# *Lead–Acid Batteries In Hybrid Electric Vehicles*

Patrick T. Moseley
Advanced Lead–Acid Battery Consortium

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## *Presentation Outline*

- Conventional lead–acid batteries are unable to cope with hybrid electric vehicle duty

-Two solutions

- Proving tests on the road

# Typical range of state-of-charge, rates of discharge and recharge and failure modes

| Duty | SLI | Deep cycle | High rate PSoC |
|---|---|---|---|
| Examples | 12 V | EV | HEV |
| Range of SoC | 85 - 90 % | 20 - 100 % | 35 - 85 % |
| Max. norm. disch. rate | 10 C | 4 C | **15 C** |
| Max. norm. charge rate | 0.5 C | 0.5 C | **8 C** |
| Life-limiting mechanisms | Corrosion, shedding | PCL 1, PCL 2 | **PCL 3** |

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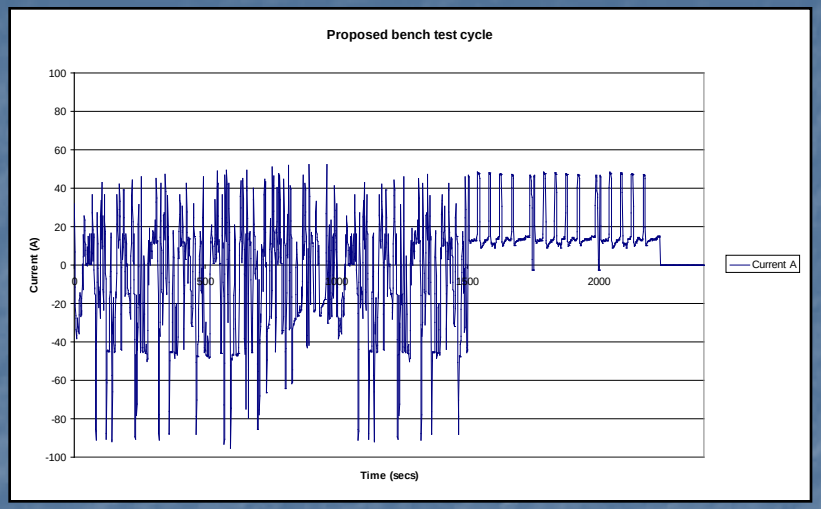
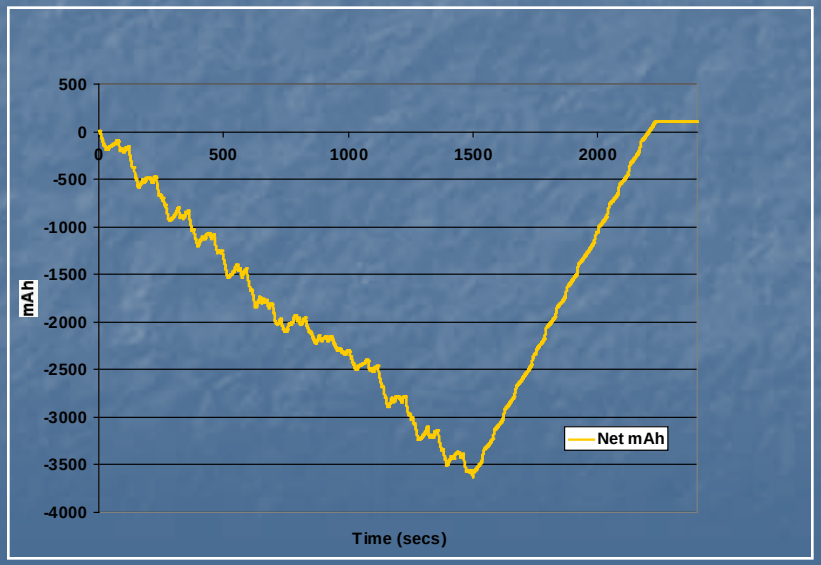
# Real-world HEV Battery Duty

Current pulses through

30 minutes driving - 2 to 5% of capacity discharged at up to 15C and charged at up to 8C.




Charge removal and return during the same period



# HEV Power-assist Performance Requirements

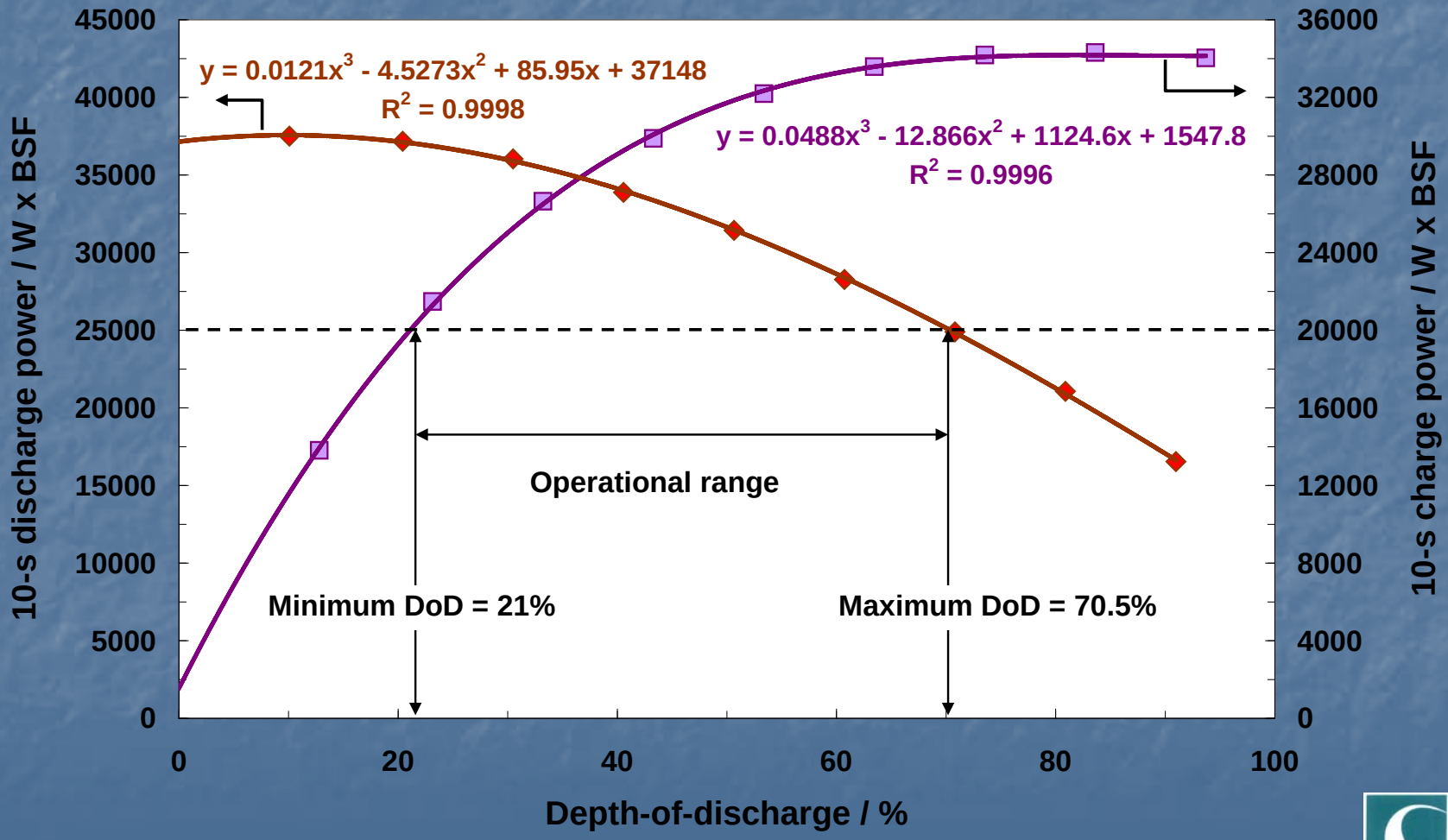
| | USABC Minimum P-A goals | NiMH use in Honda Insight |
|---|---|---|
| Maximum wt (kg) | 40 | ~30* |
| Power out (10s) kW | 25kW (625W/kg) | 14 kW (467W/kg) |
| Power in (10s) kW | 20kW (500W/kg) | 7 kW (233W/kg) |
| Energy available in HRPSoC (Wh) | 300 (7.5Wh/kg) | 450 (15 Wh/kg) |
| Cycle life | 300,000 | ? |
| Production Price ($) | 500 | 1017^ |

* Inc. BMS., ^ U.C. Davis report, 2003.

