A123Systems, Inc.
USABC HEV and PHEV Programs

Project: ES003

DOE Annual Merit Review

Dr. Steve Yoon

05-10-11

A123 Systems Global Locations

- 2,000+ employees in 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
- St. Louis, Missouri

Materials Research
- Ann Arbor, Michigan

European Sales and Engineering
- Stuttgart, Germany

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

Supplier Quality and Systems Design
- 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

Transportation

Delivering high power and energy density, long life, and excellent safety

Passenger Vehicles

Hybrid, Plug-in Hybrid and Electric Passenger Vehicles




- Fuel efficiency
- Reduced emissions
- Lighter-weight components

Commercial Vehicles

Hybrid, Plug-in Hybrid and Electric:

Trucks


- Reduced maintenance and lower life cycle costs
- Quieter operations and better acceleration

Buses


- Reduction in idle times
- Reduce emissions and fuel consumption

Off-Highway Vehicles


Drivers

PHEV Program

PHEV Program Overview

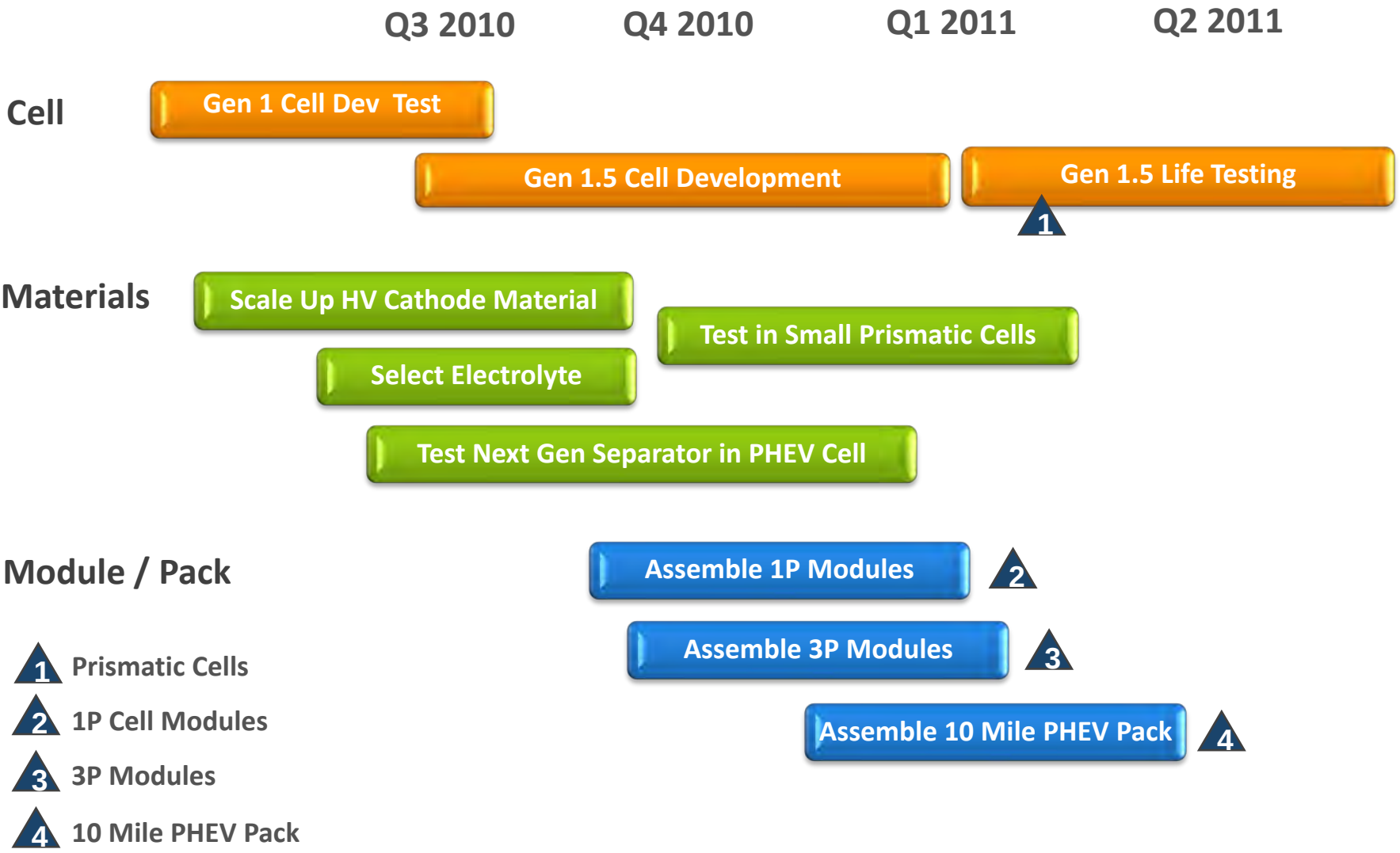
- Program Timeline
  - Original Plan: March 2008 – February 2011
  - No-cost extension: granted until June, 2011
- Program Budget
  - $12.5MM, 50:50 cost share program, between A123 Systems and USABC
- Technical Barriers
  - This original technical barriers for this program included:
    - Cycle Life
    - Calendar Life
    - System Weight and Volume
    - Cost Reduction
- Partners
  - This program did not include partners outside of A123 Systems and USABC

