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

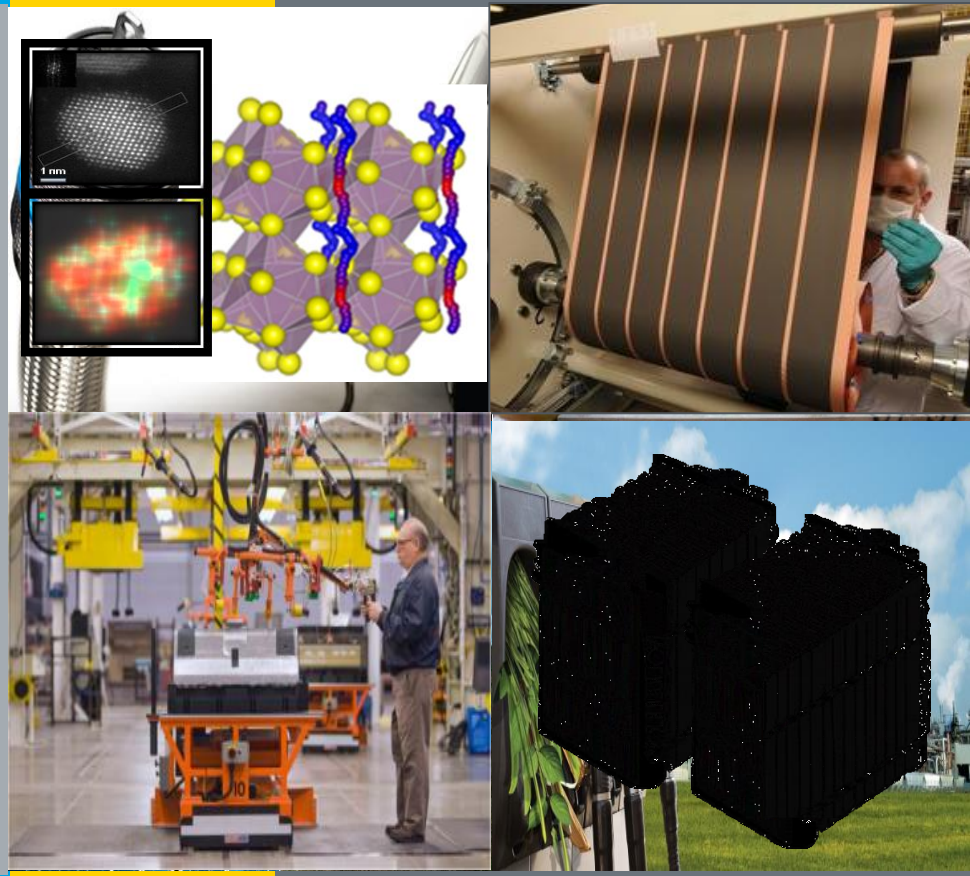
9th US-China

Battery and Electric Vehicle Technology Workshop

U.S. DOE Vehicle Battery R&D Update

August 18. 2014

Seattle, Washington, USA



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U.S.-China Bilateral Agreement

Presidents Barack Obama and Hu Jintao announced the launch of a U.S.-China Electric Vehicles Initiative – November 17, 2009

- Shared interest in accelerating the deployment of electric vehicles to
  - Reduce oil dependence
  - Cut greenhouse gas emissions
  - Promote economic growth
- Activities under the initiative will include:
  - Joint standards development
  - Joint demonstrations
  - Joint technical roadmap
  - Public awareness and engagement

U.S.-China Bilateral EVI R&D Initiative

US-China Electric Vehicle and Battery Technology Workshops

- **Sponsored by:**
  - U.S. Department of Energy
  - China's Ministry of Science and Technology
- **Three focus areas**
  - Battery Technology Progress
  - Battery Test Procedures
  - Vehicle/Infrastructure Demonstrations
- **Previous Workshops**
  - November 2009: Washington DC
  - August 2010: Argonne National Lab.
  - March 2011: Beijing
  - August 2011: Argonne National Lab.
  - April 2012: Hangzhou
  - August 2012: Boston (UMASS)
  - April 2013: Berkeley, California (LBNL)
  - September 2013: Chengdu

Mei Lan, @ the PANDA RESERVE OUTSIDE OF Chengdu, CHINA

Inscription on sign at the park, "Born in the United States (Washington DC National Zoo, Sep 2006), Mei Lan came back to China at the age of three. He is the global ambassador of the WWF Earth Hour.

