A High-Performance PHEV Battery Pack

PI: Mohamed Alamgir and Geun-Chang Chung

LG Chem Power / LG Chem

May 16, 2012

Project ID: ES002

LG Group at a Glance

- Established Lucky Chemical Industrial Corp. in 1947
- Changed its name from Lucky Gold Star to LG in 1995

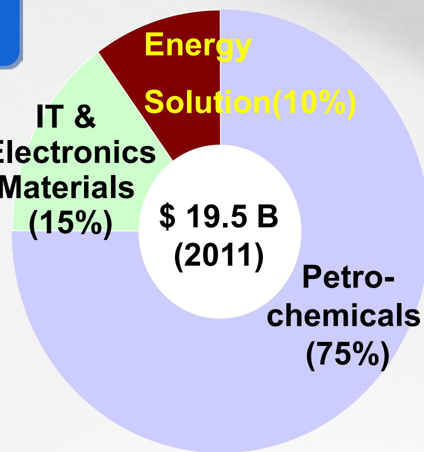
LG

- ✓ Sales (2011) – $124B
- ✓ Employees – 210,000

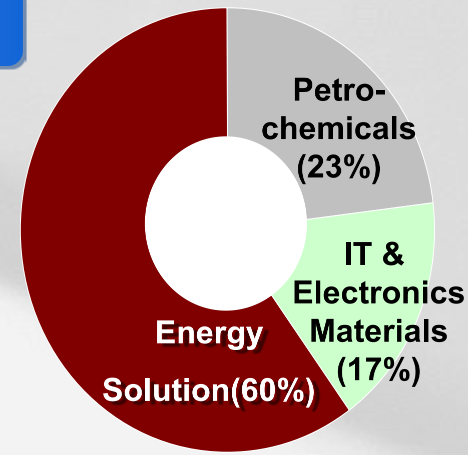
Electronics	Chemical	Telecom & Service
LG Electronics	LG Chem	LG U+
LG Display	LG Hausys	LG CNS
LG Innotek	LG Healthcare	LG Solar Energy
LG Siltron	LG Life Sciences	LG International
…	…	…
9 Companies	*13 Companies*	*33 Companies*

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

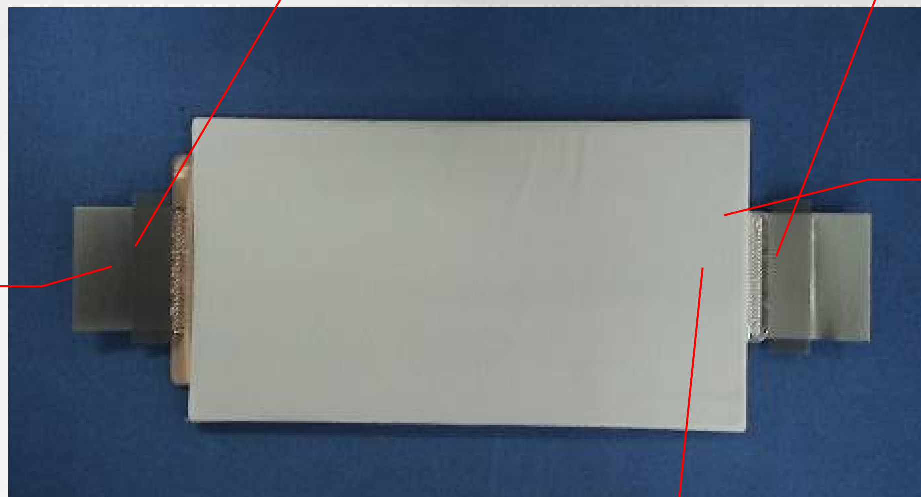
IT & Electronics Materials

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

LGCPI	LGCMI
➢ Battery Pack Concepts, Design and Prototype Builds ➢ Battery Management Systems ➢ Sales and Customer Support	➢ $300M+ investment with ARRA funding ➢ Groundbreaking: Summer 2010 ➢ Production begins in 2012
	
Troy, MI	**Holland, MI**
Sales & Pack R&D	***Cell Manufacturing***

Cell Structure: Unique Stack- and-Fold Design

Stacking of Plates & Folding

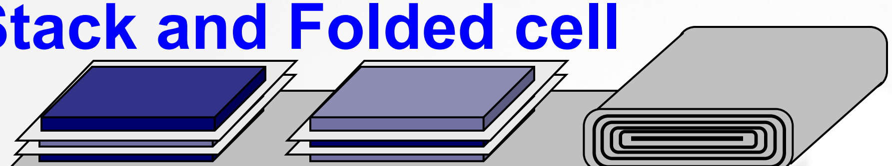


Lead film (insulation tape)

