



# Large Format Lithium Power Cells for Demanding Hybrid Applications

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2011 Joint Service Power Expo  
*Power to Sustain Warfighter Dominance*  
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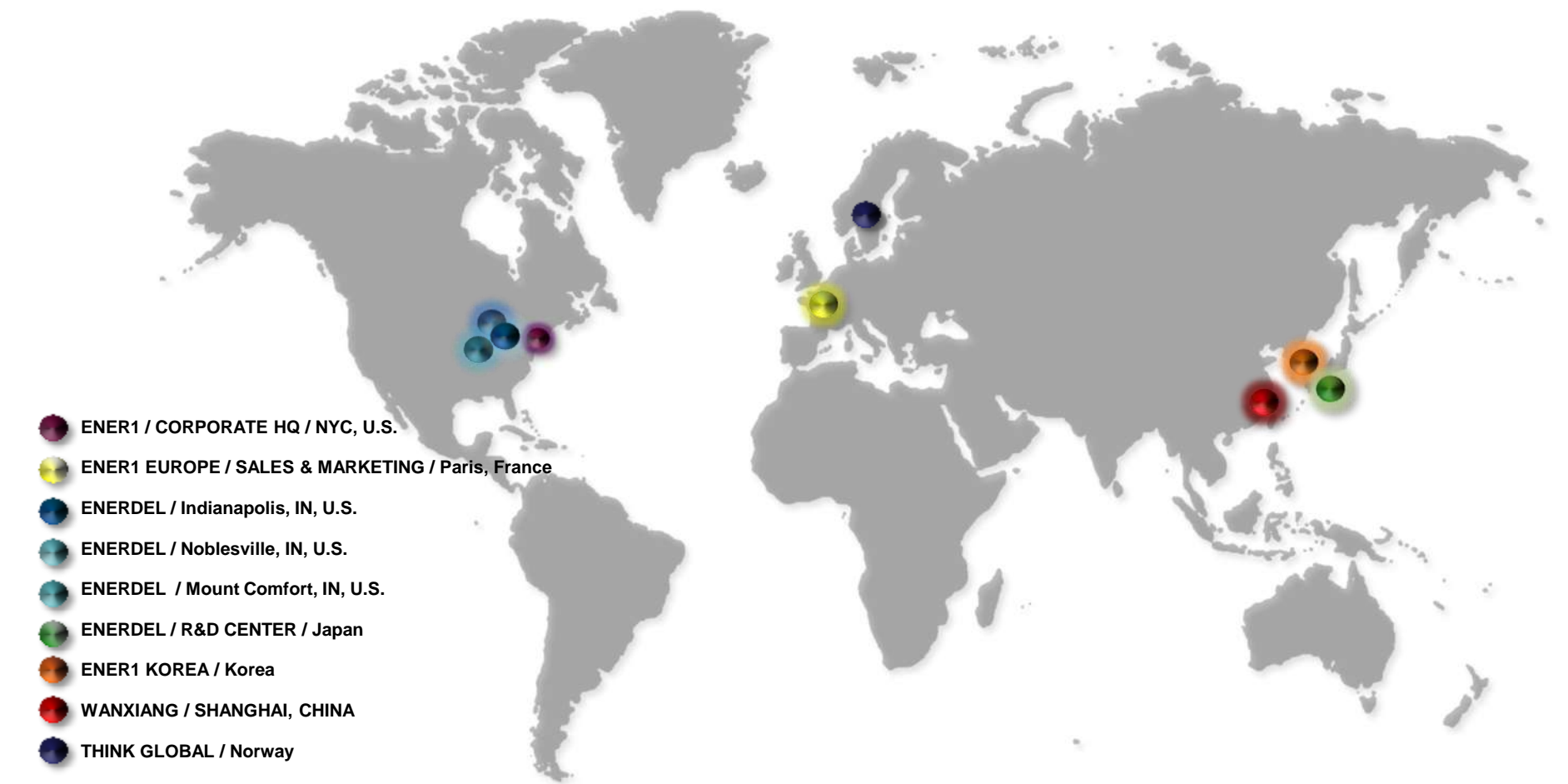
# CONTENTS

- **Ener1 Overview**
- **Negative Active Materials Comparison**
  - Lithium titanate vs. other common materials
  - Lithium titanate characteristics
- **EnerDel LTO Cell Performance**
  - Small cells
  - Large cells
  - Multiple cells in series
- **Conclusions & Final Remarks**



# GLOBAL SUPPLY STRATEGY

Total Employees: 750 (Excl. China/Think)  
Symbol/NASDAQ: HEV





# U.S. FACILITIES

Easily replicated production processes allow us to expand capacity and locate facilities in-country near clients' facilities



- Ener1 Lithium Group Established in 1990
- Delphi Lithium Group 1998
- EnerDel 2004
- Total Area: ~ 98,000 ft<sup>2</sup>
- Production & R&D of Lithium-Ion Cells for multiple applications



- Lease signed January 2010
- Total Area: 400,000 ft<sup>2</sup>
- Production Lithium-Ion Cells for multiple applications
- Final Pack Assembly Operations
- Production Launch in May
- Made possible by \$118.5 million in federal grant funding under the ARRA stimulus package



- Established in 2009
- Floor Space -38,500 ft<sup>2</sup>
- BMS Engineering & Test



# TOTAL SOLUTION PROVIDER FOR LI-ION BATTERY SYSTEM

**EnerDel battery system concept provides maximum flexibility to meet customer's requirement**

**CELL**

- Advanced Prismatic Design
- High Performance Li-Ion Cells



**MODULE**

- Easy Maintenance Module Concept
- Integrated Thermal Management
- Voltage & Temperature Monitoring



**SYSTEM**

- High Speed Vehicle Communication
- Robust Battery System
- Integrated reuse design concept

**EV System**



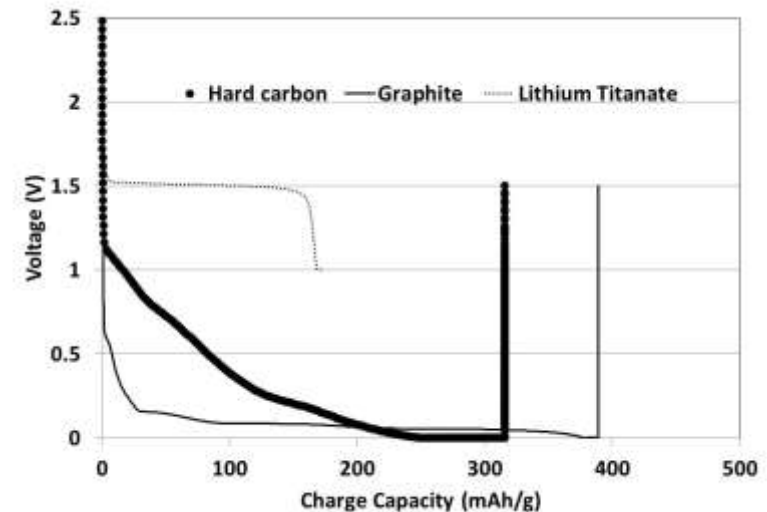
**HEV System**





# NEGATIVE ACTIVE MATERIAL COMPARISON

- Graphite
  - Most common active material for existing lithium ion cells
  - Most energy density per volume
- Non-graphite carbon
  - Less reaction with electrolyte than graphite
  - Higher power than graphite
  - Longer life than graphite
- Lithium Titanate ( $\text{Li}_4\text{Ti}_5\text{O}_{12}$ )
  - No reaction with electrolyte
  - Less impedance
  - Longer life
  - Less Energy density





