Lead–Acid Batteries In Hybrid Electric Vehicles

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Advanced Lead–Acid Battery Consortium

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ALABC

Presentation Outline

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

-Two solutions

- Proving tests on the road

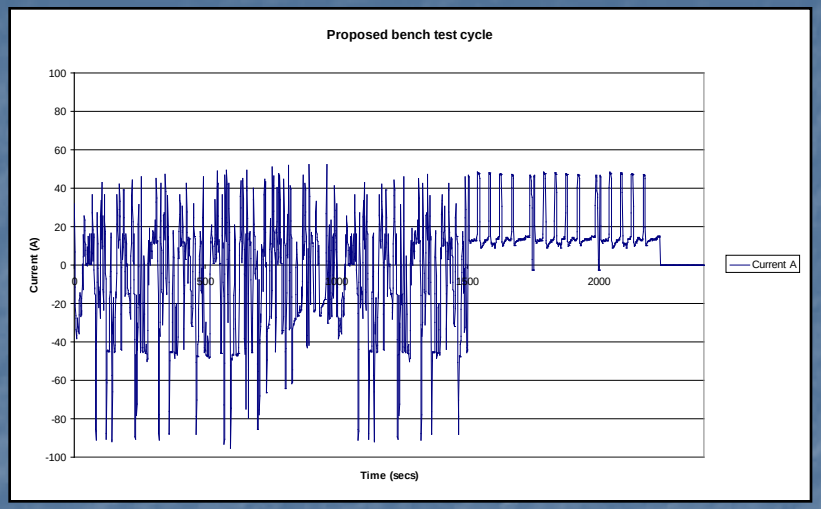
Typical range of state-of-charge, rates of discharge and recharge and failure modes

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**

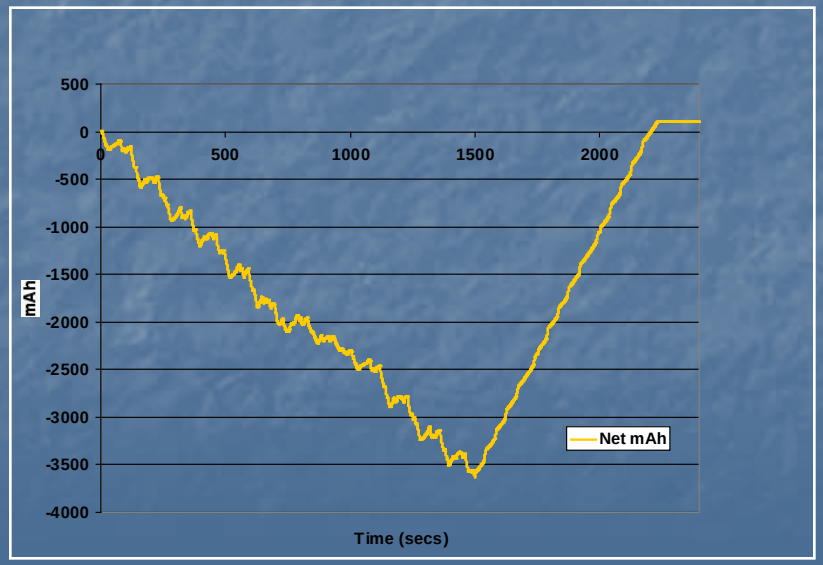
Real-world HEV Battery Duty

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

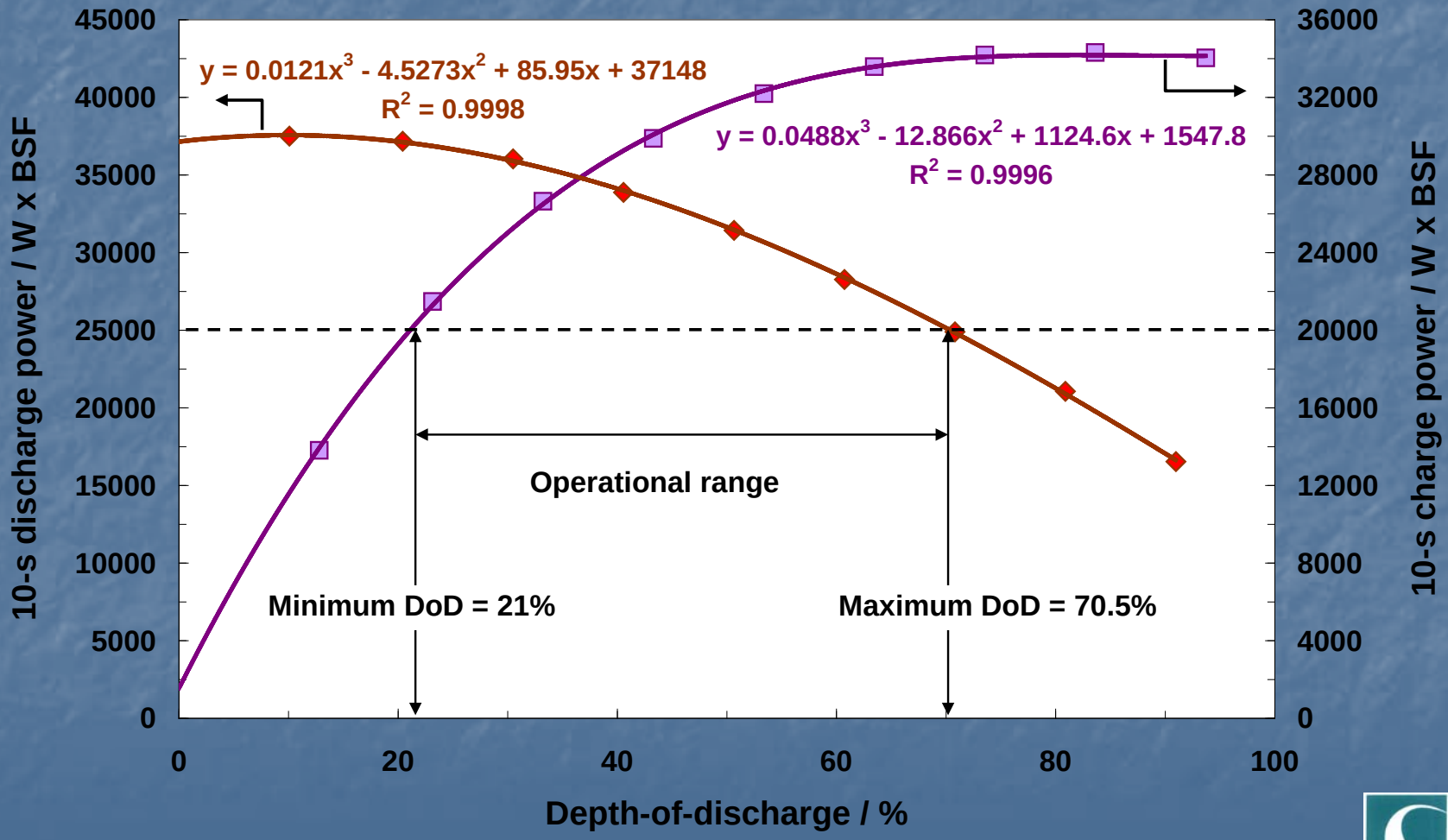
	USABC Minimum P-A goals	NiMH use in Honda Insight
Maximum wt (kg)	40	~30*
Power out (10s) kW	25kW (625W/kg)	14 kW (467W/kg)
Power in (10s) kW	20kW (500W/kg)	7 kW (233W/kg)
Energy available in HRPSoC (Wh)	300 (7.5Wh/kg)	450 (15 Wh/kg)
Cycle life	300,000	?
Production Price ($)	500	1017^