PHEV Program Relevance

- Program Objective
  - Develop prismatic pouch cell using A123 doped Nanophosphate chemistry in support of DOE objective to improve fuel economy and petroleum displacement
    - 10 mile PHEV
      40 mile PHEV
- Program Alignment with Technical Barriers
  - Cycle Life
    - Develop high energy materials , optimize electrode and pouch technology
  - Calendar Life

    Optimize thermal management through cell and module design
  - System Weight and Volume
    - Improve energy density to enable BSF reduction, efficient module / pack design
  - Cost Reduction
    - Materials development, energy density improvement, efficient module / pack design

PHEV Program Milestones



PHEV Cell & Module Deliverables

Delivery Tasks	2011			
	Jan	Feb	Mar	Apr
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				★

PHEV Program Key Accomplishments

- PHEV prismatic cell design
  - Production facility opened in Livonia, MI. in September, 2010
  - Gen 1.5 cell in production
  - Power and energy are improved vs Gen 1, enabling a 7% reduction in BSF for the 10 mile pack and an 8% reduction for the 40 mile pack
  - Life testing was conducted for the Gen 1 PHEV cell, through 3100 charge depleting cycles for the 10 mile pack and 425 days of calendar life testing at five temperatures and five states of charge
  - Cycle life and calendar life testing for Gen 1.5 cells are in progress
- 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
    - 32% reduction for the 10 mile PHEV pack
    - 20% reduction for the 40 mile PHEV pack

PHEV 10 Mile Gap Analysis

Characteristics	Unit	USABC Goal	Gen 1.5 Projected EOL
2s Discharge Pulse Power	kW	50	
10s Discharge Pulse Power	kW	45	
10s Regen Pulse Power	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-Cranking Power at -30 deg C	kW	7	
Charge Depleting Cycle-life	Cycles	5,000	
Charge Sustaining Cycle Life	Cycles	300k	
Calendar-life (At 35 deg C)	Years	15	
Maximum System Weight	kg	60	
Maximum System Volume	Liter	40	
Selling Price/System @ 100k/yr)	$	1700	
Maximum Operating Voltage	Vdc	≤ 400	
Minimum Operating Voltage	Vdc	≥ 0.55 V_{max}	
Self-discharge	Wh/day	50	
System Recharge Rate at 30 deg C	kW	1.4	
Operating Temperature Range	°C	-30 to 52	TBT
Survival Temperature Range	°C	-46 to 66	TBT

