RECELL CENTER FOCUS AREAS:

-DIRECT CATHODE RECYCLING
-OTHER MATERIALS SEPARATION

Project ID bat434

J. SPANGENBERGER
Argonne National Laboratory
June 11,2019

2019 DOE Vehicle Technologies Office
Annual Merit Review

OVERVIEW

Timeline

- Project start: October 2018
- Project end: September 2021
- Percent complete: ~15%

Barriers

- Recycling and Sustainability
  - Cost to recycle is currently 5-15% of battery cost
  - Material shortage (Li, Co, and Ni)
  - Varying chemistries result in variable backend value

Budget

Year 1	$4,615k
Argonne	*$2650k*
NREL	*$965k*
ORNL	*$550k*
UCSD	*$150k*
WPI	*$150k*
MTU	*$150k*

Partners

- Argonne National Laboratory
- National Renewable Energy Laboratory
- Oak Ridge National Laboratory
- University of California, San Diego
- Worcester Polytechnic Institute
- Michigan Technological University

RELEVANCE - RECELL CENTER

Objective:

Foster the development of cost-effective and environmentally sound processes to recycle lithium-ion batteries

Bring together battery recycling experts to bridge technical and economic gaps to enable industry adoption

Impact:

Reduced cost of ownership and helping to drive battery costs to DOE’s $80/kWh goal

Reduce primary material production to avoid material shortages and reliance upon foreign sources, increasing our nation’s energy security

Minimize environmental impacts of the battery life cycle

MILESTONES

Q1 (Center) Establish the battery recycling center’s mission and include its targets and goals

✓ COMPLETED 12/21/18:

“Decrease the cost of recycling lithium ion batteries to ensure future supply of critical materials and decrease energy usage compared to raw material production”

Q2 (NREL) Provide an initial progress report on roll-to-roll relithiation

✓ COMPLETED 3/29/19: Roll-to-roll relithiation work is progressing and the concept is currently being tested using coin cells

Q3 (ORNL) Provide an initial progress report on design for recycle initiative

In progress

Q4 (ANL) Establish the ReCell Center’s Battery Recycling Laboratory and Scale-up Facility

In progress

COLLABORATION AND ACKNOWLEDGEMENTS

Argonne NATIONAL LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

OAK RIDGE National Laboratory

Michigan Technological University 1885

WPI

UC San Diego

ReCell ADVANCED BATTERY RECYCLING

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy VEHICLE TECHNOLOGIES OFFICE

Support for this work from the Office of Vehicle Technologies, DOE-EERE, is gratefully acknowledged –
Samm Gillard, Steven Boyd, and David Howell

Shabbir Ahmed (Argonne)
Ilias Belharouak (ORNL)
Ira Bloom (Argonne)
Anthony Burrell (NREL)
Zheng Chen (UCSD)
Chris Claxton (Argonne)
Jaclyn Coyle (NREL)
Qiang Dai (Argonne)
Sheng Dai (ORNL)
Erik Dahl (Argonne)
Zhijia Du (ORNL)
Alison Dunlop (Argonne)
Kae Fink (NREL)
Tinu Folayan (MTU)
Tony Fracaro (Argonne)
Linda Gaines (Argonne)
Daniel Inman (NREL)
Andy Jansen (Argonne)
Sergiy Kalnaus (ORNL)
Matt Keyser (NREL)
Dave Kim (Argonne)
Greg Krumdick (Argonne)
Jianlin Li (ORNL)
Xuimin Li (NREL)
Albert Lipson (Argonne)

Huimin Luo (ORNL)
Josh Major (NREL)
Margaret Mann (NREL)
Tony Montoya (Argonne)
Helio Moutinho (NREL)
Nitin Muralidharan (ORNL)
Andrew Norman (NREL)
Lei Pan (MTU)
Anand Parejiya (ORNL)
Ahmad Pesaran (NREL)
Bryant Polzin (Argonne)
Kris Pupek (Argonne)
Seth Reed (Argonne)
Bradley Ross (Argonne)
Shriram Santhanagopalan (NREL)
Jeff Spangenberger (Argonne)
Venkat Srinivasan (Argonne)
Darlene Steward (NREL)
Jeff Tomerlin (NREL)
Steve Trask (Argonne)
Jack Vaughey (Argonne)
Yan Wang (WPI)
Zhenzhen Yang (Argonne)
Ruiting Zhan (MTU)

ReCell
ADVANCED
BATTERY RECYCLING

DIRECT CATHODE RECYCLING

FOCUS LEAD: JACK VAUGHEY

APPROACH – DIRECT CATHODE RECYCLING

Several phenomena contribute to the gradual breakdown in lithium-ion battery performance, including surface degradation, cathode instability, reactivity with organic electrolyte components, and surface films. These phenomena need to be reversed and performance restored.

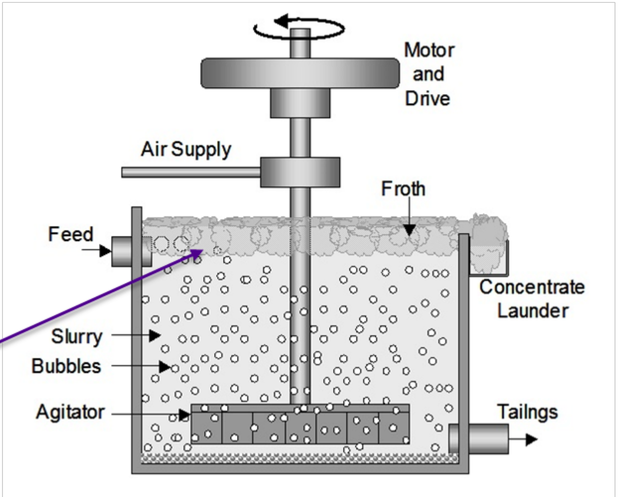
- Cathode Separation
  - Froth Flotation – L. Pan (MTU)
  - Magnetic Separation – E. Dahl (Argonne)
- Binder Removal – A. Lipson (Argonne)
- Relithiation
  - Electrochemical – J. Coyle, X. Li (NREL)
  - Solid State – J. Vaughey (Argonne)
  - Hydrothermal – Z. Chen (UCSD)
  - Ionothermal – S. Dai (ORNL)
- Compositional Change
  - Solid State – J. Vaughey (Argonne)
  - Role of Impurities – Y. Wang (WPI)

CATHODE SEPARATION – FROTH FLOTATION

A commercial waste stream may represent different cathodes, from different users, from different eras, for different devices. Direct recycling requires single battery chemistries (or compatible chemistries) to be successful in the marketplace. This effort examines using surface chemistry, pH, and froth flotation to separate different battery cathodes.

