2012 DOE Vehicle Technologies Program Review

USABC Development of Advanced High-Performance Batteries for EV Applications

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

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Introduction – About Cobasys

SAMSUNG
SAMSUNG SDI
BOSCH
SB LiMotive
A joint company of Samsung and Bosch
COBASYS

- Cobasys is a wholly owned subsidiary of SB LiMotive
- Headquarters is located in Orion, MI
- Cobasys provides world-class engineering and validation capability on location near key OEM customers
- Currently manufacturing NiMH since 2003 in Springboro, OH
- Transitioning Springboro facility to Lithium Ion pack assembly

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Overview – USABC Development of Advanced High-Performance Batteries for EV Applications

Timeline

- February 2011
- February 2014
- 36% Complete

Budget

- Total project funding
  - DOE share 49% ($4,093,834)
  - Contractor share 51% ($4,260,930)
- Funding received FY2011: $940,251
- Funding FY2012 : $1,538,253

Barriers

- Cost → Current cost for Li-based batteries ~$1000/kWh
  - Target for development: $300/kWh
- Abuse Tolerance → Safe and reliable performance required
  - Target for development: Demonstrate high abuse tolerance
- Life → Batteries should operate consistently throughout a wide range of environments over the life of the vehicle
  - Target for development: Demonstrate high cycle and calendar life performance equivalent to 10 years usage.

Partners

- USABC
- U.S. DOE
- SB LiMotive
- Samsung Advanced Institute of Technology (SAIT)
- BASF
- Toda America

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Relevance – EV Battery Pack Development

Objective:

- Develop the next generation lithium-ion cell and pack technology that will meet the USABC target of obtaining a high-energy storage and low-cost electric vehicle battery solution:
  1. Increase pack specific energy to 150Wh/kg
  2. Reduce pack cost to $300/kWh
  3. Maintain 10 years durable life
  4. Ensure high safety
- This project will help to accelerate the commercialization and proliferation of electrified vehicles to greatly lessen America's reliance on foreign energy

Parameter(Units) of fully burdened system	Minimum Goals for Long Term Commercialization	Long Term Goal
Power Density(W/L)	460	600
Specific Power – Discharge, 80% DOD/30 sec(W/kg)	300	400
Specific Power - Regen, 20% DOD/10 secW/kg	150	200
Energy Density - C/3 Discharge Rate(Wh/L)	230	300
Specific Energy - C/3 Discharge Rate(Wh/kg)	150	200
Specific Power/Specific Energy Ratio	2:1	2:1
Total Pack Size(kWh)	40	40
Life(Years)	10	10
Cycle Life - 80% DOD (Cycles)	1,000	1,000
Power & Capacity Degradation(% of rated spec)	20	20
Selling Price - 25,000 units @ 40 kWh($/kWh)	<150	100
Operating Environment(°C)	-40 to +50 20% Performance Loss (10% Desired)	-40 to +85
Normal Recharge Time	6 hours (4 hours Desired)	3 to 6 hours
High Rate Charge	20-70% SOC in <30 minutes @ 150W/kg (<20min @ 270W/kg Desired)	40-80% SOC in15 minutes
Continuous discharge in 1 hour - No Failure(% of rated energy capacity)	75	75

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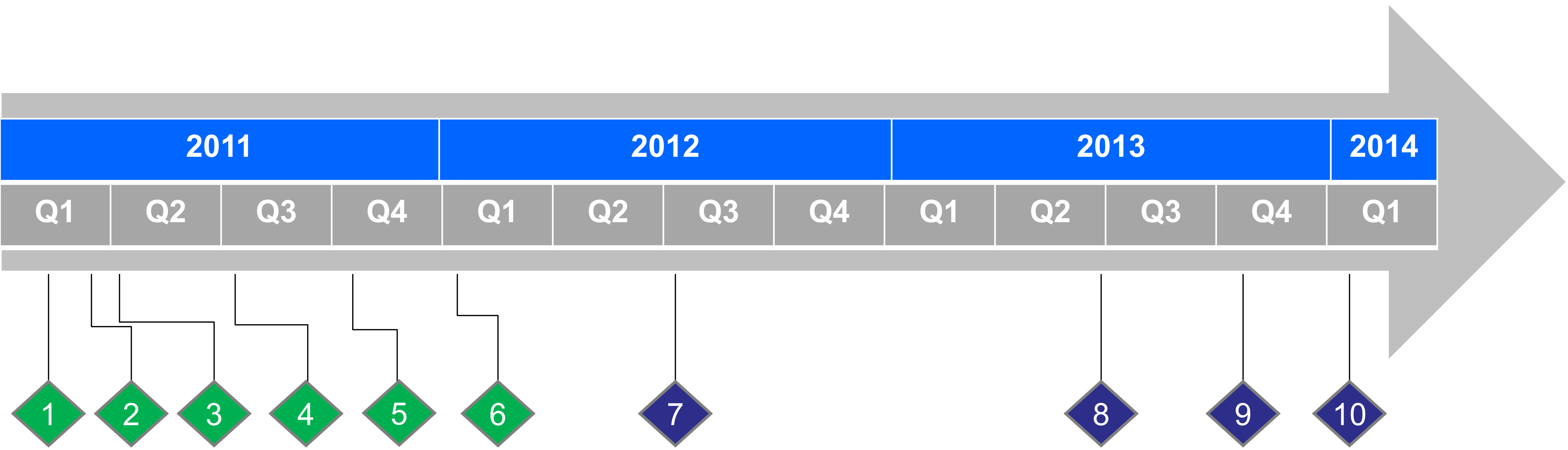
Milestones – Program Milestones and Deliverables



1. Official Kickoff (PO received)
2. Baseline test kickoff
3. 1st Quarterly Review
   (USABC members to SBL Ulsan factory, Korea)
4. State of art technology evaluation
5. Pack targets defined
6. Cell chemistry selection
7. A- Sample Cell Delivery
8. B- Sample Cell Delivery
9. B- Sample Module Delivery
10. A- Sample Pack delivery

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Approach – Cell Development

1) Material and Cell Design for High Energy Density

Input

- Composition
- Dopant
- Particle size
- Porosity, etc.

Design Active material (Powder, Coin-cell)

- Binding/Conducting material recipe
- Mixing/Coating/Pressing recipe

Design Electrode (18650 cell)

- Mechanical design (safety device, separator)
- Volume/Weight

Design Cell (Full cell)

Output

	Criteria	Candidate
Specific capacity	> const.	Material 1, Material 2, Material 3.
Tap density	> const.	
Life measure	> const.	
Safety measure	> const.	

	Criteria	Candidate
Electrode density	> const.	Electrode 1, Electrode 2, Electrode 3.
Loading level	> const.	
Current density	> const.	
Max. Voltage	> const.	

	Criteria	Candidate
Volume Energy density	> 400Wh/l	Cell 1, Cell 2, Cell 3.
Specific Energy density	> 200Wh/kg	

※ **As cathode materials, two types of NCM material are being considered:**

1) NCM with over 40% nickel content→*<u>Moderate NCM (Mod-NCM)</u>*

2 NCM with Li rich layered-layered structure→*<u>Extreme NCM (Ext-NCM)</u>*

2) Cell Life Prediction

Degradation mechanism

- Screening DOE & Experiments with stress factor
- ↓ Analysis of degradation mechanism
- ↓ Determination of life model

Cell improvement

- Verification DOE & experiments
- ↓ Life prediction of cell
- ↓ Life improvement of cell

3) Heat Flux Management

Concept	Idea screening method		Approaches
Exothermic Heat	• DSC (Joule heat, onset temp.)	•ARC (Accel. Rate Calorimetry)	Surface-treatment of active materials
			Optimization of active material mixture
			Interfacial reaction reduced Electrolyte system
Reaction Rate	• EUCAR test (temp. vs. time) • Postmortem analysis		Current path modification
			Suppressing thermal runaway event