# NEGATIVE ACTIVE MATERIAL COMPARISON

Characteristic	Graphite	Carbon	Lithium Titanate
Long Life	3	2	1
Power	3	2	1
Energy	1	2	3
Low temperature	3	2	1
Safety	3	2	1

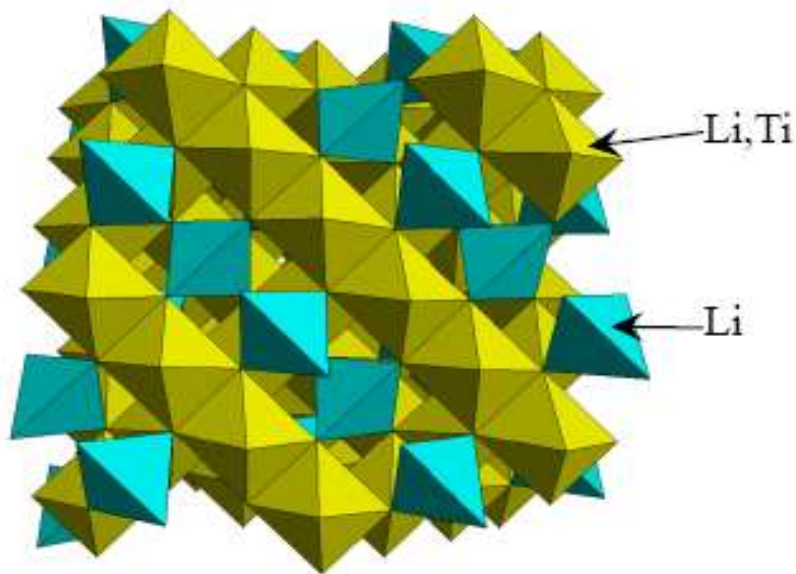
1 – BEST

2 – BETTER

3 - GOOD

Lithium Titanate cell performance will be presented in this presentation

# The Titanate Anode



- A very stable oxide best known for its safety and long cycle life
- Theoretical capacity of 165 mAh/g is about half that of graphite (372 mAh/g)
- It operates at 1.5V vs. Li which is above the voltage at which Li dendrites can occur
- Less than 0.2% volumetric change from fully discharged  $\text{Li}_4\text{Ti}_5\text{O}_{12}$  to fully charged  $\text{Li}_7\text{Ti}_5\text{O}_{12}$  titanate (for comparison, graphite is 9% and silicon is 300%)

<J. Electrochem. Soc. 146(1999) 857>



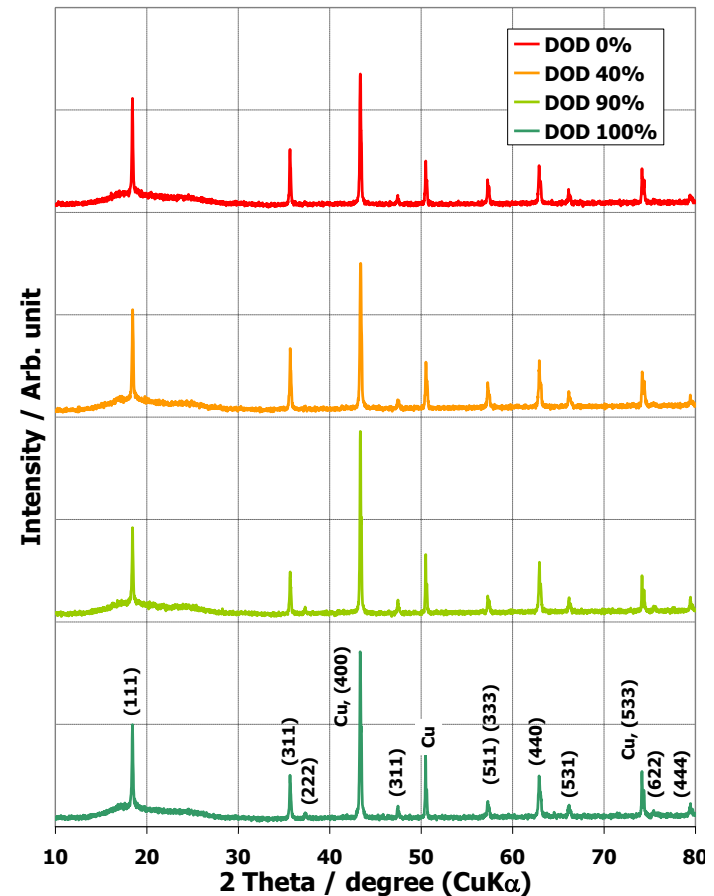


# LTO CHARACTERISTICS

- Advantages
  - Zero strain material
    - LTO  $\sim 0.02\%$  volume change
    - Graphite  $\sim 9\%$  volume change
  - No lithium dendrites
  - Less impedance than graphite

↓

  - ✓ High power
  - ✓ Good low temperature performance
  - ✓ Long life
  - ✓ Safety
- Disadvantages
  - Lower Energy Density
  - Lower Voltage



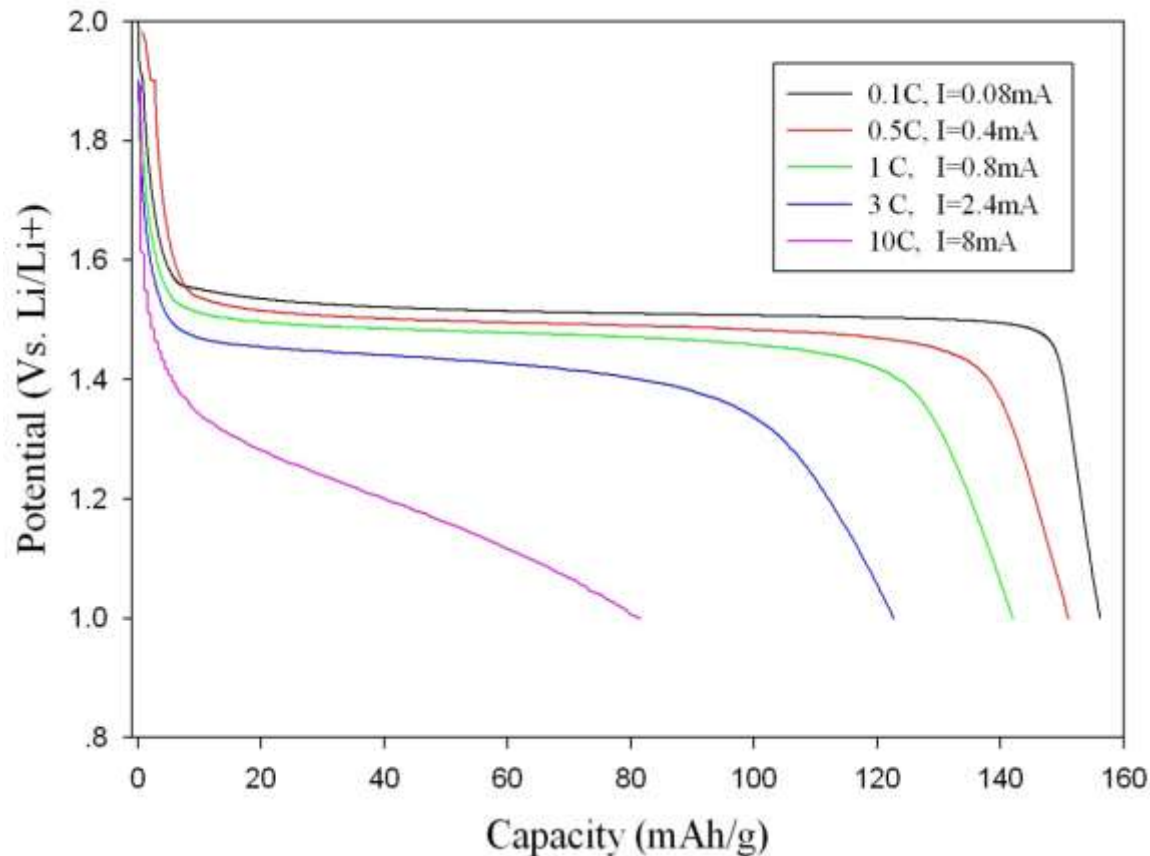
**Fig. XRD patterns of LTO material at different DOD**

