U.S. Department of Energy
Vehicle Technologies Program
Electrochemical Energy Storage

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Charter and Goals

CHARTER

- Advance the development of batteries and other 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):**

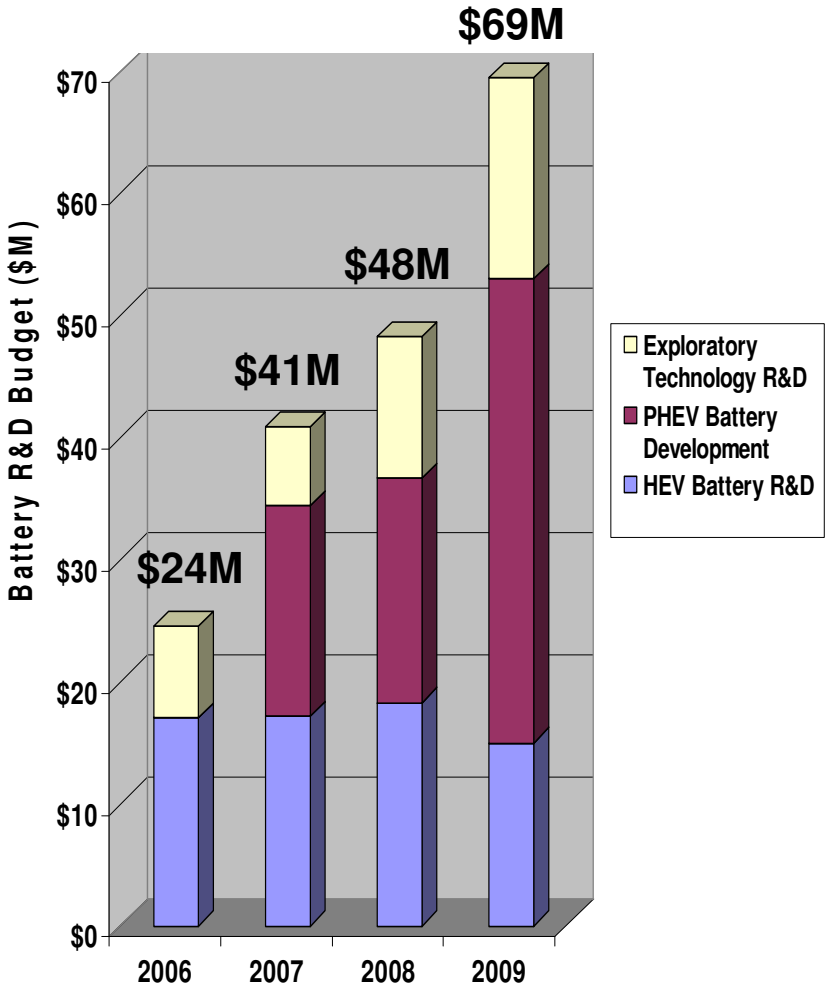
  Develop a 25 kW Power-Assist HEV battery that costs $500.

- **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

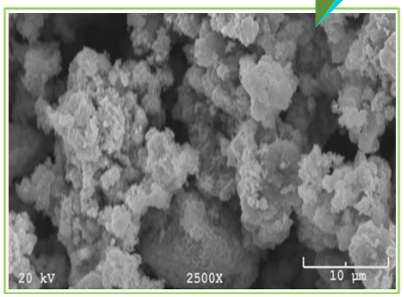
- The FY2009 budget is $69.4 million.
- The FY10 budget is $75 million.
- The DOE battery R&D budget has tripled in the past 4 years.
- Recent budget increases have focused on PHEV battery development.



R&D Program Activities

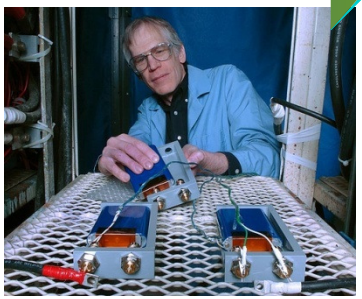
The energy storage effort is engaged in a wide range of topics, from fundamental materials work through battery development and testing.

