High Energy Lithium Batteries for Electric Vehicles

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Envia Systems

2017 DOE Vehicle Technologies Program
Annual Merit Review and Peer Evaluation Meeting
June 5–9, 2017 - Washington D.C.

Project ID: ES247

Program Overview

TIMELINE

- Project start date: Jun 2014
- Project end date: Dec 2017
- Percent complete: ~83%

BARRIERS

- Meet USABC EV energy and power cell specs
- Meet cycle life and calendar life
- Enable a cell cost target of 100$/kWh

BUDGET

- Total project funding:
  - ✓ DOE share: $3,859,246
  - ✓ Envia & partners share: $3,859,246
- Funding received in FY2016: $1,154,305
- Funding for FY2017: $736,261

PARTNERS

Nanoscale Components

A123 SYSTEMS

DAIKIN

AsahiKASEI

3M

DUPONT

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Project Relevance

• Goals:

Develop high capacity cathode and anode materials, screen commercial electrolytes and separators, optimize pre-lithiation process and integrate to build high capacity pouch cells that meet the USABC electric vehicle (EV) battery goals for CY 2020

• Barriers and Tasks:

- ✓ Develop high capacity cathode and anode materials and electrodes
- ✓ Mitigate cycle life challenges associated with Si anodes and Li-rich cathodes
- ✓ Develop an economical and manufacturable pre-lithiation process
- ✓ Cell development to ensure meeting the cell metrics, safety and cost targets

• Deliverables:

Demonstrate & deliver cells that meet the USABC EV cell targets with independent validation from the National Labs (INL, SNL, & NREL)

• USABC EV Cell Targets for 2020:

End of Life Characteristics at 30°C	Units	Cell Level
Peak Discharge Power Density, 30 s Pulse	W/L	1500
Peak Specific Discharge Power , 30 s Pulse	W/kg	700
Peak Specific Regen Power , 10 s Pulse	W/kg	300
Useable Energy Density @ C/3 Discharge Rate	Wh/L	750
Useable Specific Energy @ C/3 Discharge Rate	Wh/kg	350
Useable Energy @ C/3 Discharge Rate	kWh	N/A
Calendar Life	Years	15
DST Cycle Life	Cycles	1000
Selling Price @ 100K units	$/kWh	100
Operating Environment	°C	-30 to +52
Normal Recharge Time	Hours	< 7 Hours, J1772
High Rate Charge	Minutes	80% ΔSOC in 15 min
Maximum Operating Voltage	V	N/A
Minimum Operating Voltage	V	N/A
Peak Current, 30 s	A	400
Unassisted Operating at Low Temperature	%	> 70% Useable Energy @ C/3 Discharge rate at -20 °C
Survival Temperature Range, 24 Hr	°C	-40 to+ 66
Maximum Self-discharge	%/month	< 1

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Project Milestones and Gates

Current Status

2017 →

Task Number	Major Project Tasks	PROJECT TIME													
		YEAR 1				YEAR 2				YEAR 3				Y4	
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	
8	**SUMMARY OF MAJOR PROJECT DELIVERABLE**														
6.1.5	Ship 12 (twelve) 20 Ah baseline cells fabricated by Envia to selected National Labs for independent testing		◆												← Baseline (complete)
6.2.14	Build and test 1 Ah cells from cell build #1 as an internal build and report and use learning for future cell builds					◆									← Build #1 (complete)
6.3.14	Ship 28 (twenty-eight) 11 Ah capacity cells fabricated by Envia from cell build #2 to the National Labs for independent testing											◆			← Build #2 (ongoing)
6.4.9	Build and test 11 Ah cells from cell build #3 as an internal build and report and use learning for final cell build												◆		← Build #3 (ongoing)
6.5.14	Ship 11 Ah and 40+ Ah capacity cells fabricated by A123/Envia from cell build #4 to the National Labs for independent testing													◆	
7.1.3	Deliver final USABC project cell cost model & report													◆	
9	**REVIEW AND DECISION GATES**														
9.1	Down-select best cathode composition (Li, Ni, Co, Mn & amount of Li_2MnO_3), conducting coating (polymer, carbon or metallic) and dopant to be integrated in 1Ah cells from cell build #1				◆										← complete
9.2	Down-select best prelithiation process conditions (lithiation loading, time, speed, drying, handling, etc.) to build 1Ah cells from cell build #1				◆										← complete
9.3	Down-select and focus material development efforts on the most promising Si-based anode approach from development on Si-alloys and Si-C and SiO_x-C composites					◆									← complete
9.4	Freeze best separator material to be used in remaining cell builds											◆			ongoing
9.5	Down-select best prelithiation process to build 11 Ah and 40+ Ah cells from cell build #4											◆			ongoing
9.6	Freeze best cathode blend to build 11 Ah cells from cell build #3												◆		ongoing
9.7	Freeze best Si-based anode composite to build 11 Ah cells from cell build #3												◆		ongoing
9.8	Freeze best electrolyte formulation to be used in remaining cell builds												◆		ongoing

Approach Strategy & Partnerships

Approach:

- Anode development
- Cathode development
- Pre-Lithiation development
- Electrolyte screening
- Separator screening

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- Cell development
- Cell testing
- Cell manufacturing