U.S. Electric Drive Vehicle Sales Growth

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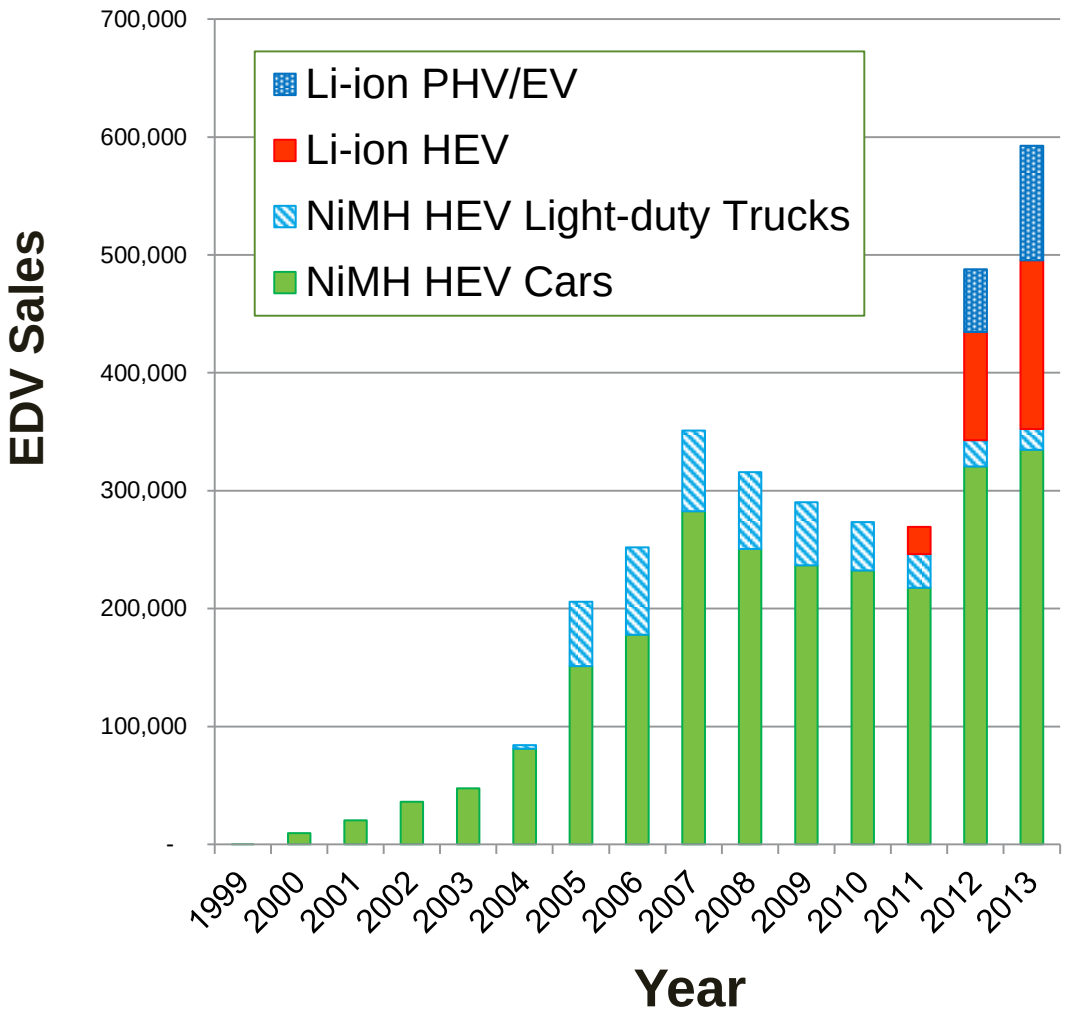
U.S. Electric Drive Vehicle Sales, by Technology (1999-2013)



