A High-Performance PHEV Battery Pack

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LG Chem Power / LG Chem

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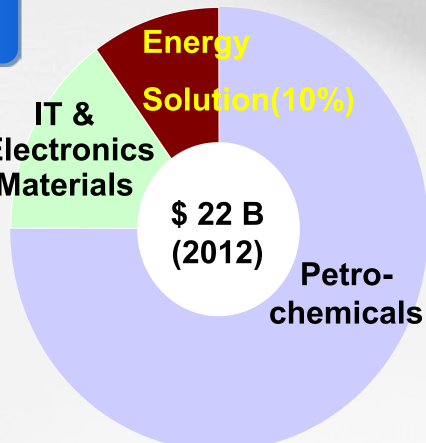
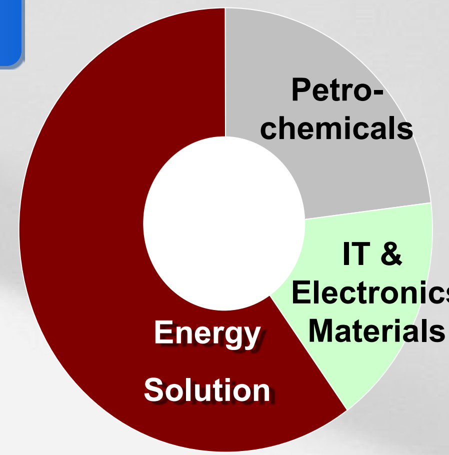
Project ID: ES002

LG Chem at a glance

Revenue



R&D Expense



Energy Solution

- Lithium-Ion Batteries for
  - Mobile Phone, Laptop, Power Tool
  - Hybrid & Electric Vehicles
  - ESS

Petrochemicals

- ABS/EP
- NCC/Polyolefin
- PVC/Rubber
- Acrylate

IT & Electronics Materials

- LCD Polarizer
- LCD Glass
- OLED Materials
- Color Filter

LGCPI

- Battery Pack Concepts, Design and Prototype Builds
- Battery Management Systems
- Sales and Customer Support

Troy, MI

Sales & Pack R&D

LGCMI

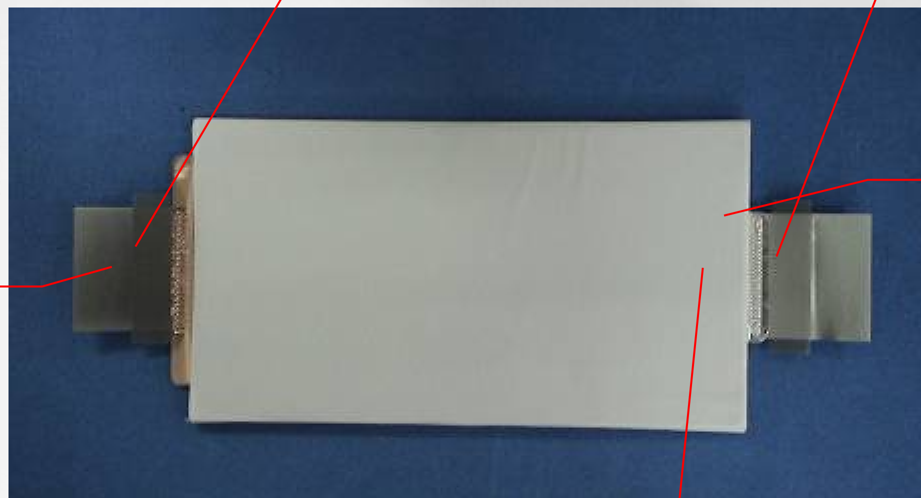
- $300M+ investment with ARRA funding
- Groundbreaking: Summer 2010
- Production begins in 2013

Holland, MI

Cell Manufacturing

Cell Structure: Unique Stack- and-Fold Design

Stacking of Plates & Folding

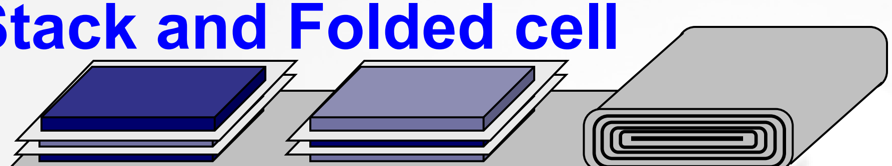


Lead film (insulation tape)

Positive terminal

Negative terminal

Stack and Folded cell



Bi-cell

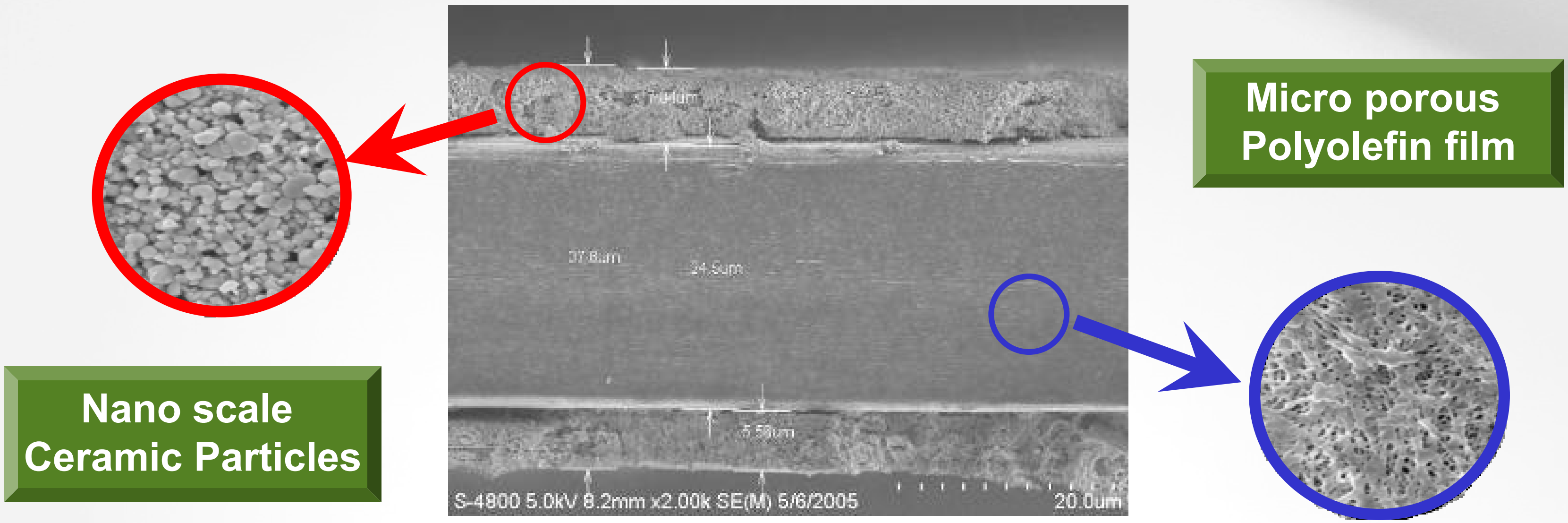
SRS™

Laminated film

Proprietary Safety Reinforcing Separator (SRS^{TM})

SRS^{TM} provides superior abuse-tolerance

- **By improved mechanical and thermal stability**
- **By preventing internal short circuit**
- **By providing lower shrinkage**



- **Significantly higher puncture strength than conventional separator**

Overview of Current Program

Timeline

- Project Start: April 1, 2011
- Project End: December 31, 2013
- Percent complete: 79%

Budget

- Total project funding: $9.6M
- DOE share: $4.8M
- Contractor share: $4.8M
- Funding for FY12: $2.0M

Barriers

- Specific Energy and Power
- Cycle- and Calendar-life
- Cell Cost goal of <$200/kWh
- Efficient Refrigerant-to-Air cooling system

Partners

- LG Chem, INL, SNL, NREL
- Project lead: LGCPI

Objectives

- Develop a cell suitable for use in the PHEV-40 Mile program using next generation, high capacity Mn-rich cathode materials.

- A key goal of the program is to lower the pack cost to close to the $3400 target.

- Improve upon the Refrigerant-to-Air cooling system we have developed in our previous program with respect to mass, volume, cost and power demand.

- Deliver cells and battery packs to USABC for testing.

