Overview and Progress of United States Advanced Battery Consortium (USABC) Activity

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ES097

Overview

Timeline

- Start – Jan 1991
- Ongoing

Budget

- Total project funding (FY2011)
  - DOE share - $13.45M
  - Contractor share - $13.45M
- Funding received in FY10
  - $12.0M
- Funding for FY11
  - $26.9M

Barriers

- Barriers
  - Battery Cost
  - Battery Performance
  - Battery Life
- Targets

DOE Goals	HEV 2010	PHEV 2015	EV 2020
Cost $ / System	500-800	1700-3400	4000
Performance Discharge Power (kW) Available Energy (kWh)	25-40 0.3-0.5	38-50 3.5-11.6	80 30-40
Life Cycles	300k *(shallow)*	3000-5000 *(deep discharge)*	750 *(deep discharge)*

Partners

- Chrysler, Ford, GM, DOE
- INL, ANL, SNL, NREL, LBNL, ORNL

Overview
(Mission)

- The United States Advanced Battery Consortium (USABC), comprised of Chrysler, Ford, and General Motors, funds pre-competitive electrochemical energy storage R&D

- Funding for development activity occurs through a cooperative agreement between USABC and DOE.

- This cooperation allows for the combined technical and financial resources of the DOE, OEM automakers, development partners, and U.S. National laboratories in jointly conducting advanced battery research and development.

Overview

(organization)

USABC — UNITED STATES ADVANCED BATTERY CONSORTIUM LLC

FreedomCAR & Fuel Partnership

*USCAR = United States Council of Automotive Research

- **USCAR* Operating Council**
  - **Chrysler** Vice President
  - **Ford** Vice President
  - **General Motors** Vice President
- **USABC Management Committee (MC)**
  - **Steve Clark** Chrysler
  - **Ted Miller** Ford
  - **Mark Verbrugge** General Motors
  - **Dave Howell** U.S.D.O.E.
  - **Eric Heim** USABC Business Manager
- **USABC Technical Advisory Committee (TAC)**
  FreedomCAR Energy Storage Tech Team (ESTT)
  - **Kent Snyder** USABC TAC Chair, USABC TT Co-Chair, Ford
  - **David Howell** USABC TT Co-Chair, DOE
  - **Ion Halalay** USABC TAC Vice Chair, General Motors
    - **Chrysler** ~ 4 Members
    - **Ford** ~ 7 Members
    - **General Motors** ~ 7 Members
    - **U.S. D.O.E** ~ 8 Members

USABC
UNITED STATES ADVANCED BATTERY CONSORTIUM LLC

Collaborations

FreedomCAR & Fuel Partnership

Development Partners

Technical Expertise
Tangible Cost Data
Applied Research Capability
Manufacturing Capability
Hardware Deliverables
Cost-Shared Funding

Automotive OEM's

Technical Expertise
Program Management
Test Method Development
Industry Experience & Input
Development Partner Assistance
Real World Requirement Perspective

