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

U.S. Battery R&D Progress and Plans

May 14, 2013

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Battery R&D Objectives

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Advance the development of batteries to enable a large market penetration of hybrid and electric vehicles.

Program targets focus on enabling market success (increase performance at lower cost while meeting weight, volume & safety).

Year	Electric Drive Vehicle Sales		Total Light Duty Vehicle Sales
	HEV	PHEV & EV	
2009	290,273	–	10,409,897
2010	274,648	345	11,590,274
2011	266,501	17,763	12,778,885
2012	434,648	53,169	14,492,398

A Track Record of Success

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

- **Nickelate technology (JCI):** BMW, Mercedes.
- **Manganese technology (LG Chem, MI):** GM Volt & Ford Focus EV.
- **Iron phosphate technology (A123Systems):** Fisker, GM Spark.

Battery R&D Budget

Battery/Energy Storage R&D Funding ($, M)	
FY 2012*	$90
FY 2013**	$88
FY 2014* (request)**	$170.5

*FY 2012 SBIR/STTR removed.
**FY 2013 full year CR inclusive of SBIR/STTR.
*** FY 2014 budget request inclusive of SBIR/STTR.

FY 2013 Energy Storage R&D Budget** ($88M)

VTO Battery R&D Activities

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Advanced Battery Materials Research

- ✓ Capacity Improvement
- ✓ Failure Mitigation

Cell Design & Electrochemistry Optimization

- ✓ Power & Capacity Increase
- ✓ Life Improvement

Advanced Battery Development

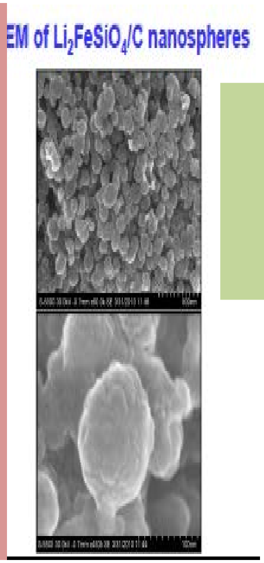
- ✓ Performance Optimization
- ✓ Cost Reduction

Battery Materials

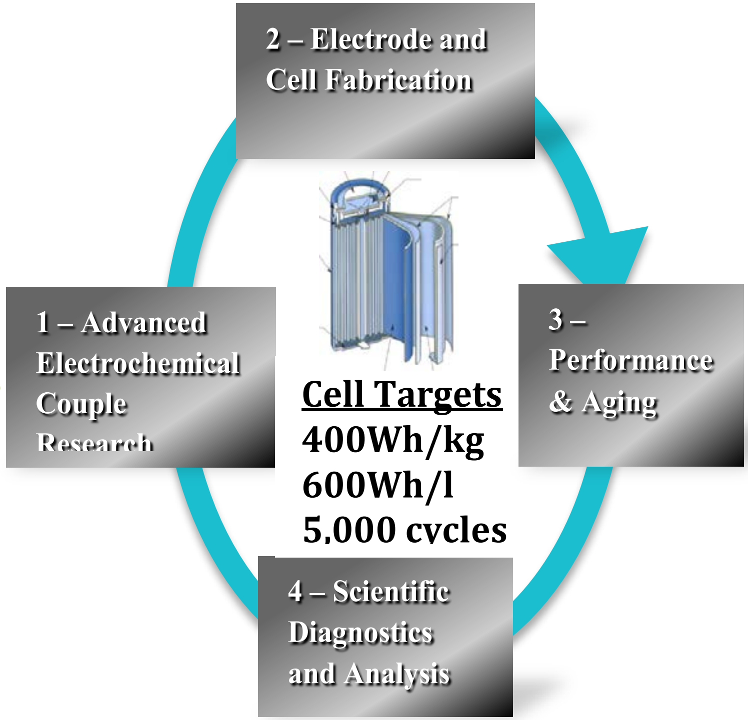
Advanced Anodes (600 mAh/g)

Advanced cathodes (300+ mAh/g)