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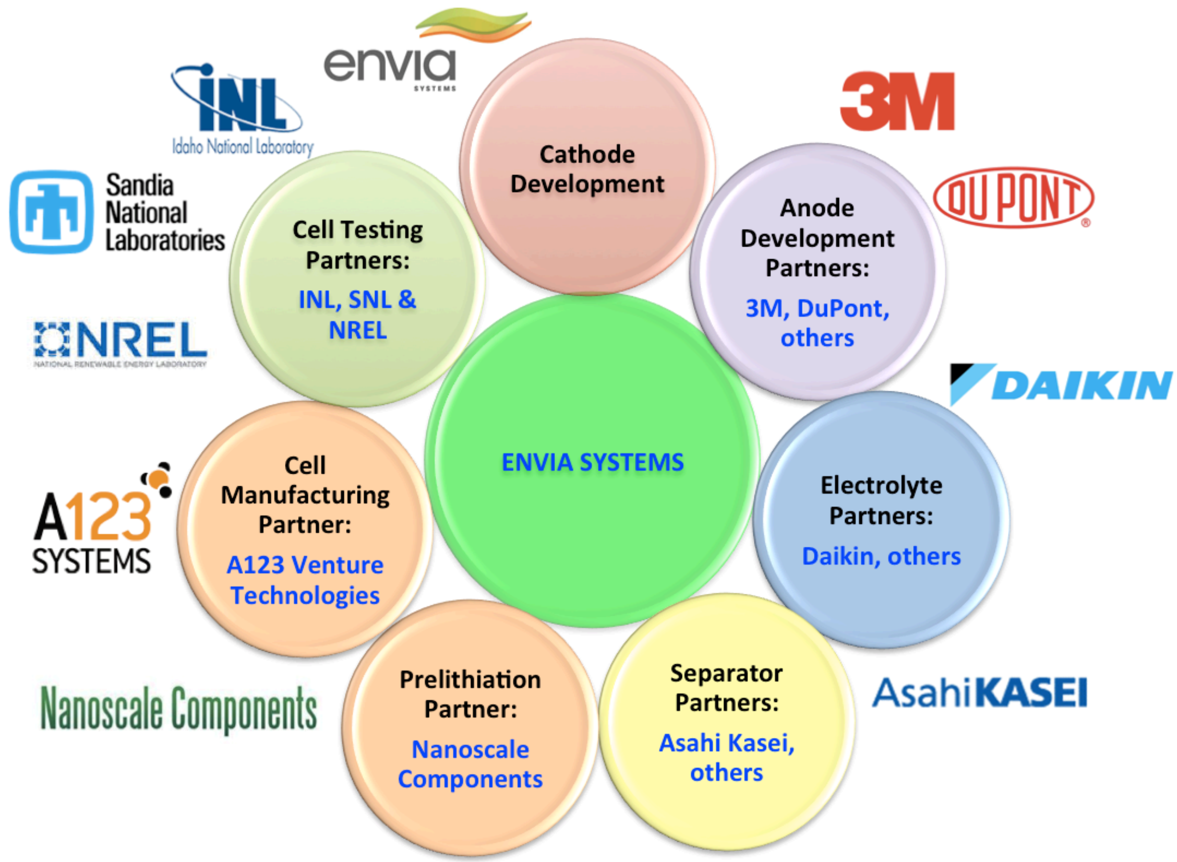
Develop and deliver high capacity cells meeting USABC EV specifications

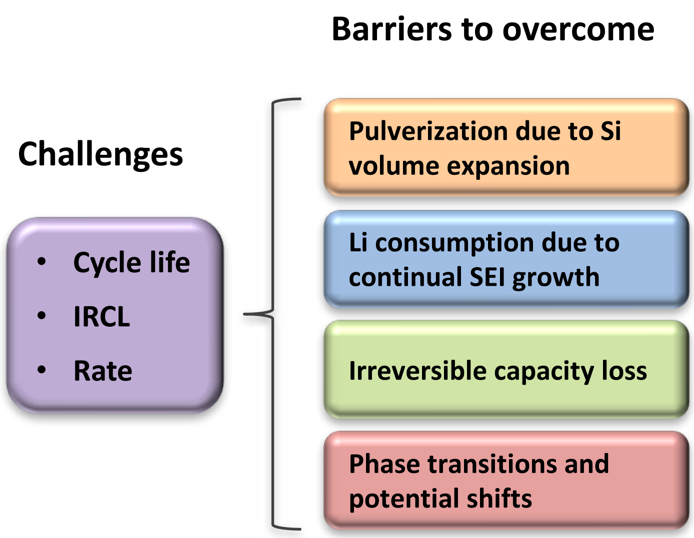
Development Areas & Partners:

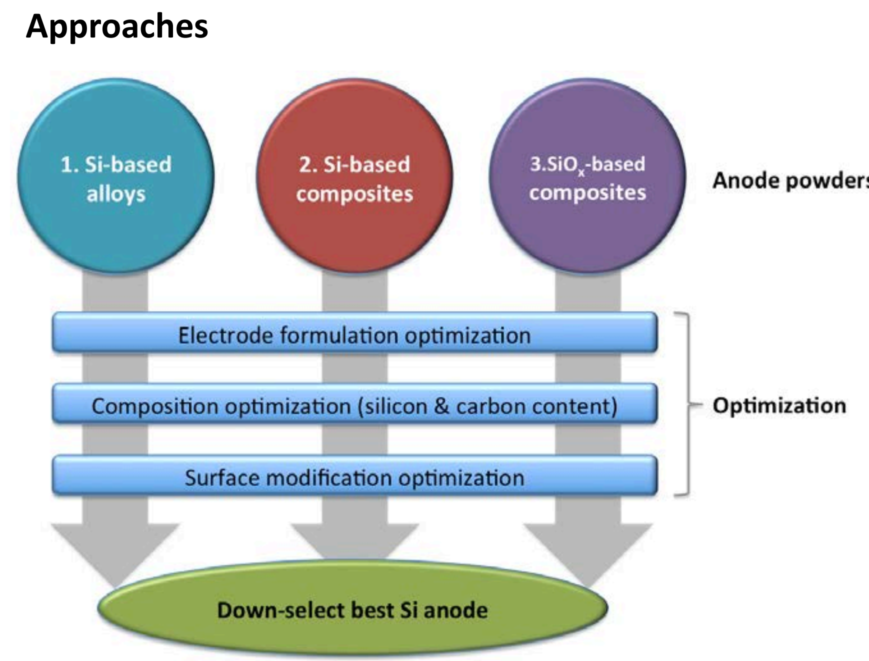


Si-based Anode Challenges & Development

Si-based anode Advantages:

Silicon-based anodes are attractive alternatives to graphite because silicon can alloy 4.4 lithium ions per silicon ($Li_{4.4}Si$) resulting in extremely large theoretical capacities of 4200 mAh/g versus graphite's 372 mAh/g.





STATUS:

- Envia is developing proprietary Si-based anodes by using commercially available SiO_x materials and applying its electrode formulation, processing, and coating know-how
- Envia is down-selecting a high capacity SiO_x-based anode to enable cells with specific energy >300 Wh/kg and 1000 cycles

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Cathode Blend Strategy & Development

In order to meet the challenging USABC EV cell targets, blending of cathodes to leverage each of their strengths is required

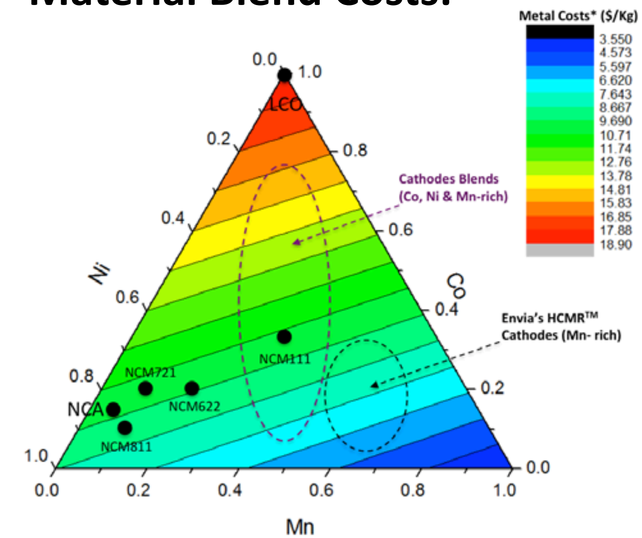
Blending Strategy:

Mn-rich Cathode
High Capacity
Improved Safety
Low Cost
High DC-R
Poor Electrode Density
Low Average Voltage
Voltage Fade

→ **Cathode Blend with combined benefits** ←

Ni-rich Cathode
High Capacity
Poor Safety
High Cost
Low DC-R
High Electrode Density
High Average Voltage
No Voltage Fade

Material Blend Costs:



* Cathode metal costs are calculated from publicly traded Ni, Co & Mn metal prices from 10-1-15

STATUS:

- Mn-rich cathodes blended with Ni-rich cathodes can enable high gravimetric and volumetric energy (350 Wh/kg and 750 Wh/L) when paired with Silicon anodes while meeting safety and cost requirements ($/kWh)
- Envia is down-selecting a high capacity cathode blend to enable cells with specific energy >300 Wh/kg and 1000 cycles

