EnerDel Presentation
LMO/LTO

Naoki Ota

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EnerDel
Lithium Power Systems

Outline

- **EnerDel Information and Resources**
- **USABC Program Summary**
  - **HEV Program**
  - **PHEV Program**
- **Cell and System Design**
  - **Cell test data**
  - **System architecture**
- **Progress Highlight**

EnerDel Mission & Goal

Mission

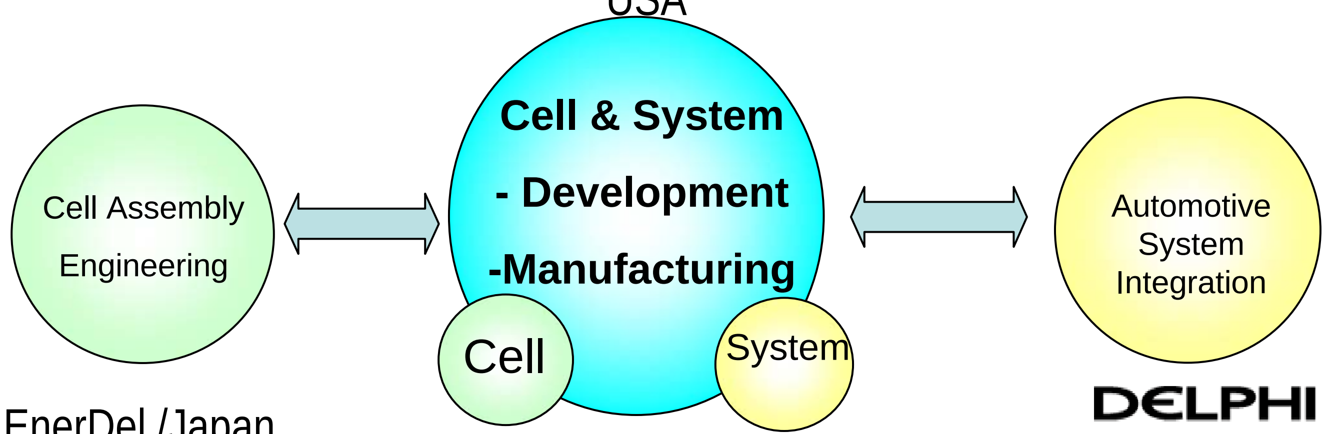
- To be a leader in the development of renewable clean energy systems
- To ensure the reduction of oil consumption and green house gases for the benefit of our planet
- To be the primary source of U.S. domestic supply of batteries for key strategic U.S. industries

Main Goal

- To be the first lithium ion battery system manufacturer in the U.S. for automobile applications: Hybrid Electric Vehicles (HEV), Plug-In Hybrid Electric Vehicles (PHEV), and Electric Vehicles (EV).
- The core strategy to achieve this goal is the merger of our revolutionary lithium ion cell technology and automobile electronics technology through our own development effort and key strategic partnerships.

US Manufacturing

EnerDel
Lithium Power Systems
USA



EnerDel /Japan

Japan

DELPHI
Driving Tomorrow's Technology

USA

- **Seek the shortest path of establishing a manufacturing site in the US with experienced partners.**

EnerDel Information

- **Location**
  - **Indianapolis, IN**
- **Full utility and infrastructure support for site**
  - **Facility built for the purpose of battery cell and pack manufacturing**
- **Existing Space**
  - **General purpose plant area (~68,000 ft^2)**
    - **Dry room facility (~6,000 ft^2)**
  - **Office area (~24,000 ft^2)**

EnerDel Resources

- **Manufacturing and testing cells**
- **Assembly and testing of packs**
  - **Full systems integration**

USABC Programs Summary

- **HEV Program**
  - **Phase1 (May/2006 to June/ 2007)**
    - **LMO / LTO Chemistry Performance Study**
  - **Phase2 (October/2007 to March/ 2009)**
    - **LMO / LTO Full Size Cell Study (3 to 5Ah)**
    - **Pack design study**
- **PHEV Program**
  - **Phase1 (February/2008 to August/2009)**
    - **High Voltage Cathode and Electrolyte**
    - **Make the best use of LTO anode.**

Characteristics of LTO Chemistry

- **Advantages**
  - **High Power**
    - **Less impedance than graphite**
  - **Outstanding Safety**
    - **No SEI layer**
      - **Remote risk of thermal runaway**
    - **No lithium dendrites**
    - **Stable active materials**
  - **Long Life**
    - **Zero strain material**
      - **LTO ~ 0.2 % volume change**
      - **Graphite ~ 9% volume change**
    - **No lithium dendrites**

Characteristics of LTO Chemistry, cont'd

- **Advantages, cont'd**
  - **Low temperature performance**
    - **Less impedance than graphite**
    - **More electrolyte choices because of LTO**
    - **No lithium dendrites**

- **Disadvantages**
  - **Lower Energy Density**
  - **Lower Cell Voltage. (1.5V on negative)**

Compared cells with graphite anode.