PHEV 40-Mile Battery Pack Goals

Characteristics at EOL	Units	Requirements for 40-Mile Program
Reference Equivalent Electric Range	Miles	40
Peak Pulse Discharge Power, 2 Sec	kW	46
Peak Pulse Discharge Power, 10 Sec	kW	38
Peak Regen Pulse Power, 10 Sec	kW	25
Available Energy, CD[4] mode, 10kW rate	kWh	11.6
Available Energy, CS[4] mode	kWh	0.3
Minimum round-trip Energy Efficiency[5]	%	90
Cold Cranking Power at -30°C, 2 sec / 3 pulses (2-10-2-	kW	7
CD Life / Discharge throughput	Cycles;	5000
	MWh	58
CS HEV Cycle Life, 50Wh Profile	Cycles	300,000
Calendar life at 35°C	Years	15
Maximum System Weight	Kg	120
Maximum System Volume	Liters	80
Maximum Operating Voltage	Vdc	400
Minimum Operating Voltage	Vdc	>0.55Vmax
Maximum Self-Discharge	Wh/day	50
System Recharge Rate at 30°C	kW	1.4
		(120V/15A)
Maximum System Production Price @100k units/year	US$	$3,400

Approach/Strategy

- Study high capacity, Mn-rich, layered-layered cathode materials from multiple vendors.
- Characterize and Improve the performance, life and abuse-tolerance of Mn-rich cathode materials.
- Optimize, fabricate and deliver battery packs based on Refrigerant-to- Fin indirect cooling system.

Technical Accomplishments/Results

- **Mn-rich cathode materials from multiple sources have been evaluated.**
- **Built cells with control of various cell fabrication parameters/processes such as electrode formulations, formation protocol etc. to identify conditions optimum for performance and life.**
- **Studied the effect of operational voltage ranges on energy, power and life.**
- **Studied the effect of electrolyte additive on life.**
- **Surface coatings on cathode particles considerably improve the durability of Mn-rich cells.**

Technical Accomplishments/Results

- 1st Gen cells (24Ah) were built and sent to National Labs for evaluation. Results showed the need for significant improvement in life.

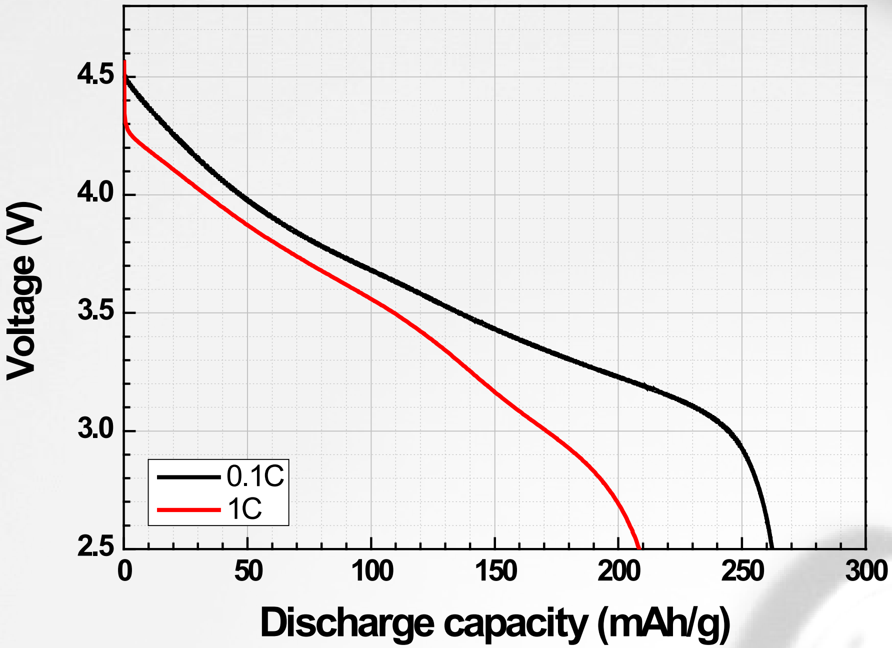
- Battery packs using refrigerant-to- fin indirect cooling system have been designed and optimized with respect to
  - Volume
  - Weight,
  - Robustness, and
  - Power demand.

- Testing of prototype packs under various heat-loads using different driving profiles have been carried out. Data show good efficacy of this cooling system.

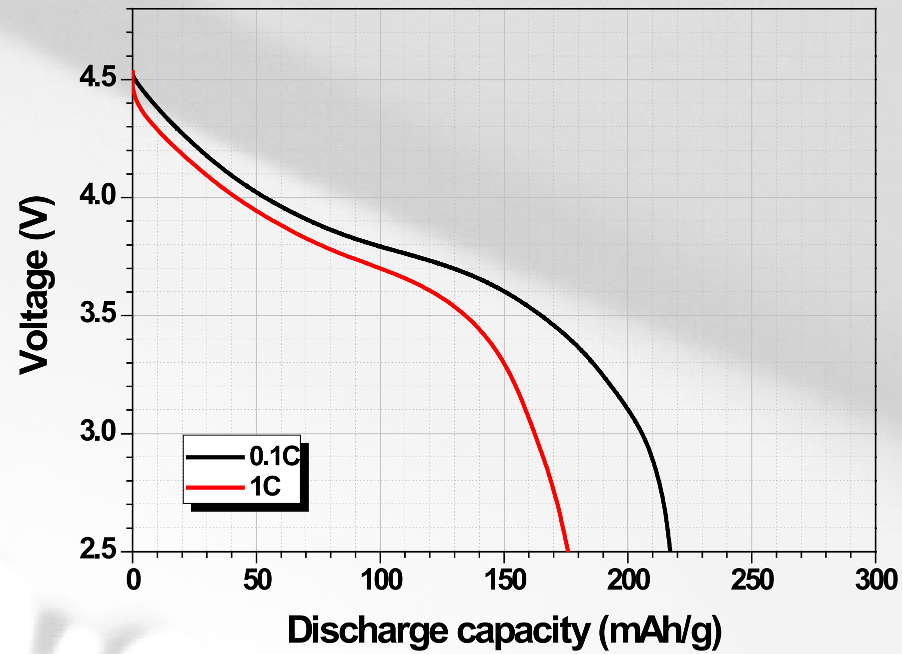
- Prototype packs have been built and delivered to National Labs for evaluating their cooling efficiency.

