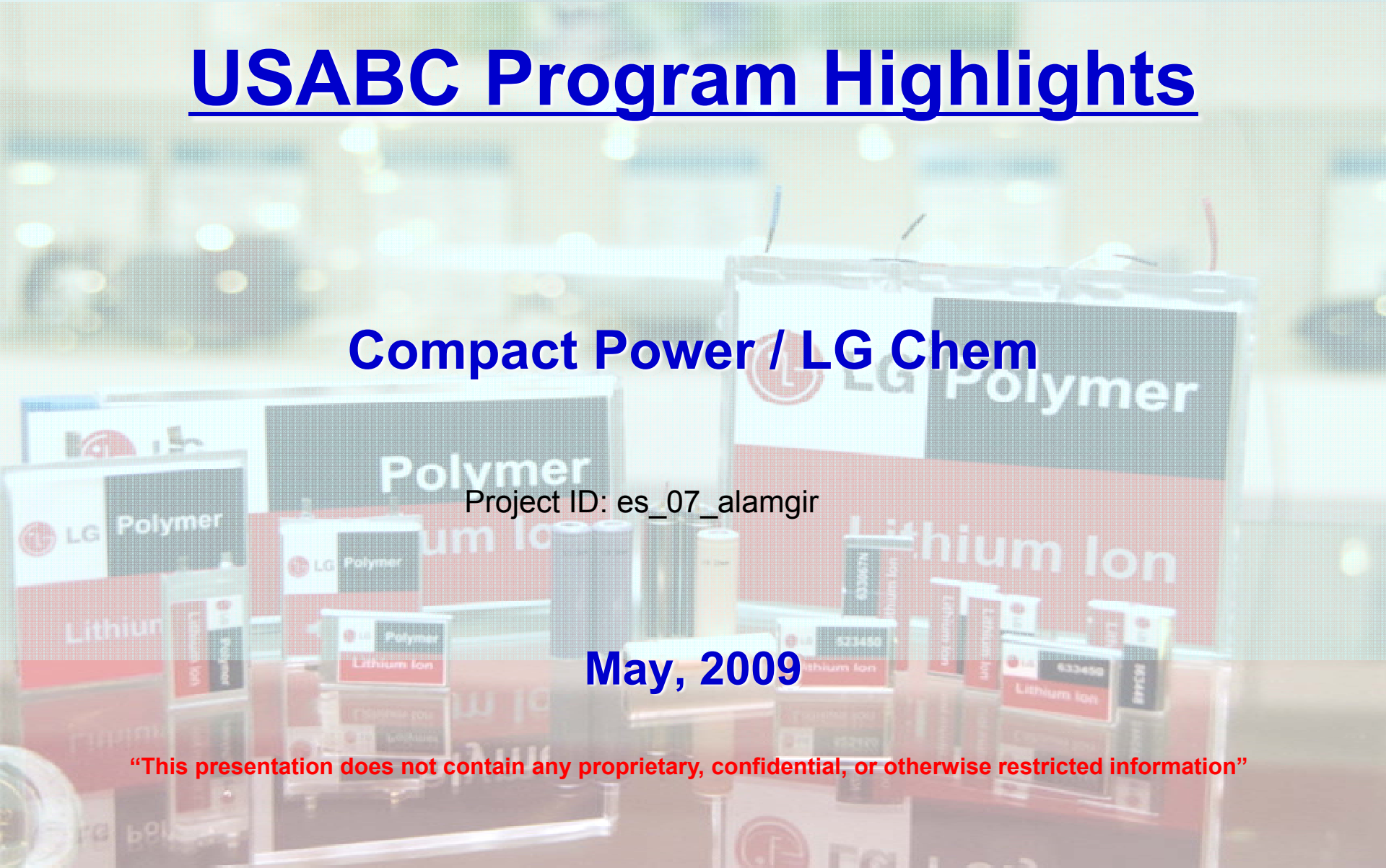
USABC Program Highlights



Compact Power / LG Chem

Project ID: es_07_alamgir

May, 2009

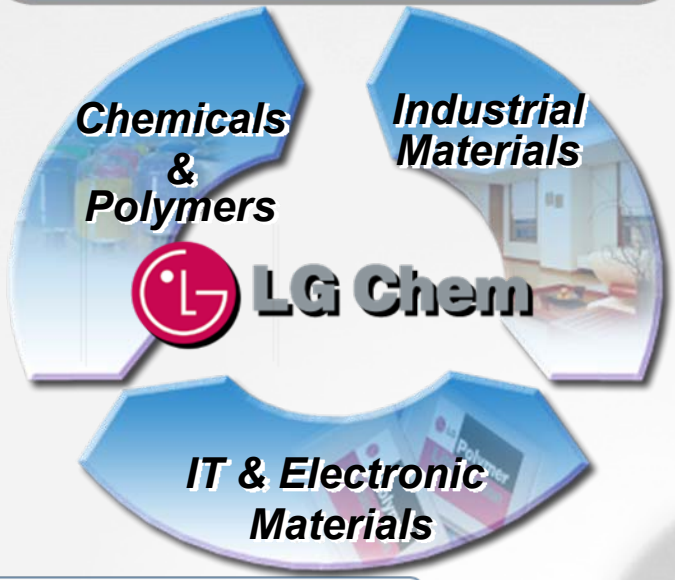
"This presentation does not contain any proprietary, confidential, or otherwise restricted information"

CPI

- **A wholly-owned subsidiary of LG Chem, based in Troy, MI.**
- **Established in Colorado in 2000 to focus on automotive batteries.**
- **Partner-of-Choice for Turn-key solutions for vehicular applications.**
- **Accumulated know-how in automotive and battery business**

LG Chem – a Global Company

Business Segments



- 40M cells/month

Global Network