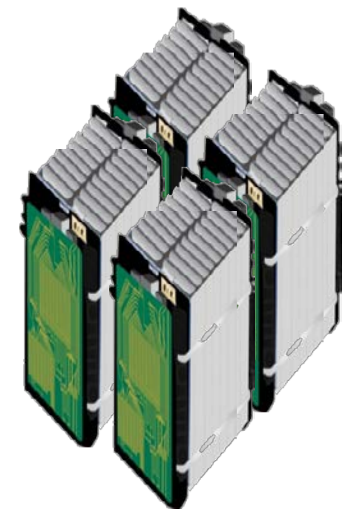
Next Generation Electrolytes (5 volt)



10-100 mAh cells



0.5 - 1.0 Ah cells



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

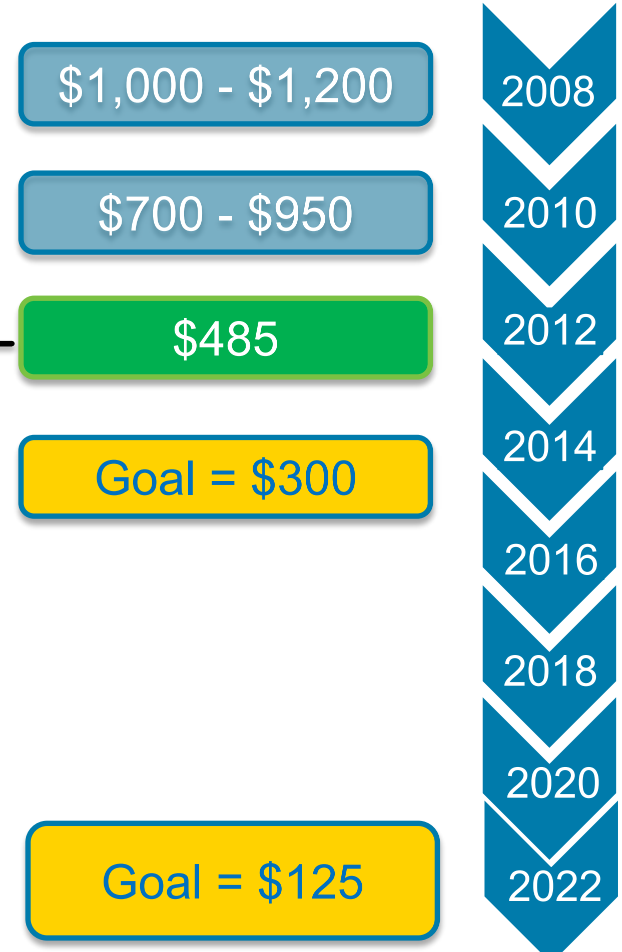
5 - 40$^+$ Ah cells

Battery R&D Progress

- Current cost estimates (for a PHEV battery) average $485/kWh of useable energy.
- Cost projections are derived by the manufacturer using the USABC's battery manufacturing cost model
  - For a production volume of 100,000 batteries per year.
  - For battery cell and module designs that meet DOE/USABC system performance targets.
  - Validated using established test procedures.
- Proprietary details of the designs and the cost models are presented at Quarterly Progress Reviews.

Progress of Battery Development Projects

Plug-In Battery Cost (per kWh of Useable Energy)