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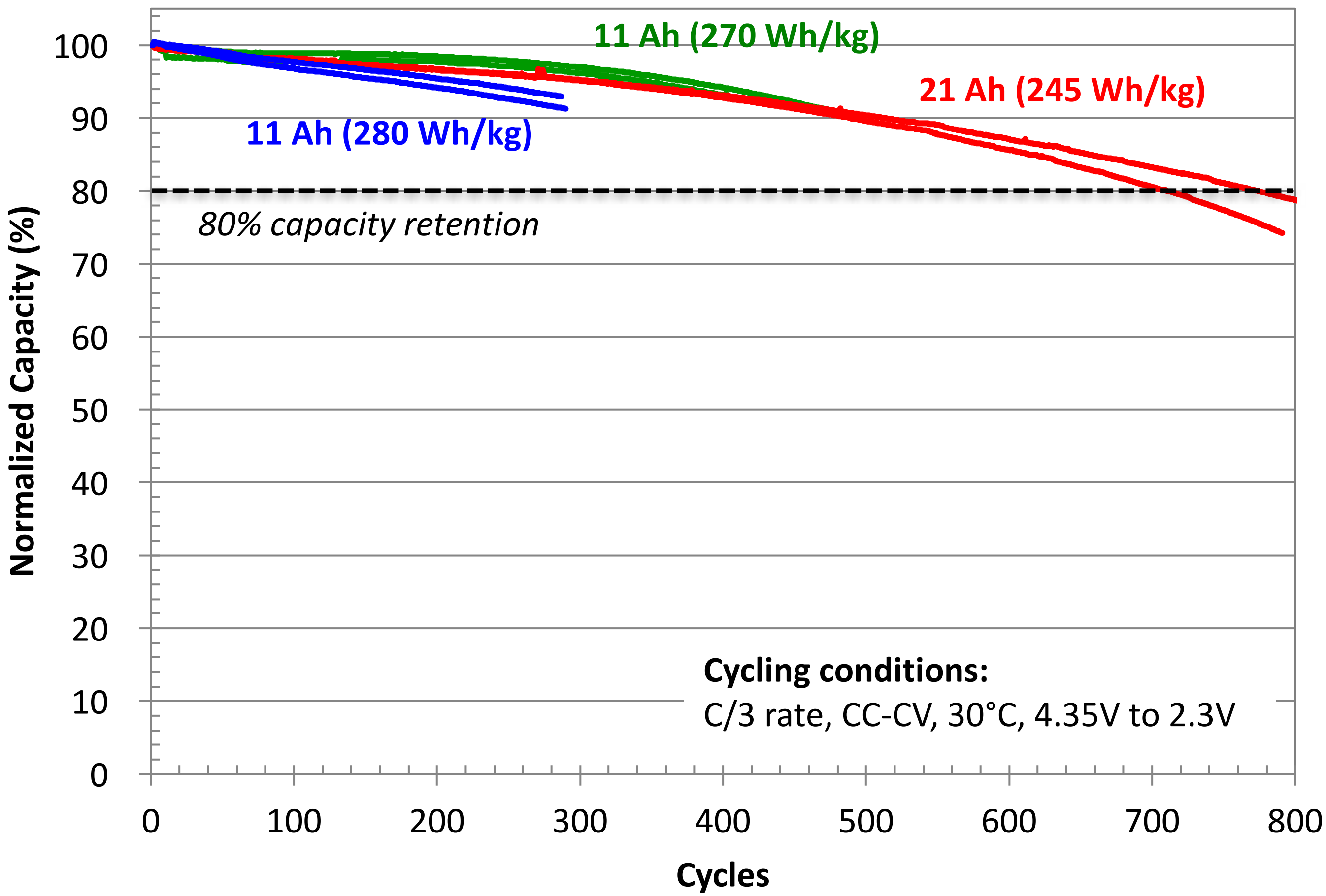
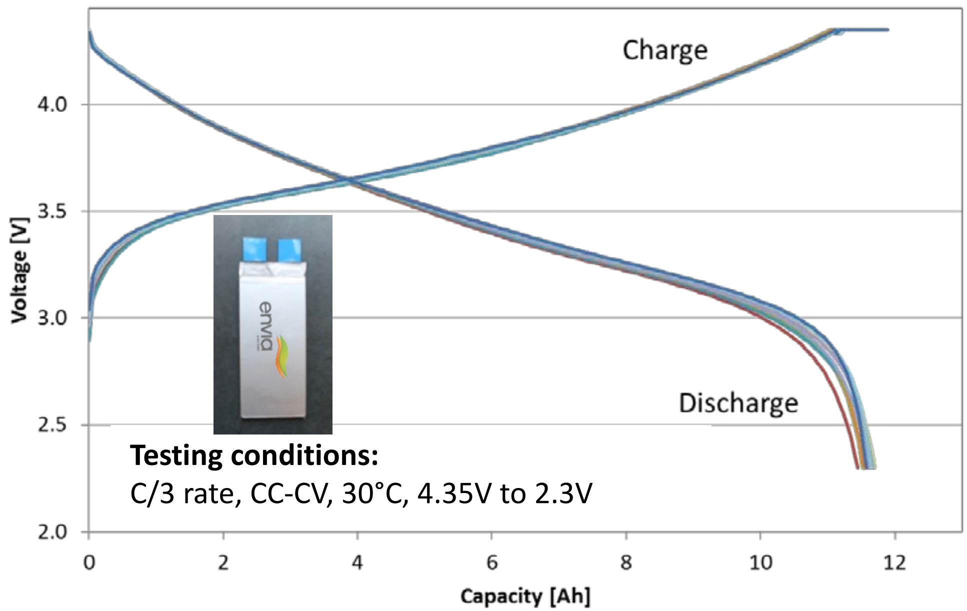
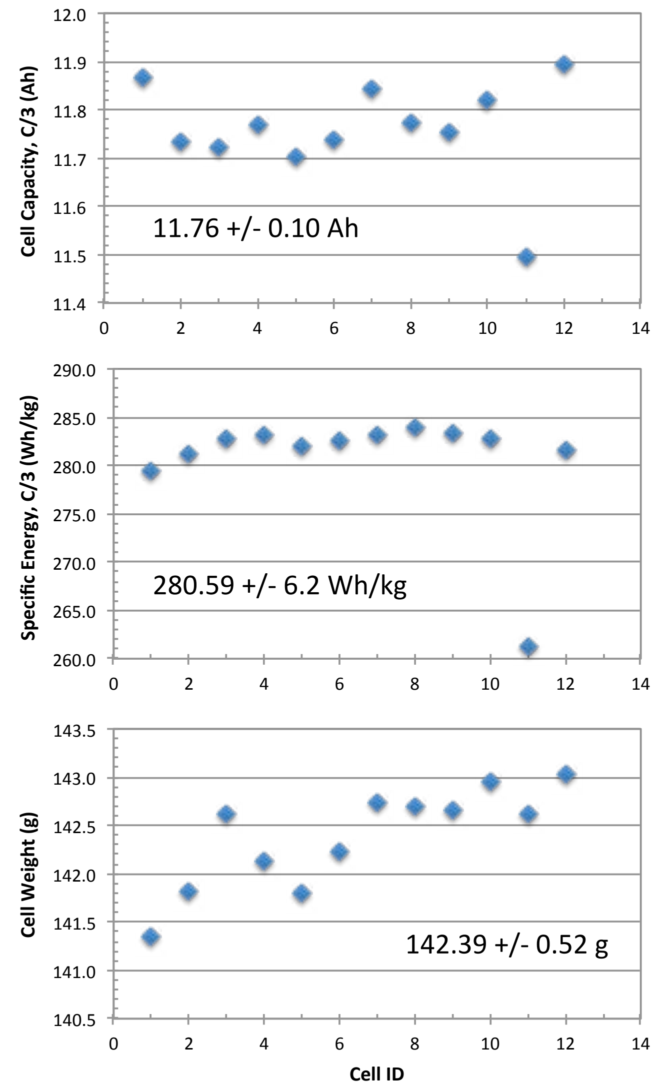
Cycle Life Status