PHEV 40 Mile Gap Analysis

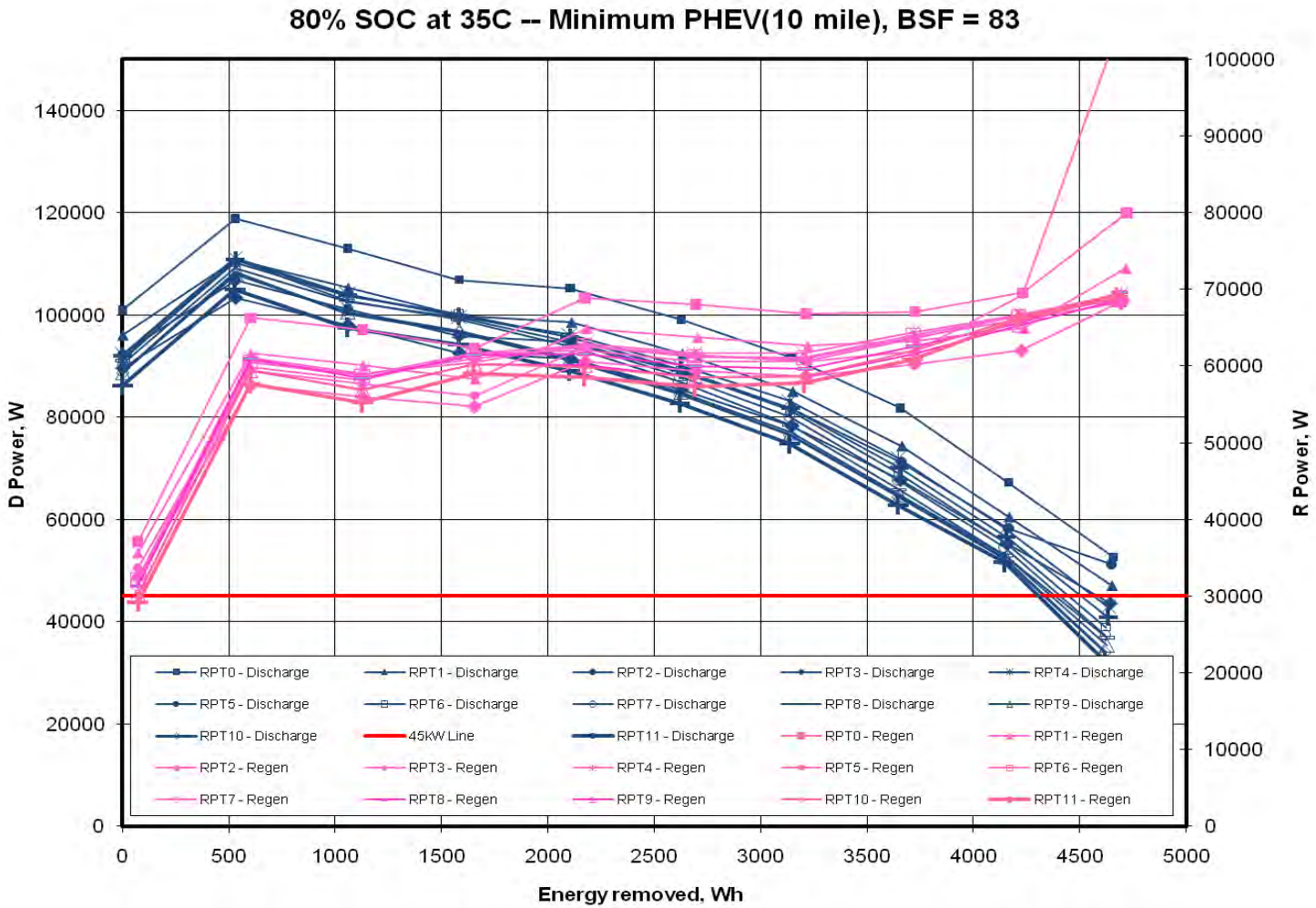
Characteristics	Unit	USABC Goal	Gen 1.5 Projected EOL
2s Discharge Pulse Power	kW	46	
10s Discharge Pulse Power	kW	38	
10s Regen Pulse Power	kW	25	
Available Energy for CD Mode	kWh	11.6	
Available Energy for CS Mode	kWh	0.3	
Min Round Trip Energy Efficiency	%	> 90	
Cold-Cranking Power at -30 deg C	kW	7	
Charge Depleting Cycle-life	Cycles	5,000	
Charge Sustaining Cycle Life	Cycles	300k	
Calendar-life (At 35 deg C)	Years	15	
Maximum System Weight	kg	120	
Maximum System Volume	Liter	80	
Selling Price/System @ 100k/yr)	$	3400	
Maximum Operating Voltage	Vdc	≤ 400	
Minimum Operating Voltage	Vdc	$\geq 0.55\ V_{max}$	
Self-discharge	Wh/day	50	
System Recharge Rate at 30 deg C	kW	1.4	
Operating Temperature Range	ºC	-30 to 52	TBT
Survival Temperature Range	ºC	-46 to 66	TBT

PHEV Gen 1 Calendar Life Testing

Number of Calendar Life Test Days Completed to Date

	Storage Temperatures					
SOC for storage (as defined by USABC)		15˚C	23˚C	35˚C	45˚C	55˚C
	20% SOC	208 days	277 days	154 days	226 days	92 days
	30% SOC	118 days	128 days	39 days	76 days	108 days
	40% SOC	82 days	189 days	172 days	31 days	112 days
	50% SOC	449 days	205 days	371 days	208 days	168 days
	80% SOC	259 days	416 days	202 days	113 days	382 days

