



U.S. DEPARTMENT OF ENERGY

**Energy Efficiency &
Renewable Energy**

Progress of DOE Materials, Manufacturing Process R&D, and ARRA Battery Manufacturing Grants

May 10, 2011

by

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NETL Battery Projects Manager



National Energy Technology Laboratory

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Energy Storage R&D

Objective

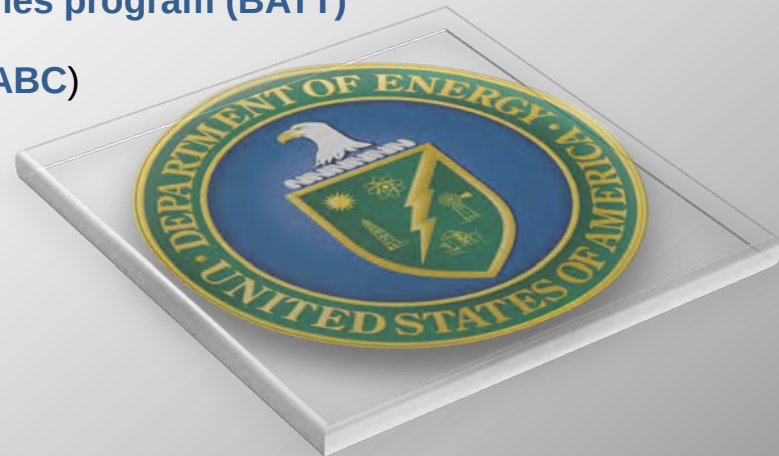
The mission of the Vehicle Technology (VT) program is to develop more energy-efficient and environmentally friendly technologies for highway transportation vehicles (cars and trucks) that will meet or exceed performance expectations and environmental requirements, and enable America to use significantly less petroleum and reduce greenhouse gas (GHG) emissions. The Energy Storage team supports this goal through several initiatives.

Batteries for Advanced Transportation Technologies program (BATT)

United States Advanced Battery Consortium (USABC)

Materials and Manufacturing Process Grants

ARRA funding of battery manufacturing facilities



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Materials and Manufacturing Process Grants

Recipient	Topic	DOE share	Total award amount
Sion Power	sulfur cathode/gel protected anode	\$832,215	\$2,828,854
EnerDel	Electrochemical shuttle	\$3,465,912	\$6,624,408
Angstrom	Silicon/carbon anode	\$1,594,303	\$3,198,240
A123	High throughput manufacturing (fast coating and electrode cutting)	\$1,089,375	\$2,178,750
NC State	Nanofiber/silicon anode	\$1,349,752	\$2,700,451
FMC	Stabilize lithium metal powder	\$2,999,424	\$5,998,849
BASF	Low cost cathode powder	\$2,502,418	\$5,004,836
3M	Silicon alloy anode	\$1,348,093	\$2,696,186
TIAX	Internal shorts	\$2,362,589	\$4,218,993
Totals		\$17,544,081	\$32,620,713



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Sion Power

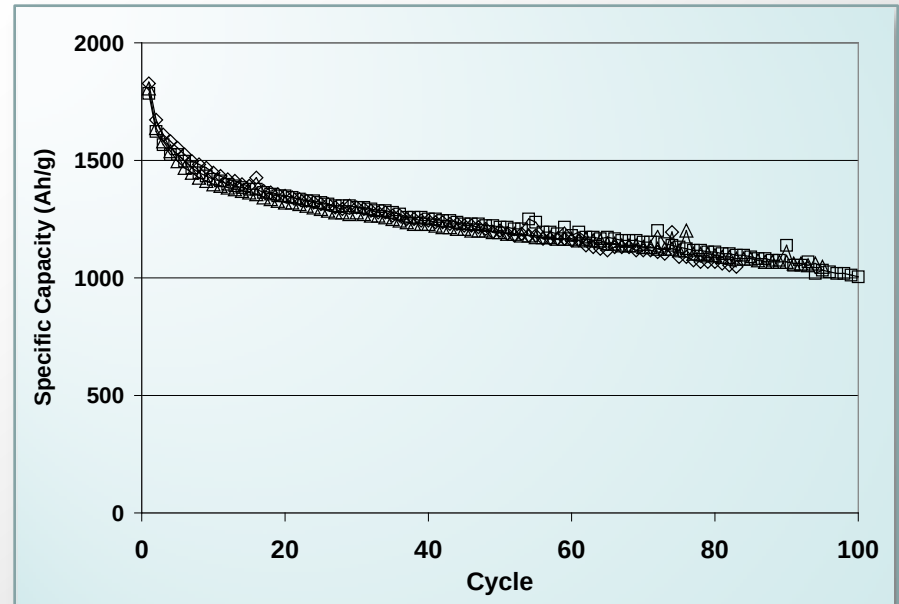
PROTECTION OF LI ANODES USING DUAL PHASE ELECTROLYTES

Li-S battery

Gel/liquid immiscible electrolyte
system, gel-polymer coated anodes.

Electrodes stack design and
manufacturing of 2.5 Ah cells with
optimized electrodes in progress.