….

Much higher available energy and voltage than Ni-MH

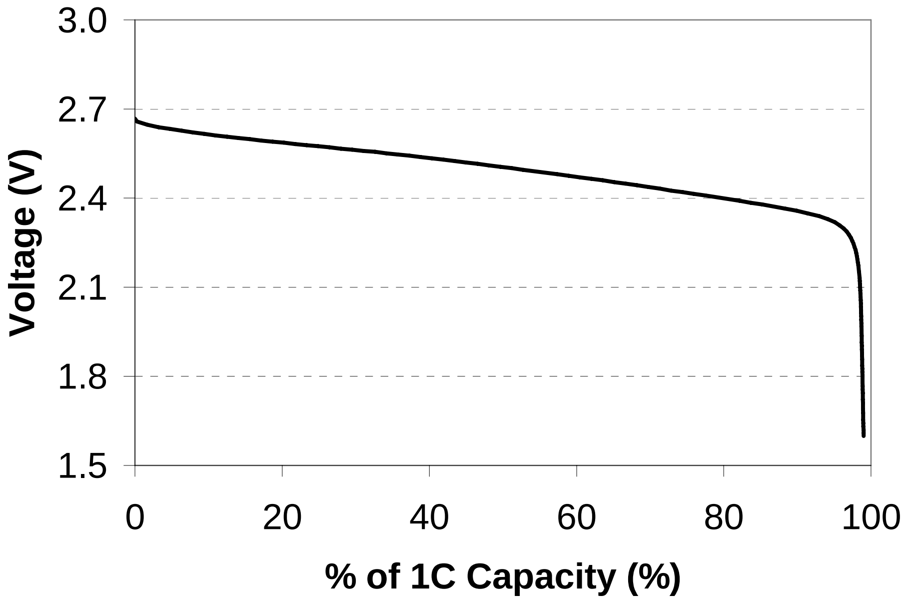
Manganese Spinel (Mn-Spinel/LMO) Advantages

- **High Voltage**
  - ***High voltage profile to couple with lithium titanate***
- **Low Cost**
  - *Manganese Spinel powder cost is 3/4 of lithium iron phosphate, 1/2 of Lithium Nickel Cobalt Oxide, 1/3 of Lithium Cobalt Oxide*
  - *Large worldwide reserves of Manganese*
- **Power Capability**
  - *Will allow for designing a small battery that can meet all the power requirements for HEV applications*
- **Outstanding Safety**
  - ***Manganese Spinel release very small amount of oxygen under high temperature.***

EnerDel's Chemistry for HEV Application

- **Positive Active Material: $LiMn_2O_4$- spinel (LMO)**
  - **$LiMn_2O_4 \leftrightarrow Li_{1-x}Mn_2O_4 + xLi^+ + xe^-$**

- **Negative Active Material: $Li_4Ti_5O_{12}$ (LTO)**
  - **$Li_4Ti_5O_{12} + xLi^+ + xe^- \leftrightarrow Li_{4+x}Ti_5O_{12}$**



