US DOE EDV Battery R&D: Funding & Key Events

**NiMH Participants**
- Ovonic
- GM Ovonic
- SAFT
- Texaco Ovonic
- Electro Energy

**Li-ion Participants**
- 3M Company
- A123 Systems
- AMS
- Amtek
- ARNL
- Celgard
- Compact Power
- Delphi
- Duracell
- Electrovaya
- EnerDel
- JCI
- Johnson Controls
- Johnson Controls-SAFT
- K2 Energy Solutions
- Leyden Energy
- Polystor
- Quallion LLC
- SAFT
- SK Innovation
- SRI
- Ultralife
- UMT
- Valence
- Varta

**National Labs**
- Argonne
- Berkley
- Idaho
- Oak Ridge
- Brookhaven

**Other Participants**
- AEG
- Bolloré
- Electrofuel
- EPRI
- Exide Corp.
- Hydro-Quebec
- Norvik
- Maxwell
- PolyPlus
- Silent Power
- SionPower
- W.R. Grace

**US Drive**

**ARRA PHEV Battery Manufacturing Initiative**

**Li-ion PHEV Battery Commercialized**

**Li-ion HEV Battery Commercialized**

**JCI-Mercedes**

**Transition to High-energy Li-ion Battery R&D**

**Ultracap R&D Restart**

**Partnership for a New Generation of Vehicles**

**FreedomCar & Fuel Partnership**

**High Energy Li-ion**

**NiMH & other**

**FY Budget ($ x million)**

1993 1995 1997 1999 2001 2003 2005 2007 2009 2011
EERE-VTO Battery Technology Highlights

Lithium-ion Battery Technology for Plug-in Electric Vehicles

- EERE VTO supported the development of the core cell technology that is currently used in the Chevrolet Volt PEV battery and the Ford Focus EV battery.

- The cell, which contains a graphitic anode and a mixture of Nickel-Manganese-Cobalt and Manganese spinel oxides, was developed in collaboration with LG Chem Michigan from early 2004 through 2012.

- The Nickel-Manganese-Cobalt cathode in the LG Chem cell was developed at Argonne National Laboratory with support from EERE VTO from 2002-2010.
ARRA-Battery Manufacturing Supply Chain

**MATERIALS**
- BASF
- Toda
- Novolyte (BASF)
- Honeywell
- Chemetall Foote
- EnerG2
- Pyrotek
- FutureFuel
- Celgard
- ENTEK/JCI
- H&T Waterbury

**CELL/PACK**
- A123
- JCI
- SAFT
- EnerDel
- CPI-LG
- DOW-Kokam
- GM

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**Domestic battery manufacturing plants are supplying batteries to several hybrid and electric vehicles including**
- Chevy Volt EREV
- Opel Ampera EREV
- Cadillac ELR,
- Chevy Spark EV
- BMW Active Hybrid 7 HEV
- Land Rover
- Mercedes S Class S 400
- Mercedes E Class HEV,
- Odyne PHEV heavy duty vehicles.
- XLHybrids (which provides fleet vehicles to FedEx, Chevy, and GMC)
- Stationary Systems
2013 sales set a record, 2014 sales fell a bit shorter
- 592,000 EDV Sales in 2013 (All-Time High), 554,000 in 2014
- 97,000 PEV Sales in 2013, 115,000 in 2014
- Over 3.8 million EDVs on the road Jan.1, 2015
  - 2011: 14% Li-ion
  - 2012: 25% Li-ion
  - 2013: 40% Li-ion
  - 2014: 42% Li-ion

Advances in battery technology and manufacturing remain critical for the market success of all HEVs & PEVs.
2.65 GWhs of Lithium-ion Batteries were installed in Electric Drive vehicles sold in the USA in 2014.
How can EERE’s actions and investments promote US clean energy manufacturing that is competitive in the global market?

<table>
<thead>
<tr>
<th>Current Vehicle LIB Value Chain</th>
<th>Value Share</th>
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<tbody>
<tr>
<td>25-40%</td>
<td>30-45%</td>
</tr>
<tr>
<td>Raw Mat’ls &amp; Processed Mat’ls</td>
<td>Electrodes &amp; Cells</td>
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1) Excess worldwide manufacturing capacity exists across the supply chain
   - As U.S. demand grows and stabilizes, packs will likely be assembled domestically, and materials production, electrode production, and cell assembly may occur regionally.

2) Cost to manufacture lithium-ion batteries in the US does not prohibit market success
   - Multiple technologies likely to be competitive for different vehicle architectures i.e. EV, PHEV, HEV, micro-hybrid.

3) Market has not settled on a technology “winner”.
   - Opportunity exists to disrupt the market through the development and commercialization of more advanced lithium ion battery materials technologies that are not being manufactured today.
The Department of Energy
EV Everywhere Grand Challenge

Enable the U.S. to be the first in the world to produce plug-in electric vehicles that are as affordable as today’s gasoline-powered vehicles within the next 10 years.