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

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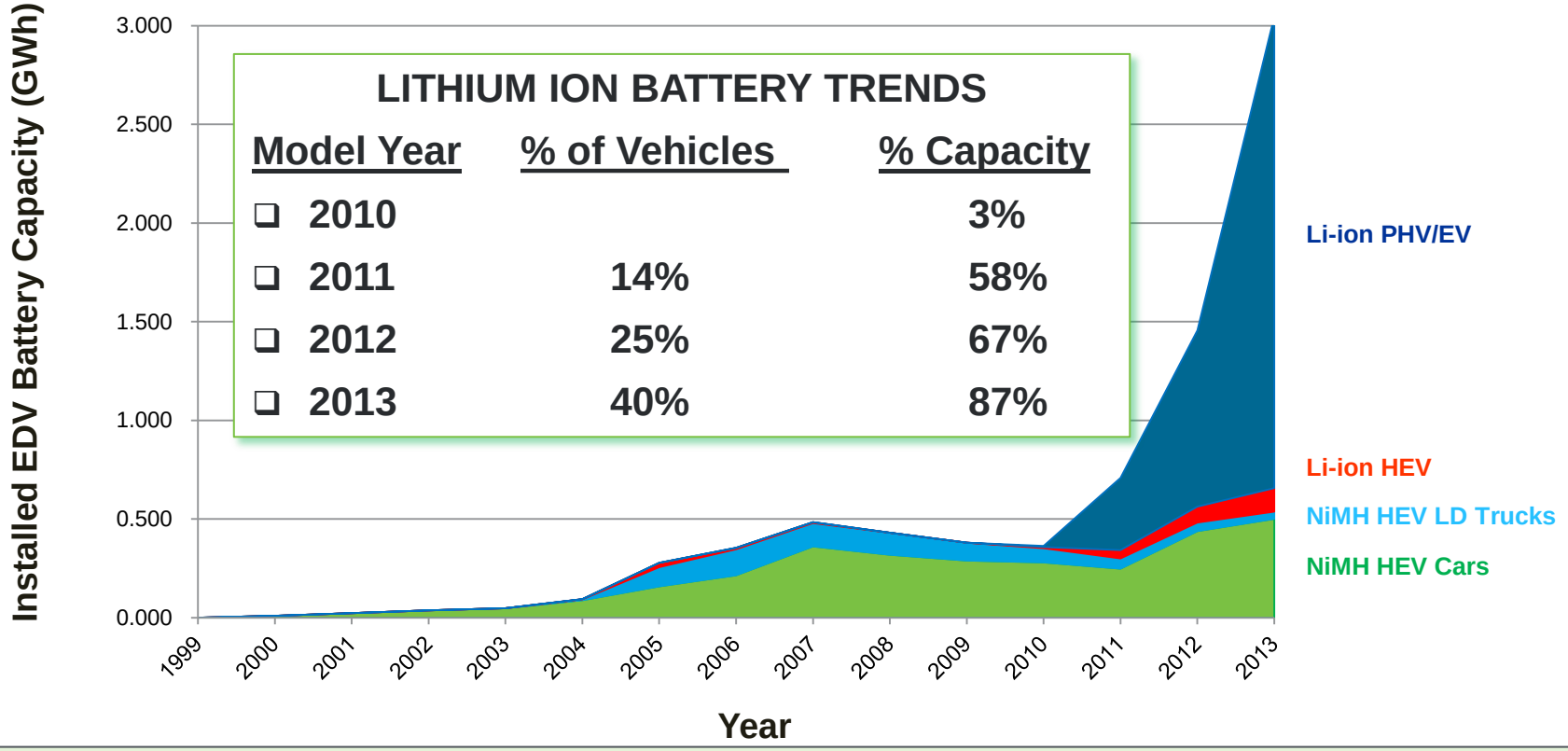
Installed Electric Drive Vehicle Battery Capacity (GWh installed in vehicles)