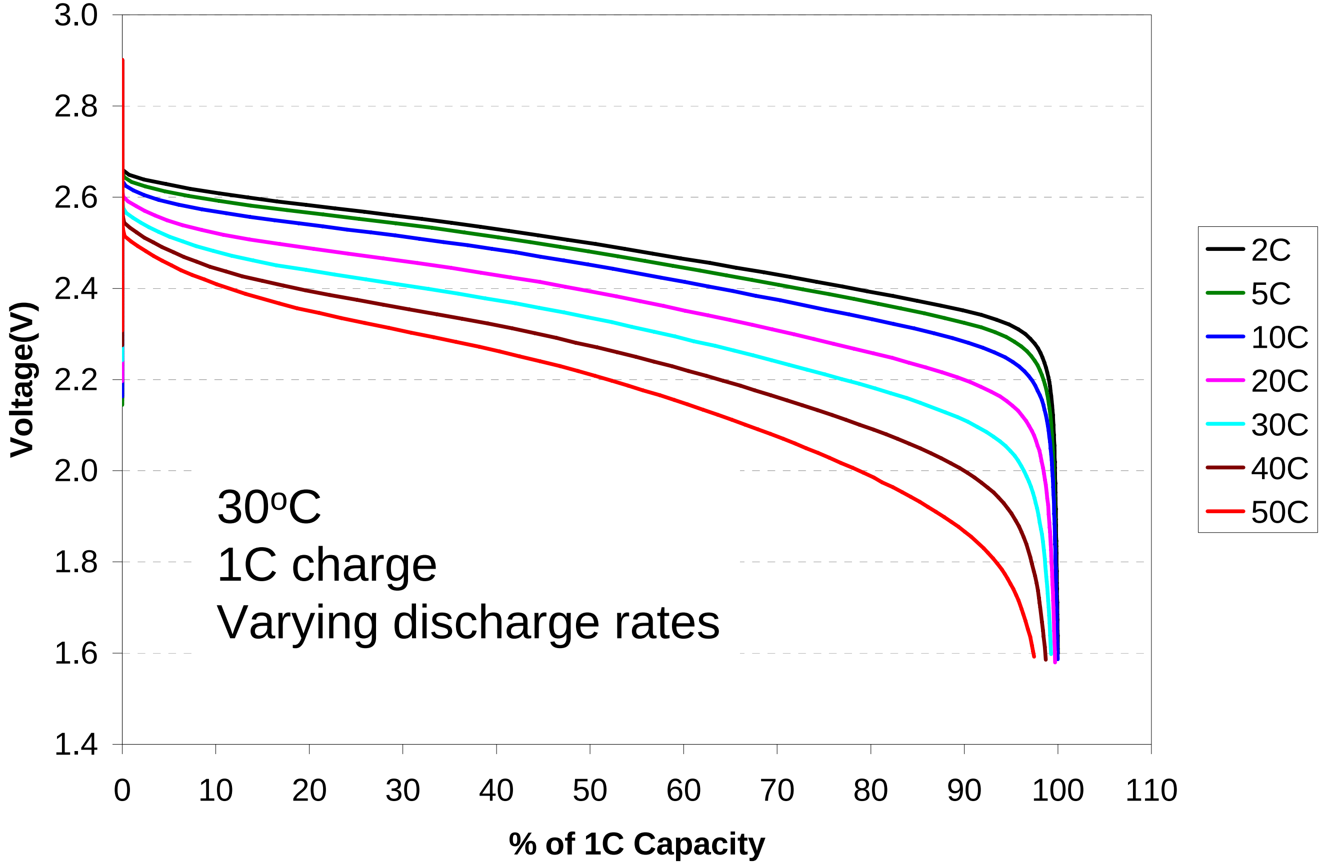
1C discharge
30°C

Cell Design

- **Prismatic**
  - **Case Neutral**
  - **Good heat dissipation**
  - **Flexible form-factor**