# Hybrid pulse power characterisation

# (minimum power assist, battery-size factor = 21)

Discharge power = 25 kW  Charge power = 20 kW

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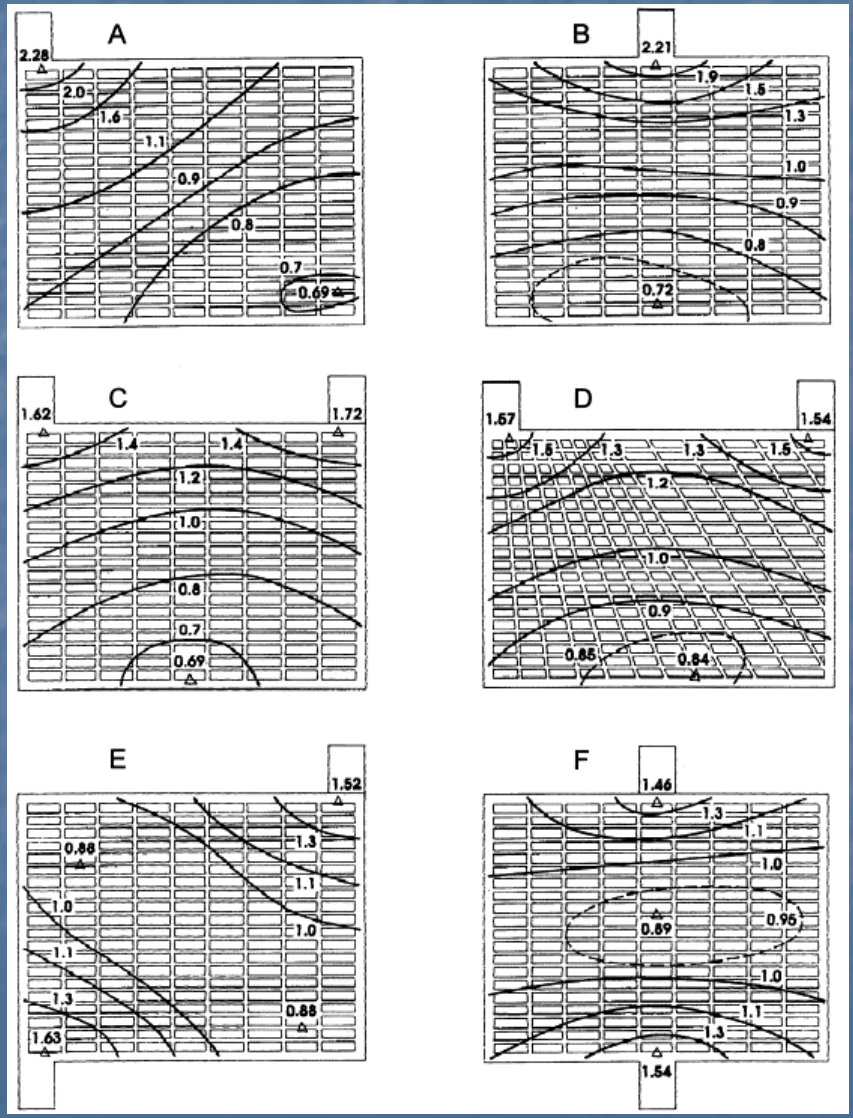
# Mechanism & solution:

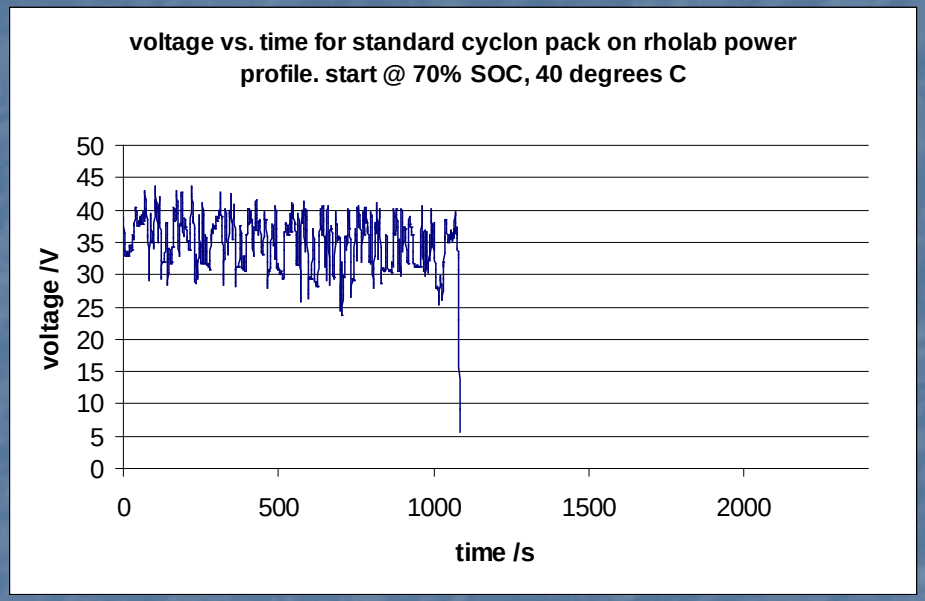
## 1. Grid design

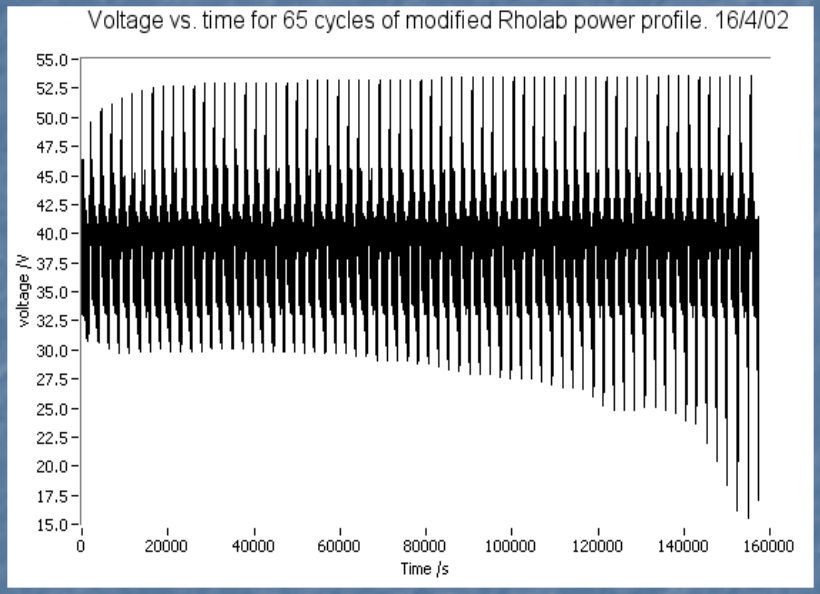
# Current density contours on twin tab arrangements



# Spiral Wound Cell with Dual Tabs

# The role of grid design for HEV duty




Purpose-designed grid connections extend life of uninterrupted HEV operation from 18 minutes to 39 hours