Li<sub>4</sub>Ti<sub>5</sub>O<sub>12</sub> - spinel (LTO)





# LTO Anode

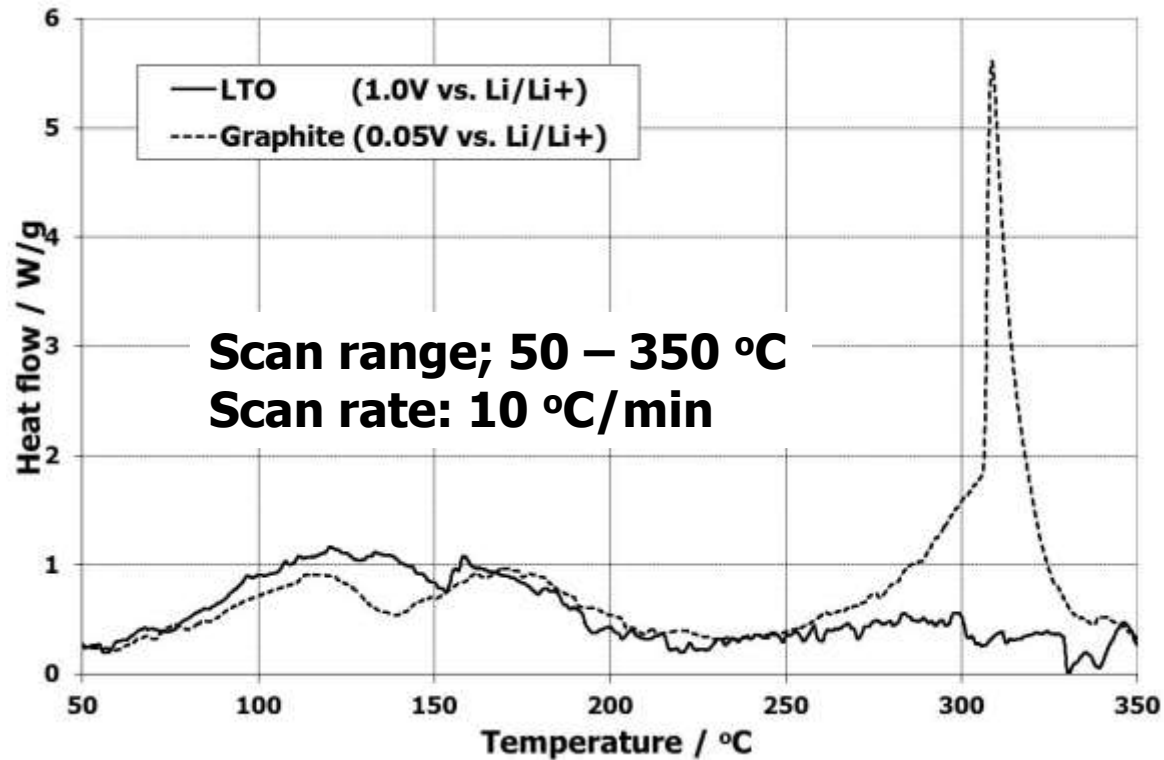


- The Li insertion in titanate occurs at ~1.5V, well above the voltage at which Li deposition occurs