Battery Technology Comparison

4X Cost Reduction

2X Size Reduction

>2X Weight Reduction

2012	
$/kWh:	<600
Wh/kg:	<100
Wh/l:	<200
W/kg:	400

2022	
$/kWh:	125
Wh/kg:	250
Wh/l:	400
W/kg:	2,000

Research Roadmap for 2015 & Beyond

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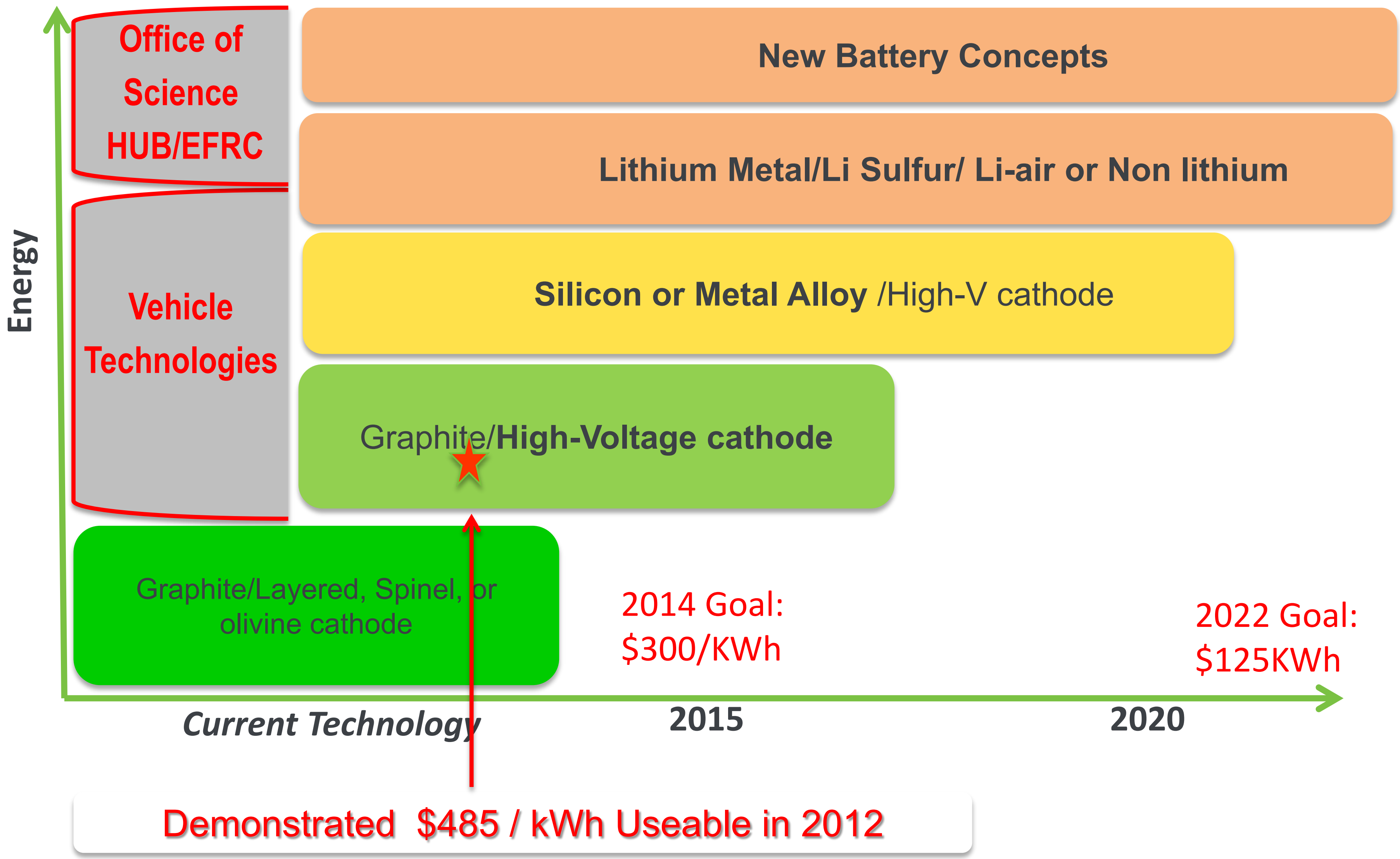


Demonstrated Attributes of Battery Technologies

	Maturity	Battery Performance (Pack Level)				
		Specific Energy (Wh/kg)	Energy Density (Wh/l)	Power (W/kg)	Current Life (cycles)	Abuse Tolerance
Lithium-ion (current status)	Pack	50-80	100-150	500-750	>5,000	Meets SAE J2929
Lithium-ion (future generations)	Cell 20Ah+	155	205	800	~500+	TBD
Lithium metal polymer (solid)	Cell 10Ah+	150	250	<100	~1,000	+ flammability - volatility
Lithium metal / Sulfur	Cell (Lab)	250-400	180-250	<100	~100	Concern
Lithium metal / Air	Lab Devices	400-600(?)	200(?)	Poor	?	Concern