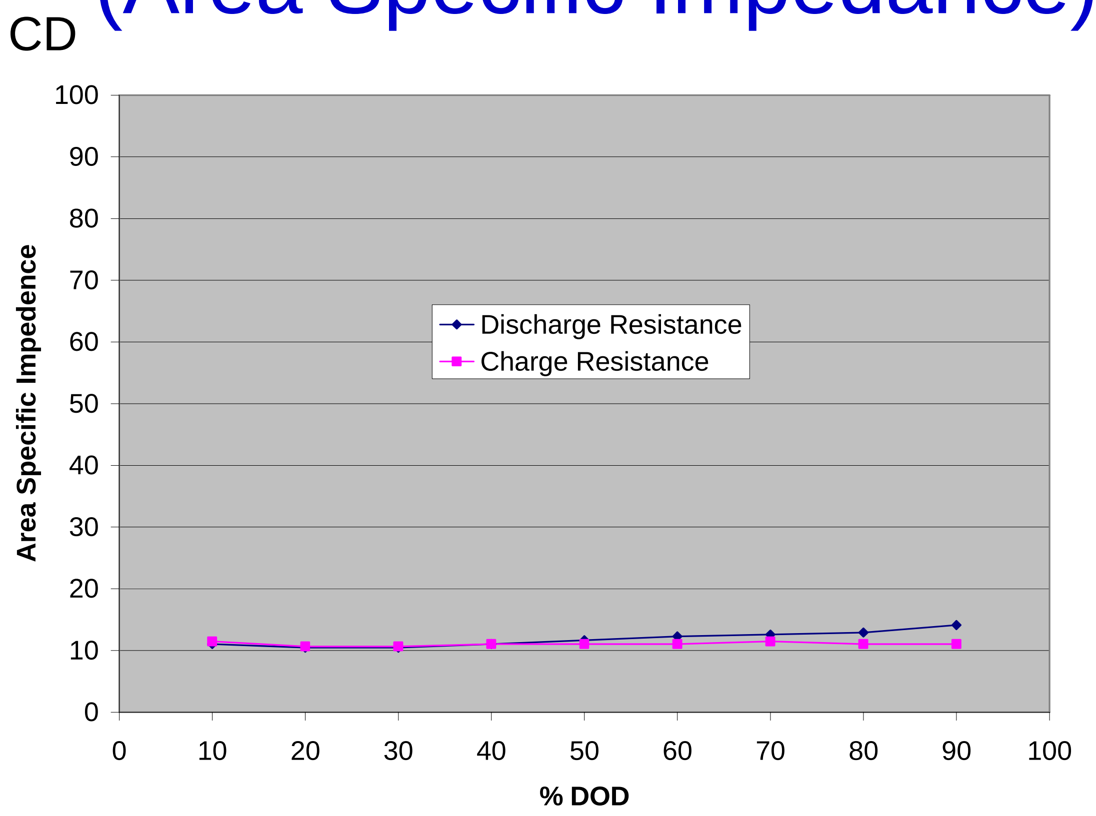
	CD Size	A5 Size
Nominal Capacity	1.8 Ah	5 Ah
Nominal Voltage	2.5V	2.5 V
Dimensions (connections included)	145mm W, 130mm L, 5mm T	200mm W, 111mm L, 5.8mm T
Packaging	Metal or Laminate	Metal or Laminate

Rate Capability of 1.8 Ah Cells



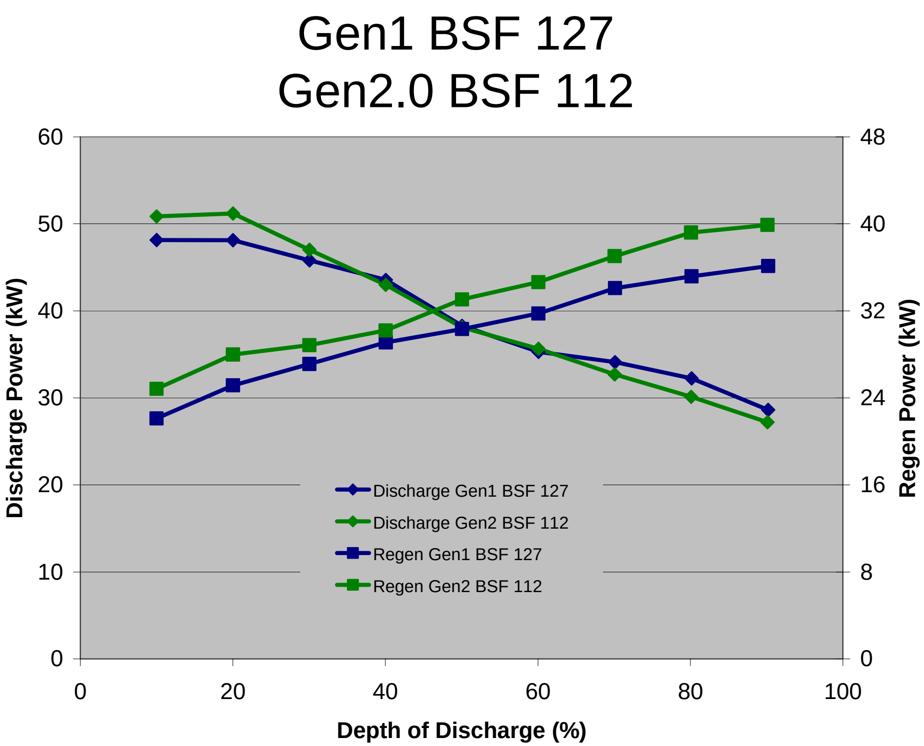
- **High discharge efficiency for rates up to 50C.**

