A Closed Loop Process for the End-of-Life Electric Vehicle Li-ion Batteries: Phase II

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Overview

Timeline
- Project start date: Mar. 26, 2018
- Project end date: Mar. 31, 2021
- Percent complete: 100%

Budget
- Total project funding: $1,083,616
  - DOE share: $541,808
  - Contractor share: $541,808
- Funding received in FY 2020: $196,173

Barriers
- Barriers addressed
  - Cost
  - Performance
  - Supply
  - Sustainability

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

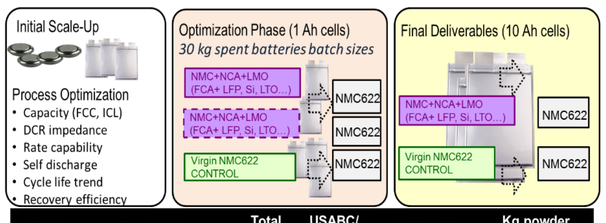
Relevance and Project Objectives

- During the course of the Phase I USABC program which focused on using recycled batteries to produce NMC111, the team has observed that the xEV battery industry is moving to higher nickel NMCs.
- Building on the successful Phase I program, the overall objective of the Phase II program is to demonstrate the recovery of NMC622 cathode materials from recycled lithium ion batteries with mixed cathode and anode chemistry, and added complexity of adhesives, silicon and LTO that are anticipated materials in the future waste stream.
- The cost model will be updated based on the new chemistry process update and scale-up.

Milestones

Time	Description
December, 2020	Recovered cathode material shows similar properties of commercial control powder (*complete*)
December, 2020	Verify the recycling process is economical feasible (*complete*)
February, 2021	Submit final report of the project (*complete*)

Cell Fabrication and Test Plan



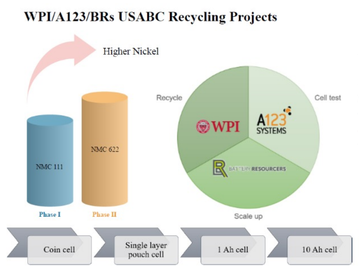
Build	Test Article	Total Made	USABC/ ANL	A123/ WPI	Kg powder per group
1	1 Ah NMC622/gr	20	12	8	6 (WPI)
1-control	1 Ah NMC622/gr	20	12	8	6 (comm.)
(2)*	(1 Ah NMC622/gr)*	(20)*	(12)*	(8)*	6 (WPI))*
3	10 Ah NMC622/gr	20	12	8	15
3-control	10 Ah NMC622/gr	20	12	8	15 (comm.)

* 2nd 1 Ah build will only be executed if required. Depends upon 1st build results.

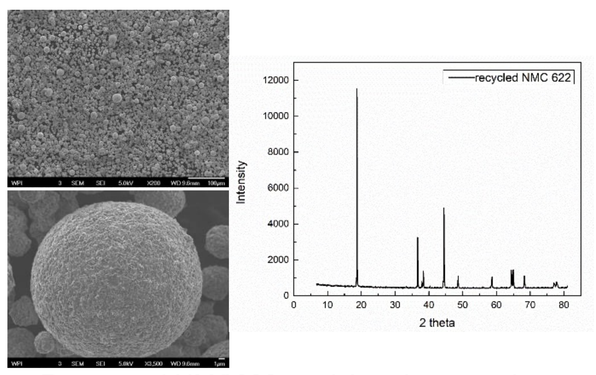
- Coin cells, 1 Ah cells and 10Ah cells will be used to evaluate the recovered NMC622

Approach: a Close Loop Process

- Develop high nickel NMC from the spent EV batteries
- Understand the impacts of different anode materials and adhesives on the recycling process
- Develop scalable coating method for NMC622
- Recovered materials are tested in large pouch cells at A123 Systems
- The scale-up and cost model of the recycling process are developed at Battery Resourcers