Envia has achieved >700 cycles with 80% capacity retention from 20 Ah capacity cells integrating high SiO_x (>50%) containing anodes and Ni-rich and Mn-rich cathode blends

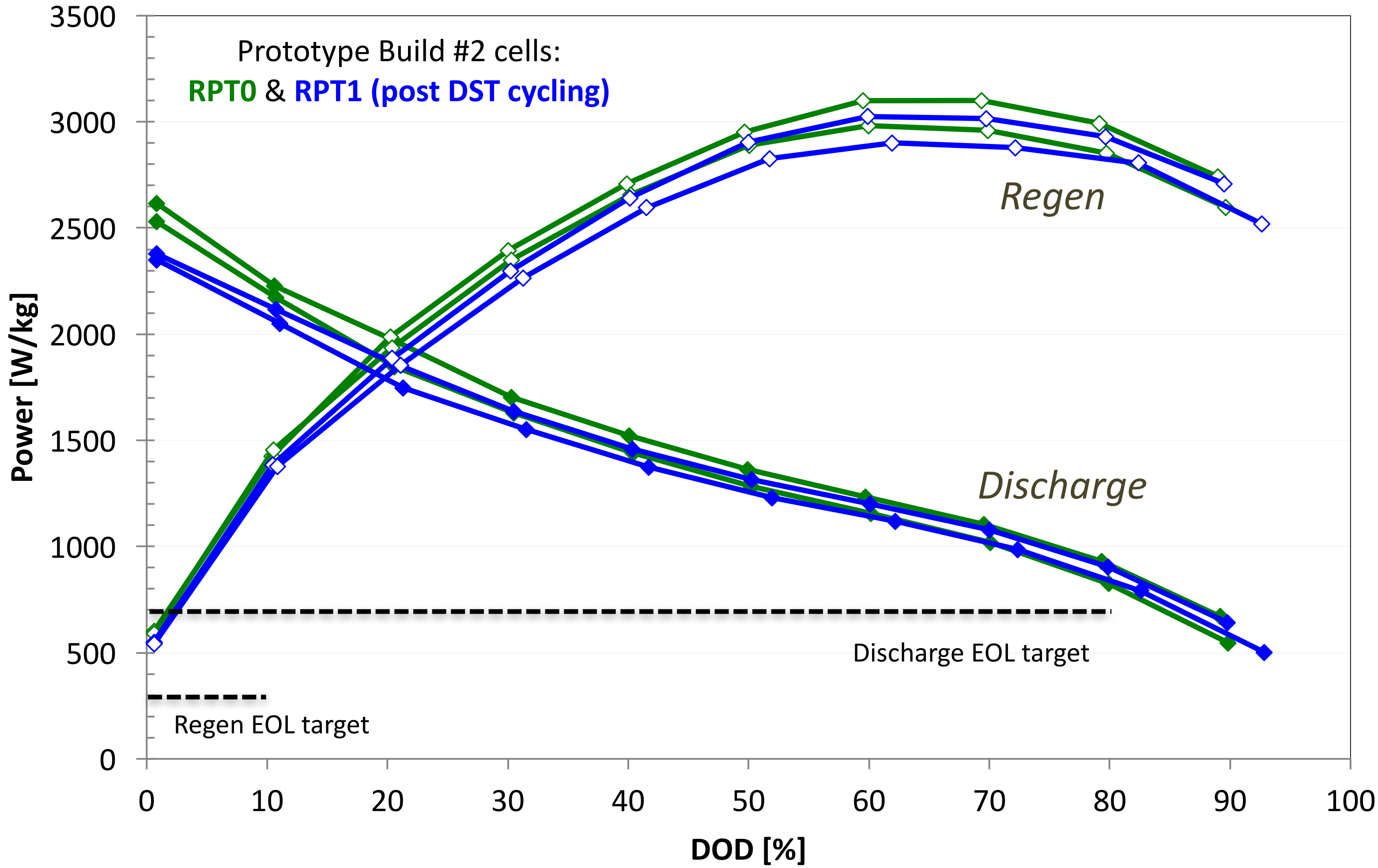
Cell Build #2 Status





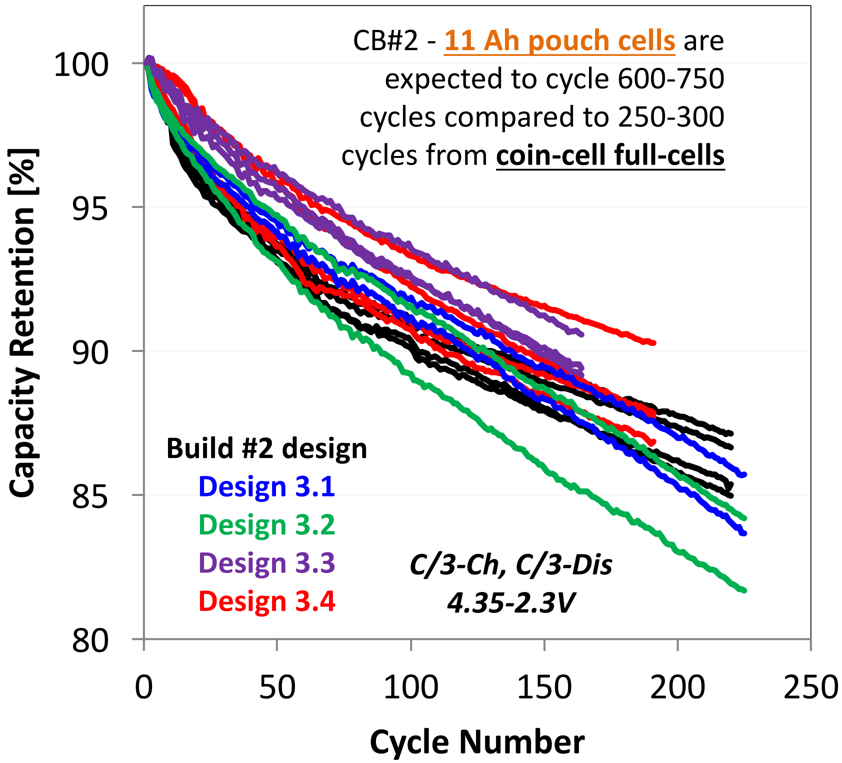
- Design for Build #2 cells was frozen and cell build is ongoing to deliver cells to the National Labs
- Prototype Build #2 cells have been assembled, tested and results show consistent cell performance and physical specifications

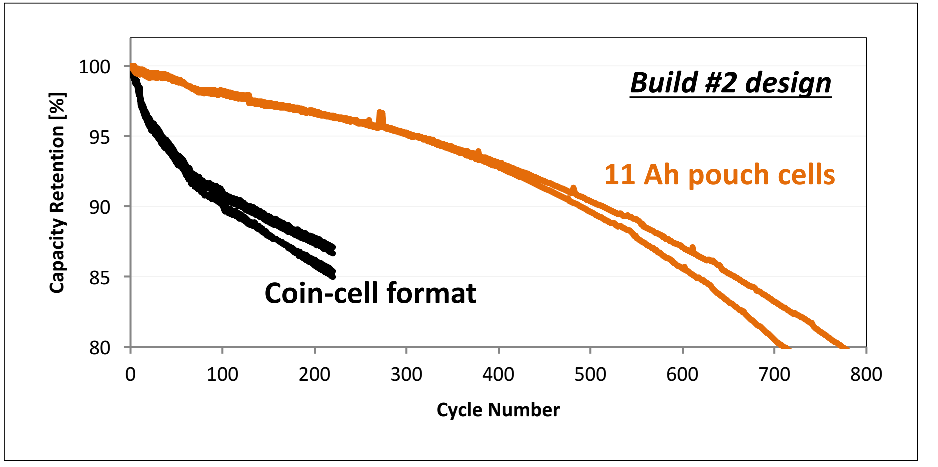
EVPC Testing of Build #2 Cells



Prototype Build #2 cells meet the EOL USABC EV peak specific Regen and Discharge power requirements after RPT1 (post 30°C DST cycling)

Cell Build #3 Development (300 Wh/kg & 1000 cyc)





Cell Build #2 (CB#2) - **11 Ah pouch cells** are expected to cycle 600-750 cycles compared to 250-300 cycles from **coin-cell full-cells**

- Cell Build #3 is an internal build to identify and freeze the optimal cell design targeting specific energy **>300 Wh/kg (BOL)** and a **cycle life of 1000** cycles
- Multiple cell designs (specific energy >300 Wh/kg) integrating higher capacity cathode blends and SiO_x-based anodes along with high energy cell designs are being evaluated
- Final program cell design (Cell Build #4) will be down-selected in July, 2017

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Pre-lithiation of Si-based Anodes

Advantages of Pre-lithiation:

1. Pre-lithiation enables the integration of high capacity Si-based anodes, by precisely compensating the high irreversible capacity loss (IRCL)
2. In the absence of pre-lithiation, compensation of the IRCL would come from the cathode which is the priciest component in the cell
3. Pre-lithiation has also been shown to improve the cycle life in various materials