10/1/2009 through 6/30/2011



250 mAh cells with butyl ether containing electrolyte formulation demonstrated high Li anode specific capacity above 1000 mAh/g over 100 cycles thus exceeding Phase 1 objective



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EnerDel

Electrochemical shuttle work

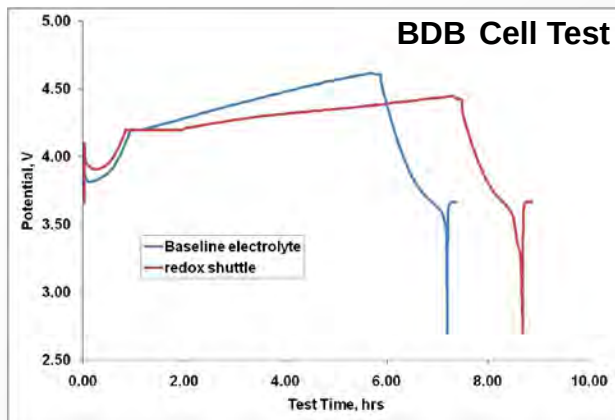
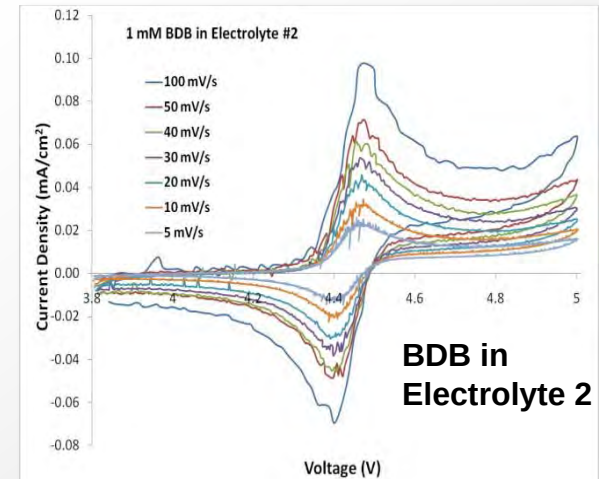
Develop a chemical shuttle agent with a redox voltage in the range of 4.4 to 4.6V to use in electric vehicles

Characterizing the redox shuttle additive in various cell types.

2-pentafluorophenyl-tetrafluoro-1,3,2-benzodioxaborole (BDB) , 2,5-di-tert-butyl-1,4-dimethoxybenzene (DDB)

Argonne National Lab to provide shuttle chemicals.

10/1/2009 through 6/30/2011



Redox Shuttle	Electrolyte Composition	Average Redox Oxidation Potential, V	Diffusion Coefficient, cm ² /sec
Li ₂ B ₁₂ F ₁₂	1M LiPF ₆ in 3:7 EC:EMC	4.6	2.1 x 10 ⁻⁵
DDB	0.5 M LiBOB in 1:2:1:2 PC:DMC:EC:DMC	3.95	1.6 x 10 ⁻⁵
Li ₂ B ₁₂ F ₁₂	#2	4.72	9.76 x 10 ⁻⁷
Li ₂ B ₁₂ F ₁₂	#1	4.70	1.55 x 10 ⁻⁵
DDB	#2	3.96	1.35 x 10 ⁻⁵
DDB	#1	3.95	1.69 x 10 ⁻⁵
BDB	#2	4.47	1.12 x 10 ⁻⁵
BDB	#1	4.45	1.08 x 10 ⁻⁵



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Angstrom

Nanofiber/Graphene/Silicon Anode

Polyacrylonitrile (PAN) electrospun precursor mat then carbonized and coated with Si by CVD

Aruna Zhamu and Bor Z. Jang, "Anode Compositions for Lithium Secondary Batteries," US Pat. Appl. No. 12/655,746 (01/07/2010).

Fluidized bed particle (carbon nanofiber) coating system also being developed

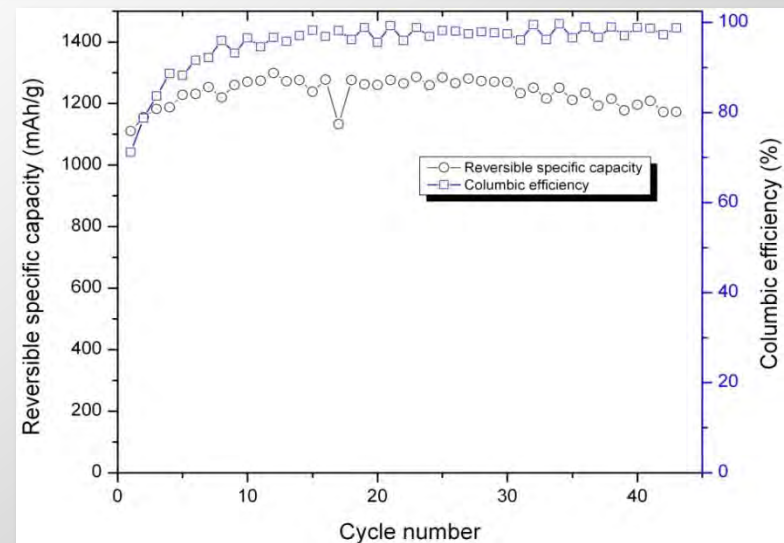
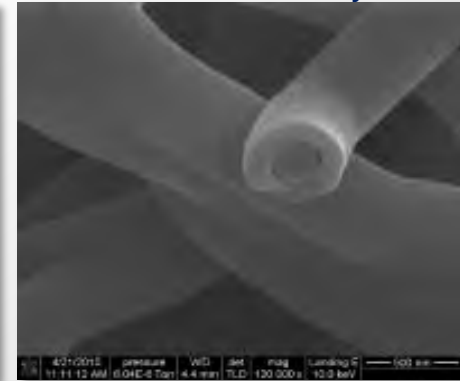
Submitted to Nano Letters: Novel Nano Graphene-Embraced High-Capacity and High-Rate Capable Li-ion Battery Anodes
Jinjun Shi, Aruna Zhamu, and Bor Z. Jang