COOPERATIVE GROUP EFFORT

National Labs

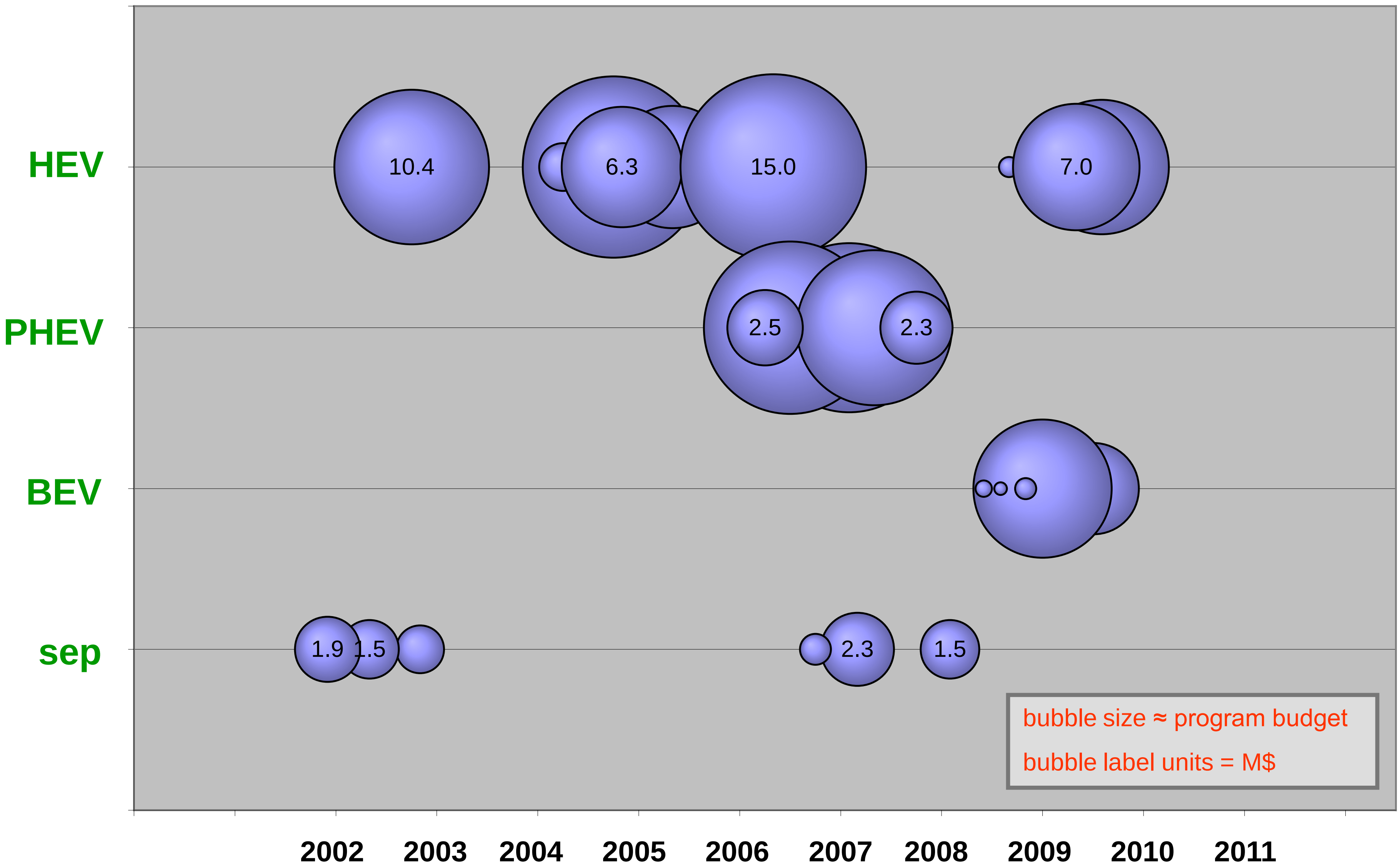
Life Prediction
Abuse Testing
Development Partner Assistance
Long Term Fundamental Research
Performance & Benchmark Testing
Thermal Analysis & Design Support
Battery Simulation and Model Development