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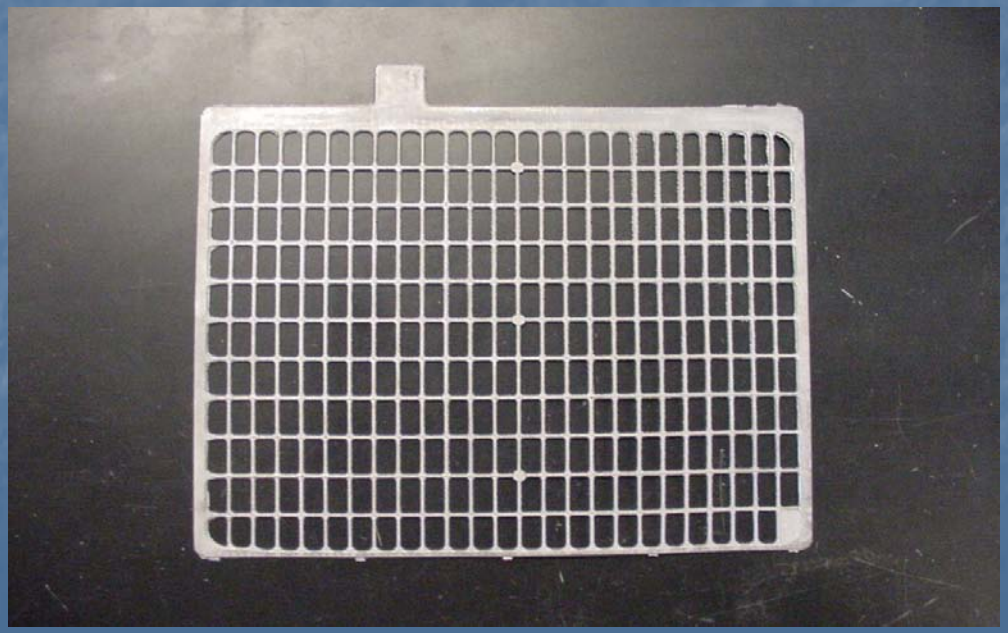
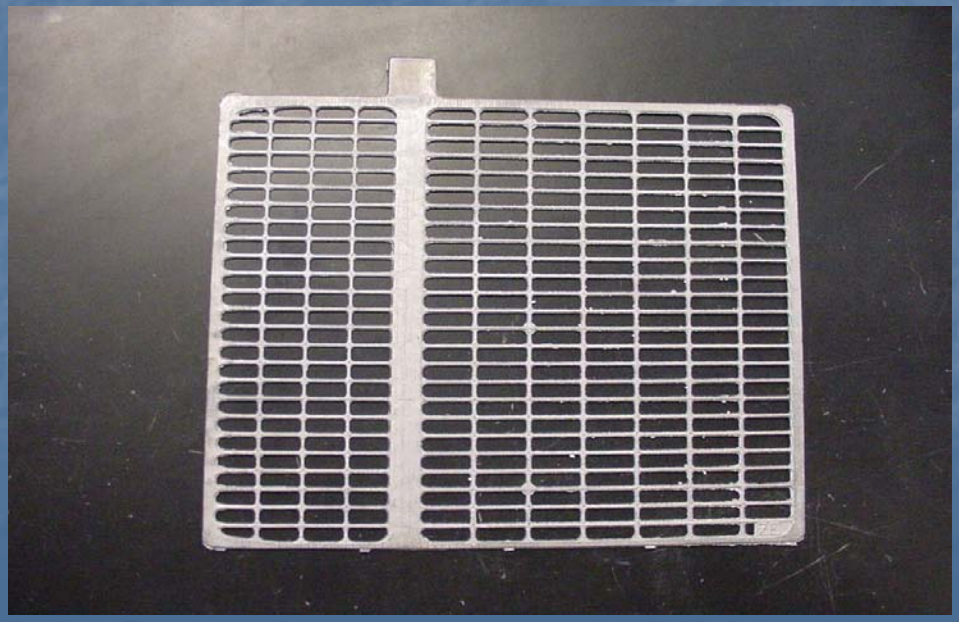
# Manufacturing