Stan Whittingham SUNY

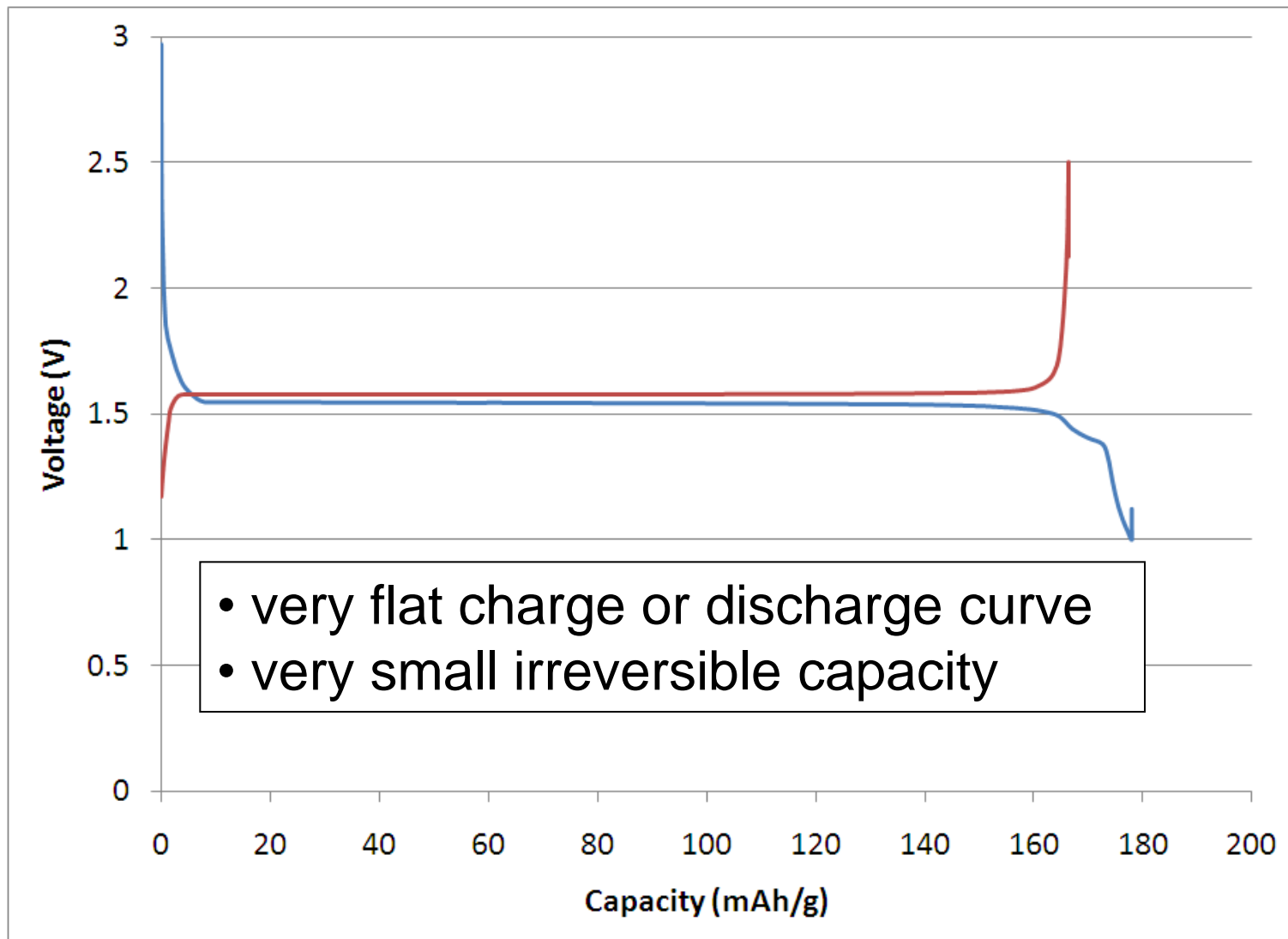


# THERMAL STABILITY OF LTO



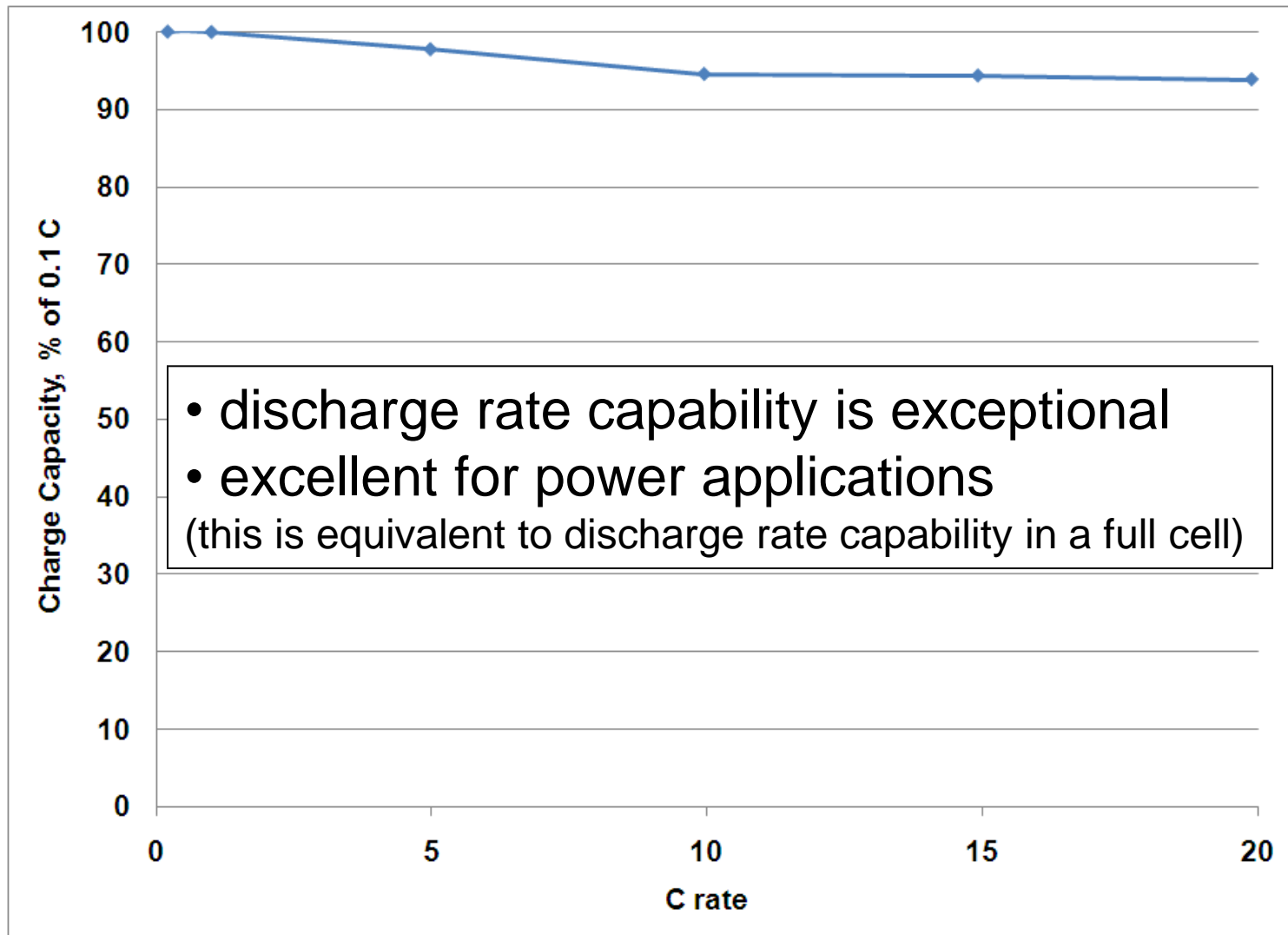
**LTO negative shows less heat generation than graphite negative**

# LTO HALF CELL RESULTS





# LTO HALF CELL RESULTS



# ENERDEL SMALL CELL DESIGN FOR LIGHT-DUTY VEHICLE APPLICATIONS



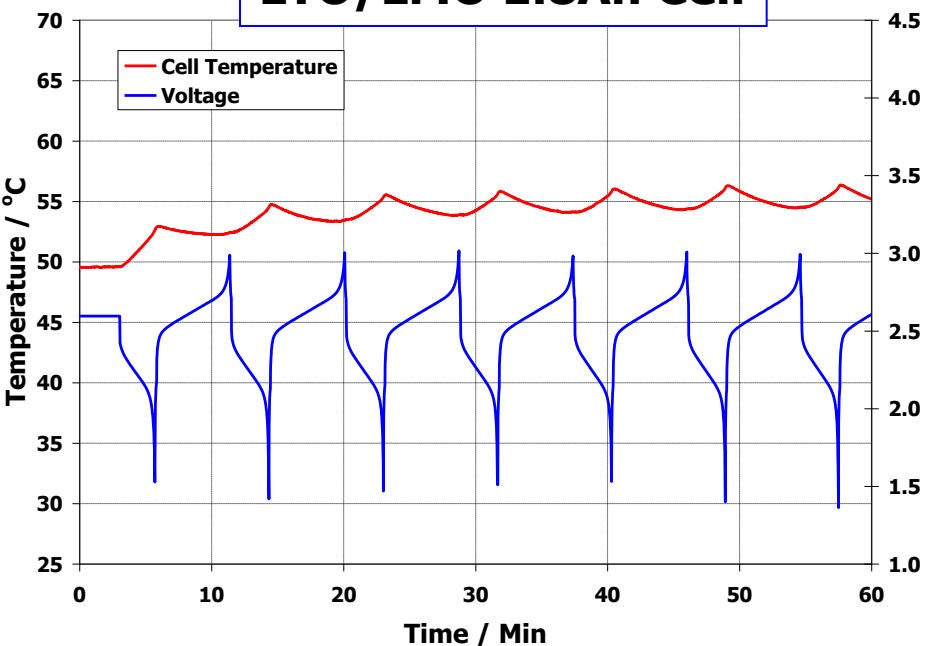
DESCRIPTION	SPECIFICATION	
Application	Light-duty vehicle	
Nominal Capacity	1.8Ah	5Ah
Max Voltage	2.8V	
Min voltage	1.5V	
Cell size	145 x 130 x 5 mm	200 x 111 x 5 mm
Chemistry	LTO/LMO	