Results- *continued……*

Sample A

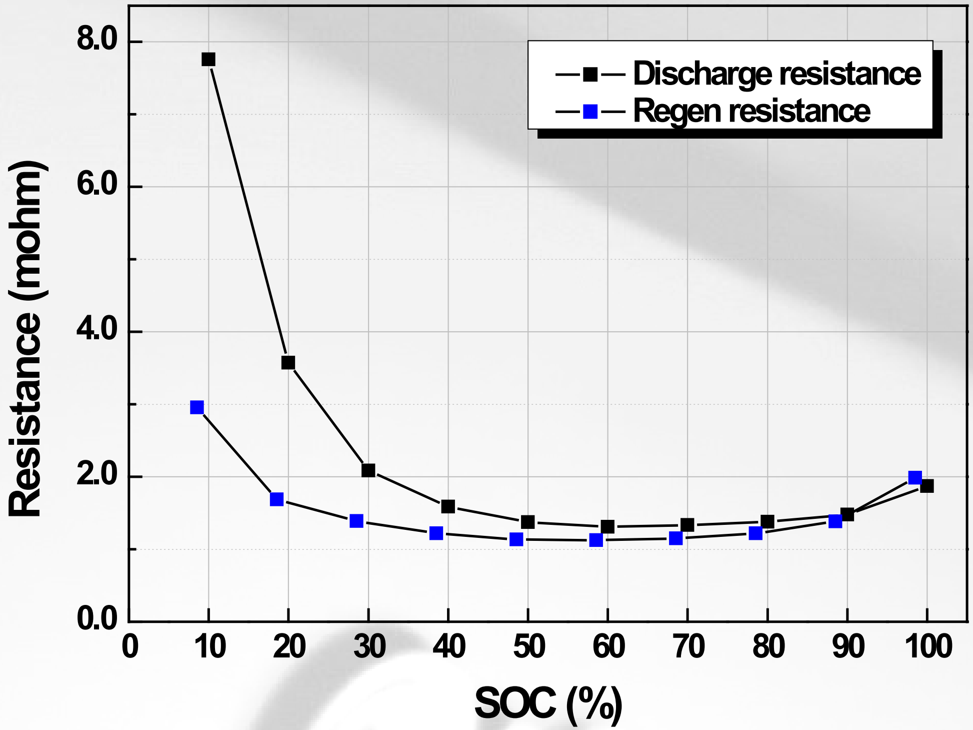


Sample B



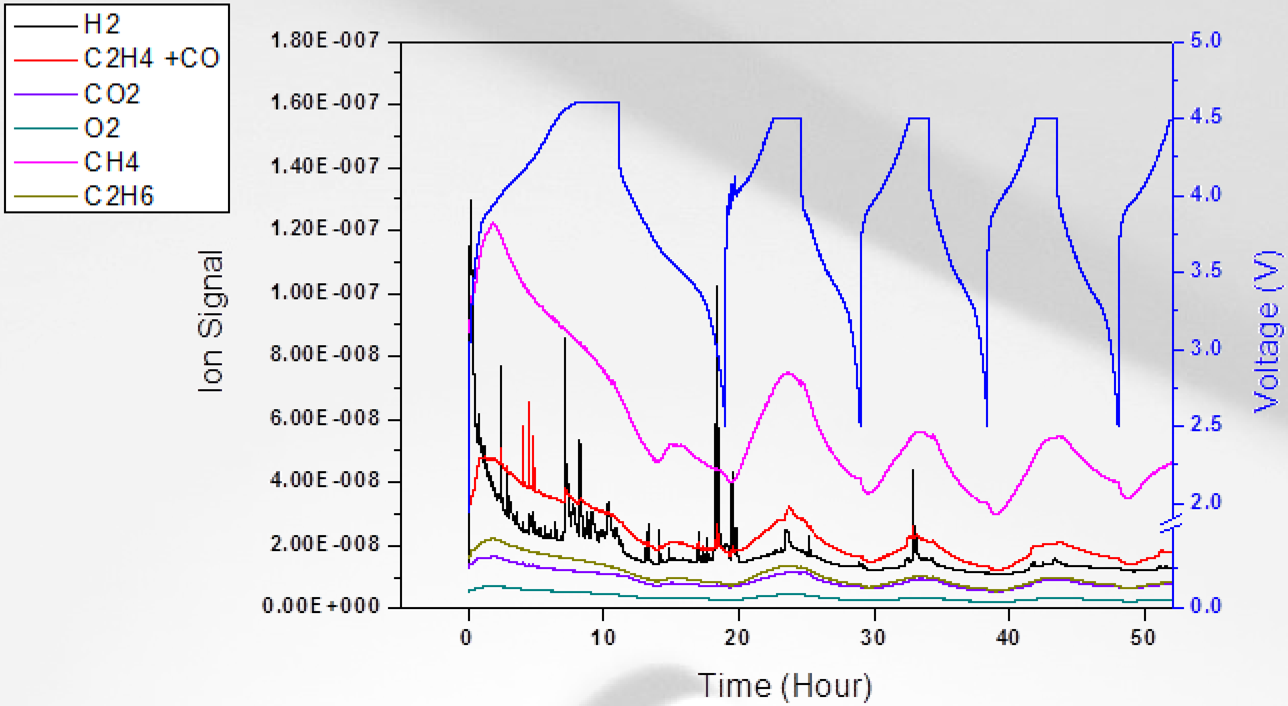
- **Baseline studies with Mn-rich cathodes show capacities as high as ~ 250 mAh/g at RT.**
- **Strong dependence on rate.**

Results- *continued……*



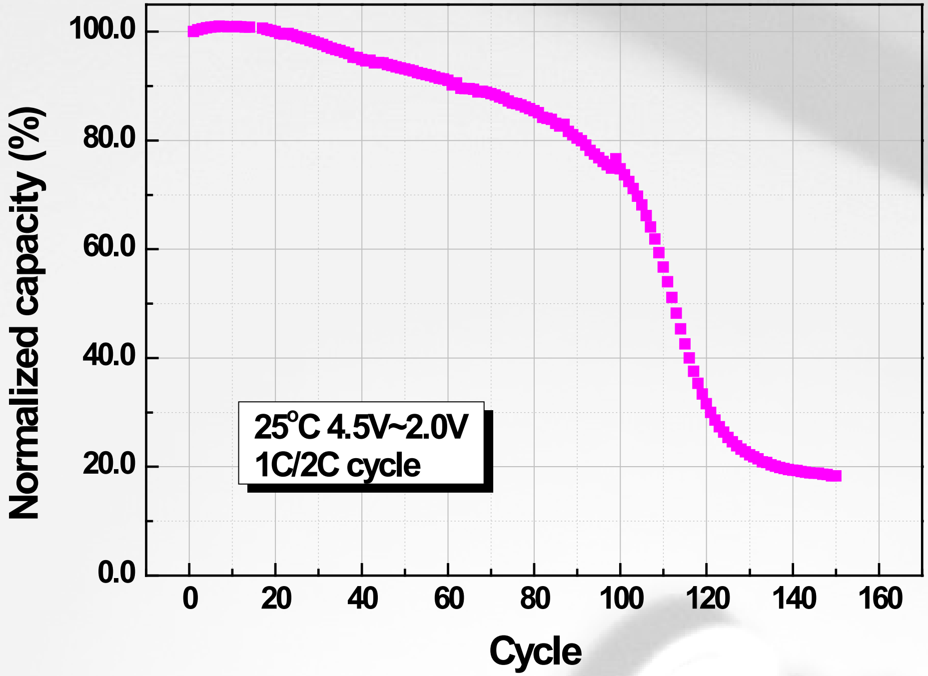
- Rapid increase in DC resistance at low SOCs.
- This can limit the usable SOC range for PHEV applications.

Results- *continued……*



- Charging to voltages such as 4.5V to access higher capacity leads to significant gas evolution. This causes swelling and premature cell failure.
- This gas generation necessitates considerable adjustment to cell processing conditions, such as formation.