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

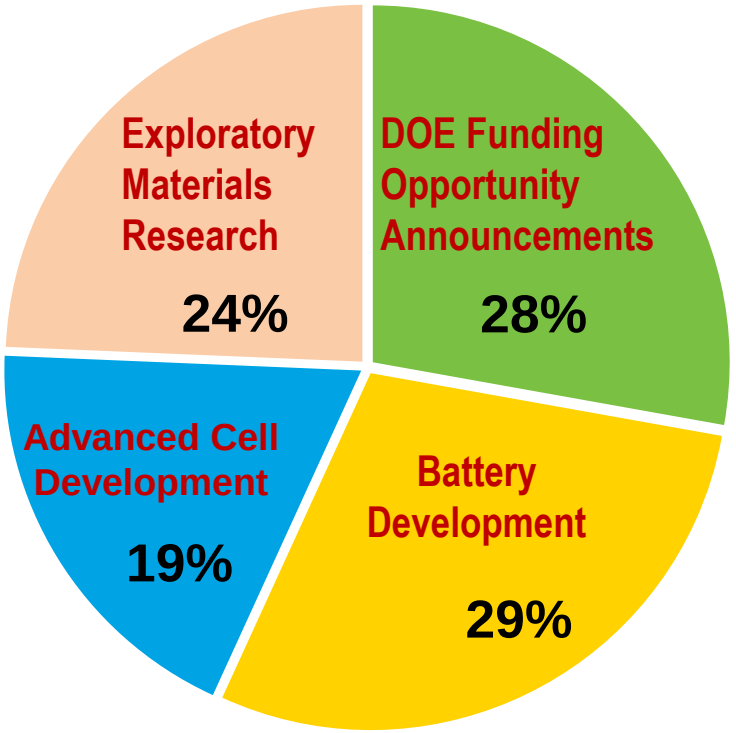
Battery R&D Budget

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

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

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

FY 2014 Major R&D Activities



Progress and Results
Cost Reduction & Energy Density

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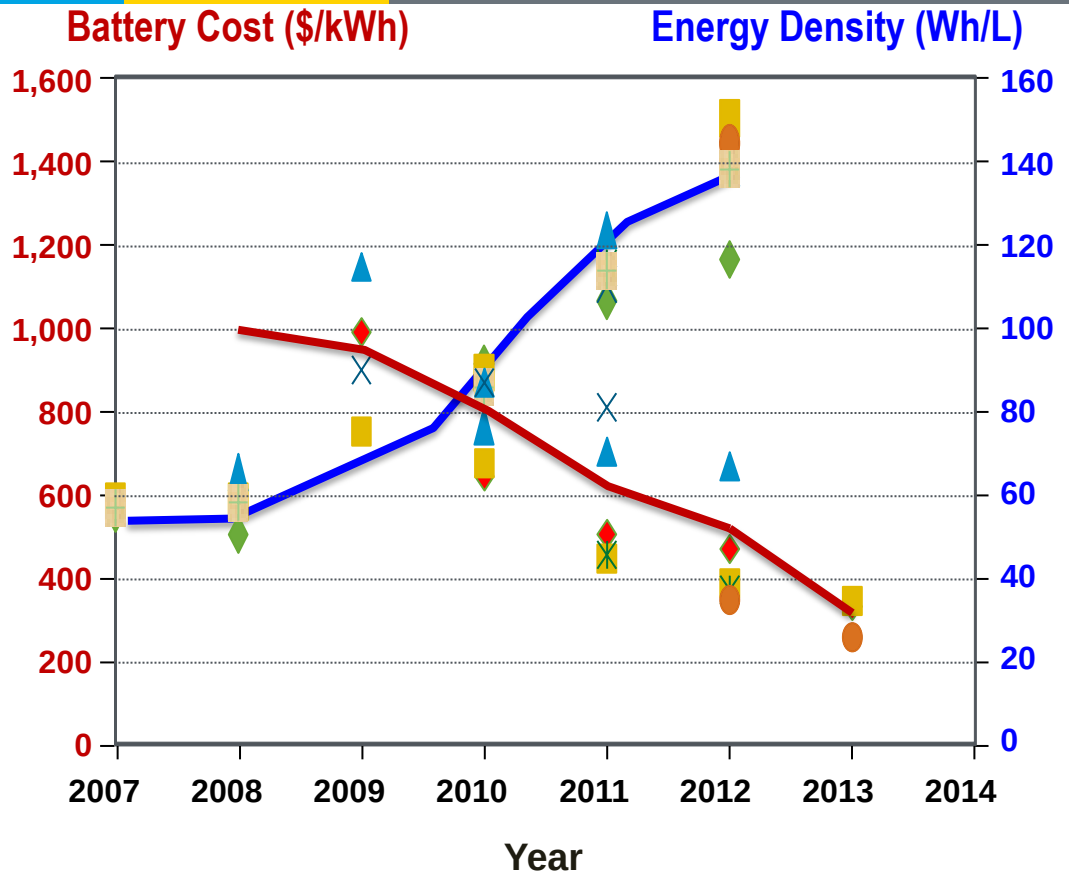
DOE/USABC reduced the cost of PEV batteries by 70% and doubled their energy density during the past 5 years

