DOE Merit Review

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EnerDel
Lithium Power Systems

Project ID # es_05_ashtiani

About EnerDel

- October, 2004 – *EnerDel*
  - Ener1 Lithium Group : 1990
  - Delphi Lithium Group : 1998
  - 135 Employees

- Cell mfg. plant – Indianapolis, IN ~92,000 sq. ft area, ~ 6,000 sq.ft. dry room facility,

- Capacity to build 15,000 EV packs/yr equivalent of 400MWh capacity

- *EnerDel* –Noblesville, IN
- 35,000 Ft^2 of Manufacturing & general purpose area
- 60 Employees

Engineering & Production Plant in Indiana, US

EnerDel has made commitment to the manufacturing of the Li-ion battery from cell to full pack integration all in the US

- **Cell Manufacturing- Indianapolis, IN**

- **Pack Manufacturing- Noblesville, IN**

HEV- Program Overview

- **Develop a $Li_4Ti_5O_{12}$ / $LiMn_2O_4$ battery system that out-performs carbon-based anode systems in rate, abuse-tolerance, life, and cost**

❑ **Timelines** ➢ **Start: August 2007** ➢ **Finish: August 2009** ➢ **Completion: ~90%**	❑ **Technical Challenges** ➢ **Scaling up the technology while maintaining or enhancing performance and life** ➢ **Demonstrating safety at full scale level**
❑ **Budget** ➢ **$6.5MM 50% Cost-shared**	❑ **Partners** ➢ **Argonne National Lab**

Program Objectives – USABC HEV II

- Phase I demonstrated scale up of $Li_4Ti_5O_{12}$/ $LiMn_2O_4$ system from a 100mAh to ~2Ahr prismatic pouch cell & met and/or exceeded performance requirements

- Phase II objectives are:
  - Develop full size HEV cells (~4-6Ah cell)
  - Demonstrate performance
  - Demonstrate life
  - Demonstrate safety
  - Provide cost basis
  - Module design & development

Program Approach

- **Task 1 – Cell development**
  - **3 cell generations (Gen2, -3, -4)**
    - **Use gen2 testing for benchmarking & assessment**
    - **Gen3 design & development in parallel**
    - **Gen4 design & development from mid-program using latest findings**
- **Task 2 – Safety / Life**
  - **Abuse testing**
  - **Cycle & calendar life testing**
  - **Prismatic pouch life testing assessment**
- **Task 3 – Module Design & Development**
  - **Preliminary module design & development**
  - **Will use latest available cells (Gen3)**
  - **Modules will be subjected to performance characterization (INL), thermal characterization(NRL), and abuse testing (SNL)**

Gap Analysis - HEV

Power Assist	USABC EOL Target	EnerDel Gen2 BOL	EnerDel Gen3 BOL	Final Pack Target BOL
10s Discharge Pulse Power (kW)	25	32.48	32.5	32.5
10s Regenerative Pulse Power (kW)	20	25.98	26	26
Available Energy (kWh)	0.3	0.47	0.5	0.500
Efficiency (%)	>90	96.7	TBD	97
Cycle Life (25Wh profile)	300k	TBD	TBD	300k
Cold Cranking Power @ -30C (kW)	5	5.1	TBD	5
Calendar Life (Yrs)	15	13	TBD	15
Maximum System Weight (kg)	40	14.3	TBD	25
Maximum System Volume (Liters)	32	10.4	TBD	18
Selling Price ($/system @ 100k/yr)	500	TBD	TBD	875
Maximum Operating Voltage (Vdc)	440	377	139.2	139.2
Minimum Operating Voltage (Vdc)	0.55 x V_{max}	207	76.6	76.6
Self Discharge (Wh/day)	50	2.3	TBD	1.3
Operating Temperature Range (Degrees C)	-30 to +52	-30 to +52	-30 to +52	-30 to +52
Survival Temperature Range (Degrees C)	-46 to +66	-46 to +66	-30 to +52	-46 to +66
BSF		130	48	48

