A High-Performance PHEV Battery Pack

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Compact Power / LG Chem

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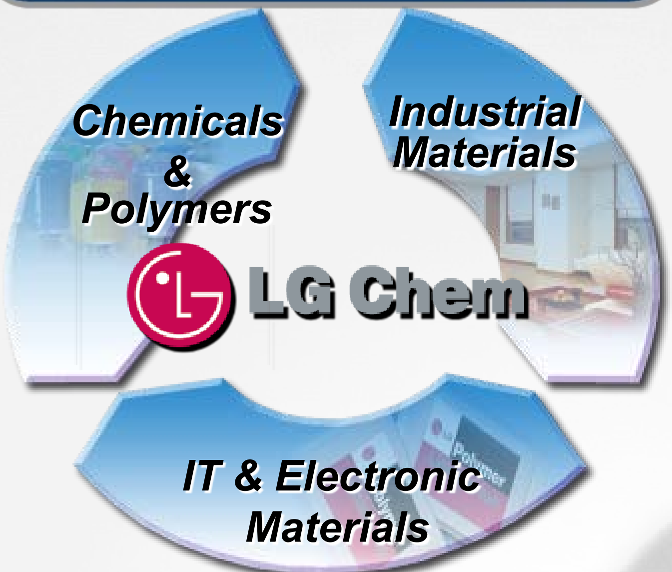
Project ID: ES002

CPI

- A wholly-owned subsidiary of LG Chem, based in Troy, MI.
- Established in Colorado in 2000 to focus on automotive batteries.
- Battery Pack Concepts and Designs
- Battery Management Systems
- Battery Pack Production and Support

LG Chem – a Global Company

Business Segments



- 40M cells/month

2007 Annual revenue : US $ 13.8b

Employees : 15,700

Global Network

- Manufacturing: China, Vietnam, India, USA, Poland
- Marketing
- Representative

Overview

Timeline

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

Budget

- Total project funding: $12.7M
  - DOE share: $4.45M
  - Contractor share: $8.25M
- Funding received in FY09
  - $2.5M
- Funding for FY10
  - $0.4M

Barriers

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

Partners

- LG Chem; INL, SNL, NREL
- Project lead: CPI

Objective

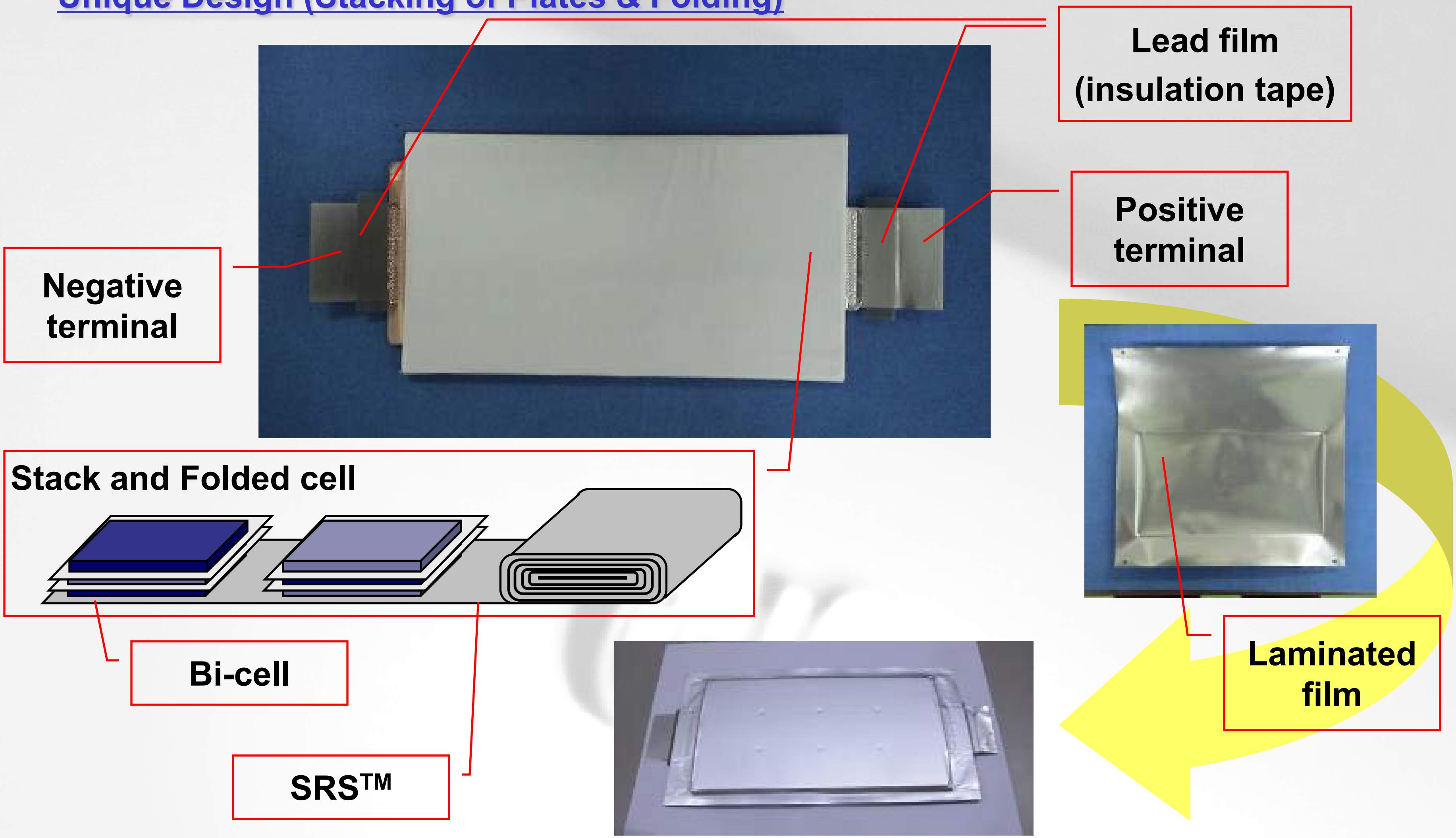
Objective: Develop a PHEV battery pack that will meet the life and cost targets of PHEV 10 mile battery.