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

2007 Annual revenue : US $ 13.8b

Employees : 15,700

CPI Focus: Pack Design/Production/Support

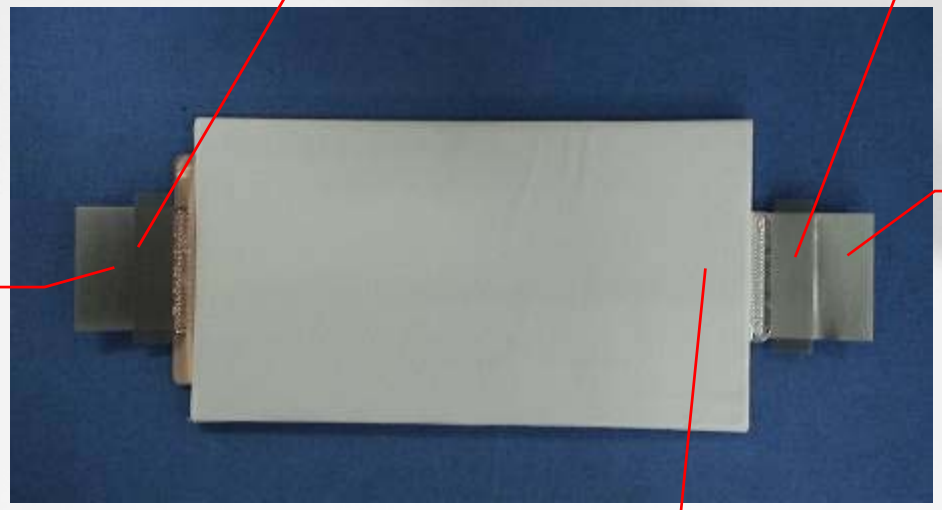
- **Battery Pack Concepts and Designs**
  - Power & Signal Architectures
  - Packaging
  - Thermal Management
- **Battery Management Systems**
  - Charge control algorithms (State-of-Charge estimation)
  - Vehicle interface
  - Diagnostics (State-of-Health estimation)
- **Battery Pack Production and Support**
  - Battery Program Management for US Customers
  - Pack-level Analysis, Validation, and Verification
  - System Integration & Test Support
  - Prototypes

