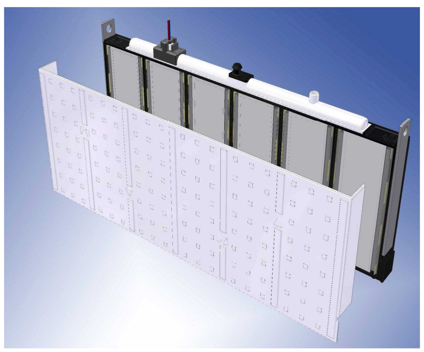
Lithium-Ion:
Enabling a Spectrum
of Alternate Fuel Vehicles

California Air Resources Board ZEV Symposium
Johnson Controls – Saft *Advanced Power Solutions*

September 27, 2006

Michael Andrew

Johnson Controls – SAFT *Advanced Power Solutions*



Johnson Controls Power Solutions

- The world's leading global automotive lead-acid battery supplier
- 2005 sales $2.9 billion
- Global capacity of over 110 million batteries
- Multi-million dollar advanced R & D Centers in 5 countries
- Advanced battery technologies for advanced vehicle systems
- Electronics and Interiors integration capabilities
- Joint Venture formed in January 2006 with SAFT

SAFT

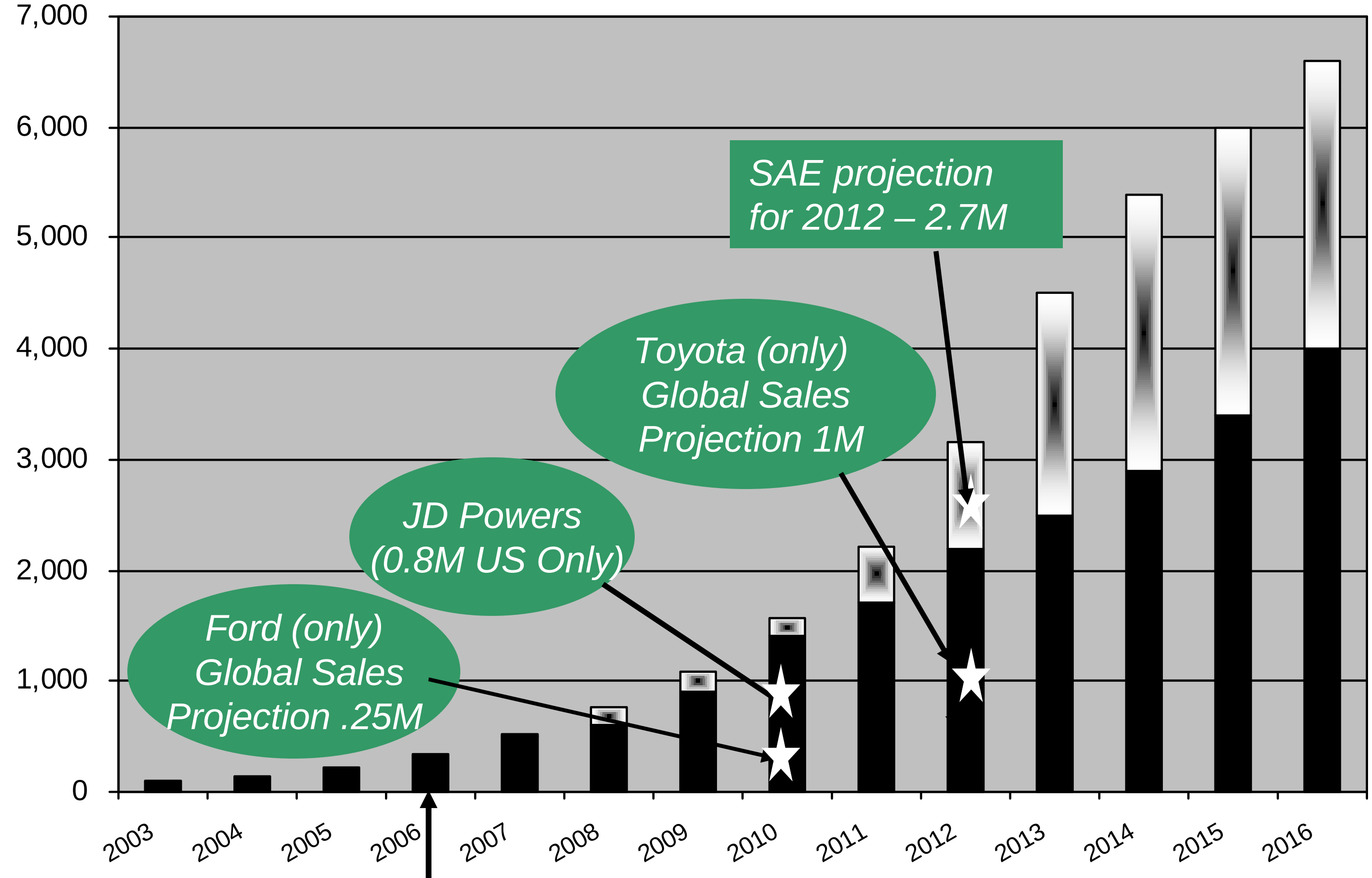
- Major supplier of battery systems to transportation, aerospace, and military markets
- Expertise in NiMH and Li-Ion technologies

The Joint Venture develops, manufactures, and sells NiMH and Li-Ion battery systems for HEVs, PHEVs, and EVs, globally.

Overview

- JCS background
- Electric power trains – they're not just for HEV's anymore
- Commercialization challenges for the battery manufacturer
- Why Li-Ion?
- System design is critical
- Conclusions and recommendations

HEV Market is Growing: Will PHEV/EV Penetration Be Significant?