Nanoscale's roll-to-roll electrochemical pre-lithiation is safe, low-cost & scalable	
Safer manufacturing	No lithium metal is used, eliminating a key fire risk
Safer cells	No lithium metal is in cells, eliminating tendency to form dendrites
Better uniformity	Electrochemical method offers more control than powder dispersion
Less swelling	Partial expansion occurs during pre-lithiation, before cell assembly
Less expensive	Lithium salt used is much less expensive than metal

Envia has partnered with Nanoscale Components to use its low cost, roll-to-roll manufacturable pre-lithiation process to fabricate large capacity pouch cells

Status of Pre-lithiation Development

STATUS:

1. Nanoscale used its 1st generation roll-to-roll pilot line to successfully pre-lithiate SiO_x-based anodes that Envia and A123 assembled into 1 Ah pouch cells
2. Nanoscale completed its 2nd generation large scale roll-to-roll pre-lithiation pilot line which is 5x wider and 10x faster throughput than the 1st generation line, with capability of supporting large-format high-capacity (>20 Ah) pouch cells
3. Using its 2nd generation pilot line, Nanoscale pre-lithiated wide anode rolls coated by Envia

NEXT STEPS:

1. Envia to freeze anode formulation to be used in final program cell build
2. Nanoscale to verify pre-lithiation of final anode to the target dosage, and to pre-lithiate sufficient anode for final program cell build

Summary & Future Work

SUMMARY:

- Achieved >700 cycles with 80% capacity retention from 20 Ah capacity cells integrating high SiO_x (>50%) containing anodes and Ni-rich and Mn-rich cathode blends
- Build #2 design was frozen and cell build is ongoing to deliver cells to the National Labs
- Internal Cell Build #3 is evaluating different 300+ Wh/kg designs to freeze design for final program cell build
- 2nd generation large scale roll-to-roll pre-lithiation pilot line was completed and is currently being used to pre-lithiate promising anode formulations

FUTURE WORK:

1. Complete Cell Build #2 and deliver cells to the National Labs
2. Down-select best pre-lithiation process to be used in final cell build
3. Complete Cell Build #3 development and freeze cell design for final program cell deliverable

Any proposed future work is subject to change based on funding levels

Responses to Reviewers Comments

Comment: "No pulse testing during cycling is reported, and the reviewer is concerned that the optimization based solely on specific energy and energy density will result in severe problems with pulse capability later in life."

Response: This year's work focused on power capability along with cell energy and cycle life. Pulse characterization results are included in the presentation after DST cycling and will continue to be highlighted during testing of Build #2 cells. Also ongoing cell development is evaluating cell resistance and power characteristics to identify and avoid problems later in the program.

Comment: "The reviewer believed that there should be a lot more test data before launching into a new cell vehicle (41 Ah cells). This could be a real problem depending on pulse and DST results."

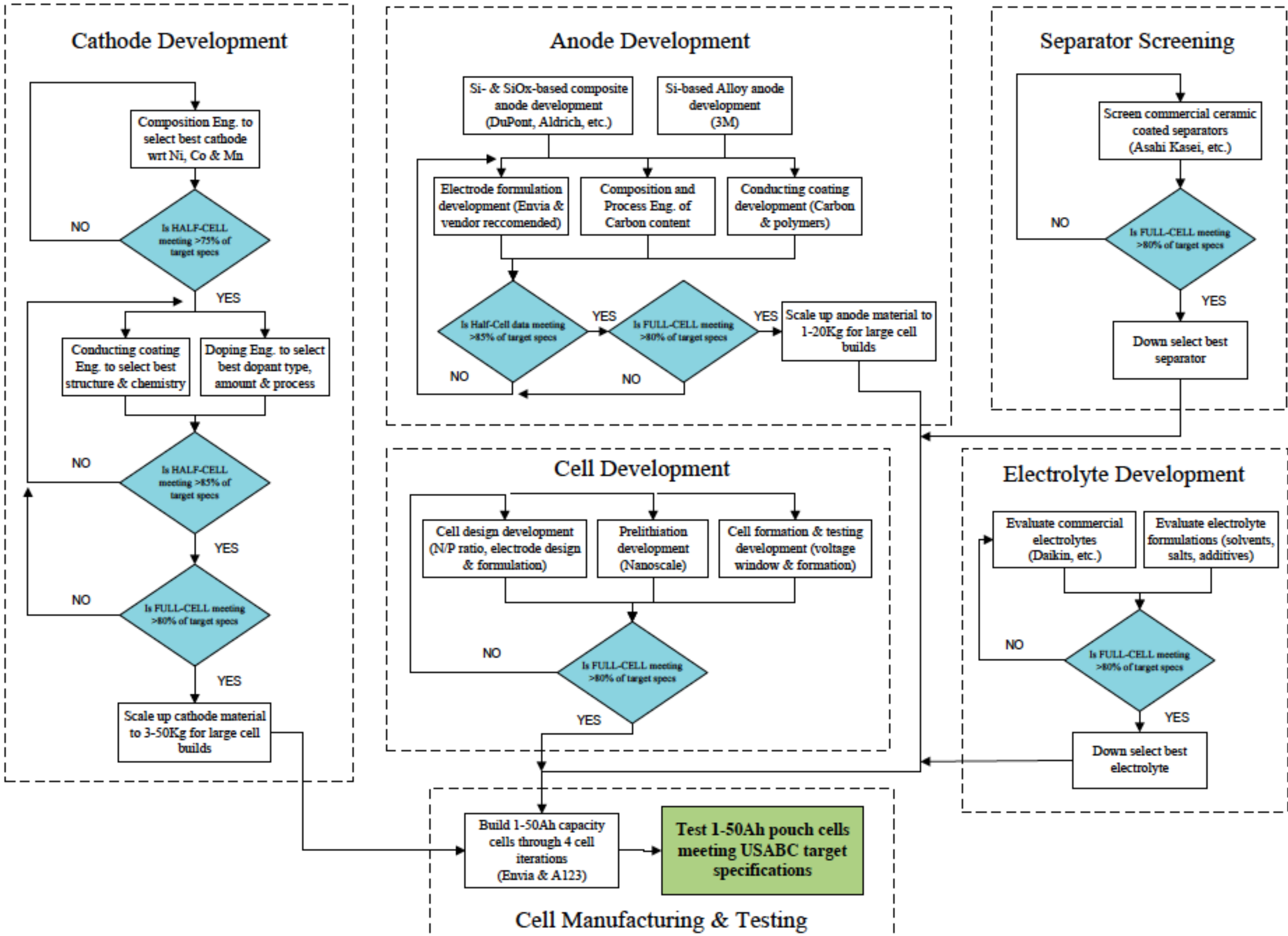
Response: The remainder of the program cell development will focus on a ~10 Ah capacity cell format and only a limited number of higher capacity cells (40+ Ah) will be delivered for evaluation at the end of the program.

