Development of Advanced Energy Storage Systems for High Power, Lower Energy – Energy Storage System (LEESS) for Power Assist Hybrid Electric Vehicle (PAHEV) Applications

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Maxwell Technologies, Inc.

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Project ID #
ES139

OVERVIEW

TIMELINE

- Project Start: Jan 2011
- Project End: March 2013
- 55% Complete

BUDGET

- Total Project Funding
  - USABC: $3,432K
  - Maxwell: 3,573K
- Funding in FY11: 1,931K
- Funding for FY12: 4,648K

BARRIERS

- Low Temperature Performance
- Overall Power Performance
- Energy Density / Voltage Window
- Total Manufactured Cost

Maxwell LEESS Targets

- System Weight = 22 kg
- System Volume= 25 L
- Cost/System = $920 (@100K units/year)

PARTNERS

- Porous Power Technologies - *Separator Development*
- University of Rhode Island - *Electrolyte Development*

RELEVANCE TO VEHICLE TECHNOLOGIES

PROJECT OBJECTIVES

Meet LEESS EOL power and energy requirements through the development of capacitor cells and a system that represents a significant advancement over commercially available capacitive technology.

- Extend upper voltage range of energy storage device to > 4.0 V
- Achieve LEESS required low temperature performance down to -30^{o}C.
- Adapt the technology to a new cell form factor amenable to low cost manufacturing
- Develop and demonstrate a new architecture for pack design which is cost effective, small and light

RELEVANCE – Y1 TECHNICAL OBJECTIVES

Feb 2011-Mar 2012

- Select best performing anode and cathode electrode formulations
- Perform electrolyte screening and down-selection
- Identify candidate separator material
- Design cell architecture
- Design and select system architecture