Cathode	Natural pH	Recovery (%)
NMC 111	8.28	9%
NMC 811	10.48	<2%
LFP	10.50	100%
NCA	10.50	<2%
LMO	7.40	6%
D-NMC 111*	6.80	<2%

The hydrophobicity of LFP powders is attributed to carbon coatings on surfaces

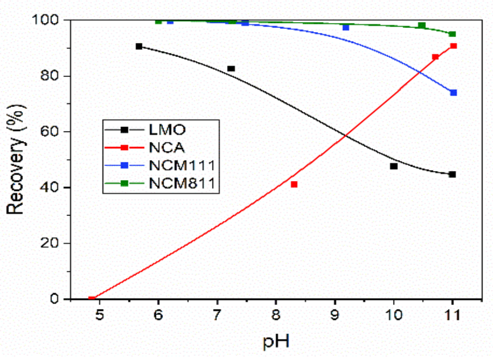


Cathode collected in froth layer (3min)

CATHODE SEPARATION – FROTH FLOTATION

Froth flotation separation of individual cathode chemistries using different collectors at different pHs has been evaluated.

Condition		D-NMC 111	NMC 111	NMC 811	LMO
Collector	**pH**				
Salicylaidixime	Natural	18%	80%	0%	72%
Salicylaidixime	6	-	76%	18%	86%
Cupferron	Natural	22%	34%	16%	38%
Cupferron	6	<2%	60%	46%	43%
Hydroxamate	Natural	95%	93%	96%	68%
Hydroxamate	6	-	96%	91%	63%
Fatty acid	Natural	100%	100%	98%	63%
Fatty acid	6	-	99%	100%	96%
Phenylthiourea	Natural	56%	33%	67%	40%
Phenylthiourea	6	-	37%	27%	47%



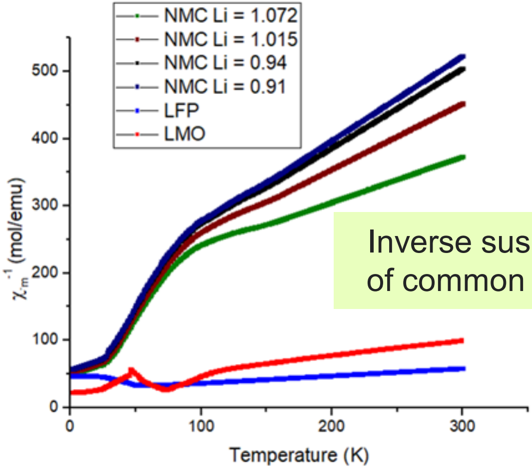
Preliminary results: both hydroxamate and fatty acid work effectively in rendering NMC 111 and NMC 811 hydrophobic. NCA at pH= 6 is hydrophilic regardless of types of collectors used.

These results suggest that both hydroxamate and fatty acid might be the candidates for separation of individual cathode chemistries.

CATHODE SEPARATION - MAGNETIC

	Percentage of Retained Material by component	
	Average	
Residual Flux Density [G]	NMC111	LMO
7000	22.4%	77.6%
8300	25.0%	75.0%
9600	29.3%	70.7%
10300	33.7%	66.3%
12300	39.4%	60.6%
13050	42.1%	57.9%
14000	43.5%	56.5%
14800	46.1%	53.9%

1:1 mixtures of LMO and NMC111 were created and passed through magnetic fields of various strengths. The higher magnetic susceptibility of LMO relative to NMC111 allows for its separation. The purest fractions of LMO are obtained under the influence of magnetic fields that lack the strength to retain NMC111.

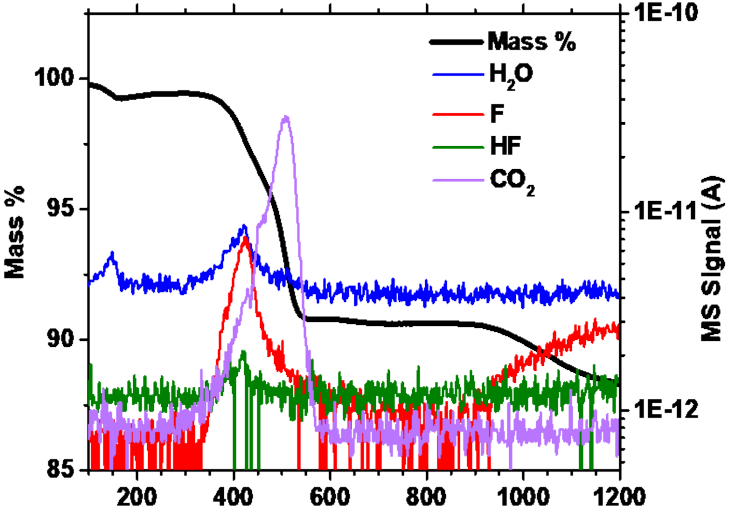


Inverse susceptibility of common cathodes

BINDER REMOVAL

The cathode materials within the black mass are mixed with other electrode components and coated with polymeric binders, such as PVDF. Three possible methods of separation are thermal degradation, dissolution, and mechanical separation.

Thermal Decomposition



TGA-MS

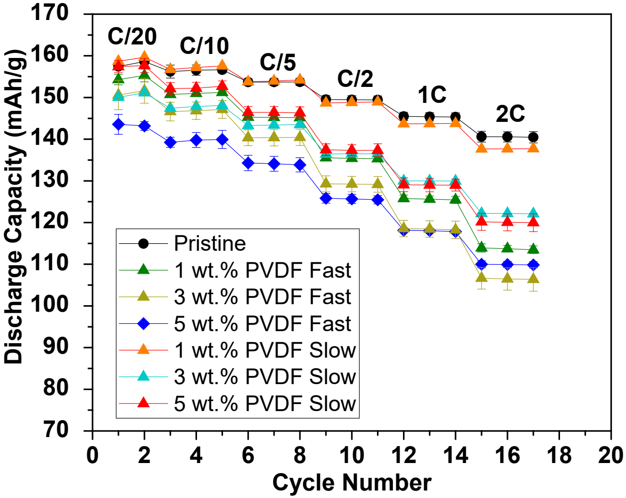
- PVDF decomposes near 400°C
- Carbon black burns near 500°C
- About 90.8% of the mass remains including 0.8 wt.% fluorides or other species remaining

Fluoride Sequestration

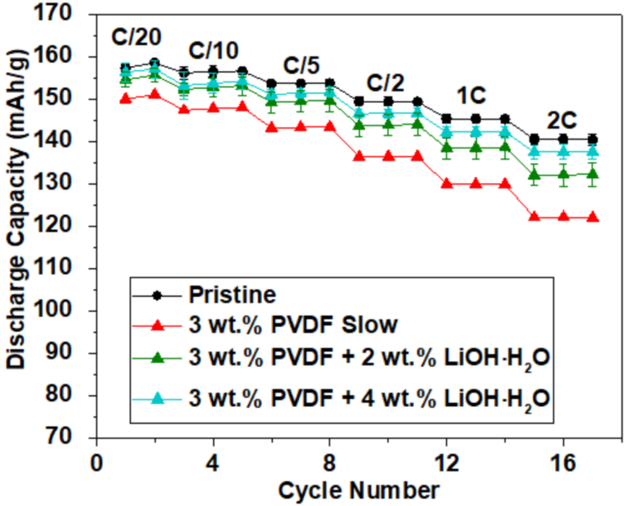
Adding LiOH to the binder burnout process sequesters the active fluoride from the PVDF decomposition as LiF, blocking a reaction with the NMC cathode.