DOE

Funding Coordination
National Lab Management
Governmental Perspective

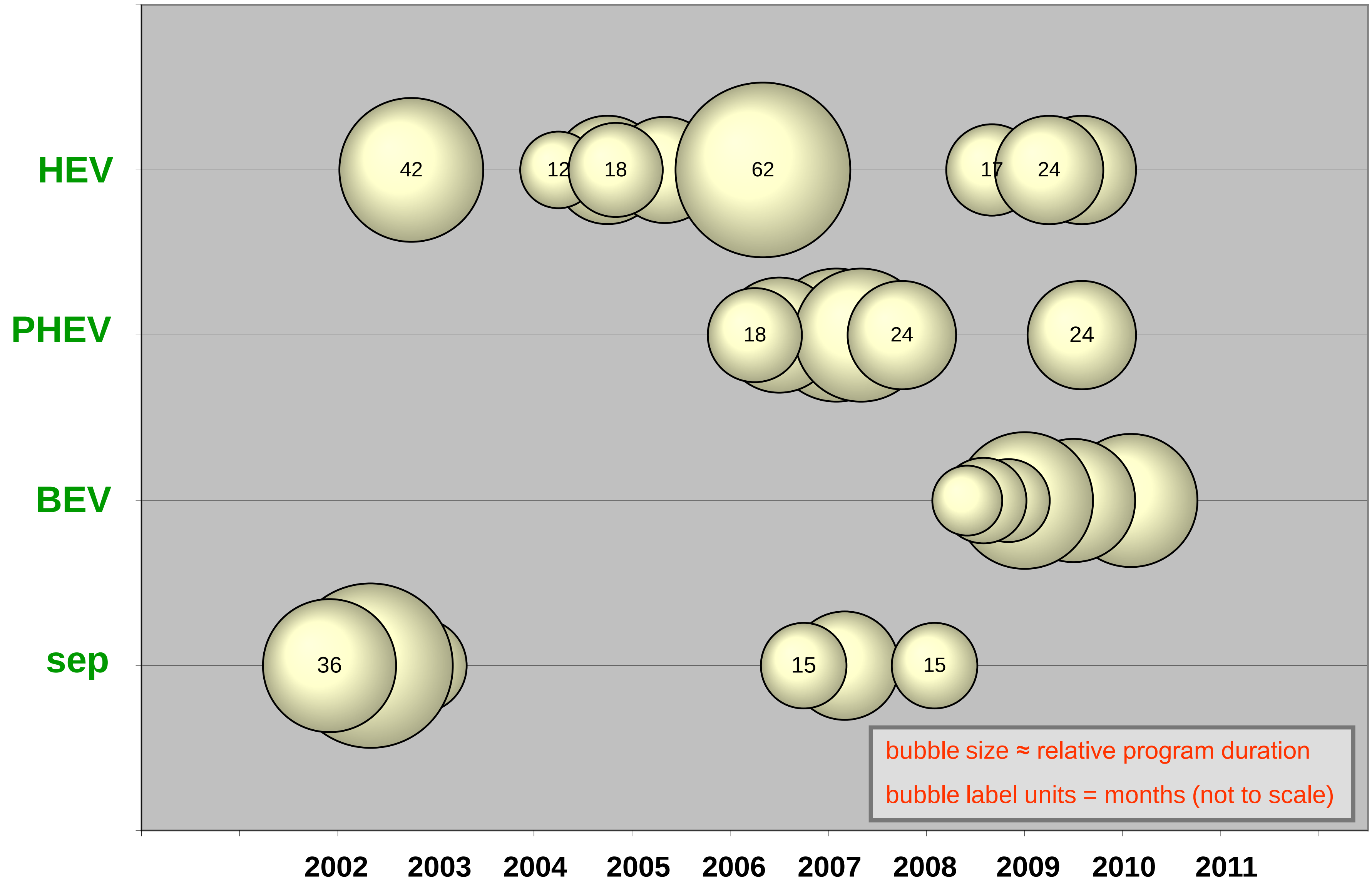
Overview

(Program Types & Budget HIstory)



Overview

(Program Relative Duration History)



FY2010 Project

Negotiate & Initiate USABC Programs
Towards New Focus Areas

Objectives:

- Receive & evaluate new proposals in open RFP process
- Down-select and negotiate new program SOW's
- Initiate and manage new programs targeting reduced cost via increased energy density in high-energy (PHEV & EV) systems, and reduced cost via lower total energy content in HEV systems

Approach *(HEV)*

For further HEV battery system cost reduction, projects initiated towards newly developed alternate HEV goals

- Reduce cost via total energy content reduction
- Maintain significant HEV power capability

Low Energy - Energy Storage System (LEESS) Power Assist HEV Goals

End of Life Characteristics	Unit	PA (Lower Energy)	
2s / 10s Discharge Pulse Power	kW	55	20
2s / 10s Regen Pulse Power	kW	40	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	
Cycle-life	Cycles	300,000 (HEV)	
Cold-Cranking Power at -30ºC *(after 30 day stand @ 30 ºC)*	kW	5	
Calendar Life	Years	15	
Maximum System Weight	kg	20	
Maximum System Volume	Liter	16	
Maximum Operating Voltage	Vdc	≤□□	
Minimum Operating Voltage	Vdc	$^{3}0.55\ V_{max}$	
Unassisted Operating Temperature Range	ºC	-30 to +52	
30 º -52º	%	100	
0º	%	50	
-10º	%	30	
-20º	%	15	
-30º	%	10	
Survival Temperature Range	ºC	-46 to +66	
Selling Price/System @ 100k/yr)	$	400	

UNITED STATES ADVANCED BATTERY CONSORTIUM LLC

Approach *(PHEV & EV)*

FreedomCAR & Fuel Partnership

For further higher-energy battery system cost reduction on a $/kWh basis :

- projects initiated towards higher-mile-range PHEV goals and historical EV goals
- $ benefit of energy density increase maximized with higher energy content systems

	10-mile PHEV	20-mile PHEV	40-mile PHEV	EV
Energy (kWh)	3.4 avail	5.8 avail	11.3 avail	40

USABC Requirements of End of Life Energy Storage Systems for PHEVs

Characteristics at EOL (End of Life)	units	High Power/Energy Ratio Battery	Moderate Energy/Power Ratio Battery	High Energy/Power Ratio Battery
Reference Equivalent Electric Range	miles	10	20	40
Peak Pulse Discharge Power - 2 Sec / 10 Sec	kW	50 / 45	45 / 37	46 / 38
Peak Regen Pulse Power (10 sec)	kW	30	25	25
Max. Current (10 sec pulse)	A	300	300	300
Available Energy for CD (Charge Depleting) Mode, 10 kW Rate	kWh	3.4	5.8	11.6
Available Energy for CS (Charge Sustaining) Mode	kWh	0.5	0.3	0.3
Minimum Round-trip Energy Efficiency (USABC HEV Cycle)	%	90	90	90
Cold cranking power at -30°C, 2 sec - 3 Pulses	kW	7	7	7
CD Life / Discharge Throughput	Cycles/MWh	5,000 / 17	5000 / 29	5,000 / 58
CS HEV Cycle Life, 50 Wh Profile	Cycles	300000	300000	300000
Calendar Life, 35°C	year	15	15	15
Maximum System Weight	kg	60	70	120
Maximum System Volume	Liter	40	46	80
Maximum Operating Voltage	Vdc	400	400	400
Minimum Operating Voltage	Vdc	>0.55 x Vmax	>0.55 x Vmax	>0.55 x Vmax
Maximum Self-discharge	Wh/day	50	50	50
System Recharge Rate at 30°C	kW	1.4 (120V/15A)	1.4 (120V/15A)	1.4 (120V/15A)
Unassisted Operating & Charging Temperature Range	°C	-30 to +52	-30 to +52	-30 to +52
30°-52°	%	100	100	100
0°	%	50	50	50
-10°	%	30	30	30
-20°	%	15	15	15
-30°	%	10	10	10
Survival Temperature Range	°C	-46 to +66	-46 to +66	-46 to +66
Maximum System Production Price @ 100k units/yr	$	$1,700	$2,200	$3,400