- Grid Design 1
- Target Weight = 65.0 grams
- Target Thickness = 1.27 mm



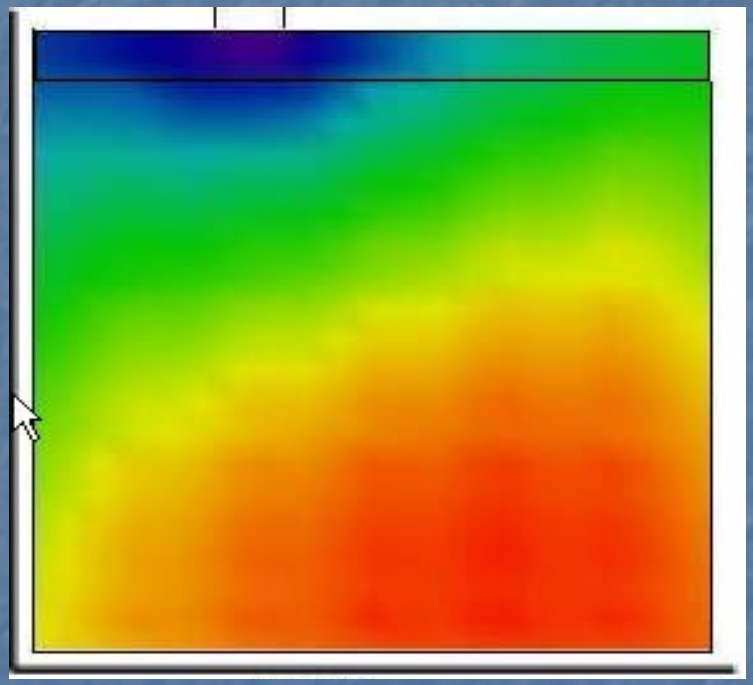
# Manufacturing

- Grid Design 2
- Target Weight = 69.0 grams
- Target Thickness = 1.27 mm

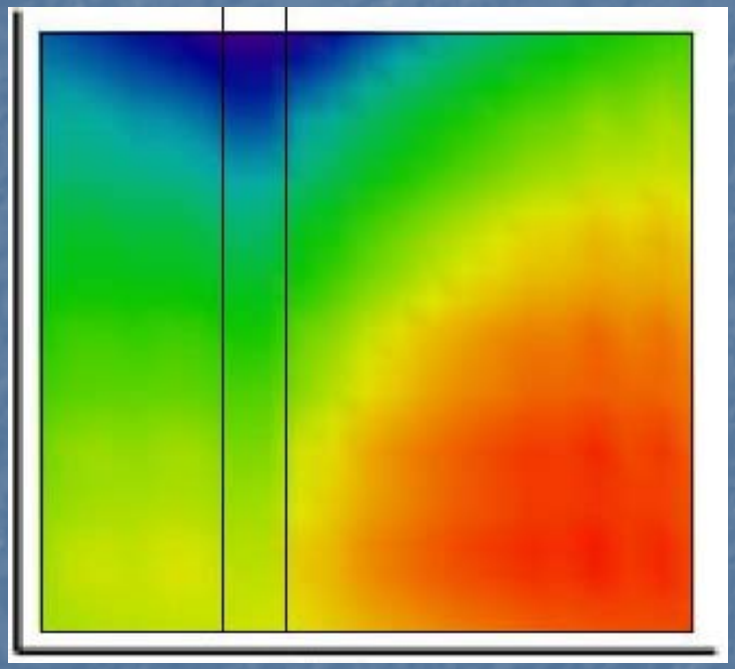


# Grid Design

- Computer Modeling: Brigham Young University Dr. John Harb



Design 1

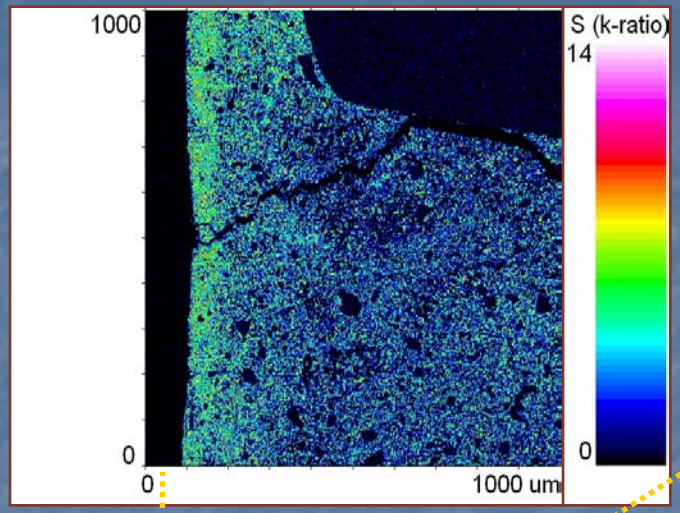


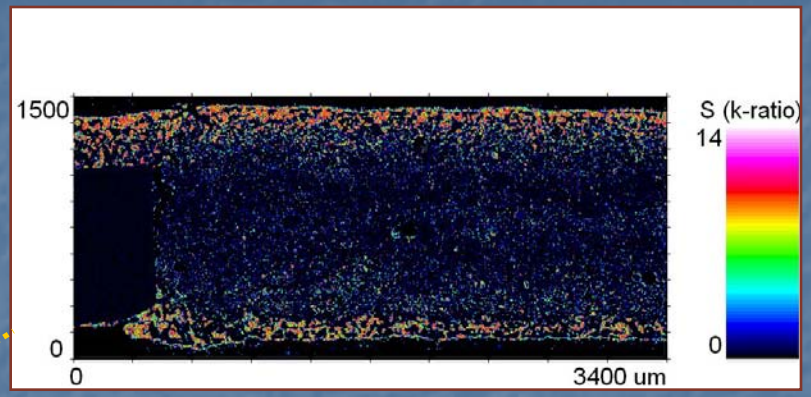
Design 2

# Mechanism & Solution:

## 2. Expander Composition

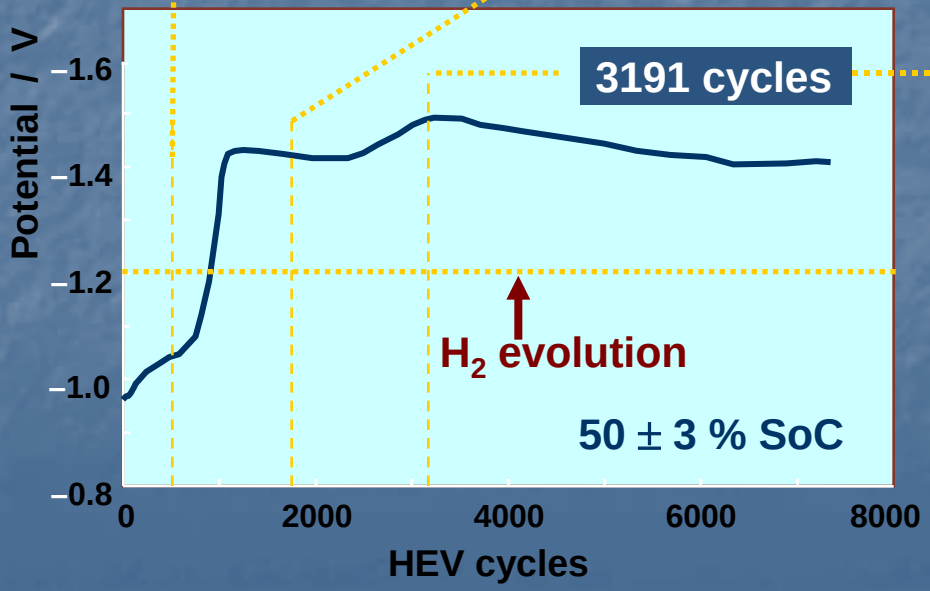
# HEV duty: sulfate build-up in negative plates