Positive terminal

Negative terminal

Stack and Folded cell



Bi-cell

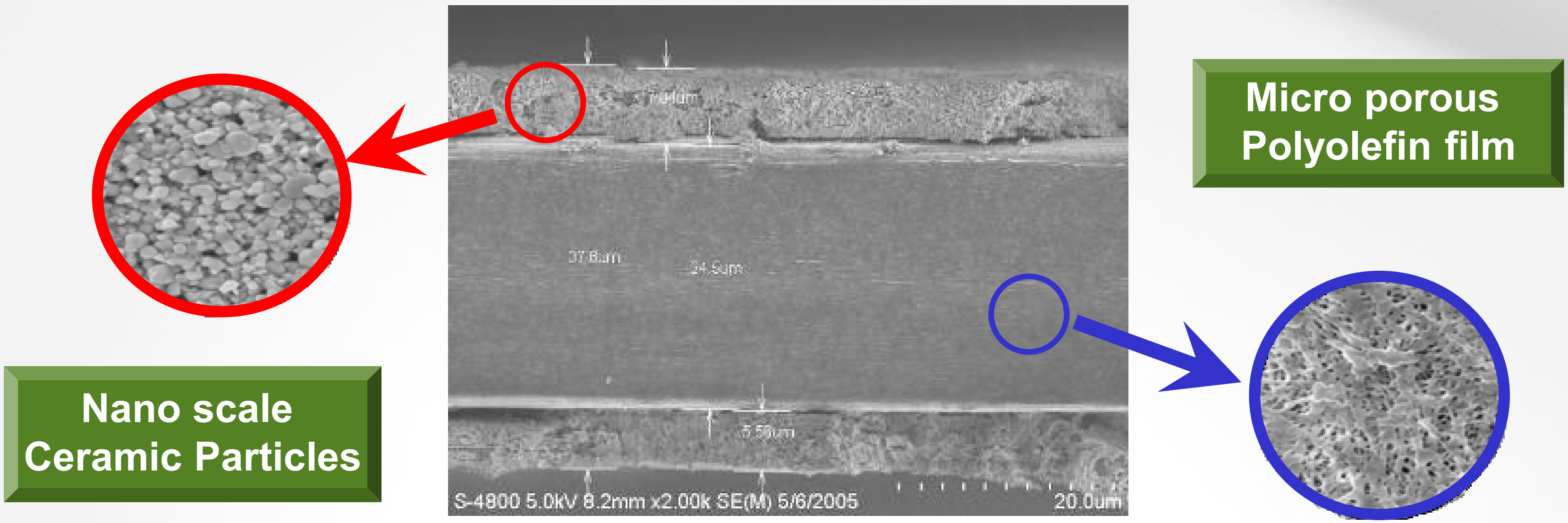
SRS™

Laminated film

Proprietary Safety Reinforcing Separator (SRS™)

SRS™ 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: March 31, 2013
- Percent complete: 50%

Budget

- Total project funding: $9.6M
- DOE share: $4.8M
- Contractor share: $4.8M
- Funding for FY11: $3.2M

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.
- Optimize 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-Air cooling system we have developed in our earlier USABC Program.**

Technical Accomplishments/Results

- Mn-rich cathode materials from two vendors have been evaluated.
- Built cells with careful 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.

Technical Accomplishments/Results

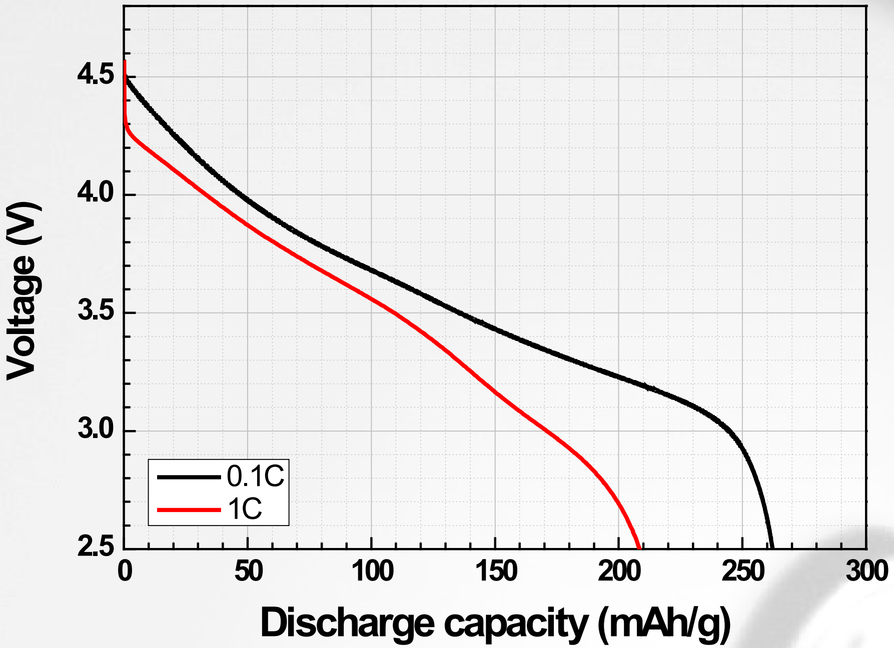
- Our 1st generation Refrigerant-to-Air pack has been redesigned and is being optimized with respect to
  - Weight,
  - Volume,
  - Power demand.

- Cell- and Module level thermal studies have been carried out to examine the efficacy of this cooling concept.

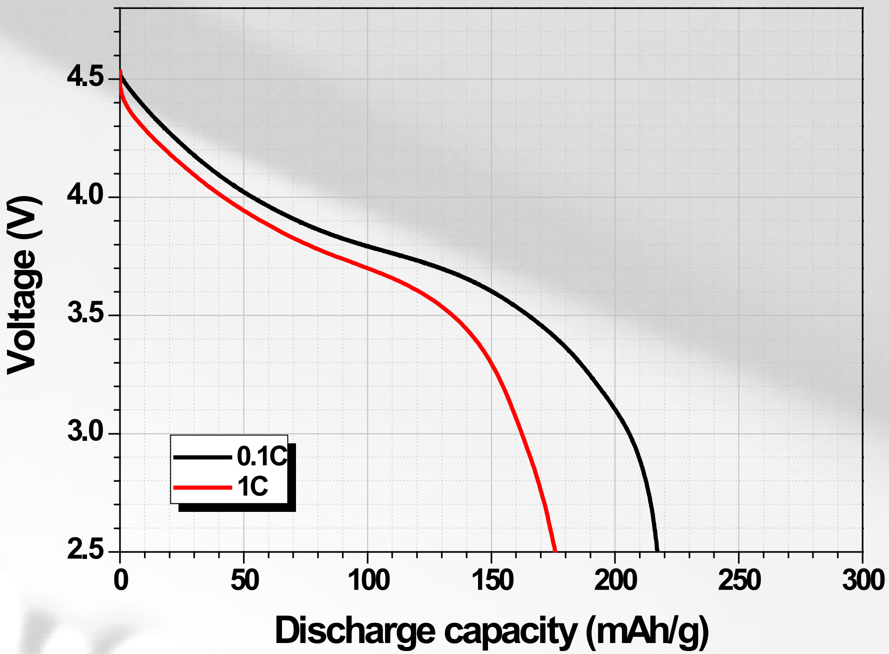
- First prototype packs have now been built and are being evaluated for cooling efficiency.