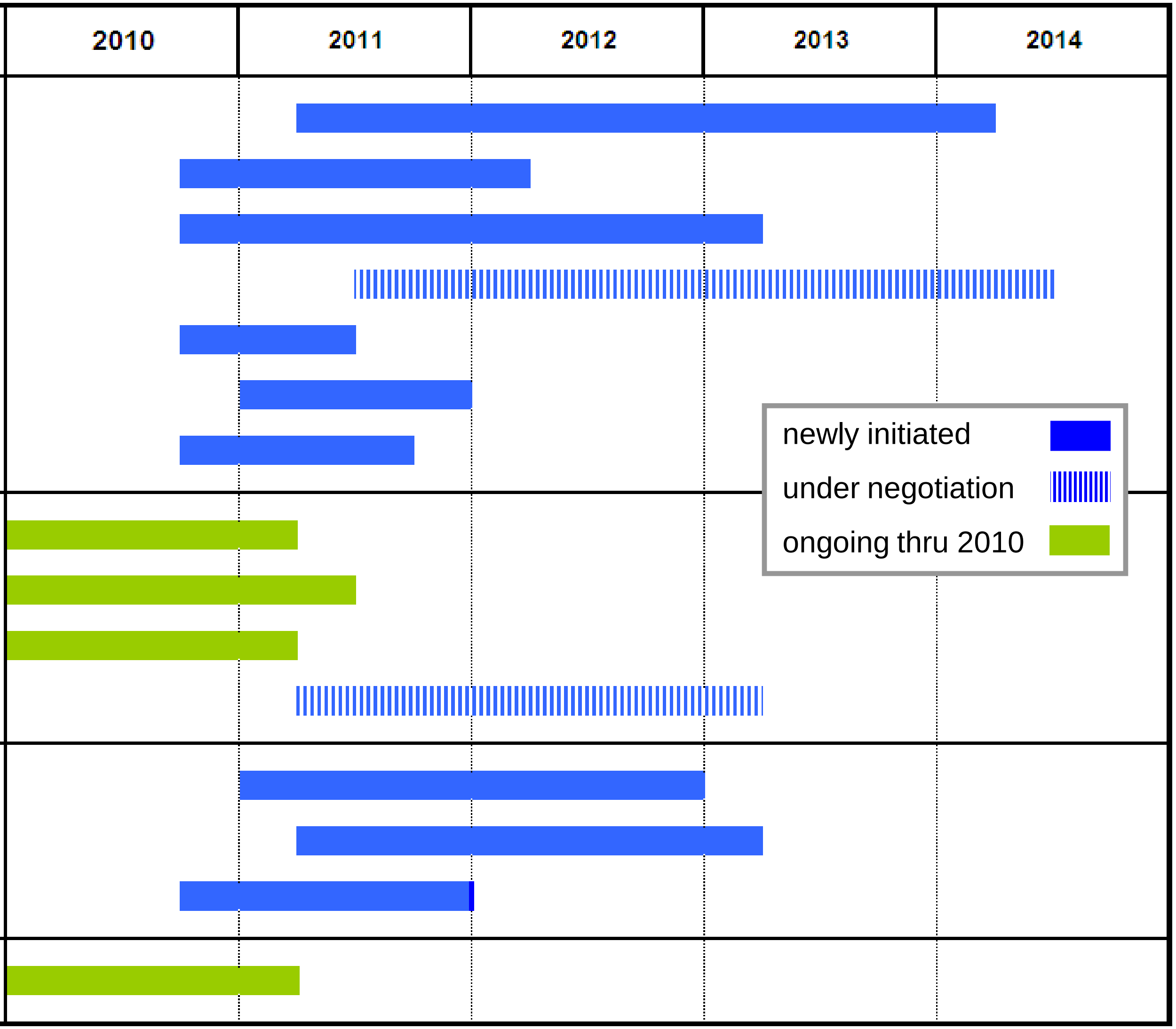
USABC Goals for Advanced Batteries for EVs