- 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.

Future Battery R&D
Advanced Battery Chemistries

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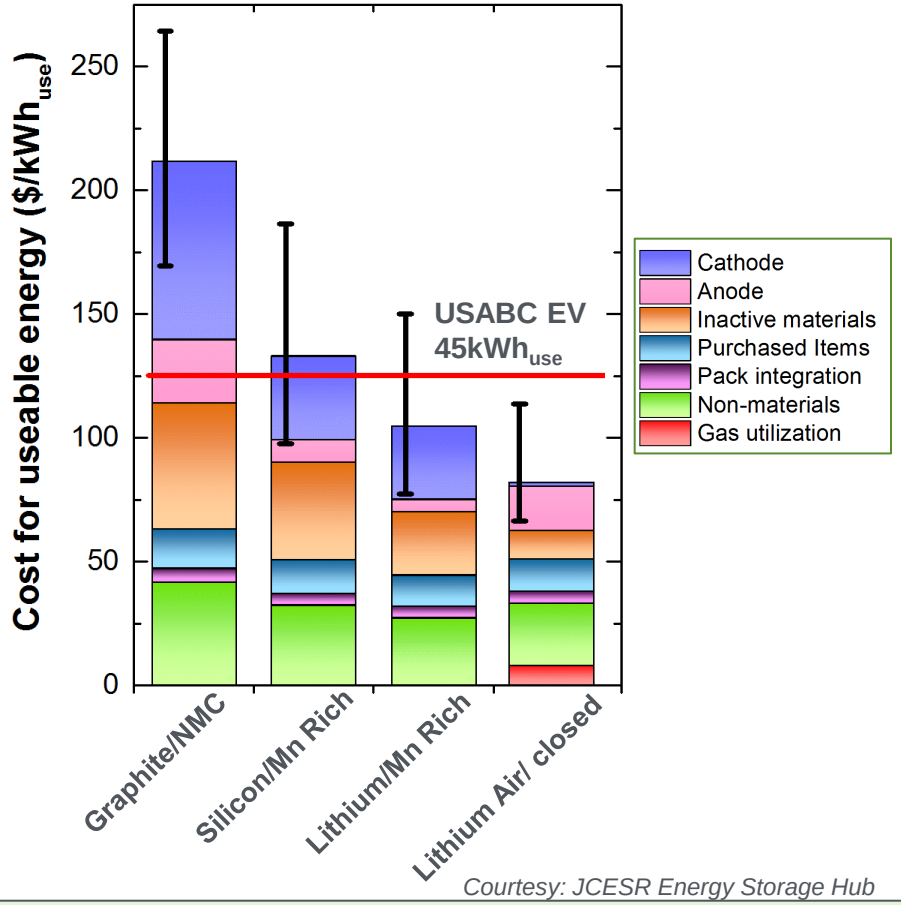
- Extensive cost modeling has been conducted on advanced battery chemistries using the ANL BatPaC model.
- Significant cost reductions are possible using more advanced lithium ion materials (see figure)
  - Lithium-ion: Silicon anode coupled with a high capacity cathode presents moderate risk pathway 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

