DEVELOPMENT OF ADVANCED HIGH-PERFORMANCE BATTERIES FOR 12V START STOP VEHICLE APPLICATIONS

Maxwell Technologies, Inc.

June 10, 2015

Project ID #
ES251

Overview

Timeline

- Start: October 2014
- Finish: April 2016
- On schedule, 25% complete*

Budget

- Project Funding
  - USABC: $1.31M
  - Maxwell: $1.37M
  - **Total: $2.68M**

Barriers Addressed†

- The enablement of a low cost prismatic ultracapacitor cell configuration
  - Gas management
  - Packaging development
- Development of an advanced energy management system
  - Efficient distribution of power and energy within the module

Maxwell System Targets

- System Weight = 10 kg
- System Volume= 7 L
- System Selling Price= $180 (@250K units/year)

*as of March 2015 † towards *DOE VT Program Multi-Year Program Plan*

Definitions

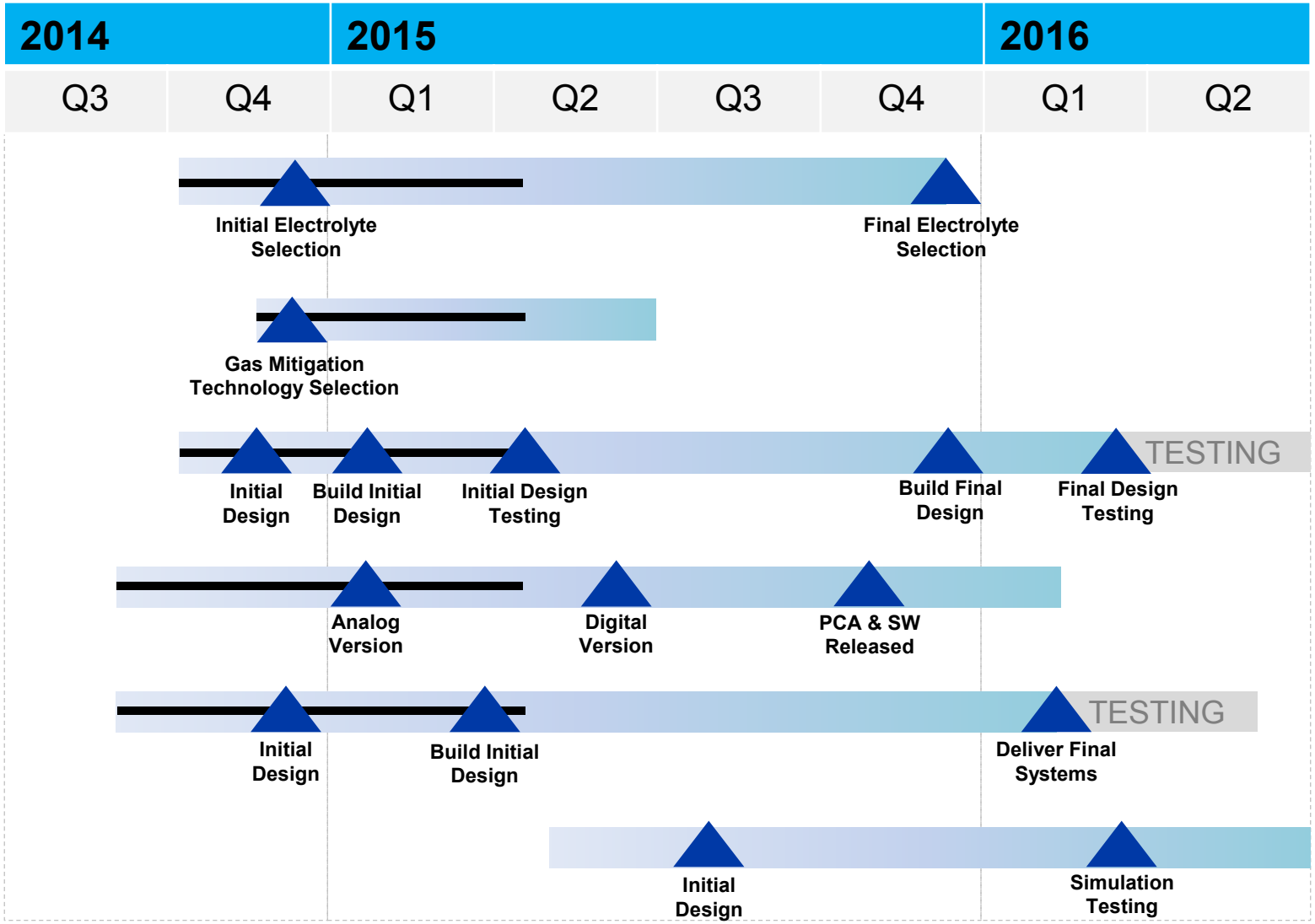
Proof-of-Concept System	• Testable module used for in-house feasibility study and for delivery to the national labs for performance evaluation. • OTS $LiFePO_4$ battery cells • Maxwell UCAP Cylindrical Cells
Prototype System	• CAD model only • Off-the-shelf LiFePO4 Pouch Cells • Maxwell UCAP Prismatic Cells