Tasks:

- To develop a cell that is capable of delivering 5000 cycle-life and 15 yr life.
- To develop a cell that will meet the 7 kW cold-cranking power
- Develop and deliver a pack that has a reliable and highly efficient thermal management system

Simple Structure and Manufacturing

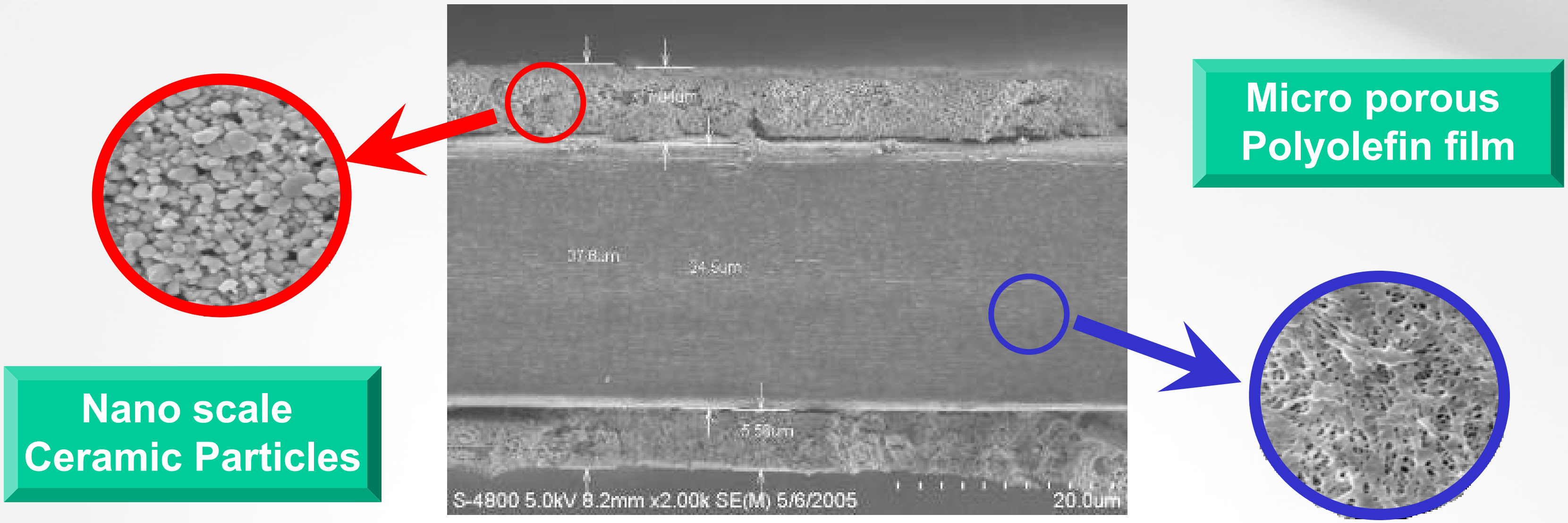
- Unique Design (Stacking of Plates & Folding)



Safety Reinforcing Separator (SRS™)

