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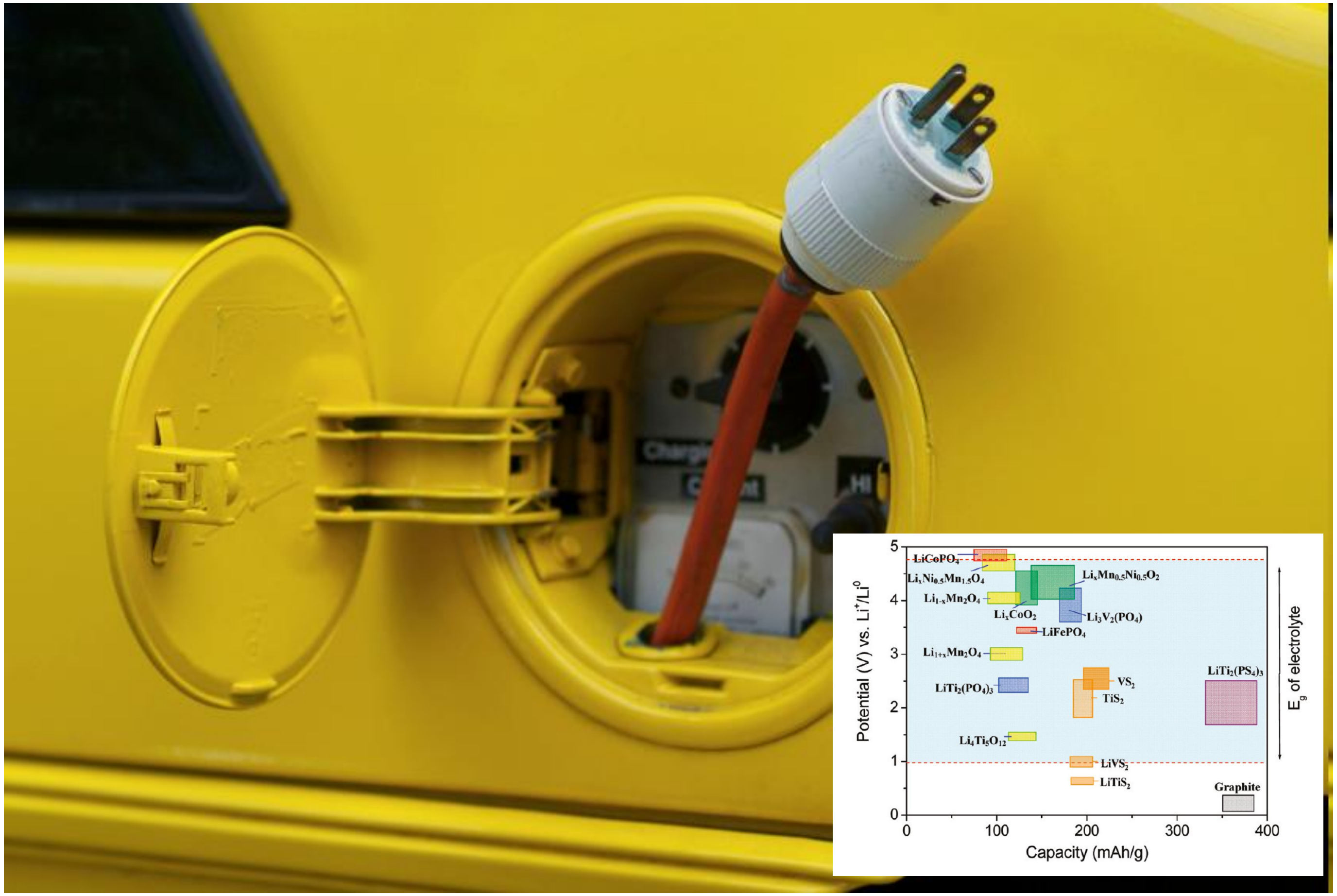

Energy Storage Technologies: Issues, Advances, and DOE Program Support

Motor Vehicle Roundtable–Federal Fleet Electrification
March 17th, 2011

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Drivetrain electrification is inherently efficient and a clear pathway to low-carbon transportation.