Cell Construction Features

- **Unique Design (Stacking of Plates & Folding)**
  - High rate capability *(easy current collection)*
  - More suitable for scaling-up *(handling of long electrodes not required)*
  - Maintains dimensional stability during cycling
  - Proven technology in mass production of small cells
- **Robust laminated packaging design**
  - Much simpler, more reliable and less expensive manufacturing
  - Easy to change cell footprint

Simple Structure and Manufacturing

- Unique Design (Stacking of Plates & Folding)

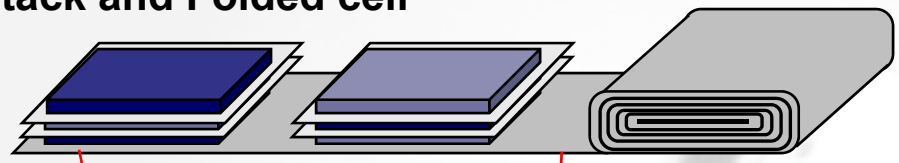


Lead film
(insulation tape)

Positive
terminal

Negative
terminal

Stack and Folded cell



Bi-cell

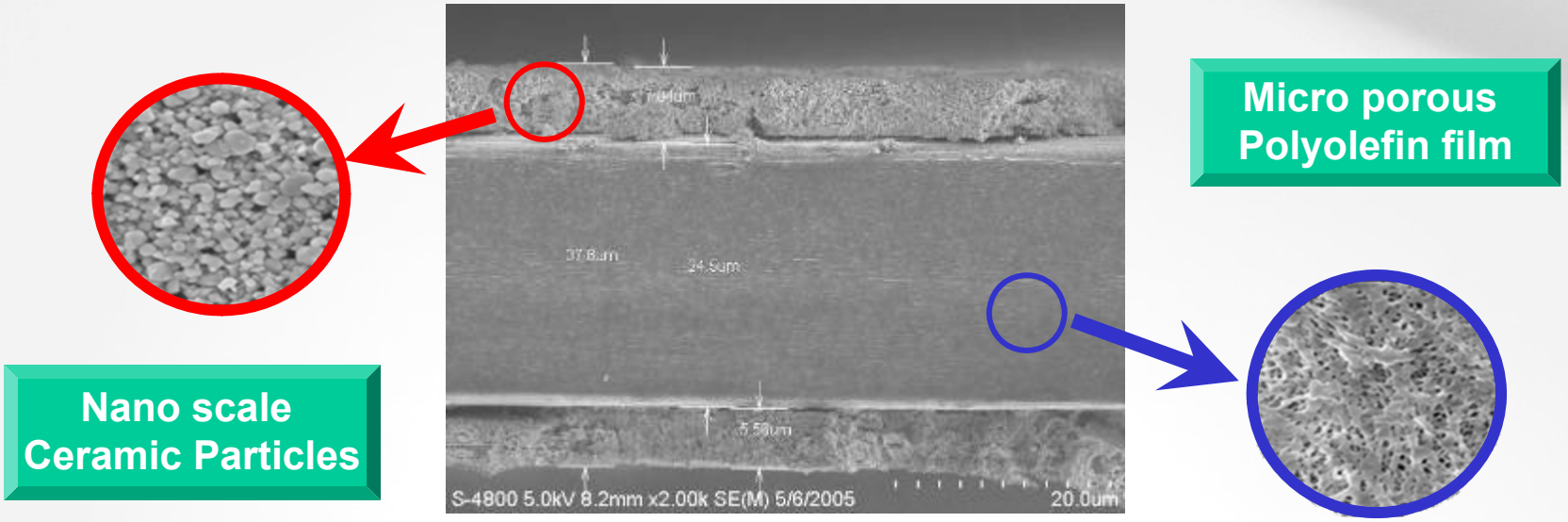
Laminated
film

SRS™

Safety Reinforcing Separator (SRS™)

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

1. By preventing internal short circuit
2. By improved thermal and mechanical strength



- Has ~6x the puncture strength of conventional separator

Cell: Cathode

	$LiCoO_2$	$LiMn_2O_4$	$LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$	$LiFePO_4$
Energy	High	Low	High	High
Power	Moderate	High	Moderate	Mod/High[1]
Abuse Tolerance	Poor	Good	Poor	Very Good
Cost	High	Low	High	High
Low Temp Perf	Moderate	High	Moderate	Moderate[1]
Life	Long	Short	Long	Long

By blending spinel with a layered compound, we have retained the superior abuse tolerance, high power, and cost advantage of spinel, while simultaneously increasing specific energy and life.