Advanced Materials Research



- High energy cathodes
- Alloy, Li anodes
- High V electrolytes
- Li air couples

High Energy & High Power Cell R&D



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

Full System Development and Testing

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

Commercialization

Significant Progress

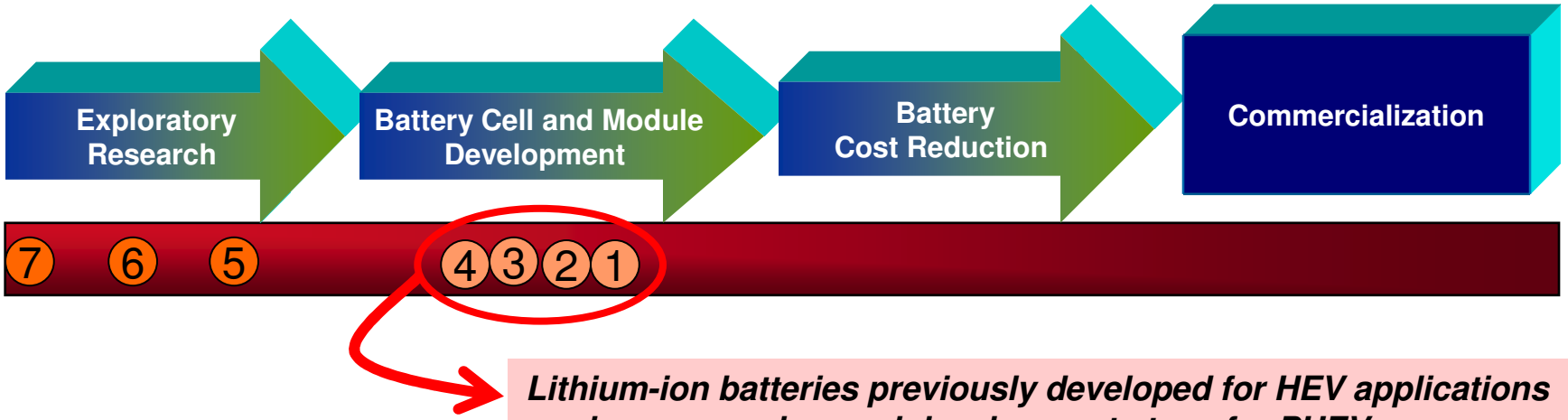
- Most HEV performance requirements have been met by Li-ion batteries developed with DOE/USABC support.
  - Mature Li-ion chemistries have demonstrated more than 10-year life through accelerated aging and 300,000 cycles through testing
- Li-ion batteries for HEVs are ready for commercialization.
  - Johnson Controls/Saft to supply HEV batteries to Mercedes, BMW
  - A123Systems is developing prototype HEV & PHEV lithium-ion batteries through contracts supported by DOE

R&D focus remains on cost reduction and improved abuse tolerance

DOE's battery R&D program has evolved to focus on high-energy PHEV systems.

Several lithium battery chemistries exist, including:

1. Graphite/Nickelate
2. Graphite/Iron Phosphate
3. Graphite/Manganese Spinel
4. Li-Titanate/High Voltage Nickelate
5. Li alloy/High Voltage Positive
6. Li/Sulfur
7. Li Metal/Li-ion Polymer



Lithium-ion batteries previously developed for HEV applications are in a more advanced development stage for PHEVs

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)

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	5000	>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	10 mile system
System Volume	40 liters	80 liters	50-70 liters	10 mile system