Vehicle Types and Benefits

HEV

Toyota Prius
50 MPG

- 1 kWh battery
- Power Rating: 150kW (200 hp)
- Vehicle Cost est $23,000
- 5.7 cents/mile

PHEV

Chevy Volt
MPGe TBD

- 16 kWh battery
- Power Rating: 170kW (230 hp)
- Vehicle Cost est. $41,000
- 3.5 cents/mile

EV

Nissan Leaf
All Electric

- ≥ 24 kWh battery
- Power Rating: ≥ 80 kW (107 hp)
- Vehicle Cost $32,780
- 2.1 cents/mile

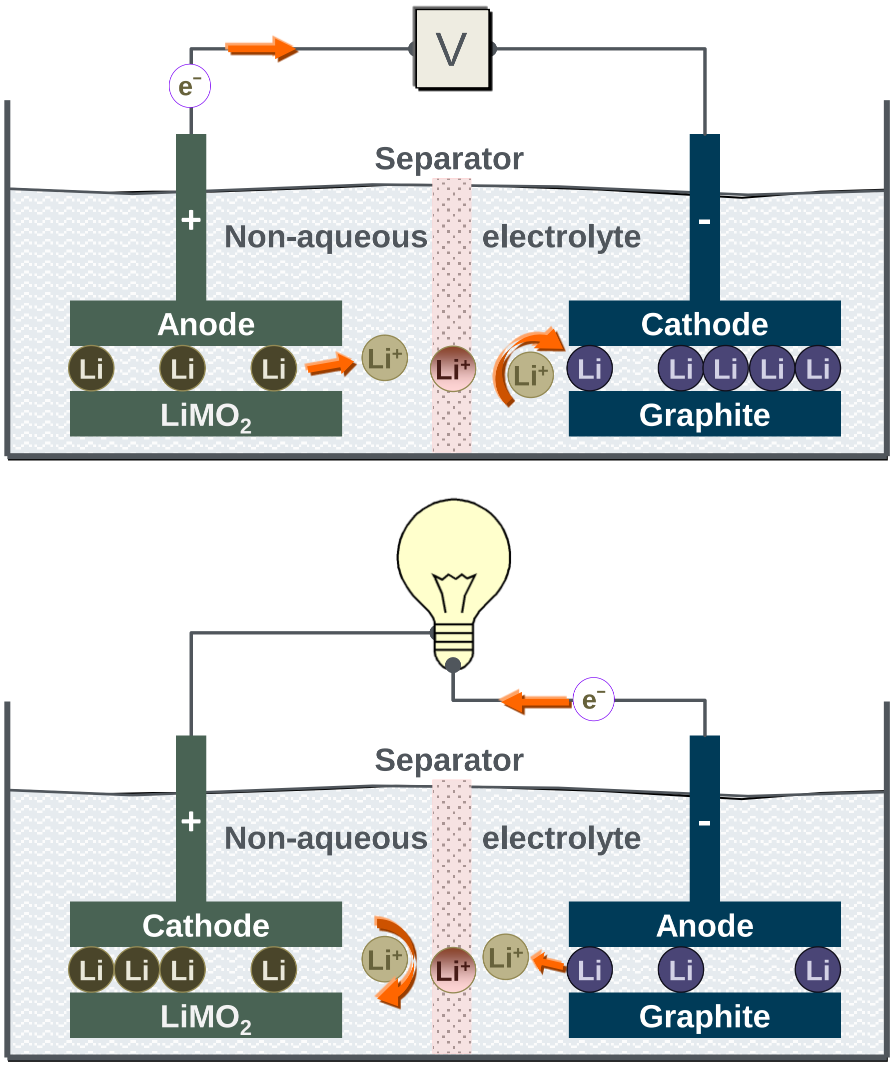
Batteries: Theoretical and Practical Properties

(Theoretical values: masses of active electrode and electrolyte components only)