Large-format Cell features

- **Spinel-based chemistry**
  - Good material base, cost, power advantages
  - Life enhanced via additives, cathode and anode compositions, etc.
- **Proprietary separator technology (SRS™)**
  - In-house development of separator coating technology
- **Laminated packaging**
  - Extensive experience with various aspects of sealing, packaging and other electrical and mechanical requirements

Basic Cell Design

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

Program Description

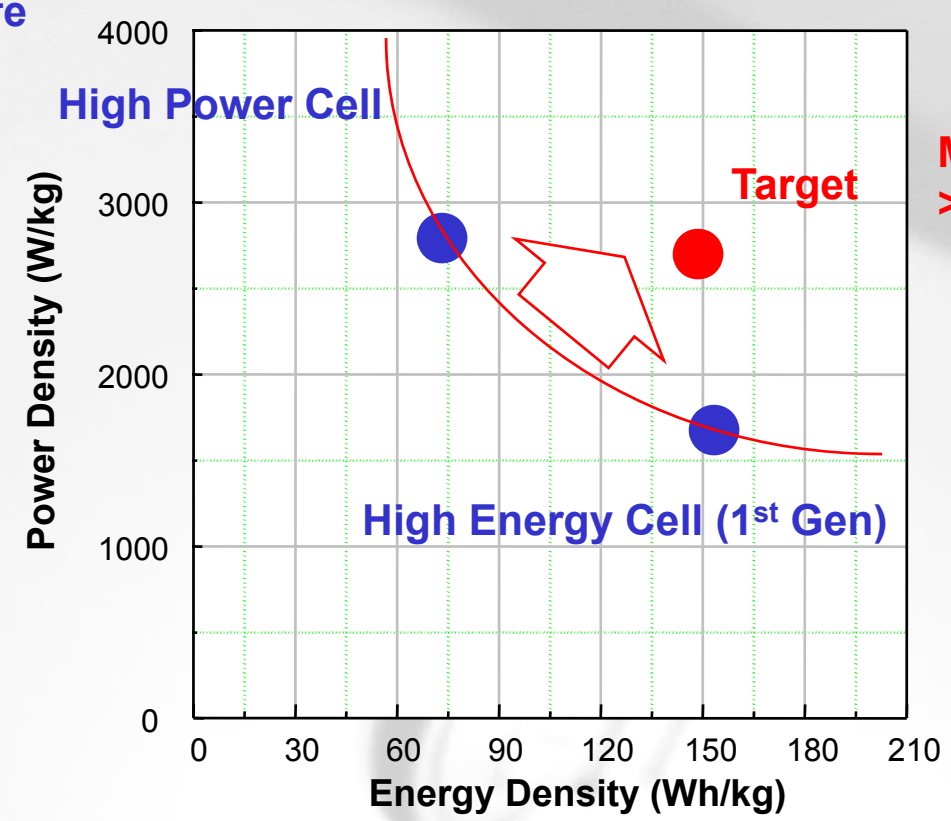
PHEV $12.9M (65/35) 27 Months

Program Objectives

- Life (Calendar- and Cycle)
- Thermal management
- Abuse-tolerance
- Cost

PHEV cell design characteristics:

300,000 cycles
>15 years of life



Meet Cycle-life with >15 years of life

Cycle life at 100% DOD <5 years of life

Improved Life

- **Base spinel**
  - Abundant, easy synthesis, low and stable cost, high power
  - But poor calendar-life due to Mn^{2+} dissolution, Mn plating on carbon anode.
- Approaches to improve calendar life while maintaining spinel advantages
  - Different dopants, morphologies, coatings, additives, blends
- **Anode**
  - Coatings, additives, blends