* 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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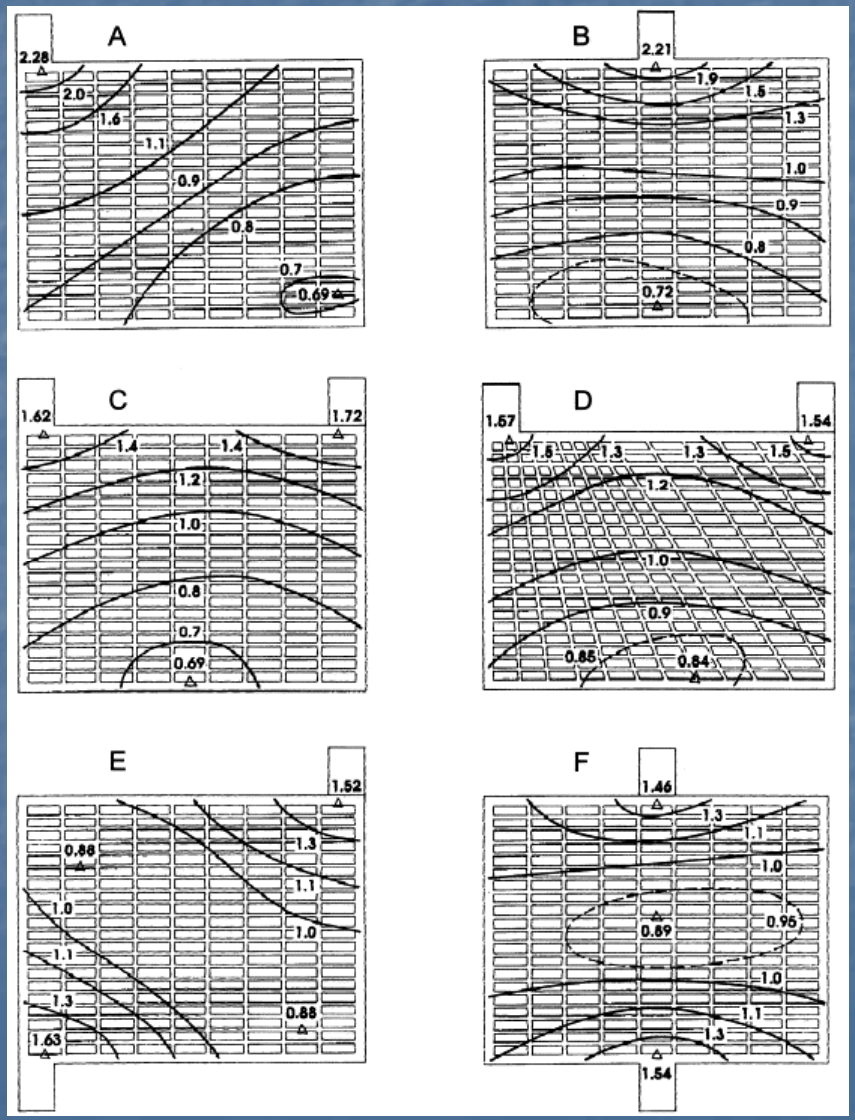
Mechanism & solution:

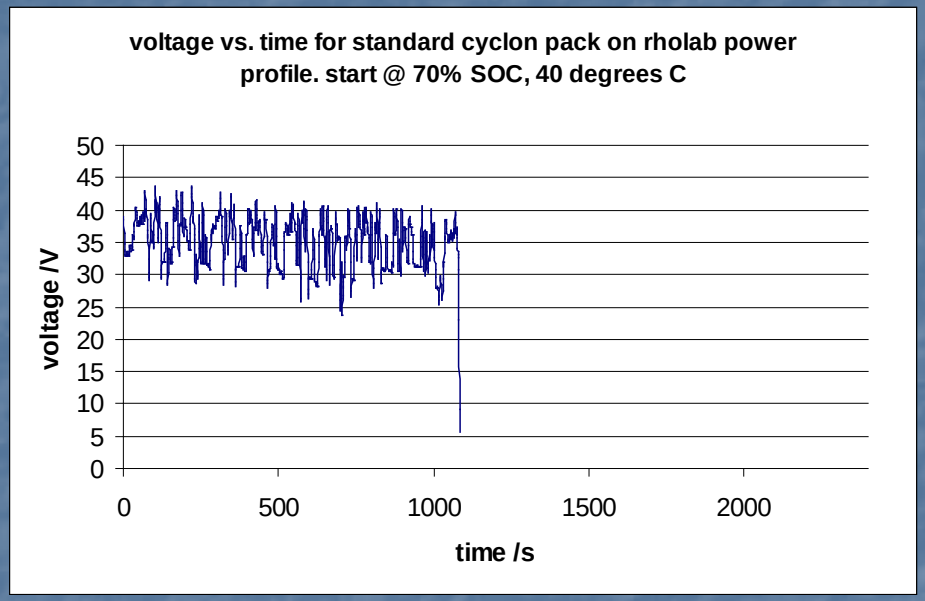
1. Grid design

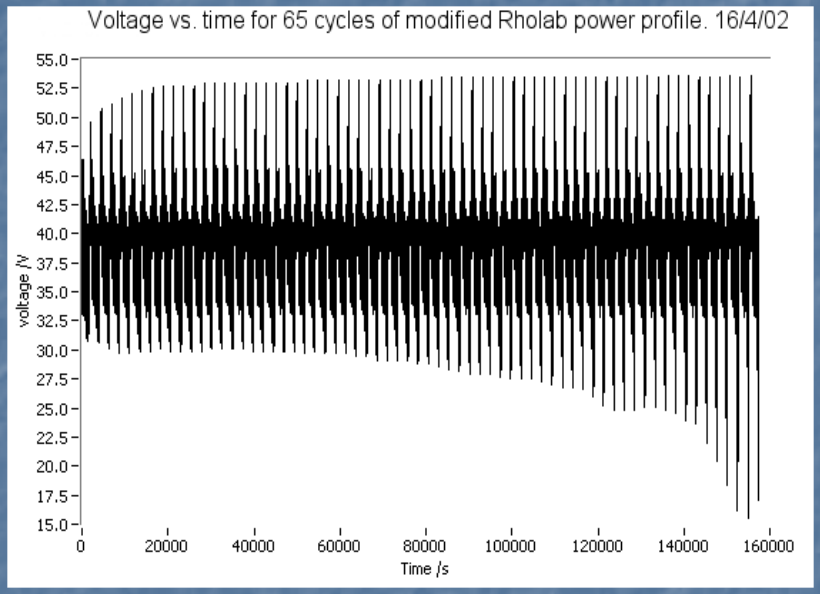
Current density contours on twin tab arrangements