Results- *continued……*

Sample A

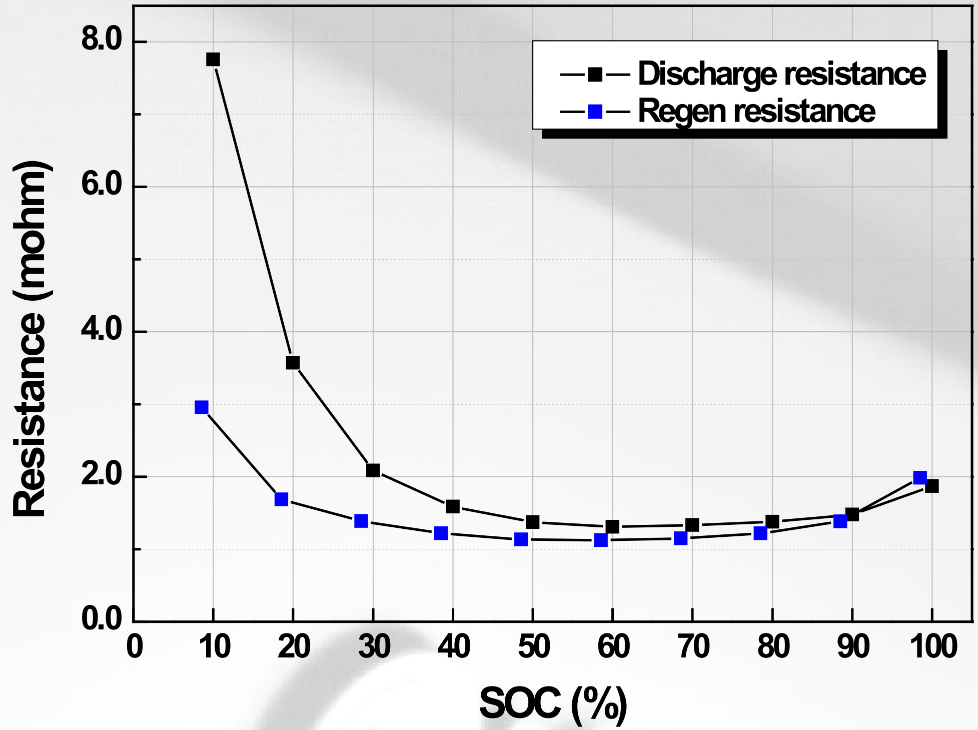


Sample B



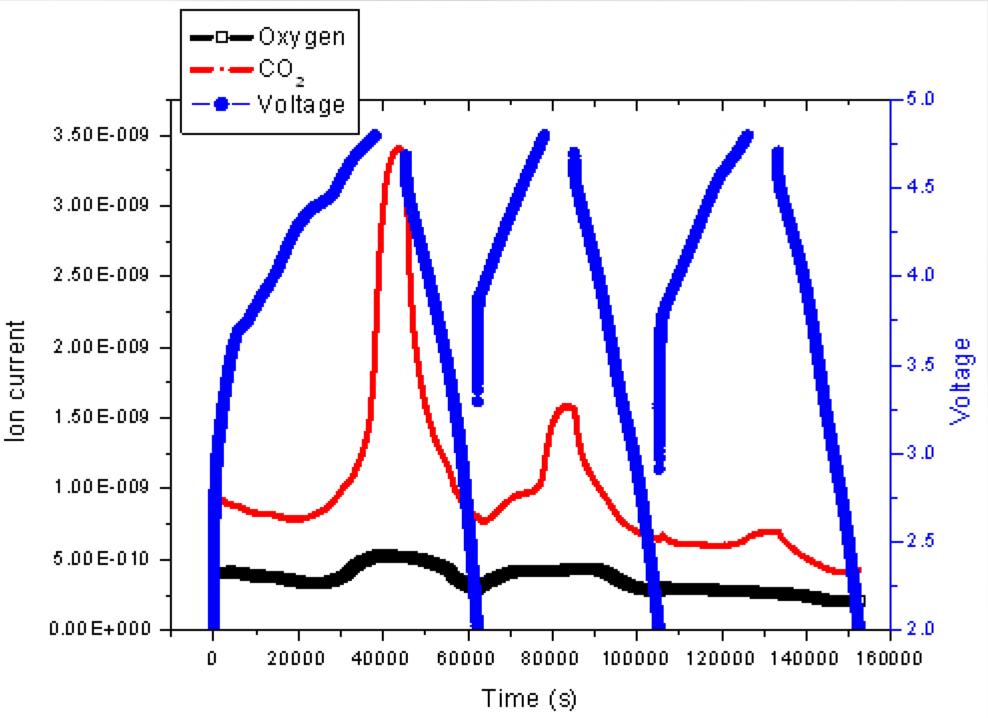
- **Baseline studies with Mn-rich cathodes show capacities as high as ~ 250 mAh/g at RT.**
- **Strong dependence on rate.**