Life data from HEV Program

- **Calendar-Life**
  - 2- 3 yrs life in 2004
  - > 10 yrs in 2006
  - > 15 yrs now
- **Cycle-life**
  - < 160k cycles in 2004
  - > 550k cycles in 2007

Improved Abuse-Tolerance

- Key Cell features enhance abuse-tolerance
  - *Spinel-based chemistry*
  - *Proprietary separator*
  - *Laminated Packaging*

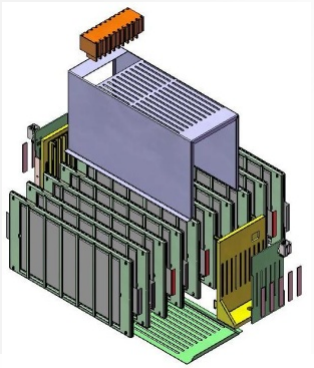
- Results: Superior Abuse-tolerance
  - Short-circuit
    - Cell bulging only, Temp <90°C
  - Nail-penetration
    - No smoke, no fire. Temp <100°C
  - Overcharge
    - No explosion, no fire.
  - Thermal stability
    - No explosion, no fire

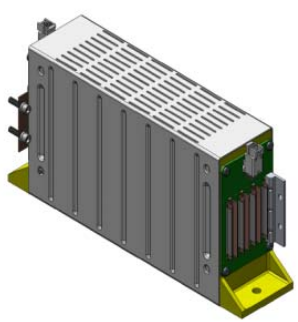
Module/Pack Technology

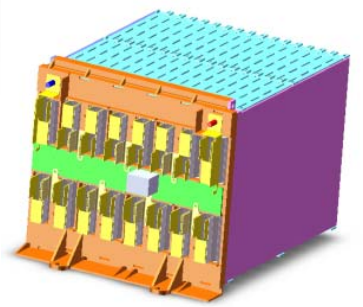
- **Engineered for**
  - High energy/Power density
  - Minimum overheads- mass, volume, cost
  - Thermal management
  - Long life (Robustness, Cell Protection)
  - Superior Abuse-Tolerance

Pack Architecture & Modularity

- 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
- Modularity, with Prismatic cells, allows more efficient space usage
  - Packs not constrained to simple rectangular shapes