PHEV Gen 1.0 Calendar Life, 80% SOC 35°C

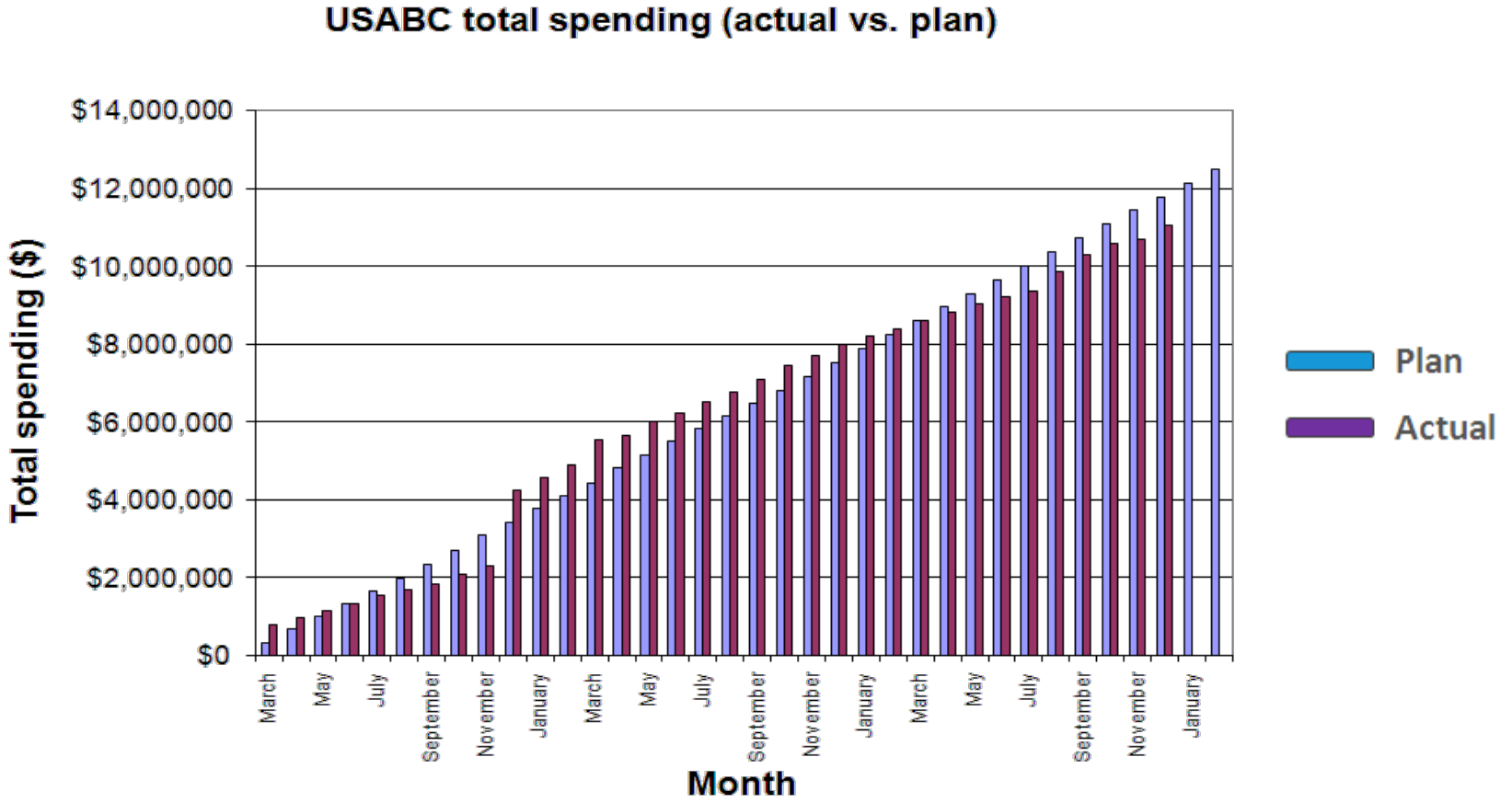


PHEV Gen 1.5 Abuse Test Result Summary

- Standard abuse test protocols were completed on Gen 1.5 PHEV prismatic cells, all cells passed with EUCAR 3 or 4
  - Nail penetration **Achieved Eucar 3**
  - External Shorting **Achieved Eucar 4**
  - Overcharge **Achieved Eucar 4**
  - Thermal Ramp **Achieved Eucar 4**
  - Crush **Achieved Eucar 3**
- UNDOT testing was completed at the module level, on three different cell configurations
  - **Modules achieved ≤ EUCAR 2**

PHEV Program Actual vs Planned Spending

- Spending was below plan through 2010 due to late delivery of Gen 1.5 cells for testing
- A no cost extension was granted to continue program testing through Q2, 2011



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 for Gen 1, update in process for Gen 1.5	✓

Cell Characterization

HPPC @ 30C	Gen 1.5 cell testing conducted for both 10 mile and 40 mile BSF	✓
Charge Depleting Cycle Life	Gen 1.5 cell testing in progress for 10 mile, 40 mile to in progress	⇨
USABC Calendar Life	Gen 1.5 cell testing in progress for 10 mile, 40 mile to in progress	⇨
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, two out of three cells with Eucar 4, 1 with Eucar 5, investigation of cause in progress	⇨

✓ Completed ⇨ In Process

PHEV SOW Checklist

Module / Pack Design

Electrical System	Completed design, need to apply to USABC prototypes	✓
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 downselected to critical formulations, testing in progress	✓
Next Gen, Multifunction Separator	Demonstrated in small and large format prismatic cells	✓

✓ Completed ⇨ In Process

PHEV Program Summary

- Power, energy, storage, abuse meet or exceed targets
- Cycle life of Gen 1 fell short of program goals, however Gen 1.5 cells show improvements in accelerated testing and are expected to meet target
- System cost expected to fall short of program goals
- A no cost extension was granted to support continued testing of the Gen 1.5 PHEV cells in both 10 mile and 40 mile applications