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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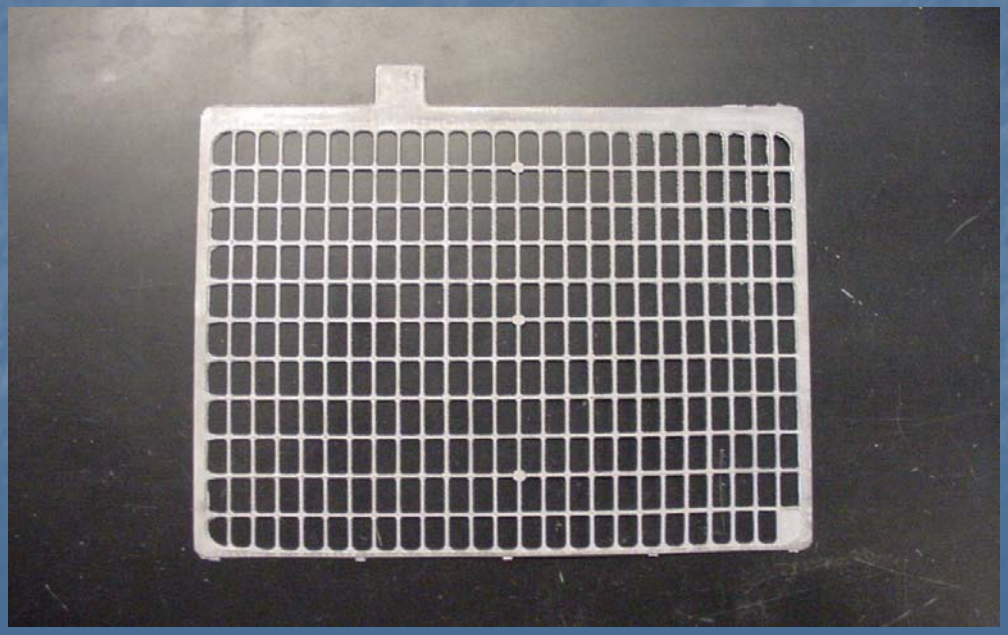
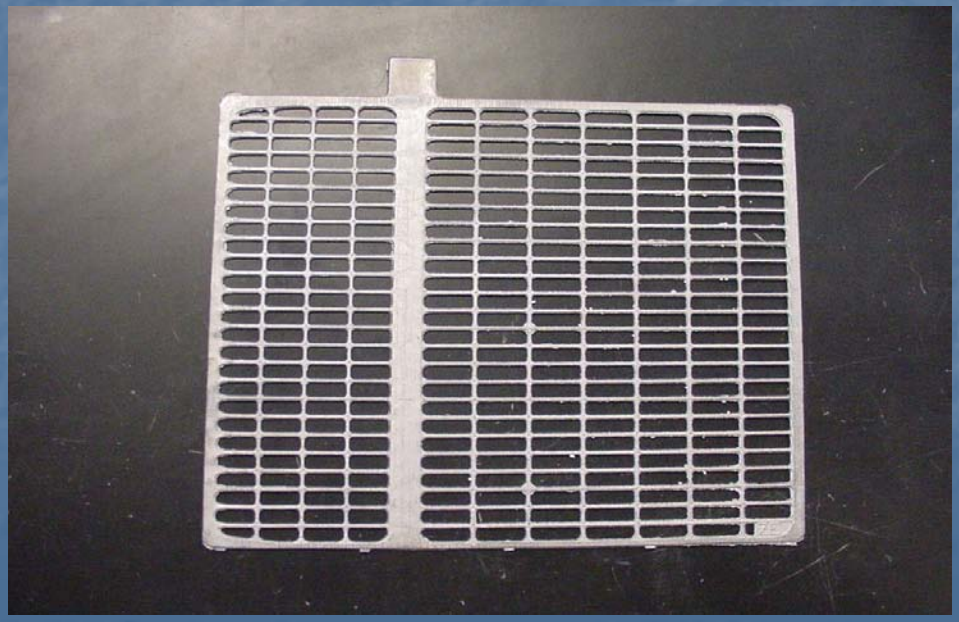
Manufacturing

