A Closed Loop Process for the End-of-Life Electric Vehicle Lithium-Ion Batteries

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Project ID #: ES293

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Overview

Timeline

- Project start date: Feb 2, 2016
- Project end date: Jan 15, 2018
- Percent complete: 60%

Barriers

- Barriers addressed
  - Cost
  - Performance

Budget

- Total project funding: $1,024,740
  - DOE share: $512,370
  - Contractor share: $512,370
- Funding received in FY 2016: $239,655
- Funding for FY 2017: $512,370

Partners

- Interactions/ collaborations: A123 Systems, Battery Resourcers, Argonne National Laboratory, General Motors, Ford, FCA, SNT
- Project lead: WPI

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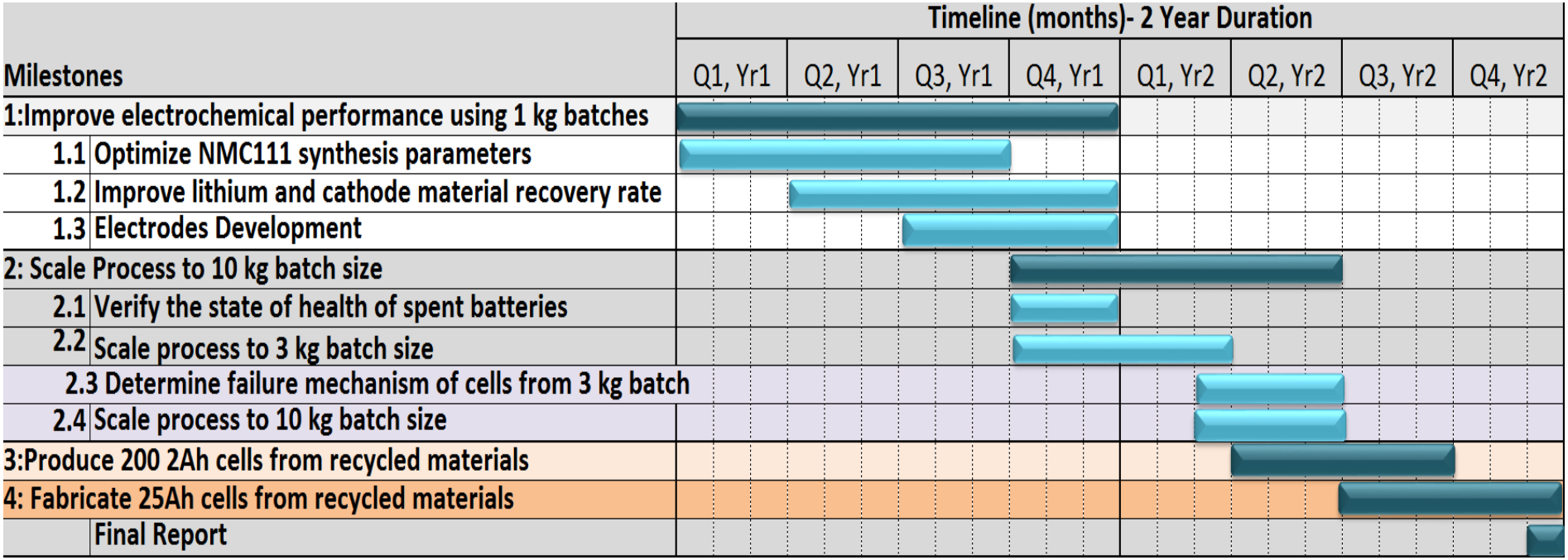
Relevance and Project Objectives

- Recycle multiple 10 kg size batches of end of life EV batteries consisting of different incoming cathode chemistries
- Produce cells of a single chemistry that could be used in a PHEV battery, to be tested according to USABC's PHEV test methods
- Improve the performance of the recovered cathode materials so that they exhibit performance on level with current commercial materials
- Recycle other materials including steel, copper, aluminum, etc.