Objectives and Relevance

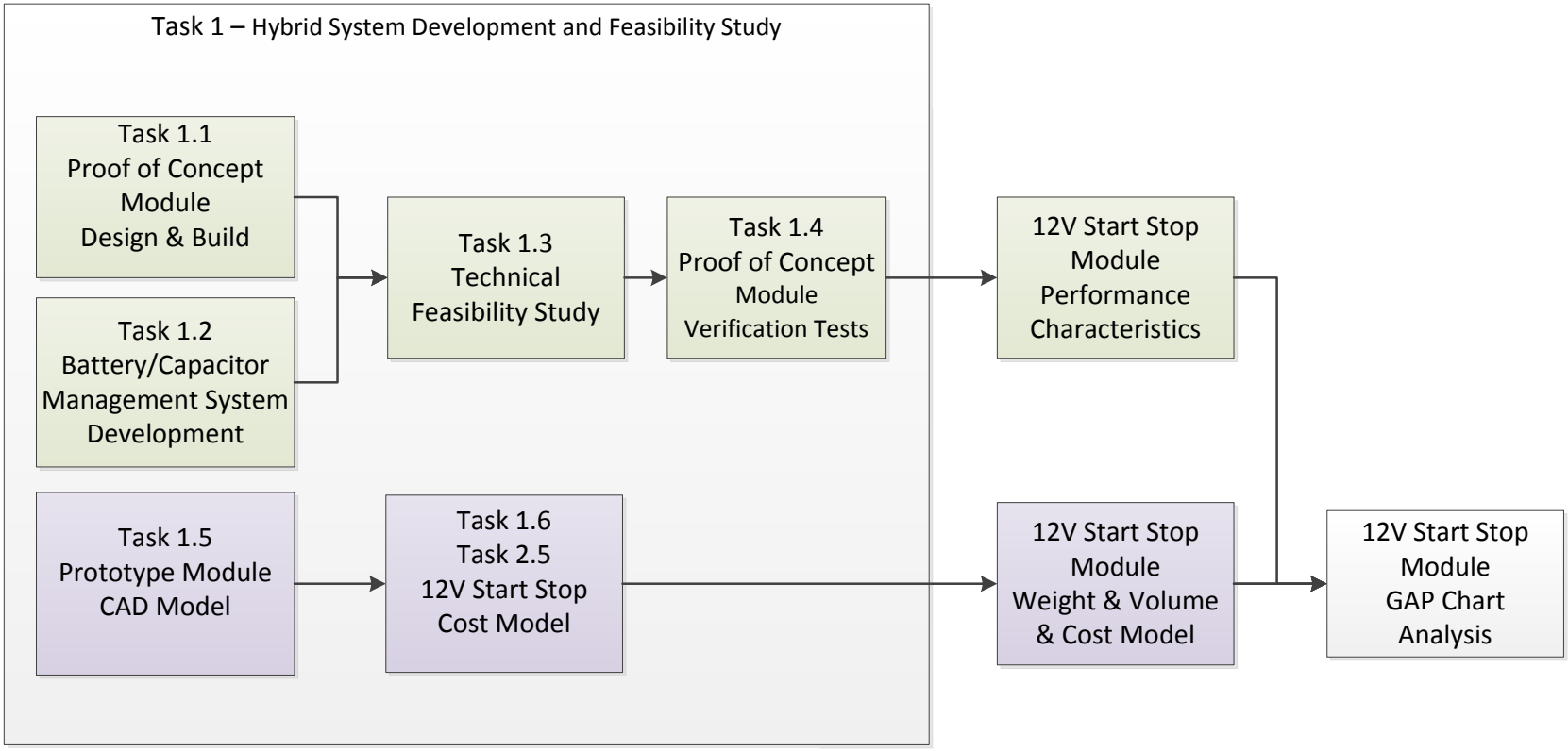
Program Objective: To demonstrate the technological and economic feasibility of a hybrid (UCAP/LIB) energy storage system in an automotive Start Stop application