Results- *continued……*



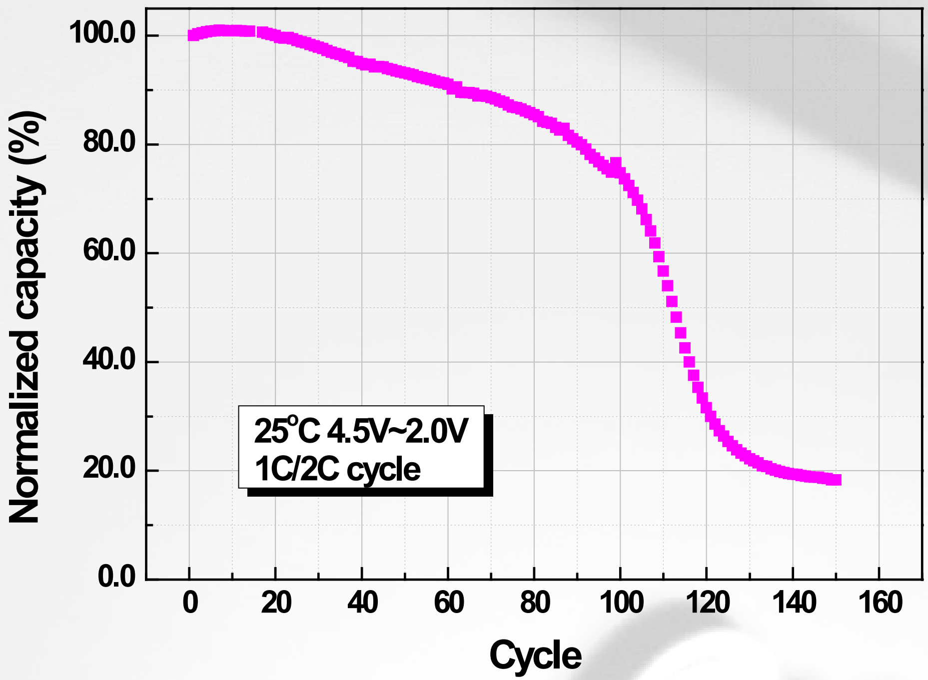
- Rapid increase in DC resistance at low SOCs.
- This can limit the usable SOC range for PHEV applications.

Results- *continued……*



- High voltage charging to access higher capacity leads to considerable gas evolution.
- This might necessitate considerable adjustment in cell processing conditions such as formation.

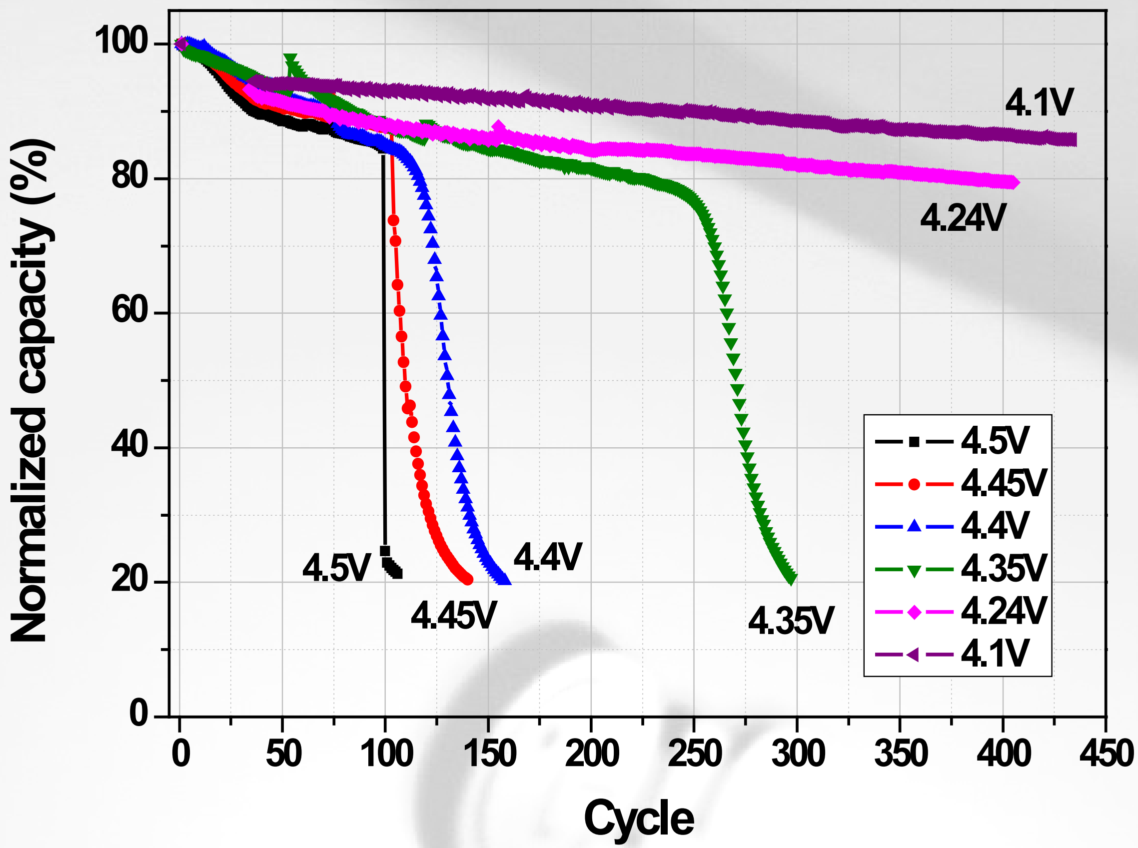
Results- *continued……*



Co	Mn	Ni
24 ppm	145 ppm	19 ppm

- **High voltage operation results in severe Mn dissolution in regular electrolyte.**
- **Need to identify suitable electrolyte**