Milestones



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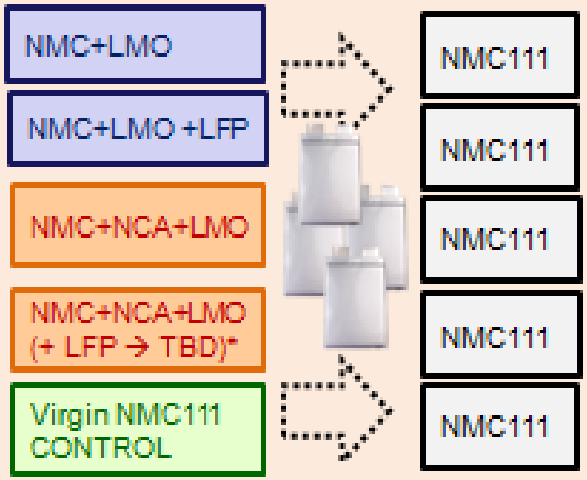
Cell Fabrication and Test Plan

Initial Scale-Up
from 1kg – 3 kg batch
(100 coin, 15 2Ah cells)

Process Optimization Metrics:

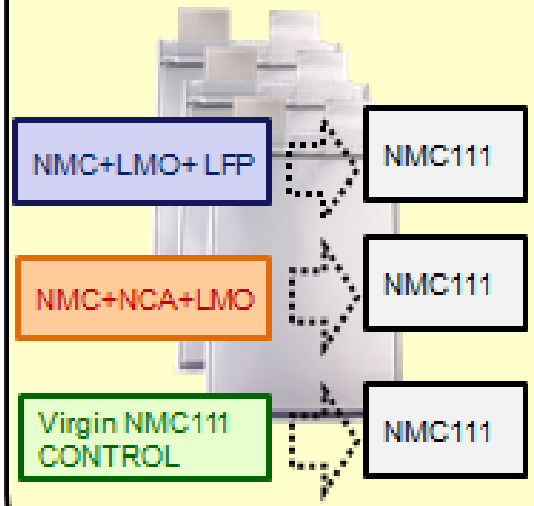
- Capacity (FCC, ICL)
- DCR impedance
- Rate capability
- Self discharge
- Cycle life trend
- Recovery efficiency

Scale-Up and Optimization Phase
(235 x 2 Ah cells) *10 kg batch sizes*



* WG will use 3 kg and 10 kg scale-up results to determine best composition for 4th group

Final Deliverables
(25 Ah cells)



Test Article	Total Made	Groups	USABC/ ANL	A123/ WPI	Comments
2 Ah NMC111/ gr cells	250	5	(5x10) 50 total	200	Majority of testing by A123/WPI to inform optimization
25 Ah NMC111/ gr cells	60	3	(3x10) 30 total	30	

WPI

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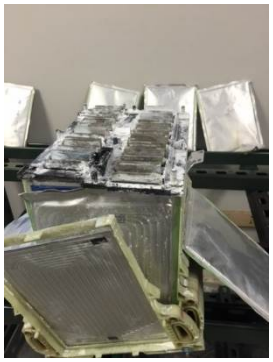
Approach: a Close Loop Process

Spent EV battery pack



Shredded pack

Recovered cathode powder

25Ah

Advantages:

- Any lithium Ion battery
- Any size and shape
- No sorting
- Synthesize new $LiNi_xMn_yCo_zO_2$ directly
- Ratio of Ni, Mn and Co can be specially tailored to customer demands