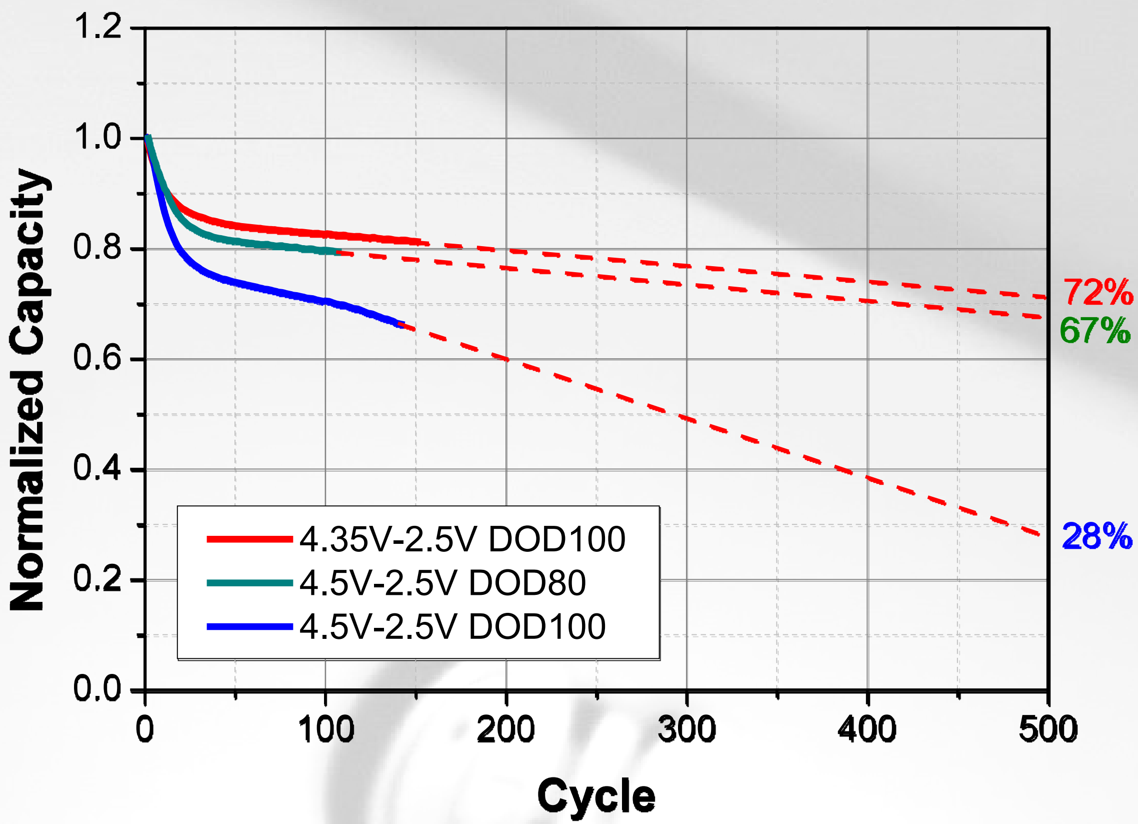
Results- *continued……*



Co	Mn	Ni
24 ppm	145 ppm	19 ppm

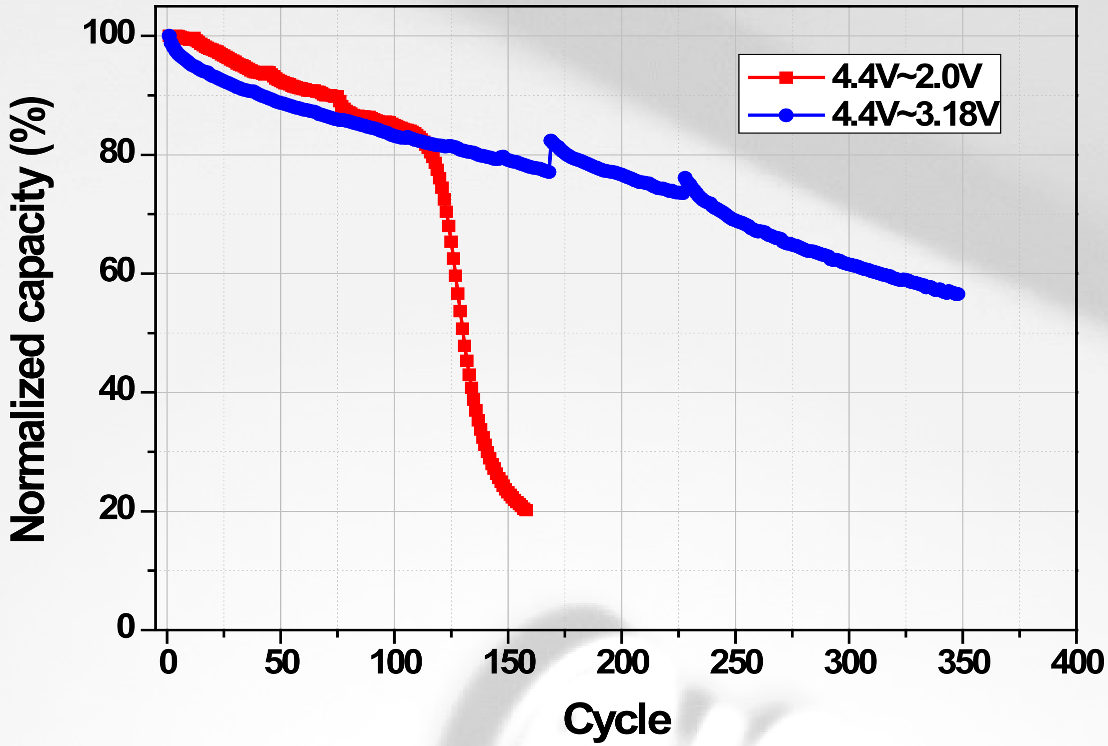
- **High voltage operation results in severe Mn dissolution in regular electrolyte.**

