USABC PHEV and USABC HEV LEESS Programs

Project ID: ES003

DOE Annual Merit Review

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Global Locations

Corporate Headquarters and R&D: Waltham, Massachusetts

- 2000+ employees in multiple locations worldwide
- >1,000,000 square feet of manufacturing facilities in United States, China and Korea

Corporate Headquarters, Research and Development
- Waltham, Massachusetts

Systems Design and Manufacturing
- Hopkinton, Massachusetts
- Westborough, Massachusetts
- Livonia, Michigan

Materials Research
- Ann Arbor, Michigan

Powder, Coating, and Cell Plants
- Livonia, Michigan
- Icheon, Korea
- Changzhou, China
- Changchun, China
- Zhenjiang, China

Supplier Quality
- Shanghai, China

Core Markets

Enabling New Products through Advanced Energy Storage

Transportation

Passenger Hybrids, PHEVs and EVs

Commercial Hybrids, PHEVs and EVs

- Fuel economy
- Reduced emissions
- Energy independence
- Lighter-weight components

Electric Grid

Regulation, Grid Reliability

Renewable Integration, Congestion Relief

- Increase grid reliability
- Enable Wind and Solar
- Increase plant efficiency/utilization

Commercial

IT & Telecomm

Medical Systems

Material Handling

Industrial Controls

- Improve performance
- Lighter weight
- Lower total cost of ownership over lead acid

Drivers

This presentation does not contain any proprietary, confidential, or otherwise restricted information

PHEV Program

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PHEV Program Overview

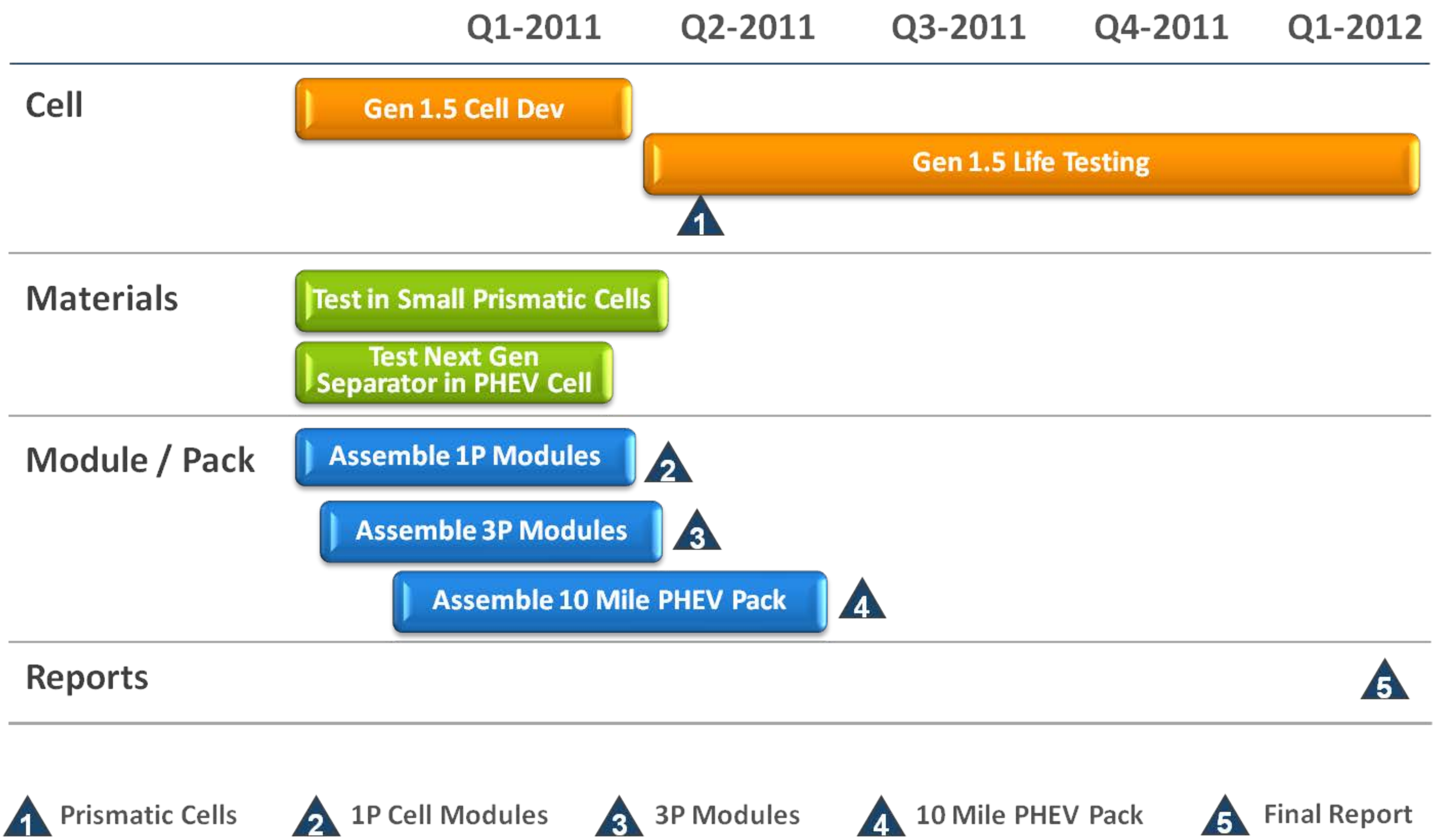
- Timeline
  - Original plan: March 2008 – February 2011
  - No-cost extensions: granted until December 2011
- Budget
  - $12.5M, 50:50 cost share program between A123 Systems & USABC
- Technical Barriers Addressed
  - A. Cost – cell & system
  - C. Performance – energy density
  - E. Life – cycle & calendar