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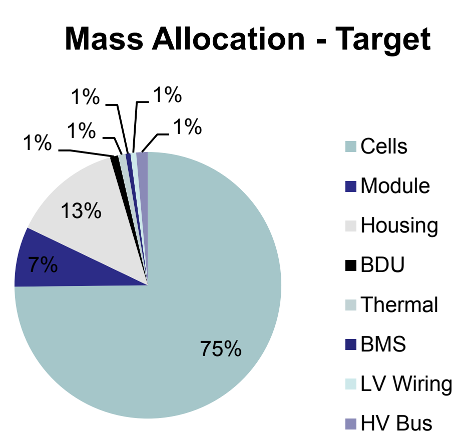
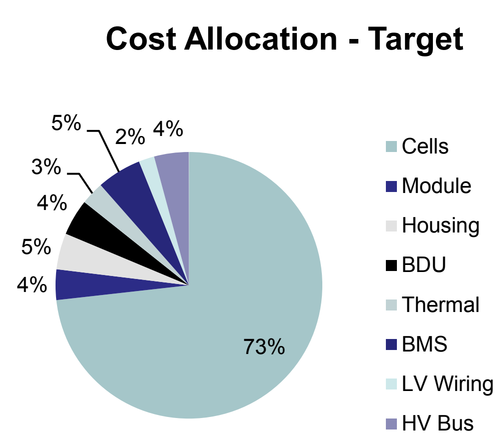
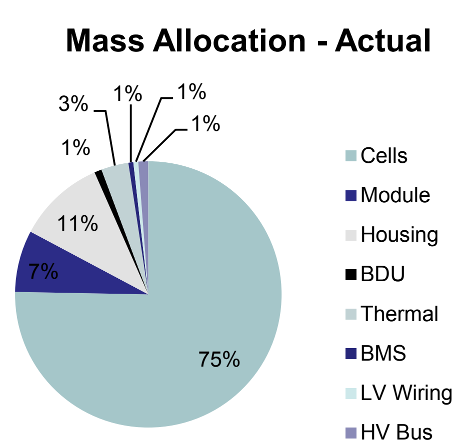
Approach – Pack Development

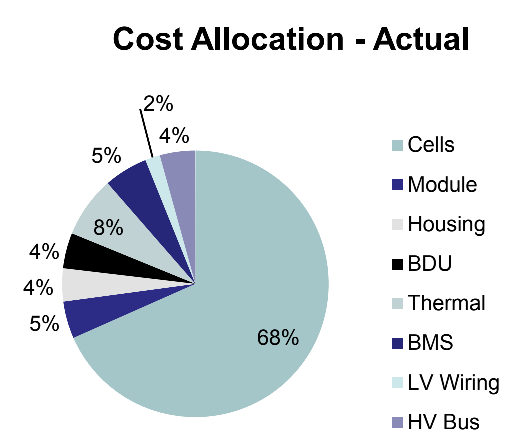
Target Management

Metric	Goal
Energy Density (Wh/L)	230
Specific Energy (Wh/kg)	150
Cost per kWh ($/kWh)	300



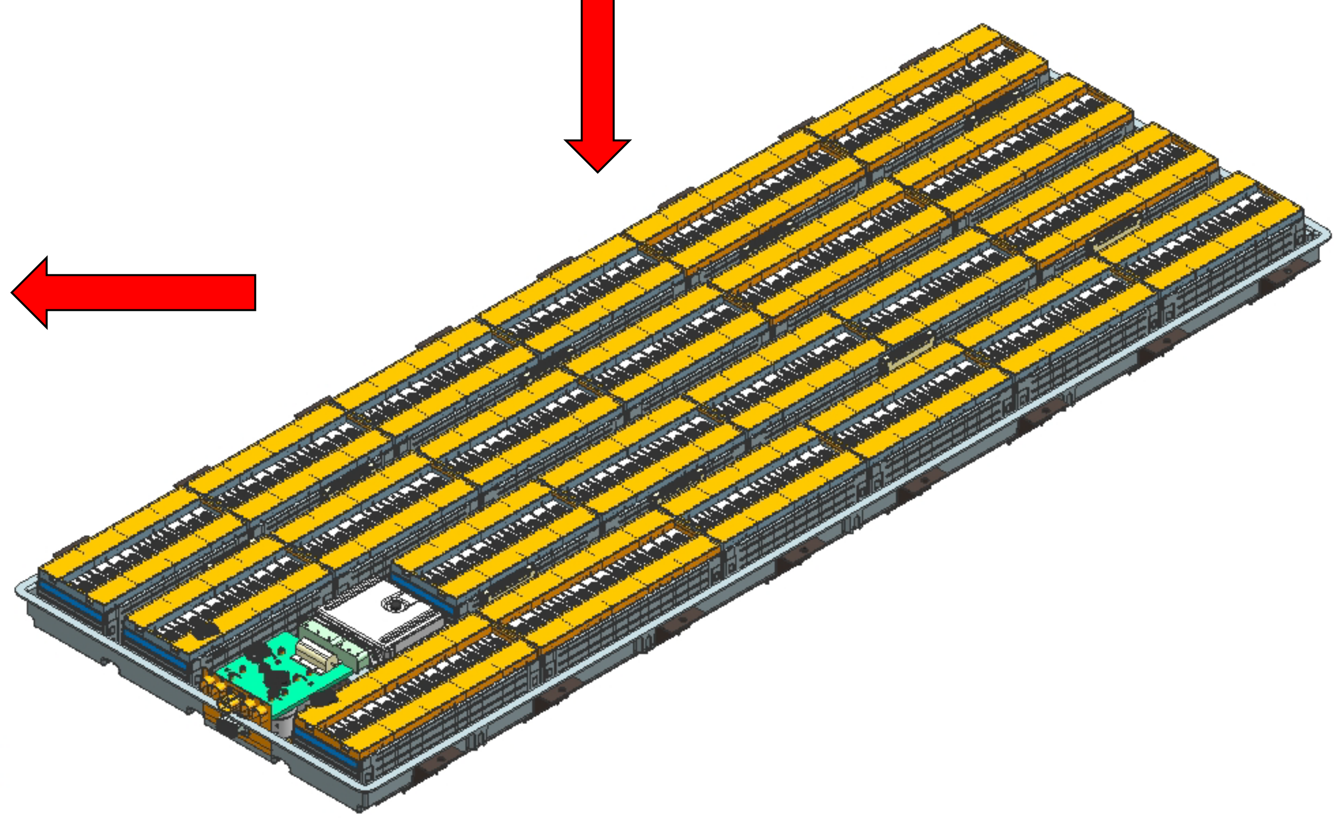






How will we reach our targets?

- Optimize pack layout
- Use of advanced materials
- Simplify, reduce or eliminate the cooling system
- Utilize design optimization tools
- Integrate components
- Easier to assemble/mass produce
- Continually track progress and status against goals



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Technical Accomplishments – Cell Development Review

❖ Cell development with Mod-NCM technology

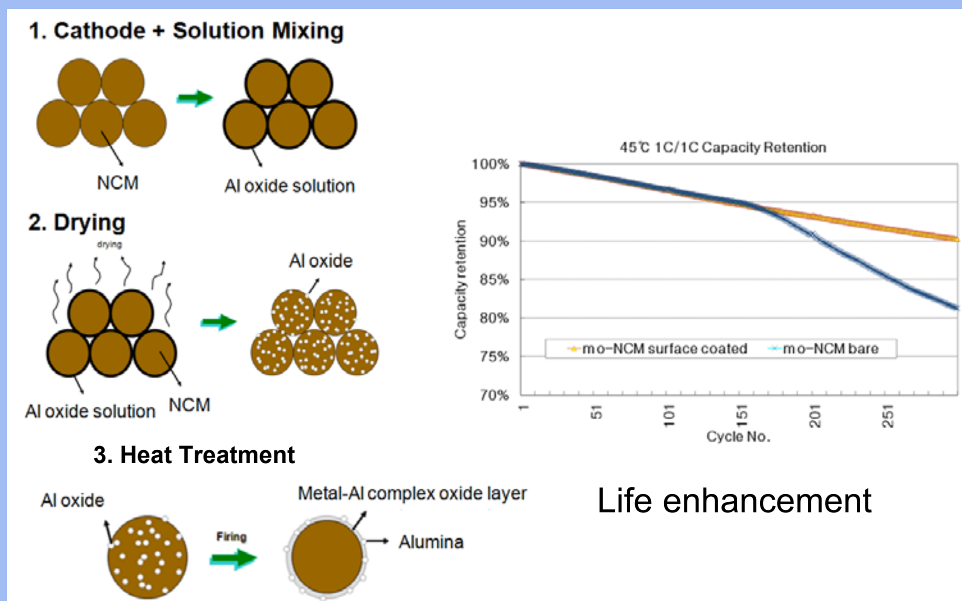
- Completed investigation of cell performance and material characteristics of Mod-NCM cathodes with specific capacity over 150mAh/g
- Demonstrated specific energy density around 165Wh/kg in large format cell and determined the optimal chemistry for balanced power, safety and life performance
- Achieved satisfactory safety performance of cells with thermally stable electrolyte and separators
- Achieved enhanced life performance via surface treatment of cathode and anode materials