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

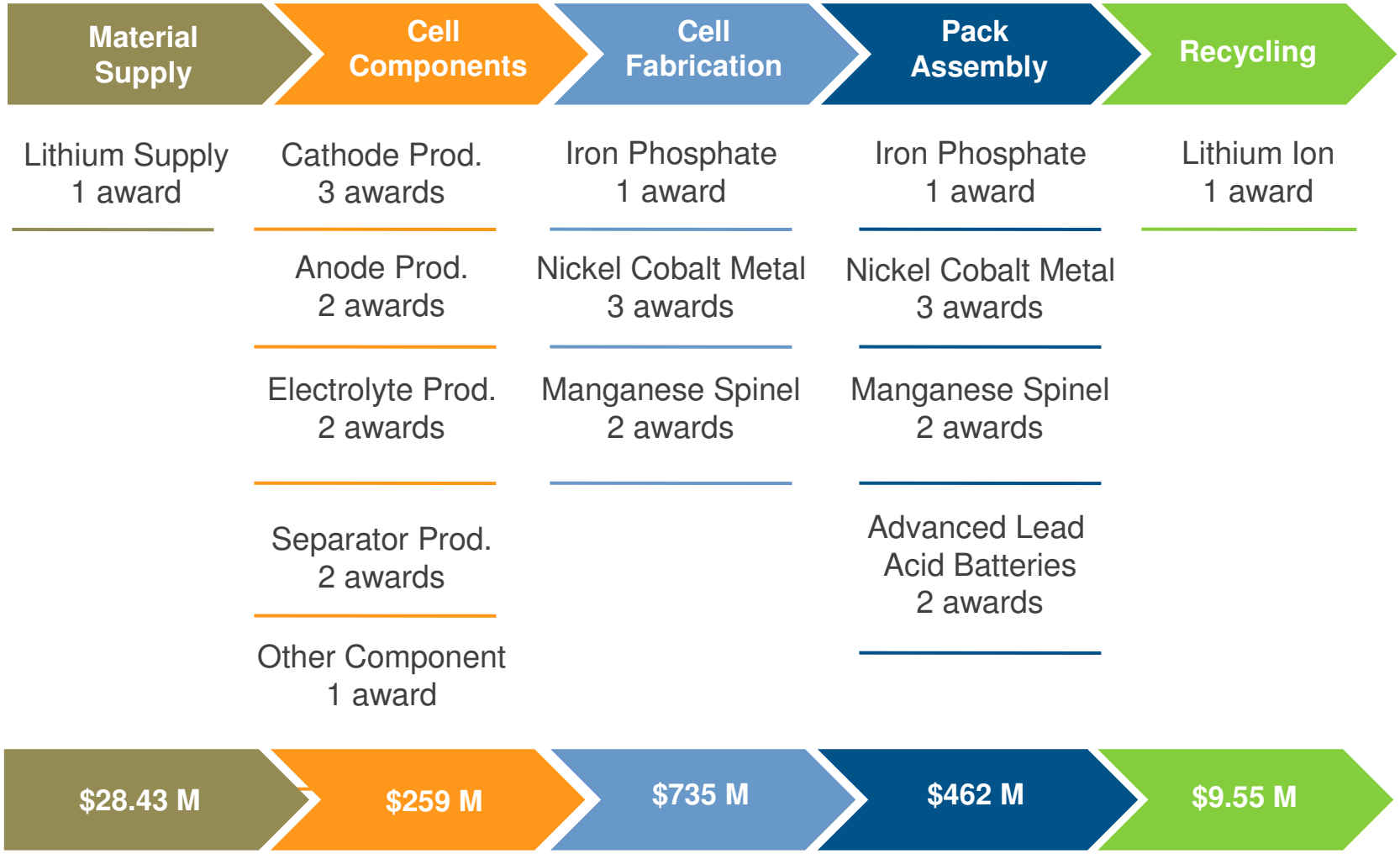
PHEV-40 performance targets are more challenging.

American Reinvestment and Recovery Act

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

$1.5 Billion for Advanced Battery Manufacturing for Electric Drive Vehicles

"Commercial Ready Technologies"



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

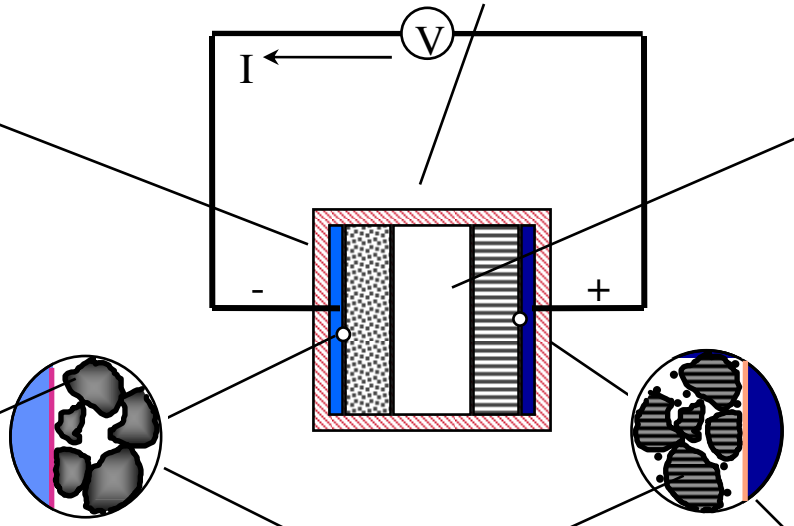
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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,
CWRU, NCSU,
UC Berkeley, U of Rhode Island, U of Utah