SRS™ provides LG Chem's lithium-ion polymer battery superior abuse-tolerance

- By preventing internal short circuit
- By improved thermal and mechanical strength



- Has significantly higher puncture strength than conventional separator

Basic Design- Large format cells

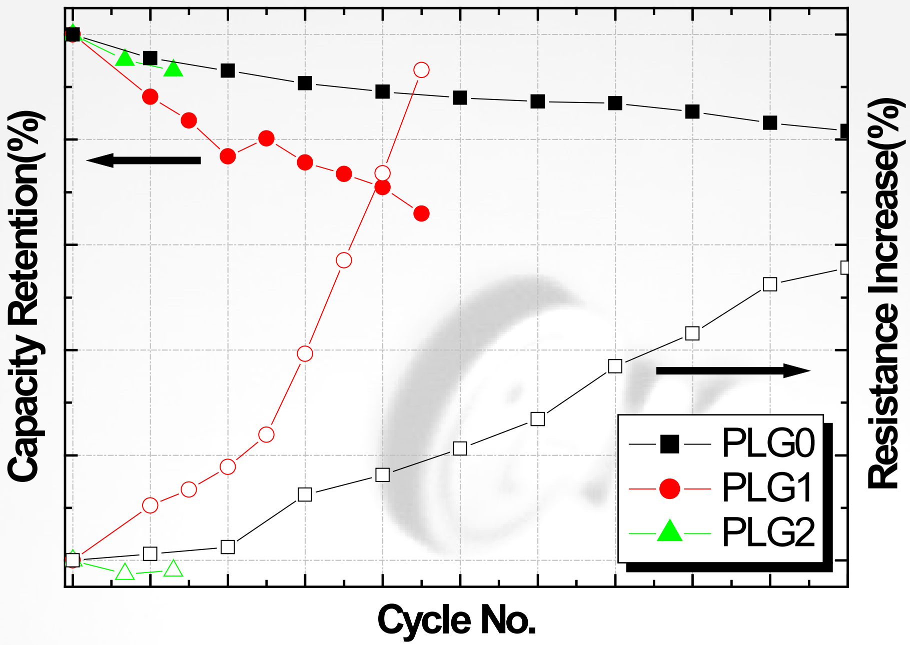
Components	Materials
Cathode	Mn-Spinel/layered mixed cathode
Anode	Graphite/Amorphous-carbon
Separator	SRS™
Electrolyte	$LiPF_6$ in Organic solvents (Gel type)
Packaging	Laminated

Cell Versions Tested

Component		PLG0	PLG1	PLG2
Cathode		$LiMn_2O_4$/layered	$LiMn_2O_4$/layered	Same as PLG1
Anode		Graphite	Graphite/Amorphous carbon	Same as PLG1
Electrolyte			• New solvent/additive compositions	• Same as PLG0
Feature	Cold-cranking Power	• Does not meet at EoL	• Higher cold-cranking power than PLG0.	• Similar power to PLG1
	Calendar life	• Poor	• Significantly better than PLG1	• Significantly better than PLG1 • Being validated
	Cycle life	• Meets target	• Does not meet target	• Expected to meet target • Being validated

Cycle-life

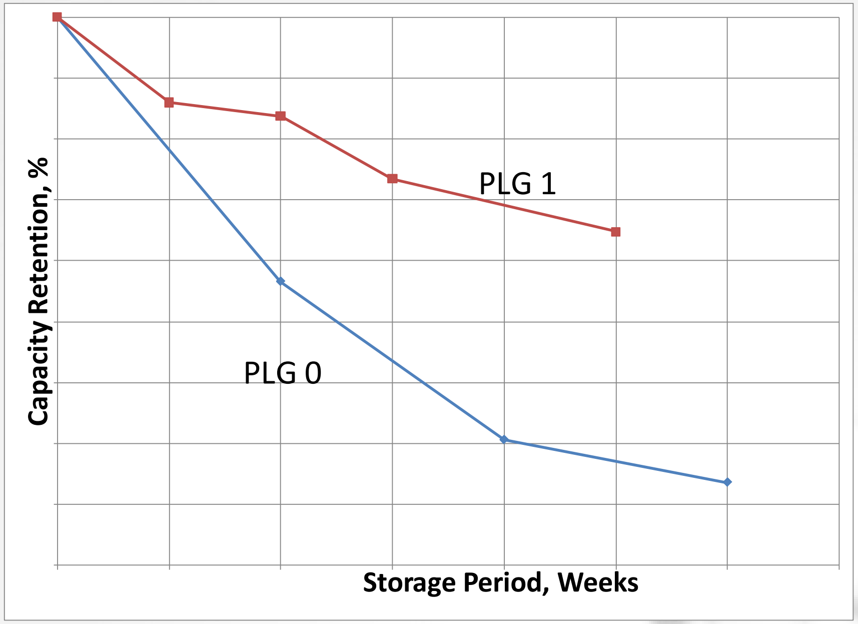
- Anode and electrolyte compositions were varied to improve cycle-life.
- PLG2 cells are expected to meet the USABC target life