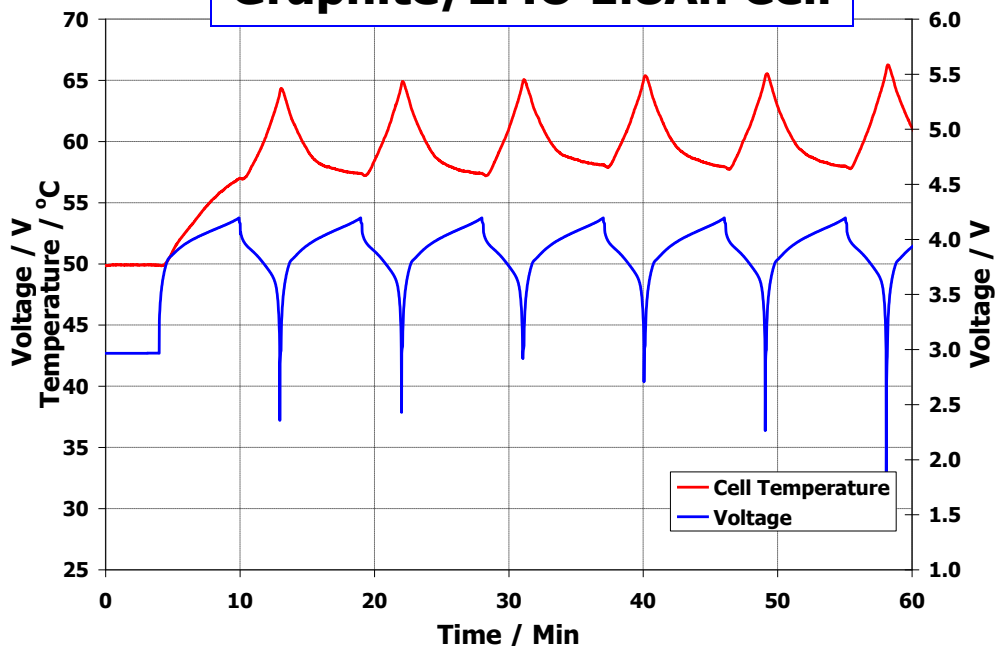


# TEMPERATURE INCREASE AT HIGH POWER CYCLE

**LTO/LMO 1.8Ah Cell**



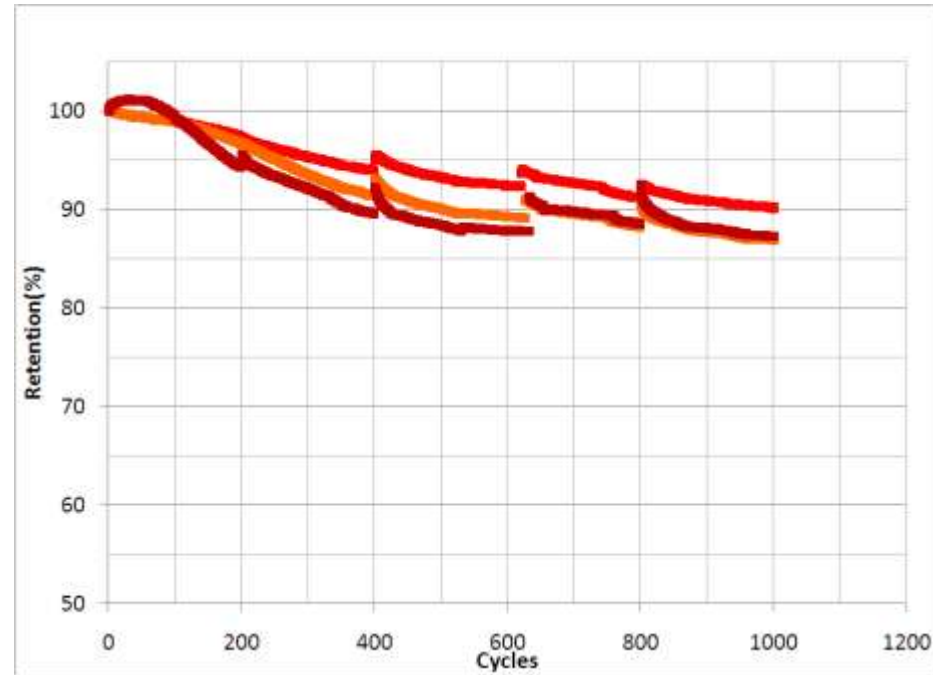
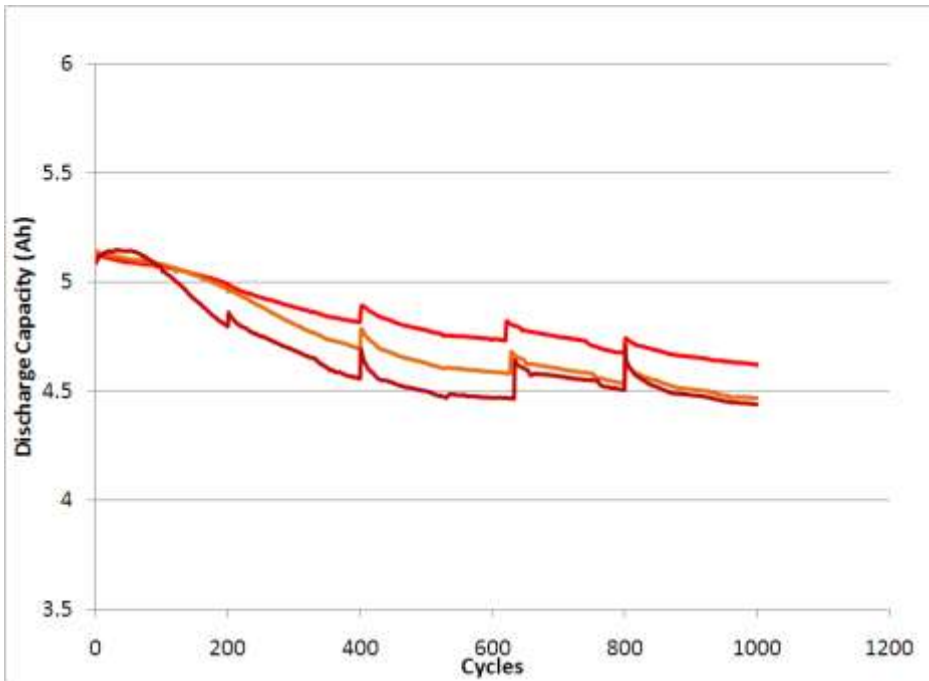
**Graphite/LMO 1.8Ah Cell**