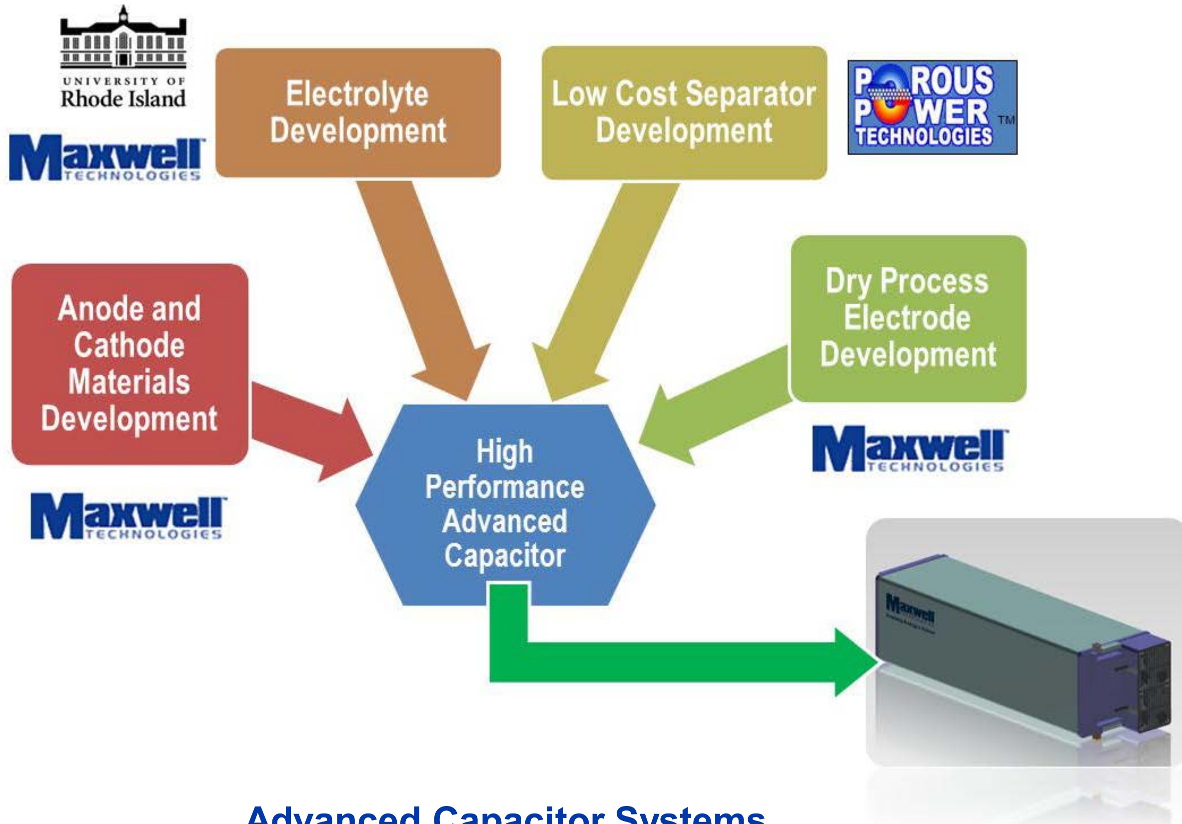
PROJECT MILESTONES/ GATES

Month/Year	Milestone or Go/No-Go Decision	Criteria	Status
May 2011	Milestone: Fabricate and deliver Generation 1 cells	Achieve a baseline performance from which to make improvements, qualified by HPPC	Complete. HPPC tests in progress
Dec 2011	Milestone: Select primary anode and cathode formulations	ESR, Capacitance, Cycling stability	Complete. Down-selected to candidates that meet performance criteria.
Mar 2012	Go/No-Go: Electrolyte Design Review	ESR, Low Temp performance, Voltage Window, Cycling stability	Anticipated “Go” decision based on performance achieved to date.
April 2012	Go/No-Go: Separator Design Review	ESR, Cycling Stability, Cost	Candidate separator testing in progress.
April 2012	Milestone: Define and cost cell manufacturing line	Price/cell at production level of 8M cells/year	In progress
June 2012	Milestone: Fabricate and deliver generation 2 cells	ESR, Capacity, Cycling Stability, Cost, qualified by HPPC	Delivered cells will have improved electrolyte and electrode formulations in final cell architecture
August 2012	Milestone: Fabricate and deliver generation 3 cells	ESR, Capacity, Cycling Stability, Cost	Cells will have final formulation, size, and architecture.
June 2012	Go/No-Go: System Design Review	Projected ability to meet cost, weight, and size goals	Anticipated “Go” decision based on use of next generation cell technology.
Sept 2012	Milestone: Construct and initiate testing on 15 production units	Manufacturability, cost	Pending outcome of design review
Jan 2013	Milestone: complete validation test report	Comprehensively address system performance	Pending outcome of production unit construction

STRATEGY

Meet LEESS Targets by:

- Identifying high performance electrolyte candidates in conjunction with URI (improve voltage window, temp range conductivity, lifetime)
- Identifying and screening low cost separator technology with Porous Power
- Increase cell performance via selection of anode and cathode electrode materials based on discrete structure-property relationships
- Leveraging economical cell design to produce the lowest cost and smallest/lightest system



Advanced Capacitor Systems

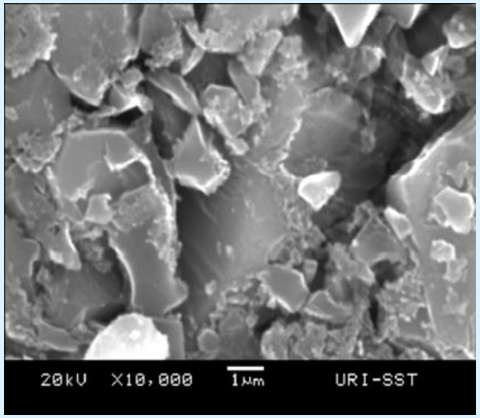
- Higher voltage
- Wider temperature window
- Smaller, lighter, more powerful

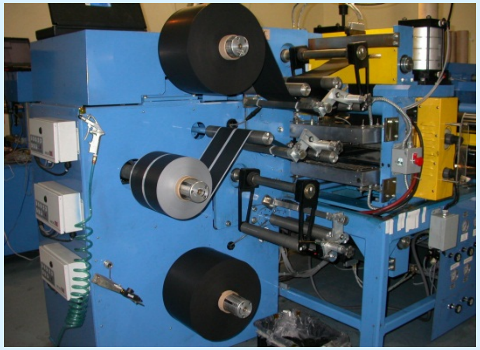
TECHNICAL APPROACH

CELL DEVELOPMENT

Improve from Baseline Cell Performance by:

- Identifying and selecting the highest performing anode and cathode carbons using XRD, BET, half- and full-cell testing, as well as high-throughput screening techniques, leveraging over a decade of previous carbon screening work.
- Identifying and selecting new electrolytes + additives using ex-situ experimentation (CV, conductivity, viscosity) and analyze electrode-electrolyte interface using microscopy (w/URI)
- Identifying and characterizing alternative separator materials with good performance but significant cost reduction
- Use of a completely dry electrode fabrication process (solvent-free, reduced processing) to decrease cell manufacturing cost and increase cell lifetime
- Quantifying performance/weight/size reduction of new cell architecture via cell-level electrochemical and physical testing





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TECHNICAL APPROACH

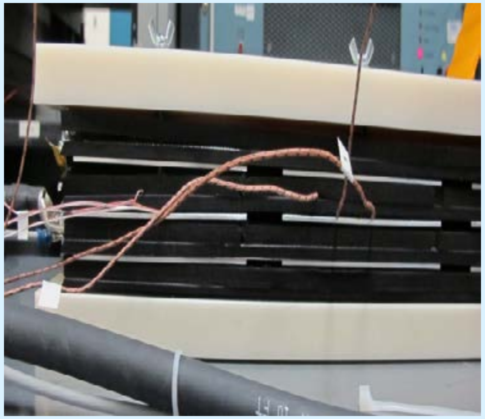
SYSTEM DEVELOPMENT

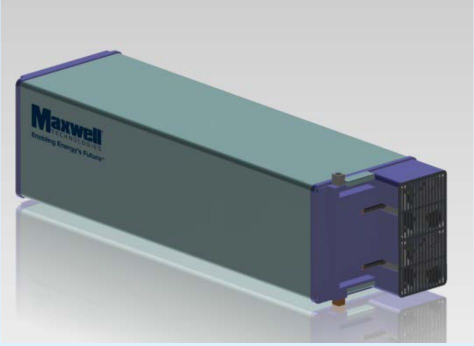
- Design modular system leveraging compact cell design for maximum efficiency in cell stacking while meeting LEESS energy and power targets

- Iterate design based on thermal modeling, heat bed testing, and improved cell characteristics.

- Perform system-level electrochemical, physical, and safety tests and identify areas where weight, size and cost savings can be achieved

- Construct and evaluate 15 production-level units to closely approximate cost and performance at volume production (100K units/year)

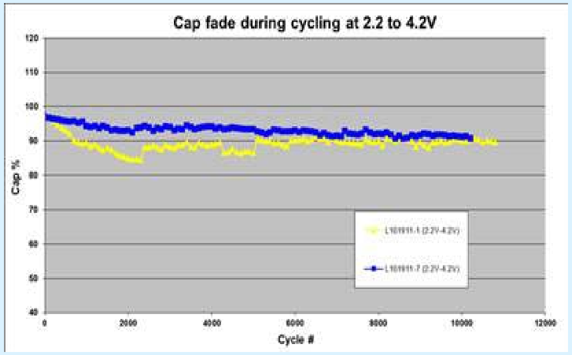




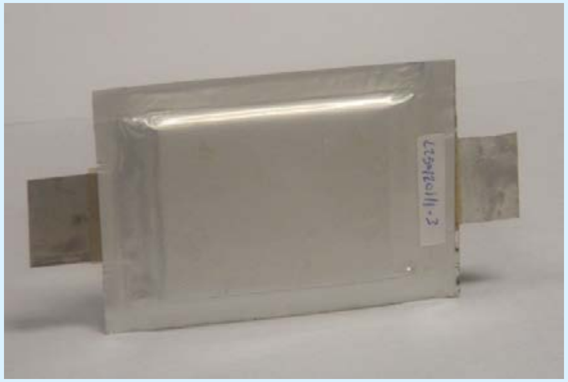
TECHNICAL ACCOMPLISHMENTS – FY11

Electrode Development

- Screened over 20 anode carbon candidates and down-selected to two key candidates. Best candidate demonstrates superior cycling stability within target voltage window. Second candidate demonstrates 20% improvement in ESR (cycling stability tests in progress).