Comment: "There seems to be an effort to include some statistical evaluations as well, which the reviewer feels is mandatory in this kind of development project."

Response: Envia has built and tested a greater number of cells to get better understanding on the reproducibility and cell performance. Preliminary results are shown in this presentation with the population to increase once Cell Build #2 is complete.

Technical Back-up Slides

Approach Strategy



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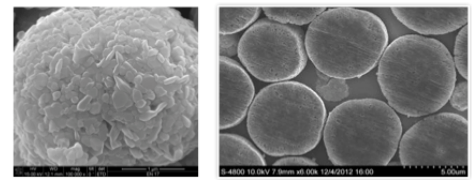
Cathode Development & Challenges

HEV, PHEV & EVs have different battery requirements ranging from power characteristics to cycle life. Envia solves the problem at the materials level by tailoring the cathode for each application



morphology

Nanocoating

<u>Morphology</u>:

- Particle size, shape, distribution, tap density & porosity

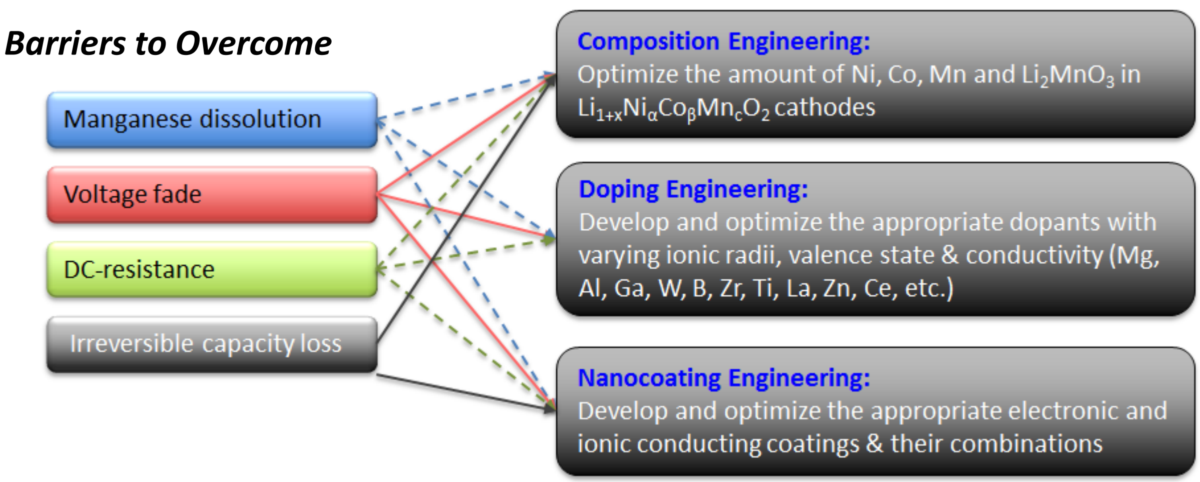
<u>Composition</u>:

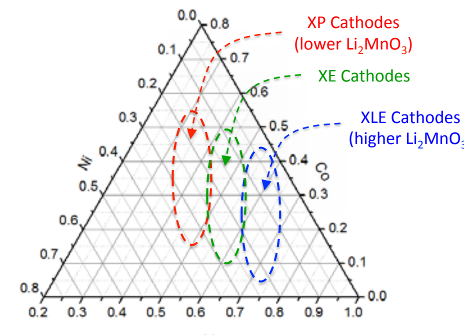
- Ni, Co, Mn ratio, & Li_2MnO_3 content
- Dopants & concentration

<u>Nanocoating:</u>

- Chemistry: fluorine, oxide, etc.
- Thickness & uniformity

HCMR™ Type	C/10 Capacity Range at 4.6V-2.0V (mAh/g)	Status
XP	200 ~ 220	Commercialization
XE	225 ~ 240	R&D
XLE	240 ~ 280	R&D





HCMR™ Cathode Phase Diagram