2006 forecast is close to projected EOY in North America: *231,000*

Market Drivers

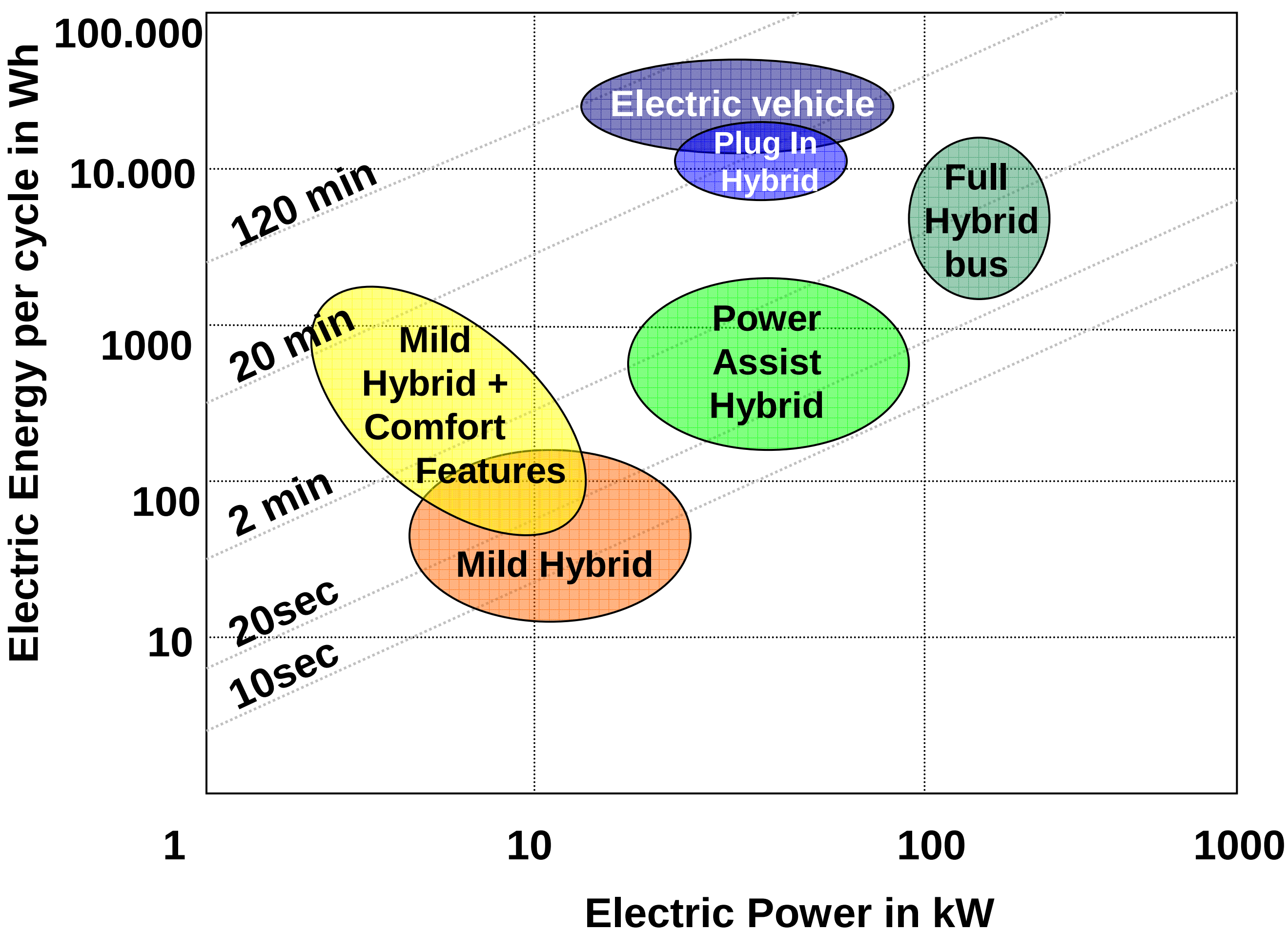
- Fuel economy
- High oil prices
- Energy security
- Global environmental concerns
  - CO_2
  - Emissions
- Vehicle performance
- Technology leadership
- National Energy Policies

Key Attributes of a Plug-In Hybrid Electric Vehicle (PHEV)

- The PHEV is functionally equivalent to a conventional HEV while driving.
- The battery in a PHEV is capable of being recharged by the grid, typically overnight, in addition to accepting regenerative braking electrical energy
- PHEVs enable significant reductions in tail pipe emissions
- The power train control strategy could favor electrical power over internal combustion engine power early in the drive cycle such that stored electricity is the preferred energy source while the battery is near full charge. However…………..
- **…….PHEV's can offer efficiency and petroleum fuel displacement advantages even without offering electric-only operating range.**

Application Requirements Show Minimal Overlap
One Battery Size and *Cell Type* DO NOT Fit All

Electric-Type Vehicle Application Matrix



Mild Hybrid (144V):
- 0.5 – 1kWh
- 10 – 15kW

Power Assist Hybrid (>200V):
- 1 – 3kWh
- 20kW – 60kW

Plug-In Hybrid

(pure electric range):
- 10 – 20kWh
- 50kW – 100kW

Full Hybrid Bus:
- 2 – 20kWh
- 80kW – 200kW

The Transition from HEVs to PHEV/EVs is Not Simply a Scale-up Opportunity

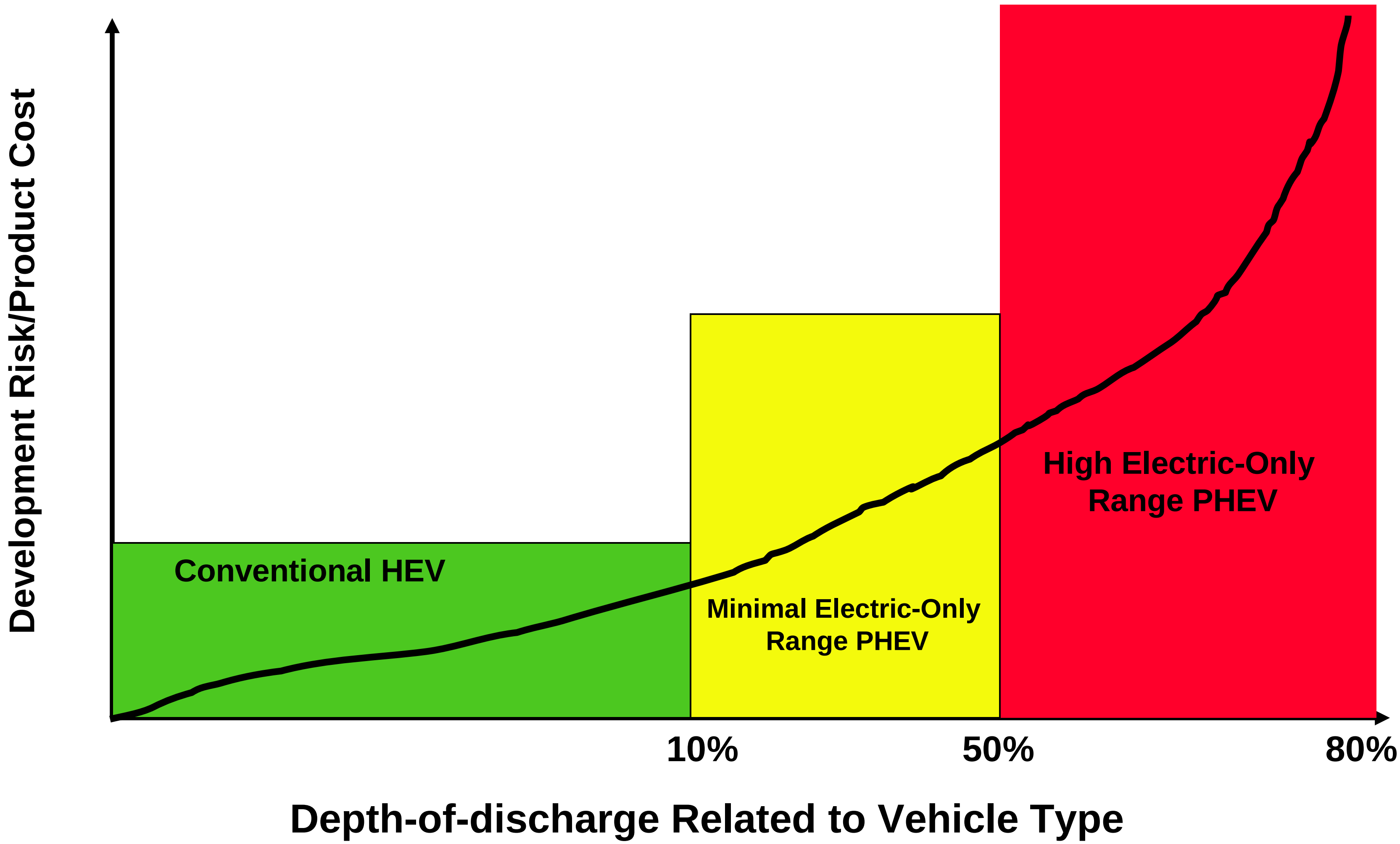
Business Case Challenges are Driven by the Following Factors:

Battery System Requirement	System Type: HEV	System Type: PHEV	Development Risk	Cost Impact
System voltage	120-350 V	200-350 V		Neutral
Cell Capacity	4 - 10 Ah	40+ Ah		High
HVAC System	Air/Other	Possibly liquid-cooled		Moderate
Depth of discharge	2-10%	2-80%		High
Battery management subsystem complexity	x	xx		Moderate
Design for abuse tolerance	x	xx		Moderate
Manufacturing Investment	x	xxx		High
Warranty structure complexity	x	xxx		Moderate*
Calendar Life	15 year	15 year		Moderate
Cycle Life	300,000	TBD		High

* High if V2G energy transfer is required

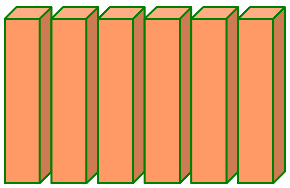
Cycle Life is a Challenge as Electrode Utilization Increases

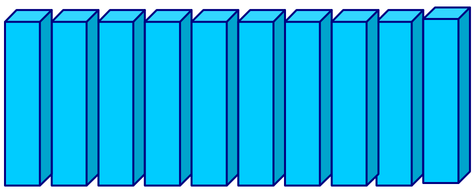
Battery Life is a function of "typical d.o.d" and the number of cycles

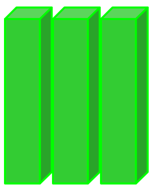


Why Li-Ion?

Lead-Acid	Nickel Metal Hydride	Lithium-Ion
V = 2.12/cell 6 Cells = 12.7 V	V = 1.25/cell 10 cells = 12.5 V	V = 3.6/cell 4 cells = 14.4 V







- Li-Ion Requires ***Fewer Cells*** for the Same System Voltage
- Substantially Higher ***(2-3x) Specific Energy*** than NiMH
- Approximately ***50% Higher Energy Density*** than NiMH

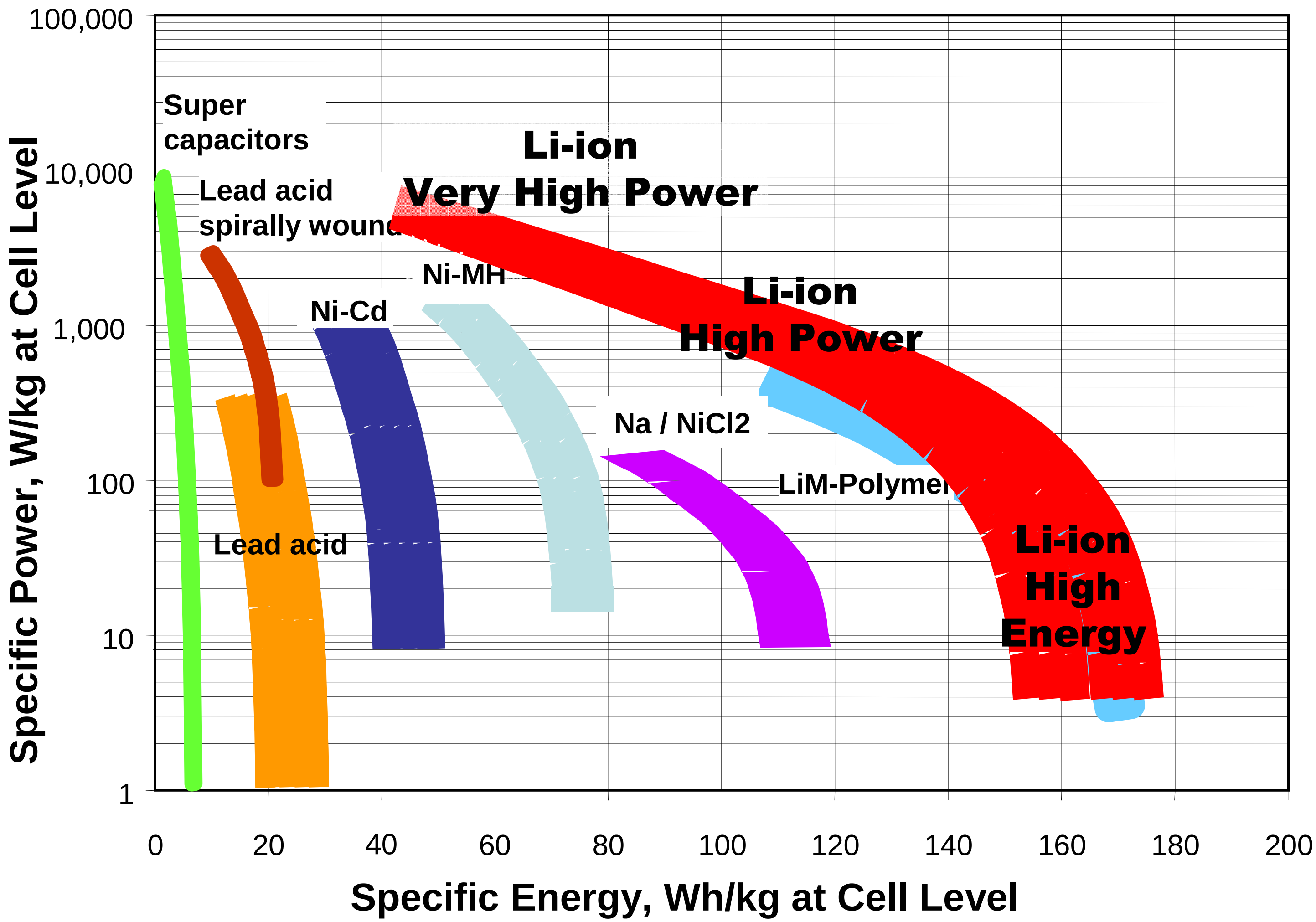
Cell Design is The Heart…………………..