Parameter(Units) of fully burdened system	Minimum Goals for Long Term Commercialization	Long Term Goal
Power Density(W/L)	460	600
Specific Power – Discharge, 80% DOD/30 sec(W/kg)	300	400
Specific Power - Regen, 20% DOD/10 secW/kg	150	200
Energy Density - C/3 Discharge Rate(Wh/L)	230	300
Specific Energy - C/3 Discharge Rate(Wh/kg)	150	200
Specific Power/Specific Energy Ratio	2:1	2:1
Total Pack Size(kWh)	40	40
Life(Years)	10	10
Cycle Life - 80% DOD (Cycles)	1,000	1,000
Power & Capacity Degradation(% of rated spec)	20	20
Selling Price - 25,000 units @ 40 kWh($/kWh)	<150	100
Operating Environment(°C)	-40 to +50 20% Performance Loss (10% Desired)	-40 to +85
Normal Recharge Time	6 hours (4 hours Desired)	3 to 6 hours
High Rate Charge	20-70% SOC in <30 minutes @ 150W/kg (<20min @ 270W/kg Desired)	40-80% SOC in15 minutes
Continuous discharge in 1 hour - No Failure(% of rated energy capacity)	75	75

FY2010 Accomplishments

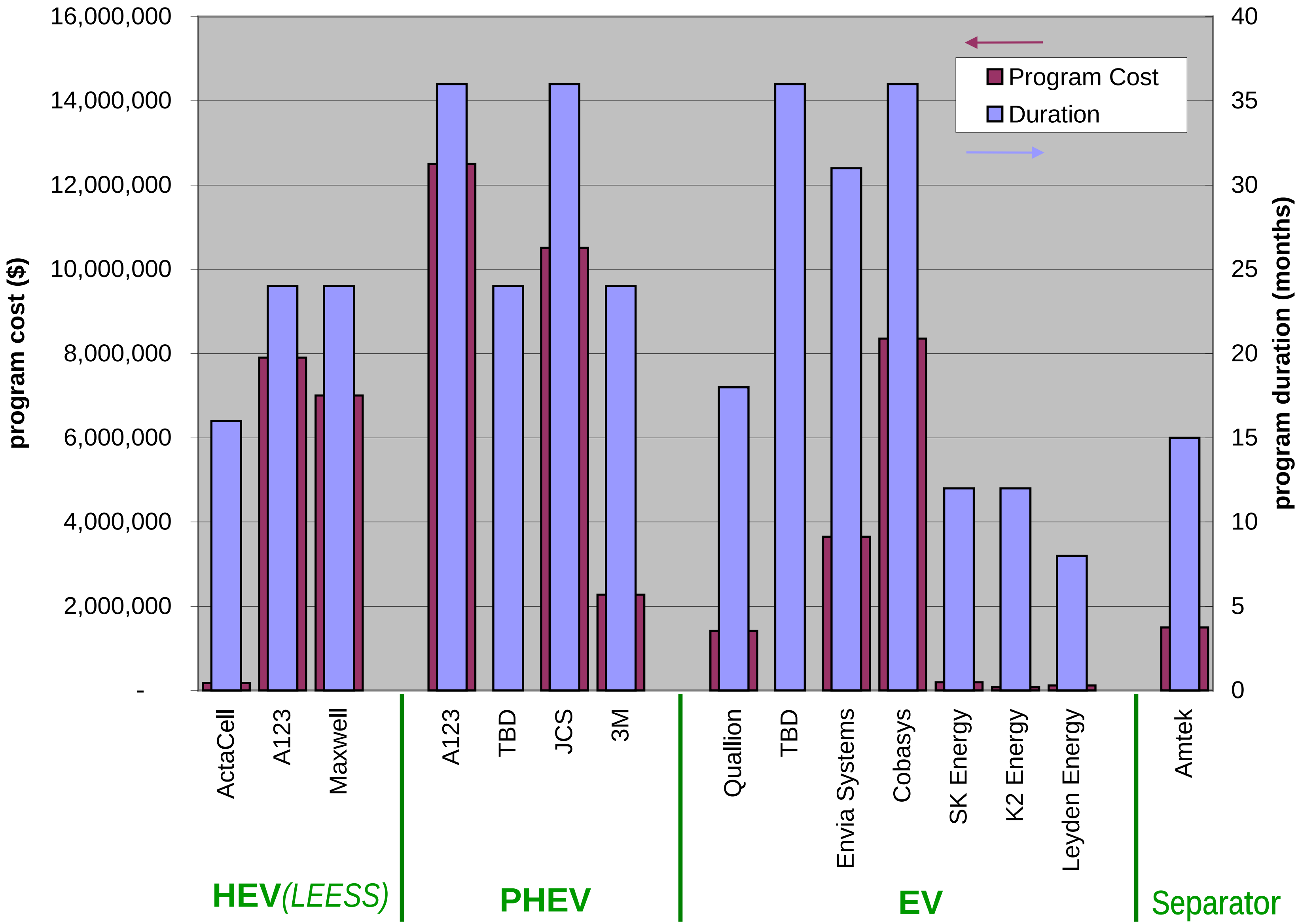
(Program Negotiations & Initiations)