High Energy Lithium Ion Project Selections

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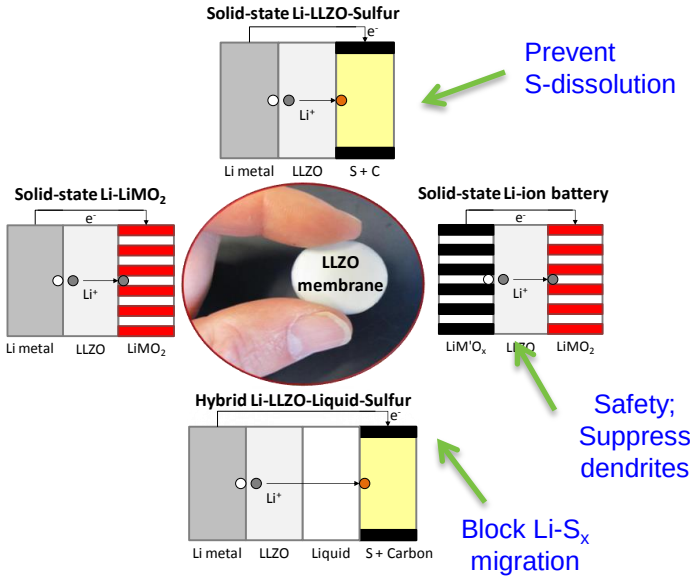
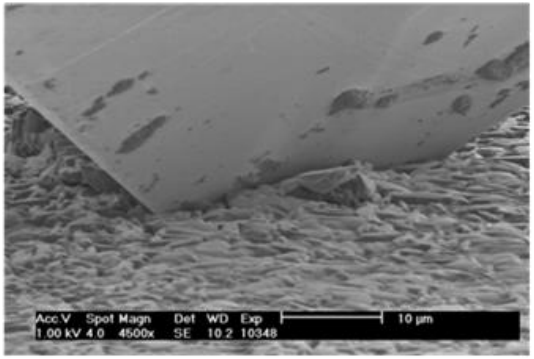
Awardee	Partner(s)	Project Description
Argonne National Laboratory	BNL, LBNL	❑ Cathode: High energy/high voltage NMC with gradient concentration ❑ Anode: Si composite with a novel polymer
3M Company	GM, Umicore Leyden, LBNL, ARL	❑ Cathode: High capacity core shell ❑ Anode: Si alloy composite with novel polymer binder ❑ Advanced electrolyte
Penn State Univ	UT-Austin, LBNL, ANL, ECPower	❑ Cathode: Ni-rich layered oxide with LFP coating ❑ Anode: Micro-sized porous Si alloy-carbon composite
Farasis Energy	ANL, LBNL, NanoSys, Dupont	❑ Cathode: High voltage Mn-rich cathode ❑ Anode: Metal alloy composite ❑ High voltage electrolyte
Envia Systems	LBNL, ORNL, GM	❑ Cathode: High capacity Mn rich cathodes ❑ Anode: High capacity Si/carbon nanocomposite
TIAX LLC	–	❑ Cathode: CAM-7 high-energy cathode ❑ Anode: Si-Composite ❑ Advanced separator