- Positive material: aluminum with metal oxide coating
- Negative material: copper with graphite coating
- Electrolyte: blend of organics with conductive salt
- Cylindrical, spirally wound type jelly roll
- Aluminum case
- Laser welding for enhanced reliability
- Abusive overpressure release through rupture area
- Integrated circuit interrupter

There is NO Lithium in Metallic Form in the Cell

Li-Ion Has Full Spectrum Applicability

Design flexibility: Very high energy to very high power



JCS Li-Ion Cell Portfolio

EV Applications

PHEV Applications

Power Applications
Full Hybrid

	VL45E	VL41M	VL27M	VL6P	VL7P	VL20P	VL30P
Capacity (Ah) C/3 @ 4V	45	41	27	6.5	7	20	30
Dia. (mm)	54	54	54	38	41	54	54
Length (mm)	222	222	163	145	145	163	222
Weight (kg)	1.07	1.07	0.77	0.35	0.37	0.75	1.10
Volume (dm^3)	0.51	0.51	0.38	0.16	0.19	0.38	0.51
Energy (Wh)	160	146	96	22	25	71	107
Power (W) Current limit (A)	710 250	850 300	760 300	720 250	670 250	1130 500	1250 500
Power (W) V limit, 2.5 V				1100	850	1600	2300
	30s – 50%SOC			10s – 50%SOC			

