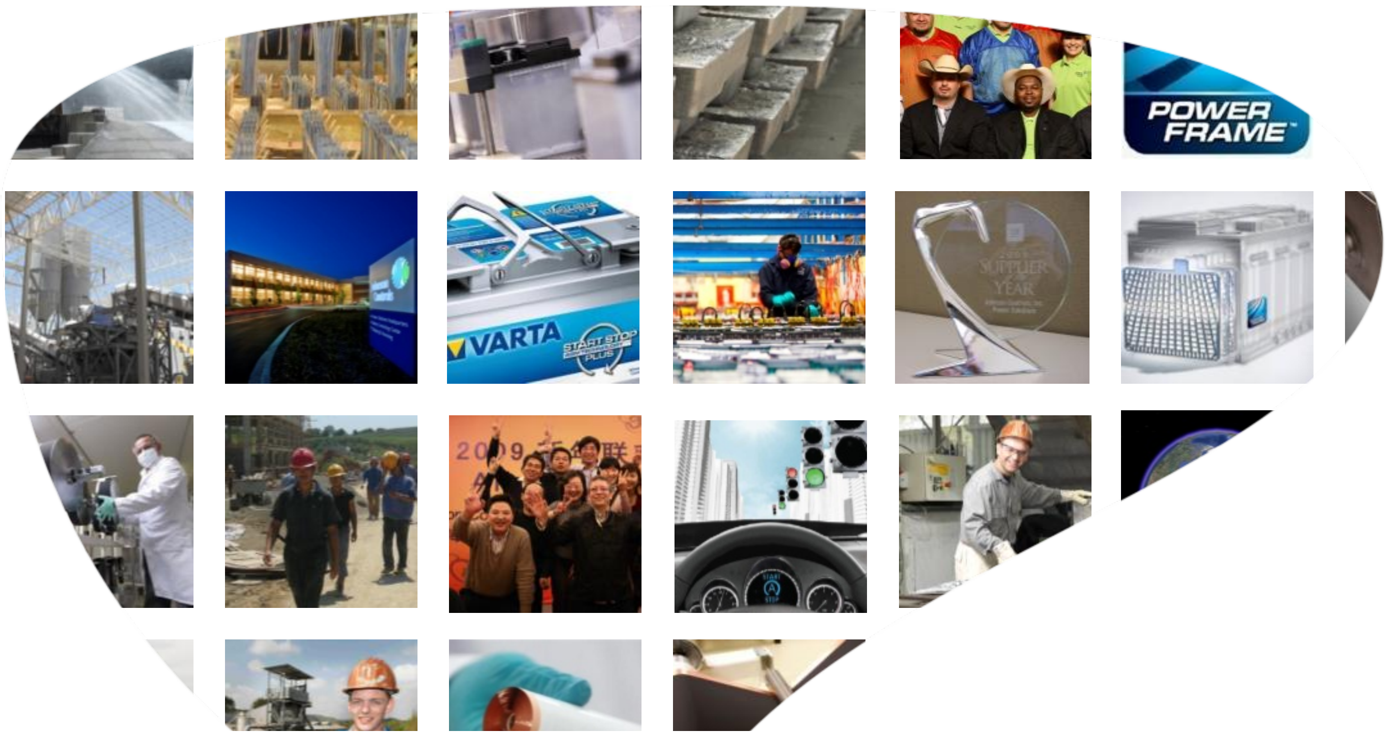
2013 DOE Merit Review ES133: **Significant Cost Improvement of Li-ion Cells Through Non-NMP Electrode Coating, Direct Separator Coating, and Fast Formation Technologies**



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5/13/2013

Johnson Controls

Project Overview

Timeline

- Start: October 2011
- Finish: December 2014
- Final report to DOE: January 2015
- On schedule, 35% completed[1]

Budget

- Total project funding
  - DOE: $3.67M
  - Johnson Controls and sub-recipients: $3.67M
- Funding received in 2012: $240k