Results- *continued……*



- **Max charge voltage has a strong influence on cycle-life.**

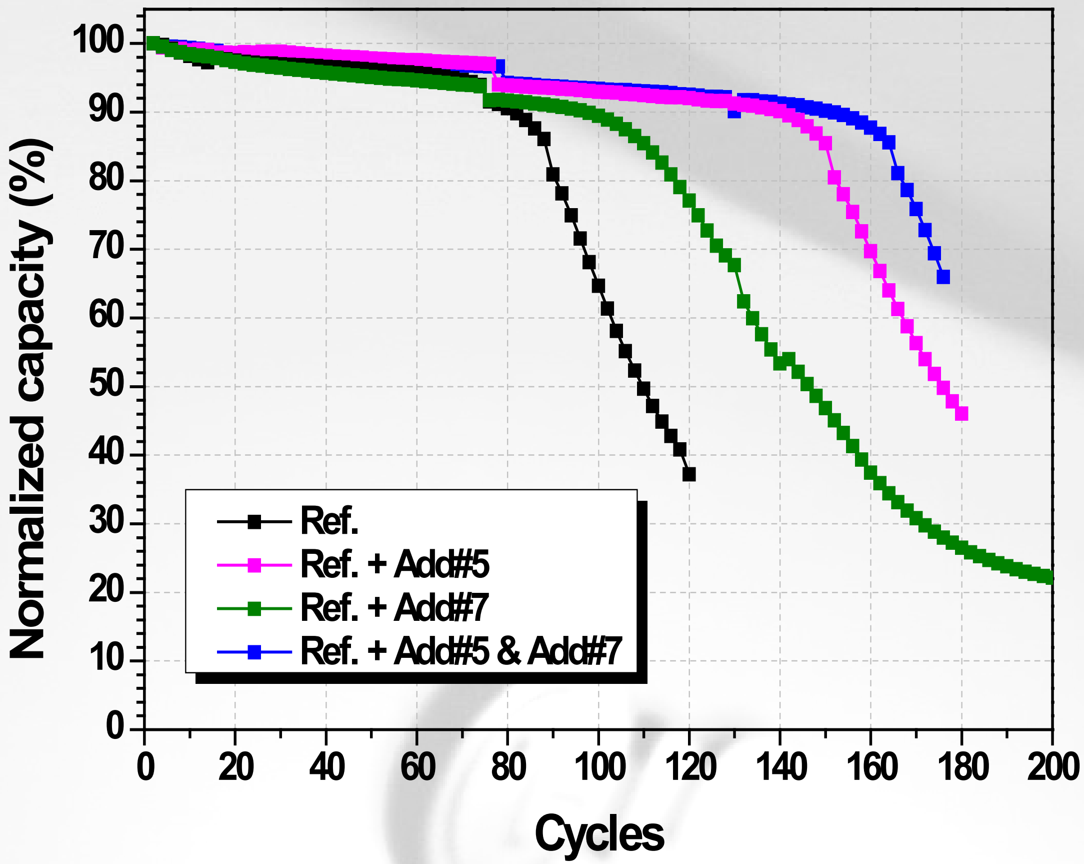
Results- *continued……*



45°C
1C/2C cycle

➤ **Discharge cut-off voltage has significant effect on cycle-life.**

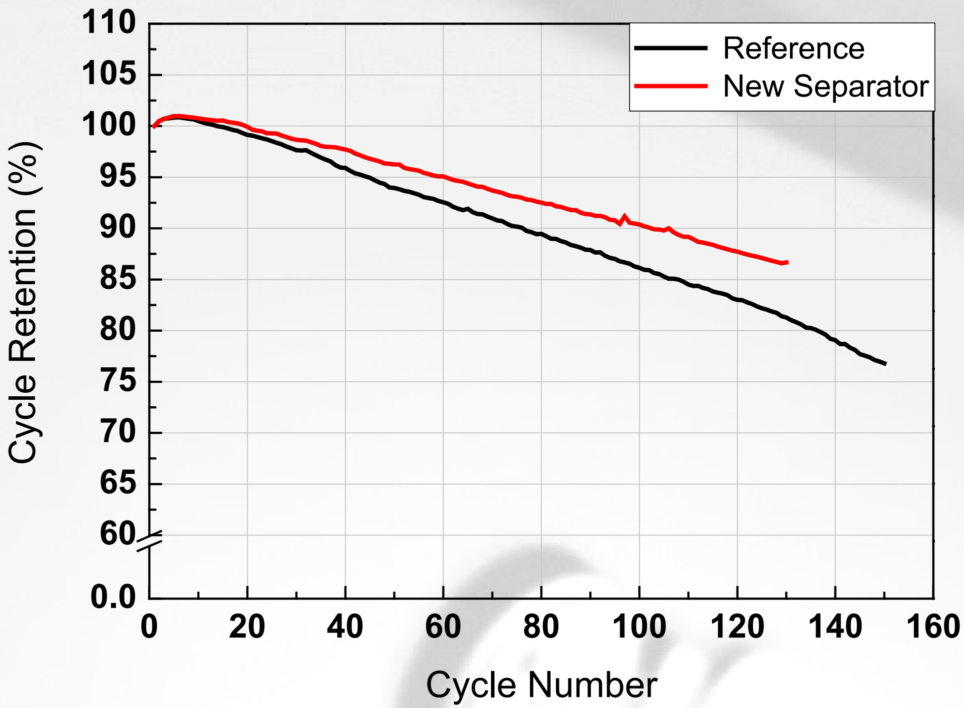
Results- *continued……*



45^{o}C 4.5V~2.0V 1C/2C cycle

➢ **Electrolyte additives appear to enhance cycle-life.**

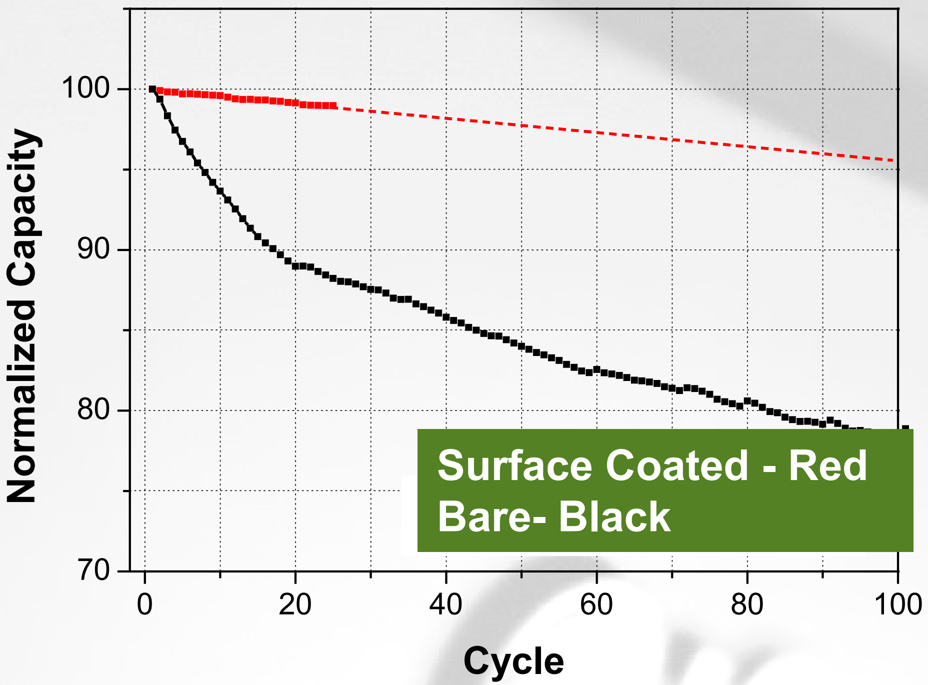
Results- *continued……*



45°C
4.45V~2.5V
0.5C/1C cycle

- **Improved separator helps to enhance cycle-life.**

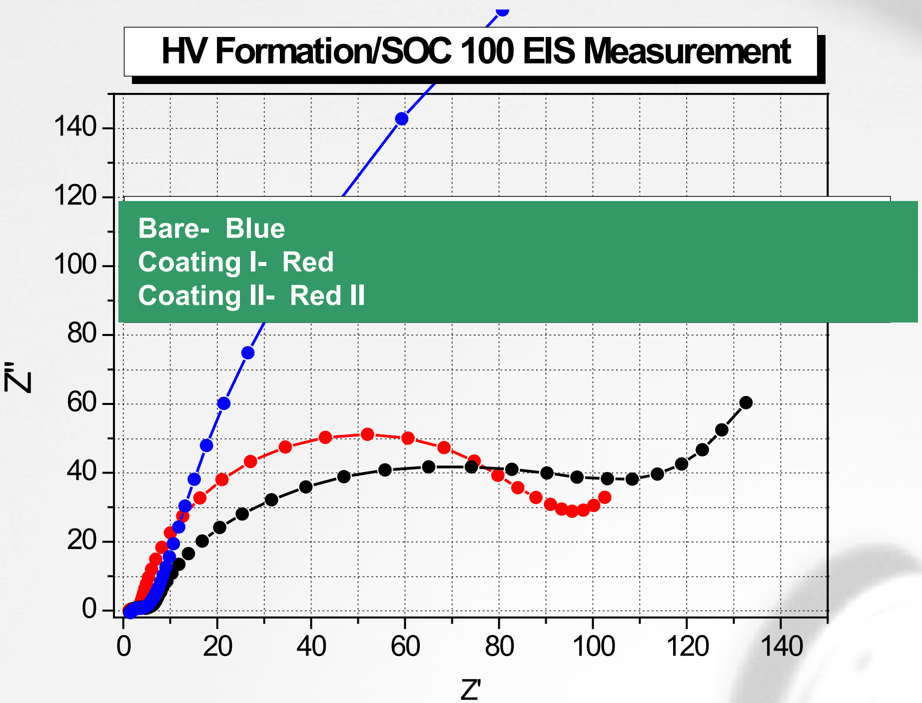
Results- *continued……*

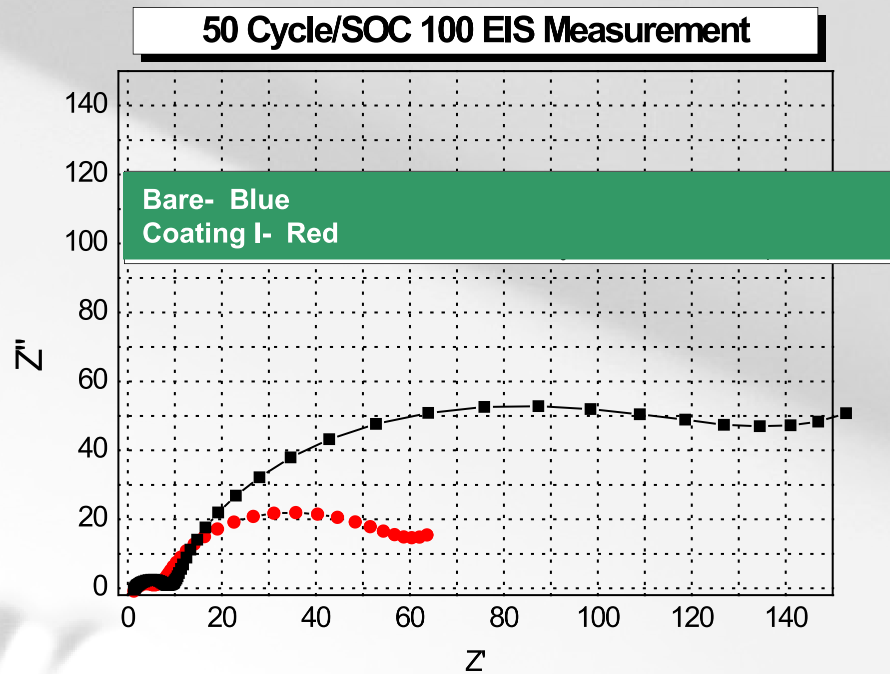


25°C
4.35V- 2.5V
0.5C/1C cycle

- **Surface coating enhances cycle-life.**

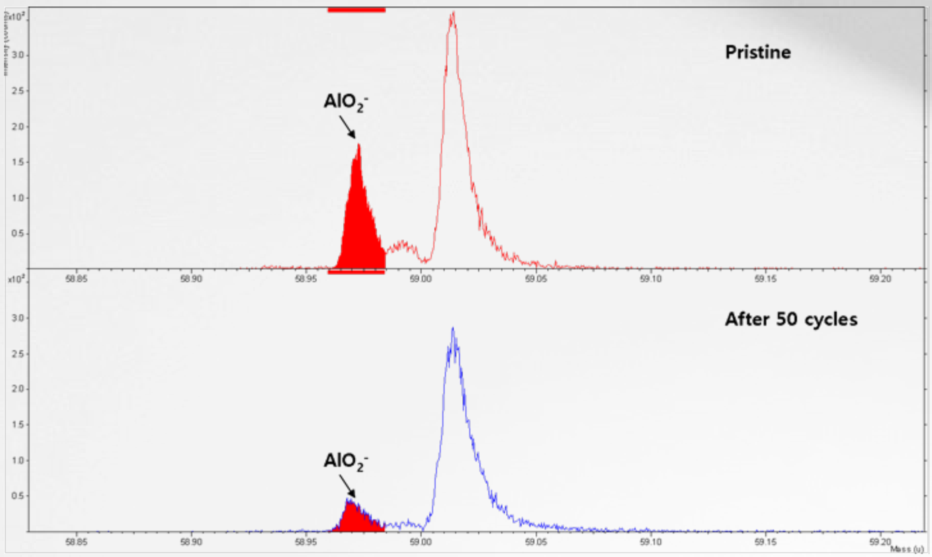
Results- *Effect of Surface coating…*



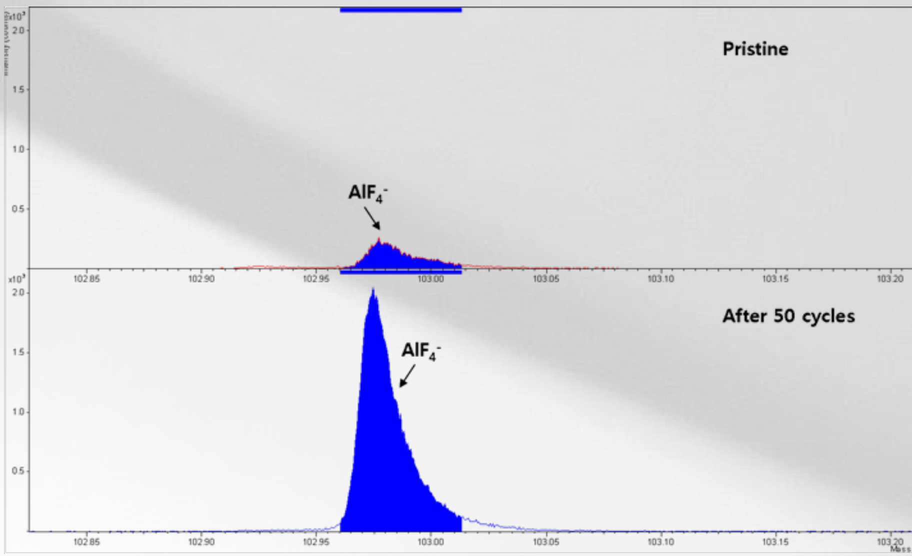