PHEV Program Plans Through Q2, 2011

- Testing and characterization of Gen 1.5 cells and pack vs USABC goals
  - Gen 1.5 Calendar Life Testing
  - Gen 1.5 Cycle Life Testing
  - Gen 1.5 EOL Cold Crank Testing
  - Pack testing for US06 and thermal characterization
- Gen 1.5 Cell based Pack Delivery

HEV Program

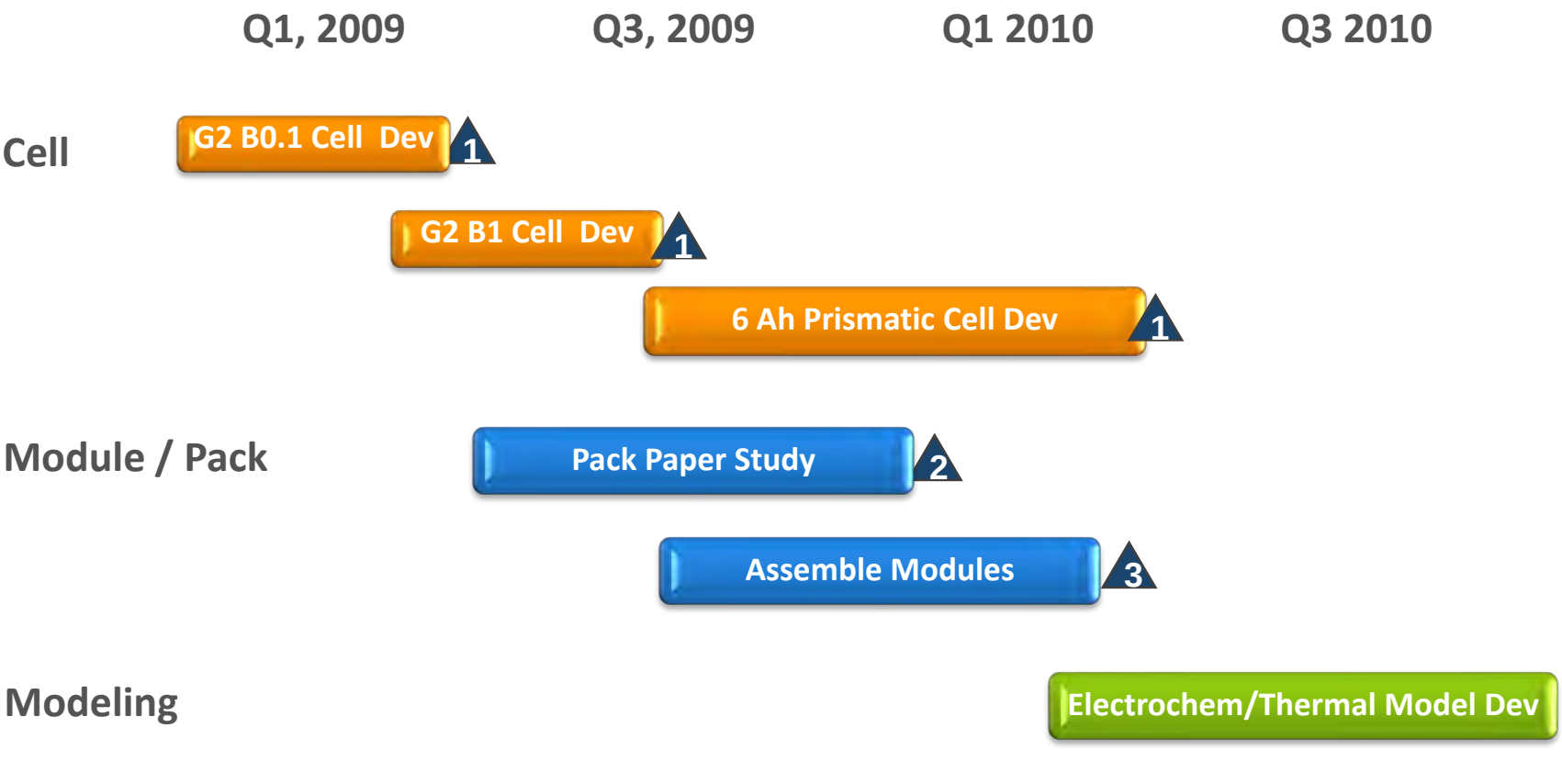
HEV Program Overview

- Program Timeline
  - Original Plan: December 2006 – December 2009
  - Two no-cost extensions: granted until December, 2010
- Program Budget
  - $15MM, 50:50 cost share program, between A123 Systems and USABC
- Technical Barriers
  - This original technical barriers for this program included:
    - Improved Calendar Life
    - Increased Cycle Life Capability
    - Increased Power
    - Improved Abuse Tolerance at Cell Level
- Partners
  - This program did not include partners outside of A123 Systems and USABC

HEV Program Relevance

- Program Objective
  - Design, build, and test cells and modules for HEV hybrid 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 Alignment with Technical Barriers
  - Calendar Life
    - Improve electrode and hardware design
  - Cycle Life
    - Improve electrode and hardware design
  - System Power
    - Increase cell energy density, through materials and design
  - Cell Level Abuse Tolerance
    - Improve cell hardware design