- Partners
  - This program did not include formal partners outside of A123 Systems and USABC
  - NREL , SNL and ANL perform independent confirmation testing

PHEV Program Relevance & Strategy

- Program Objective
  - Develop prismatic pouch cell using A123 doped Nanophosphate® material chemistry in support of DOE objective to improve fuel economy and petroleum displacement
    - 10 mile PHEV
    - 40 mile PHEV
- Program Strategic Alignment with Technical Barriers
  - Life: Cycle Life
    - Optimize materials and system design (cell compression)
  - Life: Calendar Life
    - Optimize thermal management through cell and module design
  - Performance: Energy density
    - Develop high energy materials to reduce BSF, system weight and volume
  - Cost: Reduction
    - Materials development, energy density improvement, efficient module/pack design

PHEV Program Milestones



PHEV Cell & Module Deliverables

Deliverables	2011				2012
	Q1	Q2	Q3	Q4	Q1
Deliver (38) Gen 1.5 Cells to ANL	✓				
Deliver (12) Gen 1.5 Cells to Sandia	✓				
Deliver (5) Gen 1.5 Cells to NREL	✓				
Deliver (3) single cell modules to ANL	✓				
Deliver (3) 3P cell modules to ANL	✓				
Deliver (4) 3P cell modules to Sandia	✓				
Deliver (1) 3P cell modules to NREL	✓				
Deliver one 10mile PHEV pack		✓			
Life Test Gen 1.5 Cells				✓	
Final Report					★

PHEV Program Key Accomplishments

- PHEV cell life tests
  + USABC targets for calendar life at high SOC are met/exceeded
    - 100% SOC: > 15 years at 30°C
    - 80% SOC: > 19 years at 30°C
  + For an optimized BSF, cycle tests also indicate that USABC targets will be met or exceeded
- Reduced cost
  + Continued efforts to drive down pack costs through material development and qualification , improved design efficiency and lower BSF resulted in additional cost reduction since 2010
    - 28% reduction for the 10 mile PHEV pack
    - 20% reduction for the 40 mile PHEV pack

PHEV 10 Mile Gap Analysis

- Cycle life achieved 97% of target; small BSF adjustment would have allowed this goal to be met. All other USABC targets except cold crank and system volume and price were met or exceeded.

