life.

PHEV Overview: Challenges

Plug-In Hybrids

- Lithium-ion batteries for PHEVs and EVs are further from commercialization
  - Improvement in energy density is needed to permit evolution from HEVs to PHEVs.
- Critical Barriers include:
  - Cost of PHEV batteries estimated to be $1,000 + per kWh
  - Same abuse tolerance issues as HEV batteries, yet with more available energy
  - Volume and weight are issues.
  - Life issues are unknown. Unclear how deep discharges will affect life.
  - Discharge power may be a greater issue at very low temperatures

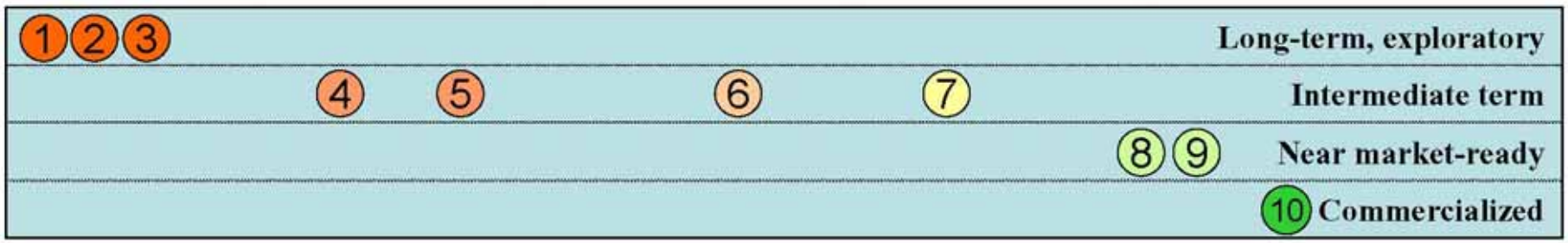
Technology Development Roadmap

Research Goals

Specific Energy: 100 Wh/kg (by 2010)
150 Wh/kg (by 2015)

Cost Goals

HEV: $20/kW (by 2010)
PHEV: $250/kWh (by 2015)



1. Li Metal/Li Ion Polymer
2. Li/Sulfur system
3. Li alloy/high V TMO system
4. Li titanate/Mn spinel
5. Graphite/Mn spinel
6. Graphite/Iron phosphate
7. Graphite/Nickelate
8. Ultracapacitors
9. Low cost separators
10. NiMH

Battery Requirements & Test Protocols

- Developed PHEV Battery Performance Requirements
  - PHEV modeling and simulation performed at ANL & NREL
  - Integrated state-of-the-art battery data into model
  - Developed PHEV battery requirements for a variety of vehicle platforms and "All Electric Ranges" (10 to 60 miles).
- Developed specifications for and procured State-of-the-Art PHEV lithium-ion Batteries
  - Saft 41Ah Li-ion battery packs
  - Cycle life testing is underway (ANL/SCE)
    - Assess current state-of-the-art
    - Develop testing protocols
  - Hardware-in-the-Loop testing and analysis (ANL)

USABC Goals for Advanced Batteries for PHEVs

Characteristics (End of Life)		High Power/ Energy Ratio Battery	High Energy/ Power Ratio Battery
Reference Equivalent Electric Range	miles	10	40
POWER AND ENERGY			
Peak Pulse Discharge Power - 2 Sec / 10 Sec	kW	50 / 45	46 / 38
Peak Regen Pulse Power (10 sec)	kW	30	25
Available Energy: Charge Depleting Mode @10 kW	kWh	3.4	11.6
BATTERY LIFE			
Charge Depleting Life / Discharge Throughput	Cycles/MWh	5,000 / 17	5,000 / 58
Charge sustaining (HEV) Cycle Life, 50 Wh Profile	Cycles	300,000	300,000
Calendar Life, 35°C	year	15	15
WEIGHT, VOLUME, & COST			
Maximum System Weight	kg	60	120
Maximum System Volume	Liter	40	80
Battery Cost	$	1,700	3,400

PHEV Battery Solicitation

- DOE and USABC issued a $28 million solicitation for PHEV battery development on April 5th
- The Purpose of this solicitation was to:
  - Fund battery developers to develop, design, build, and test PHEV battery hardware (cells and modules) which have the potential to meet the USABC PHEV energy storage performance requirements
- Proposal deadline was May 31st
  - 11 proposals received
  - Multiple awards expected during FY 2007

Exploratory and Applied Research

- **Positive Electrode Material**
  - Next-generation olivine, layered, and spinel structures
  - New high capacity positive materials (>250 mAh/g)
- **Negative Electrode Material**
  - Novel inter-metallic alloys and new binders
  - Nanophase metal oxides
  - Li metal systems
- **Electrolytes**
  - High voltage electrolytes (4.5 – 5 Volts)
  - Solid polymer electrolytes
  - Non-flammable electrolyte

- **Laboratories**: ANL, BNL, INL, LBNL, NREL, ORNL, SNL
- **Universities**: Univs of Texas, Utah, Michigan, MIT, Clemson, Brigham Young, SUNY, Columbia,

Summary

- Lithium-Ion batteries are technically feasible
  - Synergies between development of HEV and PHEV batteries
  - Batteries specifically built for this application are becoming available for testing
  - Impact of dual mode of operation during charge depleting and charge sustaining on battery life is not understood
- Cost is a potential show stopper
  - Current cost of lithium-ion battery is about $1000 /kWh
  - The short-term cost goal is $500/kWh and the long-term goal is $250/kWh
  - Cost must be reduced without degradation in battery performance
- PHEV battery requirements for a variety of vehicle architectures are being developed in collaboration with the Vehicle Systems Tech Team

Acknowledgements

- Tien Duong (DOE)
- Jim Barnes (DOE)
- Jack Deppe (LBNL)
- Gary Henriksen (ANL)
- BJ Kumar (Energetics)
- Irv Weinstock (Sentech)