❖ Cell development with Ext-NCM technology

- Completed investigation of the basic cell performance of Ext-NCM material using 2320 coin and 18650 surrogate cells and identified several key technical barriers that must be overcome to be useful for an EV cell application
- Completed a detailed post-mortem analysis on BOL and EOL cells and identified the main causes of life performance degradation during cycling and high temperature storage
- Achieved significant improvement of cycle life with an improved electrolyte system that enhances the high voltage stability of the electrolyte
- Initiated the development of large format cells (32Ah cell) with Ext-NCM material C and evaluated basic performance to compare with Mod-NCM technology

Technical Accomplishments – Cell Development Using Mod-NCM

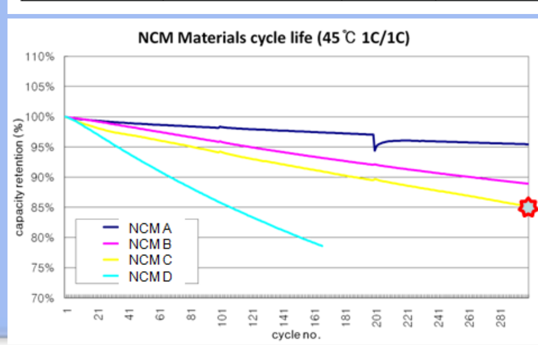
1) Surface treatment of cathode materials



Life enhancement

2) Screening of cathode materials

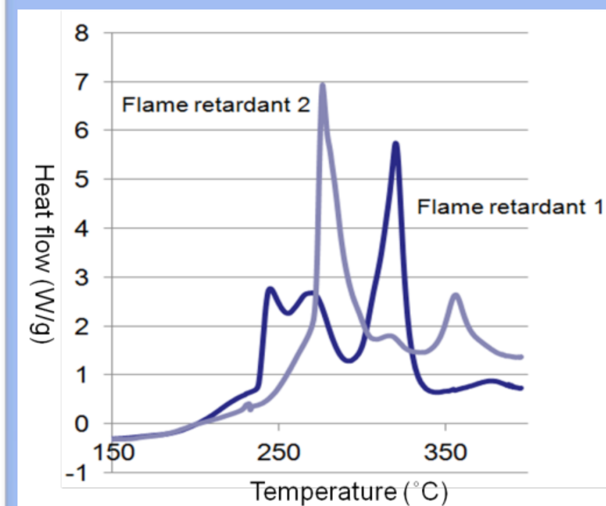
NCM type	Capacity (coin cell, 0.2C)	Cycle life	Calendar life	Safety (From DSC)	DSC	
					Peak Temp.	Exo. Heat
NCM A	147mAh/g	◎	○	◎	312.2℃	778.3J/g
NCM B	158mAh/g	○	○	△	300.9℃	1157J/g
NCM C	163mAh/g	△	○	△	307.7℃	1159J/g
NCM D	168mAh/g	×	○	×	265.9℃	1382J/g

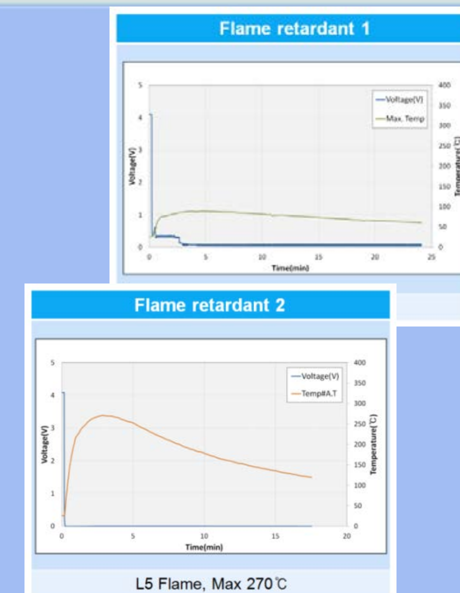


- Most balanced NCM was chosen as a main cathode material.

3) Screening of electrolyte

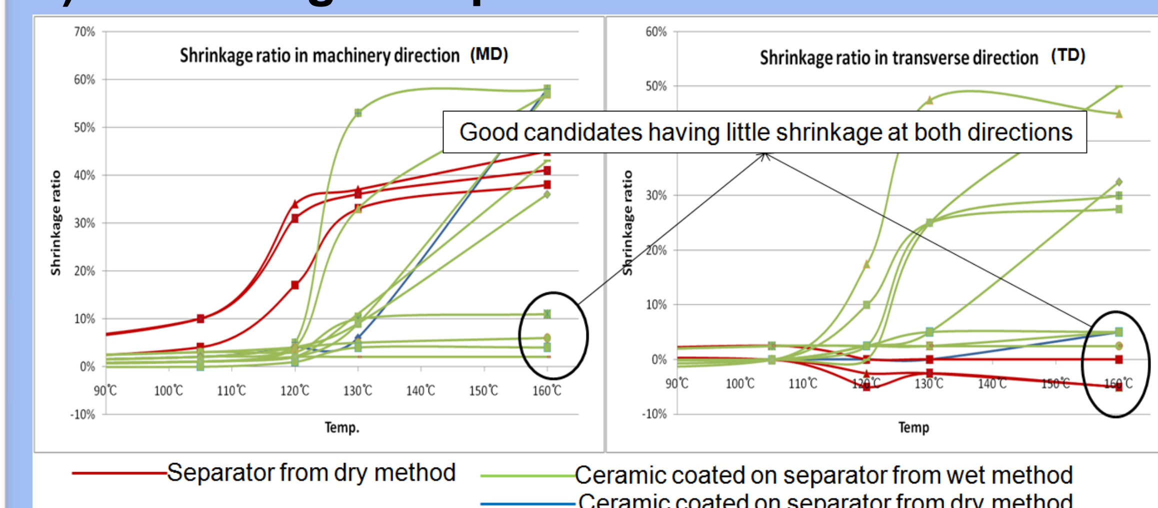
■ DSC Analysis





❖ **Nail penetration (@ SOC 90%, 3ϕ, 80mm/sec)**

4) Screening of separators



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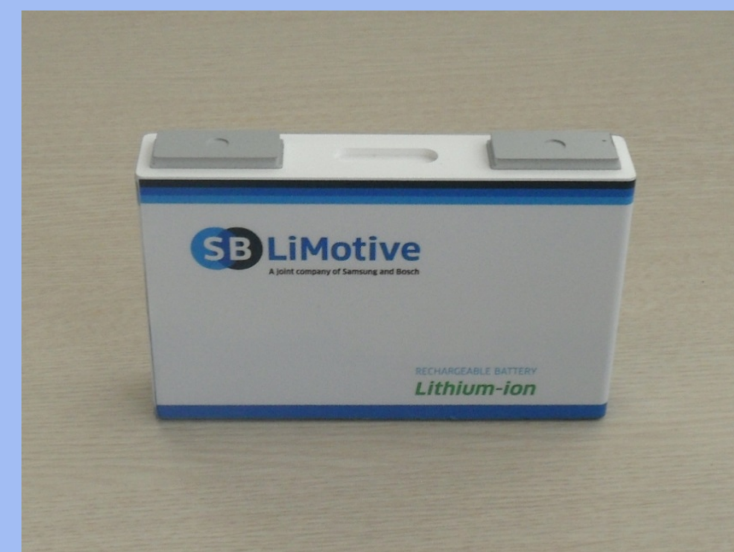
Technical Accomplishments – Cell Development Using Mod-NCM