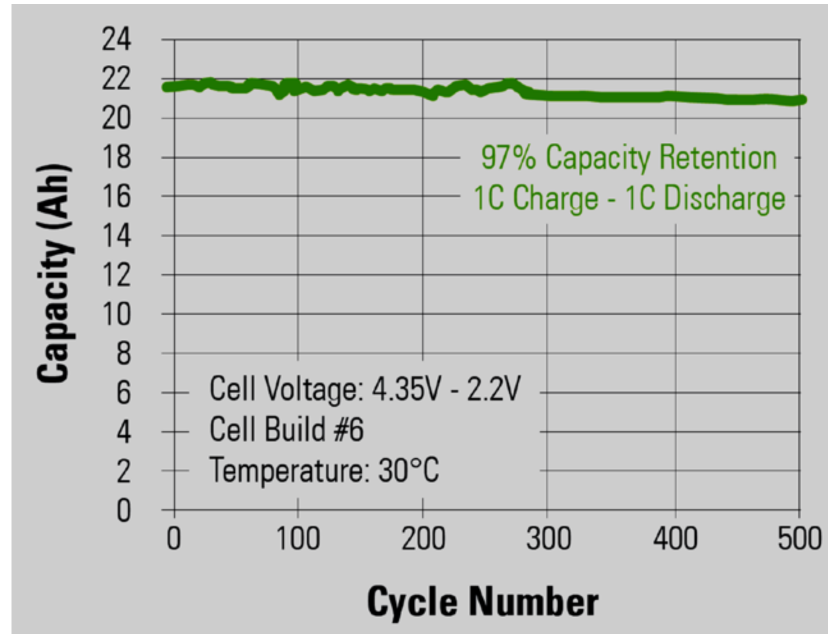
USABC
UNITED STATES ADVANCED BATTERY CONSORTIUM LLC

High Energy Lithium-ion Batteries for EVs

envia

Accomplishments:

- ❑ USABC EV battery development project
  - Pack Level Gravimetric energy density (155 Wh/kg).
  - Pack Level Volumetric energy density (205 Wh/l).
  - Power density exceeds USABC targets.
- ❑ High confidence in meeting the cycle life target of 1,000 cycles.
  - Showing 97% capacity retention after 500 cycles.
- ❑ Demonstrated that cells can operate over a wide temperature window
  - -40 C to 50 C



Cycle life of 22 Ah pouch cells

Envia 22-Ah pouch cell

USABC UNITED STATES ADVANCED BATTERY CONSORTIUM LLC

Manufacturing Cost Reduction in Lithium-ion Batteries

Johnson Controls

Accomplishments:

- Demonstrated novel cathode slurry processing techniques (paste mixing & dry compounding)
  - N-Methylpyrrolidone (NMP) plays an active role in reactions, i.e. polymerization—high cap-ex and recovery costs.
  - Reduced NMP solvent use by 32%.
  - Increased coated electrode density by 31%.
- On path to increase cell energy density by 36%.
  - from 275 Wh/L to 375 Wh/L.
- On a path to reduce cell costs by 40%
  - from $420/kWh to $250/kWh.

Trial Results			
	Solvent Used	Slurry Density	Electrode Density
Baseline	Standard	Standard	Standard
Powder Compounding	-31.9%	+22.9%	+31.4%
Paste Mixing	-24.3%	+14.5%	+15.2%

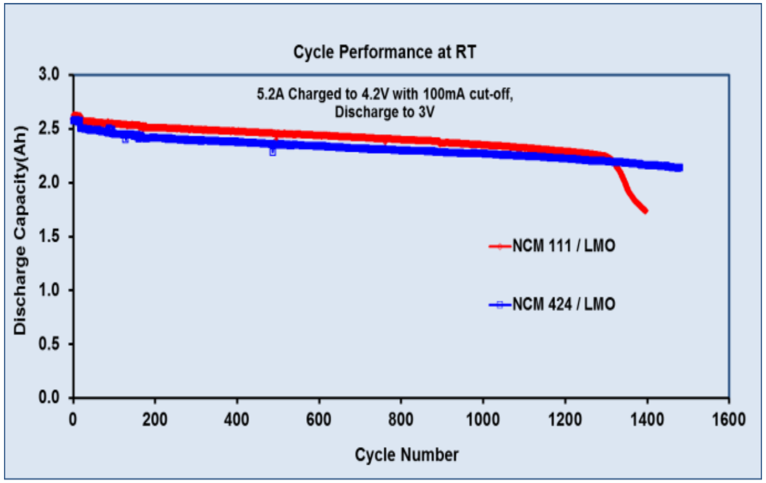
Slurry & electrode density improvement as a function of the processing approach