- **Technology Push (R&D):** targets focus on reducing PEV costs
  - Advanced batteries,
  - Electric drive systems,
  - Lighter weight structures,
  - Enabling technologies such as advanced climate control.

- **Charging Infrastructure (Enablers):**
  Critical issues include codes and standards, siting, grid integration, permitting, and signage.

- **Market Pull (Consumer Acceptance):**
  Consumer education and exposure to PEVs, innovative PEV ownership incentives, and leadership by example among public and private fleets.

<table>
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<th>2022 Battery Technology</th>
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<td>$125/kWh</td>
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<tr>
<td>250 Wh/kg</td>
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<tr>
<td>400 Wh/l</td>
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<tr>
<td>2,000 W/kg</td>
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DOE Hybrid & Electric Vehicle Systems Program
Structure, Budget, and Information Resources

FY 2015 ($144.1M)

Electric Drive
- Power Electronic ($21M)
- Drive Motors

Battery R&D
- Materials R&D
- Battery Development
- Advanced Processing

Vehicle System
- Vehicle Testing
- Modeling & Simulation
- Component Efficiency Improvements
- Grid Integration
- Codes & Standards

($82.7M)
VTO Battery R&D Activities

**FY2015 Budget: $82M**

**Battery Development**
- EDV Cell/Module Des.
- Performance Increase
- Cost Reduction

**Pack Targets:** $125/kWh
- 250 Wh/kg : 400 Wh/l
- 2,000 W/kg

**USABC, Testing, CAE**
- 5 - 40+ Ah cells

**Cell Design & Optimization**
- Electrochemical Couples
  - Power & Capacity
  - Life Improvement

**Cell Targets**
- 350 Wh/kg
- 750 Wh/l
- 1,000 “C/3” cycles

**Industry/Lab**
- 0.5 - 1.0 Ah cells

**Battery Materials R&D**
- Capacity Improvement
- Failure Mitigation

**Anodes** (600+ mAh/g)
**Cathodes** (300+ mAh/g)
**Electrolytes** (5 volt)

**Laboratory/University**
- 10-100 mAh cells
DOE/USABC reduced the cost of PEV batteries by 70% and doubled their energy density during the past 5 years.

Current cost of advanced PHEV battery technology estimates average $289/kWh, useable.

Batteries ranged from PHEV 40 packs (~14 kWh).

- These battery development projects focus on advance cathodes, processing improvements, cell design and pack optimization.
- Standard electrolyte & graphite anode were used.

Results based on prototype cells & modules meeting DOE/USABC performance targets.

Detailed USABC battery cost model used to estimate the cost of PEV battery packs assuming that 100,000 batteries are manufactured annually.
Future Battery R&D
Advanced Battery Chemistries

- Extensive cost modeling has been conducted on advanced battery chemistries using the ANL BatPaC model.

- Significant cost reductions are possible using more advanced lithium ion materials (see figure)
  - Lithium-ion: Silicon anode coupled with a high capacity cathode presents moderate risk pathway to less than 125/kWh_{use}
  - Lithium metal is a higher risk pathway to below $100/kWh_{use}

These are the best case projections: all chemistry problems solved, performance is not limiting, favorable system engineering assumptions, high volume manufacturing
Objective: by 2020, reduce critical material and manufacturing costs by 50%.

- Focus on the energy, water, environmental, and labor costs which, depending on component, can range from ~20% – 60% of the materials cost.
- Reduce energy intensity for producing materials.
- Focus on $/kWh reduction
Electrode manufacturing and cell fabrication are 30-45% of battery cost.

The cell production line comprises a number of discrete unit operations – process steps in fabricating the cell from its component materials.

**Breakthroughs Needed**
- NMP solvent substitute
- Dry processing
- Fast curing binders
- High-speed deposition
- UV, Microwave, or IR flash lamp drying
- Ultrahigh packing density
- In situ separator coatings

Currently a 3-6 week process that assures performance, life, & safety of a cell.

**Breakthroughs Needed**
- Form SEI layer during material mixing or electrode processing
- High speed In-Situ NDI techniques to detect flaws & internal shorts
Recent Accomplishments

- Johnson Controls demonstrated novel cathode slurry processing techniques that
  - reduced N-Methylpyrrolidone (NMP) solvent use by 32%
  - increased coated electrode density by 31%.

- Miltec developed stable, first-of-its-kind, UV curable binders for Li-ion cathodes and demonstrated novel cathode slurry processing techniques.
  - Reduced NMP solvent use by 100%.
  - Achieved cathode thickness and porosity similar to conventional electrodes (~60 mm and ~25%).
  - Retained 50% capacity after 2,000 1C/1C cycles

- DOE/USABC contracts with Celgard and Entek reduced Li ion separator cost from $3/m² to ~$1.20/m².

- Nanosys developed a silicon-graphite anode material (SiNANOde™) that demonstrated 850mAh/g of reversible capacity and ~500 cycles
Resources

- VTO Annual Merit Review Report


- R&D Roadmaps

- R&D Highlights (USCAR)
QUESTIONS?

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