1) Performance summary

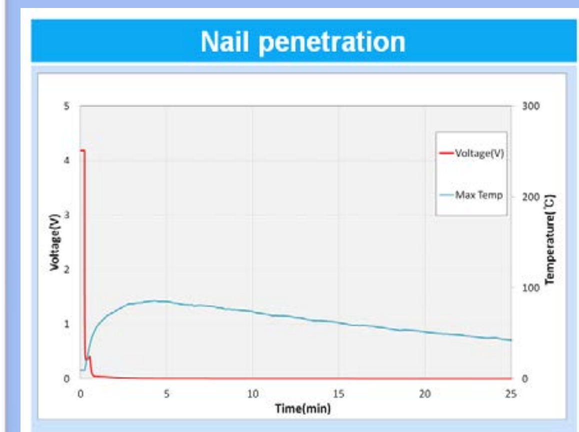
Parameter	Unit	Goal	Results (Y2011)
Power Density - 80%DOD, 10s	W/L	1500	>3000
Specific Power Dsch. - 80%DOD, 30s	W/kg	470	>500
Specific Power Regen. - 20%DOD, 10s	W/kg	200	>500
Energy Density - C/3	Wh/L	400	>300
Specific Energy - C/3	Wh/kg	200	>160
Sp. Power / Sp. Energy Ratio	-	2.4:1	>3.0

2) PHEV-2 form factor prismatic cell

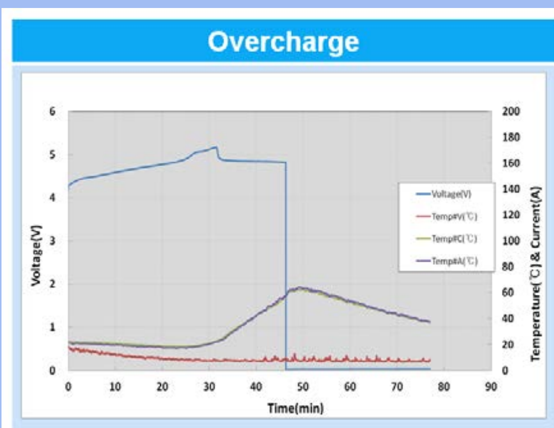


3) Safety performance

❖ Nail (@ SOC 100%, 3ϕ, 80mm/sec) ❖ Overcharge (@ 32A, 12V)

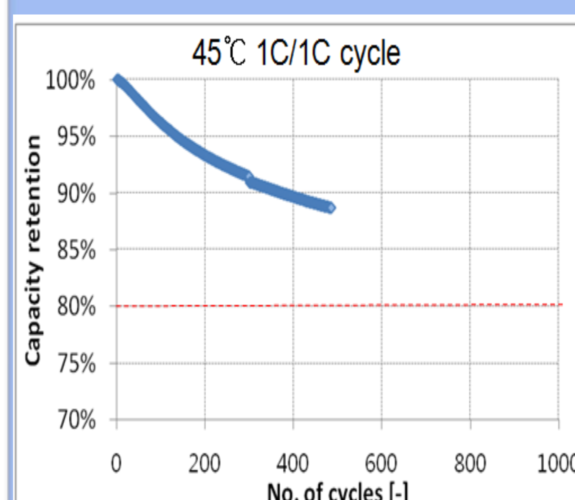


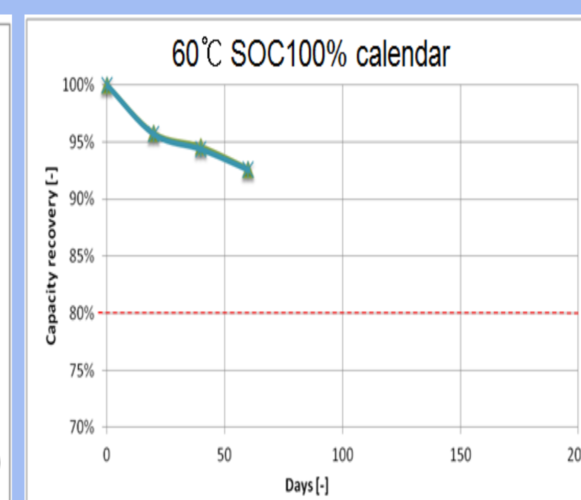
L3, Max 90.9℃



L2, Max 64.6℃

4) Life performance





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Technical Accomplishments – Cell Development Using Ext-NCM

1) Re-stated challenges for Ext-NCM A

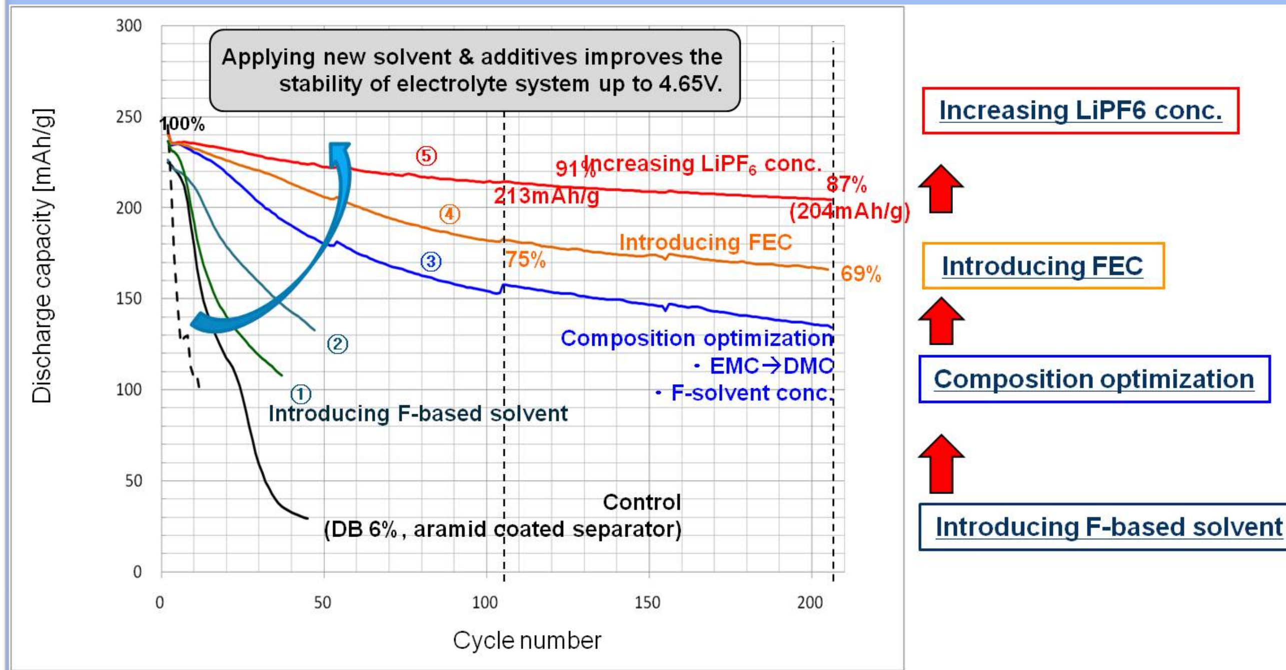
Issue	Baseline	Target	Problems	Countermeasure
Electrode density (g/cc)	2.3	> 2.8	Low 'True density'	1. Optimization of particle size distribution 2. Sintering: temp up. or addition of Li2MoO4 (promoter)
Rate performance	< level of mo-NCM	= level of Mod-NCM	Low 'Electro-conductivity' (10^{-5} ~ 10^{-6} Scm^{-1})	1. Conducting agent coating on active materials in the primary particle level 2. Fiber Type conducting agent
Thermal stability	< level of Mod-NCM	= level of Mod-NCM	1. 50℃ lower 'Peak temperature'	1. Surface treatment of active materials
Life	100 cycles @ 45°C	1000 cycles @ 45°C	1. Dissolution of metals due to high cut-off voltage 2. Oxidation of electrolyte and separator	1. New electrolyte solvent and additives against high voltage 2. New separator with anti-oxidation properties