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



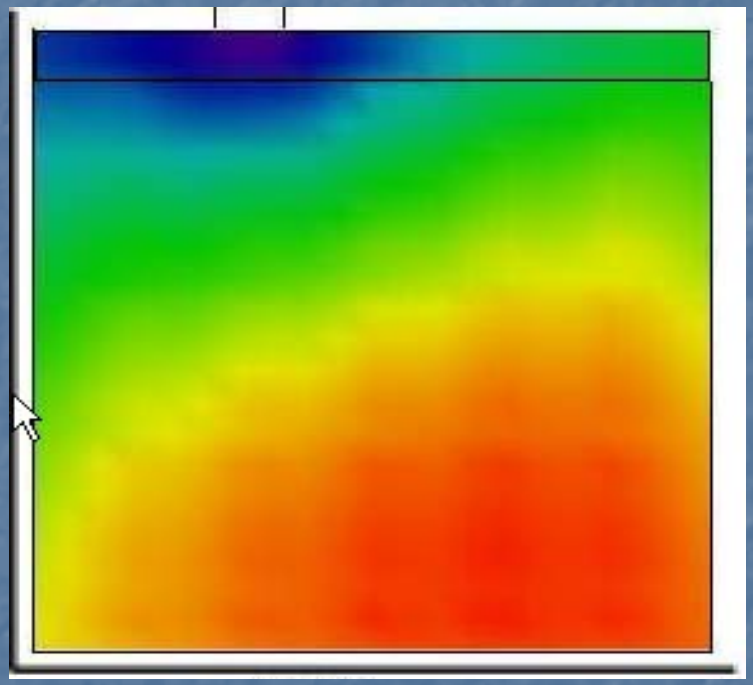
Manufacturing

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

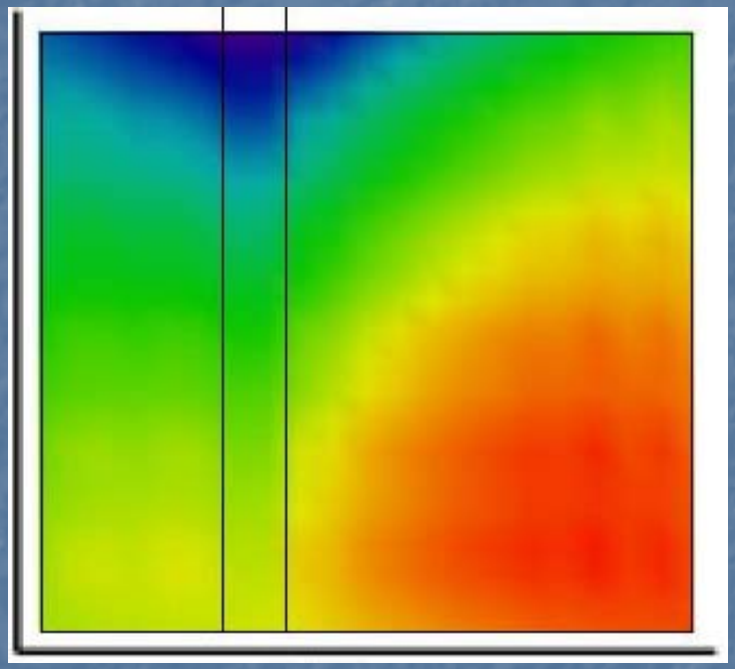


Grid Design

- Computer Modeling: Brigham Young University Dr. John Harb



Design 1

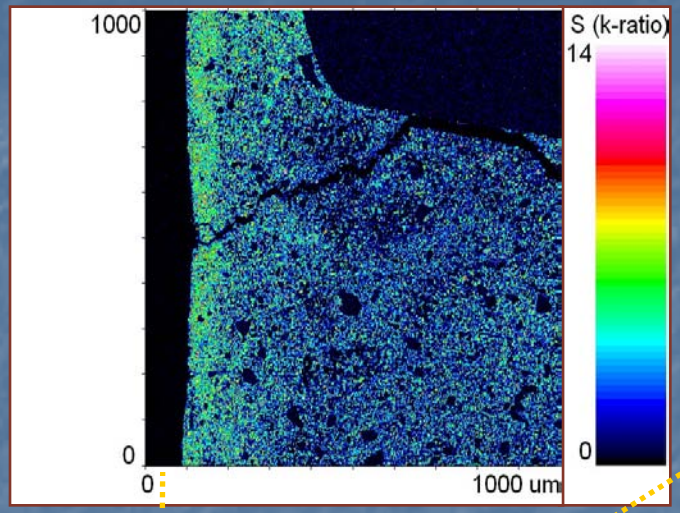


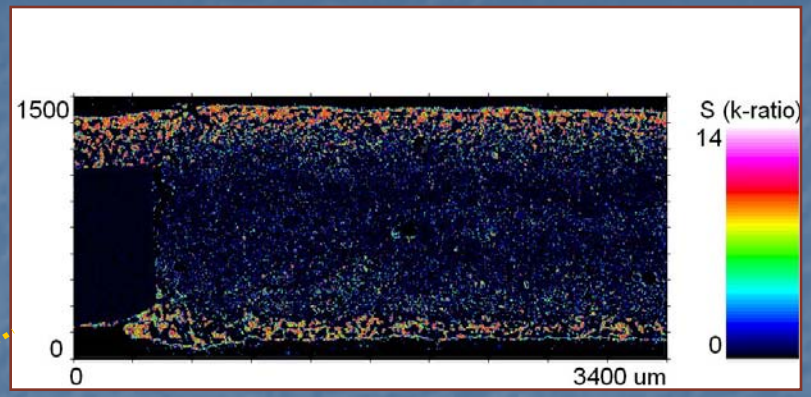
Design 2

Mechanism & Solution:

2. Expander Composition

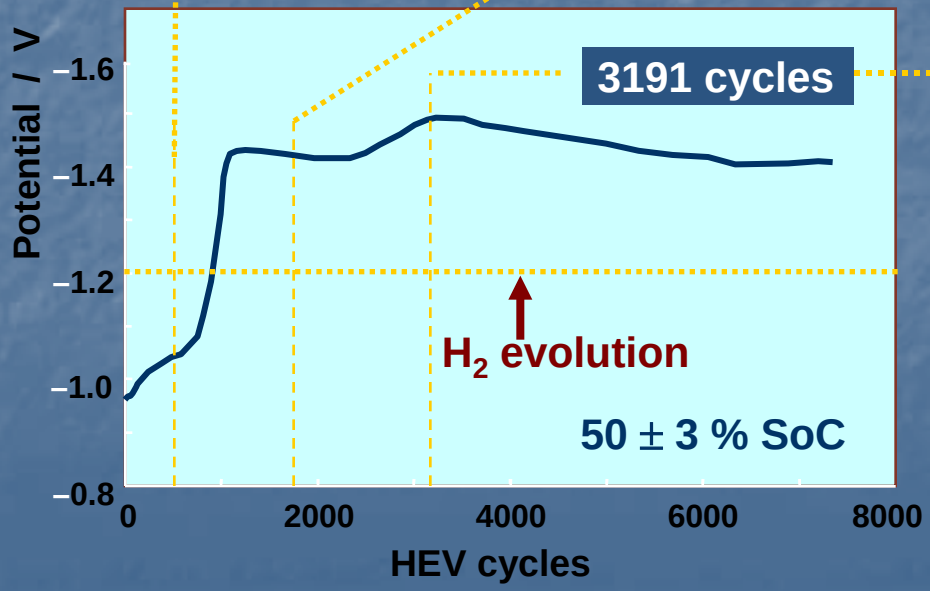
HEV duty: sulfate build-up in negative plates