# 5 AH FULL CELL: HIGH TEMPERATURE CYCLING

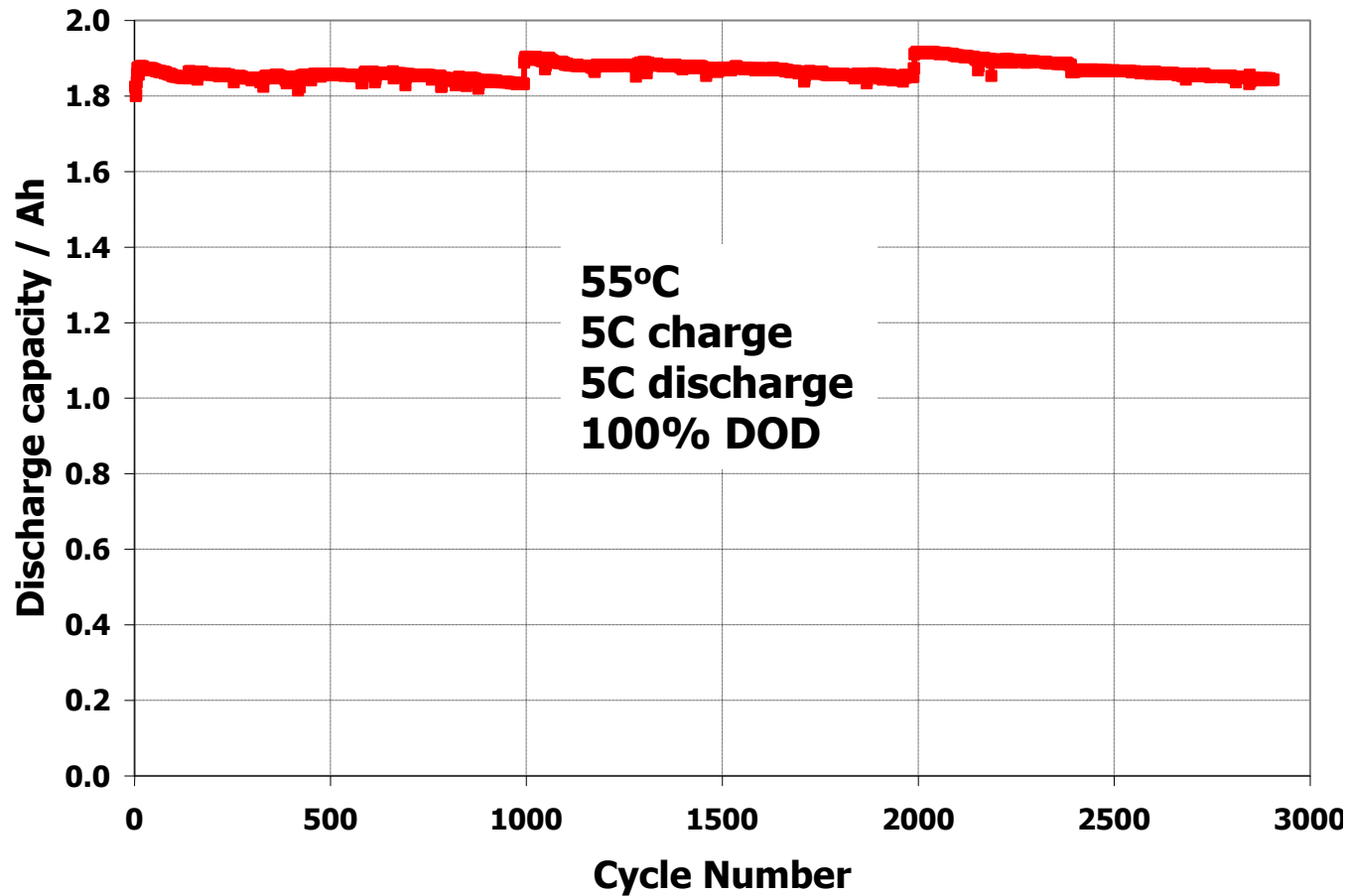


- 2C cycling at 55° C
- excellent high temperature capacity retention





# CYCLE LIFE

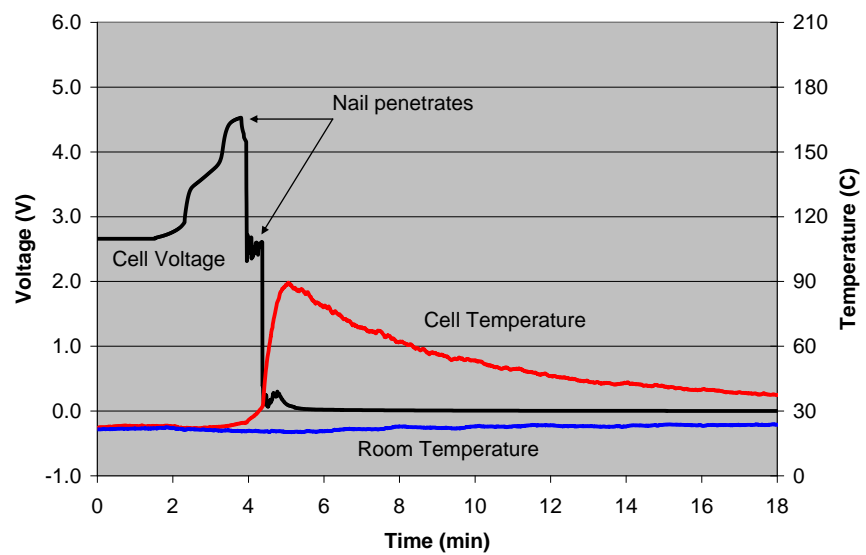


- No capacity loss under severe cycling conditions.



# EXTREME ABUSE TEST, LTO CELLS

## Overcharge and nail penetration





# HEV BATTERY PACK WITH ENERDEL LTO CELLS

We can reduce the battery size by one-half compared to existing Ni-MH pack

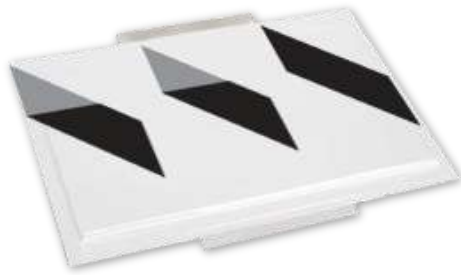
	CHEMISTRY	RATED ENERGY	AVAILABLE ENERGY	MAXIMUM POWER
Current	Ni-MH	1.2kWh	0.3 kWh	40kW
EnerDel	LTO	1.0kWh	0.8 kWh	80kW