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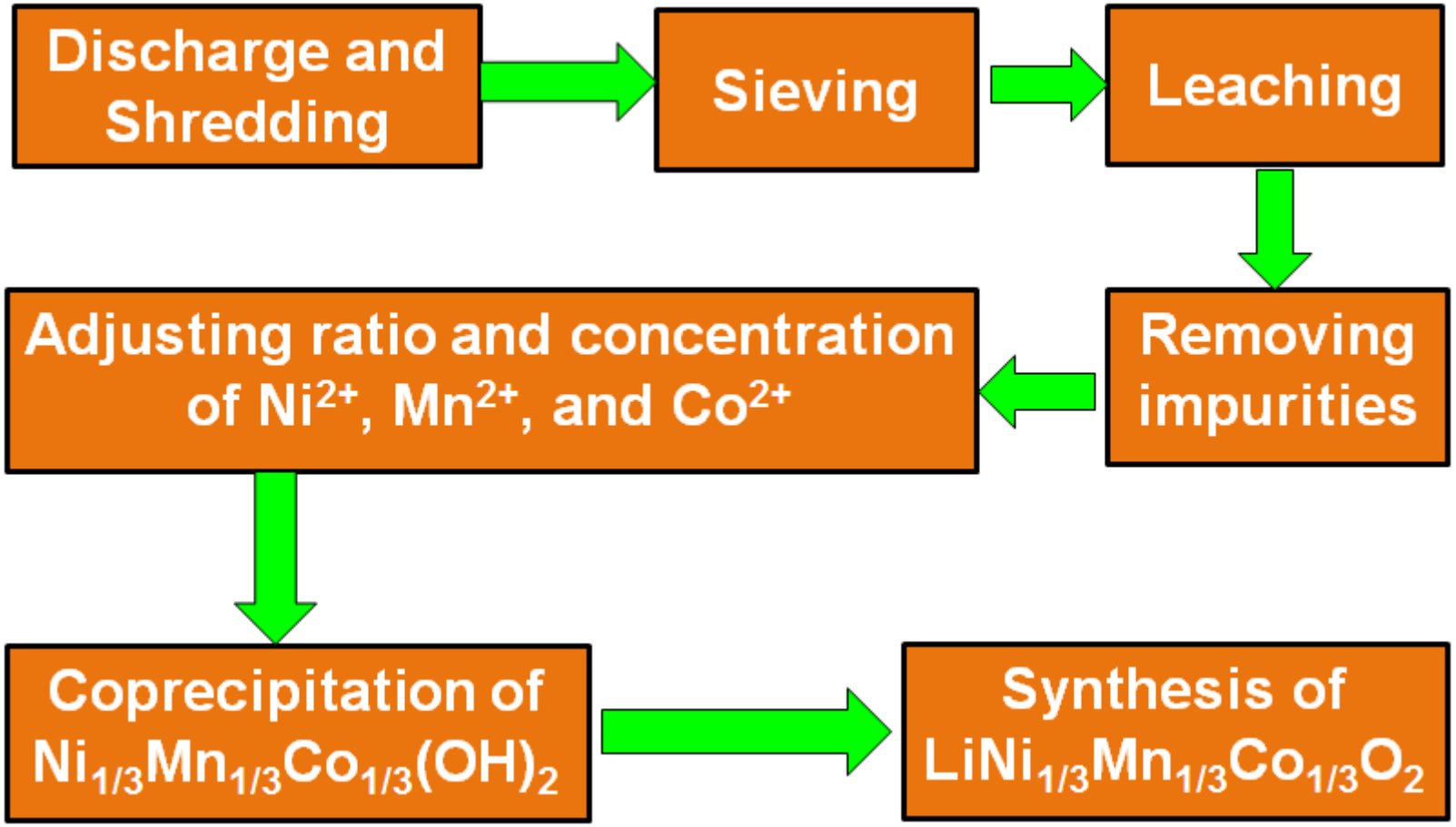
Technical Accomplishment and Progress: Recycling Process Has Been Developed



Recycling process is developed to offer a close loop process for the end of life EV batteries.