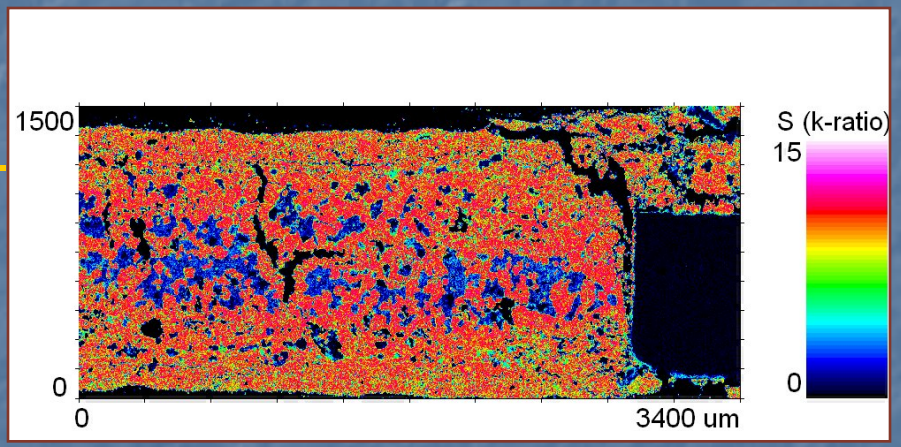




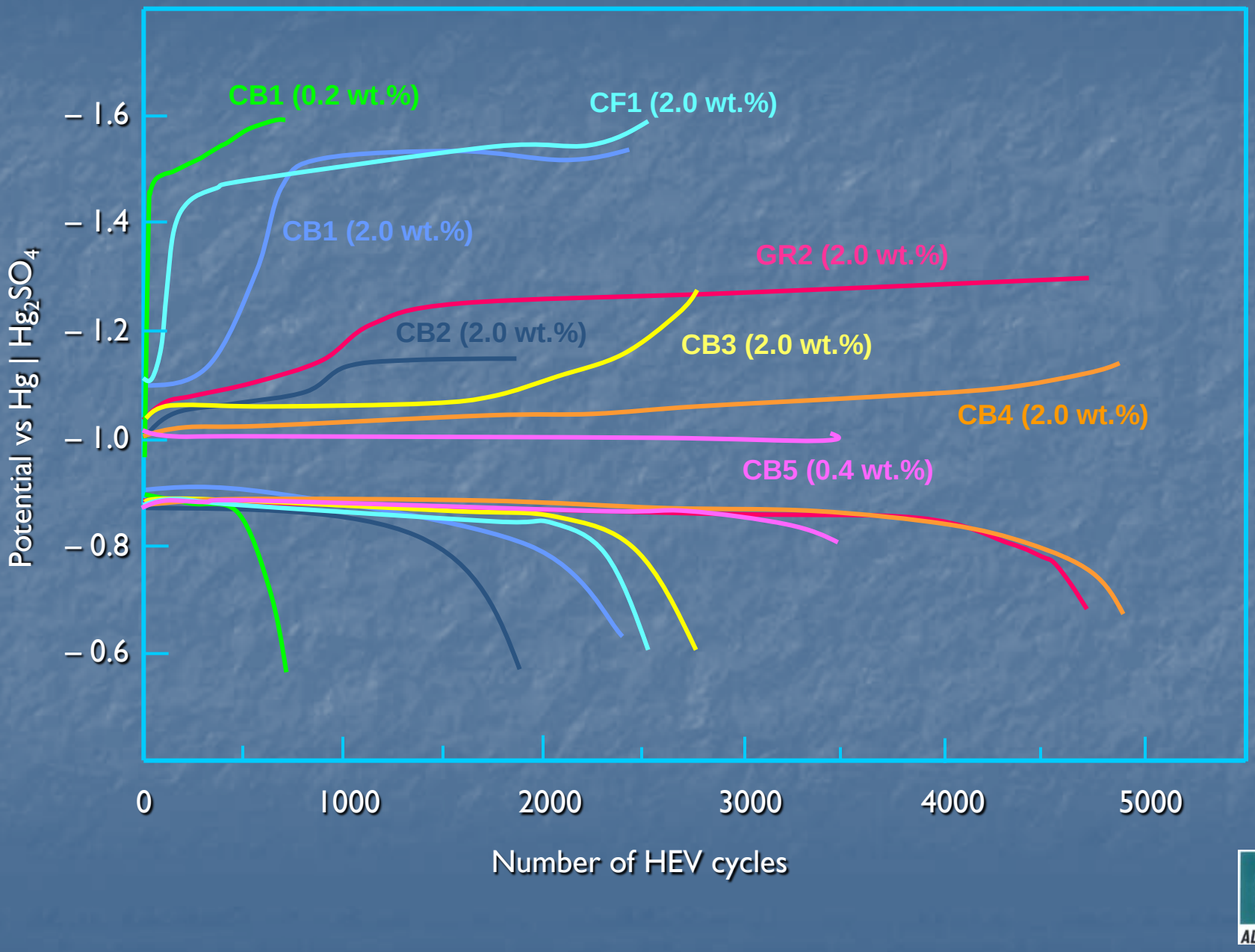
0 cycles

1735 cycles

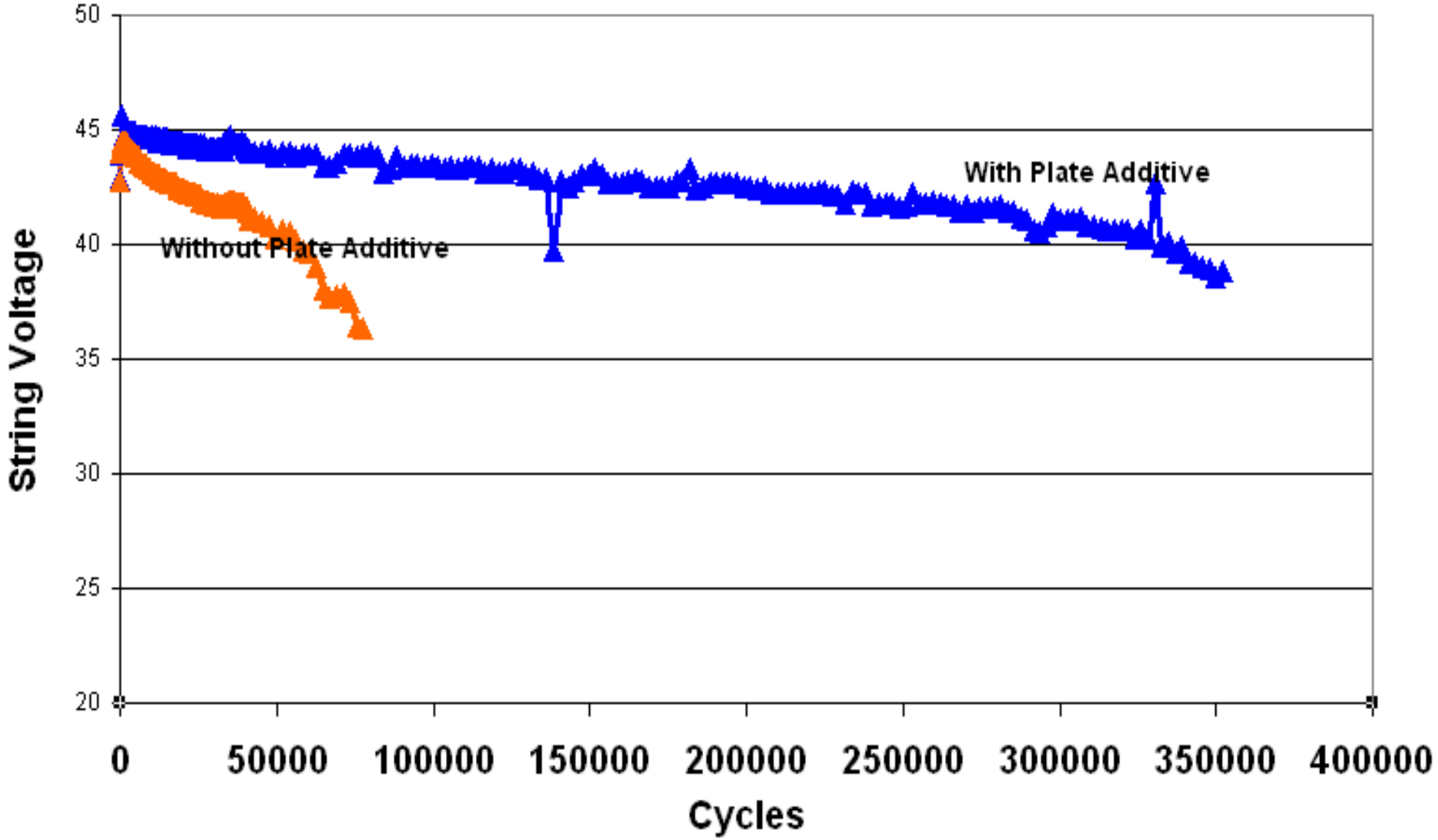




EoC and EoD potentials of negative plates in HRPSoC operation



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

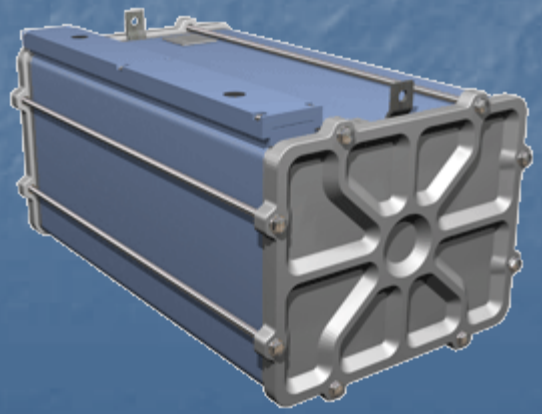
Project Effpower