# LARGER SIZE LTO CELL

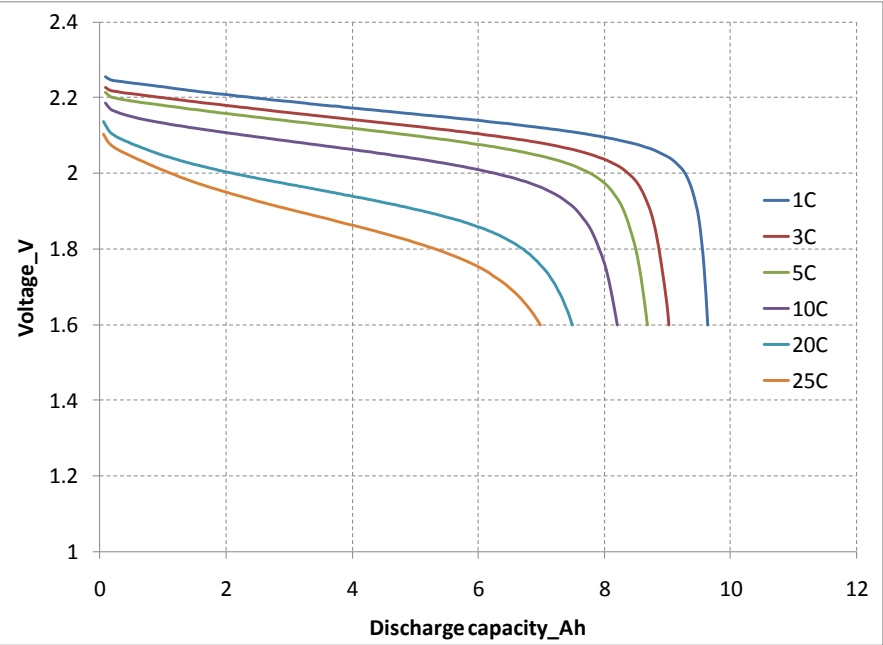
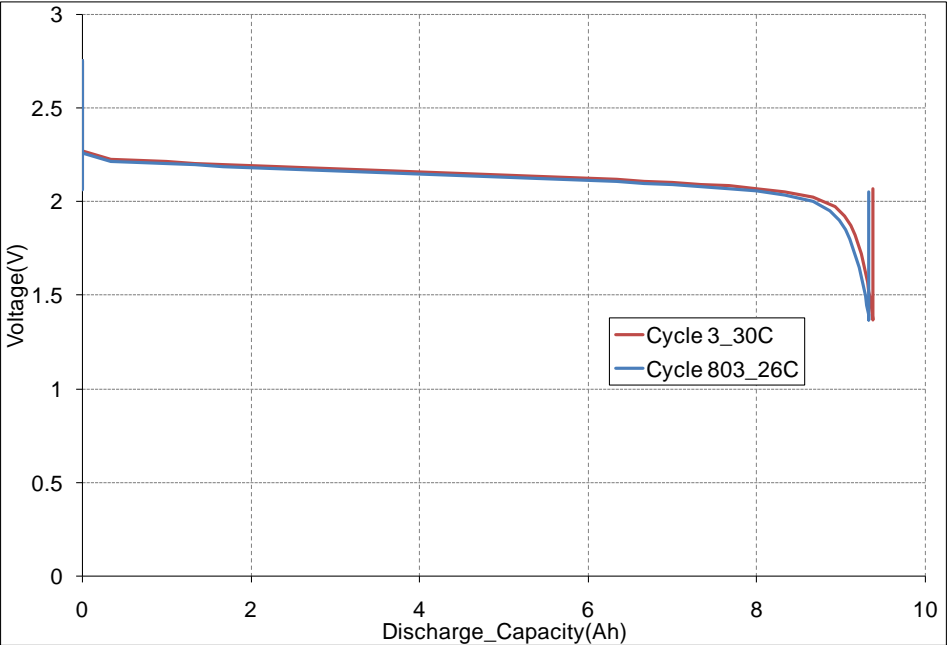
DESCRIPTION	SPECIFICATION
Application	Heavy-duty vehicle
Nominal Capacity	9.5Ah
Max Voltage	2.75V
Min voltage	1.6V
Cell size	172x 253 x 5.8 mm
Chemistry	LTO/Mixed Oxide



- Mixed oxide was used for the positive active materials instead of LMO



# DISCHARGE PROFILE– 9.5AH CELL

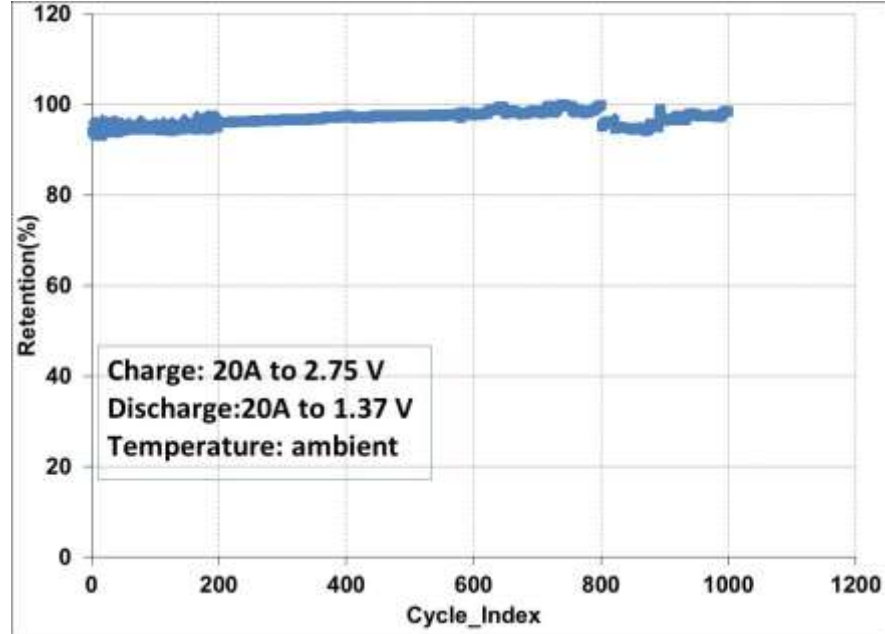
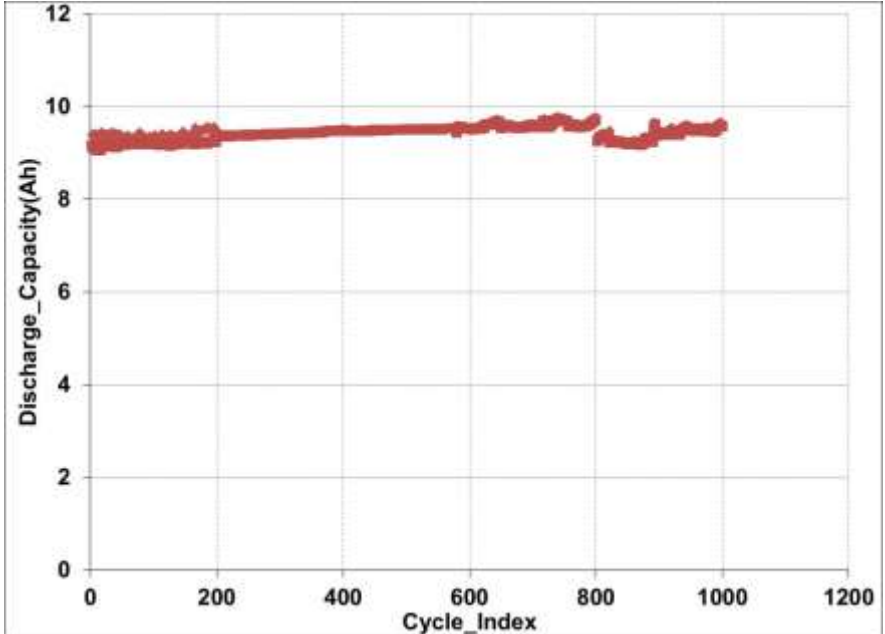