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NMC Cathode Has Been Optimized

pH	Residence time (h)	Molar ratio of NH_4OH to MSO_4	Stirring speed (rpm)	Cathode tap density (g/cm^3)	D50(µm)
10	6-T18	0.56	500	2.48	16.2
10	6-T30	0.47	550	2.65	22.6
10	6-T48	0.46	550	**2.84**	23.6
10	6-T48	0.46	550	2.52	13.7
10	6-T72	0.45	550	2.50	**10.5**

The table only shows a few experiments which we conducted.

Parameters are optimized to obtain high tap density and low particle size precursor ($Ni_{1/3}Mn_{1/3}Co_{1/3}(OH)_2$) and cathode ($LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$) powders.

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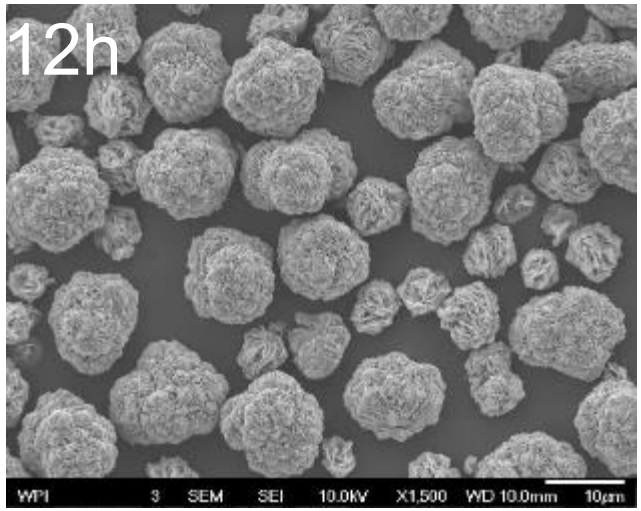
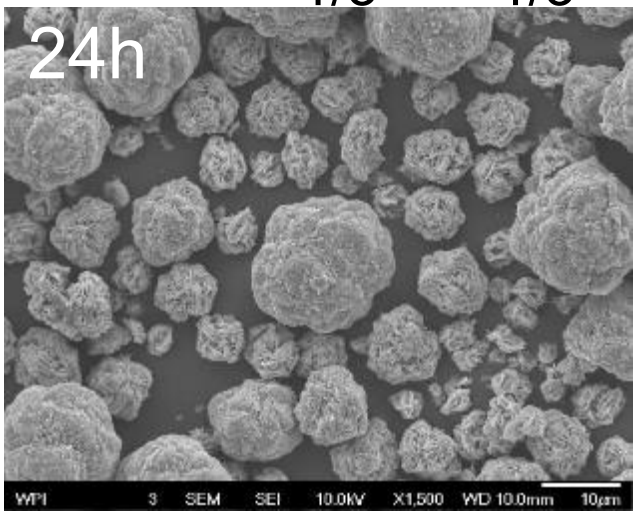
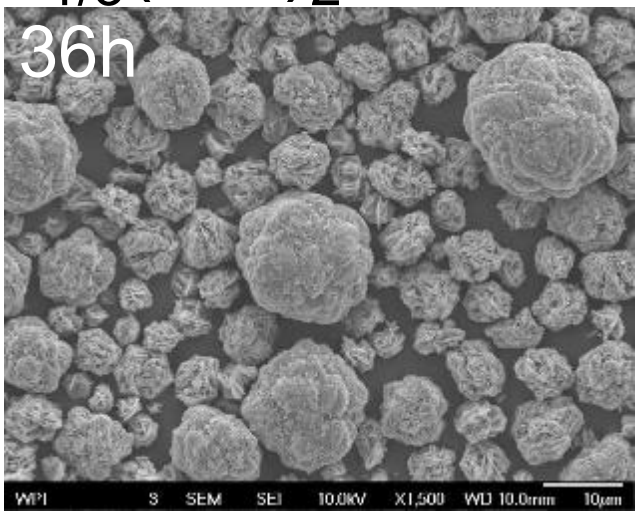
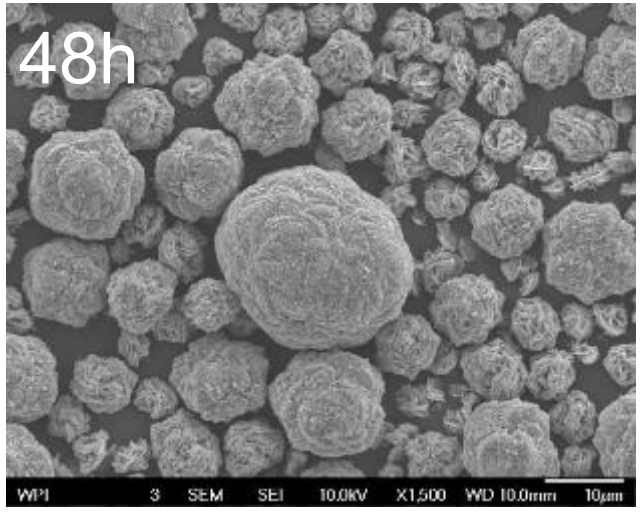
Synthesized $Ni_{1/3}Mn_{1/3}Co_{1/3}(OH)_2$