9/15/2009 through 9/15/2012

PAN nanofiber mat



Carbonized mat coated by CVD



Half-cell performance of the Si-coated electrode



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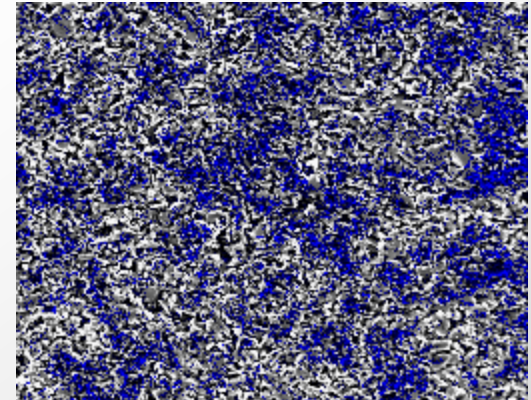
A123

HIGH THROUGHPUT FABRICATION OF 10 YEAR PHEV BATTERY ELECTRODES

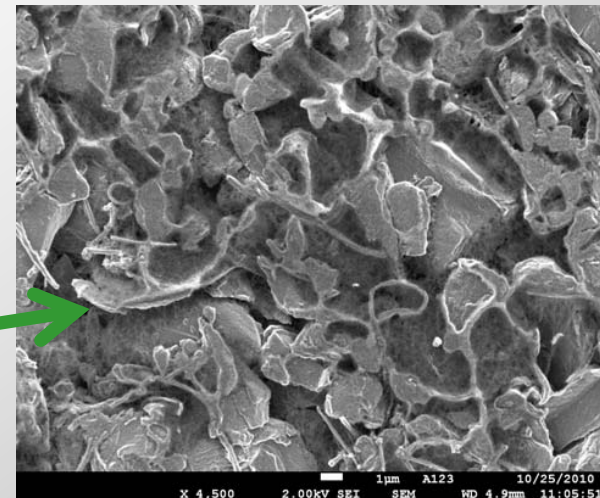
Slurry preparation, coating/drying,
manufacturing process development,
and Scale-Up Mixing/Coating/Drying

Under cost on Slurry/Coating /Drying
scale up- proposed doing high speed
stamping as added scope.

10/1/2009 through 9/30/2011



First high speed coating tests on anodes.



Adhesion at higher speed



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NC State

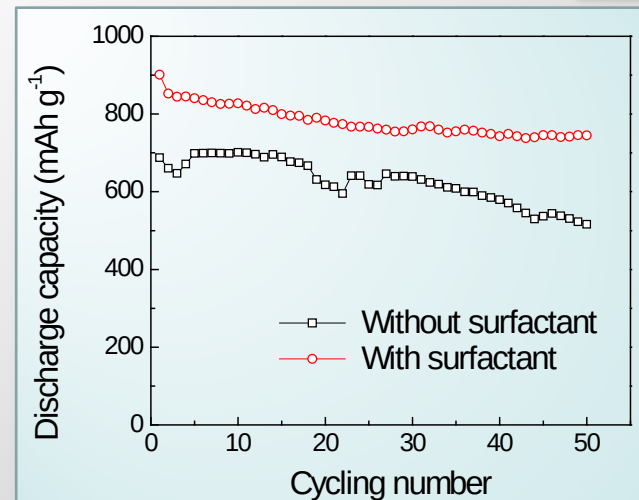
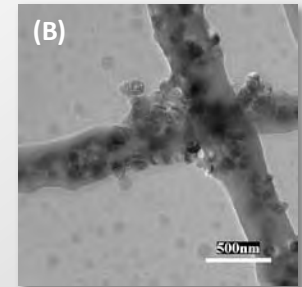
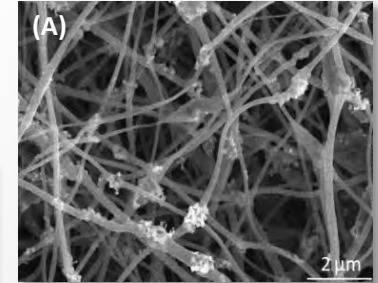
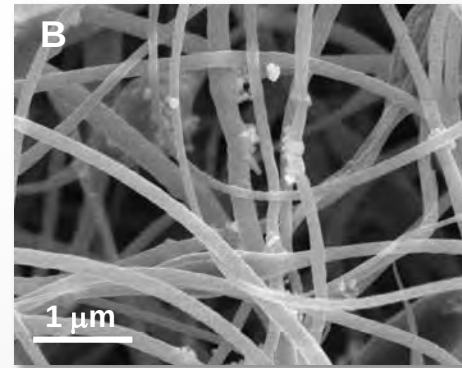
Nanofiber/Silicon Anode.

Si nano-particles embedded in PAN electro-spun mats, that are subsequently carbonized

Surfactant aides in wetting of the PAN precursor to the Si particles, and improves cycling after spinning and carbonization.

Currently working to get 15% silicon in spun fibers.