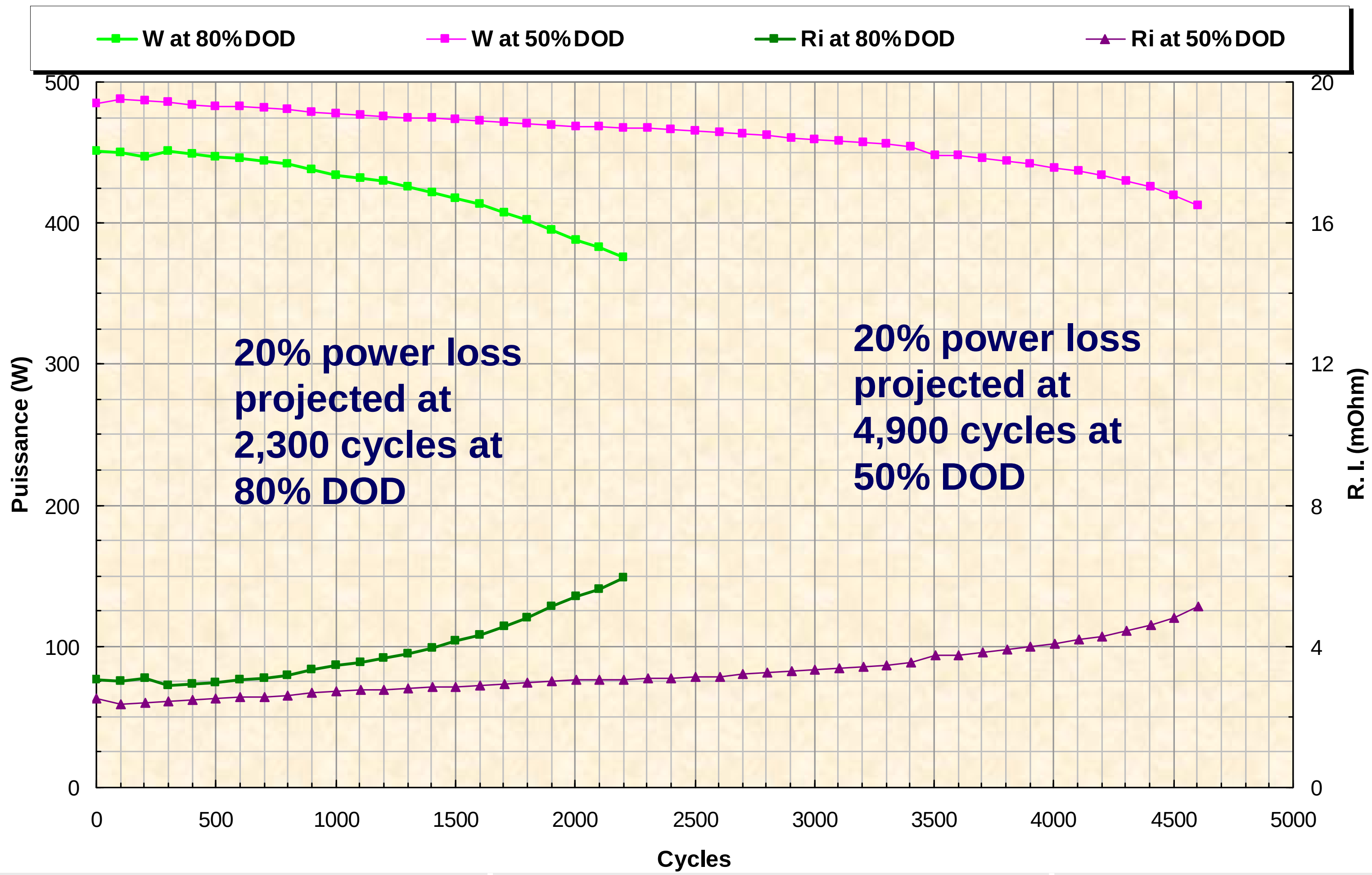
Note: Characteristics at 25℃

DST Cycle Life – Power at 20% & 50% SOC / 150 A

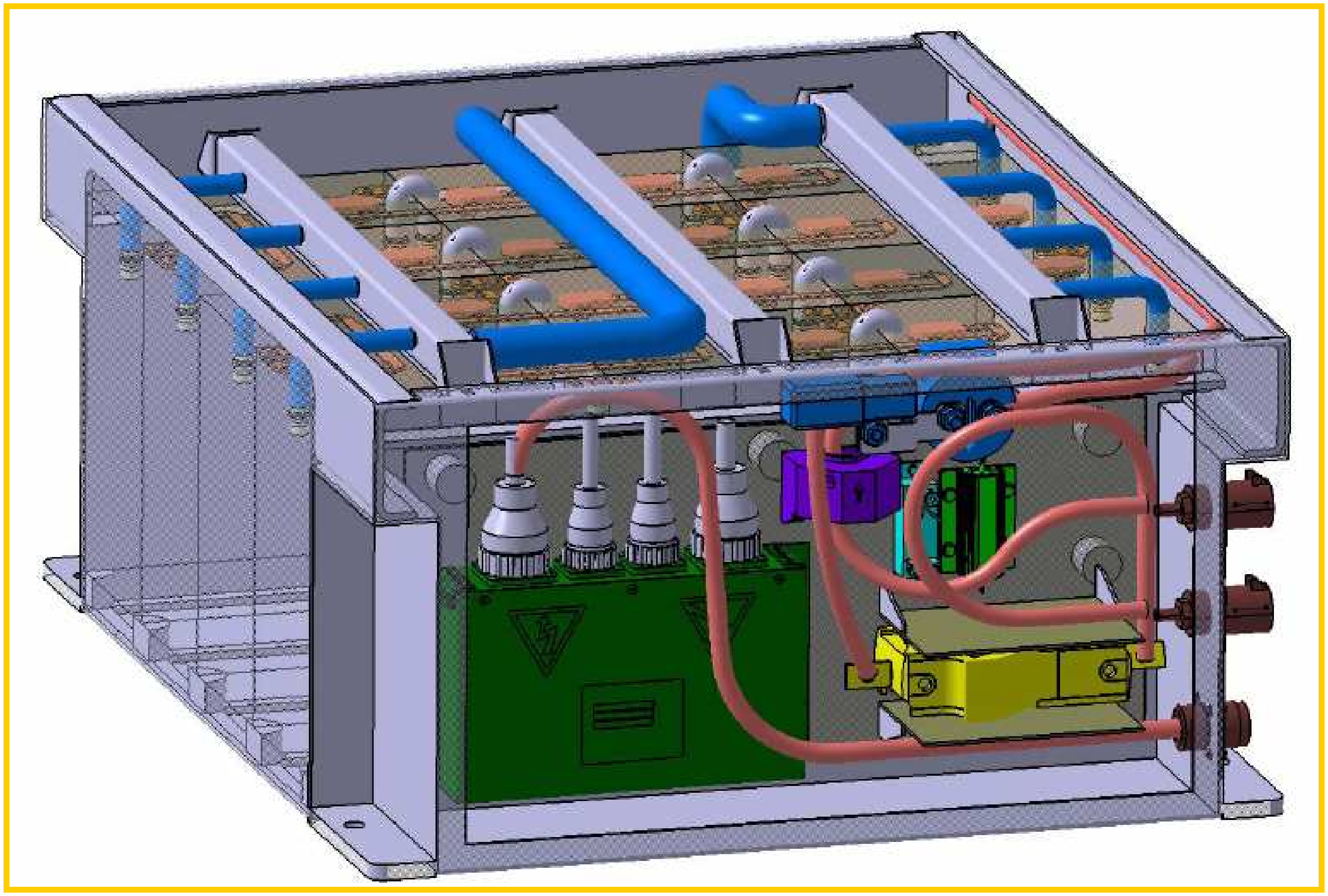
VL41M product performs comparably

Li-ion VL45E cells

DST cycle life test (240 W/kg), 80% DOD, +20°C
Current limit power at 80% DOD and 50% DOD (30s pulses)



System Design is the Brain and Nervous System…………



A Layered Strategy to Assure Abuse Tolerance in Lithium-Ion Battery Systems

Cell	Battery Module	System/BMS
• Materials • Material interactions • Design for maximum cooling • Effective vent release	• Temperature sensor(s) • Power disconnect on venting • Cell balancing circuitry • Over-discharge over-voltage protection • Optimized thermal management	• Temperature sensor(s) • Thermal fuse • Overcharge protection • Battery Management Electronics • System software

Abuse Tolerance – Cell Test Results

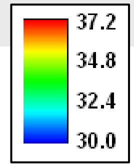
VL7P Power Design

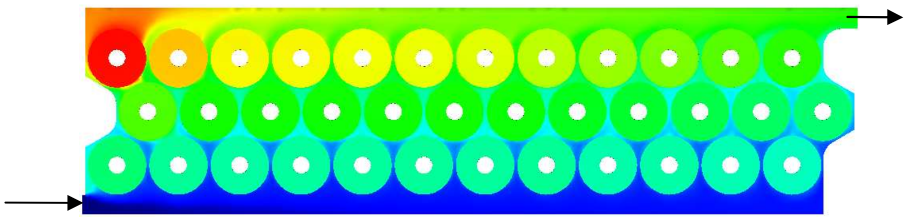
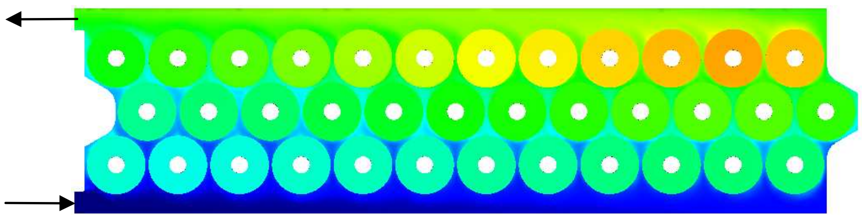
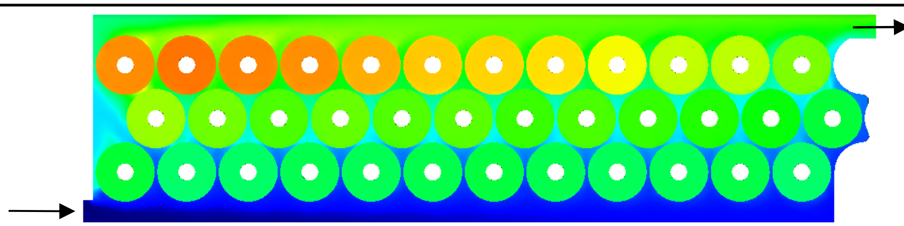
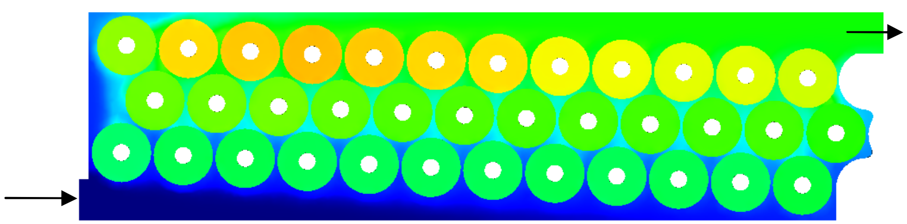
Abuse Test	Number passed/ number tested	Comments
Overcharge at 7 A	5/5	Venting, light smoke
Overcharge at 20 A	5/5	Venting , light smoke
Overcharge at 50 A	5/5	Venting, light smoke
Short-circuit with 0.3 mOhm	5/5	No venting, no smoke
Nail penetration (3mm)	5/5	Venting, grey smoke
Overheat (UL type)	5/5	Venting, light smoke
Crush Test	5/5	No voltage drop, no temperature increase