- **Surface coating reduces resistance rise during cycling.**

Results- *Effect of Surface coating…*



Before Cycling



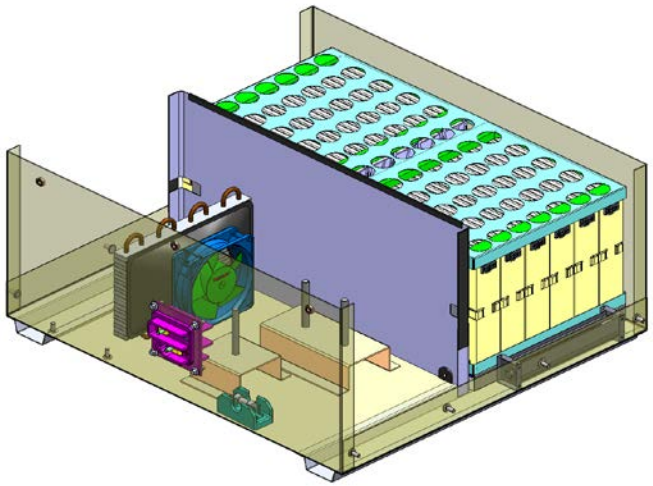
After Cycling

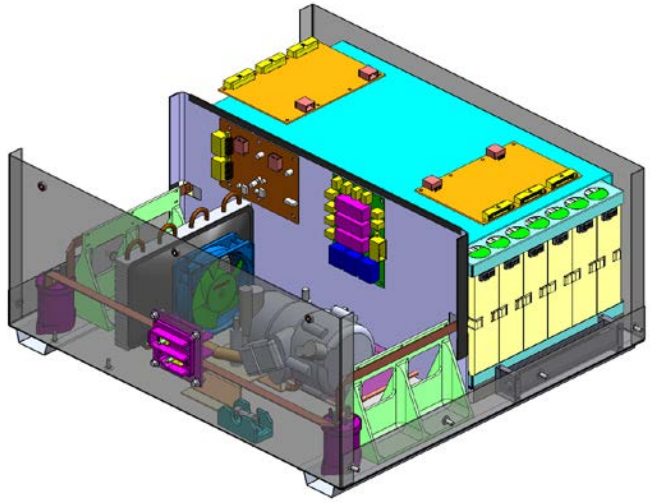
- **Amount of Al_2O_3 secondary ion (AlO^-, AlO_2^-) after cycling was decreased, while that of AlF_3 secondary ion (AlF_2^-, AlF_4^-) was increased.**
  - **Al_2O_3 was changed to AlF_3 by the reaction of Al_2O_3 with HF.**
- **AlF_3 is known to show lower resistance to Li ion diffusion than Al_2O_3.**

Results: *Refrigerant Cooling System*

- **Requires refrigerant loop; but:**
  - **Avoids coolant fill and maintenance, obviates need for complex coolant manifolds and risks of leaking.**

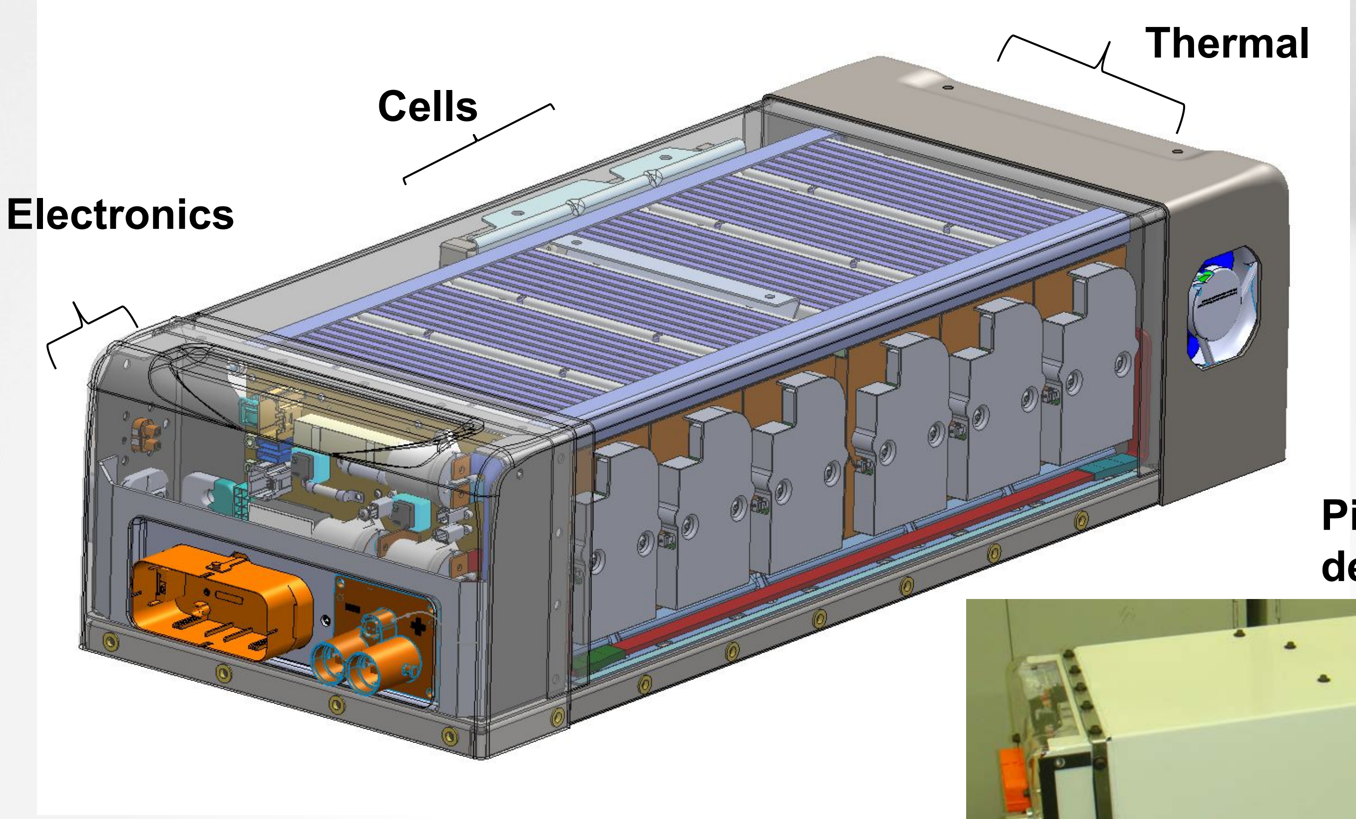
- **<u>Phase I- Two thermal zones:</u>**
  - **Refrigerated compartment (cells, evaporator, fan)**
  - **Ambient compartment (controls, compressor, condenser, fan)**