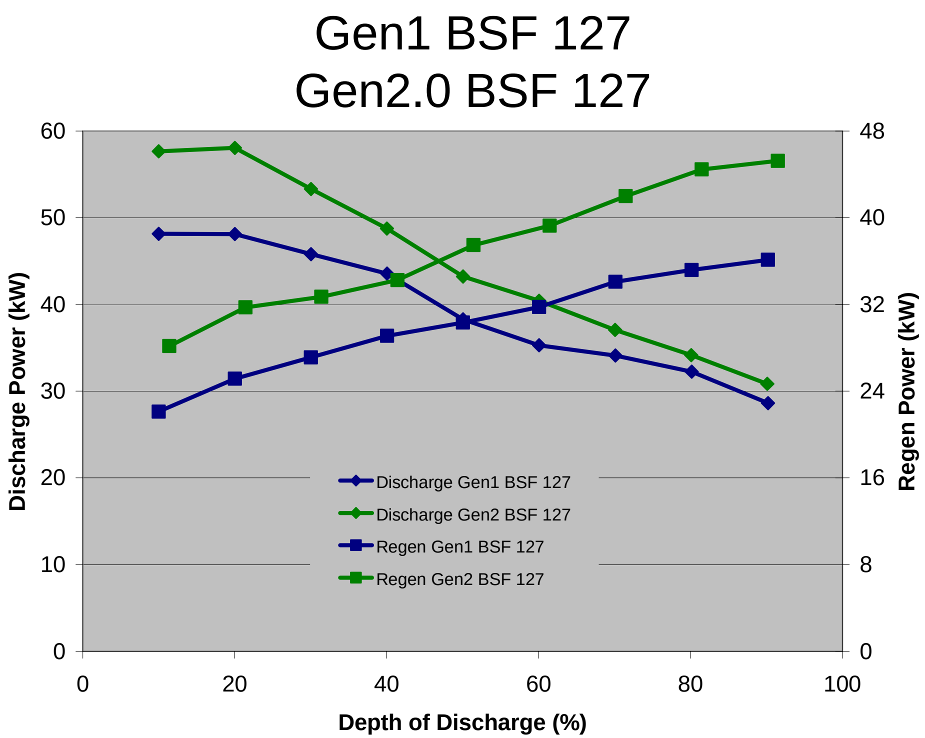
ASI
(Area Specific Impedance)



- **Very low ASI achieved on both charging and discharging under USABC testing protocol**