- High tap density, uniform spherical precursor powder.

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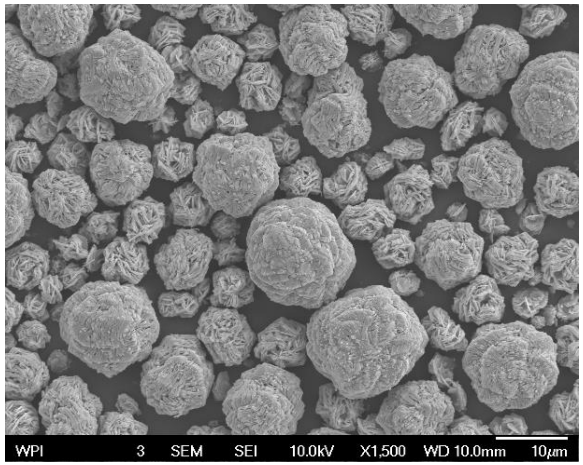
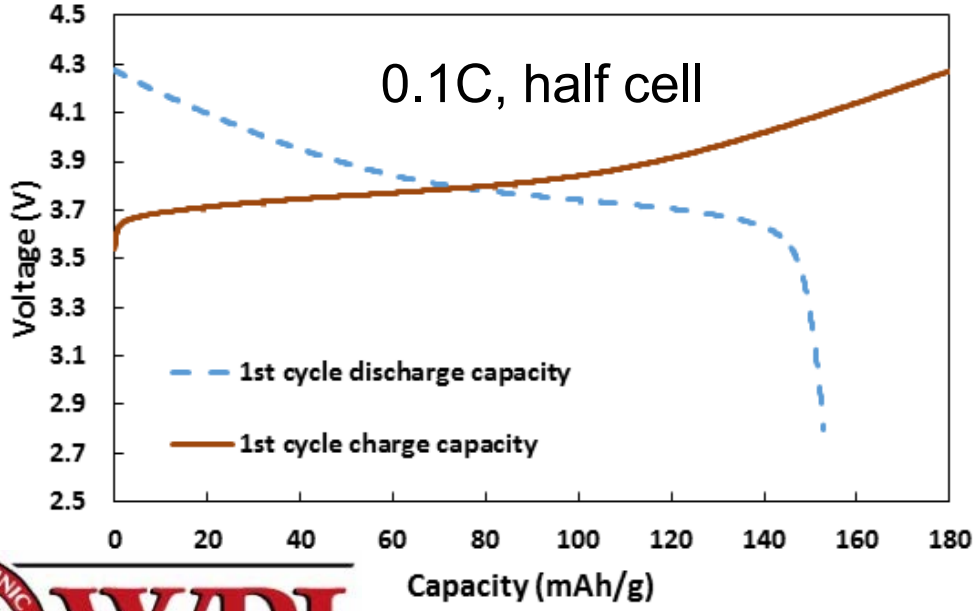
Synthesized $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$ Shows Good Performance