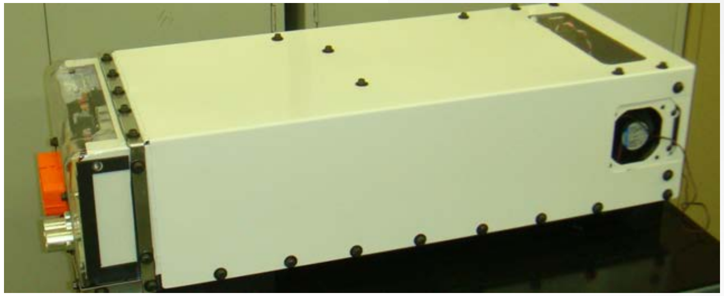


Results: *Phase II Cooling System- integrated design*

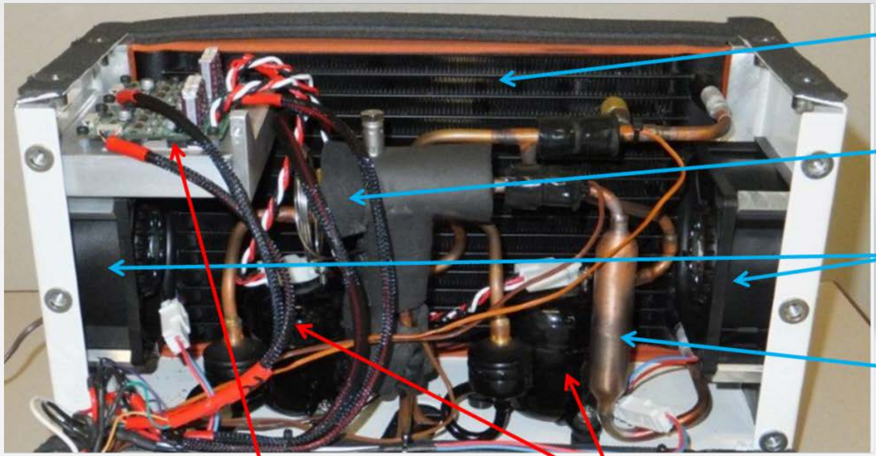
- **A refrigerant loop is used to cool the cold-plate at the bottom of the battery pack which, in turn, is attached to solid fins located between the cells.**