9/16/2009 through 8/16/2012



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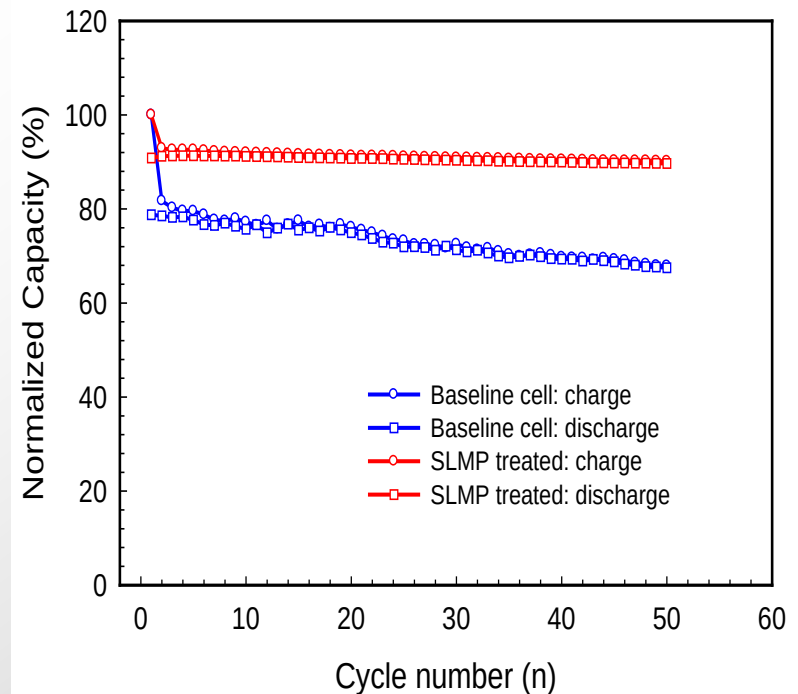
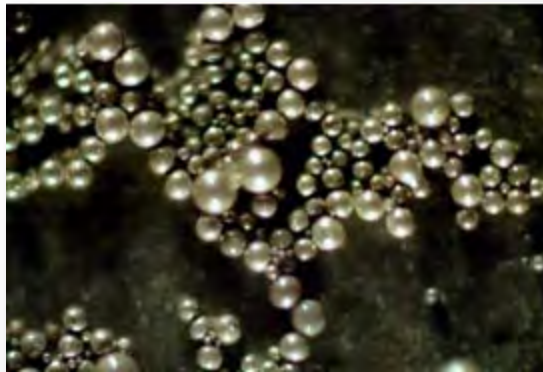
FMC

Stabilized Lithium Metal Powder

Thin Li Carbonate surface layer

Project to scale up oil dispersion method
method and dry methods to semi-
commercial scales.

3/27/2009 through 6/30/2011



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PROCESS FOR LOW COST DOMESTIC PRODUCTION OF LIB CATHODE MATERIALS

Lower cost precursor chemistry

NCM 111, NCM 523 and NCM 424 made
in pilot plant at 100Kg size

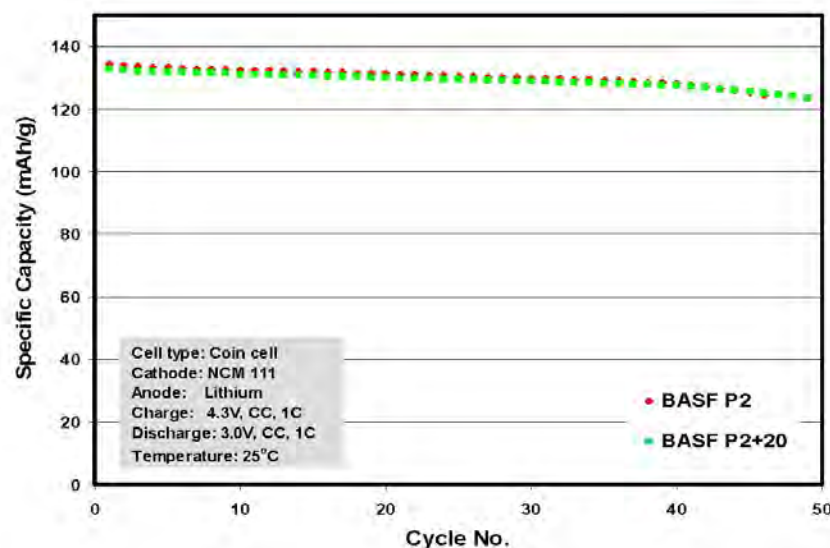
Low cost precursors and spray dried to
spherical particles followed by
calcination.

LFP production on hold because of
licensing issues.

8/31/2009 through 2/25/2012

	NCM 111	NCM 424	NCM 523	NCM 622	NCM 226
% Ni	23.7	28.6	35.6	42.5	14.4
% Co	23.7	14.3	14.3	14.2	14.5
% Mn	22.1	26.7	20.0	13.2	40.5
Raw Material Cost	-	-11%	-15%	-7%	-24%

Cost based on 07/10 Metals Market Price





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3M

Advanced Negative Electrode Materials for PHEV Lithium Ion Batteries

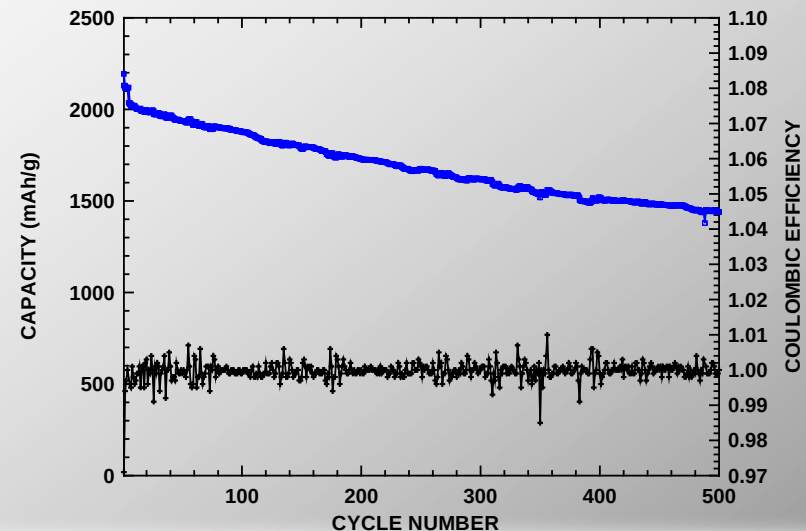
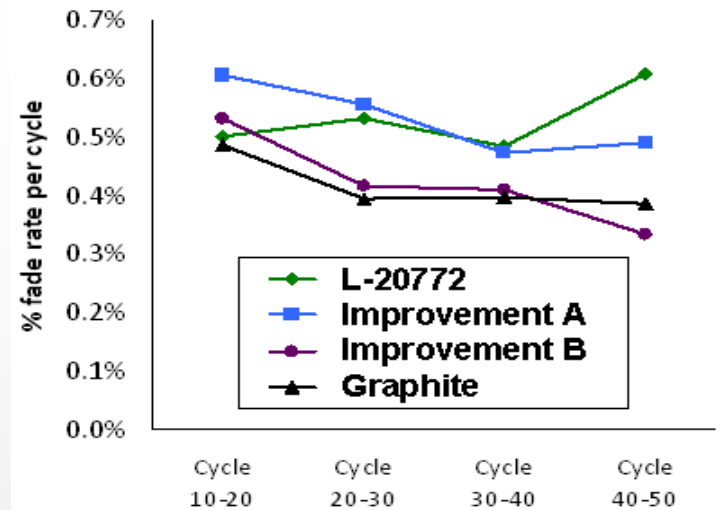
Silicon alloy anode material