Program Deliverables

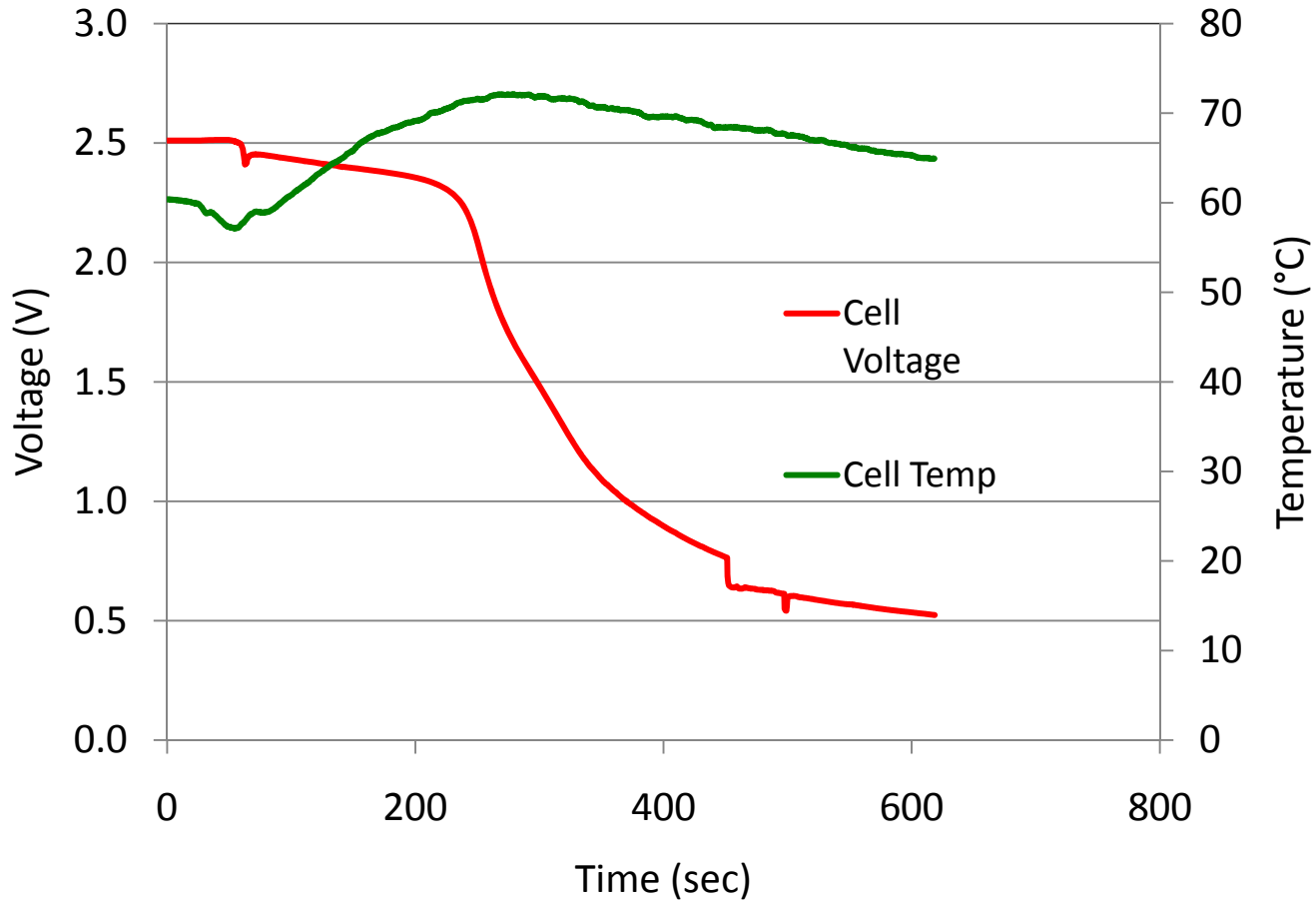
	Date	Deliverable
Task 1	31-Jul-09	29 (4.5~5Ah) cells Gen4 chemistry 12+ (4.5~5Ah) cells Gen3 chemistry
Task 2	17-Apr-09	Interim report
	31-Jul-09	Final report to include pouch study
Task 3	31-Jul-09	20 pre-modules (Gen3)

Technical Accomplishments

- Cell scale up proved that a ~5 Ah cell fully meets/exceeds USABC HEV requirements
- The scale up to ~5Ah Gen2/Gen3 accompanied with a 14% performance improvement
- Best-in-class low temperature performance
- Unparallel abuse-tolerance with the full size cell
- ~13 years life projected at RT. HT calendar life enhanced