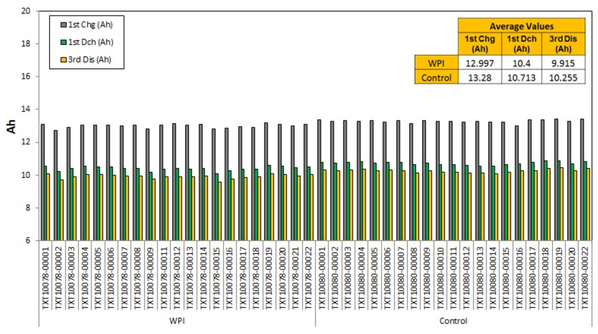


Previous Accomplishments



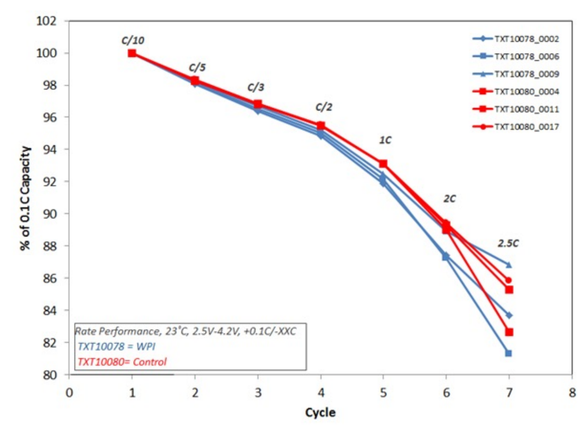
- Recovered NMC622 particles show good morphology, crystallinity and bimodal distribution.

Technical Accomplishment and Progress-10Ah Cell Formation



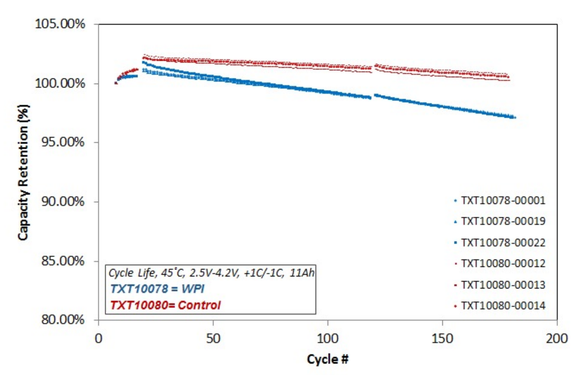
- Target cell capacity for both WPI recycled and control is reached.
- The cells have very good consistency.

10Ah Cell Rate Performance



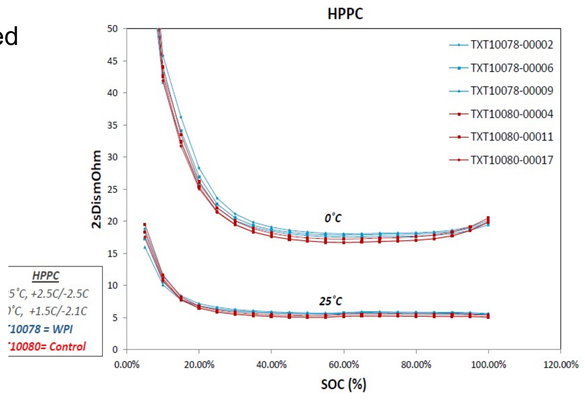
- The rate performance is similar between WPI recovered NMC622 and commercial NMC622.

10Ah Cell Cycle Performance



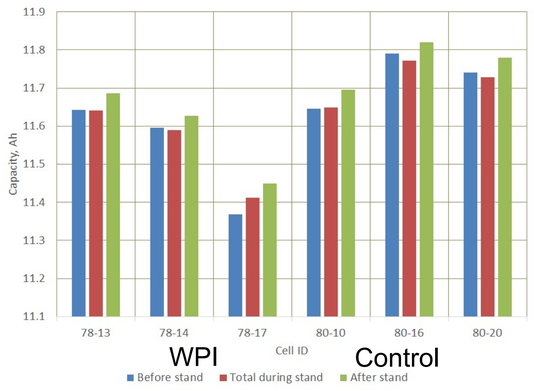
- The 10Ah cells with recovered NMC622 fade quicker than control cells.

10Ah Cell- HPPC



- The cells with recovered NMC622 have similar HPPC performance as control cells.

30-Day Stand Test



- Similar capacity loss after 30 days
- Full capacity gain on all cells occurred after 30 days
- Both meet EV requirement <1%/month

Cost Analysis- Input Battery Parameters

Recycle		
Throughput	tonne/yr	2,444
NMC(111)	%	75%
LMO	%	25%
NMC(111)	%	
Select Chemistry	%	
Select Chemistry	%	
Geographic location		U.S.
Include recycling of manufacturing scrap		Yes
Include recycling of rejected cells		Yes
Cathode Production		
Cathode chemistry		NMC(622)
Throughput	tonne/yr	1,000
Geographic location		U.S.