- The study of the electrical, life cycle and control/communication performance of the hybrid system
- Development of a low cost prismatic UCAP cell
  - Optimized weight, cost and performance
- A comprehensive CAD System Design
  - Validate the system weight, volume, and cost
  - Determine critical thermal and vibration characteristics

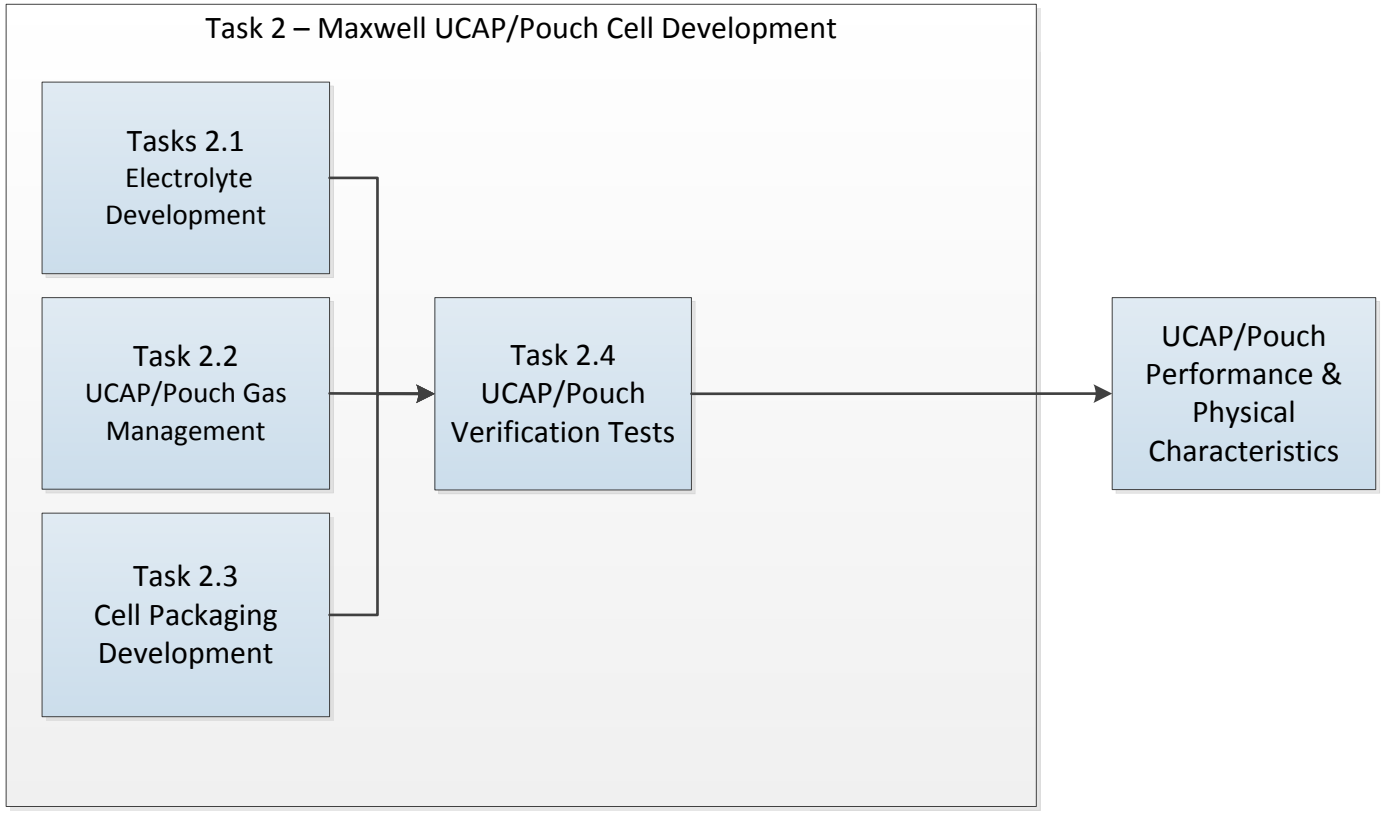
Project Milestones and Gates



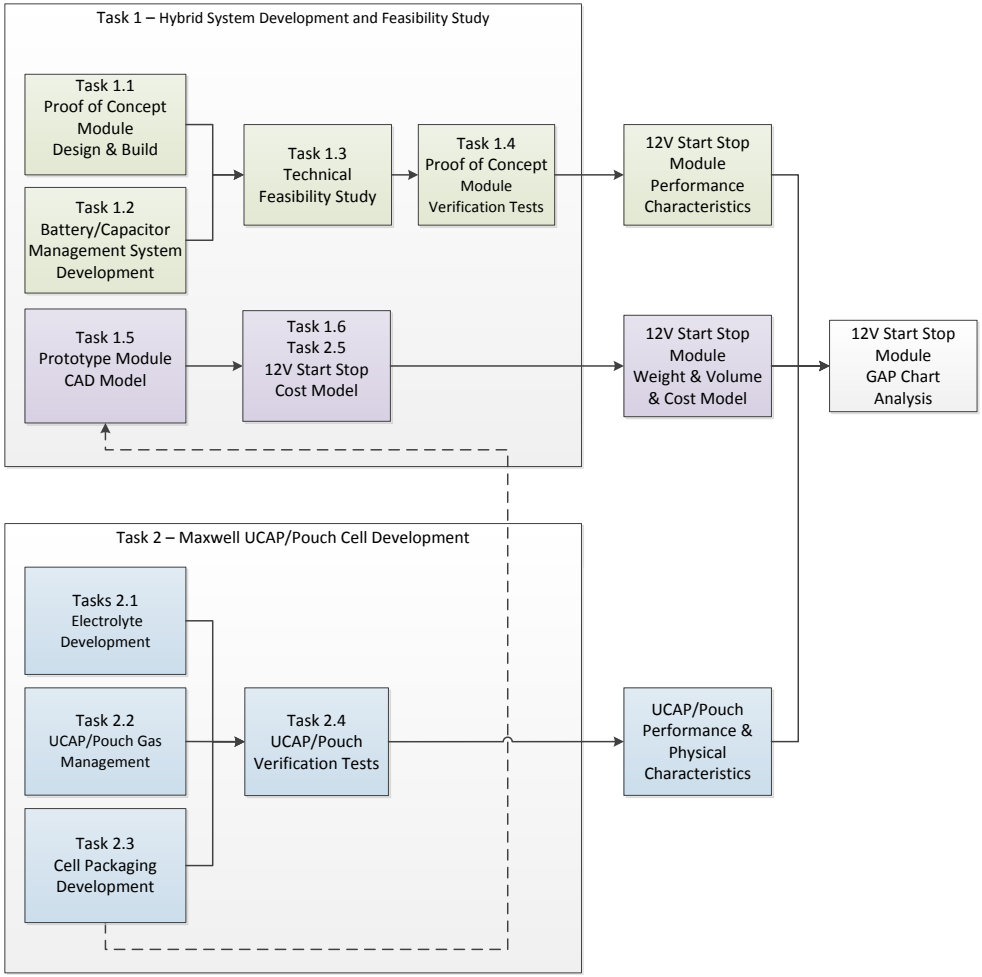
Strategy – Task 1 Hybrid System Development & Study



Strategy – Task 2 UCAP Prismatic Cell Development



Program Strategy



Technical Approach – Cell Development

Objective: Develop a robust prismatic UCAP cell string configuration for the system

- Enable a prismatic UCAP pouch cell configuration:
  - electrolyte formulation modification;
  - gas absorption additives;
  - optimization of cell packaging design.
- Build, pre-screen and ship UCAP prismatic cells to Argonne National Laboratory for confirmation of performance and abuse conformance.
- Develop a prismatic UCAP cell cost model based on prototype manufacturing results identifying a pathway to meeting program cost targets.