Characteristics	Units	10-Mile PHEV USABC Goals	EOP/EOL Gen 1.5
Reference Equivalent Electric Range	miles	10	
Peak Pulse Discharge Power, 2s	kW	50	
Peak Pulse Discharge Power, 10s	kW	45	
Peak Regen Pulse Power, 10s	kW	30	
Available Energy for CD Mode	kWh	3.4	
Available Energy for CS Mode	kWh	0.5	
Min Round Trip Energy Efficiency	%	>90	
Cold Crank Power at -30'C	kW	7	
Charge Depleting Cycle Life	cycles	5000	achieved 97%
Charge Sustaining Cycle Life	cycles	300k	
Calendar Life, 30'C 80% SOC | 100% SOC	years	15	|
Maximum System Weight	kg	60	
Maximum System Volume	liter	40	
Maximum Operating Voltage	V	≤ 400	
Minimum Operating Voltage	V	≥ 0.55 V	
Maximum Self Discharge	Wh/day	50	
System Recharge Rate at 30'C	kW	1.4	
Unassisted Operating & Charging Temperature Range	°C	-30 to 52	
30°C - 52°C %Energy | %Power Retained	%	100	
0°C %Energy | %Power Retained	%	50	
-10°C %Energy | %Power Retained	%	30	
-20°C %Energy | %Power Retained	%	15	
-30°C %Energy | %Power Retained	%	10	
Survival Temperature Range	°C	-46 to 66	
Maximum System Production Price @ 100k min /yr		$1,700	

PHEV 40 Mile Gap Analysis

- Cycle life testing is still in progress but is on-target to meet goals. Data show that all other USABC targets except system weight, volume and price were met or exceeded.

Characteristics	Units	40-Mile PHEV USABC Goals	EOP/EOL Gen 1.5
Reference Equivalent Electric Range	miles	40	
Peak Pulse Discharge Power, 2s	kW	46	
Peak Pulse Discharge Power, 10s	kW	38	
Peak Regen Pulse Power, 10s	kW	25	
Available Energy for CD Mode	kWh	11.6	
Available Energy for CS Mode	kWh	0.3	
Min Round Trip Energy Efficiency	%	90	
Cold Crank Power at -30'C	kW	7	
Charge Depleting Cycle Life / Throughput	cycles | MW	5000 | 58	>50% done
Charge Sustaining Cycle Life, 50Wh Profild	cycles	300,000	
Calendar Life, 30'C 80% SOC | 100% SOC	years	15	
Maximum System Weight	kg	120	
Maximum System Volume	liter	80	
Maximum Operating Voltage	V	400	
Minimum Operating Voltage	V	> 0.55 V * Vmax	
Maximum Self Discharge	Wh/day	50	
System Recharge Rate at 30'C	kW	1.4 (120V/15A)	
Unassisted Operating & Charging Temperature Range	°C	30°C - 52°C	
30°C - 52°C % Energy | % Power Retained	%	100	
0°C % Energy | % Power Retained	%	50	
-10°C % Energy | % Power Retained	%	30	
-20°C % Energy | % Power Retained	%	15	
-30°C % Energy | % Power Retained	%	10	
Survival Temperature Range	°C	-46 to 66	
Maximum System Production Price @ 100k min /yr	$	$3,400	

PHEV Calendar Life: Cells on Test

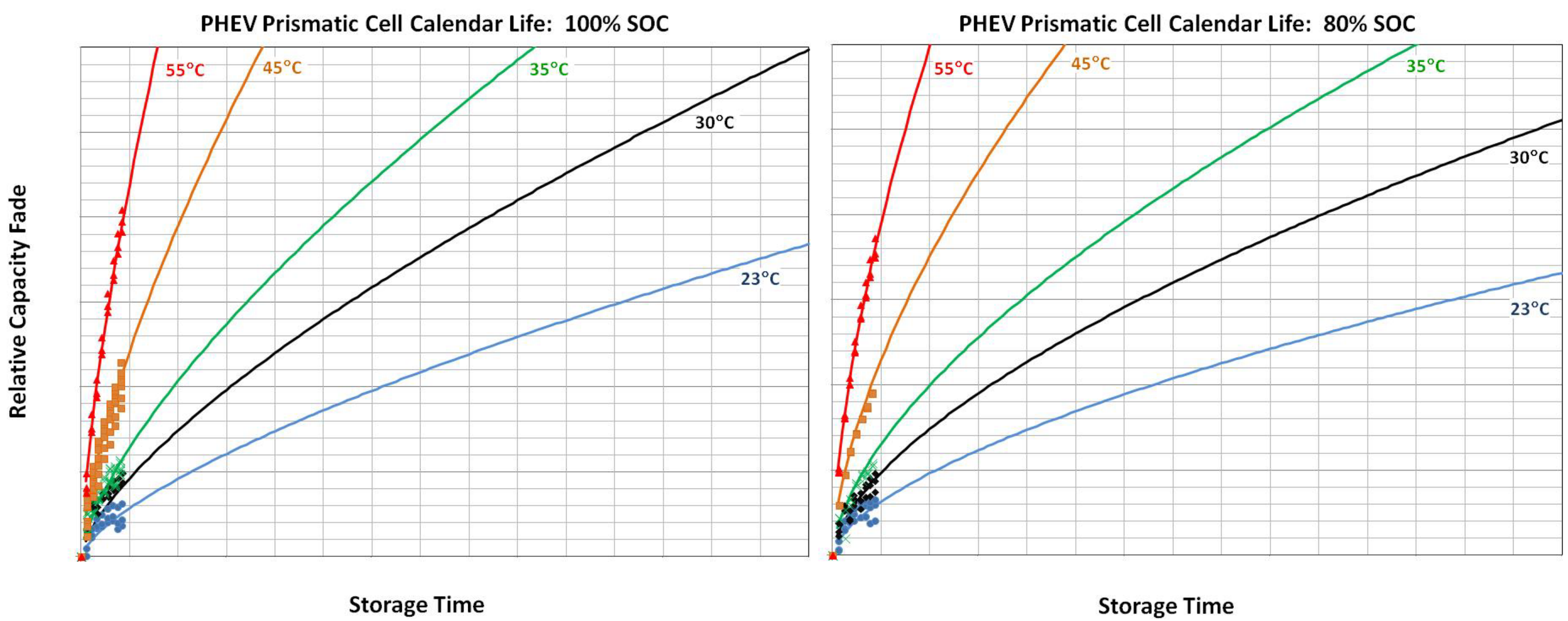
		Storage Temperatures				
		23°C	30°C	35°C	45°C	55°C
% SOC (as defined by USABC)	60%	3	3	3	3	3
	80%	3	3	3	3	3
	100%	3	3	3	3	3