Barriers

- Barriers for electrification of passenger vehicles[2]
  - Public acceptance of electrified vehicles
  - Vehicle and battery costs
  - Current manufacturing process is electrical energy intensive
- Target: reducing Li-ion manufacturing cost by > 50%

Partners

- Entek Membranes
- Maxwell Technologies
- University of Wisconsin – Milwaukee

(1) As of Feb 2012; (2) According DOE Vehicle Technologies Program, Table 1

Project Objective

Project scope

Significant cost improvement of Li-ion manufacturing process:

- Non-NMP electrode coating process
- Direct coated separator
- Fast formation process
- Optimized cell design

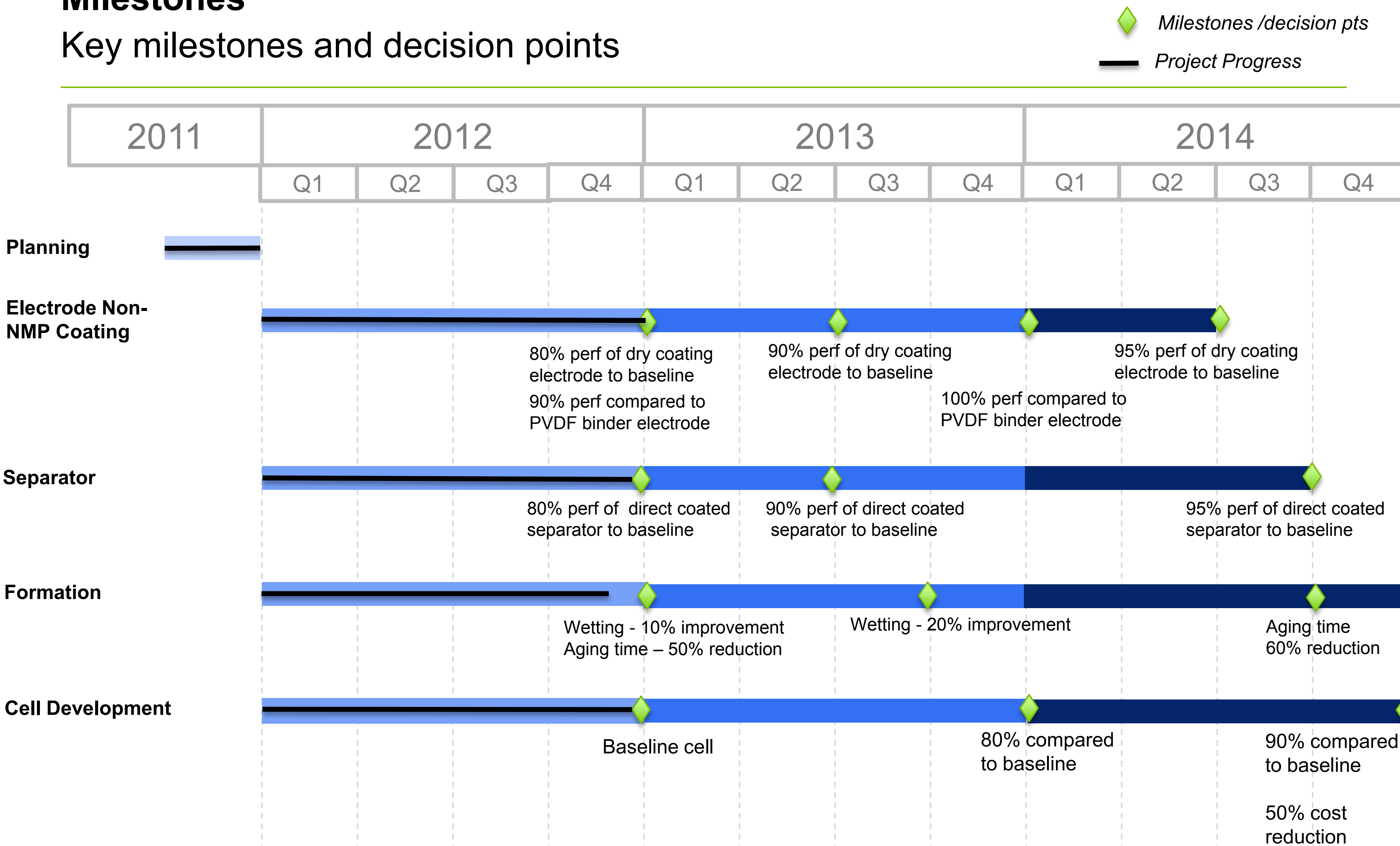
Performance target

>50% cost reduction

(Li-ion pouch cells)

Milestones

Key milestones and decision points



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Approach

Dry coated electrode

- Electrode design optimization
- Binder and electrolyte development
- Process and equipment optimization

Water based cathode binder

- Eliminate NMP solvent
- Develop material with electrochemical and chemical stability