System	Negative Electrode	Positive Electrode	OCV (V)	Th. Capacity (Ah/g)	Th. Energy (Wh/kg)	Pr. Energy (Wh/kg)
Lead – acid	Pb	PbO_2	2.1	83	171	20-40
Ni-Cd	Cd	NiOOH	1.35	162	219	40-60
Ni-MH	MH alloy	NiOOH	1.35	~178	~240	60-80
Na-S (350°C)	Na	S	2.1-1.78 (2.0)	377	754	120-150
Na-MCl_2 (300°C)	Na	$NiCl_2$	2.58	305	787	80-100
Li-Ion	Li_xC_6	$Li_{1-x}MO_2$ (M=Co, Ni, Mn)	4.2-3.0 (4.0)	158 (for x=1.0)	633	100-150
Li-polymer (80-120°C)	Li	VO_x	3.3-2.0 (2.6)	~ 340	~ 884	~ 150

Lithium-ion systems offer the best near-term opportunities

What lies ‘beyond lithium-ion’?: Li/polymer; Li-O_2, Li-S?



A Li-ion battery is a electrochemical device which converts stored chemical energy directly into electricity.

- During charging an external voltage source pulls electrons from the cathode through an external circuit to the anode and causes Li-ions to move from the cathode to the anode by transport through an liquid electrolyte.
- During discharge the processes are reversed. Li-ions move from the anode to the cathode through the electrolyte while electrons flow through the external circuit from the anode to the cathode and produce power.