Advanced anodes
8 Projects

ANL, PNNL, ORNL
SUNY Binghamton
U of Pittsburgh, NREL

Diagnostics
7 Projects

LBNL, BNL, ANL
SUNY Stony Brook, MIT

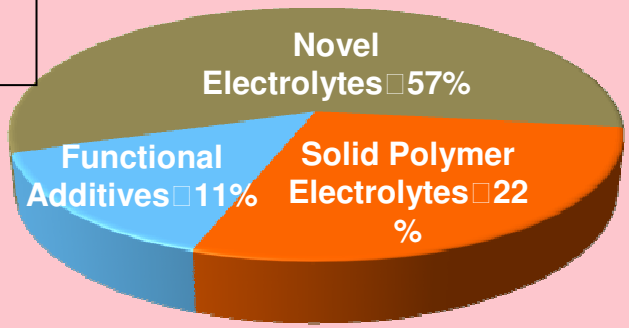
Advanced Cathodes
11 Projects

ANL, PNNL, LBNL
UT Austin, SUNY Binghamton

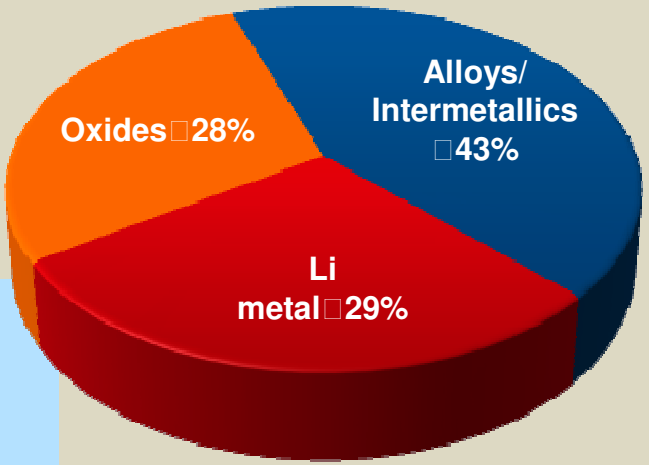
53 projects, 10 Federal Laboratories, 12 Universities, ~$30.0 million

Materials R&D: ~$10M

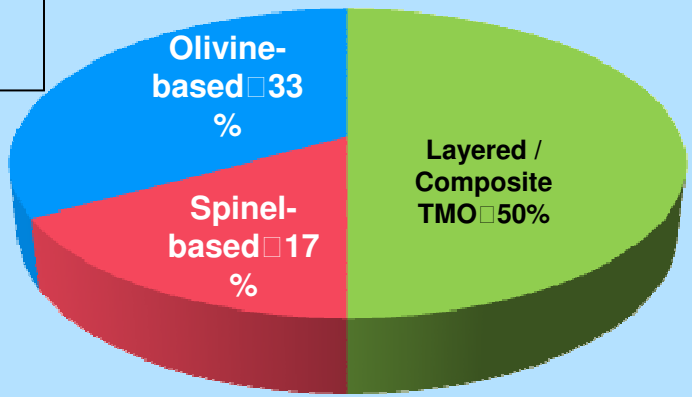
Advanced Electrolytes ~$3M



Advanced Anodes ~$3M



Advanced Cathodes ~$4M



Material Supplier and Manufacturing Improvement

DOE/NETL has selected nine 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
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