► **Abuse testing is in-progress on M and E series cells**

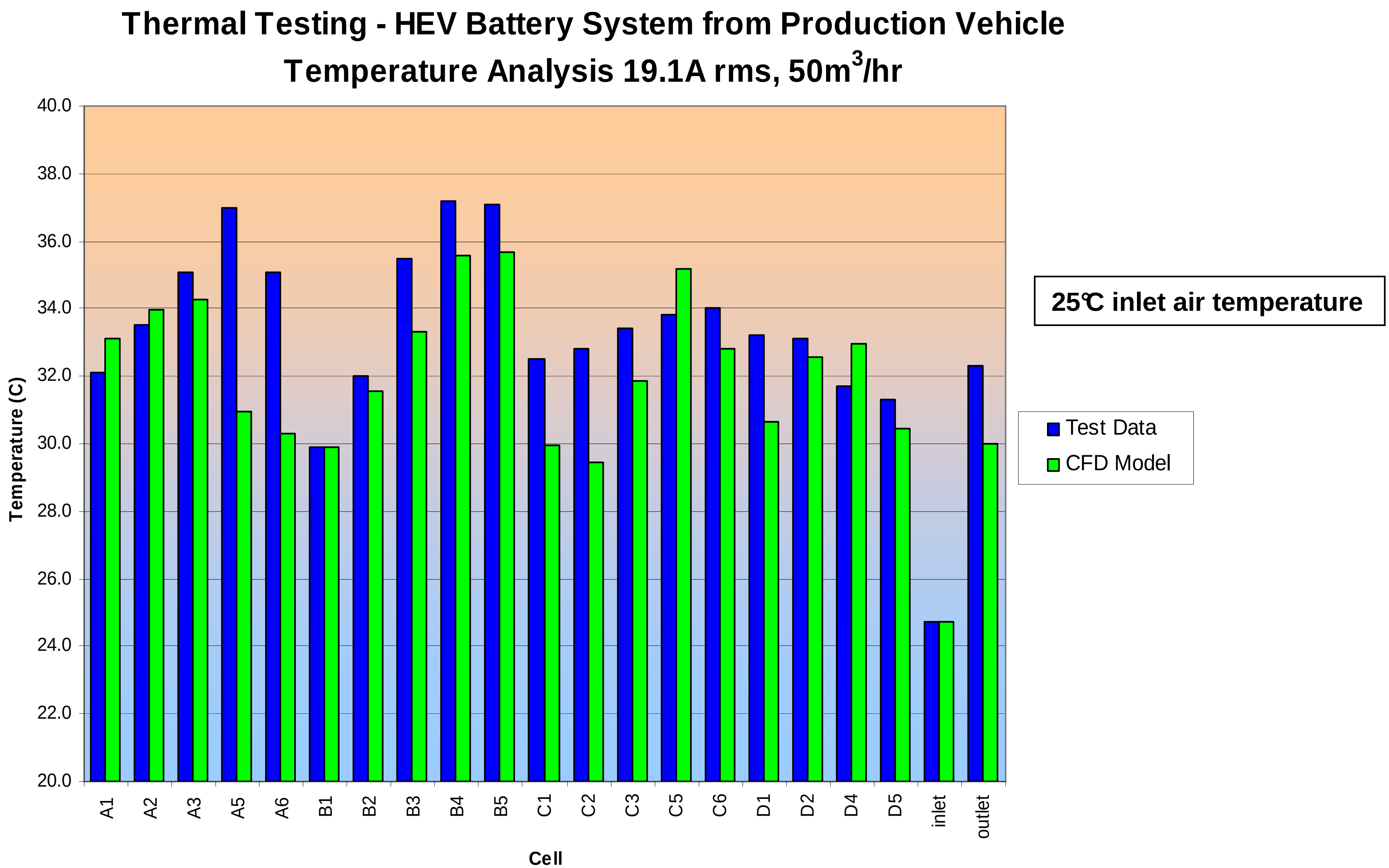
Thermal Management – A Key to Success (Life!)

Temperature Variation within Pack Must Be Minimized

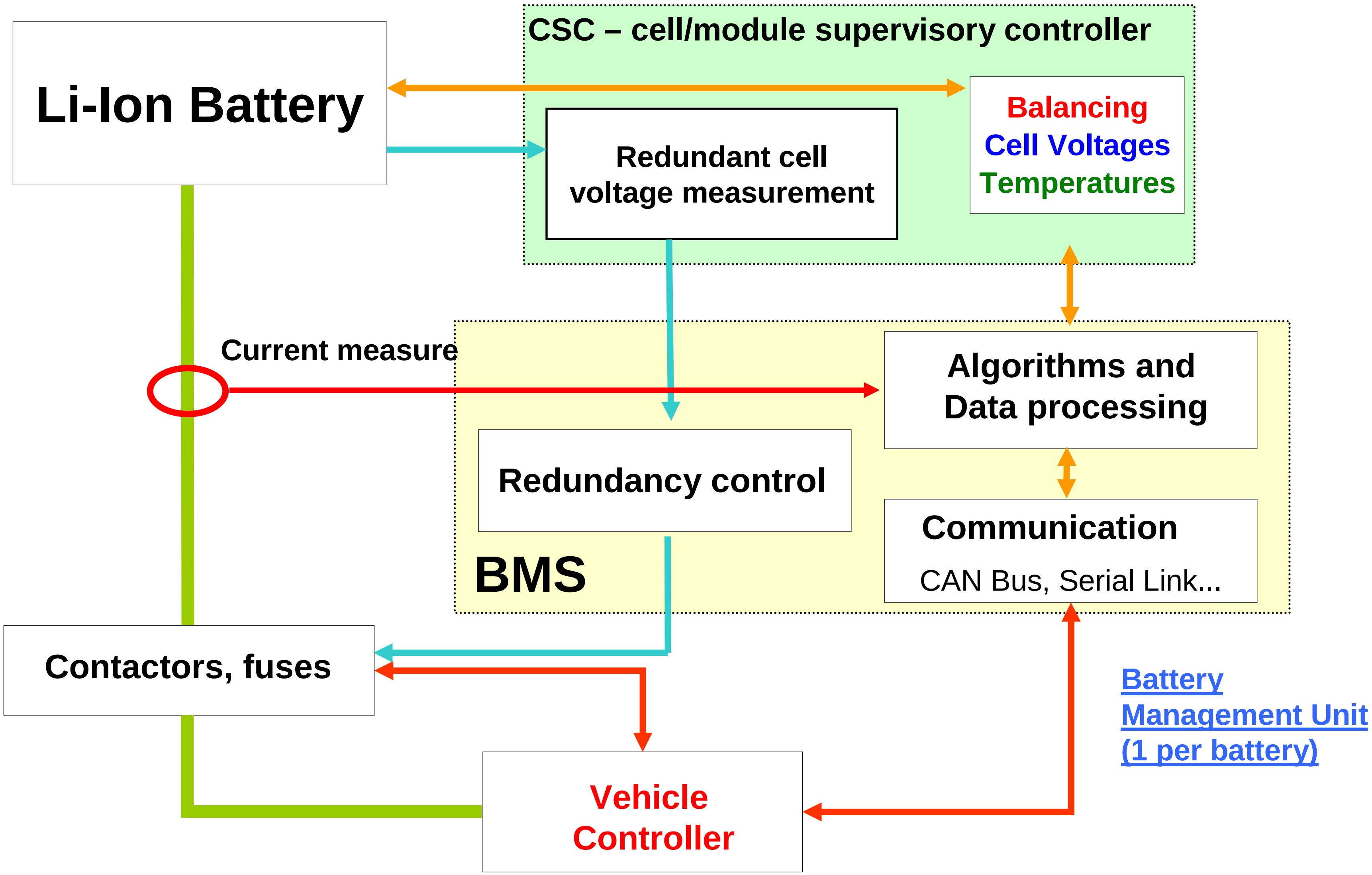


			T_{max} ℃	ΔT ℃	Δp Pa
A	Opposite end exit		37.1	5.0	15.2
B	U-turn		36.0	4.2	14.0
C	Opposite end exit with tuned flow space		36.4	3.7	15.3
D	Opposite end exit with tapered plenums		35.9	3.3	11.1