Results- *continued……*

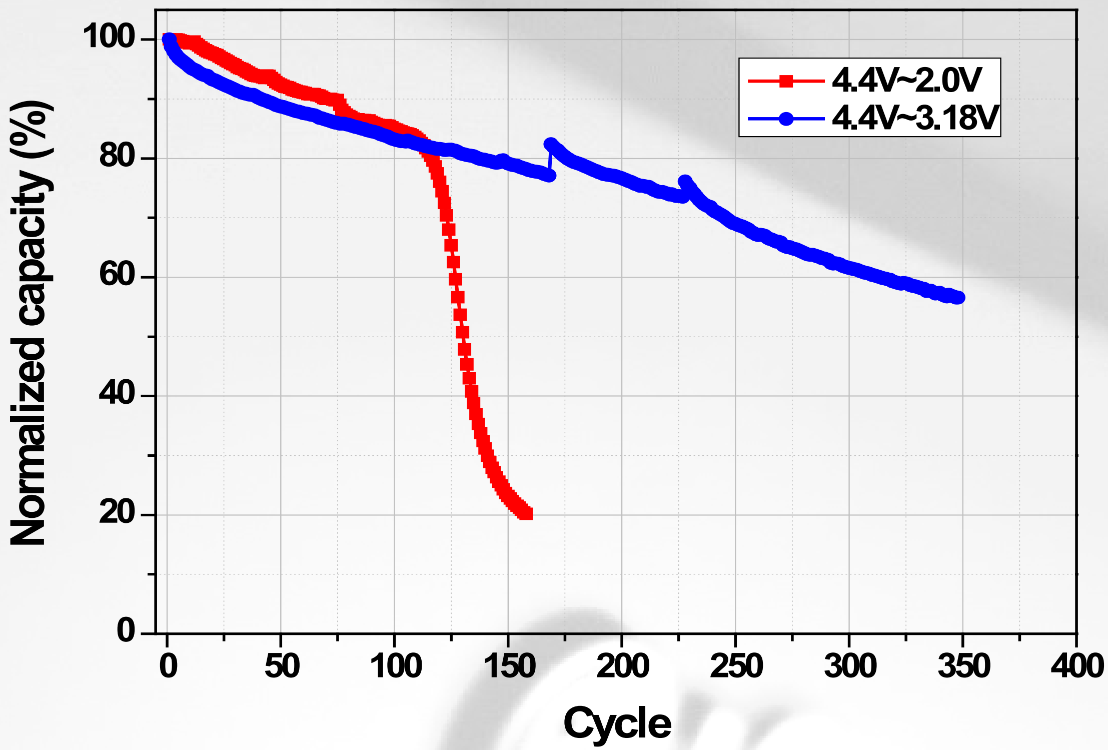


45°C

1C/2C cycle

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

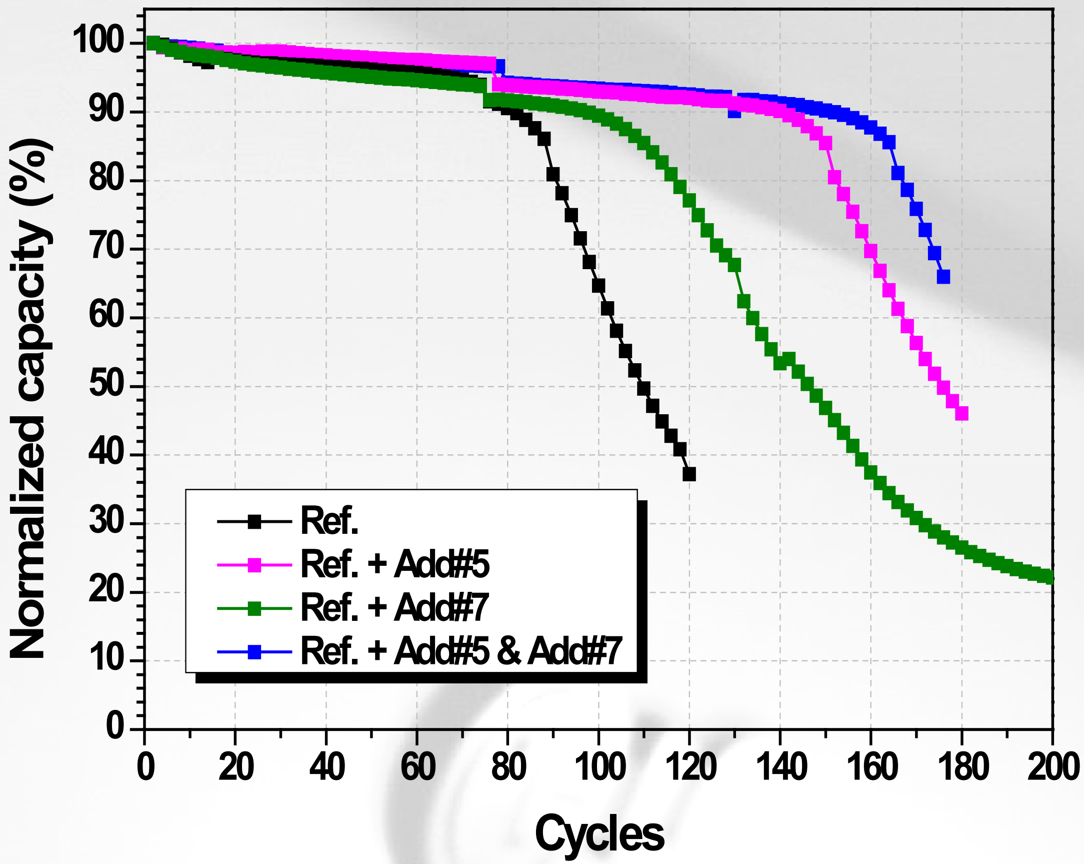
Results- *continued……*



45°C
1C/2C cycle

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

Results- *continued……*



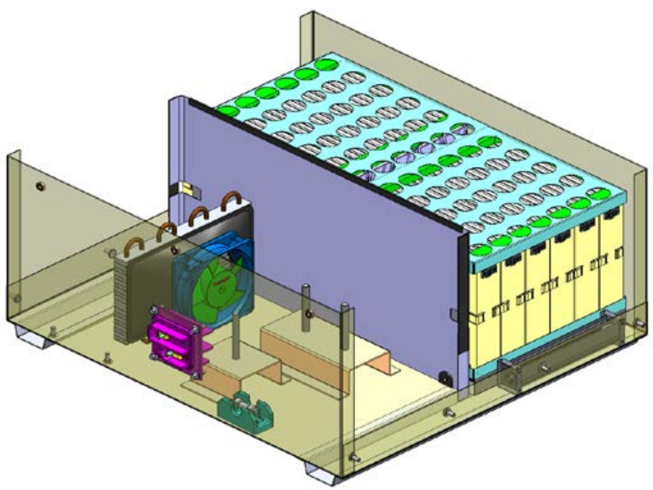
45°C 4.5V~2.0V
1C/2C cycle