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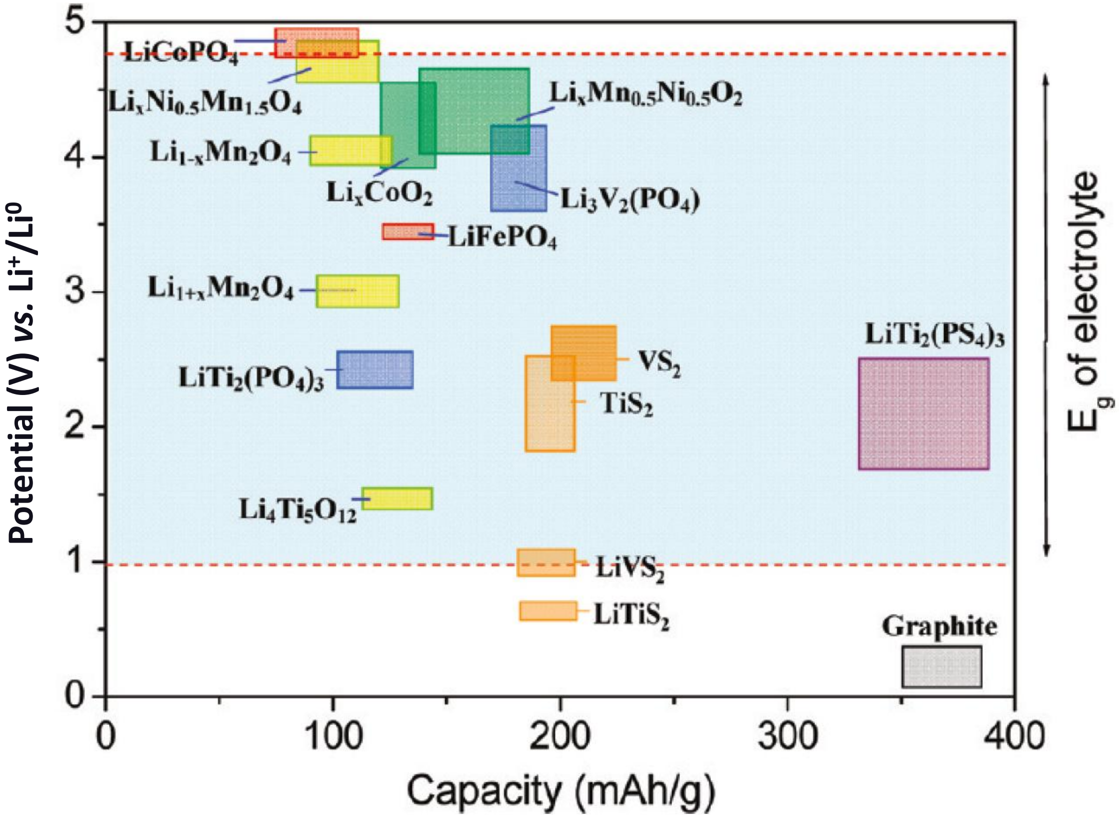
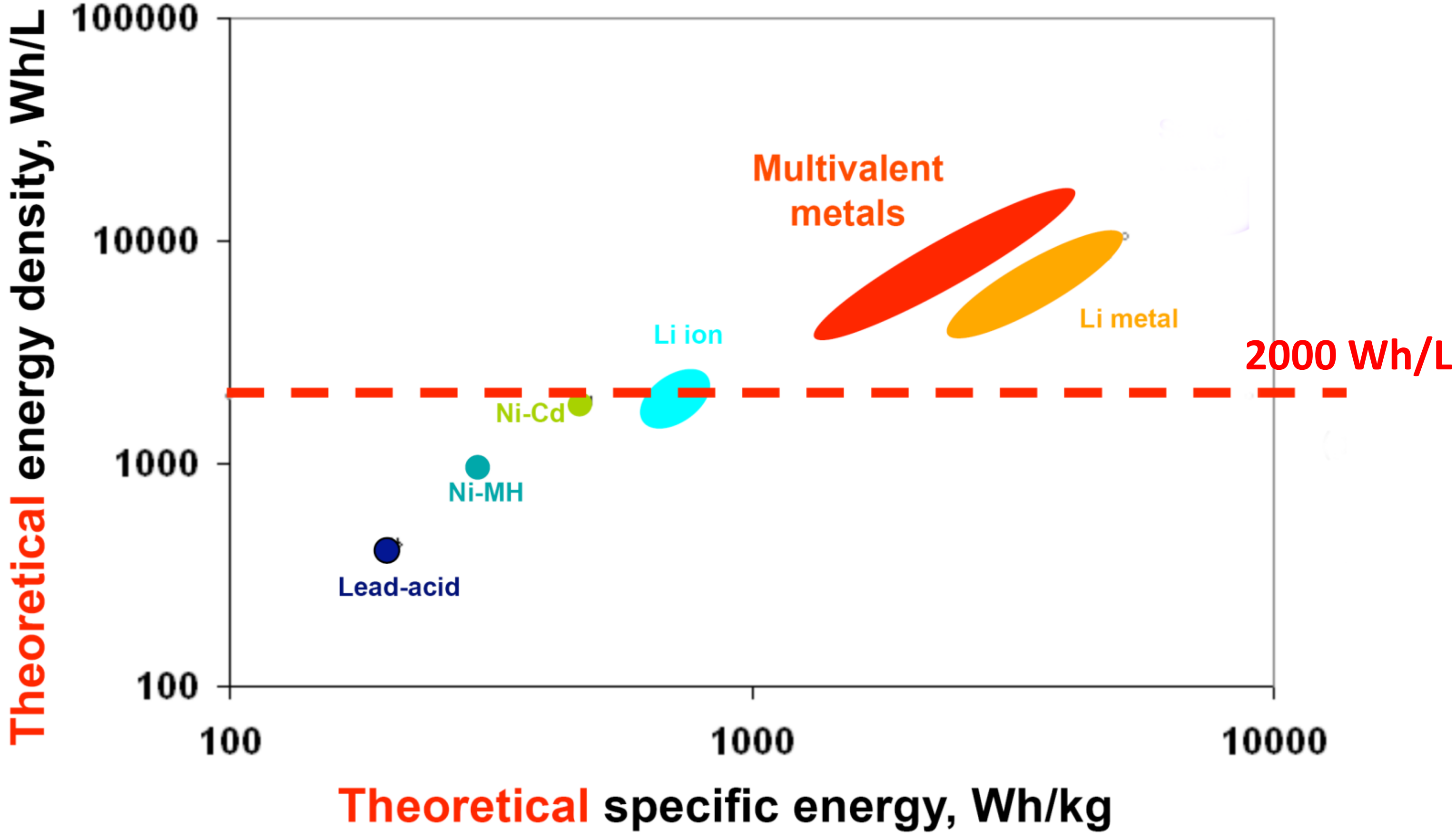