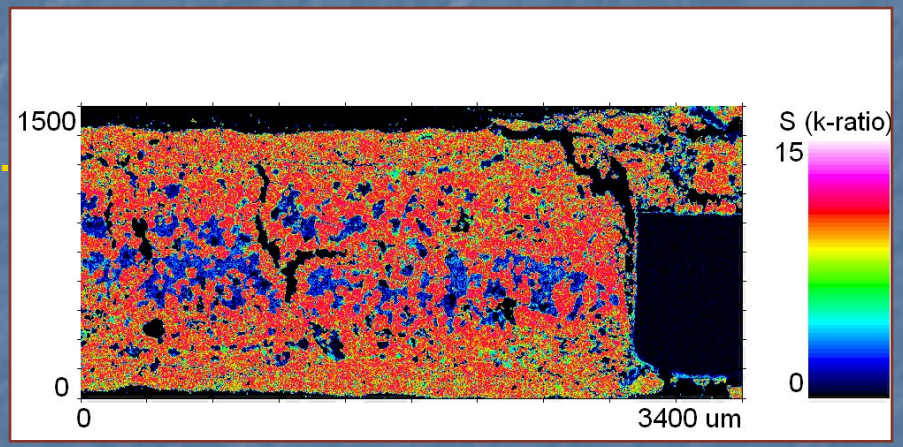


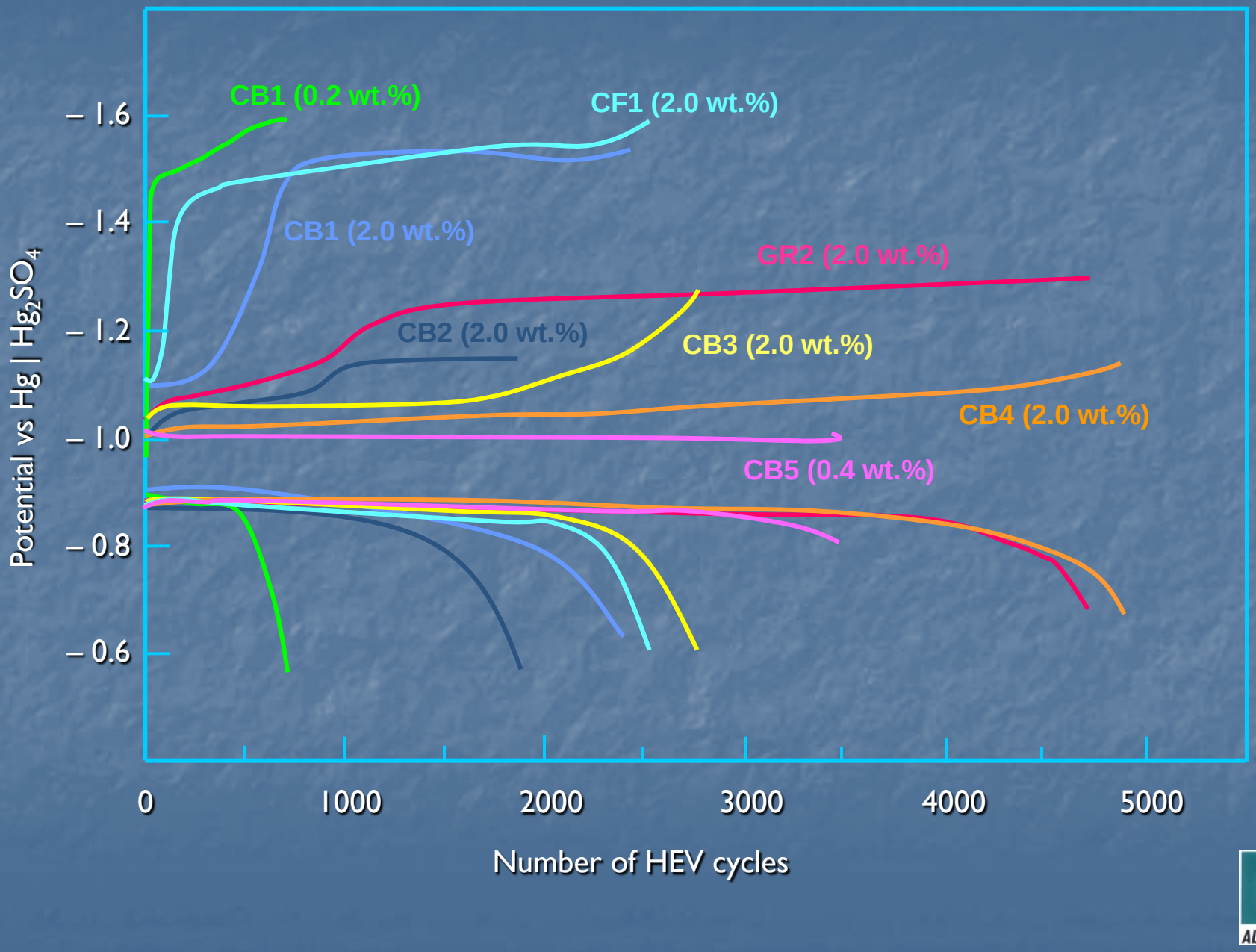

0 cycles

1735 cycles

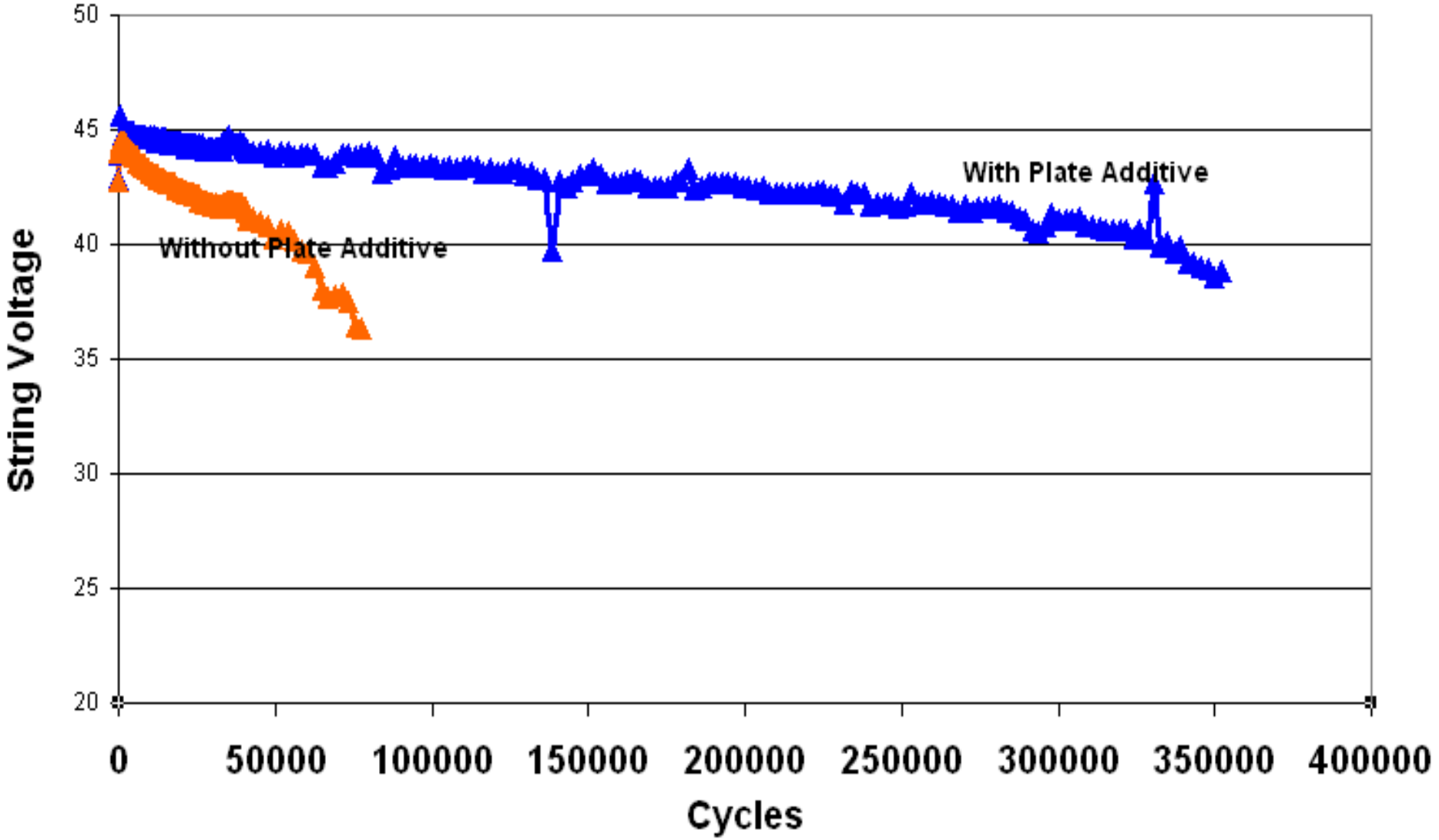


# EoC and EoD potentials of negative plates in HRPSoC operation



# Previous Work
# Comparison of End of Discharge Volts
# Control With and Without Plate Additive



# Extension of Life Under High Rate PSoC Cycling

**Failure Modes:**
- Early Gassing
- Negative Sulfation
- Recharge Resistance

**Solutions:**
- Carbon added to Negative
- Grid Design

# Types of Hybrid Electric Automobile

| | Micro- | Mild- | Medium | Full |
|---|---|---|---|---|
| EV Drive | | | | ★ |
| Motor assist | | ★ | ★ ★ | ★ ★ ★ |
| Regen. braking | ★ | ★ | ★ ★ | ★ ★ ★ |
| Engine stop | ★ | ★ | ★ | ★ |
| Battery voltage | 12 | 36 | 144 | >200 |
| Battery capacity (Ah) | 50 - 60 | 15 - 20 | 6 - 8 | 6 |

# ALABC Demonstration phase vehicles

| *Battery type* | *Capacity (Ah)* | *Voltage (V)* | *Vehicle* |
|---|---|---|---|
| Spiral | 50 | 12 (1 x 12) | Citroen C3, micro hybrid |
| Spiral | 50 | 12 (1 x 12) | Ford Fiesta, micro hybrid |
| Flat plate | 52 | 36 (3 x 12) | GM Silverado, mild hybrid |
| Spiral | 24 | 36 (6 x 6) | Ford Focus, mild hybrid |
| Spiral | 24 | 48 (8 x 6) | VW Golf, mild hybrid |
| Spiral | 8 | 144 (72 x 2) | Honda Insight, medium hybrid |
| Flat plate | 7 | 144 (12 x 12) | Honda Insight, medium hybrid |
| Bipolar | 8 | 144 (2 x 72) | Honda Insight, medium hybrid |
| Flat plate | 50 | 600 (50 x 12) | Hybrid electric ‘bus |

# Micro- and Mild Hybrids

# Orbital VRLA Batteries for HEV



**12V 50 Ah**
**RC 95 min**
**800 A CC EN**

**6V 24 Ah**
**RC 40 min**
**400 A CC EN**

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# Renault Clio - stop/start


Battery 50 Ah, 1 x 12 V, spiral

# Ford Fiesta - stop/start, regenerative braking, stall recovery


Battery 50 Ah, 1 x 12 V, spiral

# Ford Transit - Stop/start, regenerative braking, stall protection


Battery 50 Ah 1 x 36 V, spiral

# VW Golf - Stop/start, regenerative braking, launch-assist



- VW Golf IV
- **1.6 l  4 Cyl. Gasoline Engine**
- **4/12 kW ISG** (Integrated Starter Generator) System
- 5 Speed Automated Manual Transmission
- **ISG adapted Engine Management System**

NEW ORBITAL MODULES from EXIDE

8 x 6 V

**Functions**

- **Stop-Start Automatic**
- **Warm start  <300ms, Cold start <800ms**
- **Electric Boost** and Launch Assist
- **Regenerative Braking**

Battery 24 Ah, 8 x 6 V, spiral

# Medium Hybrids

# Project Able

| | |
|---|---|
| ALABC Identifier: | RHOLAB |
| Battery Type: | Enersys, spiral 8 Ah, 2V |
| Automobile: | Honda Insight |
| Voltage: | 144V |


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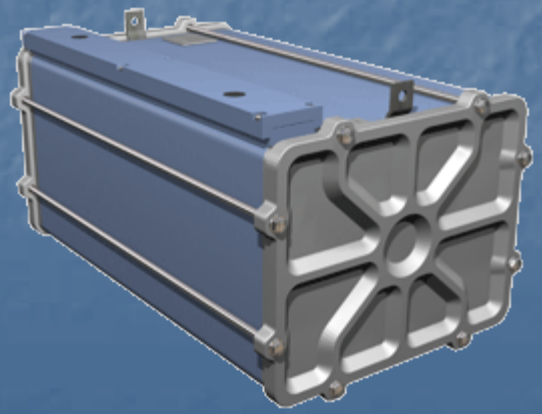
# Project Effpower