- Developed first 250F cell design with 100% yield and stable cycle life



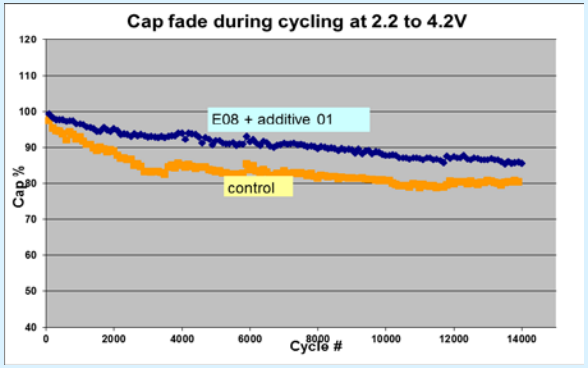
- Developed in-house capability for preparing precursor cathode carbon and initiated high-throughput screening process with Wildcat Discovery Technologies

- Selected and optimized current collector thickness, and initiated investigation of porosity. Achieved 10% reduction in total cell weight and decreased cell conditioning time by 80%.

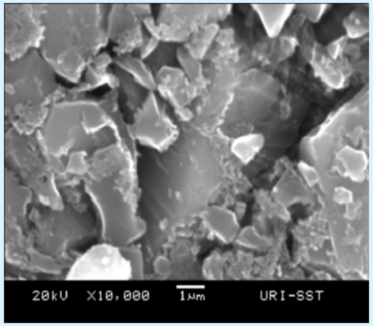
TECHNICAL ACCOMPLISHMENTS – FY11

Electrolyte Development

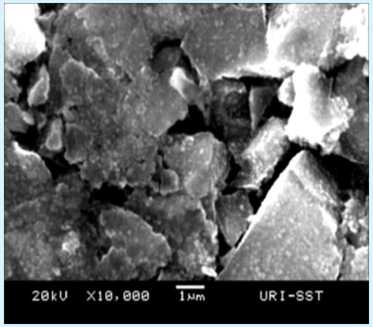
- Developed commercially relevant purification process to ensure maximum electrolyte stability
- Screened 15 electrolyte candidates and down-selected to base solvent formulation. Formulation exceeds LEESS low temperature target (-30°C) at BOL.
- Identified and screened electrolyte additives that notably improve cycling durability. Increased stability visually confirmed in conjunction with URI.



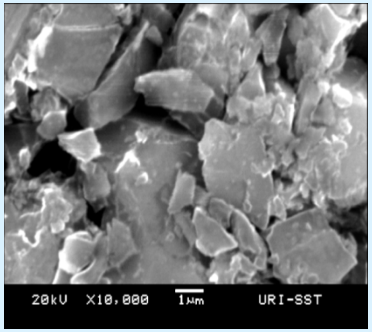
Fresh Anode



Anode from tested cell with E08



Anode from tested cell with E08+ Additive 01



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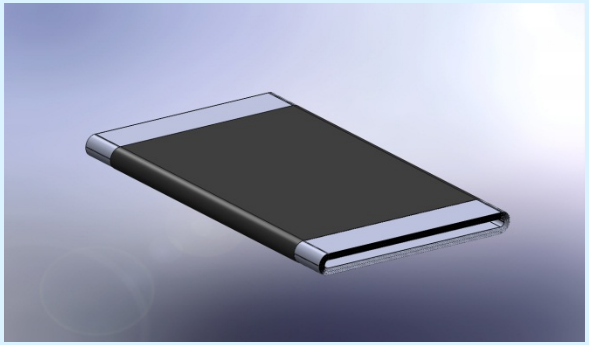
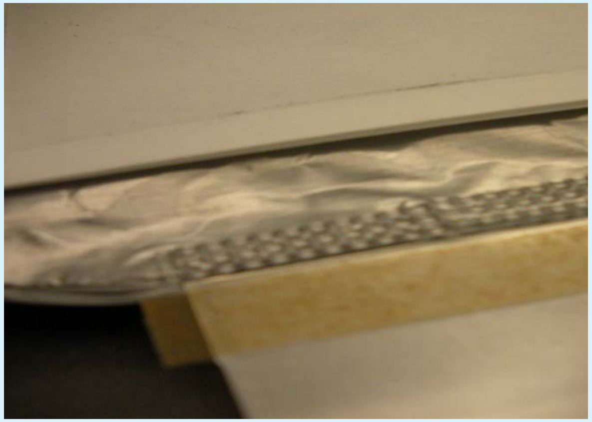
TECHNICAL ACCOMPLISHMENTS – FY11