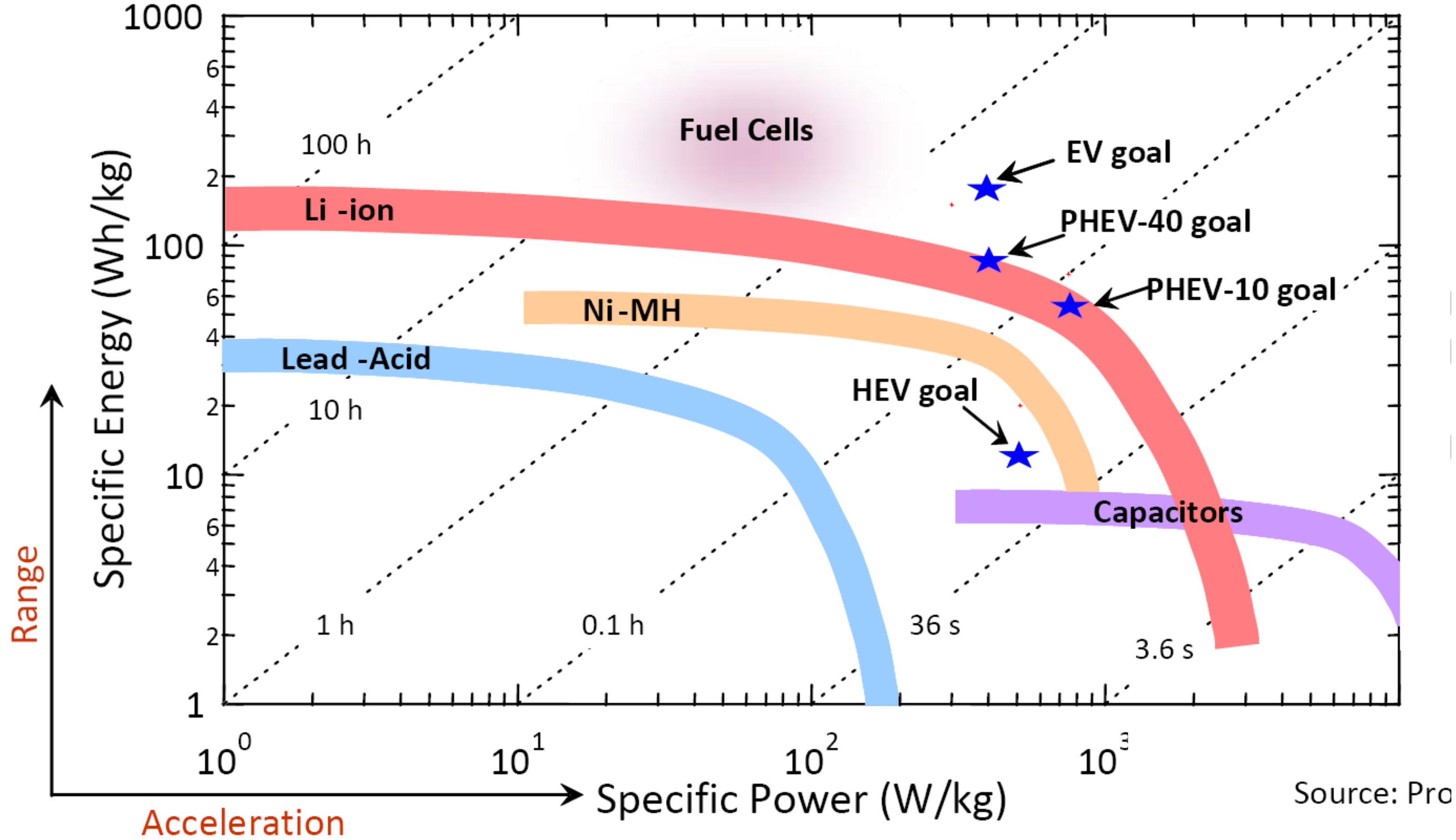
To a large extent, the cathode material limits the performance of current Li-ion batteries