ALABC Identifier: Effpower

Battery type: Bipolar, 8 Ah, 144V

Vehicle: Honda Insight

Voltage: 144V

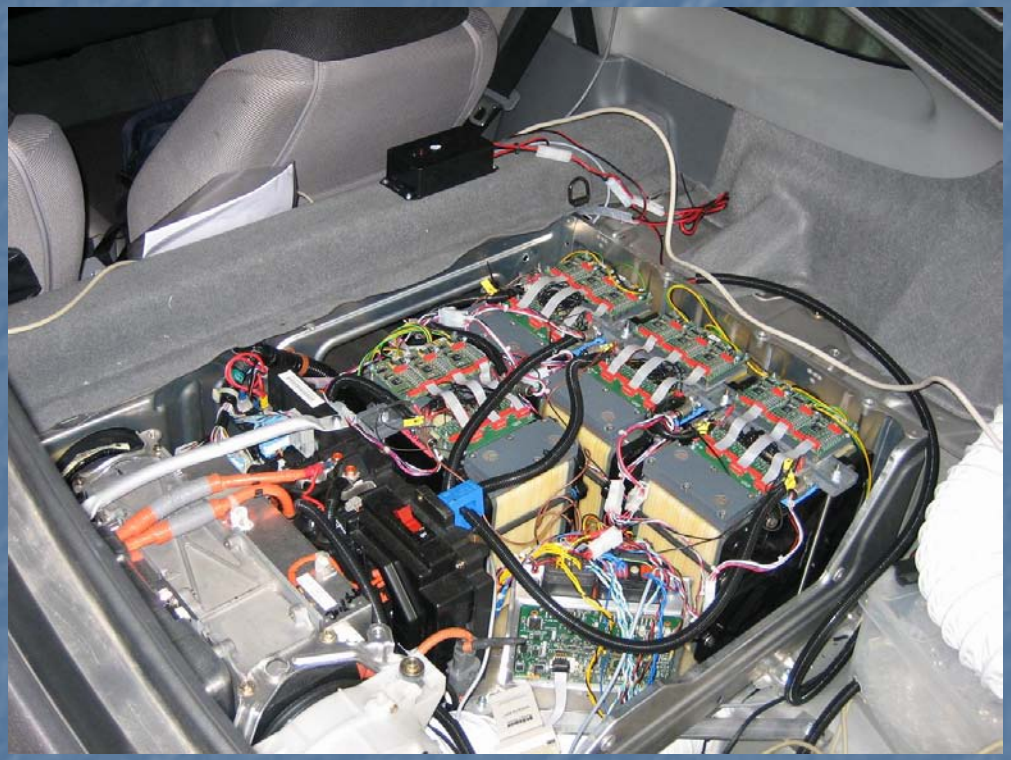


HONDA INSIGHT – OUTLOOK Q4 2006

- 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

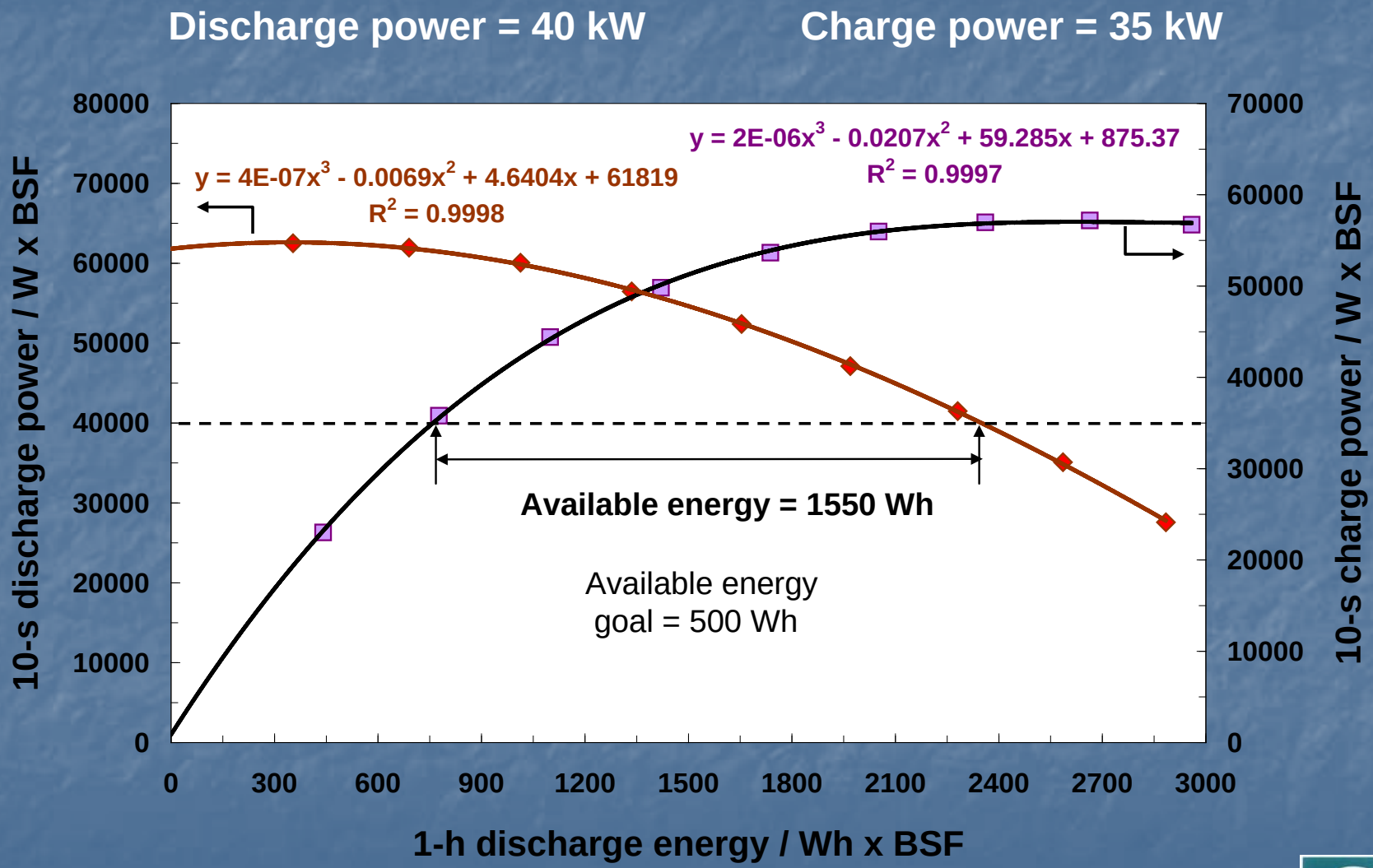
Battery type: Furukawa/CSIRO flat, 7 Ah, 12V