		Years	$
EV	Cobasys/SBL	3	8.4M
	Quallion	1.5	1.4M
	Envia	2.5	3.6M
	TBD	3	TBD
	Leyden (TAP)	0.7	120K
	SK (TAP)	1	200K
	K2 (TAP)	1	75K
PHEV	JCS	3	10.5M
	A123	3	12.5M
	3M	2	2.3M
	TBD	2	9.6M
HEV (LEESS)	Maxwell	2	7.0M
	A123	2	8.0M
	Actacell (TAP)	1.3	180K
Separator	Entek	1.2	1.5M



Accomplishments

(Ongoing Programs in 2011 & Going Forward)



Accomplishments
(Examples From 2010)

Novel Battery Thermal Management System Developed
CPI/LG Chem PHEV Program

Management of the battery temperature is critical to electrified vehicle performance and battery life. As a key element of CPI/LG Chem's multi-year PHEV battery pack system development program, CPI/LG Chem has developed a unique thermal management system, which was included as a key element of battery pack system deliverables to USABC. Figure 1 below illustrates the pack system in its as-delivered-to-USABC state.

This advanced thermal management system incorporates a pack-internal refrigerant loop, which is used to cool the air within the battery pack, while that same defined pack-internal air volume is slowly circulated around the cells. The large temperature gradient between the air and the cells facilitates efficient heat transfer without the need for high velocity air circulation.

Addressed with this design approach are vehicle usage situations where high environmental heat loads are present and conditioned cabin air is not readily available. Further, the need for complex coolant manifolds within the pack as well as the need for coolant maintenance and periodic filling operations is mitigated as well.

Over the course of this program a number of deliverables were provided to USABC as noted in Figure 2 below, ranging from cell-level deliverables in the earlier portion of the program to the full pack systems provided near the end of the program, which concluded in 2010.

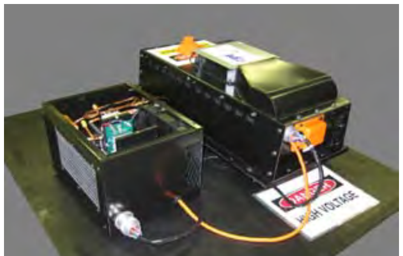


Figure 1: Developed CPI/LG Chem PHEV Lithium-ion battery pack system as delivered to USABC

	Month 9 (Sep, 08)	Month 22 (October, 09)	Month 27 (March, '10)
INL	20 Cells	40 Cells	3 Packs
SNL	12 Cells (Safety tests)	16 Cells	3 packs (+ 8 modules)
NREL	4 Cells (Thermal)	3 Cells (Thermal)	One of SNL packs makes a detour to NREL prior to SNL

Figure 2: Program deliverables leading from early cell samples through to 2010 pack system samples

Advanced PHEV Cathode Material Developed
3M Electronics Markets Materials Division

3M has developed advanced cathode materials made from $Li[Ni_xMn_yCo_{1-x-y}]O_2$ with $x \neq 1/3$ (advanced Nickel Manganese Cobalt or NMC), to provide 5 ~ 10% higher capacity (mAh/g) and ~ 15% lower raw material cost compared to the baseline NMC x=y=1/3 for PHEV applications, while maintaining comparable or higher thermal stability and cycle life performance

The raw materials costs associated with a kilogram of various cathode active materials based on high volume metals costs from 2009 are shown below in Figure 1. The baseline NMC has become a popular material in both electronics and larger format applications like automotive batteries because of its beneficial abuse tolerance and energy density as compared to LCO(Lithium Cobalt Oxide) and NCA(Nickel Cobalt Aluminum). The Gen 2 material is intended to reduce cost per kWh whilst maintaining or improving upon all of the benefits associated with the baseline NMC material, which was accomplished by a reduction in raw materials costs per kg and an increase in Ah capacity per kg.

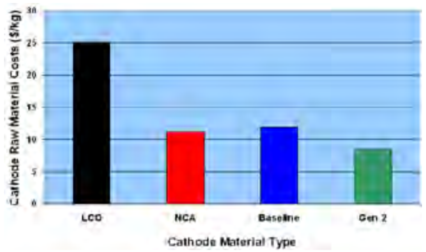


Figure 1: Raw materials costs for cathode materials based on 2009 high volume metals costs

Figure 2 below depicts specific capacity in mAh/g vs. specific current in C-rate, with data collected at both 30 °C and -30 °C. The graphs show that the rate capability of both materials are similar but the Gen 2 material offers increased capacity as compared to the Baseline material, which further increases the advantage of the Gen 2 material in terms of decreased $/kWh.