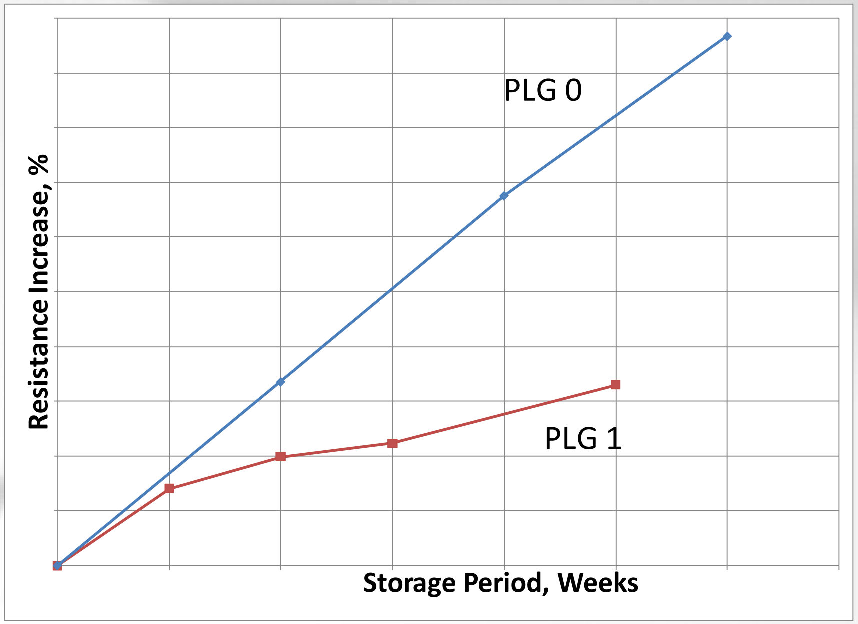


- CD Mode cycling
- 30^0C

Calendar-life

Accelerated Test: 60°C, 90% SOC

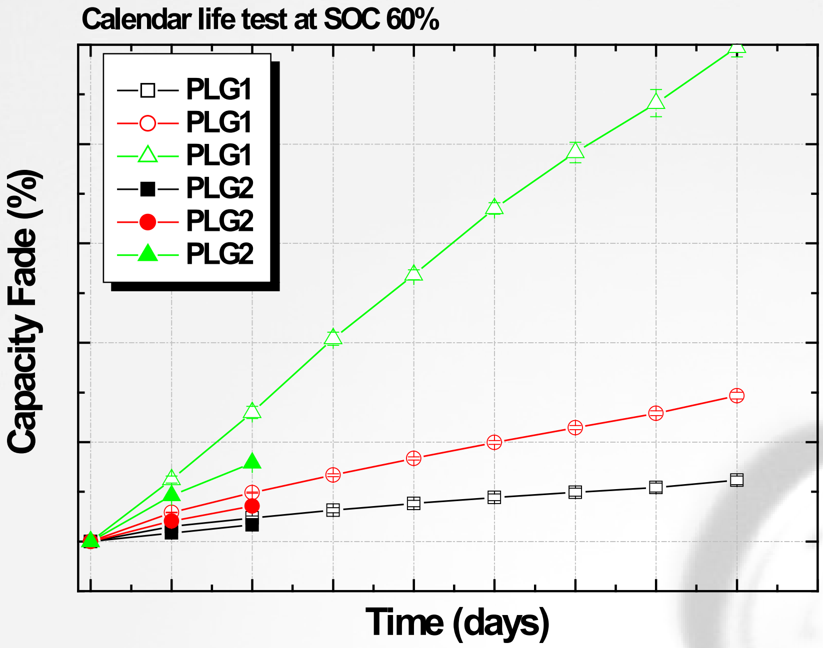


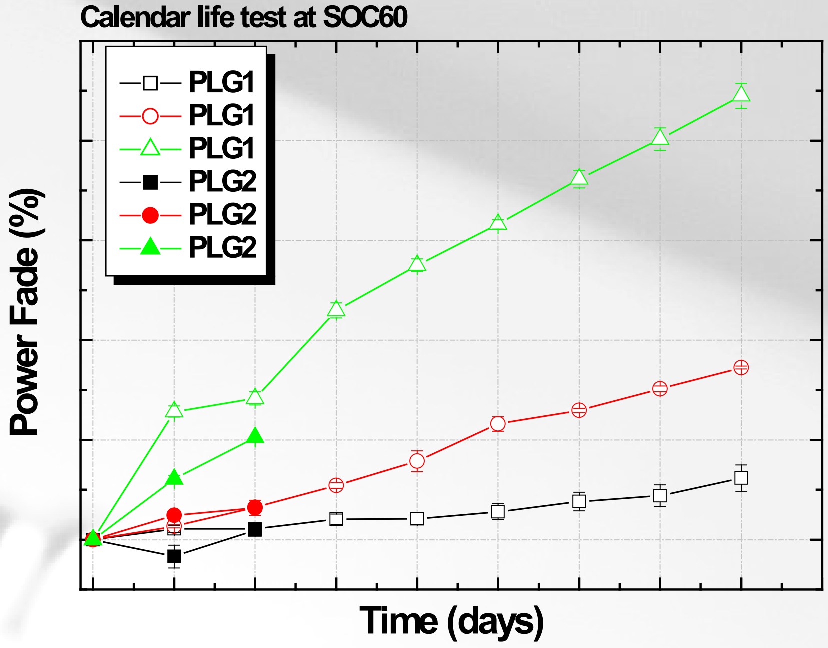


PLG0 and PLG1

Calendar-life

30, 40 and 50° C





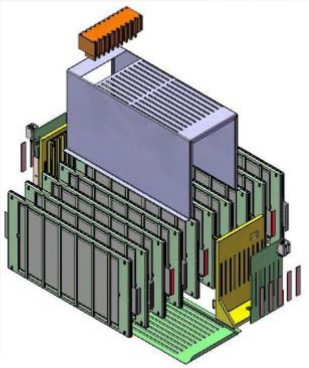
PLG1 and PLG2

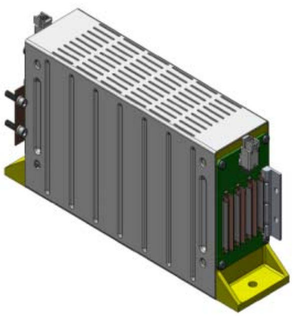
Gap Chart for PLG2

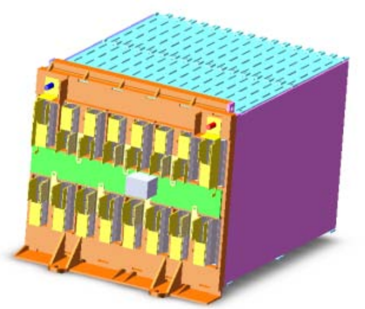
Characteristics at EOL (End-of-Life)	Condition	units	Minimum PHEV Battery	PLG1 (BOL)	PLG2 (BOL)	PLG2 (RPT2)
Peak Discharge Pulse Power for CS	10 sec	kW	45	102.6	113.6	109.3
Peak Regen Pulse Power for CS	10 sec	kW	30	68.5	75.8	72.8
Available Energy for CD	10 kW Rate	kWh	> 4.42 (BOL)	4.42	4.61	4.36
			3.4	3.4	3.4	3.4
Available Energy for CS	10 kW Rate	kWh	0.5	> 0.5	> 0.5	> 0.5
Cold cranking power	-30°C, 2sec, 3 pulses	kW	7.0	> 9.4	> 9.4	
Cycle-life (CD mode)	30° C	Cycles	5000			
Calendar-life	30° C	Years	15			
Cost		$	1750			

Pack Development: Architecture, Thermal Management

- **Laminated packaging cells** provide opportunities and challenges for module/pack building- how to hold them (vertical or horizontal), how to weld leads together etc.
- **Modular architectures enable:**
  - Lower piece cost by enabling lower cost automation, shipping, etc.
  - Lower investment (tooling) by commonizing repeating parts







Thermal Management

➢ Pack Thermal Challenges

- Remove accumulated heat from environmental soaking ("parked on hot asphalt")
- Remove operating environmental heat (exhaust, ambient road heat while driving)
- Maintain inter-cell temp $\Delta < 3\text{-}5$ C
- Remove heat generated by cells during operation
- Add heat to cells during start up in very cold climates