BINDER REMOVAL

Electrochemical evaluation of recovered cathodes: Best performance was using slow burnout (to 500 ºC over 15h), with addition of a lithium source to tie up the fluoride formed during burnout before it can form LiF with lithium from the cathode.



Thermal Binder Removal (rate and % PVDF)



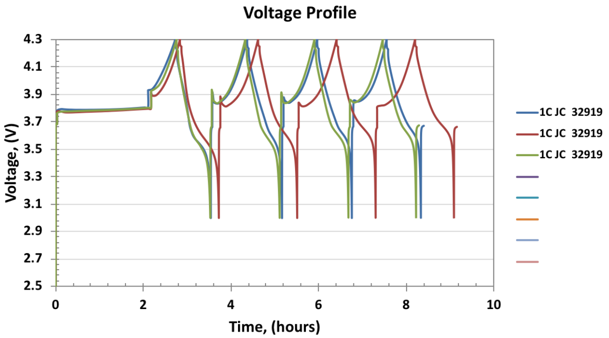
Adding 4 wt.% LiOH·H_2O shows similar rate performance and capacities to the pristine material

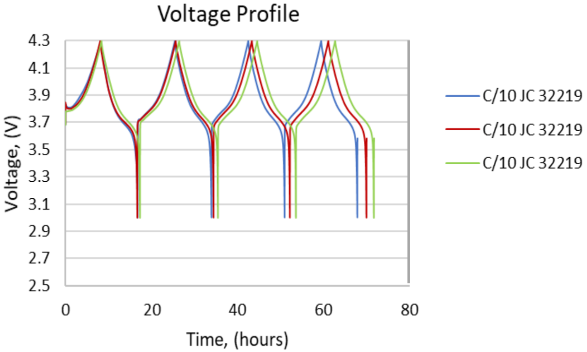
CATHODE RELITHIATION – ELECTROCHEMICAL

Half cell with delithiated baseline NMC111 cathode

Formation Protocol at 25ºC, 3.0-4.3 V:
4 Cycles of 1C Charge, 1C Discharge

Formation Protocol at 25ºC, 3.0-4.3 V:
4 Cycles of C/10 Charge, 1C Discharge





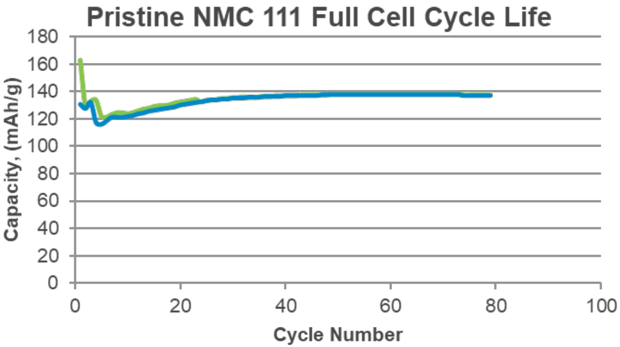
NMC 111 Chemically Delithiated Averages	1st Cycle Charge (mAh/g)	1st Cycle Discharge (mAh/g)	1st Cycle Efficiency	Reversible (3rd) Cycle Charge (mAh/g)	Reversible (3rd) Cycle Discharge (mAh/g)
1C 4x NREL (3 cells)	134	127	95%	128	126
C/10 4x NREL (3 cells)	144	141	98%	143	141

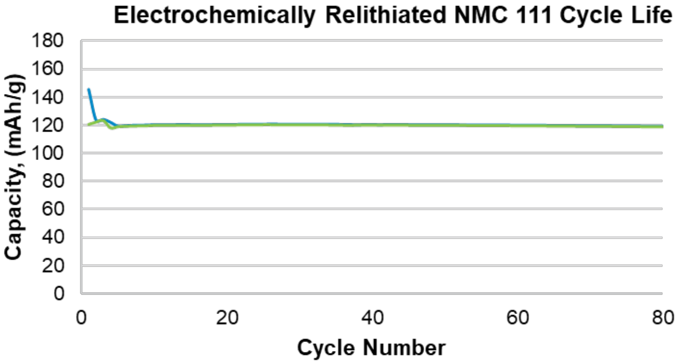
CATHODE RELITHIATION – ELECTROCHEMICAL

Full cell with electrochemically relithiated NMC111 electrode

Aging Protocol at 25ºC, 3.0-4.2V:
Pristine NMC 111/TODA graphite
4 Cycles of C/10 Formation, C/3 Discharge/Charge

Relithiated Cathode Protocol at 25ºC, 3.0-4.2V:
Relithiated Chemically Delithiated NMC111 (C/10 rate 4x)/ TODA graphite
Aging: 4 Cycles of C/10 Formation, C/3 Discharge/Charge





1st cycle "C" Capacity	162.6	mAh/g
1st cycle "D" Capacity	131.0	mAh/g
1st cycle eficency	80.6	%
Reversible "C" capacity	129.0	mAh/g
Irriversible capacity loss	33.5	mAh/g
% Capacity loss	20.6	%

1st cycle "C" Capacity	145.5	mAh/g
1st cycle "D" Capacity	120.5	mAh/g
1st cycle efficiency	82.9	%
Reversible "C" capacity	120.1	mAh/g
Irriversible capacity loss	25.4	mAh/g
% Capacity loss	17.5	%

CATHODE RELITHIATION – SOLID STATE

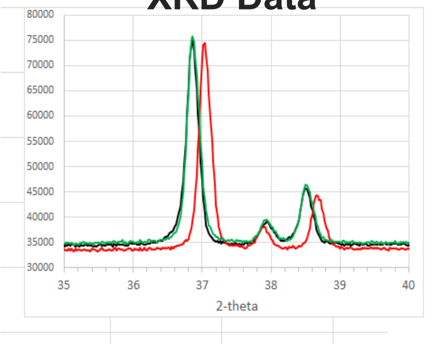
Delithiated baseline NMC111 samples were re-lithiated using a variety of lithium salts based on thermal stability of TGA measurements. Relithiation confirmed by XRD and GDOES elemental analysis.

	I_{003}/I_{104}	I_{003}/I_{104} (Post anneal)
Pristine NMC 111	1.29	1.27
Delithiated NMC 111	1.26	1.04
NMC Relithiated (LiOH H_2O)	1.20	1.13
NMC Relithiated (Li_2CO_3)	1.33	1.35
NMC Relithiated (LiOH)	1.24	1.27

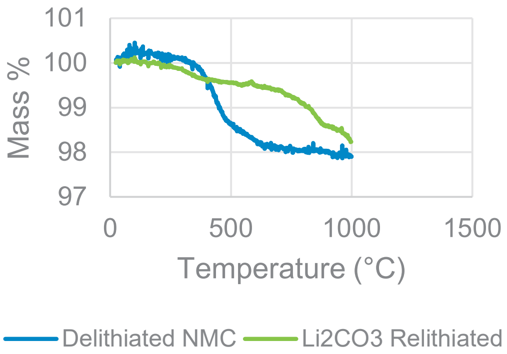
Heating samples may disorder the Li/Ni sites increasing cell impedance. The 003/104 ratio is used as a measure of this mixing.