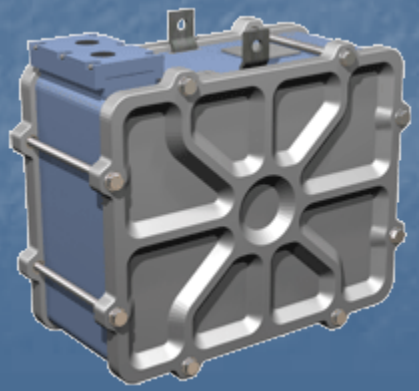
ALABC Identifier: Effpower

Battery type: Bipolar, 8 Ah, 144V

Vehicle: Honda Insight

Voltage: 144V



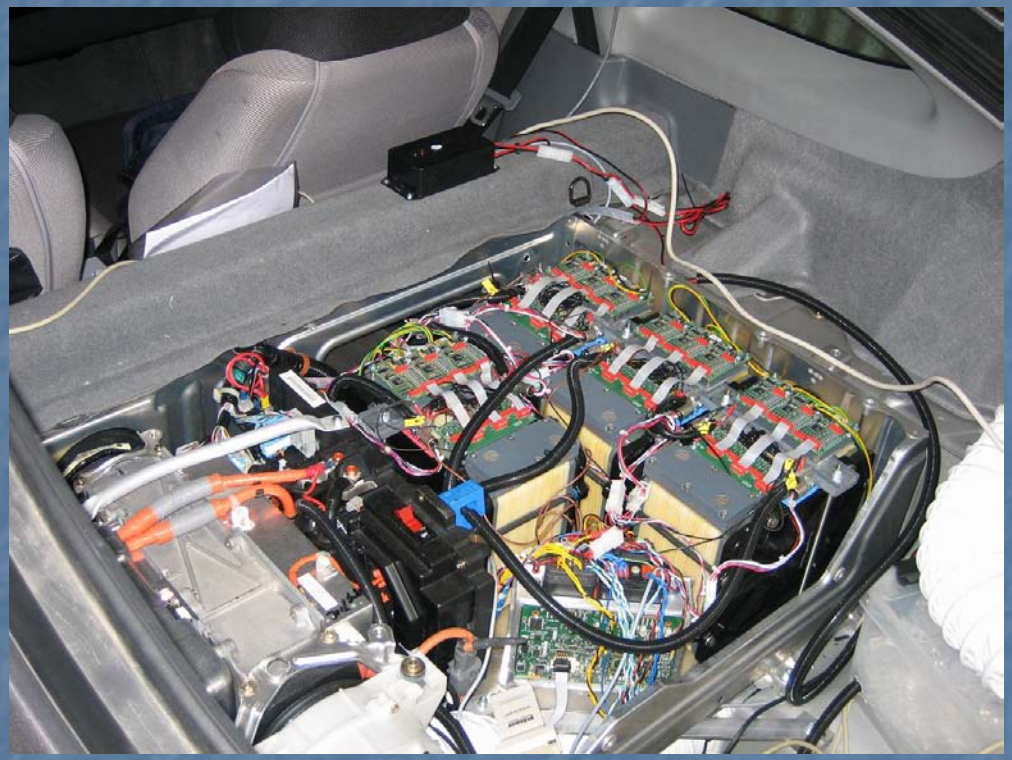


# HONDA INSIGHT – OUTLOOK Q4 2006

- Continued collection of driving data according to test cycles
- Testing to be completed in Dec-2006
- Fuel consumption in focus

# BATTERY MANAGEMENT

- Honda Insight Battery Management System supplied and installed by PROVECTOR
- Add-ons including CAN interface, OBD2 module and GPS module
- Effpower cell monitoring system



# Project ‘Ultra’

ALABC Identifier: DP 1.1

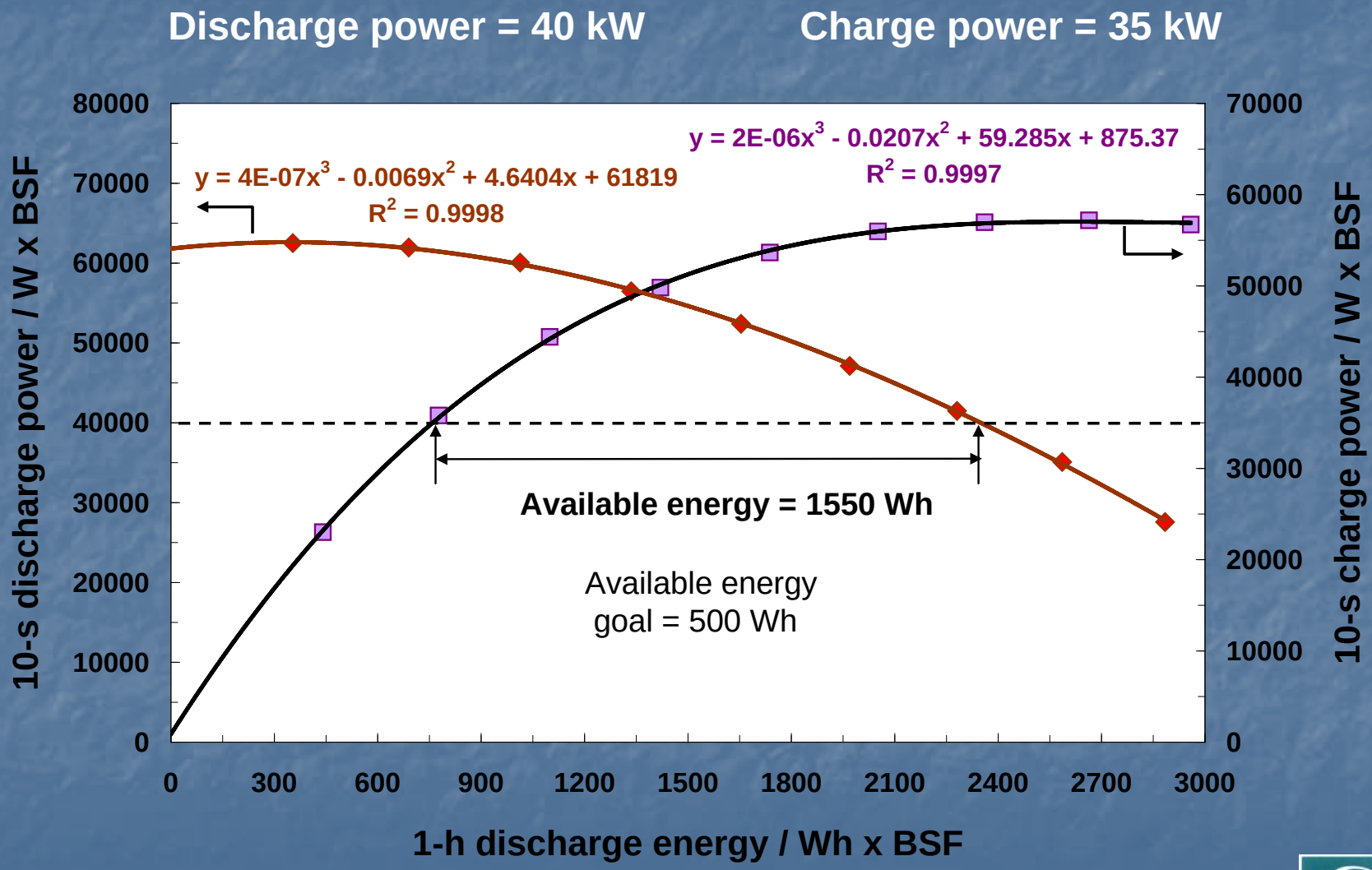
Battery type: Furukawa/CSIRO flat, 7 Ah, 12V