※ Comparison between Ext-NCM A and C*

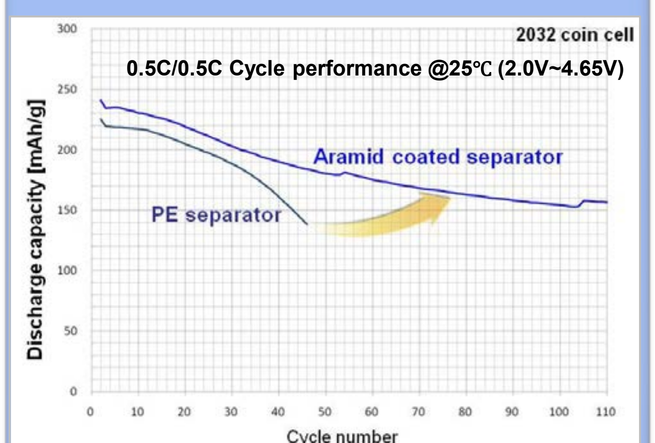
Items	Unit	Ext-NCM A	Ext-NCM C
Specific Capacity @ 0.2C	mAh/g	~240	170
Li_2MnO_3 : $Li(Ni,Co,Mn)O_2$ Ratio	—	5 : 5	2 : 8
Cut-off Voltage Range	V	4.6 - 2.0	4.4 - 2.8
Nominal Voltage	V	3. 45	3.78
Max. Electrode Density	g/cc	2.3	3.0
Energy Density	Wh/L	1904	1927

* Ext-NCM C : High stability Li rich layered-layered structure NCM

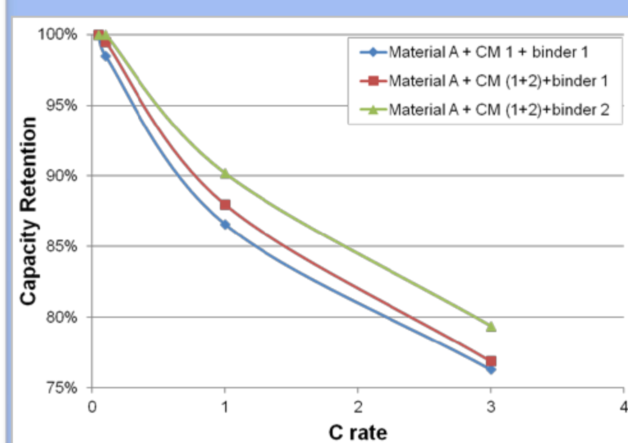
2) Improvement of cycle life with high voltage electrolyte



3) Improvement of cycle life with surface coated separator



4) Rate performance with conductive agent & binder



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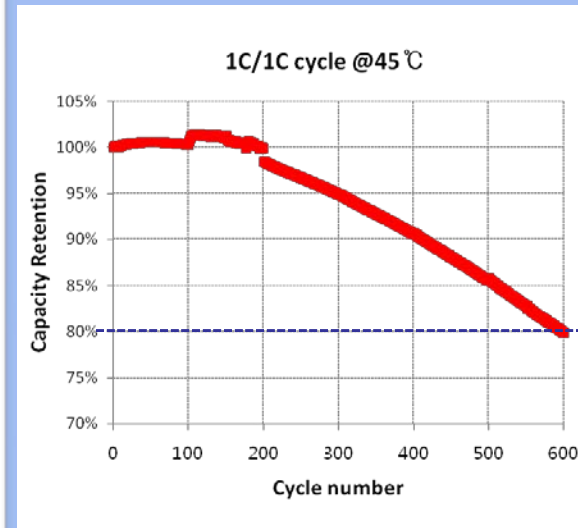
Technical Accomplishments – Cell Development Using Ext-NCM C

1) Performance summary

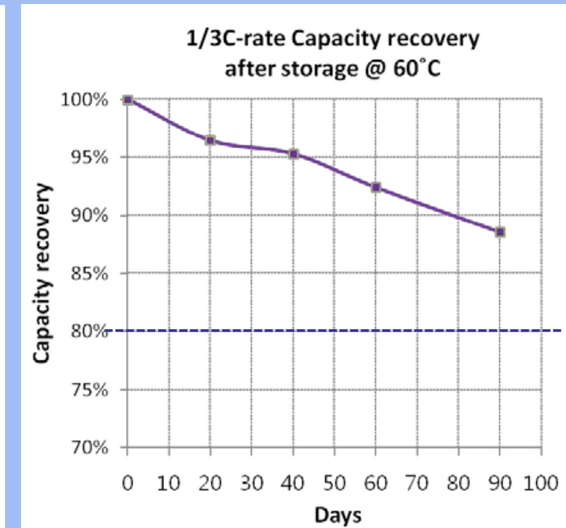
Parameter	Unit	Goal	Results (Y2011)
Power Density	W/L	1500	>4000
Specific Power Dsch. - 80%DOD, 30s	W/kg	470	>500
Specific Power Regen. - 20%DOD, 10s	W/kg	200	>300
Energy Density - C/3	Wh/L	400	>300
Specific Energy - C/3	Wh/kg	200	>160
Sp. Power / Sp. Energy Ratio	-	2.4:1	>3.0

2) Life performance

❖ Cycle life

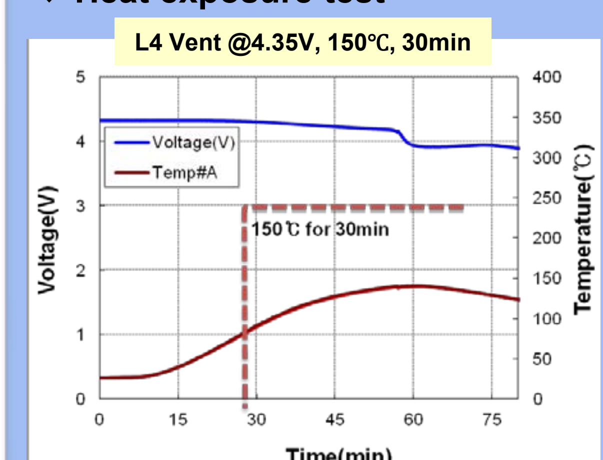


❖ Calendar life

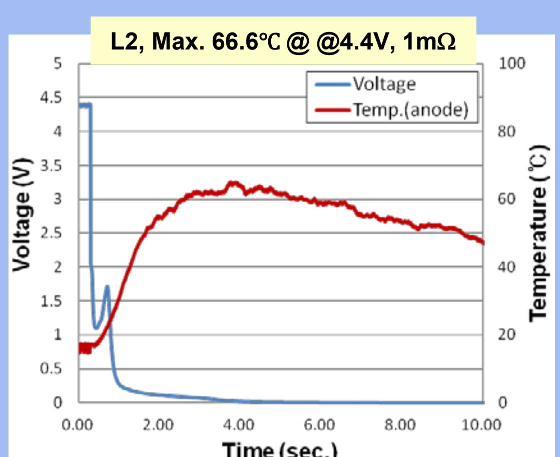


3) Safety performance

❖ Heat exposure test



❖ External short test

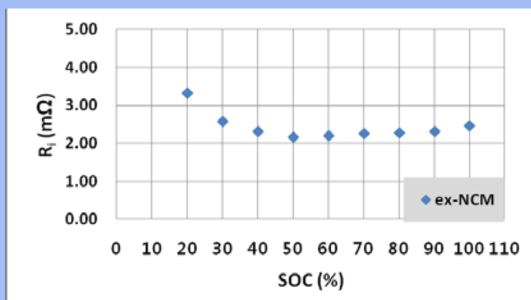


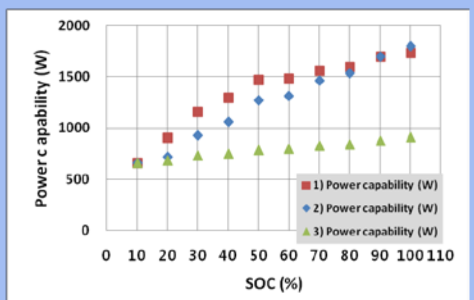
❖Nail penetration test : L5 Flame @4.3V

4) Resistance and Power evaluation

❖ Peak power test @ 30˚C

SOC (%)		100	90	80	70	60	50	40	30	20	10
30 sec discharge	R_i (mΩ)	2.46	2.31	2.28	2.26	2.21	2.16	2.32	2.58	3.32	-
	Power capability (W)	1733	1696	1596	1560	1481	1472	1297	1154	904	657
	Power capability (W)	1799	1696	1532	1465	1312	1273	1058	929	719	657
	Power capability (W)	910	875	840	825	793	783	748	728	680	657