Direct-coating of separator material on Li-ion electrodes

- Solvent/Dispersion coating
- Powder coating
- Separator lamination

Fast Formation

- Reduce formation time by optimizing cell filling and cell aging parameters.

Technical Accomplishments

FY 2012

Baseline Designs Electrodes

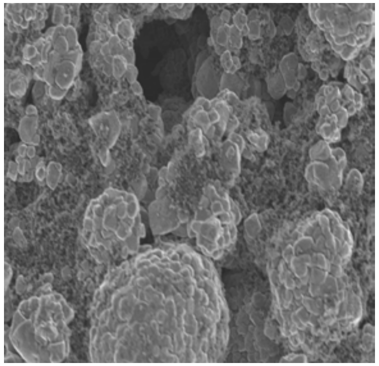
- Baseline Design completed and tested in coin cells, 3Ah and 15Ah pouch cells.

Dry Coating Electrodes

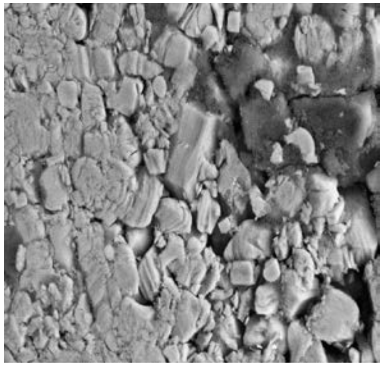
- The results are demonstrating cycle life and rate capabilities inferior to the baseline design. The root cause analysis revealed significant differences in the porous structure between baseline and dry coated electrodes induced by contrasting process. The main efforts are directed towards mixing and film formation process optimization.

Water Based Cathode

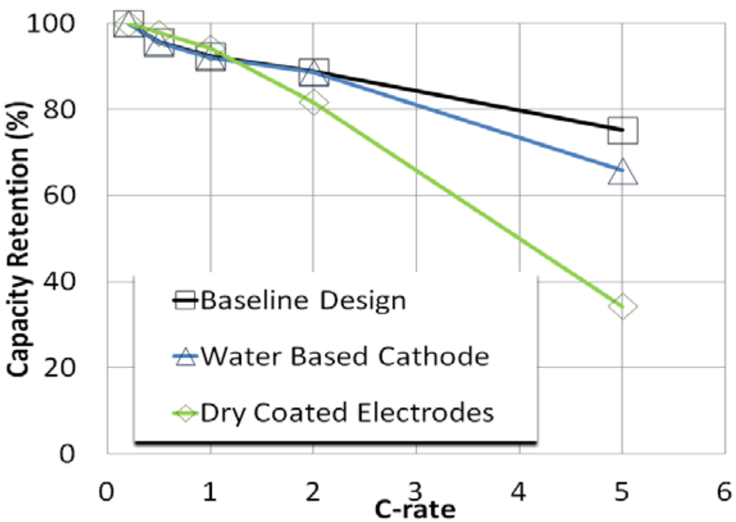
- Cycling performance meets the reference performance, while the rate performance achieves 90% of baseline. Further research is needed to improve electrode quality. The main efforts are directed toward adapting dispersion in the electrode slurry.



