VEHICLE TECHNOLOGIES OFFICE

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

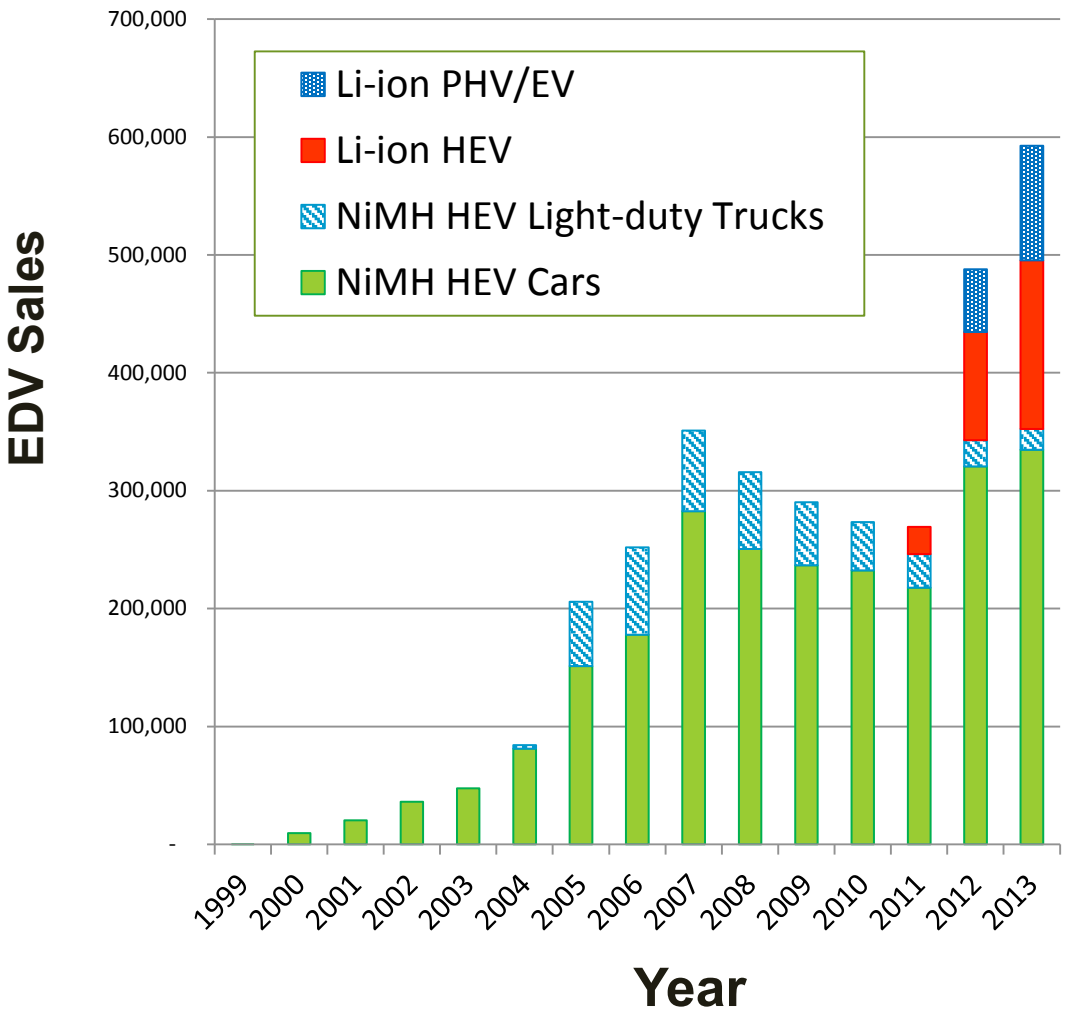
Overview of the DOE Advanced Battery R&D Program

June 16, 2014

David Howell, Program Manager
Hybrid Electric Systems
Vehicle Technologies Office

Significant Electric Drive Vehicle Sales Growth

U.S. Electric Drive Vehicle Sales, by Technology (1999-2013)