Technical Approach – System Development

Objective: Develop and demonstrate the technical and economic feasibility of the proposed Maxwell 12V Start-Stop System

- Design and construct Proof of Concept systems
- Develop a Battery/Capacitor Management System (BCMS).
- Optimize and demonstrate the feasibility of the intended hybrid system using a combination of criteria
  - USABC Gap Chart
  - FreedomCar test parameters.
- Develop a CAD model of the 12V Start Stop Module using anticipated prismatic UCAP specifications.
- Develop a system cost model

FY 2014 Technical Accomplishments – Cell Electrolyte Development

Identify an electrolyte formulation that minimizes high temperature gas generation while having no negative impact on other key cell operating characteristics

- Evaluate 20+ formulations of acetonitrile based electrolytes
  - Two promising candidates identified
- Evaluate 20+ formulations of Carbonate-based electrolytes
  - No promising candidates so far
- High purity electrolyte in-house treatment method developed to improve the electrolyte stability.
- Modeling and identification of alternative ionic salts with improved thermal and electrochemical stability - ongoing.
- Gas suppression additive development proceeding with partners. Life testing in progress
- Alternate solvent based electrolyte evaluations underway.

FY 2014 Technical Accomplishments – Cell Gas Management

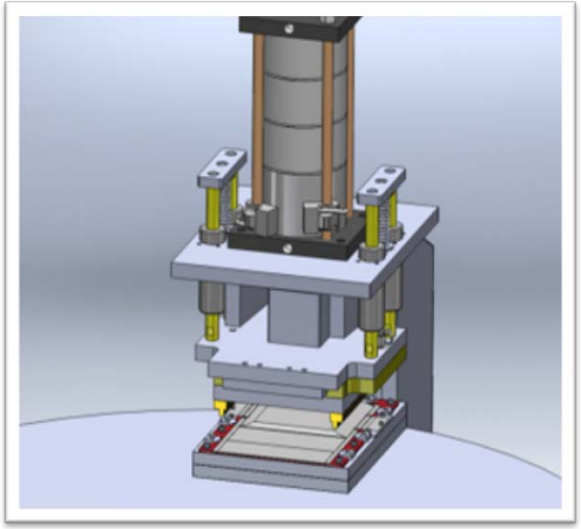
Explore the concept of a gas getter that can reduce high temperature gas pressure while having no negative performance impact on other key cell characteristics.

- Study of the gas generating mechanisms completed.
- Gas suppression additive development effort started.
- Separator development, cell testing and evaluation started.
- Gas Management strategies under evaluation to backup fundamental gas generation mitigation strategies

FY 2014 Technical Accomplishments – Cell Packaging Development

Objective: Improve the internal gas pressure containment capability of the cell

- The UCAP cell design has been completed.
- Related fixture and tooling design has been completed.
- Cell fabrication process development in process
- Initial test builds of prismatic cells have been completed
- Cell fabrication processes have been optimized for minimized ESR and gas generation



FY 2012 Technical Accomplishments – System Development

Proof of Concept Module Design and Build

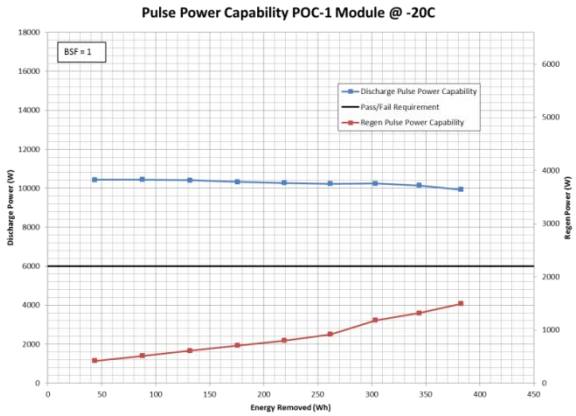
- Initial Proof of Concept system designed, built and being tested. Final Proof of Concept system design started

Battery/Capacitor Management System Development

- Analog version of the system board design for the initial Proof of Concept system complete.
- Digital version of the system board design underway.