Key

- *Black*: cells are still meeting all USABC power / energy requirements and are still running
- **Red**: cells no longer meet USABC power / energy requirements and are no longer running

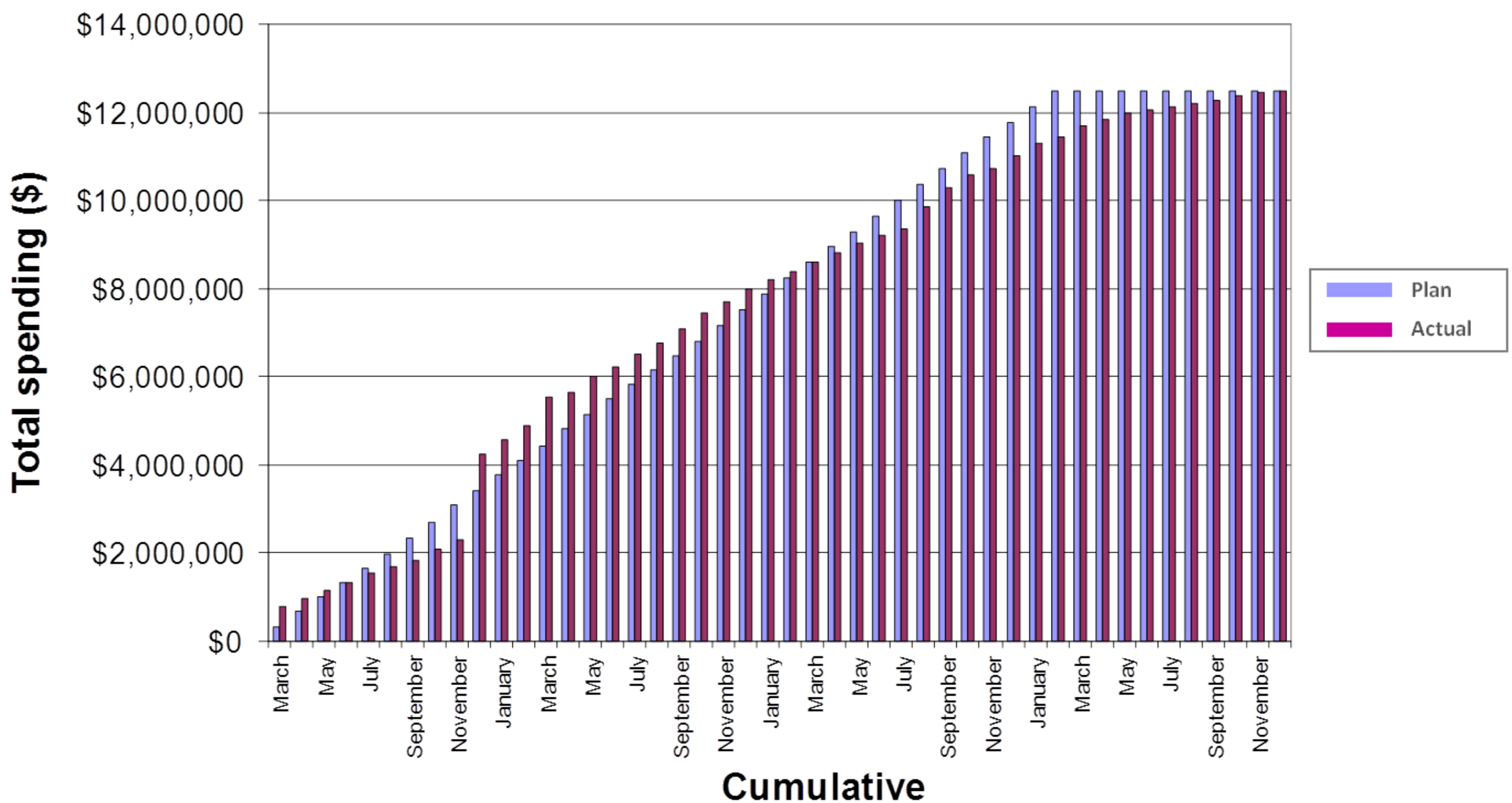
PHEV Calendar Life

- USABC targets are met or exceeded for both 80 and 100% SOC tests
  - 30°C: >15 years for 100% SOC   >19 years for 80% SOC



PHEV Program Actual vs. Planned Spending

- Program spending was completed on budget
  - No-cost extensions ended in December 2011



Accomplishments: PHEV SOW Checklist

Cell Development

Active Materials, Electrode Design	Develop and test anode, cathode, electrolyte, separator Materials selection confirmed	✔
Cell Packaging Design	Cell packaging development complete, seal integrity testing in process	✔
Cell Fabrication Capability	Production scale demonstrated in Korea, Michigan production in progress	✔
DFMEA	Completed	✔

Cell Characterization

HPPC @ 30°C	Cell testing conducted for both 10 mile and 40 mile BSF	✔
Charge Depleting Cycle Life	Cell testing deliverables complete for 10 mile & 40 mile A123 will continue testing through 2012	✔
USABC Calendar Life	Cell testing deliverables complete for 10 mile & 40 mile A123 will continue testing through 2012	✔
Crush Test	Completed, all cells passed with EUCAR 4	✔
Thermal Abuse Test	Completed, all cells passed with EUCAR 4	✔
Short Circuit Test	Completed, all cells passed with EUCAR 4	✔
Overcharge Test	Completed, all cells passed with EUCAR 4	✔