Delithiated baseline showed significant site mixing on annealing

XRD Data



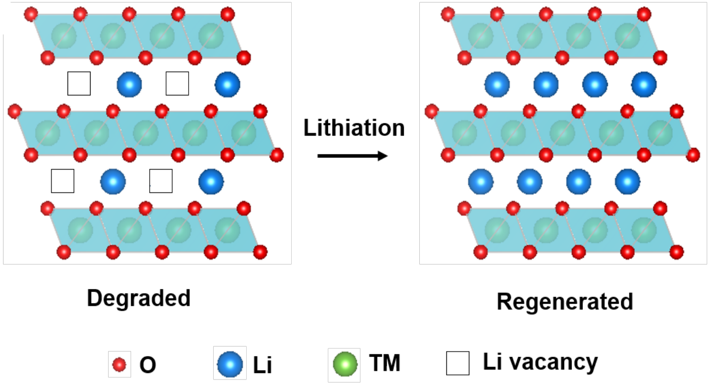
TGA Stability



Vaughey, et al., ANL

CATHODE RELITHIATION – HYDROTHERMAL

Hydrothermal relithiation was first performed on chemically delithiated NMC111 cathodes and the composition of different cathode particles was quantified using inductively coupled plasma mass spectrometry (ICP-MS) measurements.



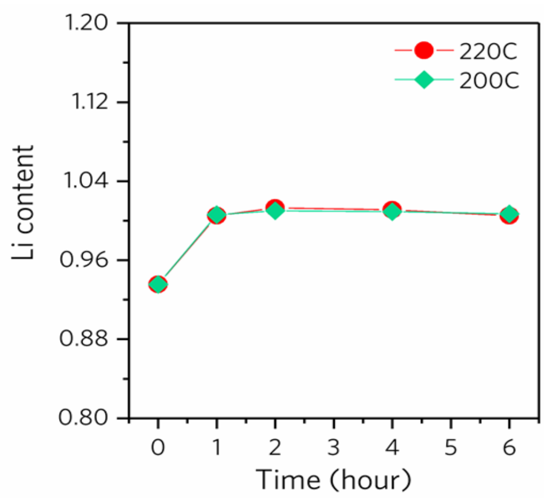
	Charge capacity	Discharge capacity	1st columbic efficieny
Pristine	182	152	83.5%
220C 0h	177	155	87.5%
220C 1h	177	149	84.1%
220C 2h	180	154	85.5%
220C 4h	181	154	85.1%
220C 6h	182	156	84.3%

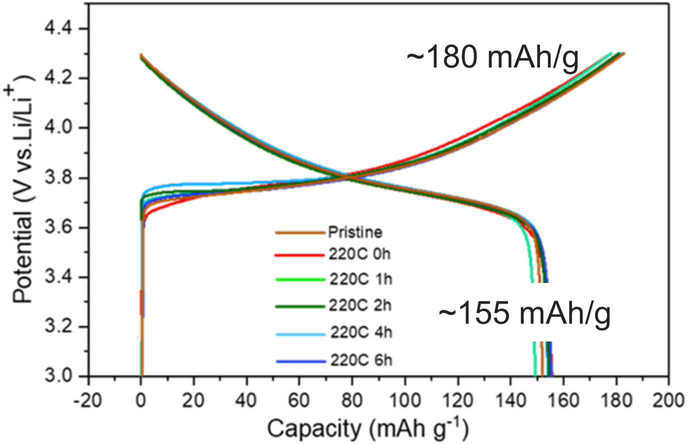
Electrochemical Cycling: Pristine vs relithiated (using LiOH) as the Li^+ source at 220 °C for various times.

Zheng Chen, et al., UC San Diego

CHEMICAL RELITHIATION - HYDROTHERMAL

Lithium content vs time



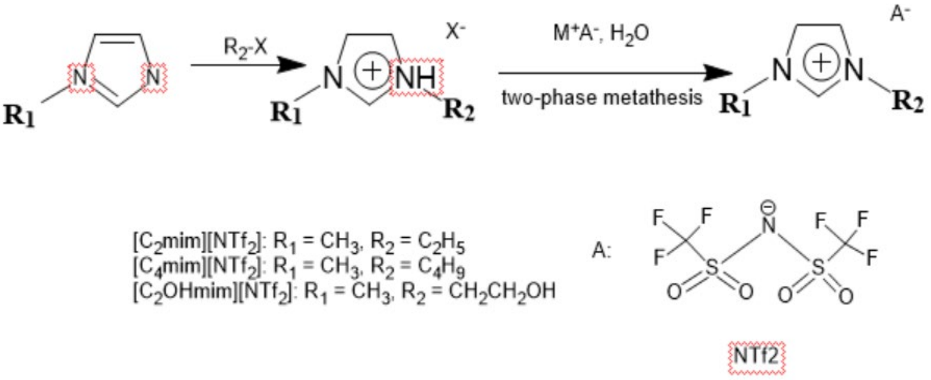


- Chemically delithiated NMC111 particles can reach >1.00 Li in about 1 hr (by ICP pristine NMC111 ~1.07 Li).

- Over 6 hrs the ratio (by ICP) varied possibly due to proton exchange, this is being investigated.

Electrochemical evaluation of relithiated particles. *Initial* cycling at C/10 based an areal mass loading of > 10mg/cm^2.

CHEMICAL RELITHIATION - IONOTHERMAL



$[C_2mim][NTf_2]$: $R_1 = CH_3$, $R_2 = C_2H_5$
$[C_4mim][NTf_2]$: $R_1 = CH_3$, $R_2 = C_4H_9$
$[C_2OHmim][NTf_2]$: $R_1 = CH_3$, $R_2 = CH_2CH_2OH$

Develop a relithiation strategy based on a salt dissolved in an ionic liquid used in the range 200-250 C