Scale-Up/Production: Low-Cost Ni/Mn/Co Cathode Material

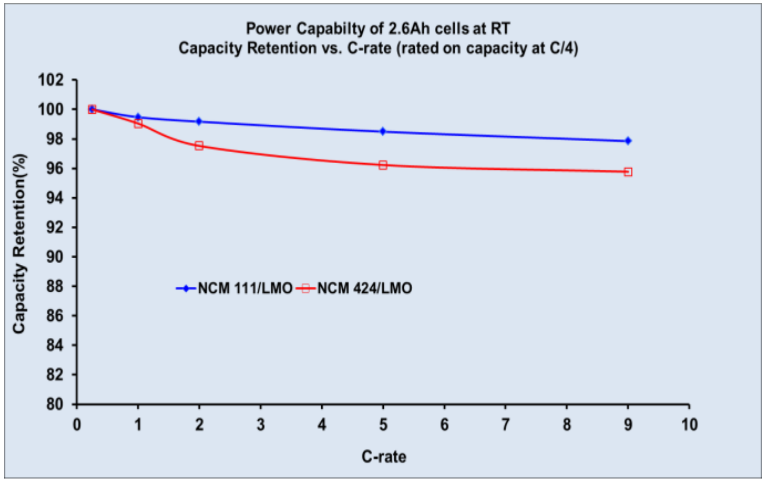
BASF The Chemical Company

Accomplishments:

- Key materials account for 45-70% of total PEV pack cost.
  - The cathode accounts for 30% of key materials cost.
- VTO supported BASF to lower NCM cathode cost through precursor improvements & process modifications.
- NCM 111, 523, and 424 in production
  - NCM 424 ($LiNi_{0.4}Co_{0.2}Mn_{0.4}O_2$) with 40% less cobalt (vs. standard NMC) yields lower cost (~15% reduction).
- High-Energy HE-NCM in R&D stage (260 mAh/g)
  - \$4.8/kWh vs. \$11.6/kWh (NMC): a potential 60% reduction in material production cost.



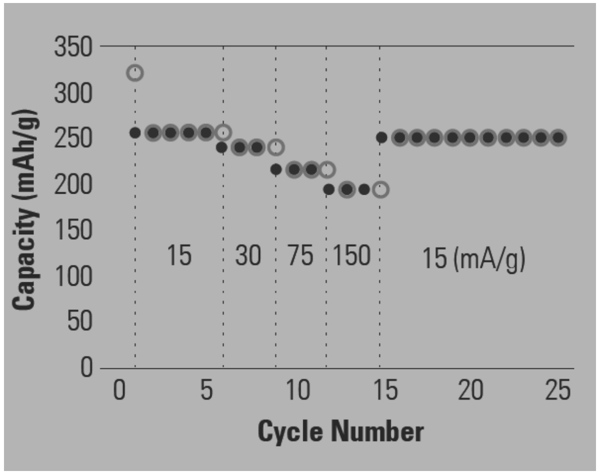
Cycle life of NMC424/LMO blend comparable to NMC111/LMO



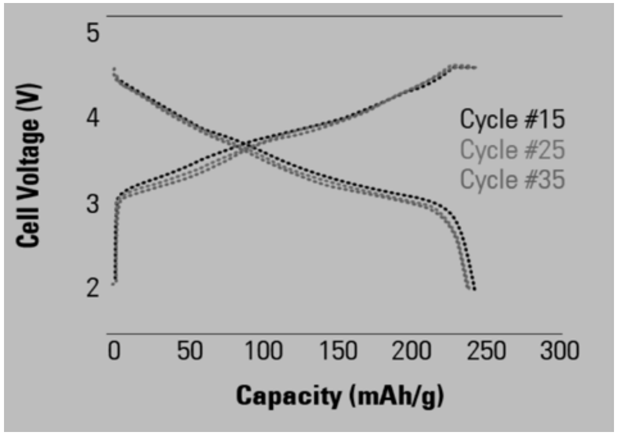
High rate capability of NMC424/LMO

A New Synthesis Approach to Mn-rich Cathodes

- $0.5Li_2MnO_3 \cdot 0.5\ LiMn_{0.5}Ni_{0.5}O_2$ cathode shows high capacities of ~250 mAh/g at low rates, and ~200 mAh/g at ~1C rate.
  - synthesized via a Li_2MnO_3 precursor
- The voltage profiles quickly stabilize with respect to the initial 10 cycles.
- This material displays good stability and capacity retention over extended cycling to high voltage.