➢ Improved Thermal Management ➔ Longer Cell Life

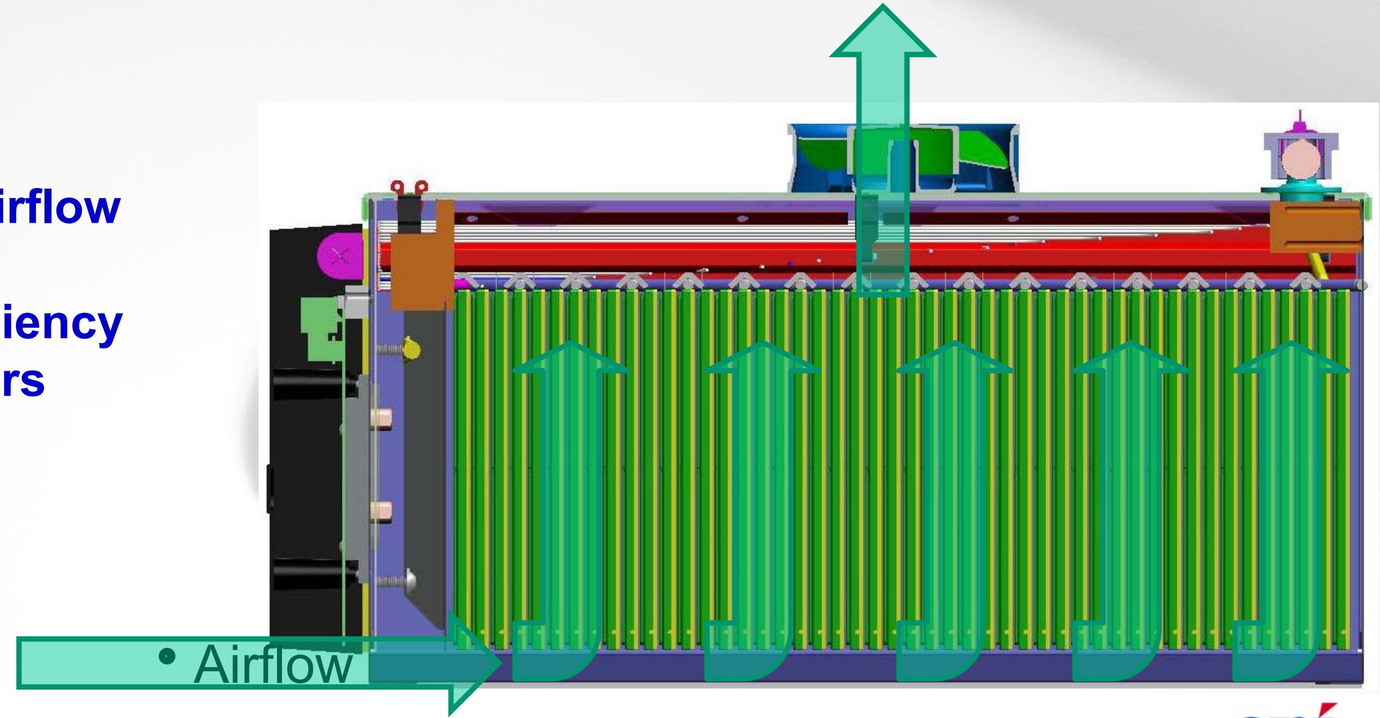
➢ Methods

- Air
- Liquid Coolant
- Refrigerant

Thermal Management: Air Cooling

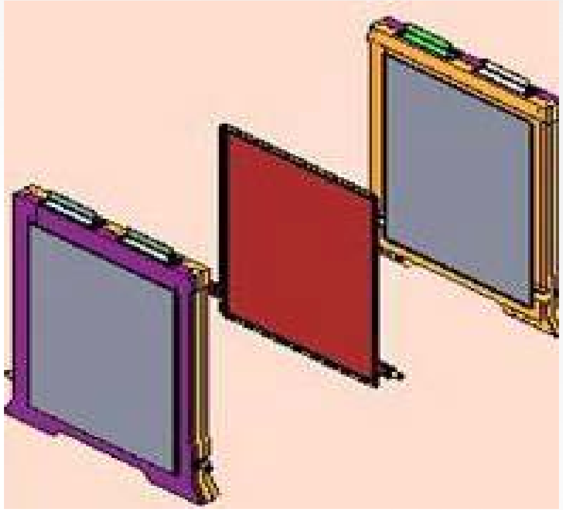
- **Attractive for most vehicle applications**
  - **Low heat generation and even thermal distribution mean low cooling demand (once environmental heat is removed)**
    - **Cabin air generally cool enough to remove heat**
    - **Blower and duct work required.**
  - **2 mm spacing between cells is generally sufficient**

- **Opportunities**
  - **Improved airflow design**
  - **Higher efficiency fans; blowers**



Thermal Management: Liquid Cooling

- An option for certain conditions
  - Very dense cell packaging
  - High environmental heat loads
  - Also enables cell pre-heating (very cold environments)
- Requires <1mm spacing per cell
- Several challenges
  - Requires cooling loop (25-35 C)
  - Coolant fill and maintenance
  - Leak-tight interfaces