HEV Program Milestones



1 Cells Deliveries

2 Pack Paper Study Delivery

3 Module Delivery

HEV Cell & Module Deliverables

Delivery Tasks	March'09	August'09	January'10	April'10	April'11
Deliver (23) Gen 2, B0.1 Cells to National Labs	✓				
Deliver (23) Gen 2, B1 Cells to National Labs		✓			
Deliver (30) Prismatic Cells to National Labs				✓	
Deliver (10) 32113 Modules to National Labs				✓	
Pack Paper Study			✓		
Final Program Report					★

HEV Program Key Accomplishments

- Developed and produced a production-ready 32113 cell which can meet USABC HEV power and energy targets
  - All testing complete, with the exception of ongoing cycle life and storage testing
  - Over 2 years of cycle life data, which expected program goal of 300k cycles
  - Calendar life projection of ~10 years at 30˚C
- Developed a 10-cell 32113 HEV prototype module
  - All cell and module deliverables completed
  - Module volume, mass significantly under program goals
- Designed a built a 6Ah HEV Prismatic cell to greatly improve on cost, energy, and power targets, delivered as prototypes to USABC

HEV Program Gap Analysis - 32113 Gen 2

Characteristics	Unit	USABC Goals	Projected EOL
10 S Discharge Pulse Power	kW	25	
10S Regen Pulse Power	kW	20	
Total Available Energy	kWh	0.3	
Min Round Trip Energy Efficiency	%	>90	
Cold-Crank Power at -30˚C	kW	5	
25 Wh Cycle Life	Cycles	300k	
Calendar Life at 35˚C	Years	15	
Maximum System Weight	Kg	<40	
Maximum System Volume	Liter	<32	
Selling Price/System @ 100K/yr	$	500	
Maximum Operating Voltage	Vdc	≤400	
Minimum Operating Voltage	Vdc	≥0.55 Vmax	
Self-discharge	Wh/day	50	
Operating Temperature Range	˚C	-30 to 52˚C	
Survival Temperature Range	˚C	-46 to 66˚C	

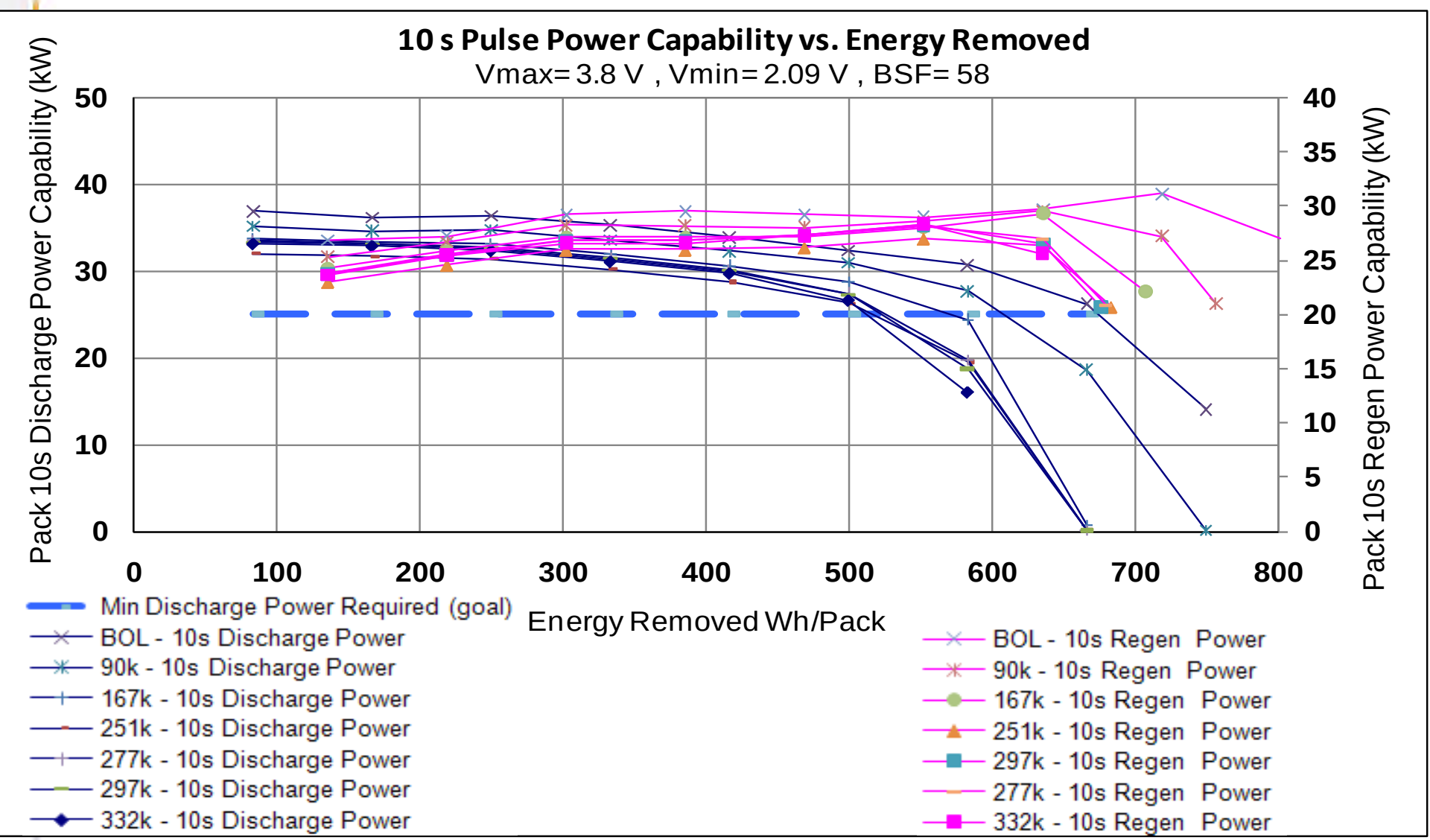
*Test results are based on Gen 2 Design. Price is based on a lower cost Gen 2.5, available in Q2 '10.