Cell Development



- Down-selected to four commercial candidate commercial separator materials, and identified primary candidate developed by Porous Power Technologies (9% higher ESR but potential for 3X cost reduction)

- Designed final system cell architecture, set specifications, and tested fabrication at bench scale using ultracapacitor technology – designed capacitance achieved



- Optimized cell tab welding process, no observation of materials separation

- Constructed detailed cell materials and manufacturing cost model to identify key cost contributors, and initiated cost-down of those contributors (at 8M/cell year production level). System cost on track to meet target.

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TECHNICAL ACCOMPLISHMENTS – FY11

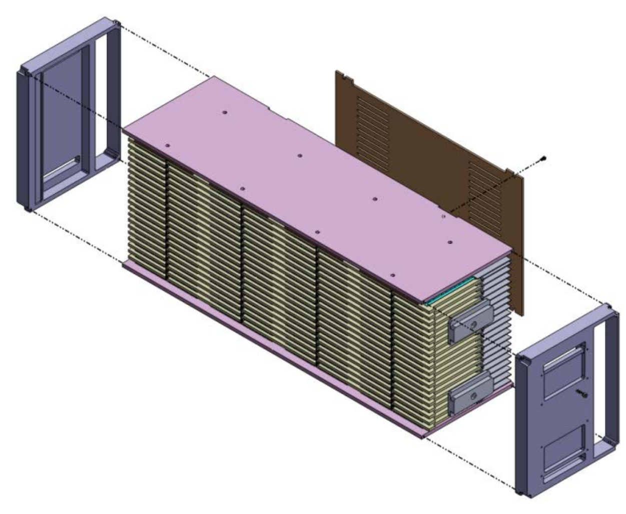
System Development

- Selected final system design (modular, stacked architecture) and modeled system sizing based on LEESS HEV profile and projected cell performance

- Designed thermal test hardware and performed heat bed modeling study

- Designed basic interconnect and system electronics scheme

- Progress towards weight/size goals:



	Weight	Size
Beginning of Program (based on Gen 1 cell BOL)	53.9 kg	67.9L
Feb 2012 (based on Gen 2 cell in system)	**35.4 kg**	**33 L**

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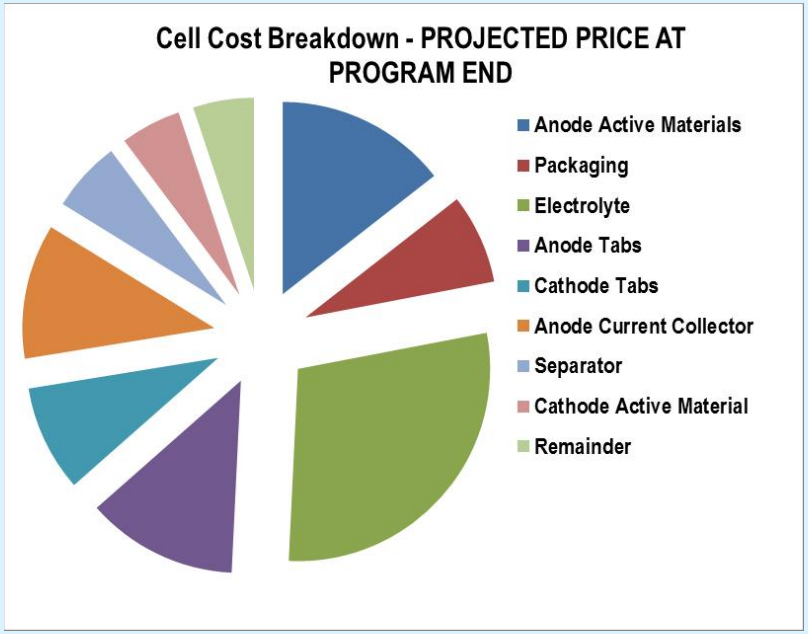
TECHNICAL ACCOMPLISHMENTS – FY11

Cost Modeling

- Developed cost model to reflect both cell and system level costs. On track to meet $920/system price. Progression:

Month	Est. System Price (100K units/yr)
Jan 2011	$2585
Jan 2012	$1046

- Identified key cell cost contributors and worked with existing and new vendors to identify potential cost savings.