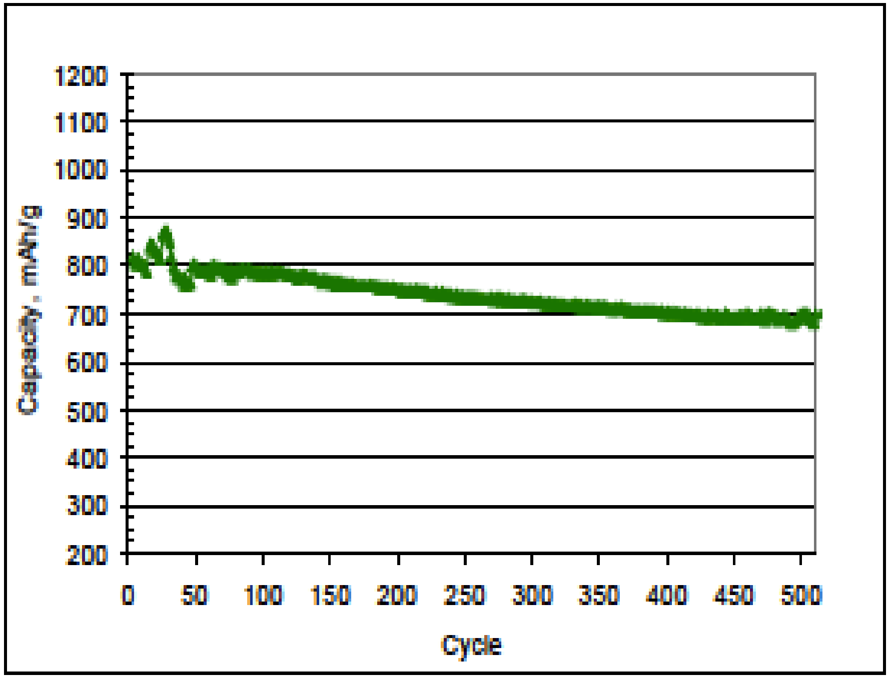
Rate data of a Li_2MnO_3-based $0.5Li_2MnO_3$-$0.5LiMn_{0.5}Ni_{0.5}O_2$ Cathode.



Stability of voltage profiles (at 15 mAh/g).

High-capacity Graphite/Silicon Anodes

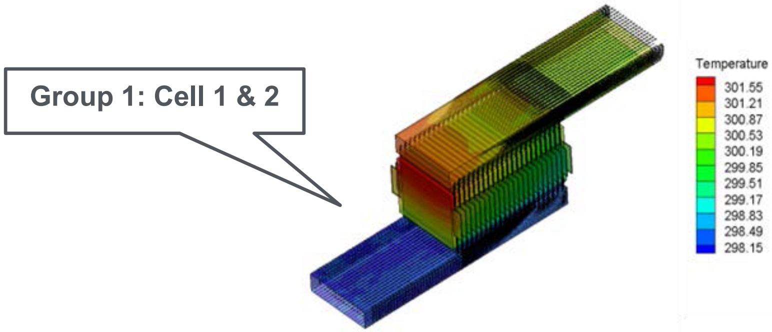
- Nanosys is developing a graphite/Si composite anode material (SiNANOde™)
- SiNANOde™ target capacity is 700~1,000 mAh/g, and >800 cycles.
- Approach: Improve stability and SEI formation through an innovative surface modification of the Si nanowire anode coupled with an optimized electrolyte and binder chemistry.
- Demonstrated 850mAh/g of reversible capacity for SiNANOde
- Demostrated cycle life of ~500 cycles at 83% capacity retention at 0.3C cycling in half cells.



500 cycles of Si half-cell using NanoSys SiNANode meterial.