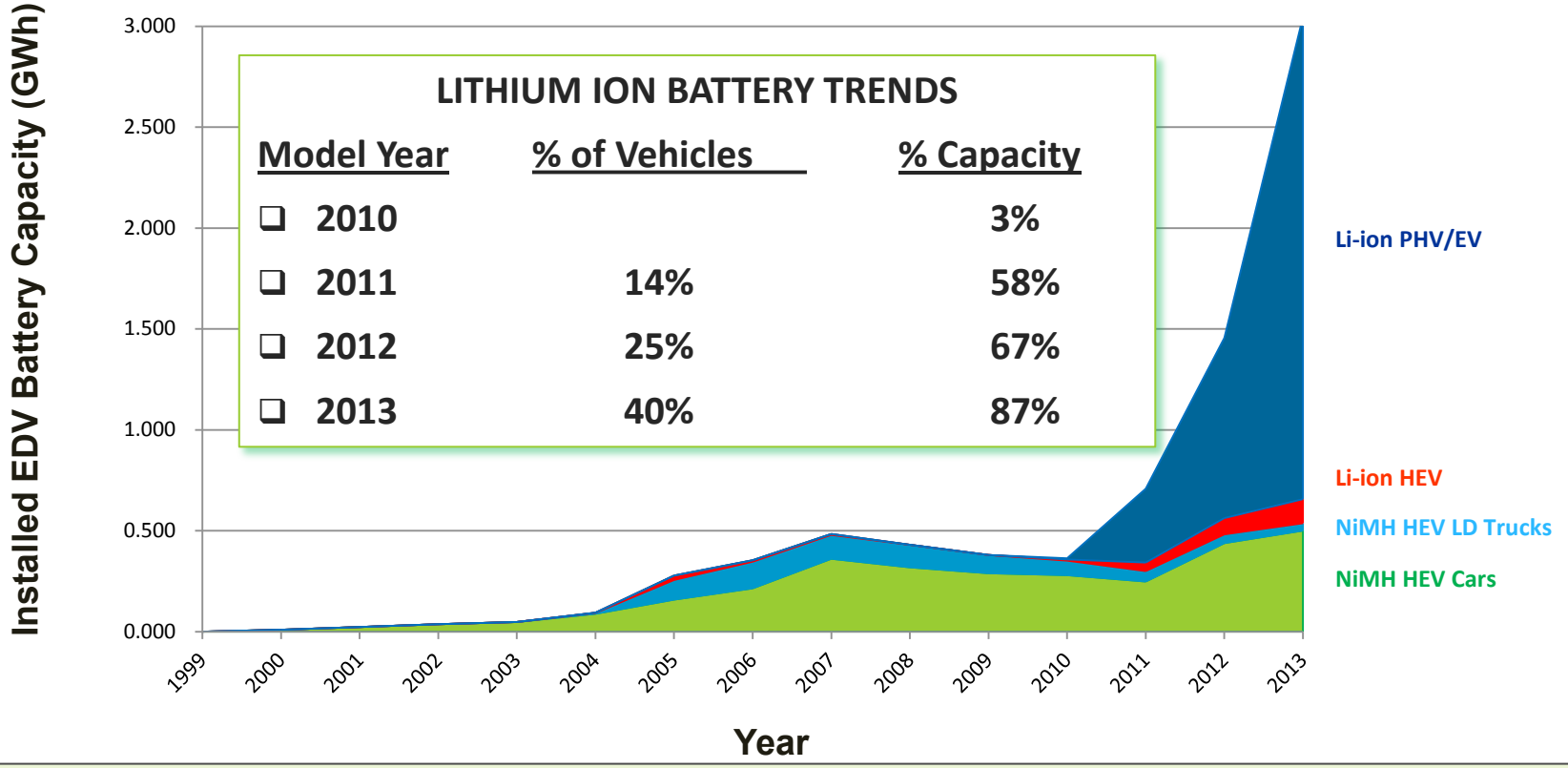
2013 Sales Set Record

- ❑ **46 EDV models were available for sale**
  - 575,000 Sales
- ❑ **~97,000 PEVs Sold. The top 6 models represent 95% of the sales :**
  - Volt (23,094)
  - Leaf (22,610)
  - Model S (19,400)
  - Prius PHEV (12,088)
  - Cmax Energi (7,154)
  - Fusion Energi (6,089)

Over 3.1 million EDVs on the road Jan.1, 2014

Significant Increase in Lithium-ion Batteries Installed in LDVs

Installed Electric Drive Vehicle Battery Capacity (GWh installed in vehicles)



~2.5 GWhs of Lithium-ion Batteries were installed in Electric Drive vehicles sold in the USA in 2013.

ARRA-Battery Manufacturing Supply Chain

Rockwood hydroxide production

GM Battery Pack Assist

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

<u>Adv. Lead-Acid</u>

- ❑ Exide
- ❑ East Penn

Domestic battery manufacturing plants are supplying batteries to several hybrid and electric vehicles, including the following:

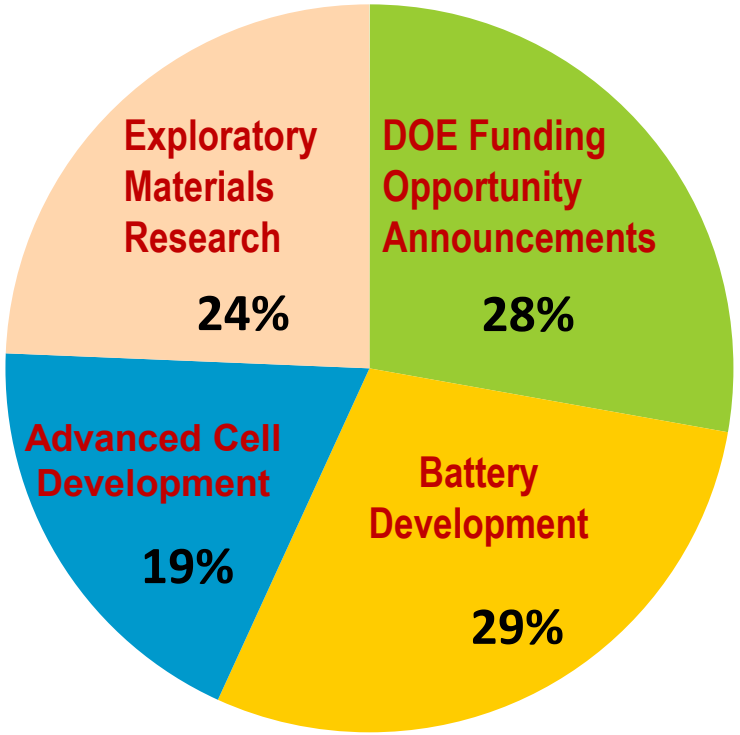
- ❑ Chevy Volt EREV
- ❑ Opel Ampera EREV
- ❑ Cadillac ELR,
- ❑ Chevy Spark EV
- ❑ BMW Active Hybrid 7 HEV
- ❑ Mercedes S Class S 400
- ❑ Mercedes E Class HEV,
- ❑ Odyne PHEV heavy duty vehicles.
- ❑ XLHybrids (which provides fleet vehicles to FedEx, Chevy, and GMC)