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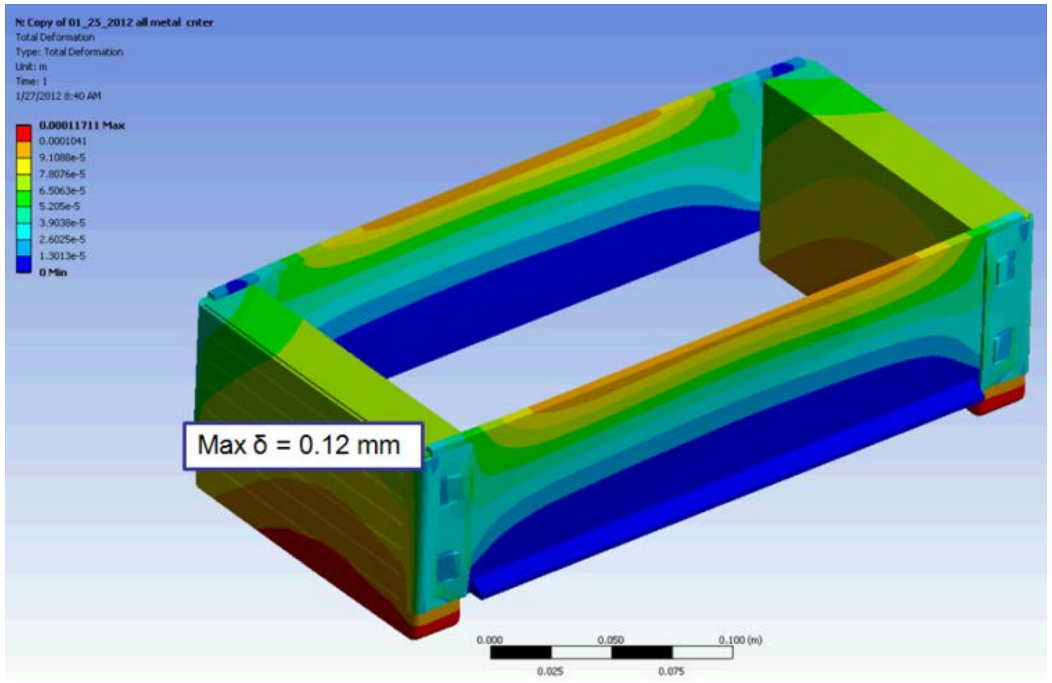
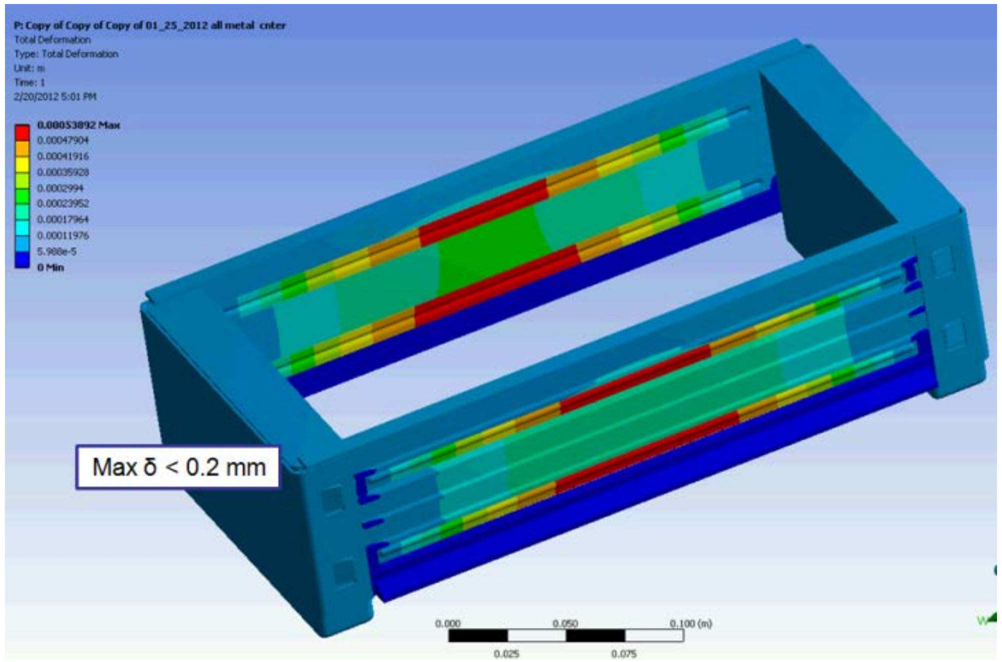
Technical Accomplishments – Pack Module Development

Cobasys utilizes CAE to optimize designs saving cost and mass

- ❖Material is applied only where structurally necessary
- ❖Metal components are being replaced by plastic or Plastic Metal Hybrid
- ❖Cell restraint systems are reducing respective masses by 50% over current technology
- ❖Structures are being optimized to have similar or better performance characteristics