Porous structure Baseline



Porous structure Dry Coated



Technical Accomplishments
FY 2012

Direct Coated Separator Technologies

- A microporous polymer film is applied to the anode.

Lamination

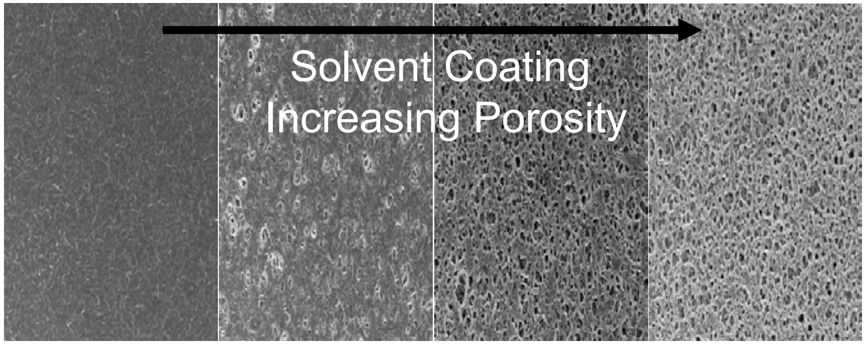
- Lamination gives the most promising results of the three methods. The cells built with laminated separator displayed superior results in cycle life and rate capability

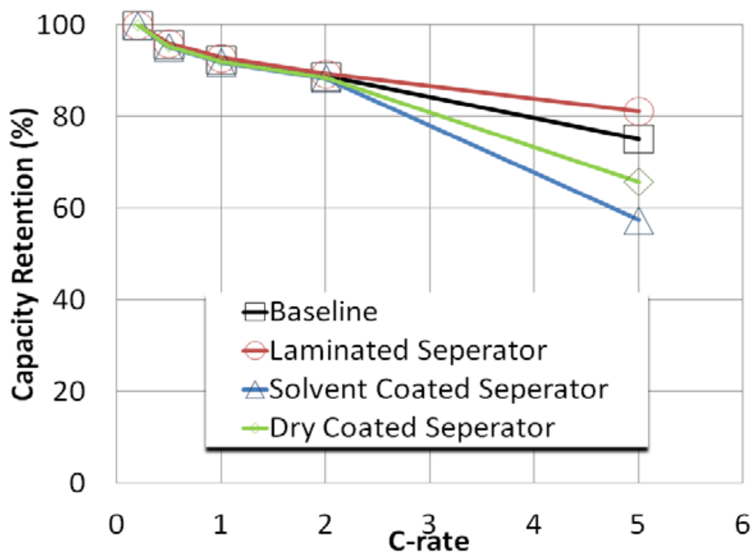
Solvent Coating

- The solvent based separator meets all desired product parameters of porosity and thickness. The cycle life is similar, but the rate capability is inferior to the baseline design.

Dry Coating

- The dry coated separator technology did not achieve the intended design parameters.





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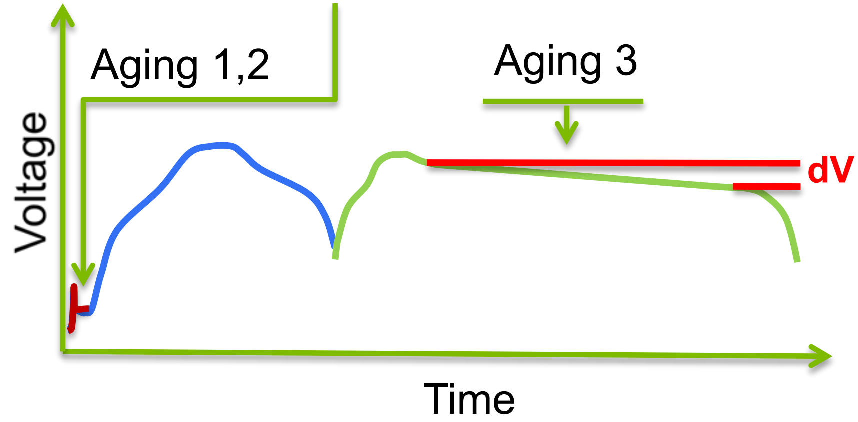
Technical Accomplishments
FY 2012