Simulations Save Time and $Money$



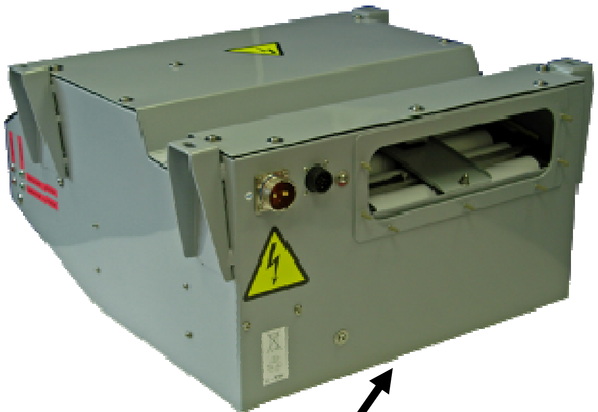
Prototype Battery Management System



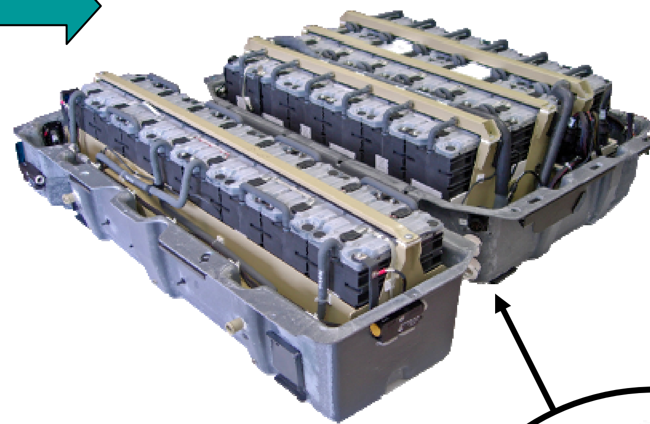
Lithium-Ion Modules & Battery Systems

HEV ← | → EV

Hybrid Demonstration Vehicle



Electric Vehicle Program



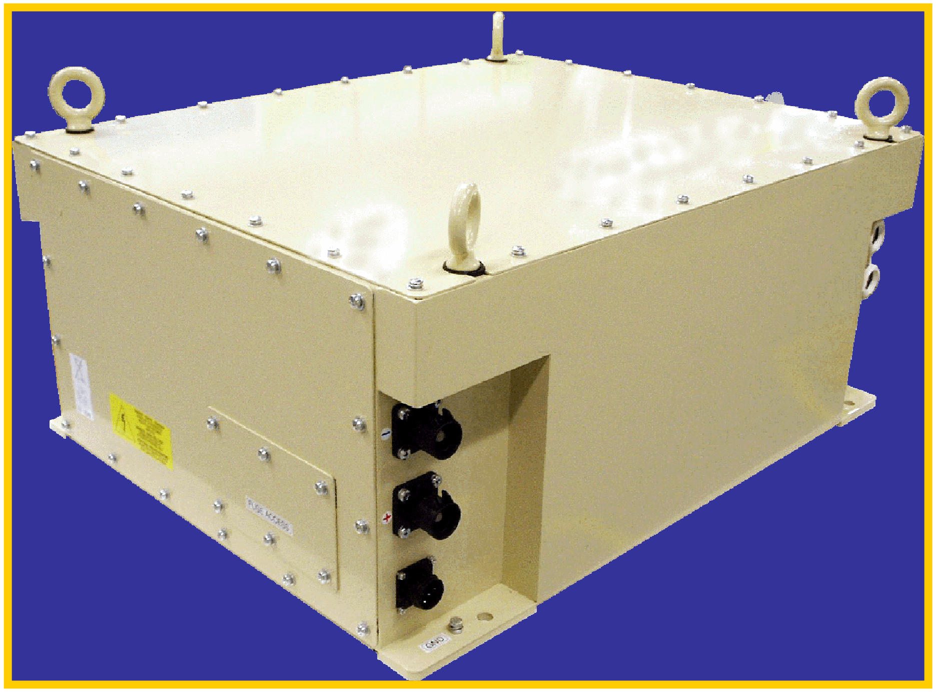
10S VL7P
Air Cooled

6S VL41M
Liquid Cooled

Fuel Cell Demonstration Vehicle

JCS Li-Ion Battery Systems are Being Evaluated in PHEV Applications

Bench Testing Underway at Argonne National Laboratory



- **12- VL41M Modules**
- **6 Cells per Module**
- **259 V**
- **61 kW @ 50% SoC for 30s**
- **Liquid Cooled**

Should Plug-In Hybrids Be Designed for Substantial Continuous All Electric Range ?

Let's Examine the Trade-offs:

	Conventional HEV	PHEV-20	PHEV High Energy
Vehicle Acceleration	+	+	+
Braking	+	+	+
Zero Emissions Drive Range	0	++	+
Plug-in ability to recharge	0	+	+
Average Fuel Economy	+	++	++
Displacement of Petroleum with Electricity (energy security)	0	++	++
Overall Fuel Cost	+	++	++
Power Train Complexity/Cost	++	0	+
Battery Size/Weight/Cost	++	0	+
Vehicle Purchase Affordability	+	-	0
Totals (Green and Red criteria equally weighted)	9+	10+	12+
Red criteria weighted 1.5 X green	12+	11.5+	15+

Definitions

Conventional HEV: Minimal electric-only range, minimal road energy contribution, no plug-in capability

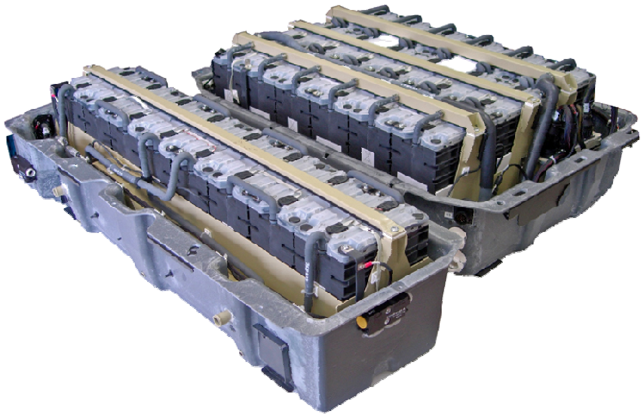
PHEV-20 AER: 20 miles of continuous electric-only range