Possible Performance Characteristics



Relative Performance of Various Electrochemical Energy-Storage Devices



Li–ion batteries must meet a range of performance criteria which vary in importance depending on the application.

Key Battery Attributes

- **Energy Density:** Total amount of energy that can be stored per unit mass or volume. How long will your laptop run before it must be recharged?
- **Power Density:** Maximum rate of energy discharge per unit mass or volume. Low power: laptop, i-pod. High power: power tools.
- **Low-Temperature Energy Density:** The amount of energy that can be recovered decreases at low temperatures due to slower charge and mass transfer.
- **Safety:** At high temperatures, certain battery components will breakdown and can undergo exothermic reactions.
- **Life:** Stability of energy density and power density with repeated cycling is needed for the long life required in many applications.
- **Cost:** Must compete with other energy storage technologies.

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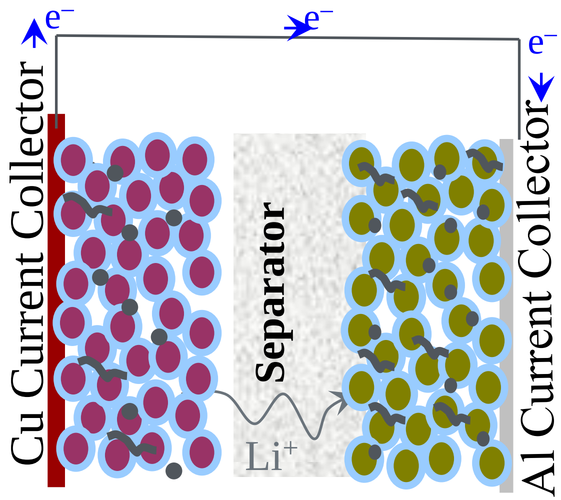
Next generation lithium-ion can increase the power and energy by 2X while decreasing cost by 70%

Anode

Today's Technology
(300 mAh/g)
-Graphite
-Hard carbon

Next Generation
(600 mAh/g)
-Intermetallics and new binders
-Nanophase metal oxides
-Conductive additives
-Tailored SEI



Electrolyte

Today's Tech (4 volt)
Liquid organic solvents & gels

Next Generation (5 volt)
-High voltage electrolytes
-Electrolytes for Li metal
-Non-flammable electrolytes

Cathode

Today's Technology
(120-160 mAh/g)
-Layered oxides
-Spinels
-Olivines

Next Generation
(300 mAh/g)
-Layered-layered oxides
-Metal phosphates
-Tailored Surfaces

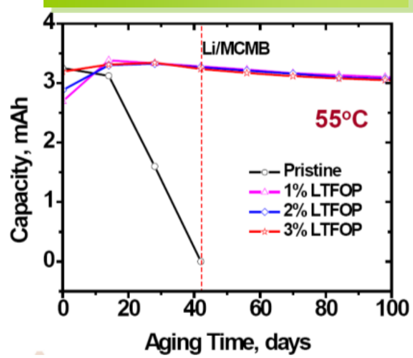
CHARTER: Develop battery technology that will enable large market penetration of electric drive vehicles.

- By *2014*, develop a *$3,400* PHEV battery pack that can deliver a 40-mile all-electric range
- By *2020* develop a *$4,000* 40 kWh EV battery

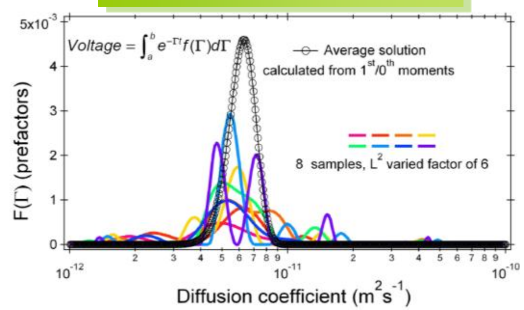
ENERGY STORAGE R&D

Battery Development $38M

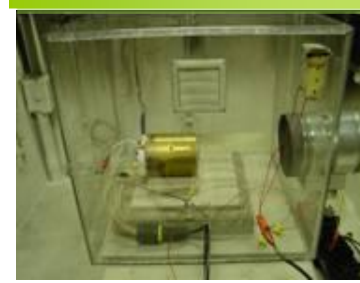
Applied Battery Research for Transportation $12M