Melt spun and low cost proprietary method

Initially they applied for a patent waiver on
the low cost method and then pulled back,
preferring to keep it as a trade secret.

6/23/2009 through 6/22/2012

18650 cycling test of a high loading coating
comprising a 50/50 blend of L-19725 alloy and
graphite active materials. This cell was cycled
between 2.6 V and 4.25 V (100% DOD) at a
cycling rate of C/2.



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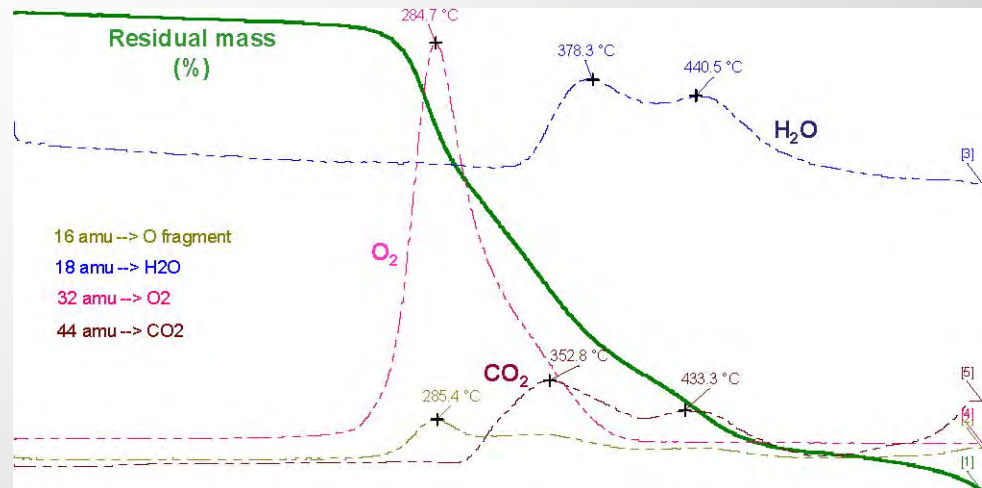
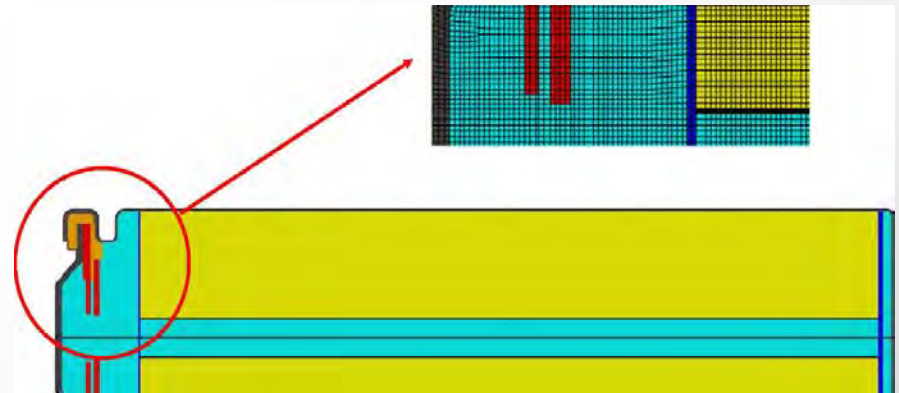
TIAX

Internal Short Circuits in Lithium Ion Cells for PHEVs

Modeling and prototyping study

Initial modeling accomplished,
low power cell heating test done
for validation, cell shorting test
analyzed and simulated for
further validation, design and
initial equipment specification
started for prototyping center.

5/14/2010 through 5/13/2013



TGA-MS of LiCoO₂ charged to 4.3V vs. Li. A 10°C/min scan shows O₂, CO₂, and H₂O evolution.



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ARRA Battery Manufacturing

Objective

Establish the supply chain capacity and market entry required for the introduction of the next generation of plug in hybrid vehicles – at volumes required to meet the Administration's goal of 1M PHEV's by 2015.

Funding

Electric Drive Vehicle Battery & Component Manufacturing

Electric Drive	\$ 0.5 Billion
Batteries	\$ 1.5 Billion

Total \$ 2.0 Billion



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ARRA Battery Manufacturing



President Obama Announces the Battery & Electric Drive Component Grant Program, March 19, 2009

\$1.5B Battery Manufacturing Initiative

Designed to accelerate transition to the next generation of hybrid vehicle transportation

Award Categories

- Cell and Battery Manufacturing Facilities
- Advanced Battery Supplier Manufacturing Facilities
- Combined applications for first two award categories
- Advanced Lithium ion Battery Recycling Facilities