Slow, Blunt Rod	Completed, all cells passed with EUCAR 3	✔

✔ Completed ⇨ In Process

Accomplishments: PHEV SOW Checklist

Module / Pack Design

Electrical System	Completed design	✓
Mechanical System	Have completed module design	✓
Reference Performance Testing	Completed for generic system	✓
Abuse Testing	Module level testing completed	✓

Smart Materials

High Energy Cathode	Demonstrated performance in small format cells	✓
High Energy Anode	Scaled up, included in production design	✓
High Voltage Electrolyte	Have down selected to critical formulations, testing in progress	✓
Next Gen, Multifunction Separator	Demonstrated in small and large format prismatic cells	✓

✓ Completed ⇨ In Process

PHEV Program Summary

- All USABC performance targets were met or exceeded
  - Power *(except 10-mile pack cold crank)*
  - Energy
  - Storage & cycle life
  - Abuse tolerance
- System cost and volume to fall short of program goals
- PHEV cells developed in this program have been successfully commercialized and are in use in vehicles today

PHEV Program Plans

- All cell and pack deliverables are complete and the formal program has ended
  - Final report will be submitted in Q1-2012
- Testing is underway at National Laboratories and will continue into 2012 and beyond
  - NREL, ANL
- A123 testing and characterization will continue in 2012
  - Gen 1.0 Calendar Life Testing
  - Gen 1.5 Calendar Life Testing
  - Gen 1.5 Cycle Life Testing