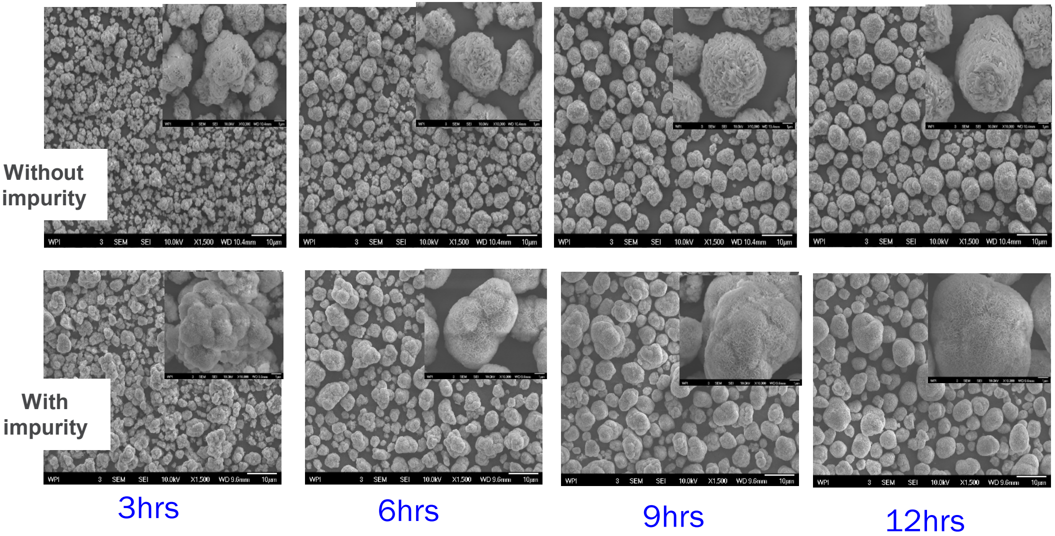
Ionic liquid	Lithiated reagent	Temp.	Mass Recovered (%)	IL recovered(%)	TGA final (%)
$[C_2mim][NTf_2]$	LiCl	250°C	22.8	92.0	97.73
	LiOAc	250°C	89.0	76.9	98.56
	LiCl	200°C	95.7	93.2	98.32
	LiOAc	225°C	81.7	73.0	98.17
$[C_4mim][NTf_2]$	LiCl	225°C	93.0	92.5	98.55
$[C_2OHmim][NTf_2]$	LiCl	250°C	78.4	90.4	96.76
	LiCl	200°C	82.8	92.7	99.06

Conclusion:
Relithiation using ILs was accomplished on test samples with recovery of lattice (XRD) and IL.

Dai, et al., ORNL

CHEMICAL RELITHIATION - IMPURITIES

Reforming cathode materials recovered from complex mixtures allows for the introduction of impurities from the process. Some of the more common metals (materials) observed are Cu ,Al, Al_2O_3, carbon, and binder materials.



Hours	Tap density (g/mL)
3 hrs	1.03
6 hrs	1.40
9 hrs	1.88
12 hrs	2.02

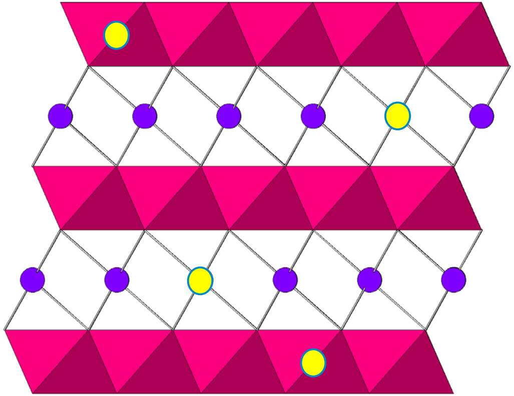
Hours	Tap density (g/mL)
3 hrs	0.79
6 hrs	1.16
9 hrs	1.31
12 hrs	1.45

Direct synthesis of 5% Cu substituted NMC samples. The differences in particle morphology was manifested in tap density measurements.

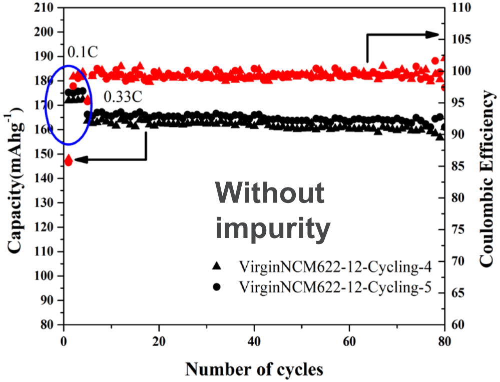
Yan Wang, et al., WPI

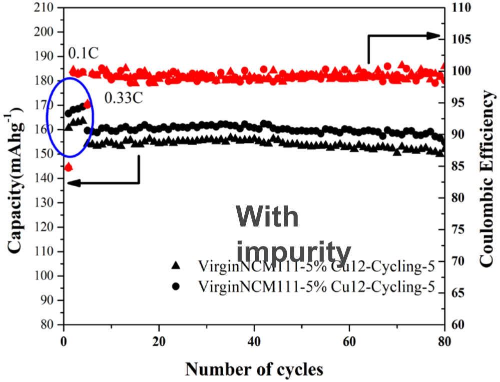
CHEMICAL RELITHIATION - IMPURITIES

NMC622 with 5% Cu was synthesized and evaluated. Due to the chemistry of Cu it can technically go to both cation sites. Li-site substitution hinders rate, TM site substitution diminishes capacity.



Possible Cu site





NMC622 with 5% Cu shows lower specific capacity and fades slightly faster than control powder.

REMAINING CHALLENGES AND BARRIERS

- Developing a process to separate similar NMC materials in a cost effective manner

- Assess the role lithium deficient cathodes with different thermal stabilities behave in the black mass isolation process (vs fully lithiated cathodes)

- Evaluate if residual carbon from the lamination or binder removal process can act as a reducing agent (under heat) and irreversibly change the oxide content of the delithiated cathode

- Scaling: how homogeneous is the delithiated cathode as a function of lithium content and time?

- Scaling: does surface damage from chemical delithiation, black mass isolation, or long term cycling have an effect on the relithiation process

FUTURE WORK

- Generate additional baseline cathode powders with higher amounts of delithiation to support the efforts of the cathode rejuvenation researchers.
- Generate additional baseline cathode powder mixtures that reflect the use of mixed powder cathode composites in the marketplace. Evaluate the role of non-homogeneous lithium contents
- Separation of cathodes by a variety of properties has been demonstrated. Optimization of surface properties is underway to improve the separation of layered cathodes from one another.
- Relithiation has been established by several methods. Evaluate the mechanism of relithiation versus methodology, notably ion exchange, thermal oxidation, and electrochemical.
- The presence of impurities is critical to recycling costs and material quality. Materials identified within black mass, if not separated, may be accidently incorporated into the product. We will develop diagnostic tools and processes to detect these low weight percent additions that may be detrimental to performance.

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

SUMMARY

- We have investigated multiple methods of the chemical rejuvenation process for relithiating recovered cathodes. A model NMC111 system has been created and dispersed upon request to team members.
- Four different relithiation studies are under evaluation and each has been shown to be effective in terms of capacity retention. Specific issues are under study including the cation site mixing, impedance changes, impurity impacts and economic considerations.
- Material separation studies have been undertaken using methods that rely on unrelated phenomena. Froth separation studies, which utilize surface properties, have been used to separate LFP from layered oxides. Surfactant addition with control of pH has shown preliminary success in separating layered oxides. Initial magnetism based separation studies have shown separation of spinel from layered cathodes
- Binder removal has been accomplished by thermal treatment of samples. Slower burnout rates and addition of extra LiOH as a fluoride getterer have been found to give the best electrochemical performance.