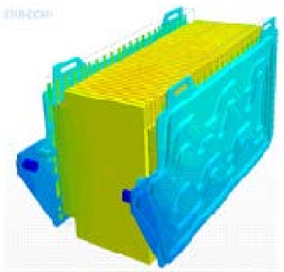
Computer Aided Engineering

AutoLion™



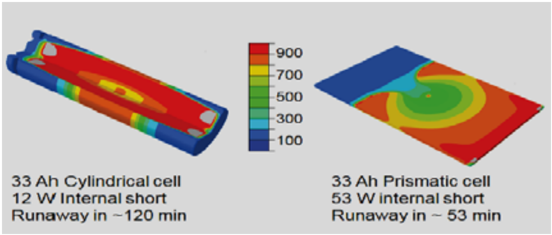
Thermal contours at t=500 seconds under cold-start discharge.

STAR-CCM⁺



Example module using 42 cells (Courtesy: Automotive Simulation Centre, Stuttgart, Germany).

sensor system for detecting & pre-empting short circuits inside a Li-ion cell.



Simulations results (from a validated FEA model) showing the effect of the cell format on thermal runaway following an internal short.

Recovery Act:
Battery Manufacturing

Cell & Pack Production

Electrode throughput

5.4M kwh per year

Cell Assembly

~250,000 (10 kWh packs) per year

EV Packs 100,000+ packs per year

On Going

- **Johnson Controls:** cell production and pack assembly at in Holland, MI
- **General Motors**: battery pack assembly at Brownstown, MI
- **LG Chem:** cell & pack capability in Holland, MI
- **SAFT:** cell production at Jacksonville, FL

Completed

- **A123Systems**: cell production & pack assembly in Livonia & Romulus, MI
- **EnerDel**: cell production & pack assembly at Fishers & Mt Comfort, IN
- **Dow Kokam:** cell production & pack assembly capability in Midland, MI
- **Exide:** advanced lead acid battery production established in Columbus, GA
- **East Penn:** advanced lead acid battery production established in PA

GM Battery Pack Assist

East Penn: Injection Molding

LG Chem Michigan Mixing Tower

Recovery Act:
Battery Manufacturing

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Materials Production

- ❑ On Going
- ■ Completed

- ❑ TODA: cathode production
- ❑ Rockwood Lithium (formerly Chemetall Foote): lithium hydroxide production
- ❑ HTTM: cell hardware production
- ❑ BASF-Novolyte: electrolyte equip installd
- ❑ Toxco: Recycling facility constructn comp

- ■ BASF: cathode production
- ■ EnerG2: anode production
- ■ FutureFuel: anode production
- ■ Pyrotek: anode production
- ■ Celgard: separator production
- ■ Entek: separator production
- ■ Honeywell: Li-salt pilot plant operational

Celgard Separator Roll

EnerG2 Freeze Dry Process

Rockwood lithium hydroxide production

VTO FY2013 FOA

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

FY13 Vehicle Technologies Office Wide FOA: $17.0M DOE $1.0M TARDEC

- **Improvements in Cell Chemistry, Composition, and Processing**
  - Focus on the development of high energy Li-ion couples that can meet the cell performance and life targets: 400-600 wh/l, 1200-1600 w/l, 1000-5000 cycles, etc…
- **Computer Aided Engineering for Electric Drive Batteries**
  - Dramatically improving the computation efficiency of current CAE Tools, or developing models capable of predicting the combined structural, electrical, and thermal responses to abusive conditions, and/or improving the accuracy of advanced life prediction
- **Advanced Electrolytes for Next-Generation Lithium Ion Chemistries**
  - Advanced electrolytes that can enable the commercialization of next generation lithium ion technologies including silicon, tin or other high-energy alloy anodes and high voltage and high capacity cathodes, such as the 5 Volt Ni/Mn spinel or the Li-rich layered/layered transition metal oxides.

FY2014 Potential Funding Opportunities

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Subject to Federal Budget Appropriations

- ❑ **Advanced Battery Development (Cooperative Agreement)**
    - ❑ **RFPI on High Energy Battery Development**
- ❑ **Incubator (Start-Up: "On-Ramping Off-Roadmap Technologies")**
- ❑ **VTO Program Wide FOA**
    - ❑ **Beyond Lithium Ion**
    - ❑ **Materials Processing and Production Improvements**
- ❑ **BATT (Solid Electrolytes: Exploratory Materials)**
- ❑ **SBIR**

For Additional Information…

QUESTIONS?

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