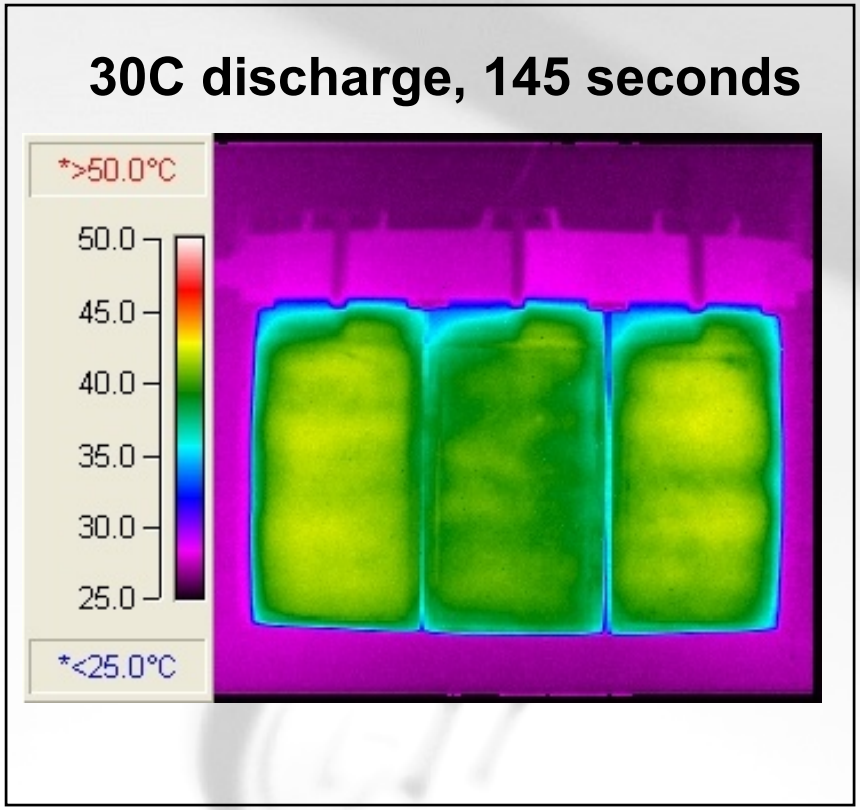


Thermal Management

- **Pack Thermal Challenges**
  1. Remove accumulated heat from environmental soaking ("parked on hot asphalt")
  2. Remove operating environmental heat (exhaust, ambient road heat while driving)
  3. Maintain inter-cell temp Δ < 3-5°C
  4. Remove heat generated by cells during operation
  5. Add heat to cells during start up in very cold climates
- **Improved Thermal Management ➔ Longer Cell Life**
- **Methods**
  - ❖ Air
  - ❖ Liquid Coolant
  - ❖ Refrigerant

Efficient Heat-Transfer

Temperature distributions at end of test

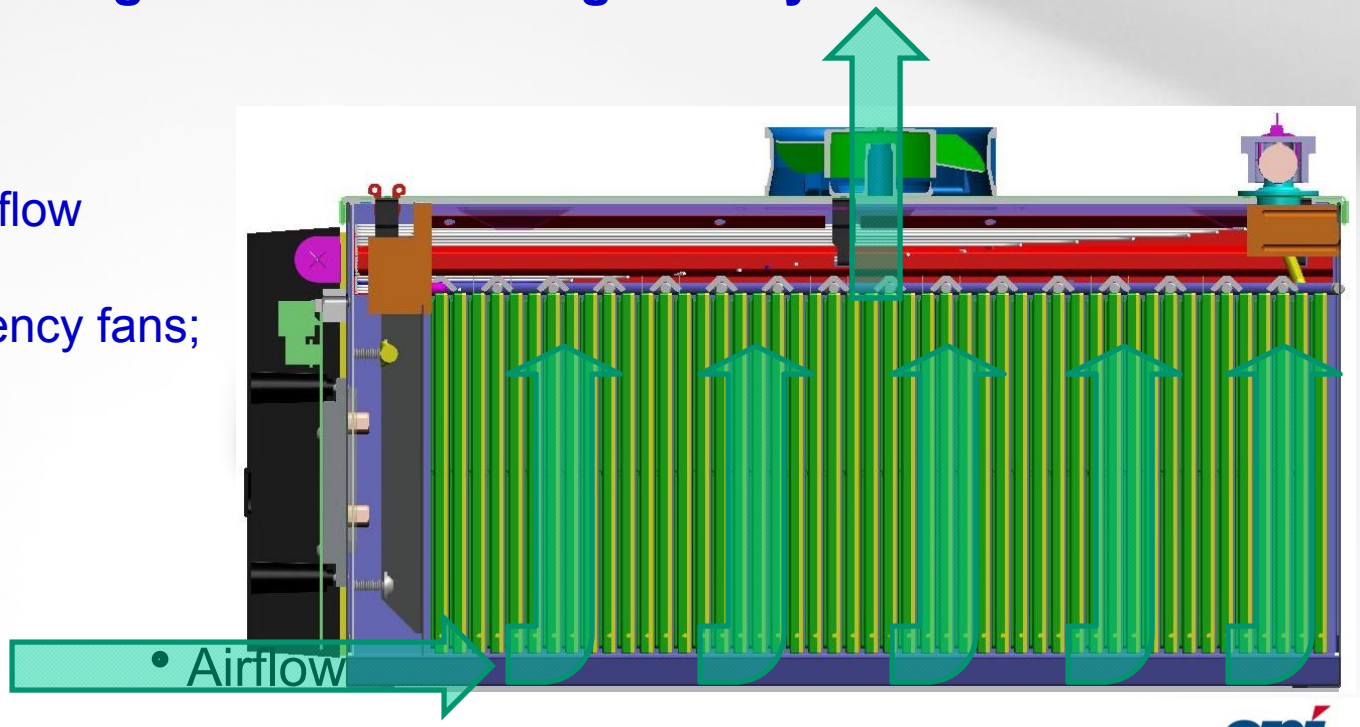


- Electrochemically active area uniform, within 2-3°C
- Courtesy of NREL: Dr. Pesaran's Team