- The plant is to recycle 2,444 tons of spent lithium ion batteries per year
- Input materials are spent lithium ion batteries with 75% NMC111 and 25% LMO.
- Output material is NMC622.

Plant Details

1.2 Plant information		
	Selected	Default
Hours per day	24	24
Actual Processing hours per day	20	20
Days per year	320	320
Plant life (yr)	10	10
Plant capacity (tonne per yr)	2,444	2,444
Throughput (tonne per year)	1,000	1,000
Process classification	Continuous	

- The plant is open 24hrs a day with 20hrs of run time.
- The plant will run 320 days per year.
- The plant life for equipment depreciation is set to be 10 years.

Total Cost of the Recycling Plant

	Pyrometallurgical Process	WPI Process		Virgin Material
I. Manufacturing Cost, $/year	$46,260,238	$20,175,804	#N/A	$26,312,017
A. Direct Product Costs	$39,407,730	$13,323,296	#N/A	$19,459,509
Raw Materials (10-50% of total product cost)	10%	10%	10%	10%
	$34,235,639	$8,441,032	#N/A	$14,509,065
Operating labor (10-20% of total product cost)	15%	15%	15%	15%
	$2,189,940	$2,189,940	$2,189,940	$2,189,940
Direct supervisory and clerical labor (10-25% of operating la	15%	15%	15%	15%
	$328,491	$328,491	$328,491	$328,491
Utilities (10-20% of total product cost)	15%	15%	15%	15%
	$503,419	$503,419	$503,419	$503,419
Maintenance and Repairs (2-10% of fixed capital investmer	5%	5%	5%	5%
	$1,226,958	$1,226,958	$1,226,958	$1,226,958
Operating supplies (10-20% of cost of maintenance and re	15%	15%	15%	15%
	$184,044	$184,044	$184,044	$184,044
Laboratory charges (10-20% of operating labor)	10%	10%	10%	10%
	$218,994	$218,994	$218,994	$218,994
Patents and royalties (0-6% of total product cost)	1%	1%	1%	1%
	$520,245	$230,418	#N/A	$298,598
B. Fixed Charges	$4,979,814	$4,979,814	$4,979,814	$4,979,814
Depreciation (10% of fixed capital investment and 2-3% of t	10%	10%	10%	10%
	$2,398,999	$2,398,999	$2,398,999	$2,398,999
Local taxes (1-4% of fixed capital investment)	4%	4%	4%	4%
	$981,566	$981,566	$981,566	$981,566.37
Insurance (0.4-1% of fixed capital investment)	1%	1%	1%	1%
	$122,696	$122,696	$122,696	$122,695.80
Rent (8-12% of value of rented land and buildings)	5%	5%	5%	5%
	$113,266	$113,266	$113,266	$113,266.00
Financing (interest) (0-10% of total capital investment)	5%	5%	5%	5%
	$1,363,287	$1,363,287	$1,363,287	$1,363,286.62
C. Plant Overhead Costs (50-70%) of operating labor, supe	50%	50%	50%	50%
	$1,872,694	$1,872,694	$1,872,694	$1,872,694
II. General Expenses, $/year = administrat	$5,764,258	$2,865,988	#N/A	$3,547,789
A. Administrative costs (15% of costs of operating labor, su	15%	15%	15%	15%
	$561,808	$561,808	$561,808	$561,808
B. Distribution and selling costs (2-20% of total product co	6%	6%	6%	6%
	$3,121,470	$1,382,508	#N/A	$1,791,588
C. R&D costs (2-5% of every sales dollar or 5% of total prod	4%	4%	5%	4%
	$2,080,980	$921,672	#N/A	$1,194,392
III. Total Product Cost, $/year = Manufacti	$52,024,496	$23,041,792	#N/A	$29,859,806
Profit (5% of capital investment)	5%	5%	5%	5%
Profit, $/year	$1,363,287	$1,363,287	$1,363,287	$1,363,287
Total Product Cost w/Profit	$53,387,783	$24,405,079	#N/A	$31,223,093
Total Product Cost to Recipient, $/kg	$51.88	$24,405.08	#N/A	$31,223.09

- The cost is based on Argonne EverBatt model.
- $23M for WPI process, $29.8M for virgin cathode manufacturing and $52M for pyrometallurgical process.