Figure 3 shows that both cells containing NMC, either baseline or Gen 2, performed almost identically in terms of hot block and thermal ramp abuse response, indicating that the Gen 2 material can offer similar abuse tolerance with decreased cost per kWh.

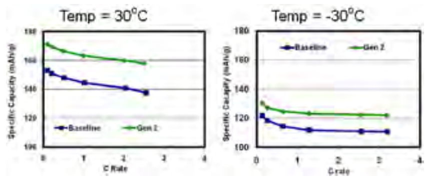


Figure 2: Specific capacity vs. specific current (as C-rate) for the Gen 2 material vs. the Baseline material for both 30 °C and -30 °C.

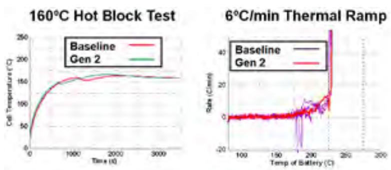


Figure 3: Results of the Hot Block and Thermal Ramp tests comparing abuse response of cells using Baseline and Gen 2 materials.

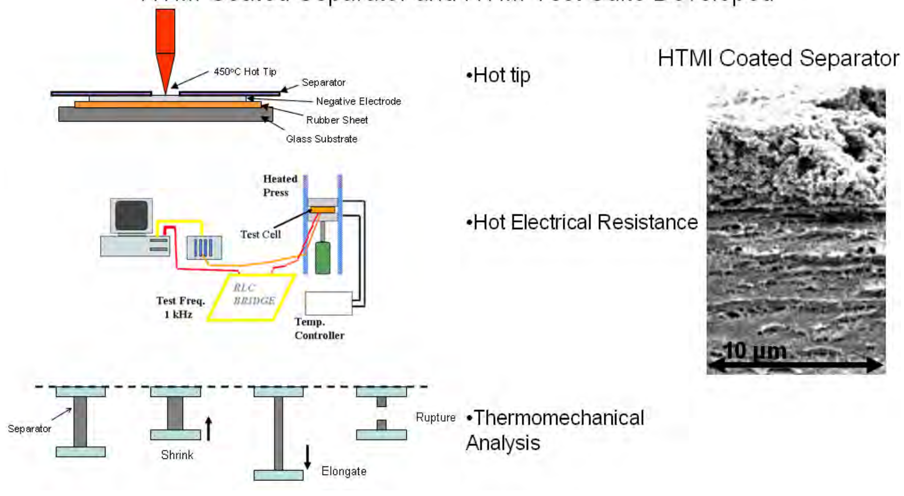
Accomplishments
(Examples From 2010)

High Temperature Melt Integrity Separator and Test Suite Developed

Celgard, LLC

One of the two major tasks that Celgard identified in the creation of a High Temperature Melt Integrity (HTMI) separator was the need for a standard methodology to rapidly screen materials for their potential HTMI behavior without building a complete battery. This tactic allows for the quick production of prospective materials on a small scale. Then, with little extra time, the samples can be validated against these standard tests outside of the battery system. Celgard has determined that there are three tests which simulate conditions within a hot battery that can focus efforts on important thermal failure modes: hot tip, hot electrical resistance, and thermomechanical analysis. With support from USABC, Celgard has been able to successfully develop and test an HTMI lithium-ion battery separator that can maintain structural integrity at temperatures where typical shutdown mechanisms can fail.