Thermal Management: Air Cooling

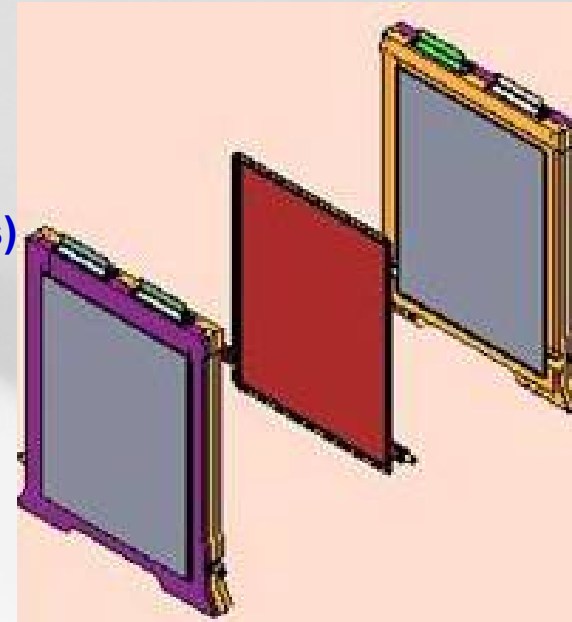
- **Attractive for most vehicle applications**
  - ❖ **Low heat generation and even thermal distribution mean low cooling demand (once environmental heat is removed)**
    - **Cabin air generally cool enough to remove heat**
    - **Blower and duct work required.**
  - ❖ **2 mm spacing between cells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

- An option for certain conditions
  - High environmental heat loads
  - Cabin air not readily available
  - Allows zonal control
- Requires refrigerant loop; but:
  - Avoids coolant fill and maintenance
  - Obviates need for complex coolant manifolding and risks of leaking

Battery Management System

- BMS alone is relatively small percentage of total pack cost, *but*
- Has big impact on cell/pack life and safety
- One key result has been the development of SOC algorithm using Kalman Filter and its subsequent versions such as the Sigma Point Kalman Filter
  - Model-based State-Space estimator, self-correcting and accounts for
    - Rapidly changing parameters (hysteresis & polarization time constants, etc.)
    - Slowly changing parameters (e.g., due to cell aging)
    - Uses current measurements for short term SOC dynamics; voltage for longer term dynamics, and
    - Uses Coulomb counting in closed-loop environment to improve accuracy
- Simulation Results: +/- 3% within 100s at > -20°C; +/- 5% @ -20°C
- Additional improvements in BMS including:
  - Application-Specific Integrated Circuits (ASIC) for repetitive, high-quantity functions (e.g., cell monitoring, balancing)
  - Distributed, multiplexed architectures (wiring, connector savings)

Production Programs

Chevy Volt

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

Hyundai Sonata

- At first to be marketed in Korea in Summer 2009.
- To be launched in the US in 2010.

Summary

- Significant progress within the past few years have been made by LGC/CPI in spinel-based chemistry to satisfy automotive battery performance, life, abuse-tolerance and cost requirements.
- Current/Future work focuses on validating the life of the cells.

Acknowledgements

- LG Chem team (Yojin Kim, Seungdon Choi, Kwangho Yoo, Youngjoon Shin and other team-members)
- USABC (DOE and Big 3) for their financial and technical support in course of these programs
- INL (Jon Christophersen, Jeff Belt), NREL (Ahmad Pesaran, Kandler Smith), LBNL (Vince Battaglia) and SNL (Pete Roth) for invaluable technical support