Vehicle: ALABC Honda Insight

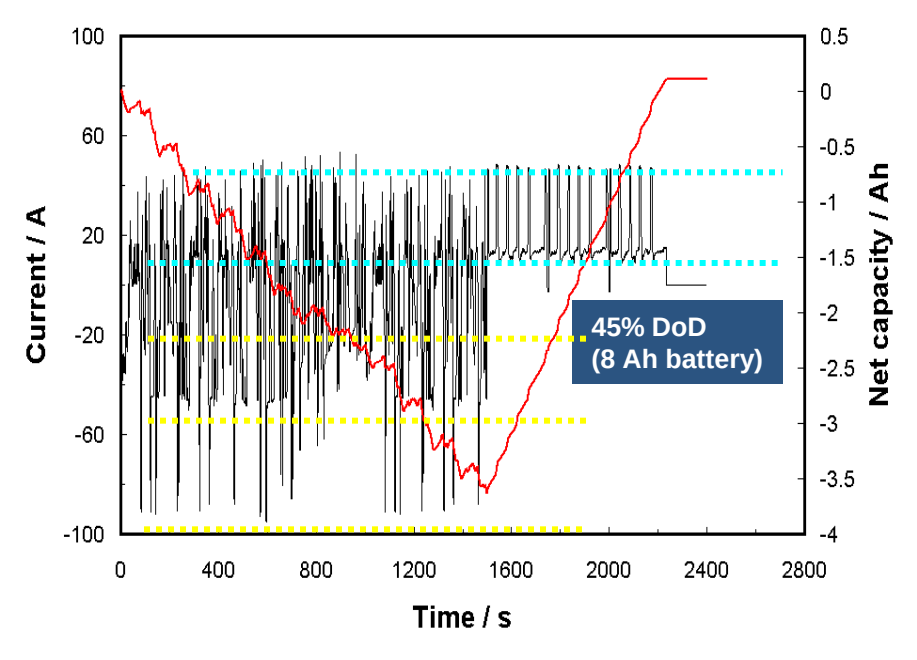
Voltage: 144V

Hybrid pulse power characterisation

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

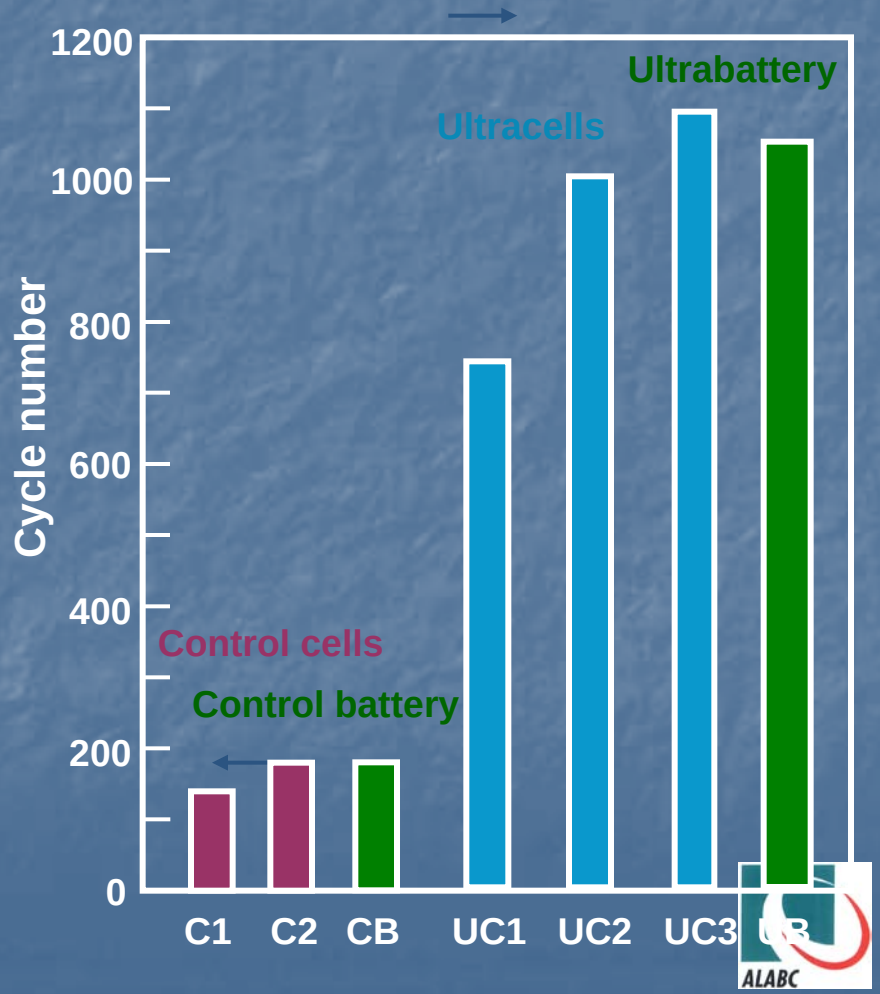


High-speed and hill-climbing driving profile