Battery R&D Budget

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

Battery/Energy Storage R&D Funding ($M)	
FY 2013	$88
FY 2014	$85
FY 2015 (request)	$100
inclusive of SBIR/STTR.	

FY 2014 Major R&D Activities



Reduce the cost of a PHEV40 battery to $300/kWh by 2014

Reduce the cost of a PEV battery to $125/kWh by 2022

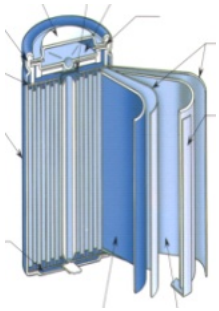
VTO Battery R&D Activities and Target Metrics

Advanced Battery Materials Research	Cell Design & Electrochemistry Optimization	Advanced Battery Development
✓ Capacity Improvement ✓ Failure Mitigation	✓ Power & Capacity Increase ✓ Life Improvement	✓ Performance Optimization ✓ Cost Reduction

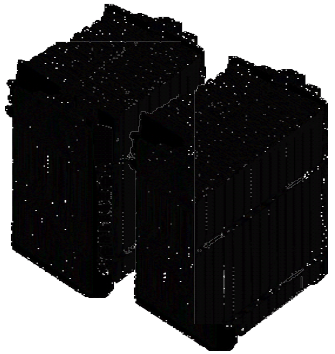
Anodes
(600 mAh/g)

Cathodes
(300+ mAh/g)

Electrolytes
(5 volt)



Cell Targets
350 Wh/kg
750 Wh/l
1,000 "C/3" cycles



$125/kWh
250 Wh/kg
400 Wh/l
2,000 W/kg

10-100 mAh cells	0.5 - 1.0 Ah cells	5 - 40+ Ah cells

Advanced Battery Materials Research

Anodes
- Intermetallics
- Nanophase metal oxides
- Tailored SEI and new binders

Cathodes
- Layered-layered oxides
- High voltage Spinel
- Metal phosphates
- Tailored Surfaces

Electrolytes
- High voltage electrolytes
- Solid Polymer
- Electrolytes for Li metal
- Non-flammable electrolytes

Beyond Lithium Ion
- Inhibit dendrite growth
- Efficient utilization of sulfur
- Bifunctional catalyst for Li-O2

Participants

- ❑ National Labs: ANL BNL, LBNL, NREL, ORNL, PNNL
- ❑ Universities/Industry
  - Arizona State University
  - Case Western Reserve University
  - Drexel University
  - Daikin
  - Hydro Quebec
  - MIT
  - North Carolina State University
  - Penn State University
  - Stanford University
  - SUNY—Binghamton
  - SWRI
  - University of California
  - UMASS—Boston
  - University of Michigan
  - University of Pittsburgh
  - University of Rhode Island
  - University of Texas, Austin
  - University of Utah
  - WildCat Discoveries/3M

POSTER SESSION, Monday/Tuesday, JUNE 16,17 (Tien Duong, with BES)

Cell Design & Electrochemistry Optimization

Power & Capacity Increase and Life Improvement

FOCUSED NATIONAL LABORTORY PROJECT

Voltage Fade Mitigation of High Capacity Manganese Rich Layered-Layered Cathode Material

CORE RESEARCH FACILITIES

Cell Fabrication Labs (ANL and ORNL)

Exploratory Materials Scale-Up Facility (ANL)

Post Mortem Analysis Laboratory (ANL)

Scientific Diagnostic Facilities (various)

2013 VTO FOA Selections High Capacity Cathodes coupled with High Capacity Anodes $2-4 million over 2 years	
Prime	**Partner(s)**
Argonne	BNL, LBNL
3M	GM, Umicore Leyden, LBNL, ARL
Penn State	UT-Austin, LBNL, ANL,ECPower
Farasis	ANL, LBNL, NanoSys, Dupont
Envia	LBNL, ORNL, GM
TIAX	–

Oral Presentations, Wednesday & Thursday June 18-19 (Peter Faguy)

Advanced Battery Development

Performance Optimization and Cost Reduction

USABC Cooperative Agreement

Support battery manufacturers to develop batteries that meet EDV performance, safety, and cost requirements.