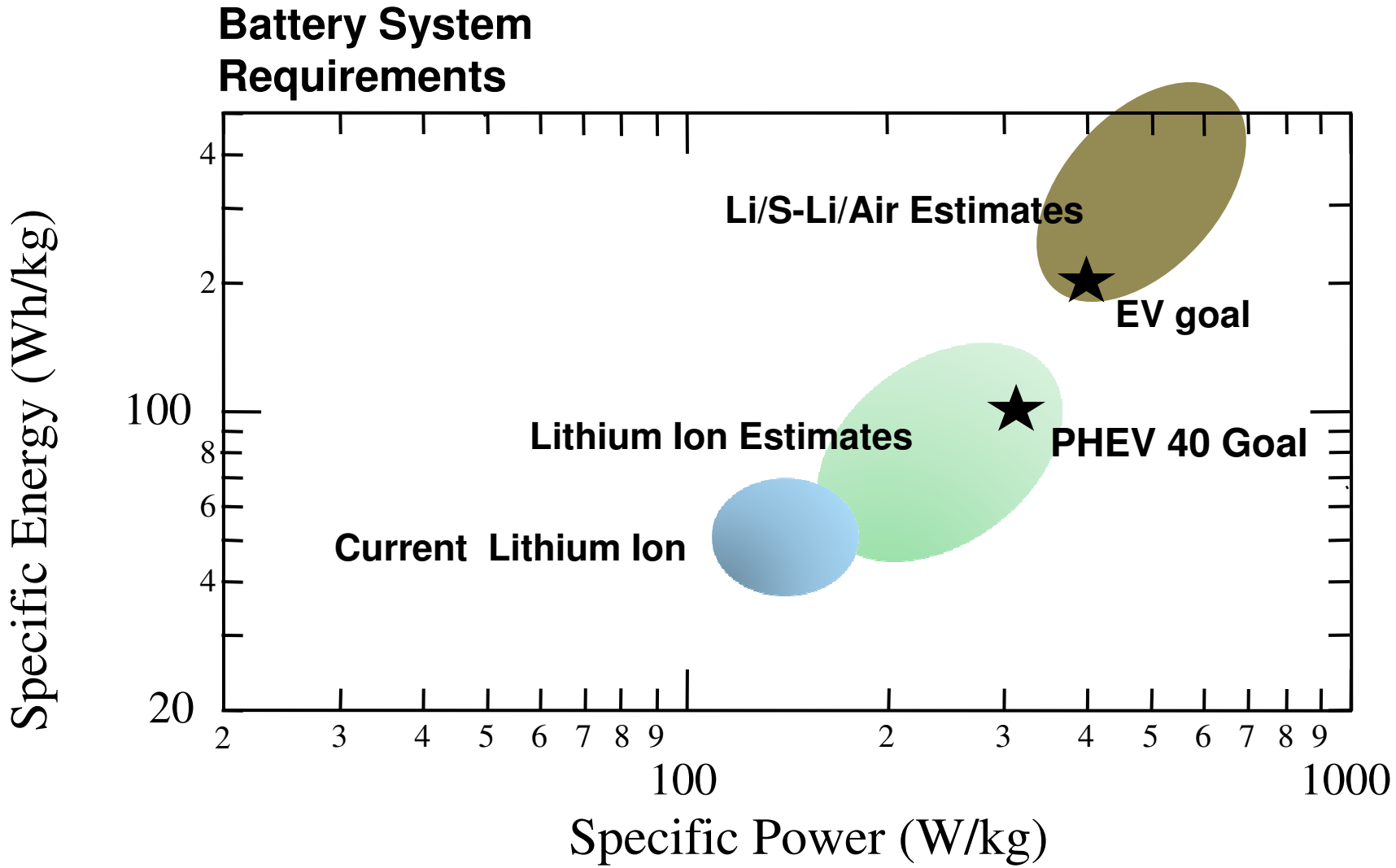
DOE cost-share: $17.8 million (cost-shared by industry)

Funding Opportunity Announcement anticipated ~ Jan 2010

Purpose is to solicit proposals for technologies that offer significant advances beyond current state of the art Li-ion battery technology in the following areas:

1. **Develop advanced cells with minimum of ~2x improvement in power and/or energy density while maintaining other performance characteristics**
   - ❑ High voltage (5V) and/or high capacity (>300mAh/g) cathodes
   - ❑ Inter-metallic alloys, nanophase metal oxides, and new binders
   - ❑ High voltage and solid polymer composite electrolytes
   - ❑ Other novel technologies or couples
2. **Develop advanced cells (batteries and ultracapacitors) that offer a ~2x reduction in cost while maintaining performance characteristics**
3. **Improving EDV Battery Design**
   - ❑ Revolutionary packaging approaches to reduce or eliminate inactive materials within a cell, thereby reducing weight/volume and cost.
   - ❑ CAD/CAM software : to enable rapid, systematic prototyping of designs.
   - ❑ Improved thermal management

End of Life EDV Battery Requirements and Technology Status/Potential



- Lithium/Sulfur (Li/S) – High Energy Battery Couple
  - **Promise:** Li/S offers one of the highest theoretical energy densities of any lithium couple – three to six times the current values
  - **Issues:** Cycle life, rate capability, poor utilization of lithium and sulfur
- Lithium/Air – Highest Energy Battery Couple
  - **Promise:** Li/Air offers the highest theoretical energy densities of any lithium couple, theoretically twice energy density of Li/S couple
  - **Issues:** Cycle life, rate capability, poor utilization of lithium, clogging of air cathode

Contact Information

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