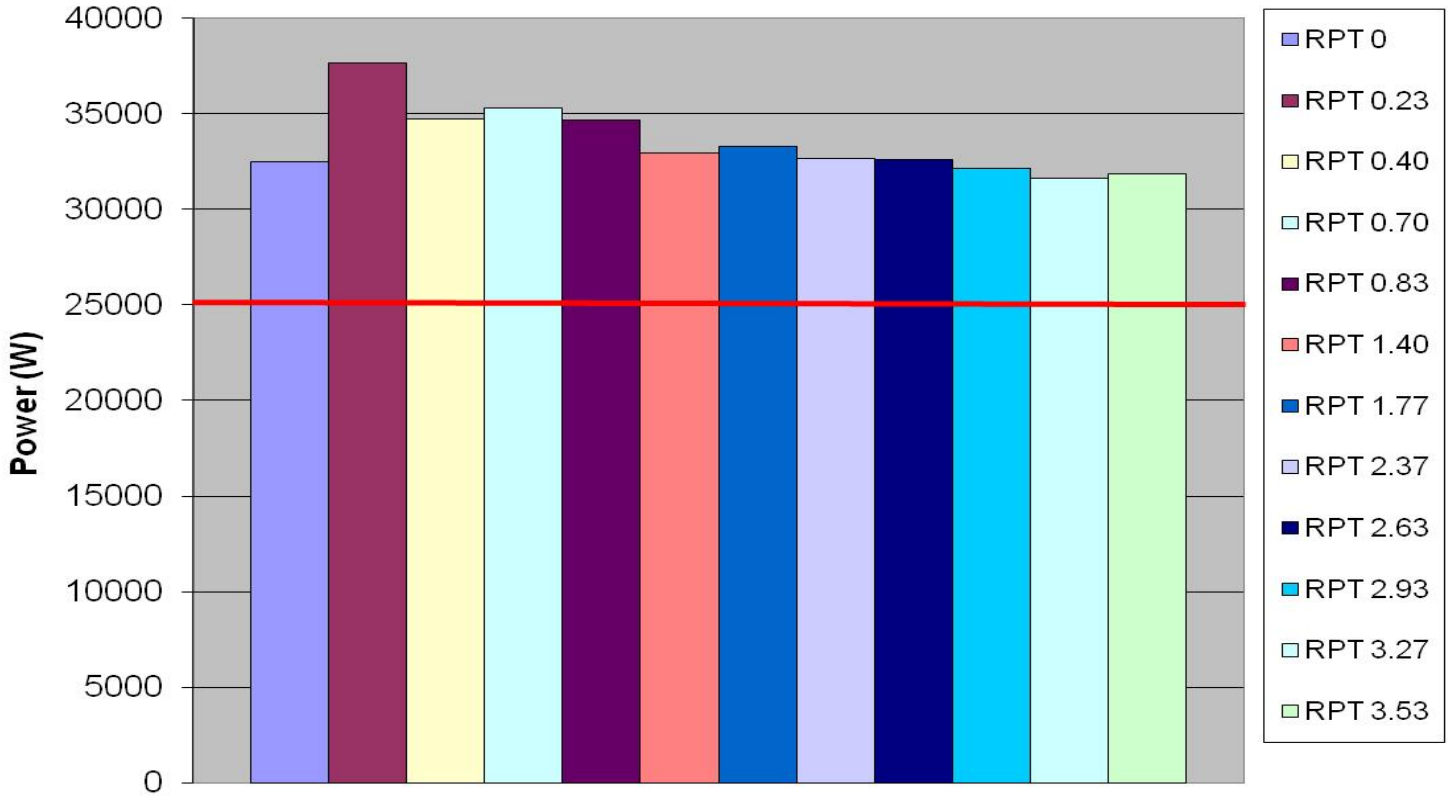
Nail Penetration Test; Worst Case

100%SOC @ 55°C



Power Retention @ Elevated Temperature

55°C, 100% SOC



Future Work – USABC HEV

- Translating the success in prototype cell elevated-temperature performance to production intent cell
- Continue design and development of the module, and pack and necessary software algorithms
- Complete performance, life, and abuse testing at the cell/module/sub-pack & pack levels

PHEV- Program Overview

- **Develop a battery system that matches the safety of the $Li_4Ti_5O_{12}$ anode with a safe high voltage 4.8V spinel cathode $LiMn_{1.5}Ni_{0.5}O_4$ (main candidate) to attain higher energy**

❑ **Timelines** ➢ **Start: March 2008** ➢ **Finish: Aug. 2009** ➢ **Completion: ~70%**	❑ **Technical Challenges** ➢ **Development of HV cathode material** ➢ **Likewise for HV electrolyte**
❑ **Budget** ➢ **$2.5MM 50% Cost-shared**	❑ **Partners** ➢ **Argonne National Lab**