OTHER MATERIALS SEPARATION

FOCUS LEAD: KRIS PUPEK

APPROACH – OTHER MATERIAL RECOVERY

To maximize the potential of the recycling process all materials that can be recovered and reused in a battery must be looked at. This effort looks at the recovery processes and their products to drive toward a profitable recycling industry

- Electrolyte Component Recovery, A. Lipson (Argonne)
- Anode/Cathode Separation, E. Dahl (Argonne)
- Hydrothermal Delamination of Electrodes, I. Belharouak (ORNL)

ELECTROLYTE COMPONENT RECOVERY

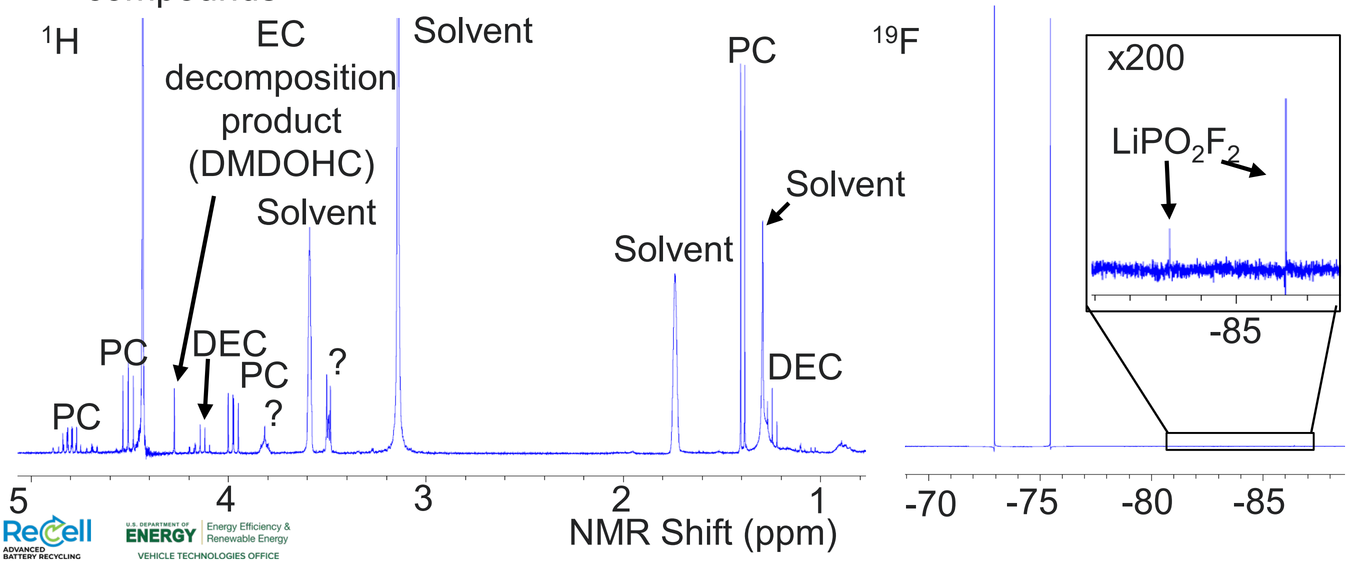
- Electrolyte needs to be removed before other materials are reprocessed The electrolyte materials will breakdown in water or at high temperatures and impact the cathode material
- Electrolyte can be removed in different ways with different materials recovered. Initial processes were chosen for simplicity and potential for being profitable

Process	Recovers $LiPF_6$	Recovers Volatile Organics	Recovers Ethylene Carbonate (EC)	Generates LiF	Chosen for Initial Study
Thermal Drying	No	Yes	No	No	No
Supercritical CO_2	No	Yes	Yes	No	No
Supercritical CO_2 + Cosolvent	Yes	Yes	Yes	No	No
Solvent Extraction	Yes	Yes	Yes	No	Yes
Water Washing	Yes/No	No	No	Yes	Yes

ELECTROLYTE COMPONENT RECOVERY

Analysis of Extracted Electrolyte (NMR)

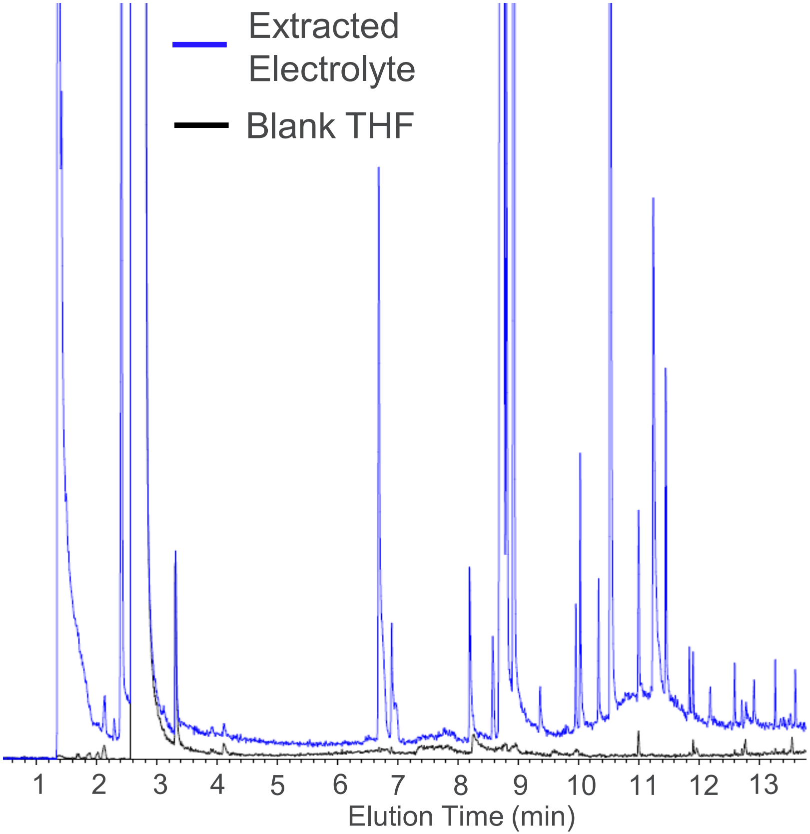
- Utilized cycled commercial battery electrodes to extract electrolyte from
- Solvents chosen were acetonitrile (ACN), dimethyl formamide (DMF), tetrahydrofuran (THF), and diethyl carbonate (DEC)
- All extracts contained similar components (showing THF)
  - Carbonates, EC decomposition product, small quantities of other unknown compounds



ELECTROLYTE COMPONENT RECOVERY

Analysis of Extracted Electrolyte (GC-MS)