COLLABORATORS

Multi-functional team addressing all key areas of the project:

Porous Power Technologies

- Small business subcontractor - developing and providing new, low cost separator materials

University of Rhode Island – Dr. Brett Lucht

- University subcontractor - screening new electrolytes and additives, and performing electrode interface analysis using microscopic and other analytical techniques

INL

- FFRDC, cell and system performance characterization

NREL

- FFRDC, thermal modeling and testing

SNL

- FFRDC, abuse testing

FUTURE WORK

Detail of Activities/Milestones for FY12-13

- Finalize anode and cathode electrode materials, electrolyte, and separator based on FY11 down-selection results. Manufacturing and cost risk has been mitigated through the selection of several candidates that meet performance criteria and have been pre-evaluated for volume cost. Performance against goals will be quantified per USCAR PAHEV test manual.

- Fabrication of cells from pilot line
  - Gen 2 cells will have optimized electrodes and electrolyte, in final architecture
  - Gen 3 cells will have the above, plus optimized separator and be sized for the system

- Fabricate and test hybrid ultracapacitor cells in final system architecture. Risk in fabrication of this new architecture has been significantly reduced through the construction and testing of ultracapacitor cells of equivalent dimension.

- Milestone: Construct and test prototype systems containing the latest generation of hybrid ultracapacitor cells. This process will identify outstanding issues which will be resolved before the construction of production level systems.

- Complete full manufacturing cost model for both cell and system

- Construct and initiate testing on production systems. Report outputs from this testing will be used to make recommendations and depict final performance against LEESS goals.

SUMMARY

USABC LEESS PAHEV PROGRESS vs. TARGETS

Performance of Gen 1 (beginning of program cell, delivered May 2011) as of Jan 2012. Gen 2 cells due to initiate testing in July 2012.

End of Life Characteristics	Unit	PA (Lower Energy)		P305 Cell 15	
				BOL	RPT0
2s / 10s Discharge Pulse Power	kW	55	20	33.03	33.59
2s / 10s Regen Pulse Power	kW	40	30	49.54	50.39
Discharge Requirement Energy	Wh	56		34	34
Regen Requirement Energy	Wh	83		71	77
Maximum current	A	300			
Energy over which both requirements	Wh	26		195	192
Energy window for vehicle use	Wh	165		301	302
Energy Efficiency	%	95		92.9%	
Cycle-life	Cycles	300,000 (HEV)			
Cold-Cranking Power at -30ºC (after 30	kW	5			
Calendar Life	Years	15			0
Maximum System Weight	kg	20		53.9	
Maximum System Volume	Liter	16		67.9	
Maximum Operating Voltage	Vdc	400		3.8 / 31092	
Minimum Operating Voltage	Vdc	0.55 V_{max}		2.2 / 18000	
Unassisted Operating Temperature	ºC	-30 to +52			
52°	%	100		145%	
0°	%	50		83%	
-10°	%	30		59%	
-20°	%	15		35%	
-30°	%	10			
Survival Temperature Range	ºC	-46 to +66			
Selling Price/System @ 100k/yr)	$	400			
Hardware Level				cell	
Ampere Hour Capacity				0.015	
Battery Size Factor (BSF)				8182	

Data collected by INL

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SUMMARY

This project directly addresses LEESS PAHEV goals:

- Cell materials improvements address power, energy and temperature requirements
  - Higher voltage: extended upper voltage window to >4V
  - Wider temperature window: successful operation at -30^{o}C BOL
  - Smaller and lighter: new cell architecture
- Use of cost as a factor in down-selection drives overall system cost down, and use of large scale manufacturability as a factor in down-selection facilitates production and commercialization
- Partnerships with Small Business, University, and Govt. laboratories position the project to address all key aspects of HEV power system development
- Promising progress in FY2011 indicates the project is well-positioned to meet FY2012 goals.