Exploratory Technology Research $22M



Battery Testing, Analysis & Design $15M



Battery Development & Cost Reduction

New Materials R&D, Diagnostics, Modeling

Next Generation Cell R&D

Standardized Testing Life/Cost Projections Design Tools

Track Record

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- **1990s Nickel Metal Hydride**
  - Cobasys NiMH technology: Every HEV sold uses intellectual property developed in the DOE battery program. The US Treasury received royalty fees.
- **1998 High Power Lithium-Ion (HEVs)**
  - JCS nickelate technology: BMW, Mercedes and Azure Dynamics /Ford Transit Connect
- **2004 High Energy Lithium-Ion (EVs)**
  - **A123Systems nano iron phosphate technology:** Fisker, BAE, and Hymotion's Prius
  - **CPI/LG Chem manganese technology:** GM Volt extended range PHEV. Ford Focus EV, use

Commercial Application

COBASYS → **Prius, Escape, Fusion**

Johnson Controls / SAFT → **Mercedes S400 HEV**

A123 SYSTEMS → **Fisker PHEV**

cpi compact power, inc. / LG Chem → **Chevy Volt PHEV**

Time to Market

From Lab to Commercialization

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Johnson Controls $LiNiCoAlO_2$ (~$60M/10+ year investment in Lab, University, Industry R&D)

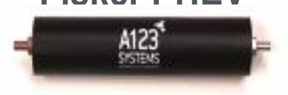
- Early R&D ($0.5M)
- Material Development (~$5 M)
- Electrochemistry Optimization (~$30M)
- Development (~$25M DOE, $25M Industry)

Mercedes S400 HEV

A123 Systems $LiFePO_4$ (~$20M/10+ year investment in Lab, University, Industry R&D)

- Material Development (~$4 M)
- SBIR R&D ($0.9M)
- Electrochemistry Optimization (~$1M)
- Development (~$14M DOE, $14M Industry)

Fisker PHEV



ANL Cathode Material (~$29M/10+ year investment in Lab, University, Industry R&D)

- Early R&D ($0.1M)
- Material Development (~$4 M)
- EERE Electrochemistry Optimization(~$15M)
- Development (~$10M DOE, $17M Industry) LG Chem, Envia

Chevy Volt PHEV

Legend: Basic Science | Exploratory R&D | Applied R&D | Development

Timeline: 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010

On Track to Meet Administration's Goal of 1 Million EVs by 2015

Year	Battery Cost ($ per kWh)	US Battery Production Capacity – ARRA	US Battery Production Capacity – ATVM	Vehicle Production (cumulative, announced)
2008–2009	$1,000-$1,200	0	0	0
2010–2011	$700-$950	50,000		45,600
2012	Goal = $500	150,000	144,000	223,200
2013				486,200
2014	Goal = $300			854,200
2015		500,000	488,000	1,222,200