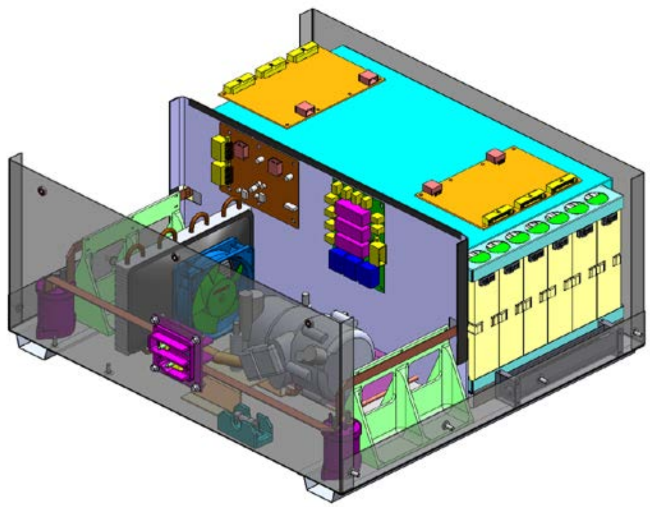
➢ **Electrolyte additives enhance cycle-life.**

Results: *Refrigerant Cooling System*

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

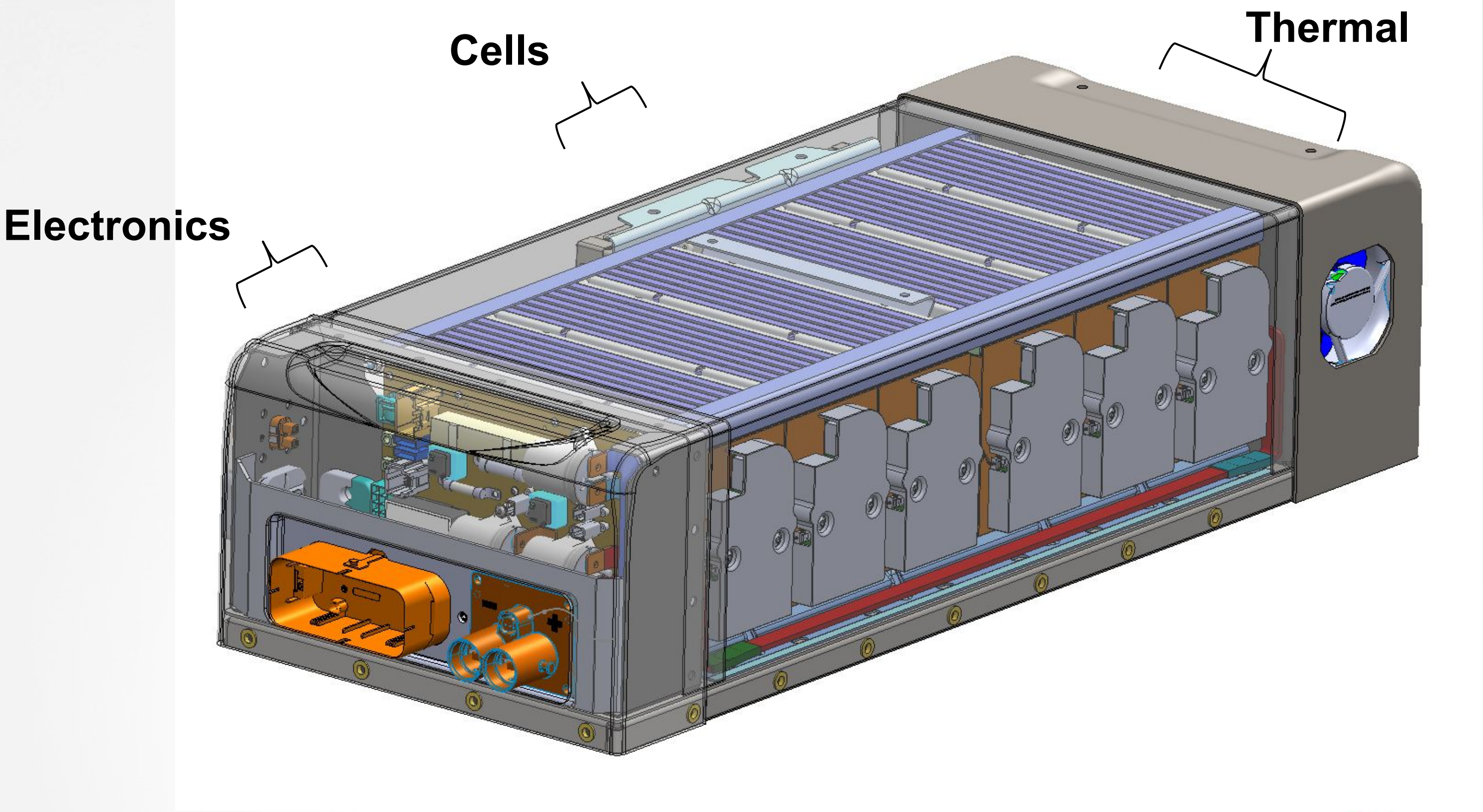
- **Phase I- Two thermal zones:**
  - **Refrigerated compartment (cells, evaporator, fan)**
  - **Ambient compartment (controls, compressor, condenser, fan)**