HTMI Coated Separator and HTMI Test Suite Developed

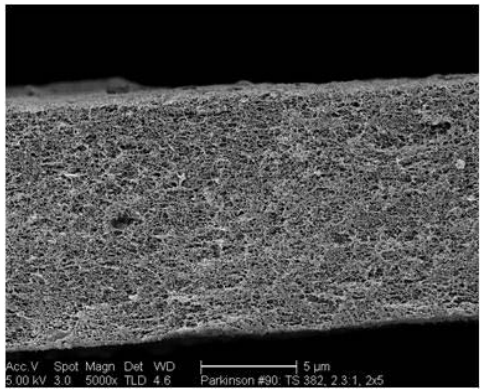


Advanced Separators for HEV/PHEV Applications

ENTEK Membranes LLC

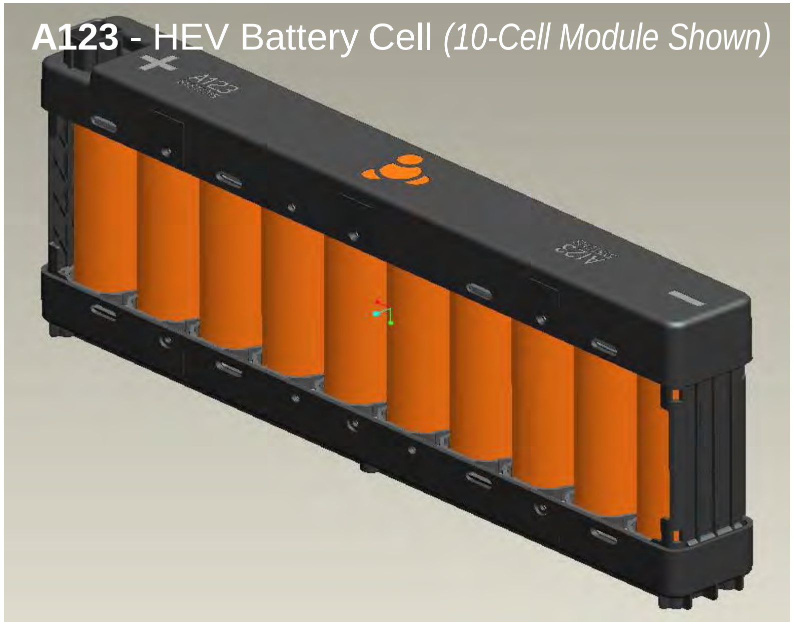
Separators are an integral part of the performance, safety and cost of Li-ion batteries. ENTEK is focused on manufacturing separators with an interconnected three dimensional inorganic network that prevents high temperature shrinkage and internal shorts. ENTEK has produced a 20-30 microns thick, inorganic-filled separator that shrank less than 3.3% after heating the separator in an inert atmosphere for one hour at 200°C, compared with a shrinkage of nearly 100% for traditional Li-ion battery separators under the same conditions.

These separators have been produced without compromising other desirable properties such as high porosity (> 65%), excellent wettability and very low resistance derating factor (MacMullin Number < 3). The excellent stability of the separator at high temperature is expected to improve abuse tolerance of Li-ion cells (e.g. internal short circuit). Electrochemical testing in standard battery(18650 format) cells indicated improved performance with ceramic-filled separators compared to unfilled separators: better capacity retention on both cycling (>1000 full depth cycles) and long-term stand at high temperature (60°C). Future work is focused on evaluating the abuse tolerance of Lithium-ion cells built with such separators.

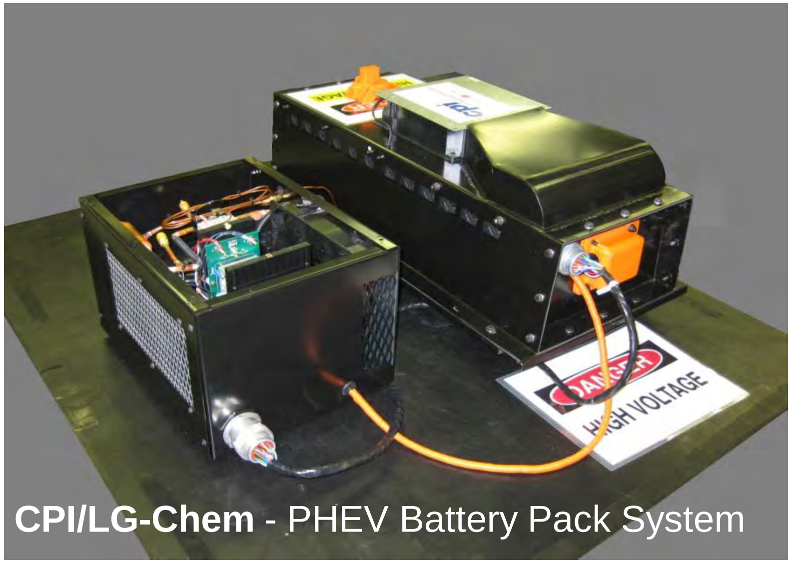


Accomplishments

(Developed Hardware Examples)



A123 - HEV Battery Cell *(10-Cell Module Shown)*



CPI/LG-Chem - PHEV Battery Pack System

JCS - PHEV Battery Cell

Collaborations

- Battery & Battery Material Development Partners !!!
- Chrysler, Ford, GM
- DOE
- Idaho National Labs, Argonne National Labs, Sandia National Labs, National Renewable Energy Labs, Lawrence Berkely National Labs, Oak Ridge National Labs

Future Work

- Manage newly initiated development and technology assessment programs towards tangible technical progress and hardware deliverables
- Progress remaining open program initialization negotiations to finalization
- Prioritize focus of potential new program opportunities and activity in battery materials areas (separator, electrolyte, electrode active materials, etc)
- Demonstrate advancements in deliverable hardware energy density increase for higher-energy applications and in reduced projected cost for high-power systems

Summary

- Open RFP process conducted and ~20 proposals received targeting both higher energy PHEV & EV applications as well as reduced energy / high power HEV applications
- Independent review teams established to consider and rate proposals leading to down-selection of 11 proposals for further consideration and negotiation
- 9 of 11 program SOW's negotiated and programs initiated
- Remaining 2 of 11 program negotiations nearing finalization
- Tangible hardware deliverables and results expected in 2011 and beyond