PHEV High Energy: Minimal electric only range, but significant road energy contribution from electricity

Answer: Commercial affordability dictates a lower cost power train

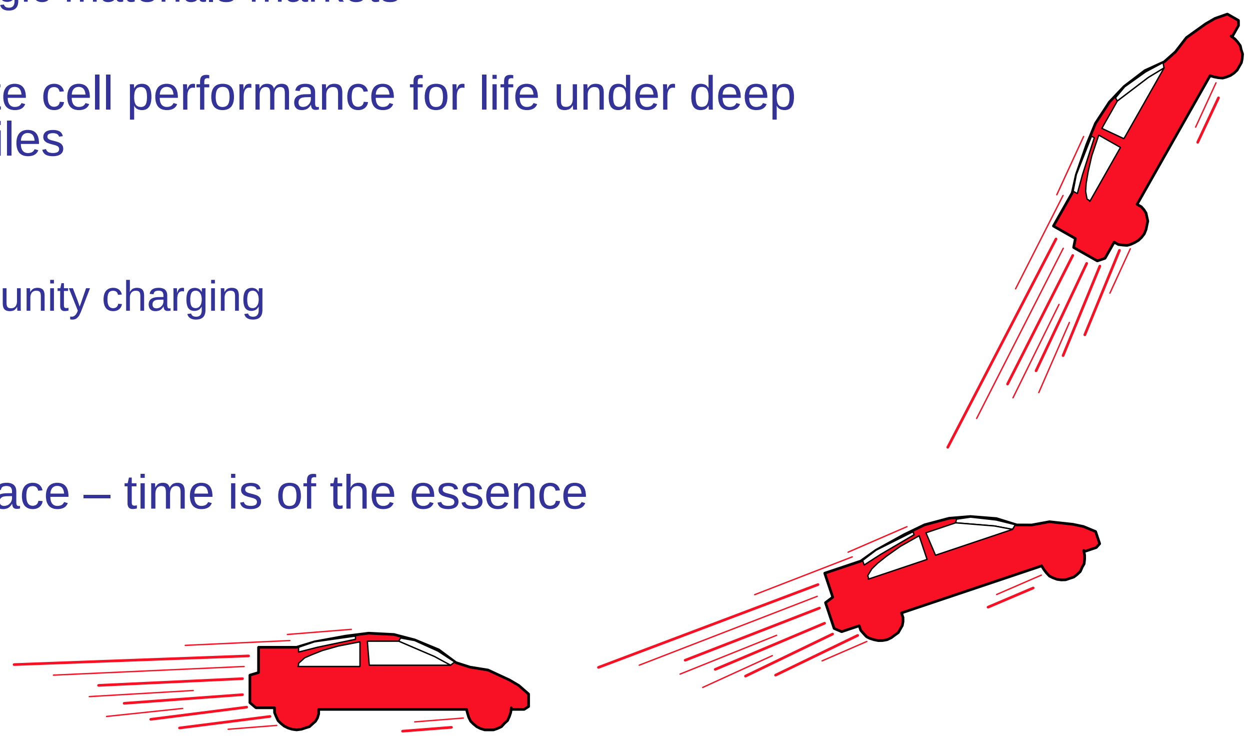
JCS Has Extensive Li-Ion EV Experience

- **Li-Ion Systems - road demonstration programs started in 1996**
- **300,000 mile field returns**
- **Prototypes and demonstrators**
  - Renault Scenic VE 2000
  - Cleanova I, II, III
  - DaimlerChrysler Voyager
  - Peugeot 106 Vedelic
  - Ford e-Ka
  - Volkswagen Bora
  - Fiat Seicento
  - E-motion
  - GM/Opel prototype



Challenges Going Forward

- Perform detailed cost/benefits analyses of PHEV vehicles with respect to:
  - Vehicle Cost/payback
  - Petroleum displacement
  - Recycling infrastructure and environmental impact
  - Investment
  - Impact on strategic materials markets
- Design and validate cell performance for life under deep cycling usage profiles
  - Cycle life
  - Calendar life
  - Impact of opportunity charging
  - Impact of V2G
- We're in a global race – time is of the essence



Summary and Recommendations

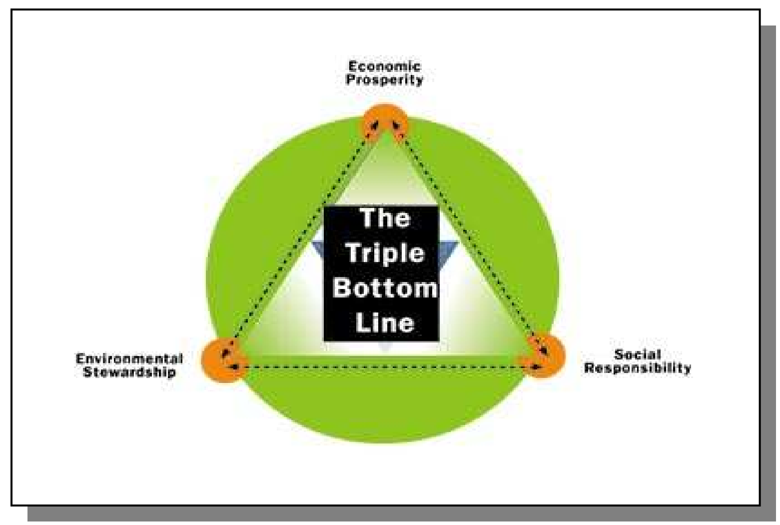
- JCS believes the potential for PHEVs to improve the energy/environmental health of the United States and the world is real – commercial feasibility should be vigorously investigated.
- We support the Advanced Energy Initiative proposed by President George W. Bush.
- We applaud the work being done by organizations like DOE, EPRI, AQMD, CARB, and OEMs to better understand the cost/benefit trade-offs for PHEVs.
- On-going discussions with all stakeholders should be accelerated. This is an excellent opportunity for the United States to assert both environmental and technological leadership.

Johnson Controls is Committed to its Leadership Role in Environmental Stewardship and Social Responsibility

- Founding member, Green Buildings Council and developer of LEED (Leadership in Energy and Environmental Design), the certification standard for green buildings
- 2004 World Environment Center Gold Medal for International Sustainable Development
- U.S. DOE Energy Star partner
- Member: minority business "Billion-Dollar Roundtable"
- Dow Jones Sustainability Index
- Igniting Creative Energy Contest for K-12 students
- **USABC/DOE hybrid vehicle battery partnership**

UNITED STATES ADVANCED BATTERY CONSORTIUM

2005 Johnson Controls/USEA Energy Forum, Washington, DC
Johnson Controls Chairman and CEO John Barth welcoming President George Bush



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