HEV LEESS Program

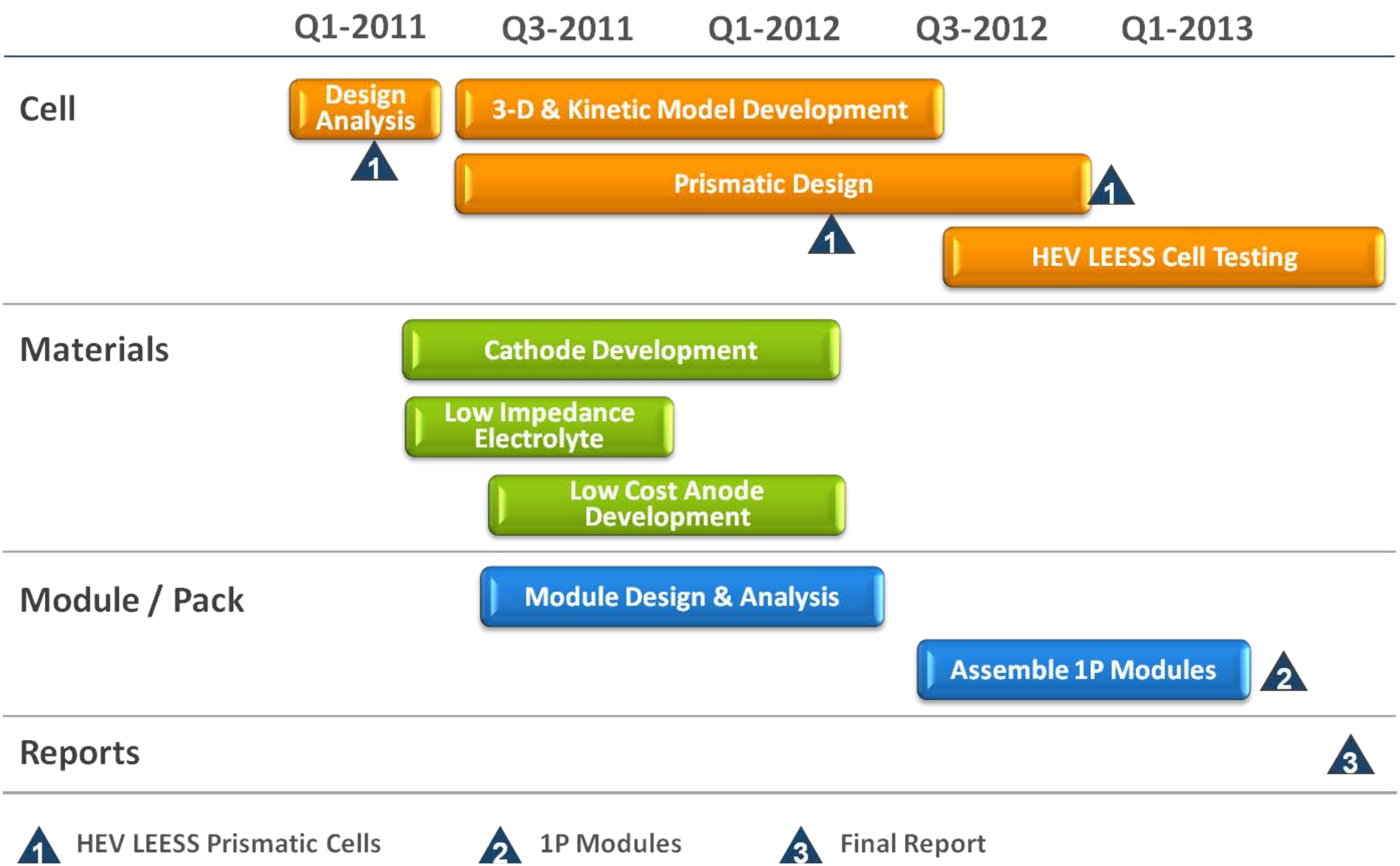
HEV LEESS Program Overview

- Timeline
  - March 2011 – February 2013
- Budget
  - $7.8MM, 50:50 cost share program between A123 Systems & USABC
- Technical Barriers Addressed
  - A. Cost – more efficient cell design
  - C. Performance – improve regen power, cold crank power
  - E. Life – optimizing materials and electrode design
- Partners
  - Dr. J. Meyers, U Texas Austin: 3-d electrochem & thermal modeling
  - Dr. N. Meethong, Khon Kaen U: low temp kinetics of Nanophosphate®
  - NREL , SNL and ANL perform independent validation testing