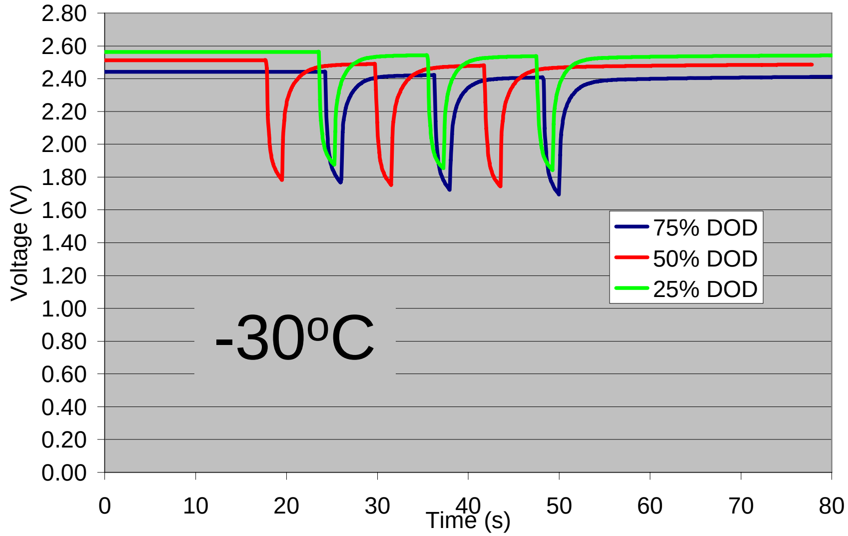
Power Capability



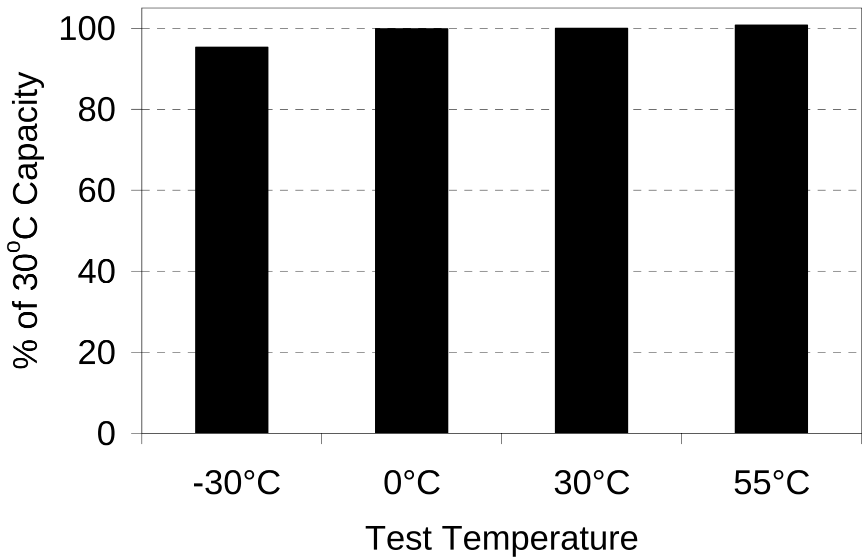


- **Gen2.0 cells show more power when comparing with the same BSF value.**
- **Gen2.0 has ~20% more power capability**