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ARRA Battery Manufacturing

Recipient	DOE Award	Total Project	Technology
LG Chem, MI	\$151.4	\$388.2	Lithium Ion Polymer Cells
Exide Technologies	\$34.3	\$70.0	Absorbed Glass Mat (AGM) Lead Acid Batteries
General Motors LLC	\$105.7	\$235.5	Automotive Battery Pack
East Penn Manufacturing Co.	\$32.5	\$131.0	Valve Regulated Lead-Acid Batteries and the UltraBattery
Saft America Inc.	\$95.5	\$191.0	Lithium Ion Cells, Modules and Batteries
EnerDel Inc.	\$118.5	\$236.0	Two Lithium Ion Cells and Batteries
DOW Kokam, MI LLC	\$161.0	\$604.0	Lithium Ion Polymer Batteries (SLPB)
Honeywell International Inc	\$27.3	\$54.6	Electrolyte Salt (LiPF ₆)
Celgard, LLC	\$48.8	\$101.6	Polymer Separator Material
BASF Catalysts, LLC	\$24.6	\$49.2	LNMC O Layered Cathode
Novolyte Technologies Inc.	\$20.6	\$41.2	Lithium Ion Electrolyte Solutions
Toda America Incorporated	\$35.0	\$70.0	Lithium Ion Cathode Materials
Pyrotek Incorporated	\$11.3	\$22.6	Graphitization of Carbon Anode
Chemetall Foote Corp.	\$28.4	\$57.0	Lithium Carbonate and Hydroxide
FutureFuel Chemical Company	\$12.6	\$25.2	Carbon Anode Precursor
H&T Waterbury	\$5.0	\$10.0	Aluminum Cans Cells
EnerG2, Inc.	\$21.3	\$28.0	Nano-Carbon for Ultracapacitors
A123 Systems, Inc.	\$249.1	\$875.0	Nanophosphate Cathode, Cell Fabrication, Complete Battery Systems
Johnson Controls, Inc	\$299.2	\$599.4	Cell Production, Pack Assembly, Separator Production
TOXCO Inc.	\$9.5	\$19.1	Recycling of Lithium Ion Batteries



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Funding Breakout by Category

Total: \$1.5 Billion



- **Lithium Ion Material Supply & Cell/Pack Manufacturing (94%)**
- **Advanced Lead Acid Manufacturing (4%)**
- **Ultracapacitor (Carbon) Manufacturing (1.4%)**
- **Lithium Ion Recycling (0.6%)**



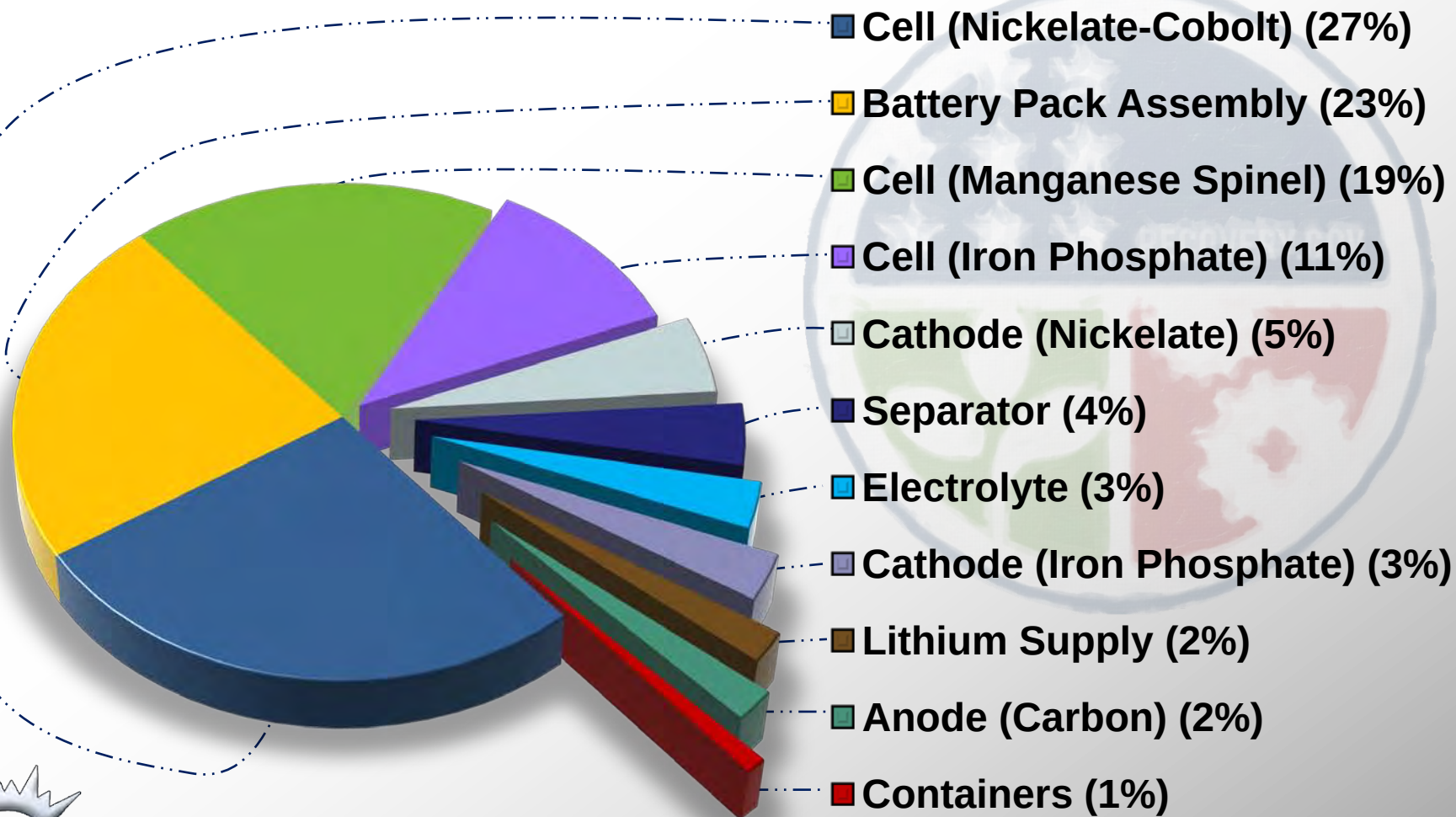
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Lithium Technology Funding Breakout