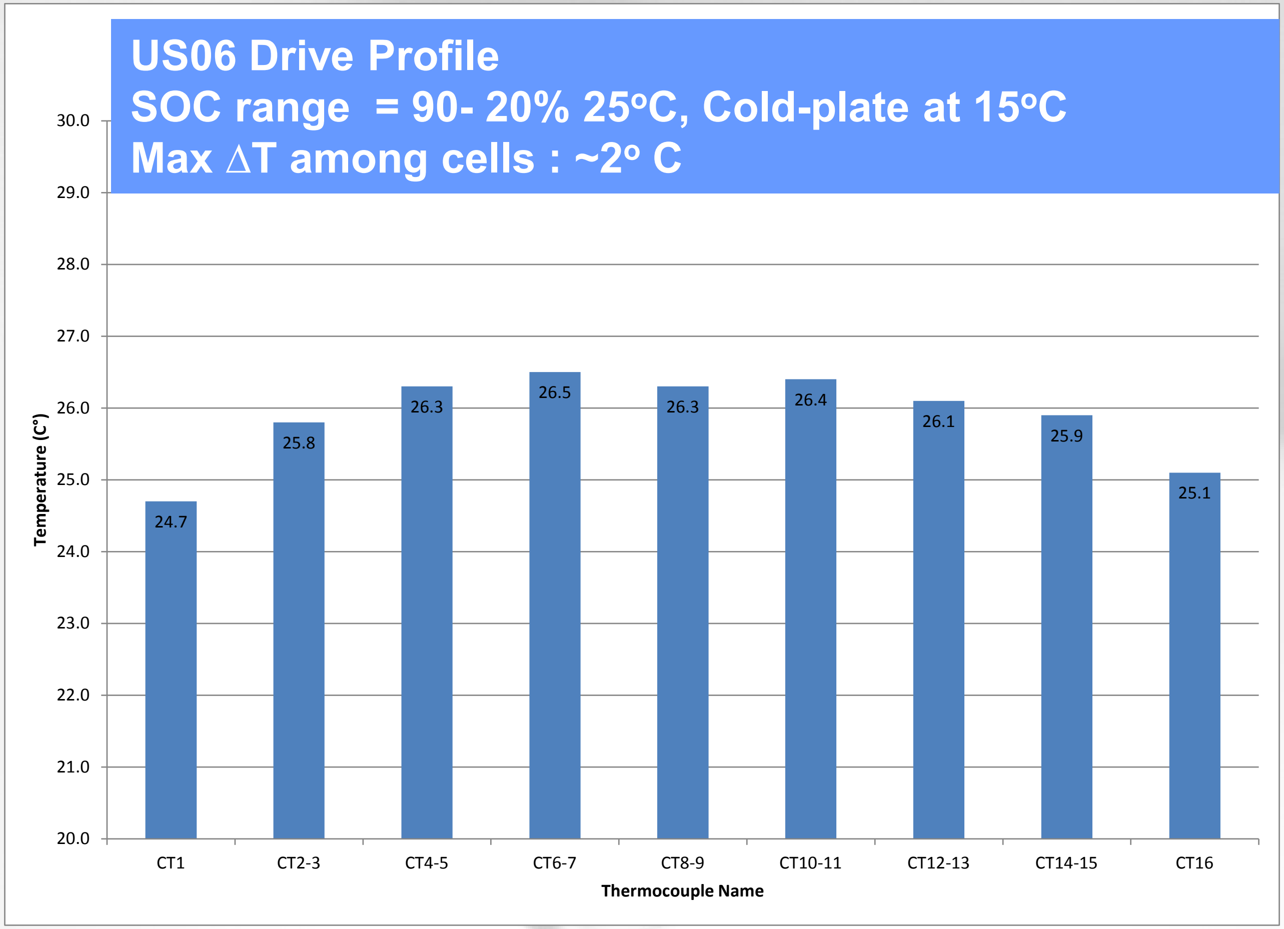


Results: *Phase II Cooling System- integrated design*

- **A refrigerant loop is used to cool the cold-plate inside the battery pack which in turn is attached to fins sandwiched between the cells.**