Battery Resoucers Cost Model vs EverBatt Model

	BR Model Recycled (1kton)	BR Model Recycled (2.5kton)	BR Model Virgin (1kton)	EverBatt Model BR/recycled (1 kton)	EverBatt Model Virgin (1 kton)
BR (75NMC111/25LMO)	$18.34/kg		$22.52	$23.0	$29.86
SG&A removed				$20.04	$26.2
NMC622 input	$17.27	$15.88			
NMC111 input	$17.97	$16.52			

- Both models are consistent.
- Recycling will lower the cathode cost
- Scaling will lower the cathode cost.

Responses to Previous Year Reviewers' Comments

Comment 1: The reviewer believed the idea is to collect Li-ion cells and, independent of the chemistry, collect the internal material and convert it to NMC622. This is a reasonable team where A123 will make and test cells, Battery Resourcers will collect the Ni-based cathode, and then Worcester Polytechnic Institute will determine how to make fresh NMC622 from the material. The goal of the project is to make an NMC622 that is cheaper than starting from scratch. The team needs to perform the cost analysis.
Response: A detailed cost analysis has been conducted and is included in this poster.

Comment 2: It appeared to the reviewer that the team is using a relatively well known and understood cathode manufacturing processes. The technical accomplishment is not clear. Where is the value in this work?
Response: The value of this work is to convert spent lithium ion batteries with different chemistry to NMC622. Although cathode manufacturing is well known, recovering high quality NMC622 from spent lithium ion batteries is not trivial. Some technical accomplishments include 1. impurity removal, 2. synthesis of NMC6622 precursor with complex systems

Comment 3: It is important to build a cost model to show the economic benefits. Moving to NMC811 is also right direction. The reviewer also suggested performing an assessment on the nature of resource savings, like how much Co and Li are reused in the batteries.
Response: A cost model has been developed. In our process, over 80% Co, and Li are reused in the batteries.

Collaboration and Partners

- Scale-up and commercialization
- Fabricate commercial cells
- Disassemble EV battery packs
- Evaluate cells fabricated with recycled materials
- Provide battery packs

Proposed Future Work

- **A phase III program** has been awarded to further develop the recycling technology.
- The overall objective of phase III program is:

1) to lower the cathode cost by >30% through adding >80% recycled materials for metal sulfate solution (<20% virgin materials);
2) to develop LiNixMnyCozAlaO2 (x≥0.8) from the spent EV batteries;
3) to improve the performance of the recovered NMC622 (mainly solve the gas generation and cycle life) in order to be comparable with commercial material.

Hardware Deliverable	Description	Source Material	Qty	Recipient	Delivery Date
Coin cells	Coin cells (NMC622)	Spent batteries	50-75	A123	M10
Coin cells	Coin cells (NMCA)	Commercial control	100	A123	M15
Coin cells	Coin cells (NMCA)	Spent batteries	100-200	A123	M15
Small cells	Prismatic 1Ah cells (NMC622)	Spent batteries	12	USABC	M12
Small cells	Prismatic 1Ah cells (NMC622)	Spent batteries	8	A123	M12
Small cells	Prismatic 1Ah cells (NMCA)	Commercial control	12	USABC	M18
Small cells	Prismatic 1Ah cells (NMCA)	Commercial control	8	A123	M18
Small cells	Prismatic 1Ah cells (NMCA)	Spent batteries	12	USABC	M18
Small cells	Prismatic 1Ah cells (NMCA)	Spent batteries	8	A123	M18
EV cells	Prismatic 10Ah cells (NMCA)	Commercial control	12	USABC	M33
EV cells	Prismatic 10Ah cells (NMCA)	Commercial control	8	A123	M33
EV cells	Prismatic 10Ah cells (NMCA)	Spent batteries	12	USABC	M33
EV cells	Prismatic 10Ah cells (NMCA)	Spent batteries	8	A123	M33

- Cell Deliverables in Phase III Program

Summary

•The recycled powder shows good morphology, crystallinity and particle size distribution.

•Recovered NMC622 shows similar capacity as the commercial NMC622 powder

•10 Ah cells with recovered NMC622 show similar properties with the control powder except for the cycle life, which will be addressed in phase III program

•Cost model shows the economical feasibility of the WPI recycling technology

•Scaling will lower the cathode cost

2021 DOE Annual Merit Review

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