Discharge profile comparison at 3<sup>rd</sup> cycle and 803<sup>rd</sup> cycle

Rate Capability



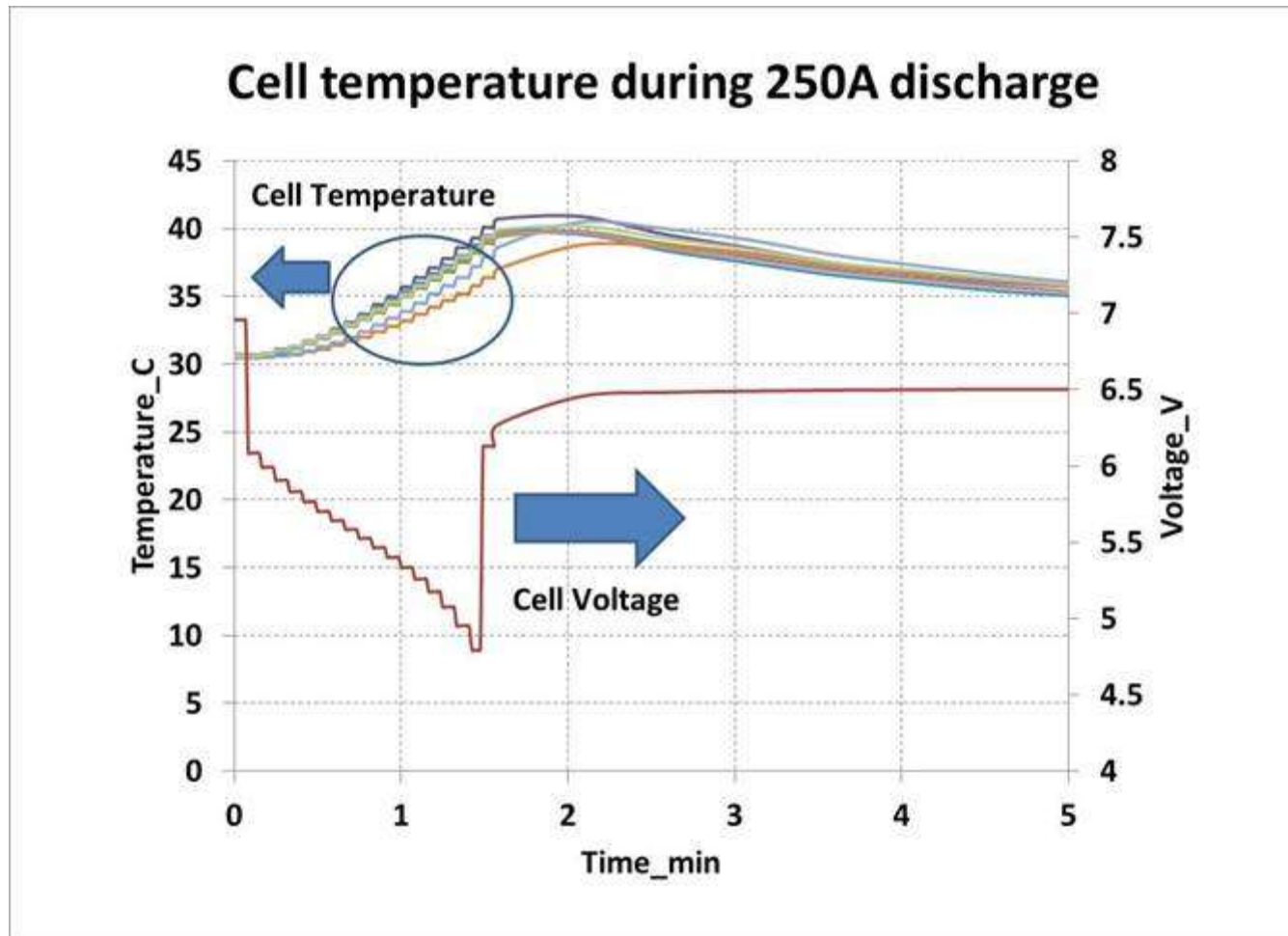
# CYCLE LIFE – 9.5AH CELL



Capacity loss is not observed through first 1000 cycles.



# THERMAL TEST WITH 3 CELLS IN SERIES (30° C)



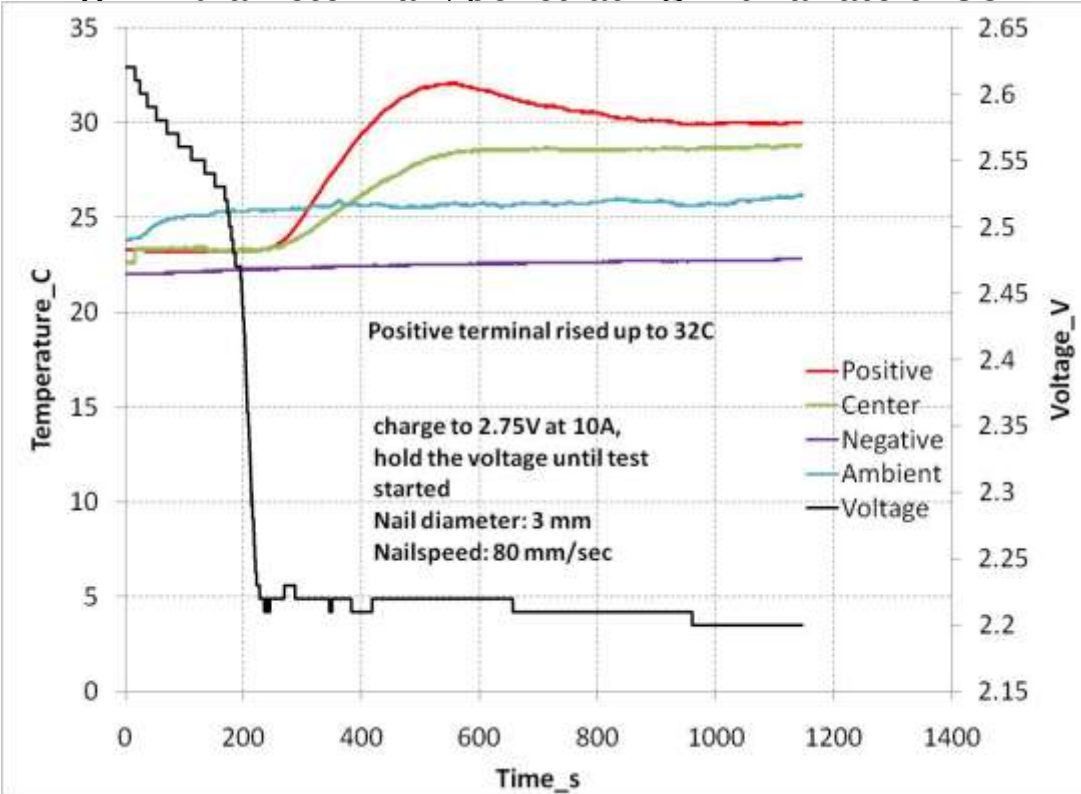
8 points of the cell temperature were measured  
Max 10°C increase with 25C continuous discharge



# NAIL PENETRATION (9.5AH CELL)



3mm diameter nail, penetrating with a rate of 80 mm/s



- No thermal event was observed. No explosion, no fire, no flame, no smoke. Irreversible cell damage.
- EUCAR /SAE J2464 hazard level = 2
- Cell was not shorted right away. It took 1 hr for the cell voltage to reach 0V
- Positive terminal temperature reached 32° C



# CONCLUSIONS



- SAFE
- LARGE FORMAT
- HIGH POWER
- LONG LIFE
- MECHANICALLY STABLE
- MADE IN THE UNITED STATES
- COMPATIBLE WITH EXISTING ENER1 MODULE STRUCTURE



# ACKNOWLEDGEMENT



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# THANKS FOR YOUR ATTENTION!

PLEASE VISIT US IN BOOTH #110

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