Focus

Cell Design/Fabrication
Module/Pack Design & Fab
Material Specs, Formulation & Synthesis
Electrode Design & Coating
Battery Control & Safety
Detailed Cost Modeling

2011 VTO FOA Selections	
Johnson Controls	3M Company
A123Systems	Applied Materials Inc.
Amprius	Penn. State University
XALT Energy (formerly Dow Kokam)	MILTEC
Nanosys/LG Chem	Optodot
SEEO	Denso

Battery Design (CAE), Testing, and Analysis

POSTER SESSION – Monday/Tuesday JUNE 16,17
ORAL PRESENTATIONS - TUESDAY, JUNE 17

David Howell
Brian Cunningham

FY2014 Funding Opportunities

- **Advanced Battery Development (USABC Cooperative Agreement)**
  - RFPI on EV Battery Development
  - RFPI on PHEV Battery Development
  - RFPI on 12V Micro-Hybrid Battery Development
  - RFPI on 48V Micro-Hybrid Battery Development
- **VTO Program Wide FOA (Exploratory Materials Research)**
  - Beyond Lithium Ion and Solid Electrolytes
- **Incubator**
- **Small Business Innovative Research (SBIR)**

Progress and Results

Successful Battery R&D Investments

Recent Benefit-Cost Analysis

- Significant Link Between DOE-Funded R&D and the Most Prominent EDV Battery Technologies - NiMH and Li-ion
- VTO R&D Strongly Contributed to Electric Drive Vehicle Success and lead to a Domestic Automotive Battery Industry

"The major economic impact of VTO's R&D investments [in battery technology] is primarily realized through the increase in the market adoption of EDVs."

Industry Consensus (BCE Report, p.5-2)

VTO's Investments

- Total VTO Investment - $971M
- Investment with USABC - $315M
- USABC Matching Funds - $358M
- R&D Involved 148 Companies Universities, and National Laboratories

Oil Savings

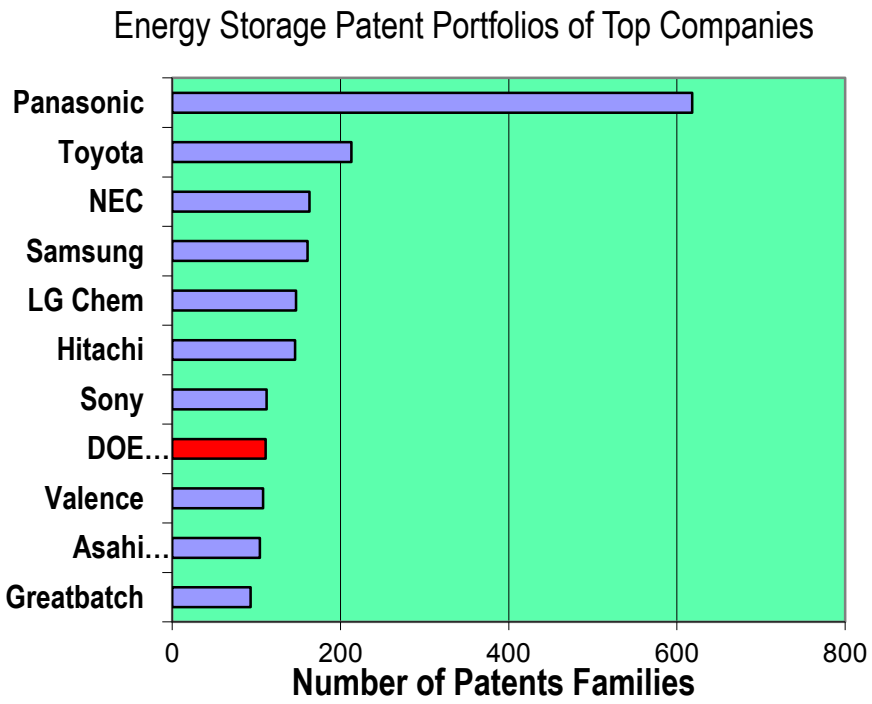
Life-Cycle Benefits From EDV Sales (1999 Through 2012)