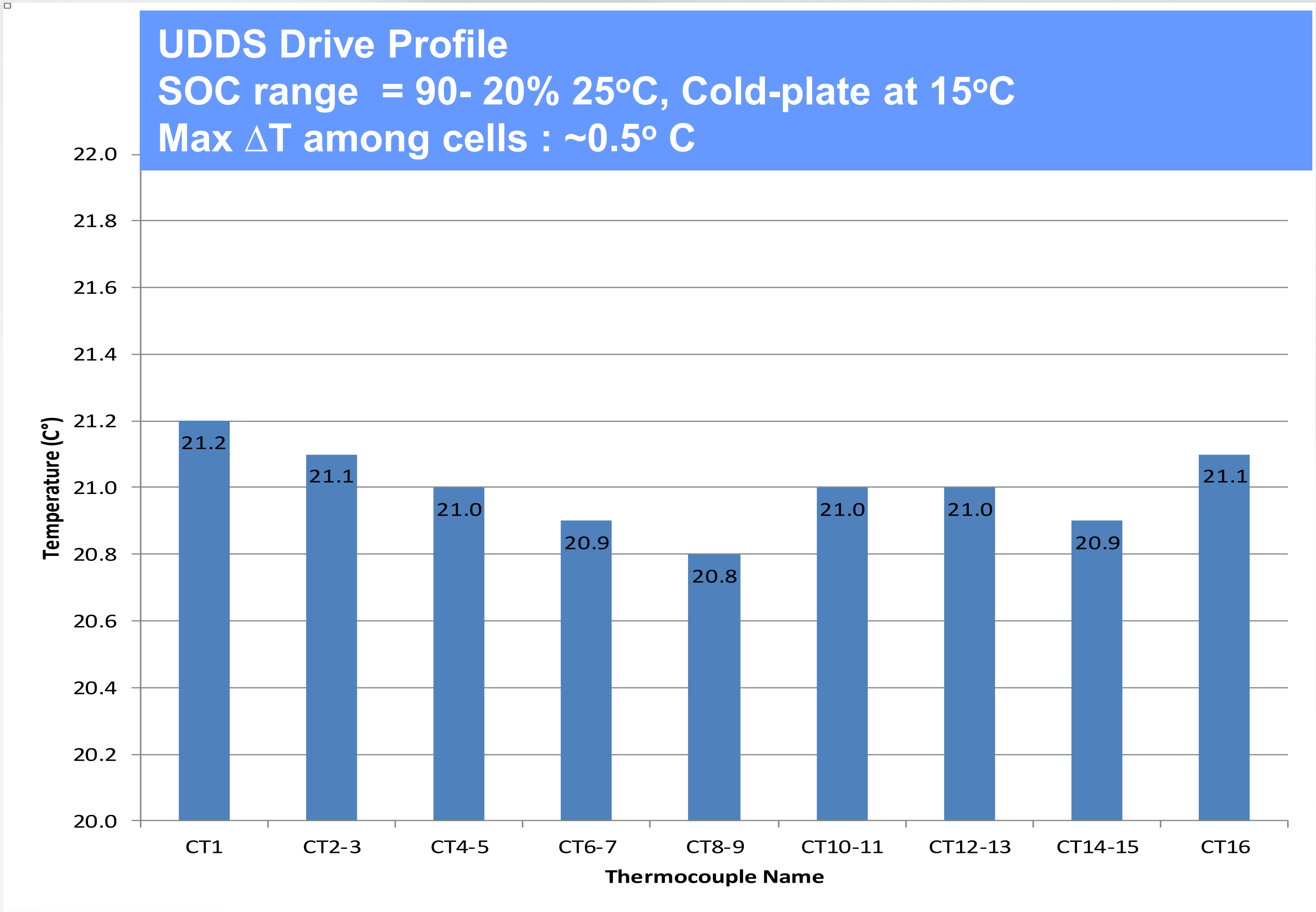


Results: *Cooling System- Module Level Testing*



➢ **Efficient cooling- satisfies target**

Results: *Cooling System- Module Level Testing*



Future Work

- Studies to improve power and life will include, among others
  - Surface-modified cathodes
  - Different electrolyte compositions/additives.
- Delivery of cells to National Labs for evaluation with improved power and life.
- Testing of prototype packs under various heat-loads using different driving profiles and additional optimization of the thermal system.
- Delivery of packs to National Labs.

Overview of Last PHEV Program

Timeline

- Project Start: Jan 1, 2008
- Project End: March 31, 2010
- Percent complete: 100

Budget

- Total project funding: $12.7M

Barriers Addressed

- Cycle-life
- Calendar-life
- Cold-Cranking Power
- Efficient/reliable thermal management system

Partners

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

Highlights of Past PHEV Program

Timeline

- Project Start: Jan 1, 2008
- Project End: March 31, 2010

Budget

- Total project funding: $12.7M

Barriers addressed

- Cycle-life
- Calendar-life
- Abuse-tolerance

Cell/ Approach

- Oxide-blend cathode/graphite
- Refrigerant-to-air cooling system

Key Results

- Cycle-life improved significantly: 5000 cycles
- Calendar-life needs additional improvement

Highlights of Past HEV Program

Timeline

- Project Start: Sep 1, 2006
- Project End: Feb 29, 2008

Budget

- Total project funding: $6.3M

Barriers addressed

- Cycle-life
- Calendar-life
- Cold-Cranking Power

Cell/ Approach

- Spinel/Hard-Carbon
- Approaches used:

  coatings, dopants, use of electrolyte additives

Key Results

- Cycle-life improved significantly: > 550k cycles
- Calendar-life: > 10 yrs
- Excellent abuse-tolerance

Use of LGC's Cells in Production Vehicles

OEM	Vehicle	Cell
GM	Chevy Volt	PHEV
Ford	Focus BEV	PHEV
Hyundai	Sonata Hybrid	HEV

- **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, Song-Taek Oh, Jaepil Lee)
- USABC for their financial and technical support in course of these programs.
- Paul Groshek- Program Manager
- INL (Jeff Belt), NREL (Ahmad Pesaran, Kandler Smith), LBNL (Vince Battaglia) and SNL (Chris Orendorff) for invaluable technical support