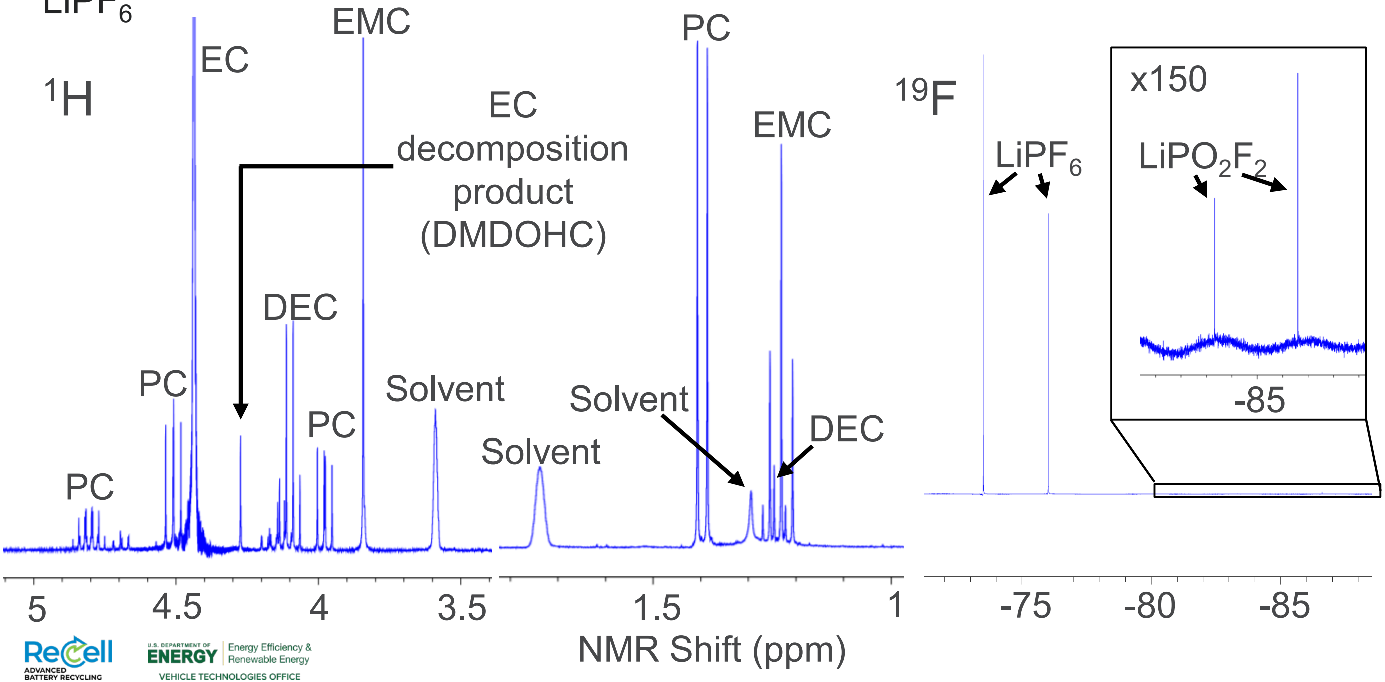
- THF peak at 2.607 min
- Most prominent THF + Cathode peaks
  - POF$_3$ at 1.360 min (25.996%)
  - EC at 8.758 min (31.670%)
  - PC at 8.932 min (8.058%)
  - Possible organosilicon compound at 10.534 min (8.999%)
- All other peaks > 0.5% have large molar masses, suggesting complex structures



ELECTROLYTE COMPONENT RECOVERY

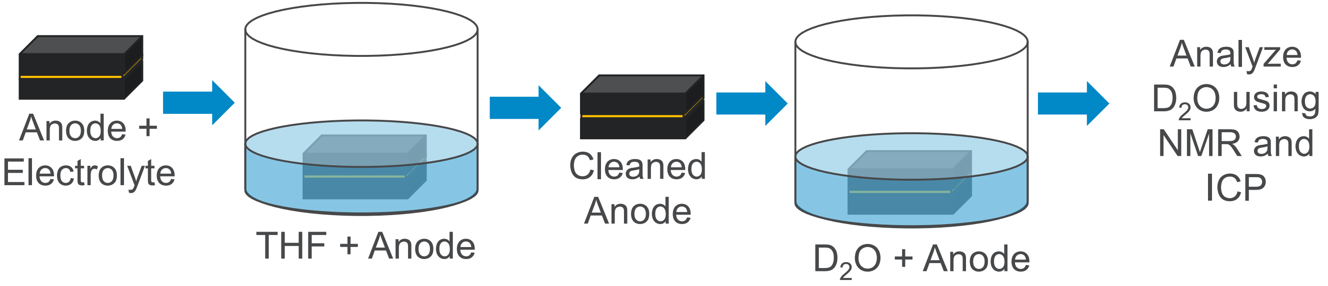
Analysis of Recrystallized Electrolyte (re-dissolved for NMR)

- Evaporating off the volatile solvents leaves behind fewer impurities. No obvious deleterious compounds remaining
- In DEC (shown) and DMF there was a similar amount of $LiPO_2F_2$ as the just-extracted electrolyte. ACN and THF showed substantial hydrolysis of the $LiPF_6$



ELECTROLYTE COMPONENT RECOVERY

Possibilities for extracting additional Li from the anode



Anode + Electrolyte

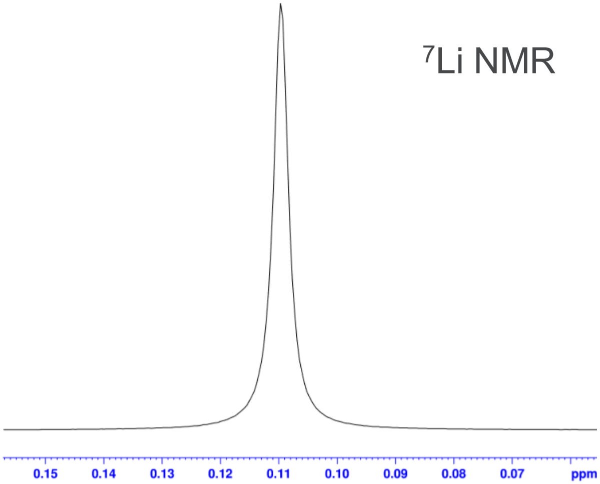
THF + Anode

Cleaned Anode

D_2O + Anode

Analyze D_2O using NMR and ICP

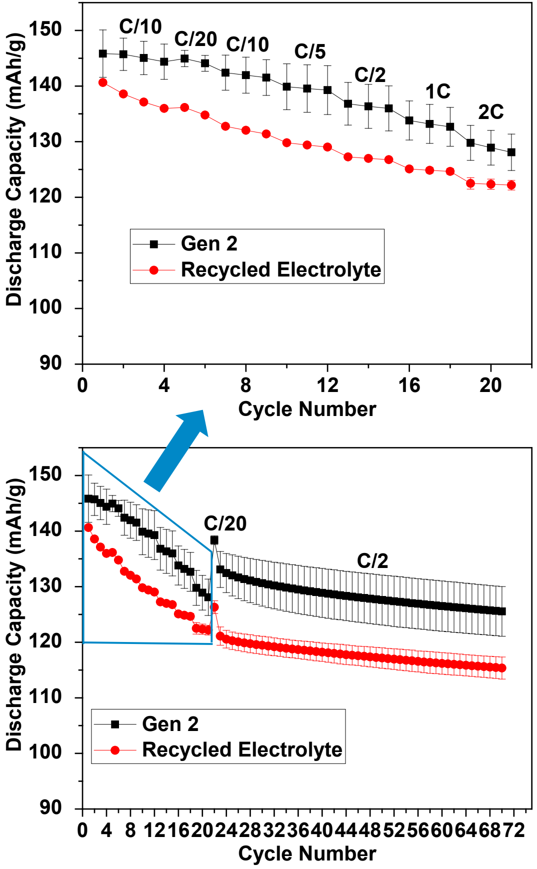
- Li appears to be a single species in the solution
  - Likely $LiCO_3$ or LiOD
- ICP indicates 2.2 wt.% Li in the anode that could be extracted by water
  - This corresponds to about 16% of the Li that was in the cathode