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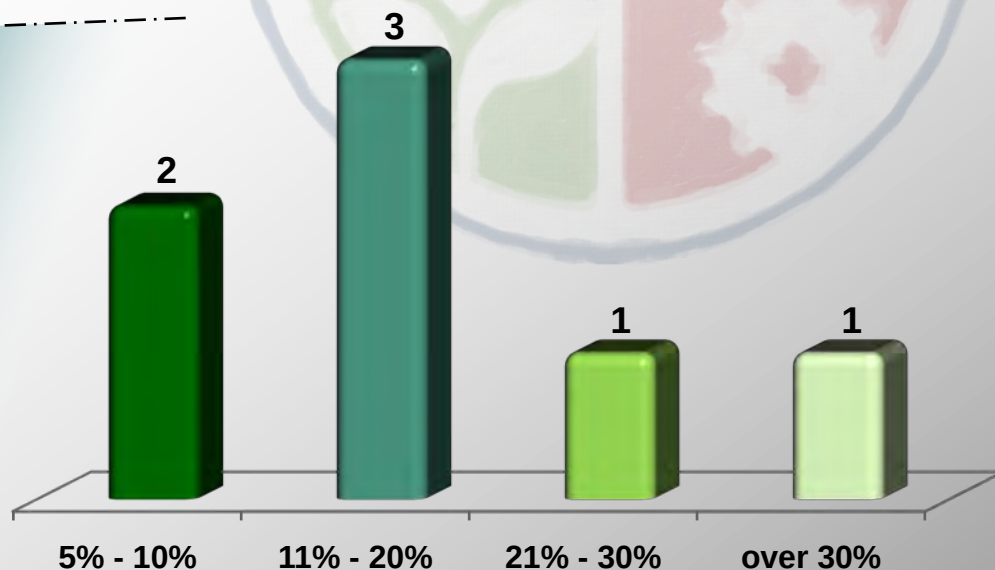
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Battery Projects with Production Capacity as of 12/31/10

- Projects in Pre-Production Phase
- Projects with Production Capacity

7 Out of 20 Projects Are Already Reporting Production Capacity



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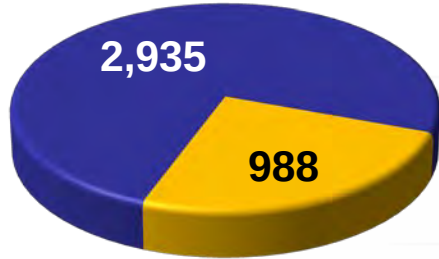
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Cumulative & Planned Payments & Direct Jobs Summary