PHEV Gen 1 Calendar Life Testing

Number of Calendar Life Test Days Completed to Date

	Storage Temperatures			
SOC for storage (as defined by USABC)		23˚C	45˚C	65˚C
	20% SOC	**325 days**	**225 days**	**225 days**
	50% SOC	**325 days**	**225 days**	**225 days**
	80% SOC	**325 days**	**225 days**	**225 days**

HEV Cycle Life Testing on 32113 Gen2
(BOL,90k,167k,251k,277k,297k,332k cycles)



HEV Abuse Tolerance Testing, Gen 1 & 2 32113

- No issues in abuse tolerance testing were observed:

Abuse testing	Spec / Procedures / Notes	Gen 1 Status	Gen 2 Status
Short Circuit Tet	USABC	4 EUCAR 2, 1 EUCAR 4	EUCAR 2
Overcharge Test	USABC (4.7V, 32A, 200%)	EUCAR 2	EUCAR 2
Overdischarge Test	USABC	EUCAR 2	EUCAR 2
Thermal Stability Test	USABC (modified temp to 150˚C)	EUCAR 2	EUCAR 2
Nail penetration Test @ RT	USABC (w/ blunt steel nail 8mm dias. @ 8 cm)	EUCAR 3	2 EUCAR 3, 3 EUCAR 4
Nail Penetration Test @ 55˚C	USABC (w/ blunt steel nail 8mm dias. @ 8 cm)	Not conducted, due to Gen 2	EUCAR 3
Crush Test (in X & Y axis)	USABC	EUCAR 2	EUCAR 2
Mechanical Shock Test	USABC	EUCAR 2	EUCAR 0