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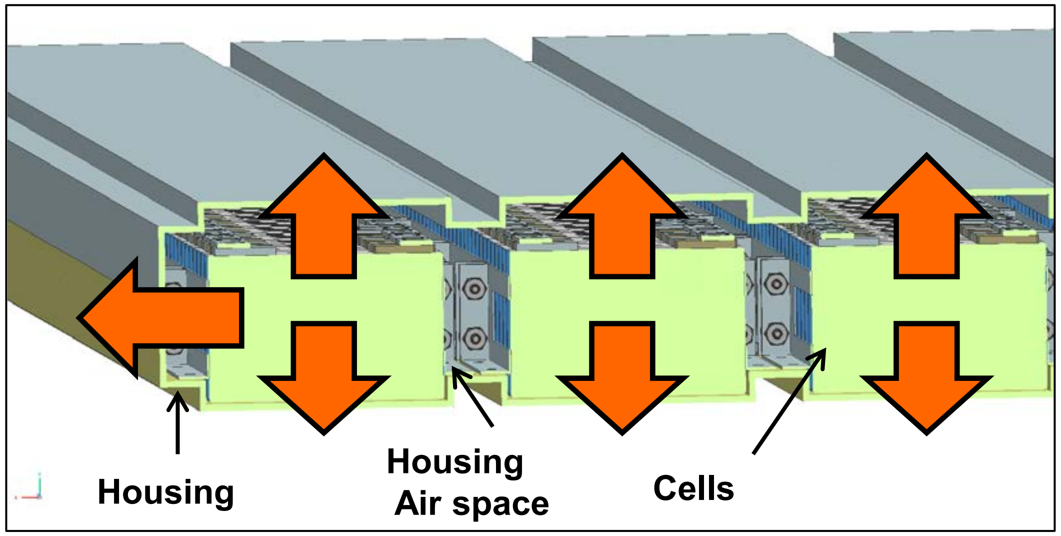
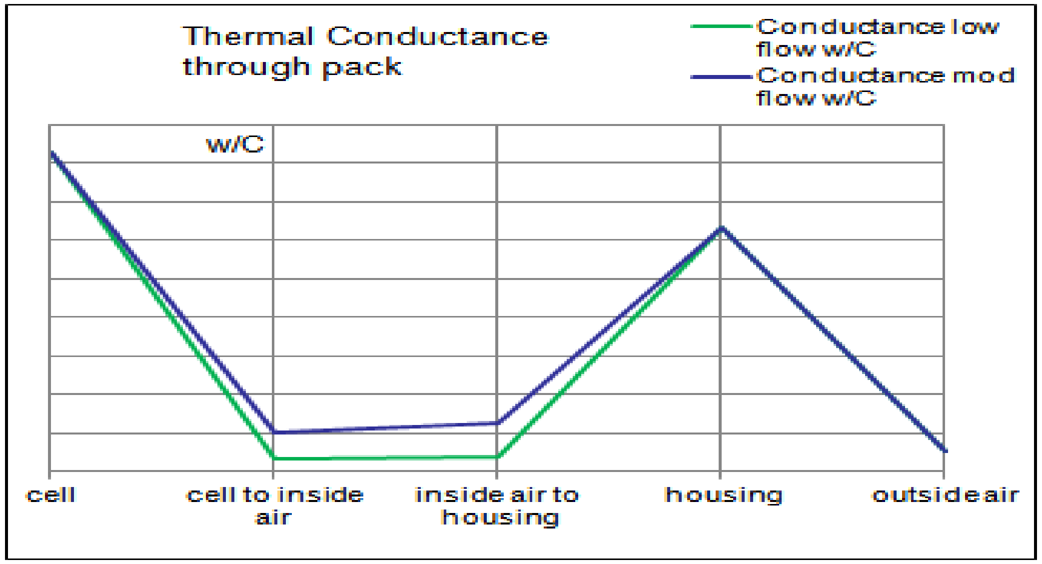
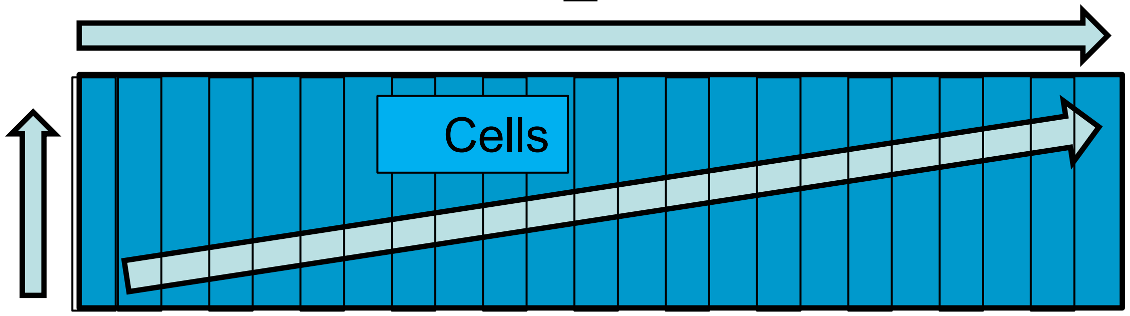
Technical Accomplishments – Pack Thermal Development



- Focus on increasing temperature during cold operation and minimizing thermal gradients to balance cell life and performance
- 60% Improvement in battery cell output at -25C with minimum temperature to -40C
- 20% Improvement in battery cell life for high power rated cooling system
- 10% Improvement in cell life for low power rated cooling system
- Thermal gradients held within 5C





Balanced Temperature Gain and Gradient

Technical Accomplishments – Pack Model Development

Normal Usage:

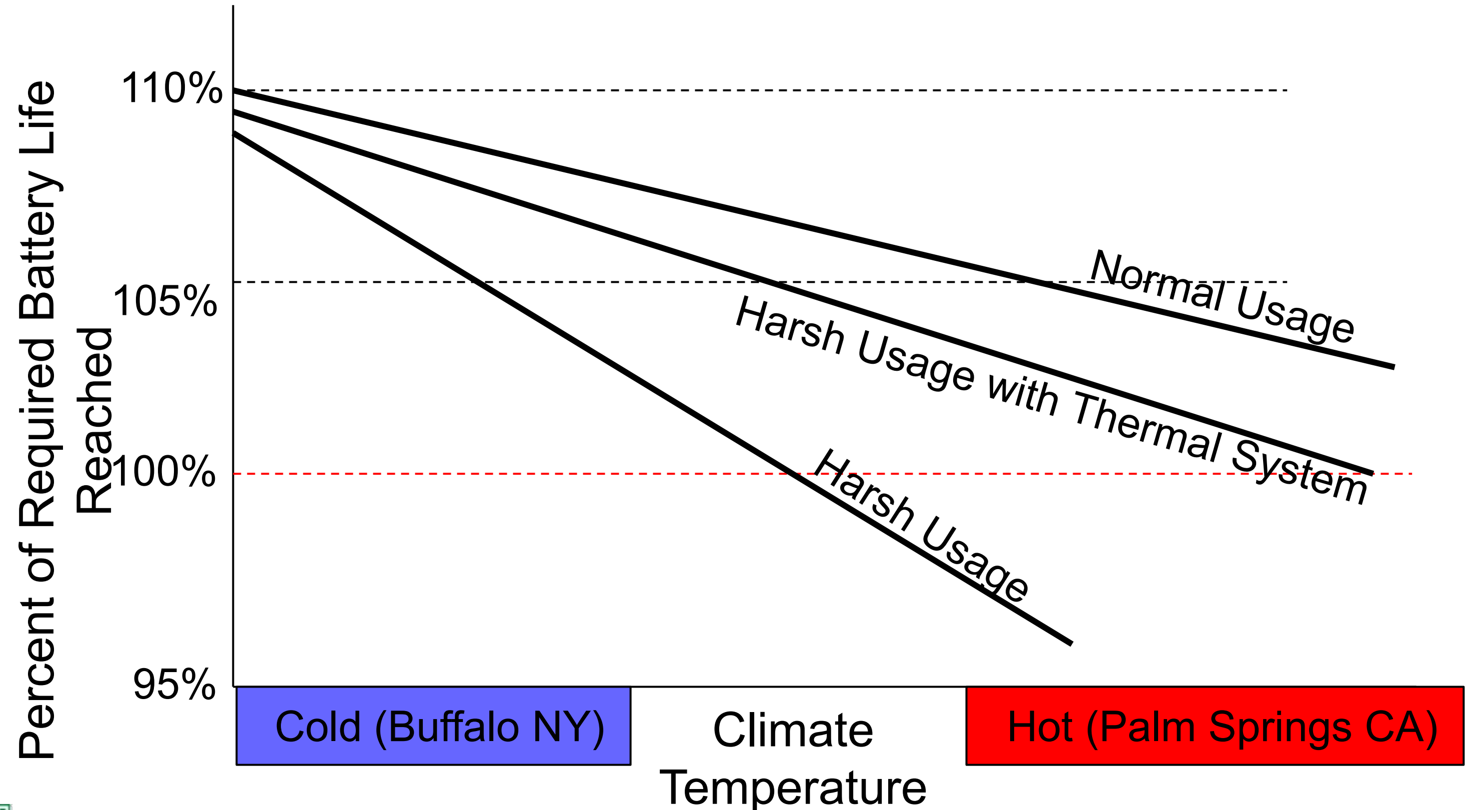
- EV cells are expected to meet cell life requirements with Normal Usage due to limited EV cell heat generation

Harsh Usage:

- EV cell life due to Harsh Usage in Hot Environment is estimated to fall short of required Life.
- Thermal Management System is integrated into the battery pack to mitigate the negative effects of Harsh Usage and Hot Environment

USABC Program Life Goal
10 Years or 1000 Cycles

	Hot	Cold
Normal Usage	Meets Life	Exceeds Life
Harsh Usage	Does Not Meet Life	Exceeds Life
Harsh Usage with Thermal System	Meets Life	Exceeds Life