$16.6 Billion

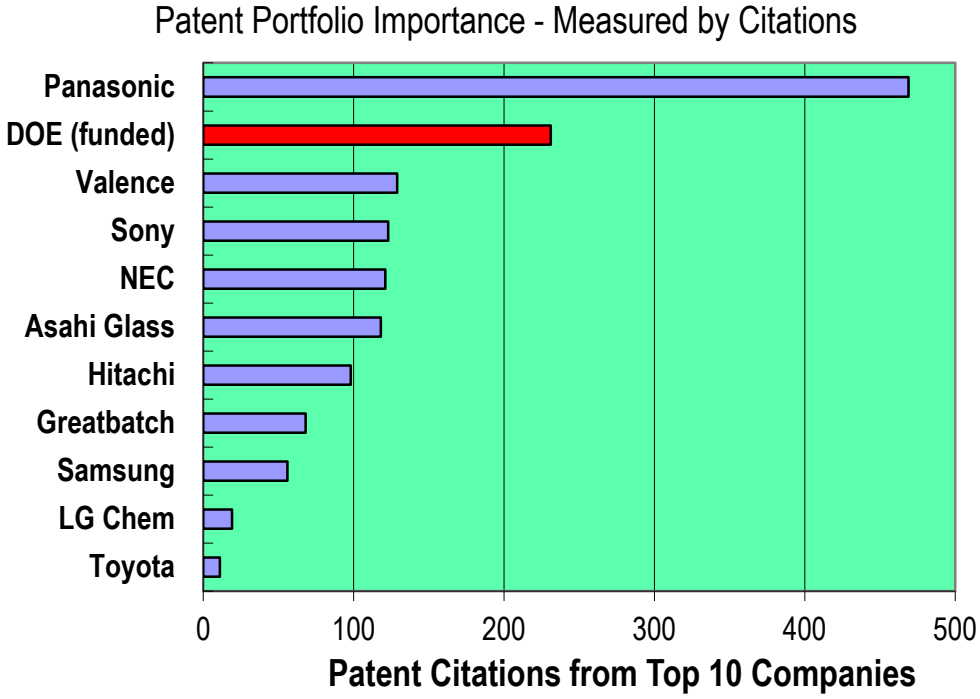
Progress and Results

Knowledge Benefits Evaluation

VTO Ranks Eight Among the Top Ten Companies with Energy Storage Patents



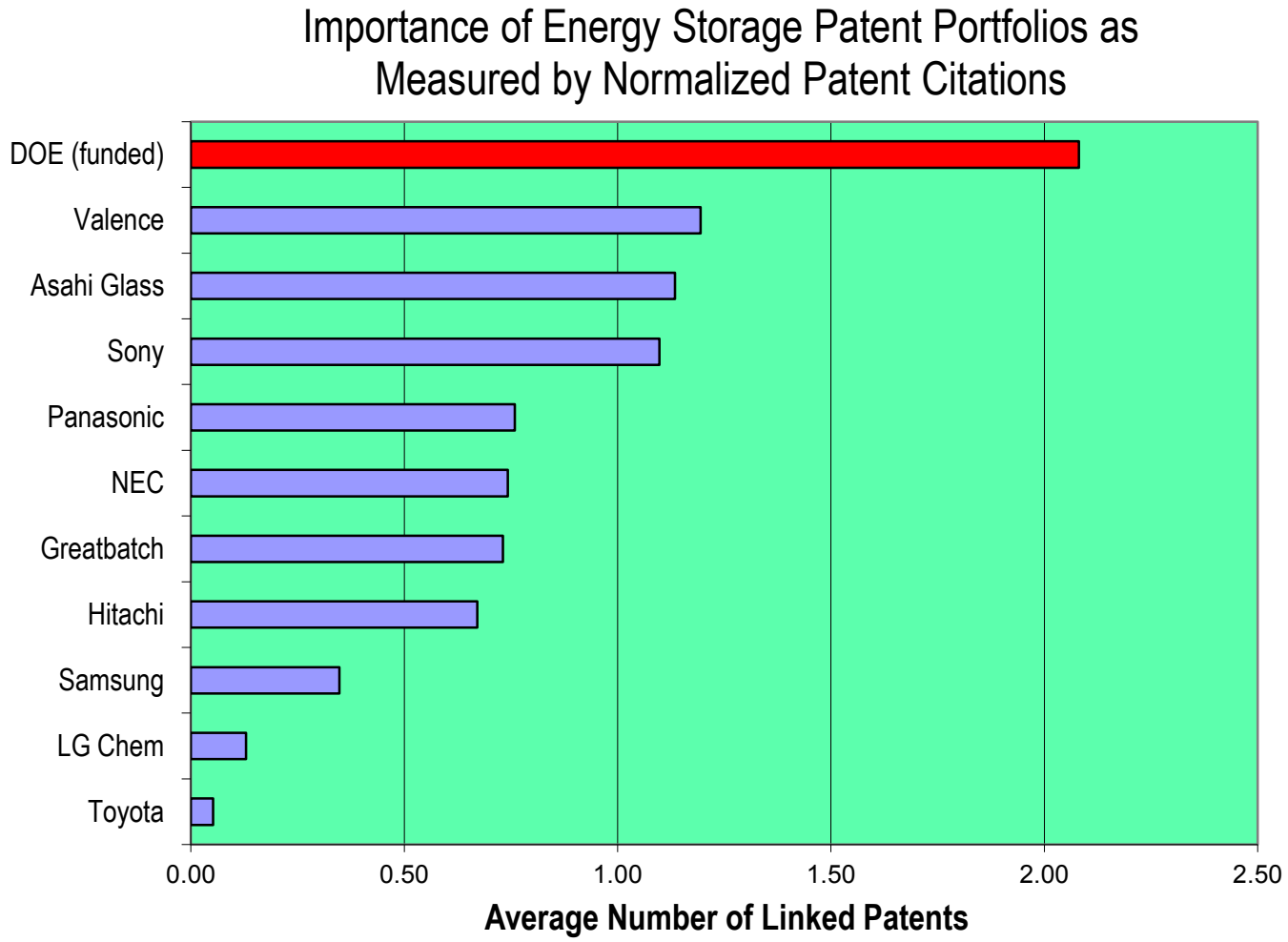
VTO Ranks Second Among the Top Ten Companies in Total Citations



"The intellectual capital developed with VTO funding was found to have a broad influence with knowledge spillover in multiple application areas." BCE Report p. 7-3