Low Temperature Performance



Cold Cranking
Equivalent to 5kW of power

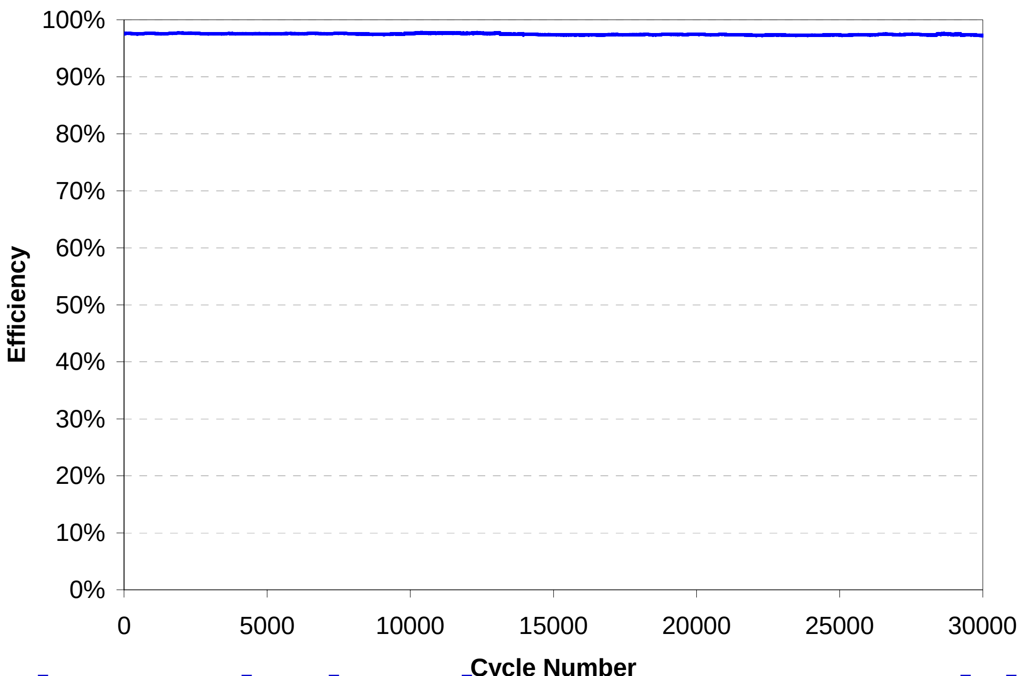


1C Discharge

- **High power and full discharge capability at low temperatures.**

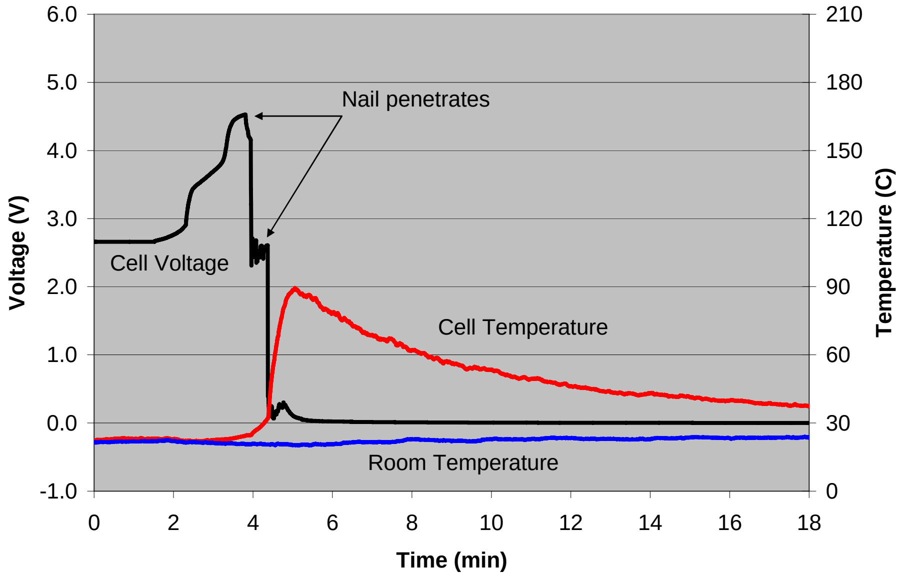
Energy Efficiency

- 30^{o}C, 30,000 cycles
- > 97% efficiency



- **No degradation in power capability after 30,000 energy efficiency cycles.**

Safety: Nail penetration video

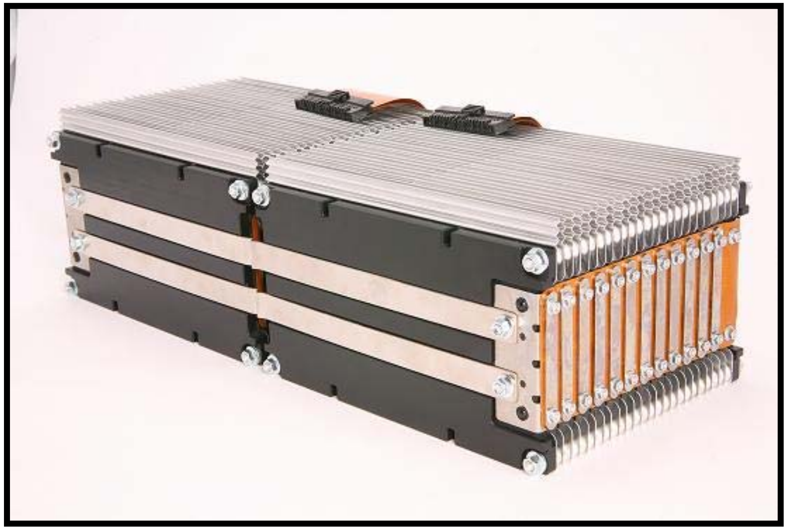


10% Overcharged Cell

System Design Features

- **Safety**
  - **System control redundancy**
  - **Ultra - low voltage assembly (non-lethal, easy maintenance)**
- **Packaging Efficiency**
  - **Stacking efficiency of prismatic cells**
  - **Elimination of discrete wires for voltage / temperature sensing**
- **Architectural Flexibility**
  - **Modular design offers multiple arrangement configurations**
- **Mechanical Robustness**
  - **Designed for ease of assembly / error proofing features**
- **Thermal management**
  - **Design allows for air or liquid cooling**

HEV Battery Concept Modules



Integration of EnerDel battery system into an HEV (Prius)

	Chemistry	Energy	Available Energy	Maximum Power
Current	Ni-MH	1.2kWh	0.3 kWh	40kW
EnerDel	LTO/LMO	1.0kWh	0.8 kWh	90kW

HEV Phase 1 Progress Highlights

- **EnerDel demonstrated the very high power capability of the LMO/LTO system in a scalable cell format (1.8 Ah).**
- **The LMO/LTO system is able to provide high power across a broad range of usable energy and showed a good safety performance under preliminary test.**
- **Achieved low temperature performance USABC requirements.**

Acknowledgements

- **DOE/USABC team.**
- **Argonne National Laboratory**
- **Idaho National Laboratory**

Argonne NATIONAL LABORATORY

FreedomCAR & Fuel Partnership

USABC UNITED STATES ADVANCED BATTERY CONSORTIUM

INL Idaho National Laboratory