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

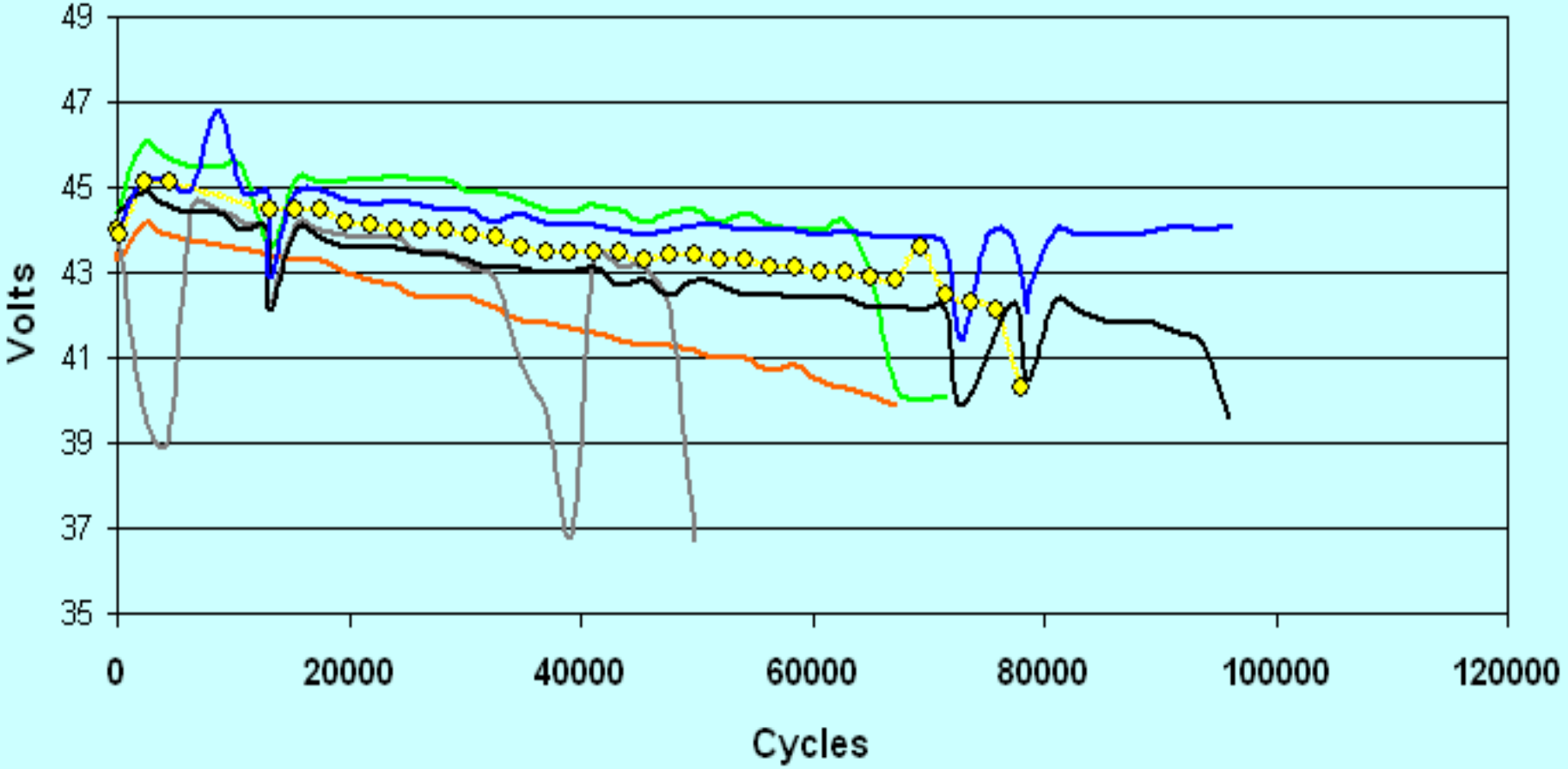


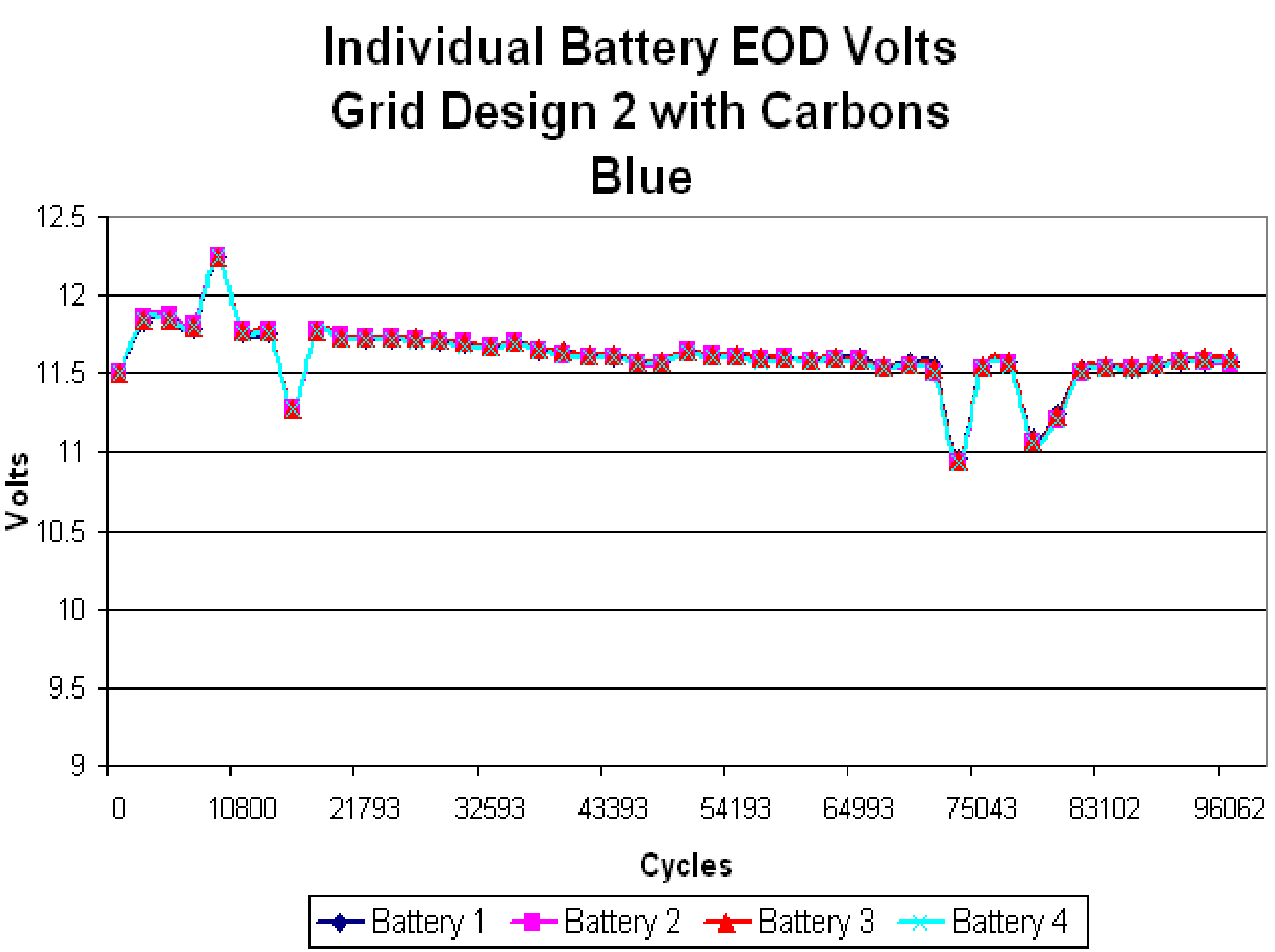
Hybrid Electric Buses

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

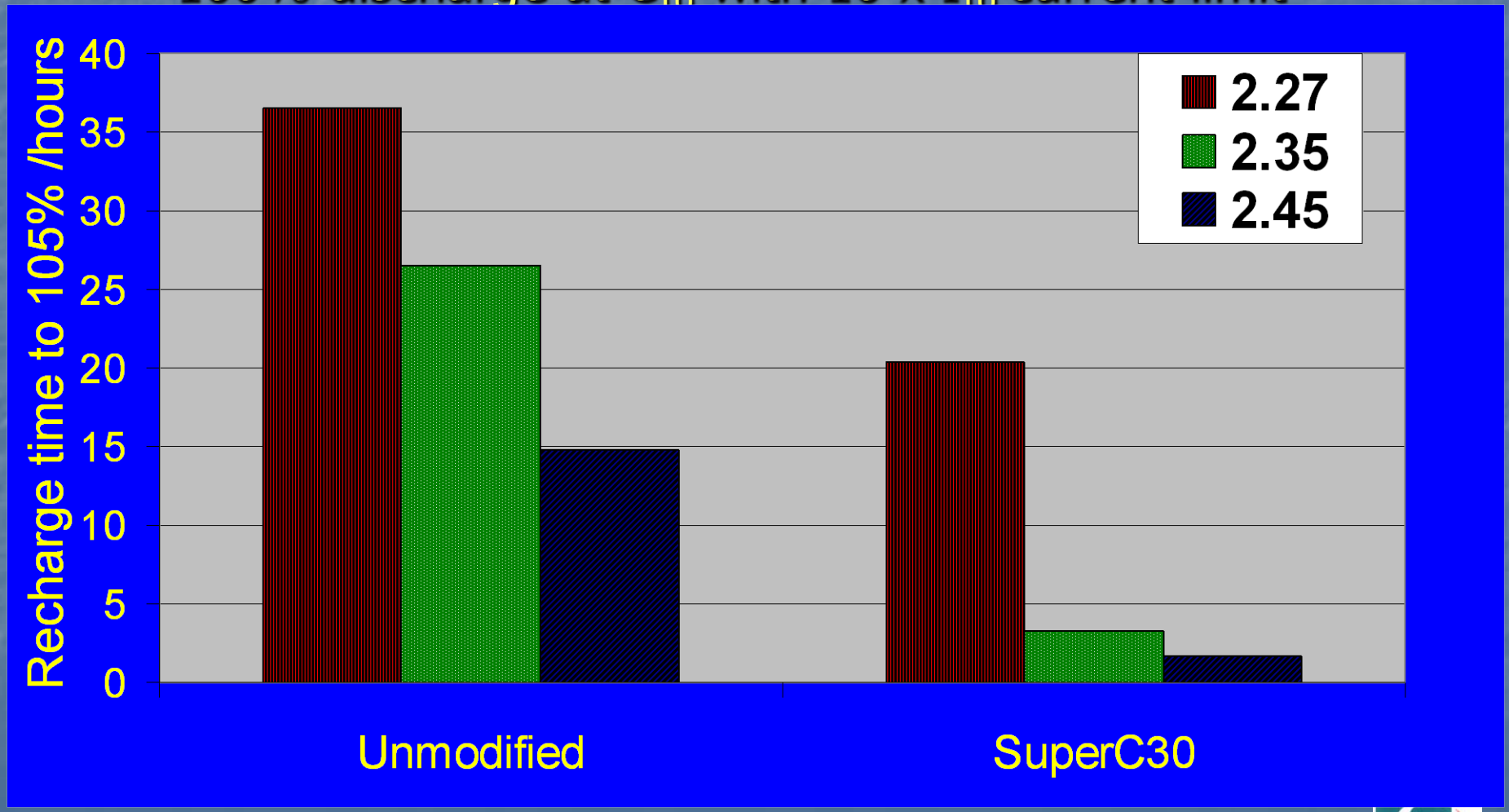
ALABC

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.