HEV LEESS Program Relevance & Strategy

- Program Objective
  - Design, build, and test cells and modules for Low Energy Power-Assist HEV battery systems that will achieve DOE / USABC performance and cost targets
  - Develop and demonstrate performance and cost impact from innovative, smart materials and designs
- Program Strategic Alignment with Technical Barriers
  - Cost: Reduction vs. Cycle & Calendar Life
    - Improved electrode designs
    - Optimized electrolyte formulations
  - Performance: Regen Power
    - Improved electrode designs
    - Optimized electrolyte formulations
  - Performance: Cold Crank Power
    - New models for 3-d effects & low temperature kinetics to support cell design
    - Optimized electrolyte formulations

HEV LEESS Program Milestones



HEV LEESS Cell & Module Deliverables

Deliverables	2011				2012				2013
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	H1
Deliver (15) 6Ah HEV Prismatic Cells to National Labs	✓								
Deliver (12) 1.3Ah LEESS Prismatic Cells to National Labs					★				
Deliver (40) 3.8Ah Final LEESS Prismatic Cells to National Labs								★	
Deliver (4) 4-Cell Modules to National Labs									★
Life Test 3.8Ah LEESS Prismatic Cells								★	
Final Program Report									★

HEV Program Key Accomplishments

- Cell design analysis
  - Design for lower cost cell assembly
- Materials optimization
  - Materials DOEs and down-selected high performance / low cost materials
  - Preliminary electrode design to achieve performance targets
- Electrode optimization
  - New binders for reduced impedance and adhesion
- Module design
  - Concept design and initial cell thermal CFD

HEV LEESS Program Gap Analysis

- All USABC performance targets are projected to be met by end of program

Characteristics	Units	PA-HEV LEESS USABC Goals	EOP/EOL Projection
Discharge Pulse Power, 2s	kW	55	
Discharge Pulse Power, 10s	kW	20	
Regen Pulse Power, 2s	kW	40	
Regen Pulse Power, 10s	kW	30	
Discharge Requirement Energy	Wh	56	
Regen Requirement Energy	Wh	83	
Maximum Current	A	300	
Energy Over Which Both Requirements are Met	Wh	26	
Energy Window for Vehicle Use	Wh	165	
Energy Efficiency	%	95	
Cold Crank Power at -30°C	kW	5	
Cycle Life	cycles	300k	
Calendar Life	years	15	
Maximum System Weight	kg	20	
Maximum System Volume	liter	16	
Maximum Operating Voltage	Vdc	≤ 400	
Minimum Operating Voltage	Vdc	≥ 0.55 V	
Unassisted Operating Temperature Range	°C	-30 to 52	
30°C - 52°C %Energy | %Power Retained	%	100	
0°C %Energy | %Power Retained	%	50	
-10°C %Energy | %Power Retained	%	30	
-20°C %Energy | %Power Retained	%	15	
-30°C %Energy | %Power Retained	%	10	
Survival Temperature Range	°C	-46 to 66	
Maximum System Production Price @ 100k min /yr	$	$400	

Cell Design & Materials Optimization

- Small cell testing confirms design concepts
  - Cathode formulation DOEs optimized to balance resistance, adhesion and performance
  - Anode formulation DOEs optimized performance and cost
  - Low cost assembly process preserves cycle life performance