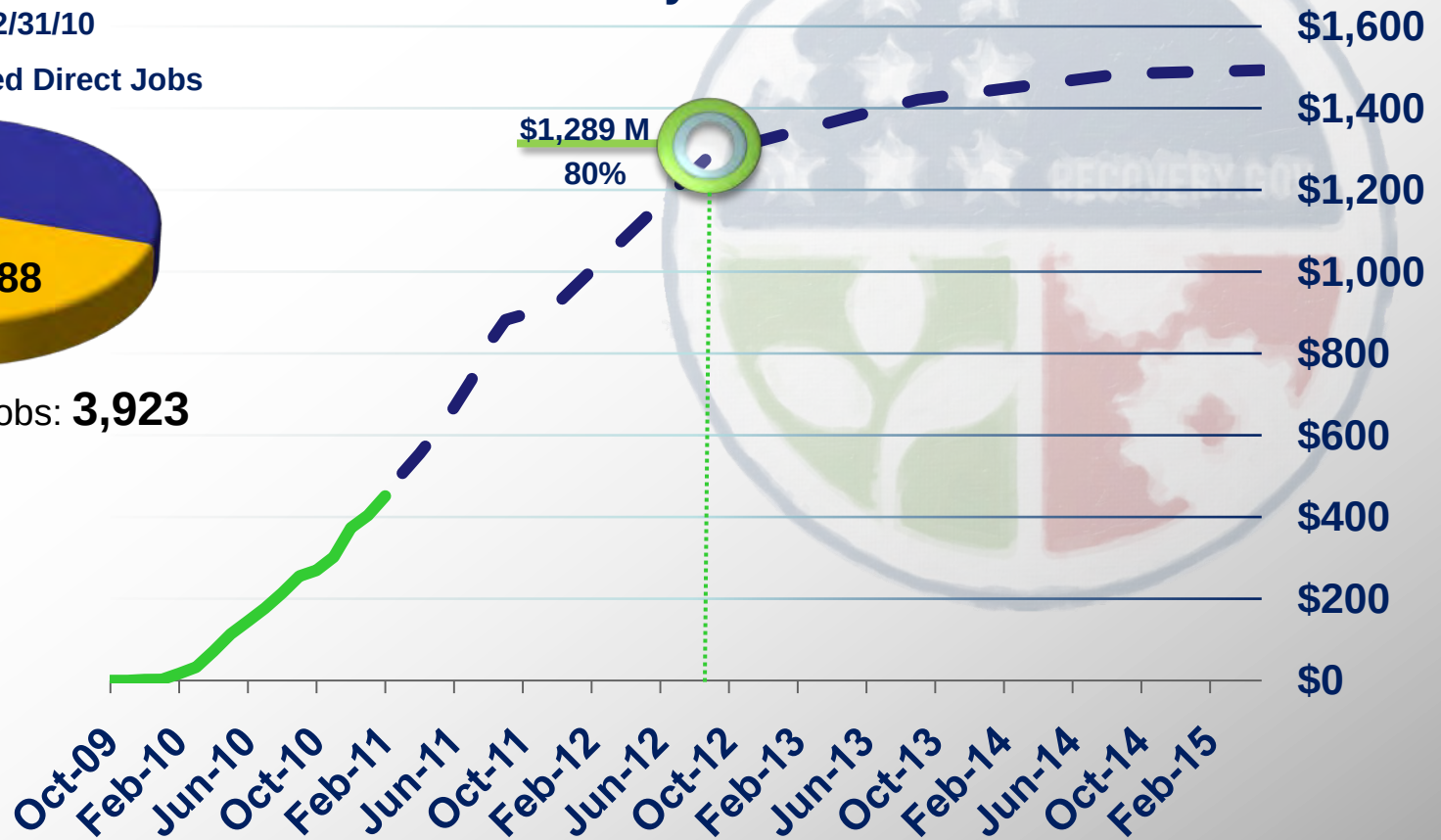
■ Direct Jobs as of 12/31/10

■ Remaining Projected Direct Jobs



Projected Direct Jobs: **3,923**

— Cumulative Payments
— Payments Plan



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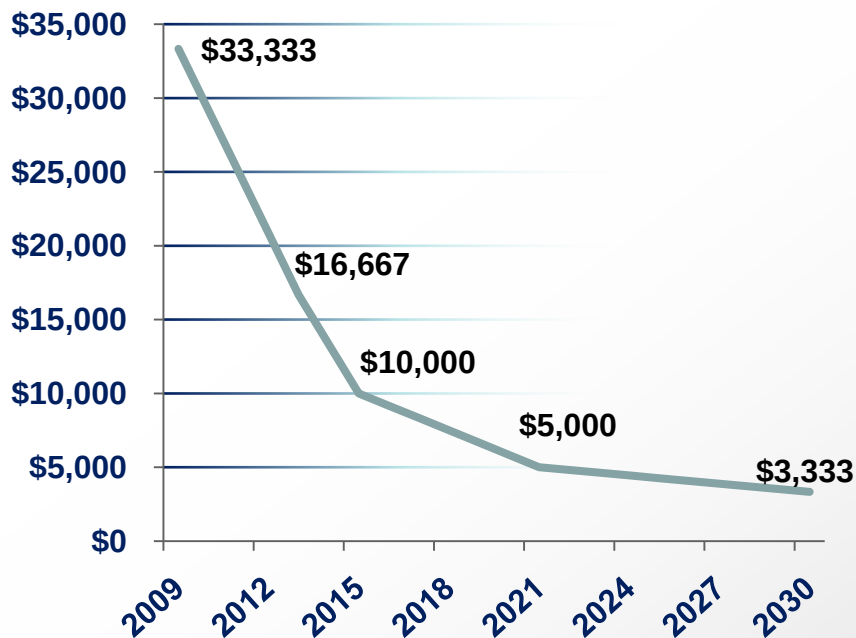


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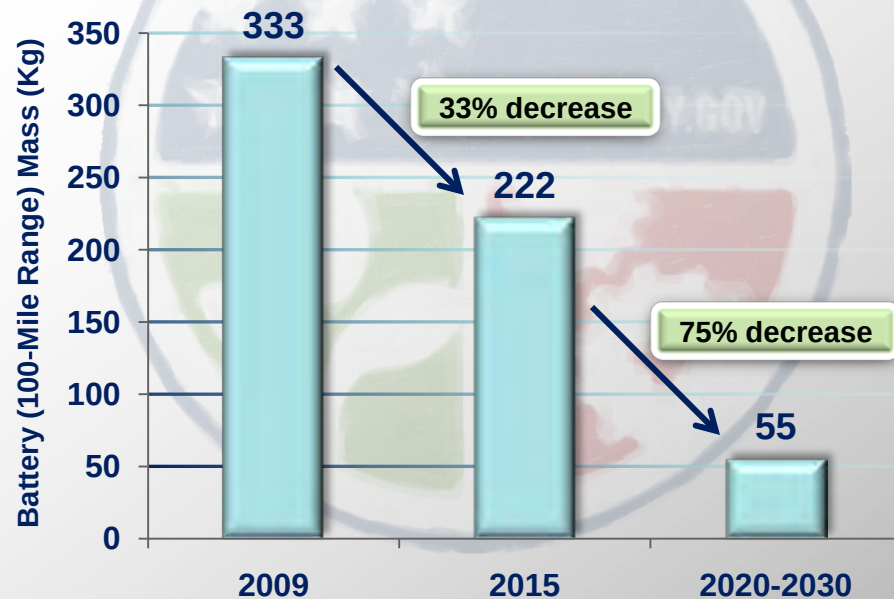
EV Battery Forecast

Forecasted Cost of a Typical Electric-Vehicle Battery



Assumes 3 miles per kilowatt hour and 100-mile range.
Source: U.S. DOE Vehicle Technologies Program

Forecasted Weight of a Typical Electric-Vehicle Battery



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Questions??



Vice President Joe Biden tours the Ener1 Inc. battery factory in Greenfield, Indiana, Jan. 26, 2011. (Official White House photo by David Lienemann)



U.S. Energy Secretary Steven Chu talks with General Motors Chairman and CEO Ed Whitacre after the first Chevrolet Volt battery came off the assembly line at the GM Brownstown Battery plant January 7, 2010. (by Jeffrey Sauger for General Motors)

The DOE directly supports President Obama's goal of making the United States the first country in the world to put one million advanced technology vehicles on the road by 2015.



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