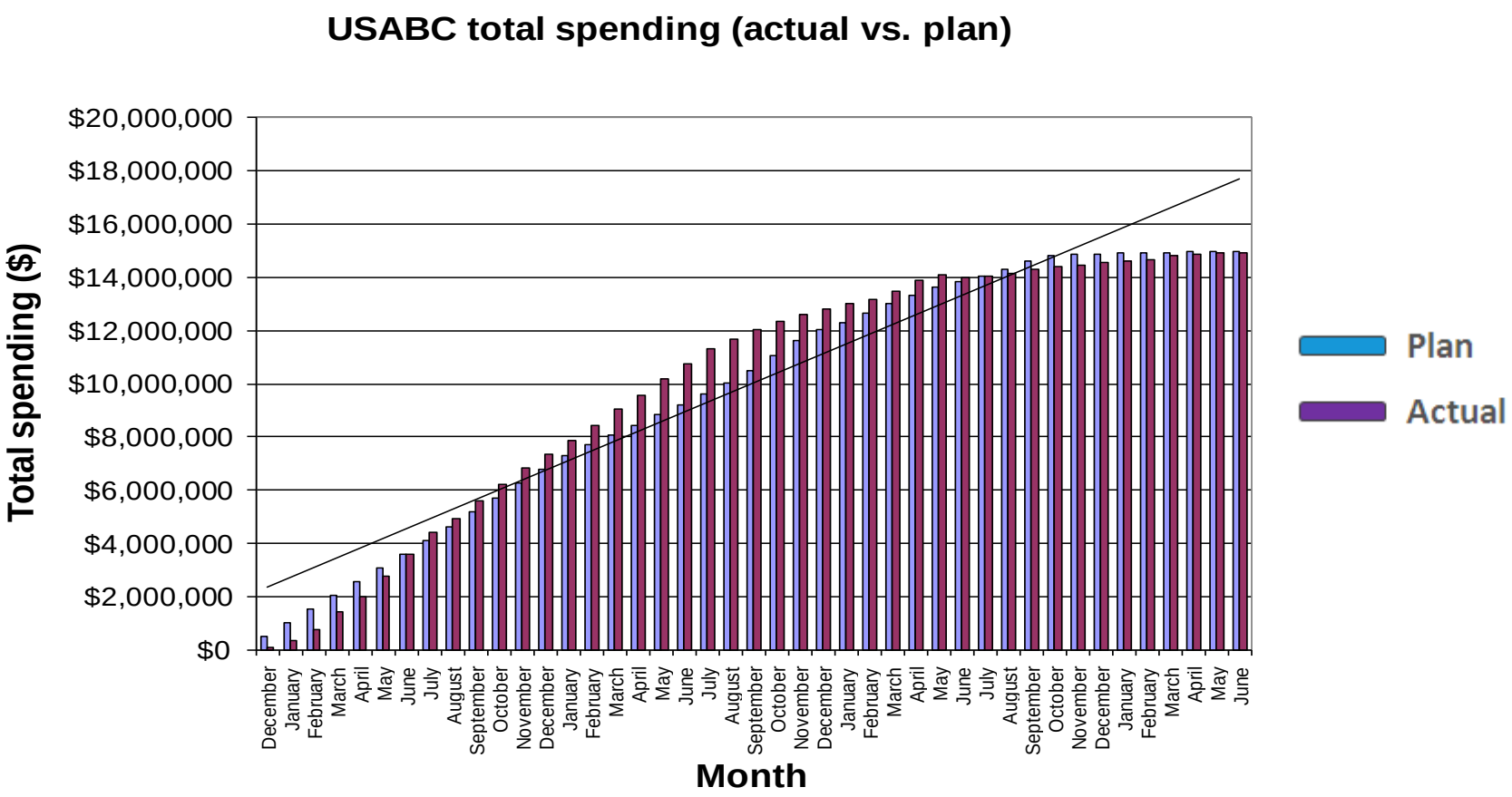
3D Electrochemical / Thermal Model

- A 3-D electrochemical-thermal model , based on Newman's porous electrode theory, was developed in collaboration with Prof. Meyers at U. Texas, Austin
  - The model calculates 3-D transient current, potential, temperature distributions and pseudo-3-D concentration profiles in a prismatic battery
- The 3D Electrochem Model is used to understand the effect of tab placement, current collector thickness, and electrode design on temperature distribution, cell impedance, and rate capability.
- This program has supported extension to cylindrical geometry
  - Meshing algorithm developed
  - Debugging is still in progress

SEI resistance(T)	Separator	Cell geometry
Coating Thickness	Thickness	Height, width
Porosity	Porosity	Tab positions
Vol. frac. active	Heat capacity(T)	Heat-transfer coef's at boundaries
OCV(cs,T)	Thermal conductivity(T)	
Diffusivity(cs,T)	Tortuosity	Foils
Tortuosity		Foil thickness
Charge-transfer resistance(cs,T)	Electrolyte	Electrical conductivity(T)
SEI resistance(T)	Salt concentration	Thermal conductivity(T)
Electrical conductivity (T)	Conductivity(c,T)	Heat capacity(T)
Thermal conductivity(T)	Diffusivity(c,T)	
Heat capacity(T)	Activity coefficient(c,T)	
	Transference number(c,T)	
green: accurately measured		
orange: measurement error > 5%		

HEV Total Spending, Actual vs. Plan

- Program spending was met, with two no-cost extensions



HEV SOW Checklist

Cell Deliverables	Develop and test Gen 1 and Gen 2 32113 vs USABC Targets	✓
23 32113 Gen 2, B0.1 cells	Cells delivered to the National Labs in March, 2009	✓
23 32113 Gen 2, B1 cells	Cells delivered to the National Labs in August, 2009	✓
10 32113 Cell Modules	Modules delivered to the National Labs in April, 2010	✓
Paper Pack Study	Study delivered to USABC in January, 2010, and included thermal management system, electronics and controls, and estimated Cost	✓
30 A Sample Prismatic Cells	Cells delivered to the National Labs in April, 2010	✓
HEV Program Final Report	Final report to be delivered by April, 2011	⇨

✓ Completed ⇨ In Process

HEV Program Summary

- Gen 1 and Gen 2 32113 cells met requirements for the 25 Wh Cycle Life test
  - Gen 1 has completed 400k cycles to date, with a projection of 450 while maintaining required energy and power
  - Gen 2 has completed 332k cycles to date while maintaining required energy and power
- Abuse tolerance test results on Gen 1 and Gen 2 cell designs resulted in EUCAR 4 results or less
- Over 300 days of calendar life testing have been completed to date, with a projected calendar life of ~10 years at 30˚C, based on anANL projection using A123 data

HEV Program Plans

- Submit final report to USABC in April, 2011