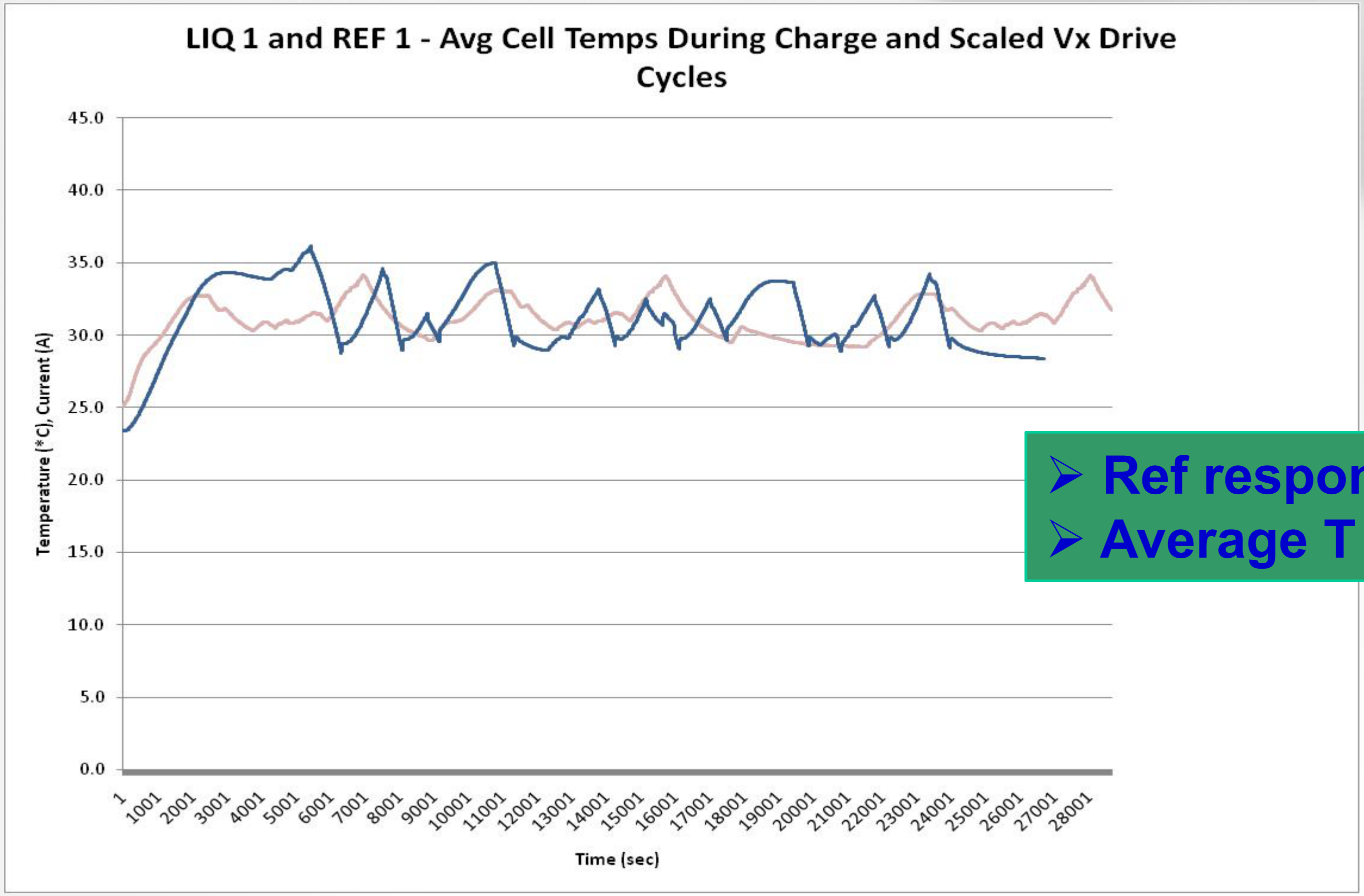


Thermal Management: Refrigerant Cooling

- A refrigerant loop is used to cool the air within the battery pack, which is then slowly circulated around the cells.
- The large temperature gradient between the air and the cells facilitates efficient heat transfer without the need for high velocity air circulation.
- An option for certain conditions
  - High environmental heat loads, cabin air not readily available and allows zonal control.
- Requires refrigerant loop; but:
  - Avoids coolant fill and maintenance, obviates need for complex coolant manifolding and risks of leaking.
- Challenges include balancing of chilled air flow around the cells.