Progress and Results

Knowledge Benefits Evaluation



- 108 Patent Families Since 1992
- VTO Ranks First Among Top Companies Based on Average Citations by the Top Companies
- 2337 Publications & Presentations Since 2000

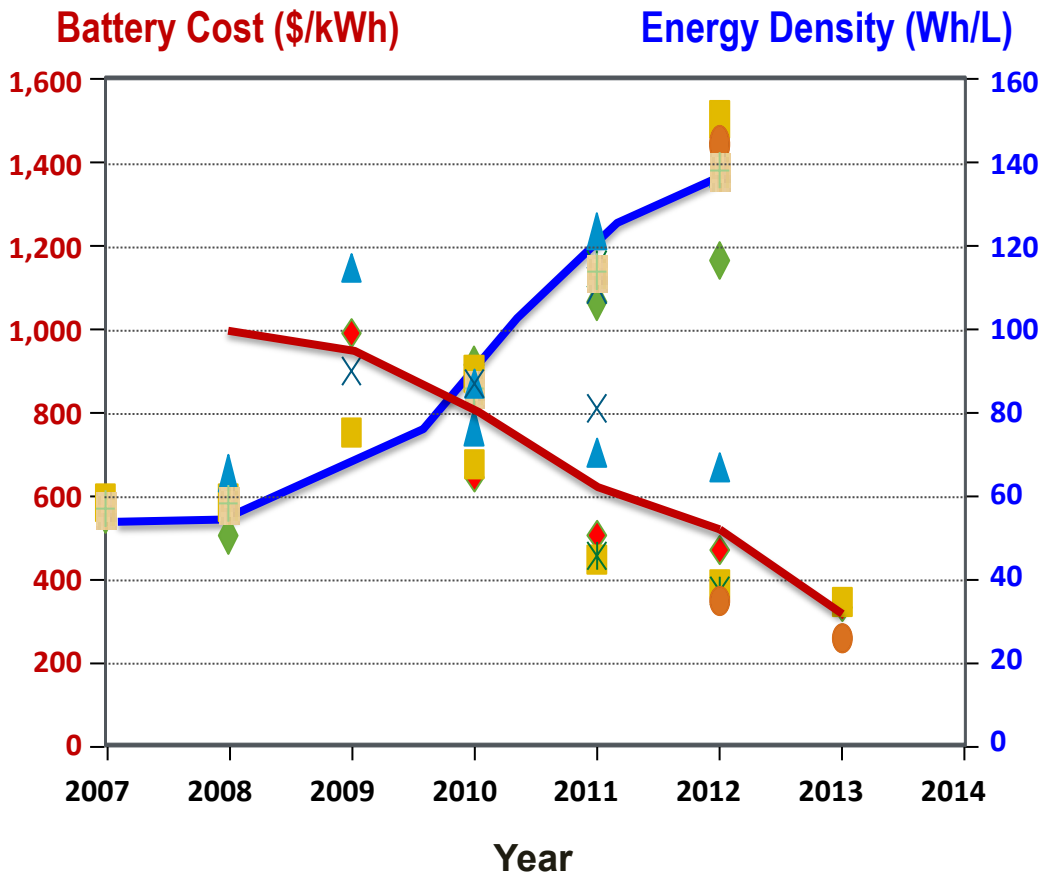
"A comparison of average citation rates of VTO-attributed patent families with the average of leading innovative companies in the field showed VTO to rank highest" (BCE Report, p. 7-2)

Progress and Results

Cost Reduction & Energy Density

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 **$325/kWh**, useable
- 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.

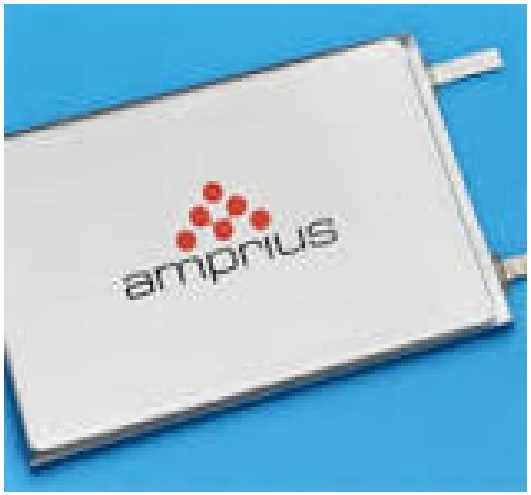


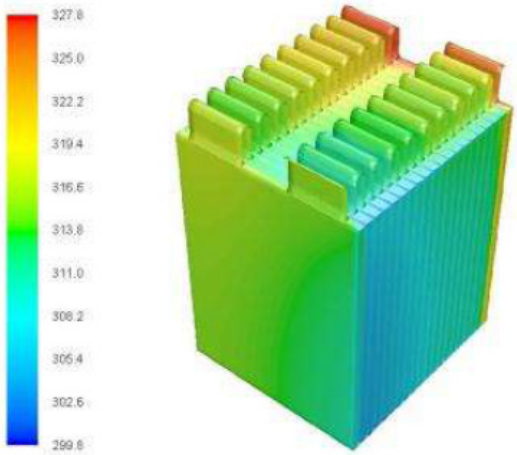
- Batteries ranged from PHEV 40 packs (~14 kWh) to EV packs (40kWh).
- These battery development projects focus on advance cathodes, processing improvements, cell design and pack optimization.
- Standard electrolyte & graphite anode were used.