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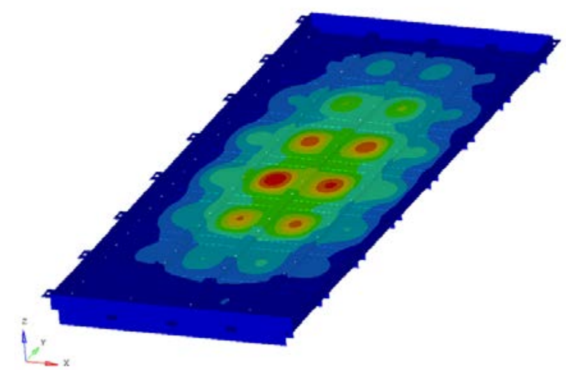
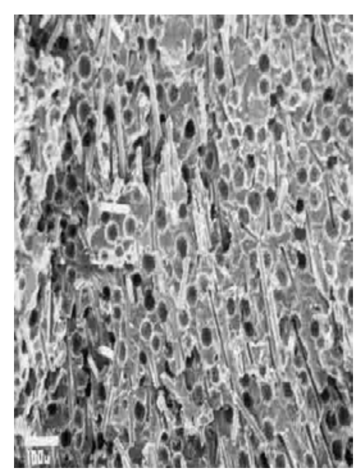
Technical Accomplishments – Pack Housing Development

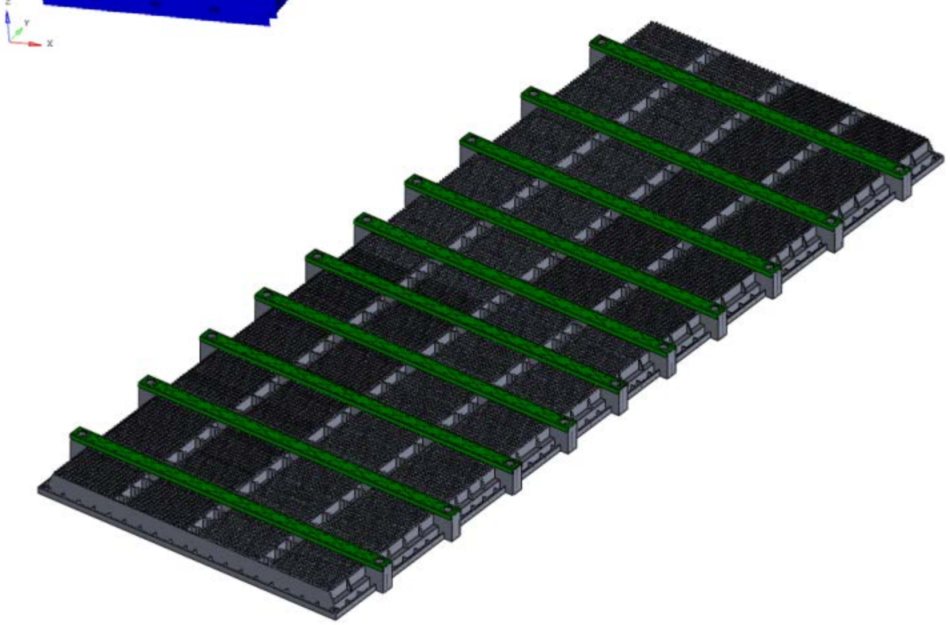
- Cobasys and supplier partner BASF have jointly developed a Plastic Metal Hybrid (PMH) battery structure:
  - •BASF developed structural nylon to meet automotive demands of battery case
  - •System meets structural and durability requirements (NVH, Shock, Vibe)
  - •System is 33% lighter than conventional stamped steel enclosure w/ supports
- Foaming technology added to high pressure injection process to reduce mass, injection pressures, clamping force and improve dimensional stability of finished part

Mass Savings Using Aluminum or Plastic Housing Materials		
Reference	**Aluminum Housing 4mm thick**	**PMH Housing**
Steel Housing – 1.5mm thick	7%	33%



Gas is used as foaming agent





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Technical Accomplishments – Project Scorecard

Parameter	Unit	Goal	Current State -of-the-Art	Status on 16JAN2012			
			NCM/LMO blended(>115 Wh/kg)	mo-NCM (>140 Wh/kg)	mo-NCM (>160 Wh/kg)	mo-NCM (>180 Wh/kg)	ex-NCM
Power Density	W/L	460	1066	1437	1900	2328	2296
Specific Power Dsch. - 80%DOD, 30s	W/kg	300	770	1465	448	-	450
Specific Power Regen. - 20%DOD, 10s	W/kg	150	147	694	433	-	285
Energy Density C/3	Wh/L	230	109	154	177	187	171
Specific Energy C/3	Wh/kg	150	79	111	131	138	130
Sp. Power / Sp. Energy Ratio		2.0	9.7	13.2	3.4	-	3.5
Total Pack size	kWh	40	40.5	39.9	40.3	40.1	-
Life	Year	10	> 13 @ 25 °C (estimated)	> 13 @ 25 °C (estimated)	> 13 @ 25 °C (estimated)	> 13 @ 25 °C (estimated)	-
Cycle Life - 80%DOD	Cycle	> 1000	> 2700 @ 25°C(0.7C/1C), full SOC	> 2700 @ 25°C(0.7C/1C), full SOC	> 2700 @ 25°C(0.7C/1C), full SOC	> 2700 @ 25°C(0.7C/1C), full SOC	-
Power/Cap. Fade	% rated	< 20	20	20	20	20	-
Selling Price - 25,000 units @ 40kWh	$/kWh	332	-	388	355	318	-
Operating Environment	°C	-40 to 50	-30 to 80	-30 to 80	-30 to 80	-30 to 81	-
Normal Recharge Time	hr	6	> 5 CC/CV, 1/50 C	> 5 CC/CV, 1/50 C	> 5 CC/CV, 1/50 C	> 5 CC/CV, 1/50 C	-
High Rate Charge		20-70%SOC in < 30min, 150 W/kg	50% SOC in < 30min, 113 W/kg	50% SOC in < 30min	50% SOC in < 30min	50% SOC in < 30min	-
Continuous Disch. 1 Hr.	% rated capacity	> 75	> 90	> 90	> 90	> 90	-

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Collaborations – Cobasys Strong R&D Network

Partner	Contribution
SB LiMotive (A joint company of Samsung and Bosch)	• Cell Development and Manufacturing • Battery Management System
Samsung Advanced Institute of Technology	• Fundamental materials evaluation
BASF The Chemical Company	• Ext- NCM material supplier • Battery pack housing development
TODA America	• Mod- NCM material supplier • Ext- NCM material supplier
ECOPRO	• Mod- NCM material supplier • Ext- NCM material C supplier
USABC United States Advanced Battery Consortium	• Project management • OEM customer feedback and support
U.S. Department of Energy	• Strategic direction and funding partner

Future Work – Cell and Pack Development

- Cell development with Mod-NCM materials
  - Analysis of electrical properties of NCM cathode materials with specific capacity over 170mAh/g
  - Investigation of electrical and physical properties of cells with specific energy density over 180Wh/kg
  - Overcoming trade-offs of safety and life and increasing specific energy density
  - Optimization of cell design for mechanical and thermal configurations of module and pack
- Development of Ext-NCM materials
  - Analysis of the effect of low current density to cycle life enhancement
  - Improvement of active material by surface coating and doping for a better rate performance
  - Needs for the development of the electrolyte in order to use at high voltage range
- Pack Development
  - Elimination or further reduction of the cooling system
  - Additional optimization and integration of components
  - Reduced cost of purchased components (connectors, MSD’s, fittings, temperature sensors, etc.)
  - Reduce complexity of the wiring systems

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Summary

- As an intermediate step toward the development of 200Wh/kg EV cells, cell specific energy density performance over 160Wh/kg was targeted and achieved in 2011. Several cell design factors and materials were investigated to achieve desired power, safety and life.
- Challenges in Ext-NCM development were identified and significant improvement of cycle performance was achieved through improvement of the electrolyte system, resulting in 87% capacity retention at 200 cycles.
  - Ext-NCM cathode material C fabrication and evaluation of large format cells was performed and the results are comparable to Mod-NCM technology cells, with an exception of nail penetration safety .
- Emphasis on new pack materials and component integration as well as assembly process improvement are having significant benefit toward target attainment.

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