Vehicle: ALABC Honda Insight

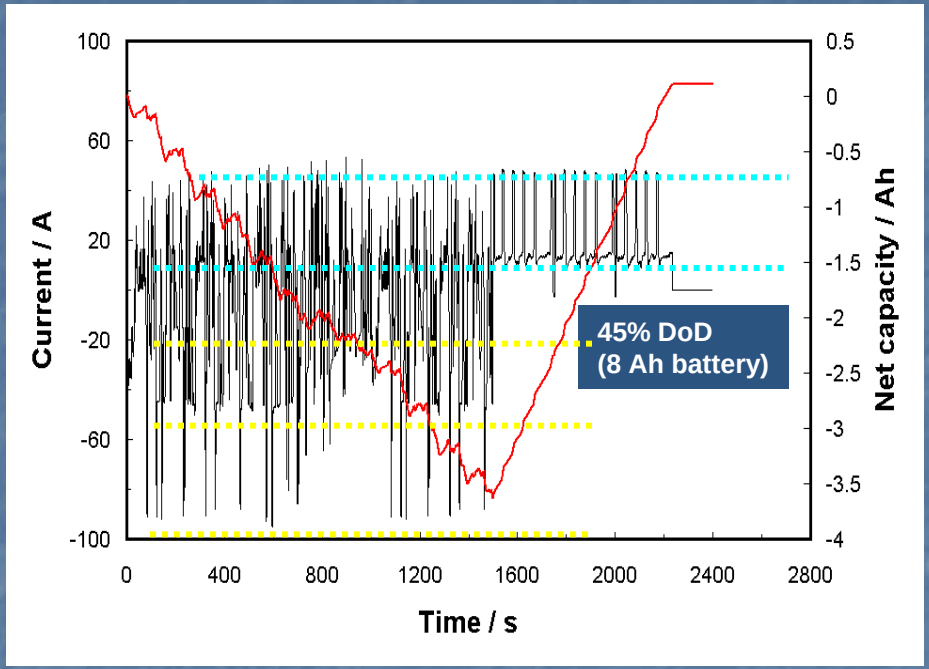
Voltage: 144V

# Hybrid pulse power characterisation

# (maximum power assist, battery-size factor = 35)

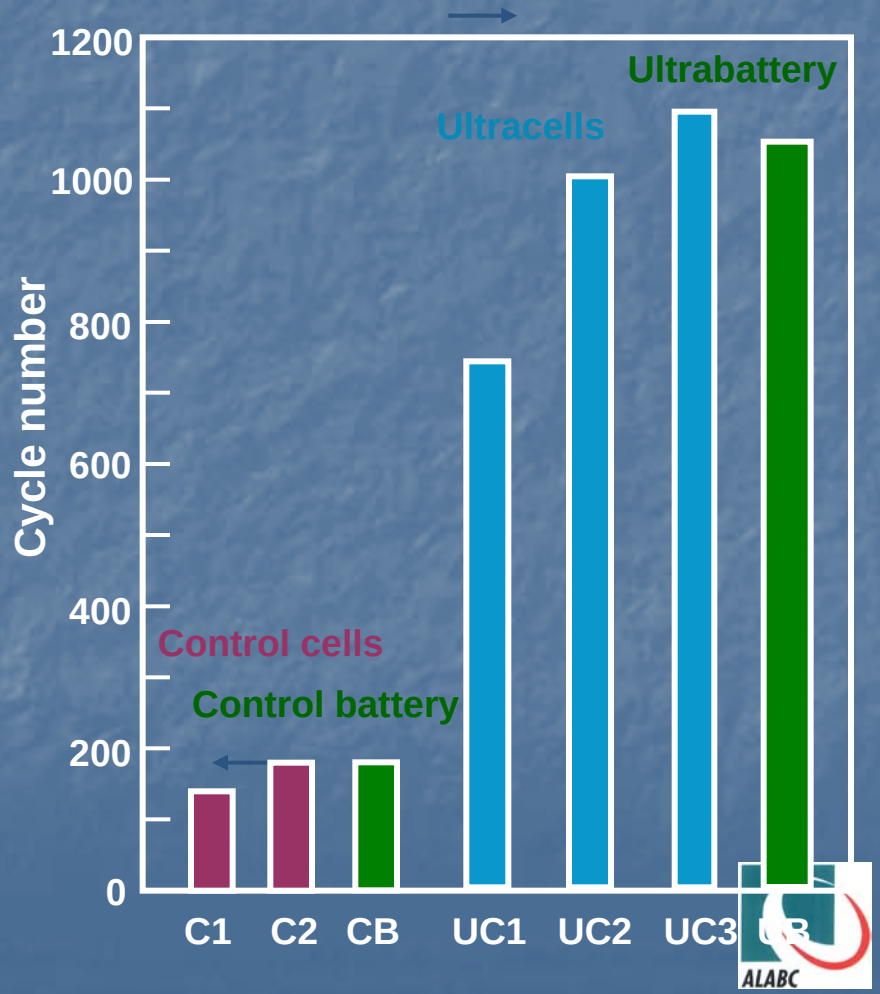


# High-speed and hill-climbing driving profile




**Cycling procedure:**
discharge the cell/battery to 80% SoC and then subject to the above profile repetitively until the minimum voltage reaches 0 V.