Solid State Electrolytes

- ***LLZO garnet solid state electrolyte***
  - ***Michigan St Univ: Prof. Jeff Sakamoto***
  - Partners: Univ of Michigan, Army Research Lab, ORNL
  - LLZO has good conductivity, stable against Li metal and air. Project will characterize, understand and control defects in the structure
- ***LLZO garnet interface study***
  - ***Univ of Maryland: Prof. Eric Wachsman***
  - Experimental and computational approaches to reduce large interfacial impedance in solid state cells
- ***Nanoindentation of LLZO/Li interface***
  - ***Oak Ridge National Lab: Dr. Nancy Dudney***
  - Partners: Michigan State Univ, Univ of Tennessee
  - Use nanoindentation to study flaws of solid electrolytes, changes in Li when cycled, and to view defective lithium, nucleation and annealing of defects

A unifying technology for Beyond Li-ion batteries

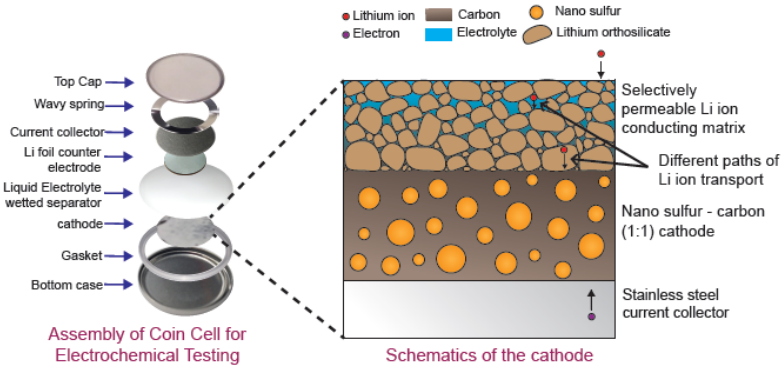


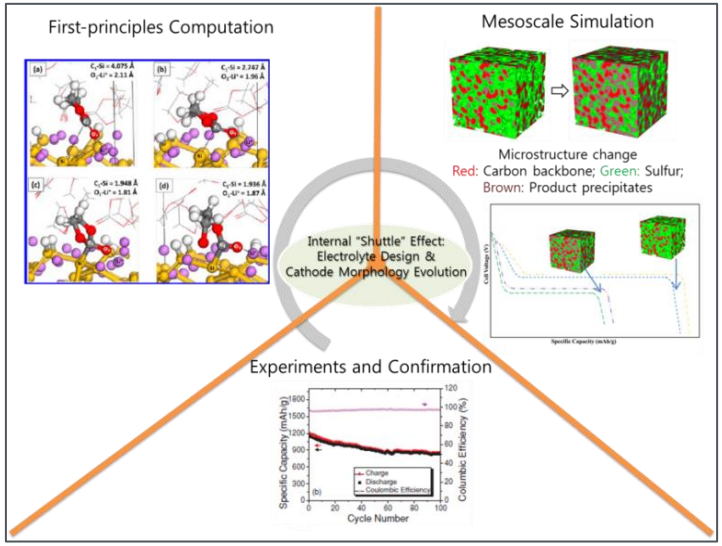


Polymer electrolyte indented in SEM

Lithium Sulfur

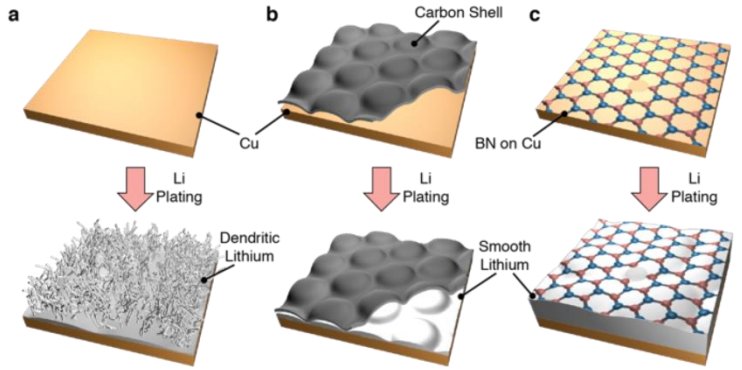
- ***Li/S laminated and doped cells***
  - ***Univ of Pittsburgh: Prof Prashant Kumpta***
  - Use doping to improve inherently low S conductivity and coating (with a Li ion conductor) to minimize S/electrolyte contact
- ***Anodeless Li/S technology***
  - ***Brookhaven National Lab: Dr. Hong Gan***
  - Partners: Stony Brook University
  - Dual Functional Cathode Additives will (1) improve cathode electronic conductivity, (2) provide Li, (3) reduce polysulfide dissolution.
- ***Modeling and synthesis of Sulfur cathodes***