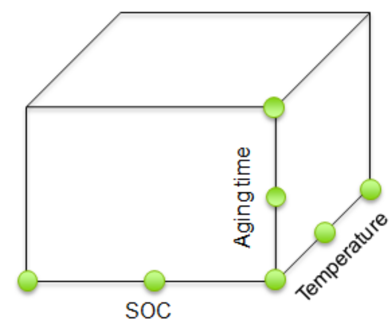
Fast Formation Process

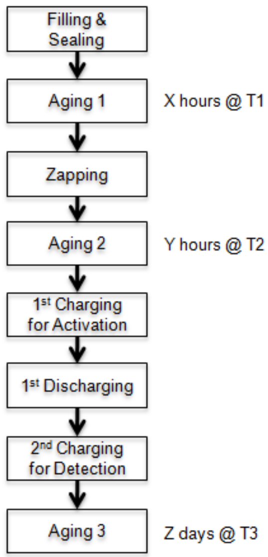
- The target of this task is to reduce the formation time by optimizing the aging conditions in the process steps (see flowchart, Aging 1-3).

Aging 2

- For the investigation into the aging conditions a design of experiment (DOE) was performed. The result of the DOE showed that long aging time, along with a low SOC and temperatures greater than ambient are beneficial for the resistance and capacity of the product.
- The design of experiment allows us to estimate the impact of reducing the aging time 2 (T2) to 12h.







Technical Accomplishments
FY 2012

Cell Design

- We up scaled the initial 3Ah cell to a 15Ah design. The new design displayed significant improvement compared to the initial design. Both designs serve as test cell and deliverables. The 15Ah cell with integrated advanced technology is the final deliverable for Q4/2014.

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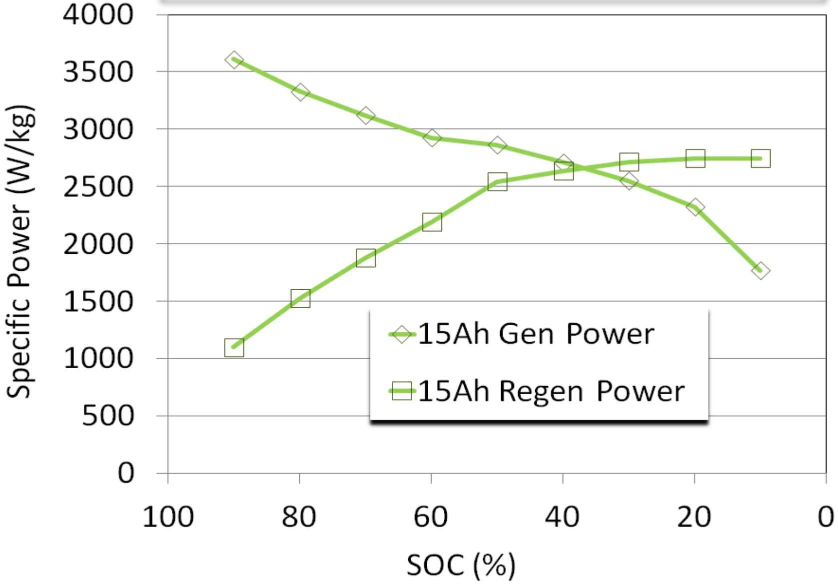
Property	15 Ah cell	3Ah cell
Capacity	15.3 Ah	3.2 Ah
Spec. Energy	155 Wh/kg	145 Wh/kg
Spec. Power	2640 W/kg[1)]	2310 W/kg[1)]
Energy density	300 Wh/l	251 Wh/l
Resistance	2.9 mOhm[2)]	16 mOhm[2)]

1) At 40% SOC; 2) DCR, 10s, room temperature.