Program Approach

- **Task 1 – Positive Material Development and Scale-up**
  - Successively larger batch sizes to be developed at ANL
  - EnerDel to validate material properties & build successively larger cells
- **Task 2 – Electrolyte Development**
  - Approach similar to cathode material development
- **Task 3 – Cell optimization and Design**
  - EnerDel to continue cell design & optimization
- **Task 4 – Cell Testing & Evaluation**
  - Cells will be tested at EnerDel & INL for performance, and life, and at EnerDel for abuse tolerance

Gap Analysis - PHEV

Attribute	Unit	USABC	EnerDel Gen0 BOL	EnerDel Gen1 BOL	EnerDel GenX BOL
Reference Equivalent Electric Range	miles	10	10	10	10
Peak Pulse Discharge Power - 2sec / 10sec	kW	50 / 45	100, 10sec	190, 10sec	65 / 58.5
Peak Regen Power (10sec)	kW	30	65, 10sec	126, 10sec	39
Available Energy for CD mode, 10kW rate	kWh	3.4	4.4	4.4	4.4
Available Energy for CS mode	kWh	0.5	0.5	0.6	0.65
Mininum Round-Trip Energy Efficiency (USABC HEV Cycle)	%	90	TBD	TBD	>97
Cold cranking power at -30°C, 2sec - 3pulse	kW	7	TBD	TBD	7, min V: 1.5
CD Life / Discharge Throughput	Cycles/MWh	5,000 / 17	TBD	TBD	5,000 / 17
CS HEV Cycle Life, 50Wh Profile	Cycles	300,000	TBD	TBD	300000 (TBD)
Calendar Life, 35°C	year	15	TBD	TBD	15 (TBD)
Maximum System Weight	kg	60	360	74, cells only	60
Maximum System Volume	Liter	40	240	42.5, cells only	40
Maximum Operating Voltage	V dc	400	360	360	360
Minimum Operating Voltage	V dc	>0.55 x Vmax	198	198	198
Maximum Self-discharge	Wh / day	50	TBD	TBD	<10
Thermal Performance @-30°C			TBD	TBD	10%
Thermal Performance @-10°C			TBD	TBD	30%
Thermal Performance @0°C			TBD	TBD	50%
Thermal Performance @50°C			TBD	TBD	>100%
System Recharge Rate at 30°C	kW	1.4 (120V/15A)	TBD	TBD	1.4 (120V/15A)
Unassisted Operating & Charging Temperature Range	°C	-30 to +52	TBD	TBD	-30 to +52
Survival Temperature Range	°C	-46 to +66	-46 to +66	-46 to +66	-46 to +66
Maximum System Production Price @ 100k units / yr	$	1,700	TBD	TBD	2,544
Battery Size Factor			80,000	510	100

Technical Accomplishment

- Scale-up of the positive LMNO material in four batches per plan
- Tests of material physical, structural, and electrochemical properties indicate consistency during scale-up
- 130 mAh/g (vs. theoretical 147) and 630 mWh/g have been achieved with $LiMn_{1.5}Ni_{0.5}O_2$
- First generation subscale 3.2Ah prismatic cells have been constructed and tested for performance

Deliverables

- Gen1 Cells (20)
  - Scheduled for delivery in month 10 (Mar 09) using the latest HV positive materials, LTO, and/or HV electrolyte
  - Planned for performance testing, abuse testing, and initial life testing
- Gen2 Cells (20)
  - Are scheduled for delivery in month 17 (Aug 09) and will represent the best functional materials of and optimized design

Future Work

- Current Gen1 cell has much more power than required. Design optimization in progress to increase E/P ratio
- Cyclic voltammetry of several classes of HV electrolytes individually and in half cells with LNMO will be conducted to establish electrolyte stability
- Continue positive material scale-up and subsequent cell scale-up & optimization per plan
- Develop & test materials, additives, and other strategies to enhance life

Summary

- **USABC HEV Program**
  - Successful cell scale up from 2 to 4.5Ah
  - 14% performance improvement from 2Ah cell
  - Best in-class abuse-tolerance and cold-temp performance with the full size cell
  - 13 years life at RT & enhanced HT calendar life
- **USABC PHEV Program**
  - Material scale-up followed per plan and consistency of properties demonstrated
  - The HV positive has a specific energy of 630 mWh/g
  - First generation 3.2Ah cell LNMO/LTO built & tested

Acknowledgements

USABC
UNITED STATES ADVANCED BATTERY CONSORTIUM

FreedomCAR & Fuel Partnership

Argonne NATIONAL LABORATORY

INL Idaho National Laboratory

Thank you for supporting and sharing EnerDel's vision