9.88 MWh per year production capacity in 2015

>7.7 MWh per year capacity demand in 2015

Research Roadmap for 2015 and Beyond

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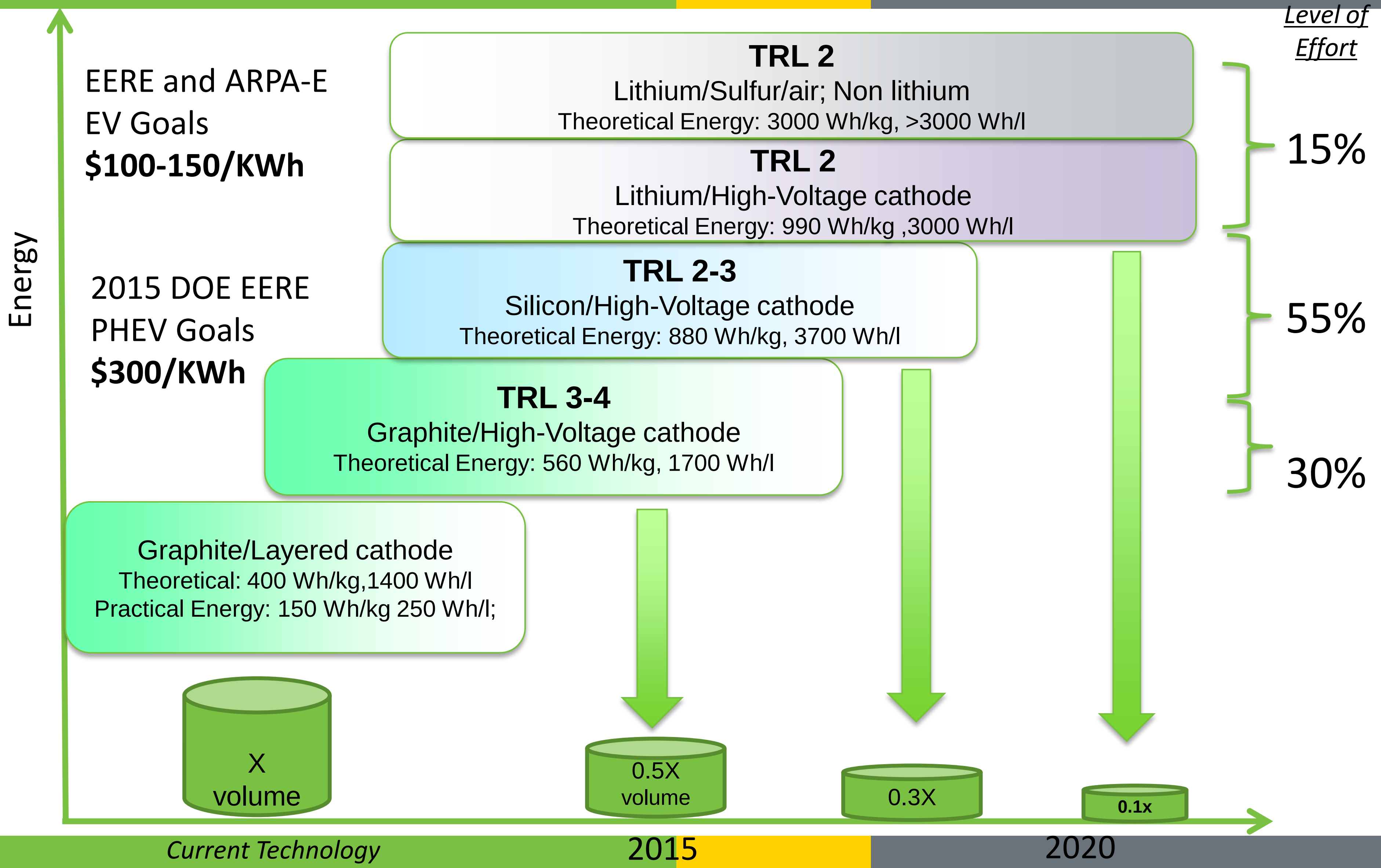
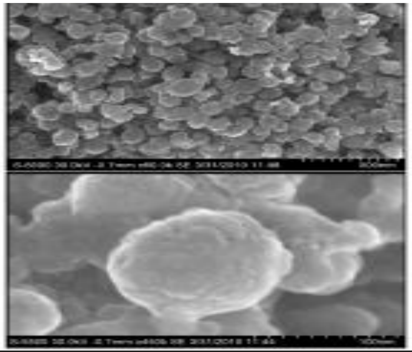


- Track record of success
  - DOE R&D has brought NiMH and Li-ion batteries into the automotive market

- Clear pathway to meet 2015 goals
  - On track to meet cost and performance targets

- Technologies in the pipeline to go beyond 2015
  - Research program focused on Li metal systems
  - Closely coordinated with ARPA-E and the Office of Science



THANK YOU!

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www.vehicles.energy.gov

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