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Cost Model

Validate and finalize baseline - Q1 2013

- Selectively refine process adjustments for cell comparison b/w 15Ah and production cells
  - *Formation steps*
  - *Fine-tuning of scaling (Ah based)*
- Finalize 15Ah baseline for savings comparison

Build out savings logic and assumptions - Q2 2013

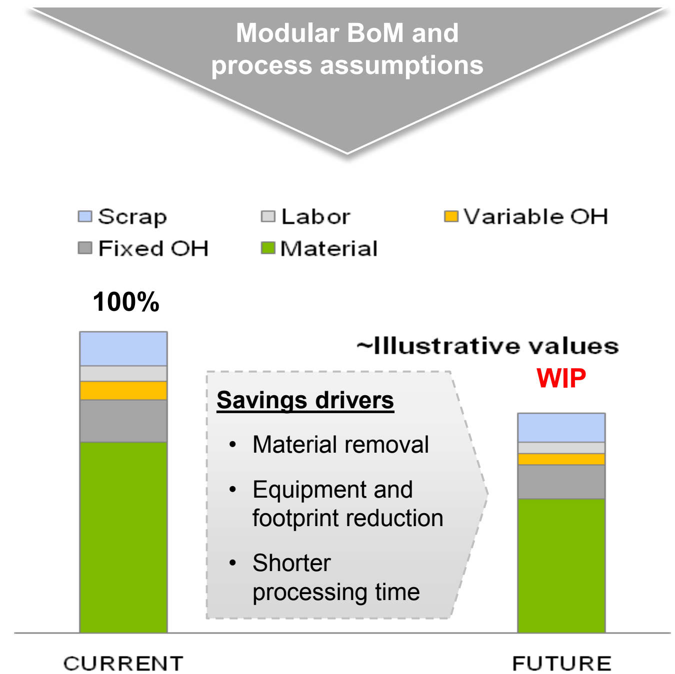
- Define process cost and BoM assumptions for novel process steps; fine-tune initial estimates in FY12
- Validate overhead savings assumptions based on today's Capex / Opex with Johnson Controls finance

Consolidate estimates for design options – Q3 2013

- Modular cost model design and roll-up

Building estimates for multiple design (illustrative)

	Cathode	Separator	Anode
DESIGN #1	Baseline	Baseline	Baseline
DESIGN #2	Dry coating	Laminated	Dry coating
DESIGN #3	Aqueous	Laminated	Baseline
DESIGN #4	Dry coating	PVDF	Dry coating



Future Work
FY 2013

Remainder of 2013

- Build and evaluate advanced processes with 3Ah cells
- Build interim cell cost model
- Deliverables to DOE:
  - 18 of 3Ah advanced cells
  - Interim cost model
  - Cell test results

Remainder of the project

- Build and evaluate new 15Ah incorporating technology advancements
- Optimize dry coating and non-NMP electrode approaches
- Optimize advanced direct coated separator technology
- Finalize fast formation process
- Deliverables to DOE:
  - 2014: 24 final15Ah cells and final cost model

The Partners

Maxwell Technologies

- Award sub-recipient
- Leader in ultracapacitor technology
- Focus on dry coating electrode research

University of Wisconsin – Milwaukee

- Partner in innovation
- Leading institute in material science and energy storage
- Focusing on fast formation modeling and cell characterization

Entek Membranes

- Award sub-recipient
- Leader in microporous membranes
- Focus on direct coated separator

Maxwell TECHNOLOGIES

UNIVERSITY of WISCONSIN UWM MILWAUKEE

ENTEK MEMBRANES