- Highly uniform cathode powder
- Good electrochemical properties

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Performance Comparisons (tested at A123)

Parameter (Units)	Before the Program	Current Status	Old Control	New Control	EOP Target
Particle size (D_{50})	N/A	10.5	7.4	9.2	**~10 um**
Tap Density (g/cc)	1.60	2.36	2.28	2.84	**>2.30**
Impurities	ICP results for Na, S, Cu, Fe, Al equal to or below commercial NMC				
FCC/FCD	170/150	181.7/159.1	164.6 / 145.9	174.7/157.2	**Within 5% Difference**
Efficiency	88.2	87.6	88.6	90.0	
1C (mAh/g)	N/A	129.1	132.9	130.9	
2C (mAh/g)	N/A	120.5	122.3	119.4	
5C (mAh/g)	N/A	39.6	36.7	40.4	
Dry adhesion (gf/in)	N/A	N/A	94.3	N/A	
Ni recovery effic. (%)	~70	80.1			**>80**
Mn recovery effic. (%)	~70	89.7			**>80**
Co recovery effic. (%)	~70	85.0			**>80**
Li recovery effic. (%)	~60	70.07			**>70**

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Responses to Previous Year Reviewers' Comments

Comment 1: The reviewer commented that the approach used in this effort is very effective at addressing the technical barriers identified for this project. One area of concern for this effort will be the quality of the materials that are generated as part of this recycling process. The reviewer advised that this is an area that needs to be more thoroughly addressed as the program proceeds.

Response: In the past year, the team has made very good progress on the synthesized cathode materials. In fact, the team spent most of the resources on this area.

Comment 2: The approach mentioned the need for recovery of Cu and aluminum, but the reviewer noted that there did not seem to be any specific work to accomplish this activity. The reviewer added that the approach to NCM recovery seemed valid.

Response: Although we recover Cu and Al in the recycling process, this is not our main focus.

Comment 3: The reviewer opined that collaboration and coordination with other institutions is one of the only weaknesses in this effort. The reviewer recommended that the program would significantly benefit from a broader collaborative team to include battery manufacturers that have a NMC or mixed metal oxide cathode as part of their base offering. This would provide the team with valuable input regarding the quality of the recycled materials that are being generated from their process and be key at identifying potential issues early in the development process.

Response: Our collaborator (A123 Systems) has significant experience on NMC materials although the main product is LiFePO4. We have benefited a lot from such collaboration. This is confirmed by our research progress.

Collaboration and Partners

Scale-up and commercialization

Fabricate commercial cells

Disassemble EV battery packs

Evaluate cells fabricated with recycled materials

Provide battery packs

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Remaining Challenges and Barriers

- Scale up

  Scale up the recycling process to 20kg spent Li-ion batteries.

- Cell fabrication

  2 Ah and 25 Ah cells will be fabricated and tested from different recycling stream.

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Proposed Future Work

- Scale-up the recycling process to generate 3kg cathode powder from each recycling stream
- Deliver recovered cathode material to A123 Systems for 2Ah and 25Ah cell fabrication
- Compare the performance of recovered cathode materials with commercial powder

Note: any proposed future work is subject to change based on funding levels

Summary

- A new technology has been proposed and developed by the researchers at WPI which is capable of recovering $LiNi_xMn_yCo_zO_2$ cathode material.
- The recycling technology offers a close loop process and can recycle Li-ion batteries with any shape, size and chemistry and sorting is not needed.
- Recovery efficiency has been optimized to enable good economic potential.
- The synthesized $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$ shows promising material and electrochemical properties.