Progress and Results

Recent Accomplishments

- **Amprius**: Silicon nanowire anodes for enhanced energy and reduced cost:
  - Provide 260Wh/kg, ~50% more than SOA cells
  - Good cycle life, less than 5-7% fade after 290 cycles
- **GM/Ansys/ESim/NREL**: Creation of a battery design software suite to reduce battery development time and cost:
  - First release in 12/2013
  - Permits thermal response, cycle life modeling, abuse response modeling of battery cells and pack
  - Customers currently using tool for battery design





Progress and Results

Recent Accomplishments

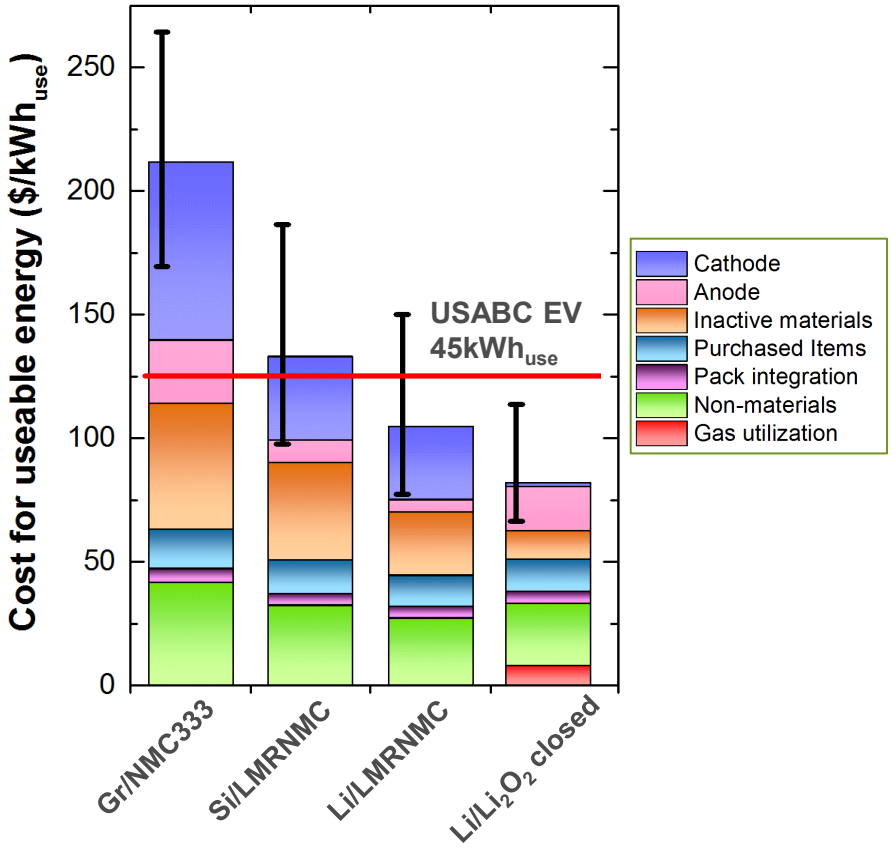
- Johnson Controls demonstrated novel cathode slurry processing techniques that
  - reduced N-Methylpyrrolidone (NMP) solvent use by 32%
  - increased coated electrode density by 31%.
- Miltec developed stable, first-of-its-kind, UV curable binders for Li-ion cathodes and demonstrated novel cathode slurry processing techniques.
  - Reduced NMP solvent use by 100%.
  - Achieved cathode containing 87% NMC.
  - 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