  - ***Texas A&M: Prof. Perla Balbuena***
  - Partners: Purdue University
  - Rational design of electrolyte chemistry and improved S cathode architecture based on enhanced understanding from first-principles atomistic and mesoscopic modeling.





Lithium metal, Lithium Air, and Conversion Reaction

- ***Lithium anode protection***
  - ***Stanford University: Prof. Yi Cui***
  - Partners: Stanford Univ, SLAC National Accelerator Lab
  - Use nano-engineering to control the interface between Li metal and electrolytes to reduce dendrite growth and formation of mossy Li



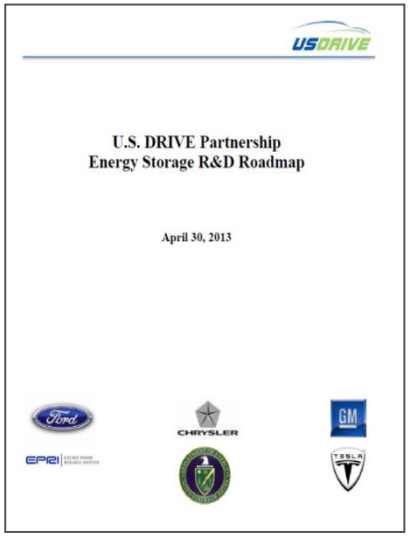
- ***Composite C/Sn/Fe anode and advanced cathodes***
  - ***Binghamton University: Prof. Stan Whittingham***
  - Enable cells exceeding 1 kWh/liter.
  - Use a high energy cathode, such as $VOPO_4/Li_2VOPO_4$ or CuF_2/Cu-LiF.
  - Sn-Fe-C composite anode

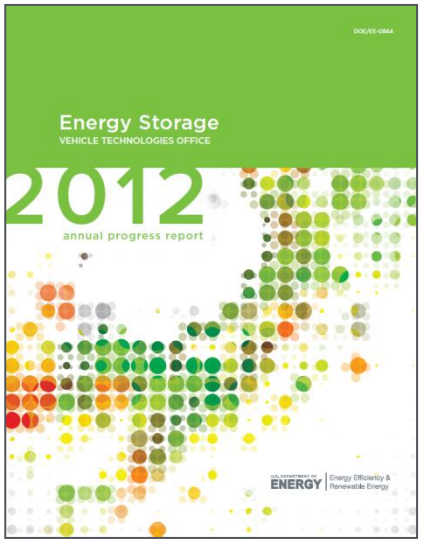
- ***Li/air with a molten salt electrolyte***
  - ***Liox Power: Dr. Vincent Giordani***
  - Partners: Univ California-Berkeley, Cal Tech
  - Use a molten nitrate electrolyte that is inert in the air electrode, has high solubility for Li_2O_2 and can cycle under ambient air vs pure O_2.

USDRIVE Energy Storage R&D Roadmap

- Includes performance and cost targets for EDV batteries.
- Describes ongoing/planned R&D efforts
- 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 battery 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.

For Additional Information…

QUESTIONS?

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