Refrigerant-to-Air vs Liquid Cooling

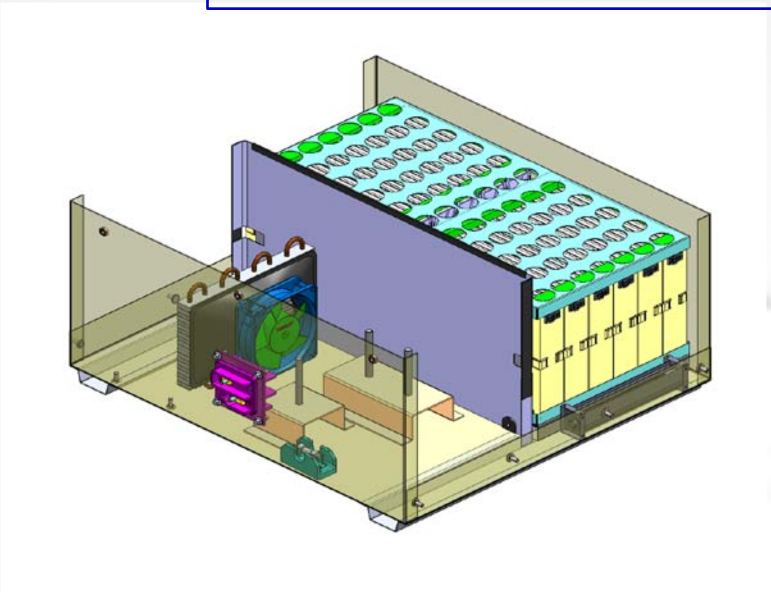
- Initial development work
- Test article: surrogate pack
- Drive profile: proprietary

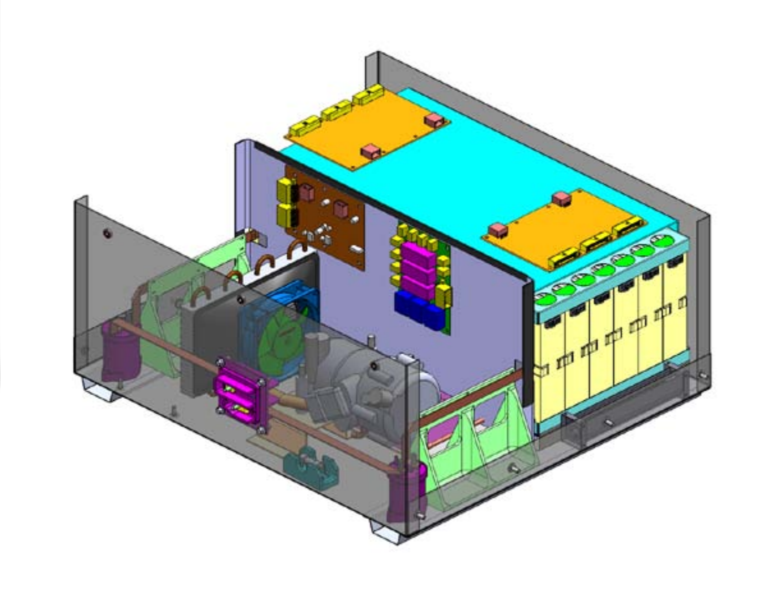


- Ref responds faster
- Average T similar

Refrigerant-to-Air Cooling

- Prototype system design
- Two thermal zones:
  - Refrigerated compartment (cells, evaporator, fan)
  - Ambient compartment (controls, compressor, condenser, fan)





Refrigerant-to-Air Cooling

Picture of a Pack delivered to USABC

Program Deliverables

	Month 9 (Sep, 08)	Month 22 (October, 09)	Month 27 (March, '10)
INL	20 Cells	40 Cells	3 Packs
SNL	12 Cells (Safety tests)	16 Cells	3 packs (+ 8 modules)
NREL	4 Cells (Thermal)	3 Cells (Thermal)	One of SNL packs makes a detour to NREL prior to SNL tests

SUMMARY

- By tailoring the compositions of the anode and the electrolyte, the cycle- and calendar-life of the PLG cells were significantly improved.
- We believe that the PLG2 cells will be capable of meeting the cycle-life target.
- The calendar-life of these cells needs to be validated and it is also in progress.
- We have developed a non-traditional thermal management system which we believe will be very efficient and reliable.

Acknowledgements

- CPI team (Martin Klein, Bill Koetting, Josh Payne, Dan McNeill)
- LG Chem team (Kwangho Yoo, Yojin Kim, Seungdon Choi, Youngjoon Shin, Jaepil Lee)
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- Harshad Tataria, Program Manager.

Chevy Volt

- GM selected LG Chem to be the cell as well as the electronics supplier for the Volt program (Jan 2009).
- Initial packs were manufactured by CPI/LGC. GM will produce the packs in high volume. Launch Nov 2010.

Thank You!