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}$

Projected Cost for a 100kWh Battery Pack

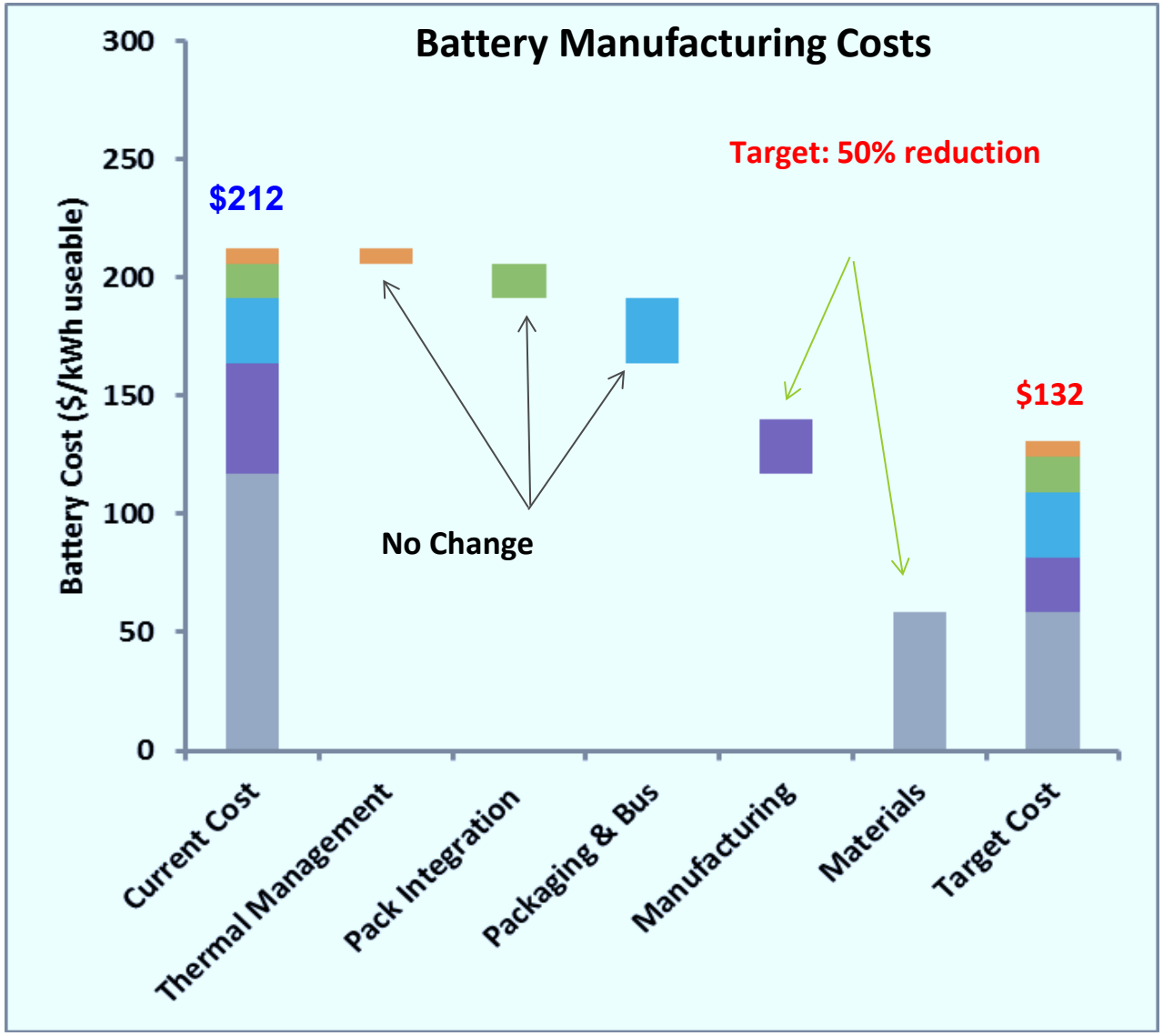


Courtesy: JCESR Energy Storage Hub

These are the best case projections: all chemistry problems solved, performance is not limiting, favorable system engineering assumptions, high volume manufacturing

Future Battery R&D

Materials Processing and Electrode Manufacturing



Objective: by 2020, reduce critical material and manufacturing costs by 50%.

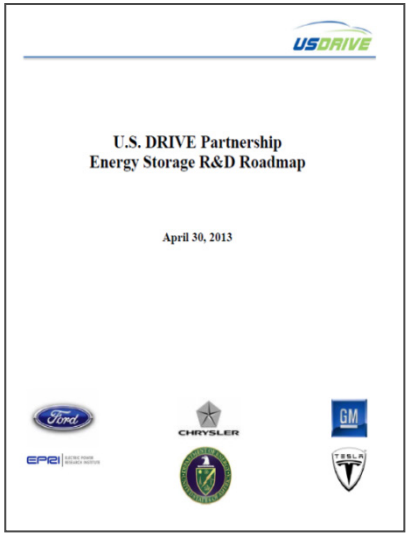
- Focus on the energy, water, environmental, and labor costs which can range from ~20% – 60% of the materials cost.
- Reduce energy intensity for producing materials.
- Focus on $/kWh reduction

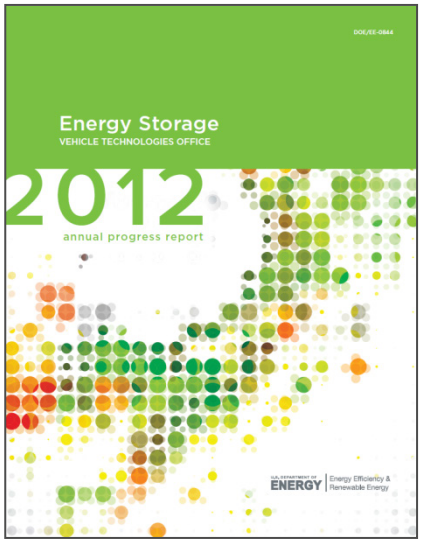
VTO Battery R&D Roadmap

USDRIVE Energy Storage R&D Roadmap

- Tabulates performance and cost targets for HEV batteries and EV batteries.
- Describes ongoing /planned R&D efforts on EDV battery technologies.
- For a copy of the roadmap, visit:

  http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/electrochemical_energy_storage_roadmap.pdf.





Energy Storage R&D Annual Progress Report for FY 2013

- Describes all energy storage R&D projects funded by DOE Vehicle Technologies Office (VTO) at a national laboratory or in partnership with industry.
- For obtaining a copy of the Annual Progress Report, visit:

  http://www1.eere.energy.gov/vehiclesandfuels/resources/vt_es_fy13.html.

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