**Performance:**
at least *four times* longer in cycle-life than the state-of-the art VRLA cells

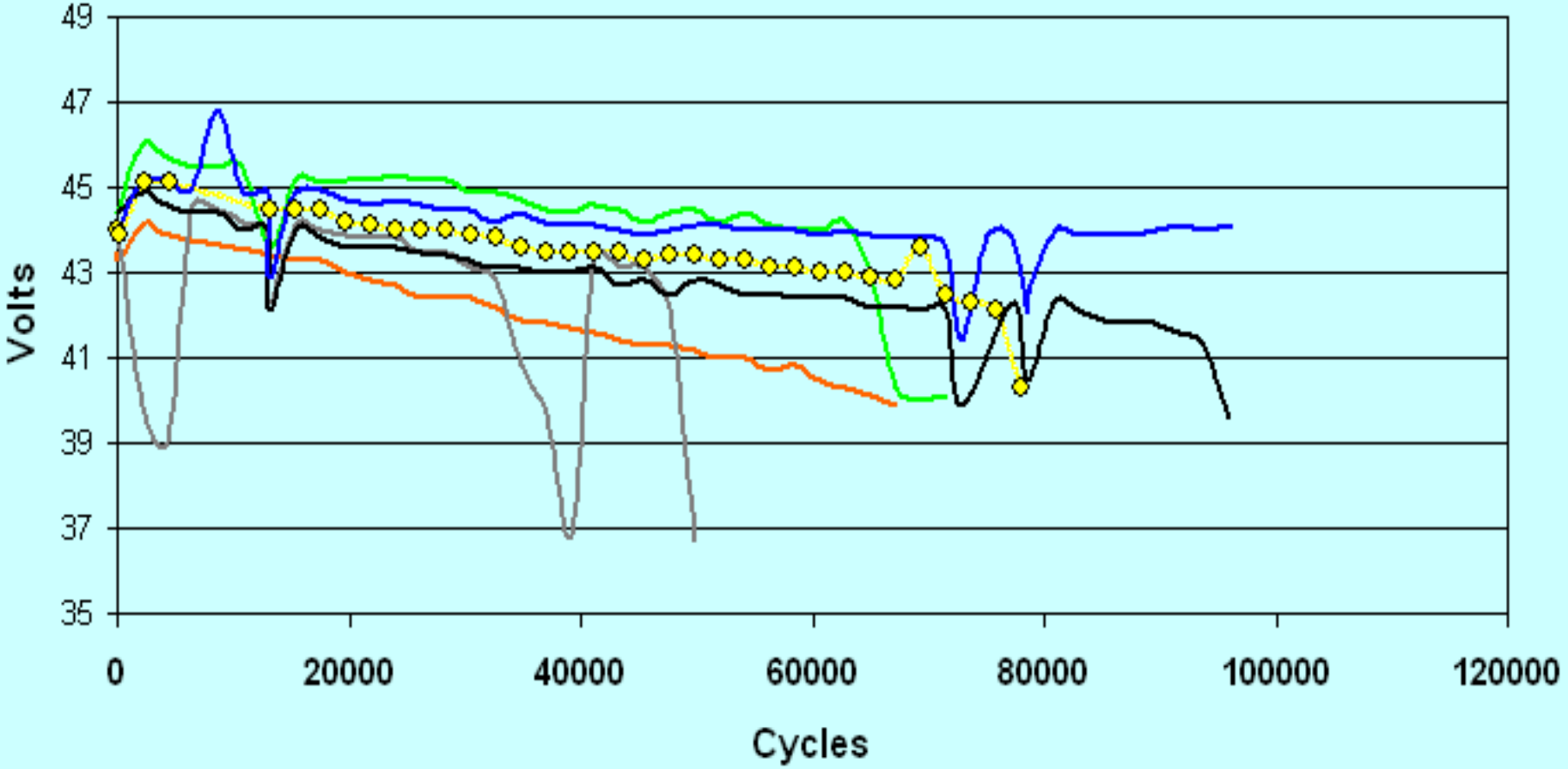


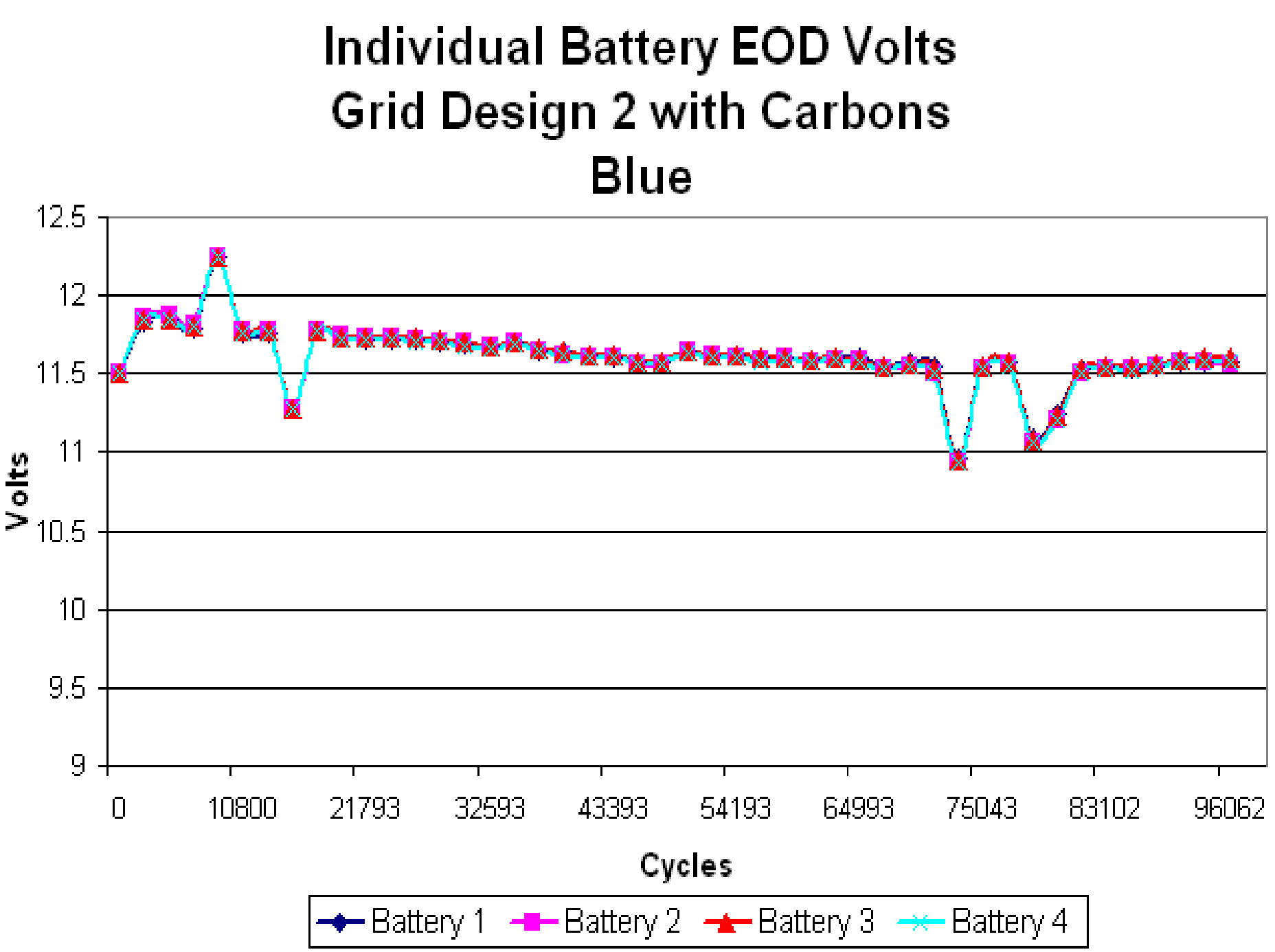
# Hybrid Electric Buses

# Project East Penn

| | |
|---|---|
| ALABC Identifier: | DP 1.3 |
| Battery Type: | East Penn, flat, 50-60 Ah, 12V |
| Vehicle: | Hybrid Bus |
| Voltage: | 600V |

# End Of Discharge Voltage
# Hybrid Bus Cycle Life




Individual Battery EOD Volts
Grid Design 2 with Carbons
Blue
12.5
12
11.5
11
10.5
10
9.5
9
Volts
0
10800
21793
32593
43393
54193
64993
75043
83102
96062
Cycles
Battery 1
Battery 2
Battery 3
Battery 4

# Project Northstar

ALABC Identifier: DP 1.6

Battery Type: 4.1 = North Star, flat, 25 Ah, 12V
4.2 = North Star, flat, 52 Ah, 12V

Automobile: 4.1 = Ford Fiesta (12V) &
Chevrolet Silverado (36V)
4.2 = Simulated HEV Bus

Voltage: 12V-36V

NORTHSTAR
BATTERY COMPANY
NOTHING IS MORE RELIABLE

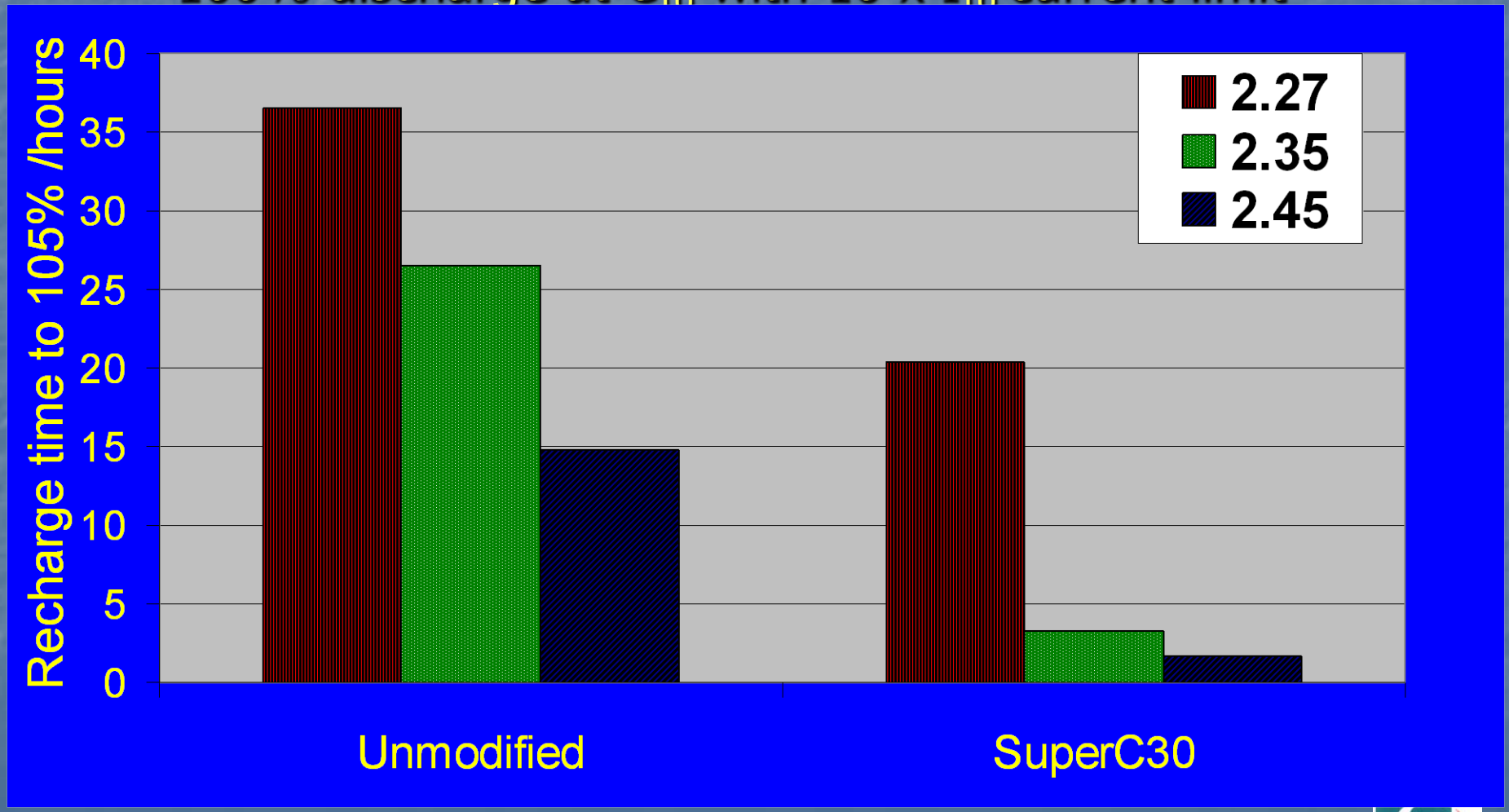
ALABC

# Advanced HEV Screening Test

| | Advanced HEV Cycles to TOC limit |
|---|---|
| Unmodified | ~ 1,000 |
| ALABC Super C30 | ~ 7,000 |

# Recharge Behavior

Recharge time to 105% coulombic charge return following 100% discharge at $C_{10}$ with 10 x $I_{10}$ current limit



## Future road vehicles

*…will incorporate more extensive electrical function.*

Micro hybrid, mild hybrid, full hybrid designs all feature in the future plans of major manufacturers.

*A continuing program of research has shown how, with simple adjustments to conventional design, lead–acid batteries can perform the requisite Function successfully.*