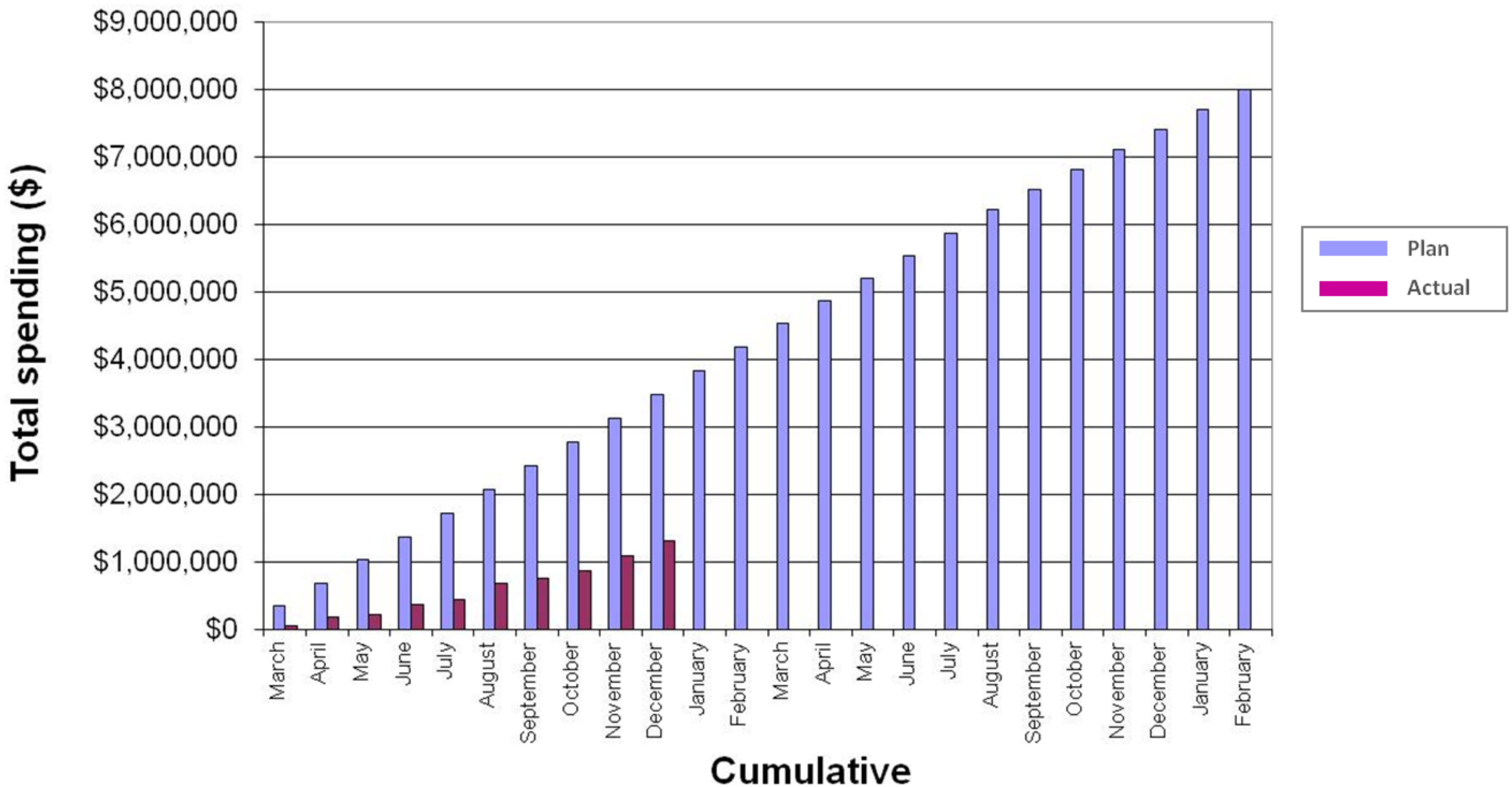
Partners for Cell Modeling

- Prof. J Meyers, U Texas Austin: 3-D electrochemical models
  - Based on Newman's porous electrode theory
  - Model calculates 3-D transient current, potential, temperature distributions and pseudo-3-D concentration profiles
  - Preliminary model scheduled for delivery Q2-2012

- Dr. N Meethong, Khon Kaen U: Low temperature kinetics
  - Model to understand the low temperature kinetics of Nanophosphate® and implications for new materials

HEV LEESS Program Actual vs. Planned Spending

- Program spending is behind plan
  - Delay in cell build activities has pushed expenses out but overall spending totals will be unchanged



HEV LEESS Program Summary

- Cell design developed
  - Materials have been down-selected
  - New cell design was developed to enable low cost assembly
  - Small format prototype cells have been fabricated and testing is in progress

- Low cost module concept design completed
  - Final design of hardware and software is underway

HEV LEESS Program Plans

- HEV LEESS cell development
  - Materials optimization and final cell design
  - Cell delivery to National Laboratories for testing
- Complete HEV LEESS module and pack development
  - Detailed hardware and software design for simplified assembly and low cost
  - Module delivery to National Laboratories for testing
- Cell testing
  - Performance and abuse tolerance
  - Cycle and calendar life start

Acknowledgements

- A123 Systems teams
  - Chemistry R&D
  - Engineering Services
  - Automotive Solutions Group
- USABC for program funding & technical support
- USABC program leadership from Ron Elder (Chrysler)
- ANL (Ira Bloom and Panos Prezas) and NREL (Matt Keyser) for technical & test support