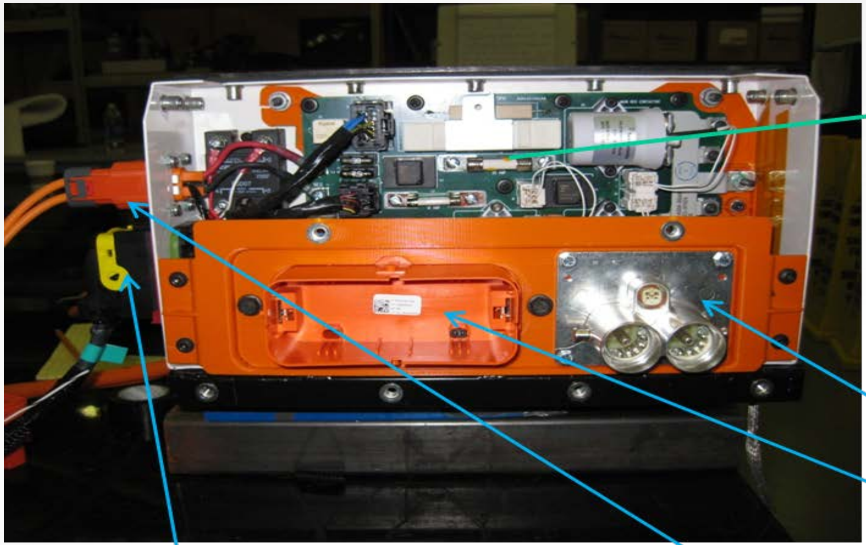


Picture of a Pack delivered to USABC

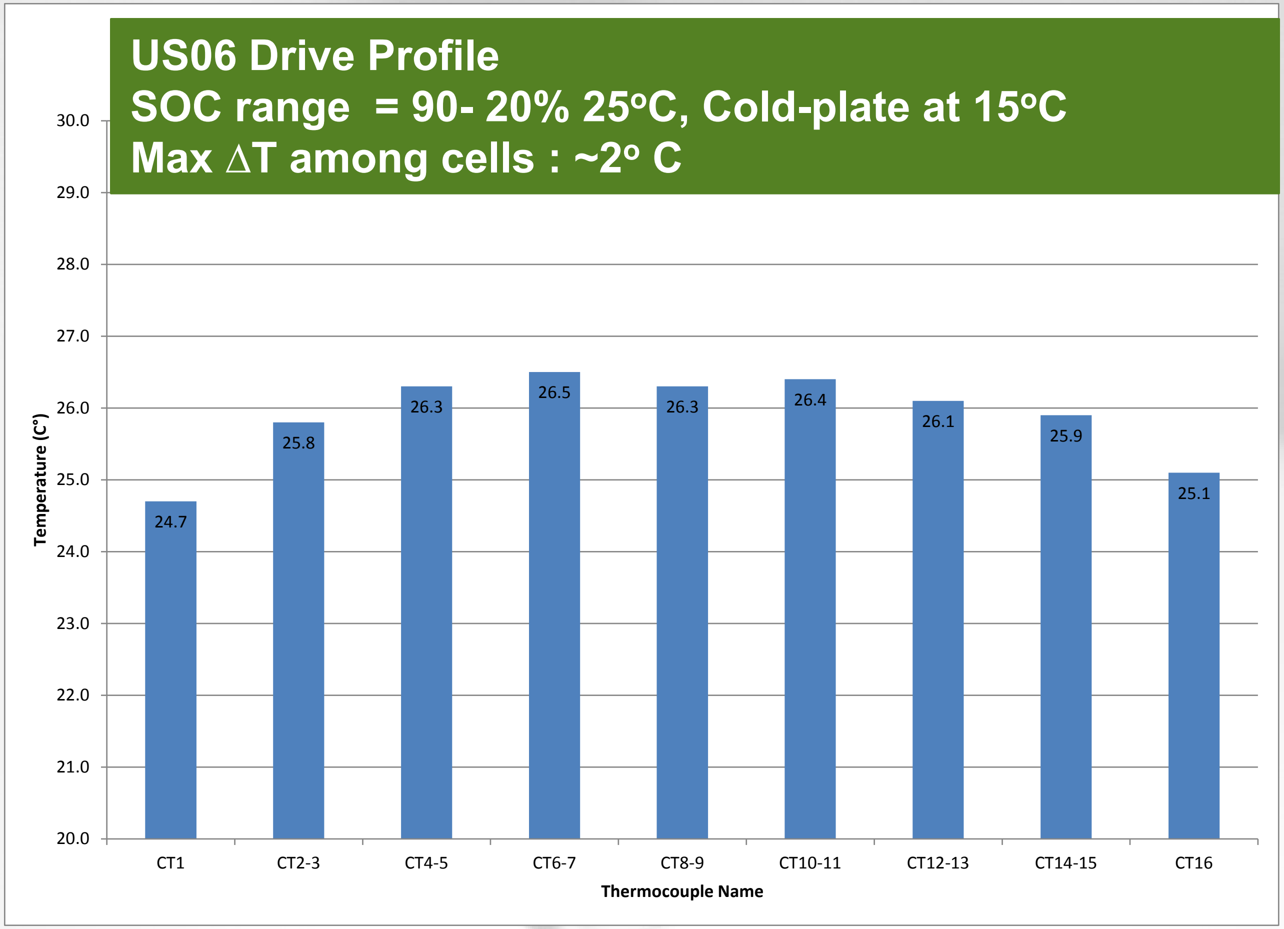


Results: *Thermal and Electrical Compartments*





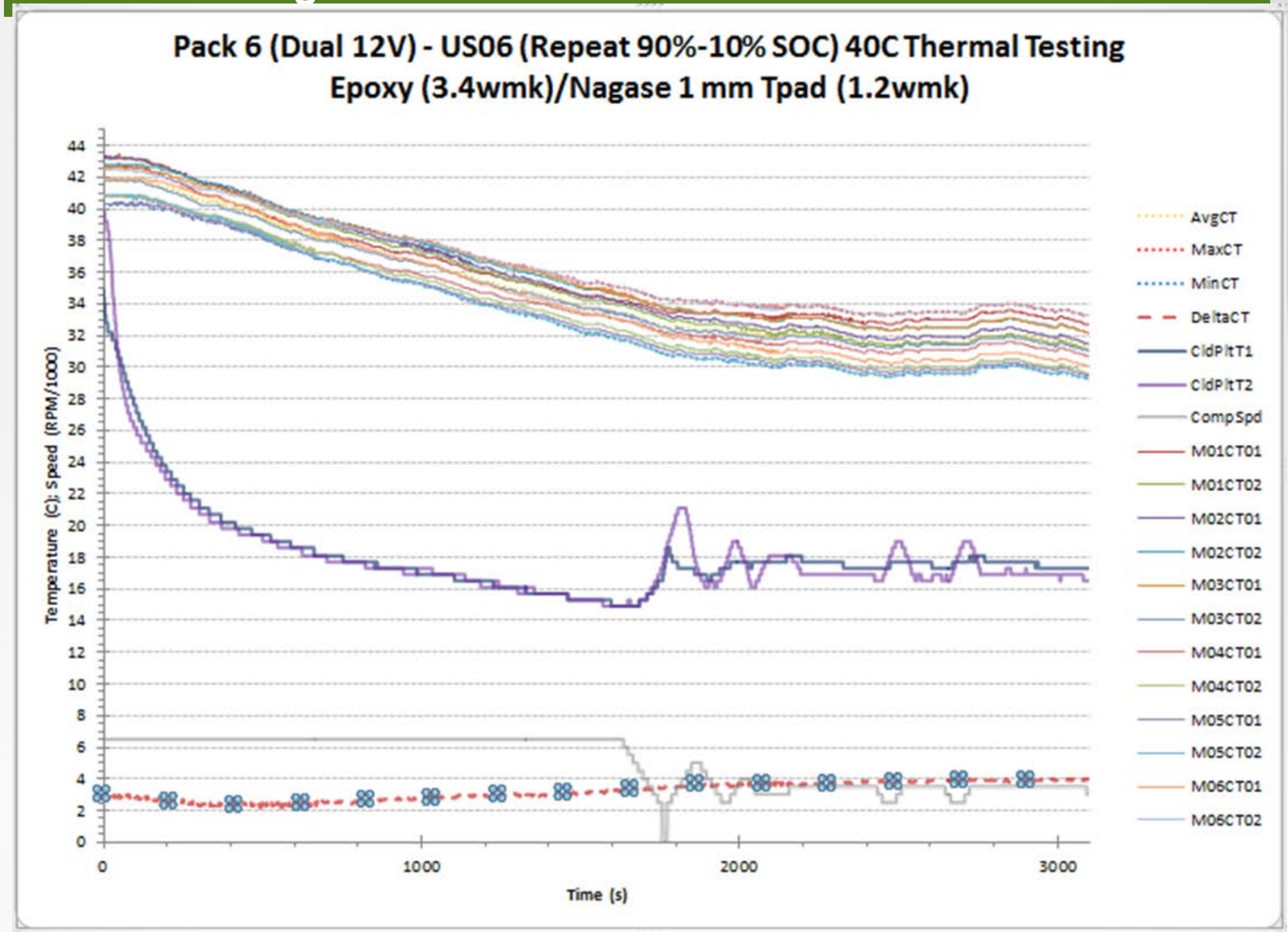
Results: *Cooling System- Module Level Testing*



- **Efficient cooling- satisfies target**

Results: *Cooling System- Pack Level Testing*

UDDS Drive Profile
SOC range = 90- 20% 25°C, Cold-plate at 15°C
Max ΔT among cells : ~0.5° C



Results: *Cooling System- Pack Level Testing*

UDDS Drive Profile
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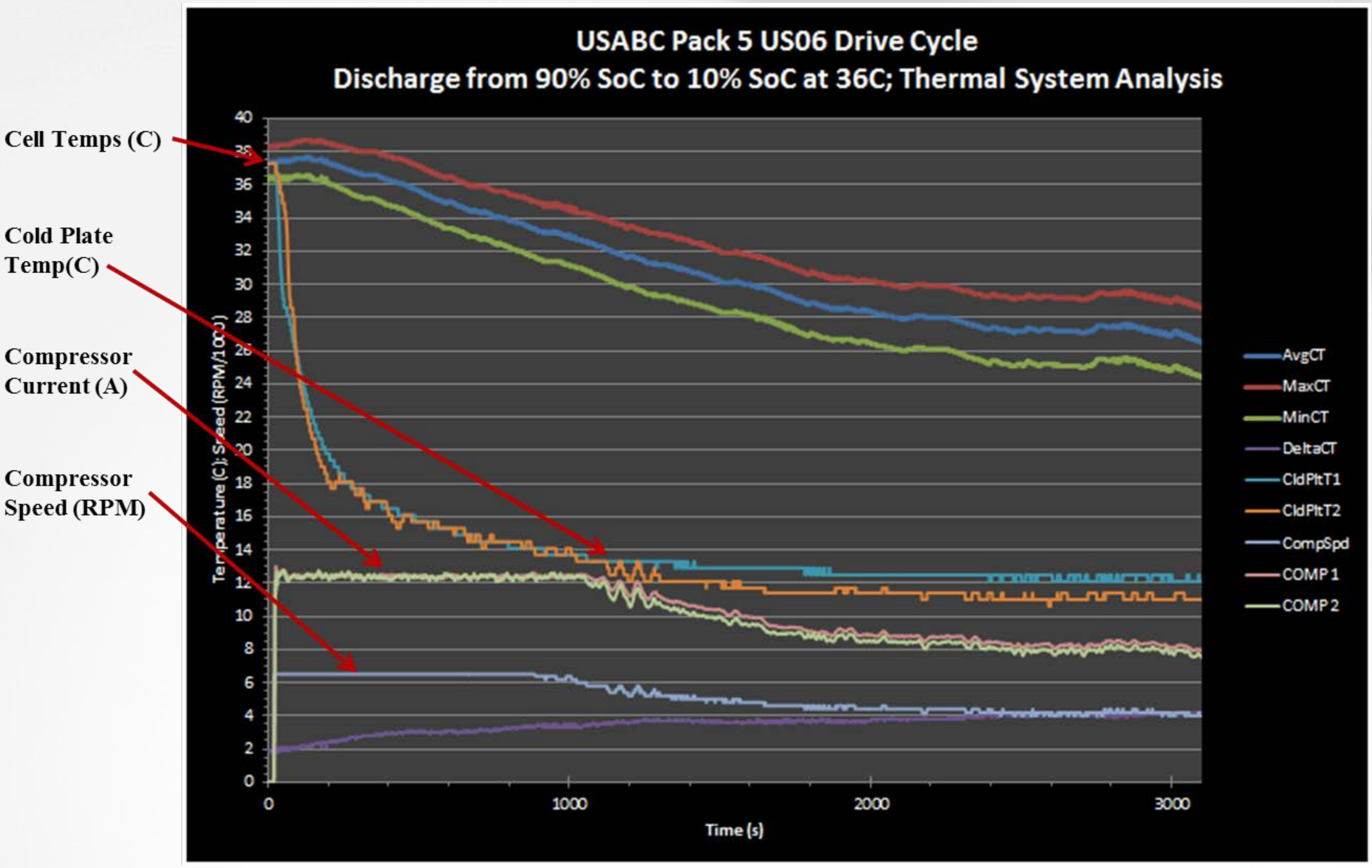

Future Work

- Studies to develop Gen 2 of cells having improved life and performance are currently underway. These include:
  - Use surface-modified cathodes
  - Use of new electrolyte compositions/additives.
- Delivery of Gen 2 cells to National Labs for evaluation with improved power and life.
- Delivery of final packs to National Labs.

Use of LGC's Cells in Production Vehicles

OEM	Vehicle
GM	Chevy Volt
Ford	Focus BEV
Hyundai	Sonata Hybrid
Volvo	XC 60
Renault	Zoe

- **These cells benefitted directly from the development programs LGCPI had with USABC.**

Acknowledgements

- LGCPI team (Paul Laurain, Satish Ketkar, Jongmoon Yoon and Kwangho Yoo)
- LG Chem team (Geun-Chang Chung, Hoejin Ha, Song-Taek Oh, Jaepil Lee)
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