Technical Feasibility Study

- Initial Proof of Concept Module used to gauge current design performance vs gap chart numbers.
- HPPC data performed w/BSF = 1
- Cold Crank simulated with single 4kW, 4.75s pulse. Positive results



Cost Model

Objective: Develop a cost model for the proposed Maxwell 12V Start-Stop system assuming a (250K systems annually)

- A comprehensive cost model will be developed
- Efforts focused on both traditional cost down strategies and innovative new cell manufacturing techniques.

	Est. System Price (250K units/year)
Beginning of Program	$230
Maxwell End of Program Target	$199
USABC Maximum Selling Price	$180

Collaborators

ANL
FFRDC, cell and system performance characterization

NREL
FFRDC, thermal modeling and testing

Future Work – FY 2015

- Continue the development of the UCAP Prismatic Cell
  - Electrolyte component analysis and evaluation
  - Gas suppression additive development and testing
  - Evaluate new varieties of electrolytes for positive influence on performance
- Complete the design and build of the final *Proof of Concept System* (Dec 2015)
- Initiate Proof Of Concept System full testing at Maxwell and independent test labs (Feb 2016)
- Initiate the development of the CAD model of *Prototype System* (April 2015)
- Initiate the development of the Maxwell 12V Start Stop Cost Model (July 2015)

Gap Chart Analysis

Performance as of Mar 2015 (Proven Status based on in-house tests)

	Units	USABC Not under hood target	SOW proposal	expected end of program status	Current proven status
Discharge Pulse, 1s	kW	6	6.5	6.5	15
Max current, 0.5s	A	900	1200	1200	1000
Cold cranking power at -30 °C (three 4.5-s pulses, 10s rests between pulses at lower SOC)	kW	6 kW for 0.5s followed by 4 kW for 4s	3 cranks: 6 kW for 0.5s followed by 4	3 cranks: 6 kW for 0.5s followed by 4 kW for 4s	1 Crank
Min voltage under cold crank	Vdc	8	8.2	8.2	10.24
Available energy (750W)	Wh	360	360	360	440
Peak Recharge Rate, 10s	kW	2.2	2.6	2.6	2.7
Sustained Recharge Rate	W	750	750	750	750
Cycle life, every 10% life RPT with cold crank at min SOC	Engine starts/mile	450k/150k	450K	450K	0
Calendar Life at 30°C, 45°C if under hood		15 at 30°C	15 at 30°C	15 at 30°C	0
Minimum round trip energy efficiency	%	95	95	95	0
Maximum allowable self-discharge rate	Wh/day	2	1.7 at 30°C	1.7 at 30°C	0
Peak Operating Voltage, 10s	Vdc	15	15	15	0
Sustained Max. Operating Voltage	Vdc	14.6	14.6	14.6	14.6
Minimum Operating Voltage under load	Vdc	10.5	10.5	10.5	11.8

Gap Chart Analysis

Performance as of Mar 2015 (Proven Status based on in-house tests)

Operating Temperature Range (available energy to allow 6 kW (1s) pulse)		-30 to +52°C	-30 to +52°C	-30 to +52°C	0
30 °C to 52 °C	Wh	360	360	360	440
0 °C	Wh	180	324	324	400
-10 °C	Wh	108	144	144	400
-20 °C	Wh	54	72	72	380
-30 °C	Wh	36	36	36	0
Survival Temperature Range (24 hours)		-46 to +66	-46 to +66	-46 to +66	0
Maximum System Weight	kg	10	9.6	9.6	10
Maximum System Volume	L	7	7	7	12.7
Maximum System Selling Price (@100k units/year)	$	$180	$230 with path to $199	$230 with path to $199	

SUMMARY

There is a very strong technical and economic case developing in the energy storage industry for the hybrid combination of ultracapacitors (UCAP) and batteries in a variety of applications.

- The program has advanced on both tasks – UCAP low cost prismatic cell development and full 12V Start Stop system design.
- The UCAP prismatic cell development is working to overcome the electrochemical challenges Initial results are pointing to a solution based on a combination of the major mitigation factors – electrolyte, additives, gas management strategies via cell design.
- The 12V Start Stop system design is on schedule and the Battery/Capacitor Management System has shown excellent results in initial tests.