ELECTROLYTE COMPONENT RECOVERY

Electrochemical performance of recovered salt in full cell

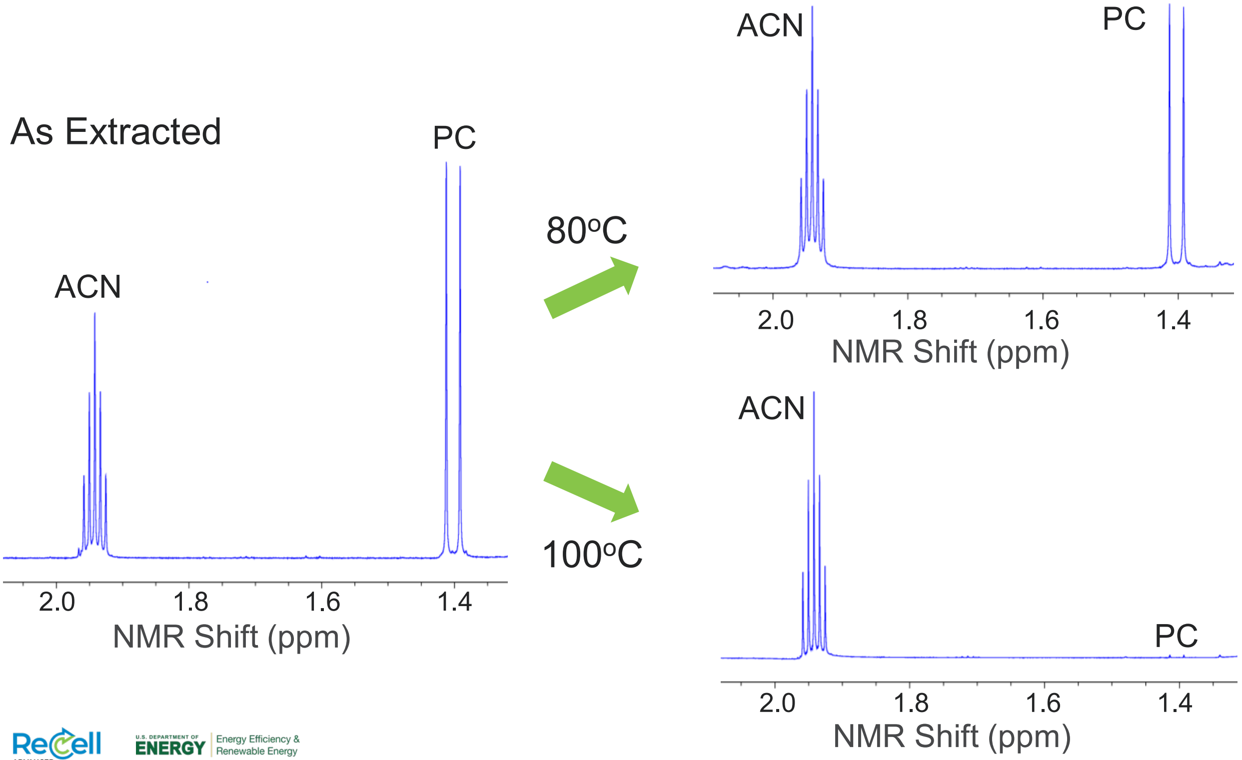
- Recycled electrolyte shows capacity fade in the initial cycles
  - This electrolyte contains PC, which requires additives to prevent degradation of the graphite anode
    - Insufficient additives likely remain to effectively mitigate this issue
  - PC either needs to be removed or additives added
- Rate performance is good despite capacity fade



ELECTROLYTE COMPONENT RECOVERY

Purification of $LiPF_6$

- Effectively removed PC using a vacuum oven at 100°C
  - Real process will require a process without vacuum



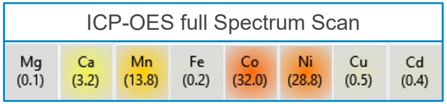
ANODE/CATHODE SEPARATION

- Evaluate multiple methods of separation and purification
  - Screening, air classification, and magnetic separation
- Characterize real black mass from end of life cells
  - Identify contaminants
  - Identify and characterize materials requiring removal
- Create model black mass for experimental use
  - Start with simple binary mixtures
  - Increase complexity of mixtures as techniques are refined
- Economic evaluation of separation methods
- Down select most effective methods

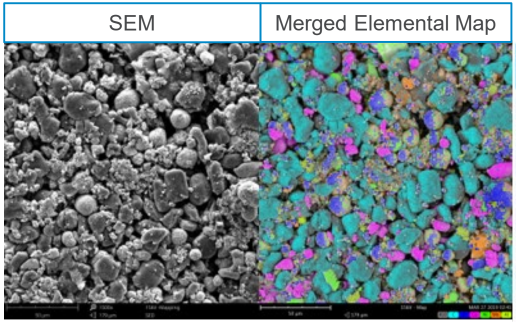
ANODE/CATHODE SEPARATION

Technical Accomplishments – Study of Black Mass

- Black mass from shredded, unsorted end of life lithium ion cells was analyzed using various methods
  - Multiple cathode chemistries were present
    - NMC, LMO, LFP, NCA, LCO
  - Abundance of 5-20 µm aluminum and copper particles were found

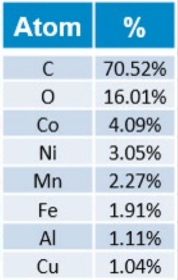


ICP-OES full Spectrum Scan							
Mg (0.1)	Ca (3.2)	Mn (13.8)	Fe (0.2)	Co (32.0)	Ni (28.8)	Cu (0.5)	Cd (0.4)



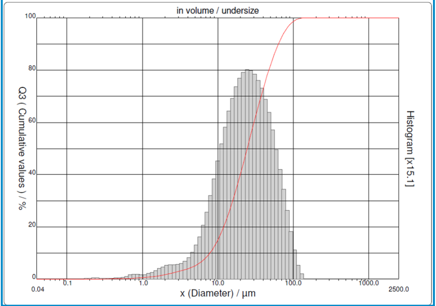
SEM

Merged Elemental Map



Atom	%
C	70.52%
O	16.01%
Co	4.09%
Ni	3.05%
Mn	2.27%
Fe	1.91%
Al	1.11%
Cu	1.04%

Particle Size Analysis

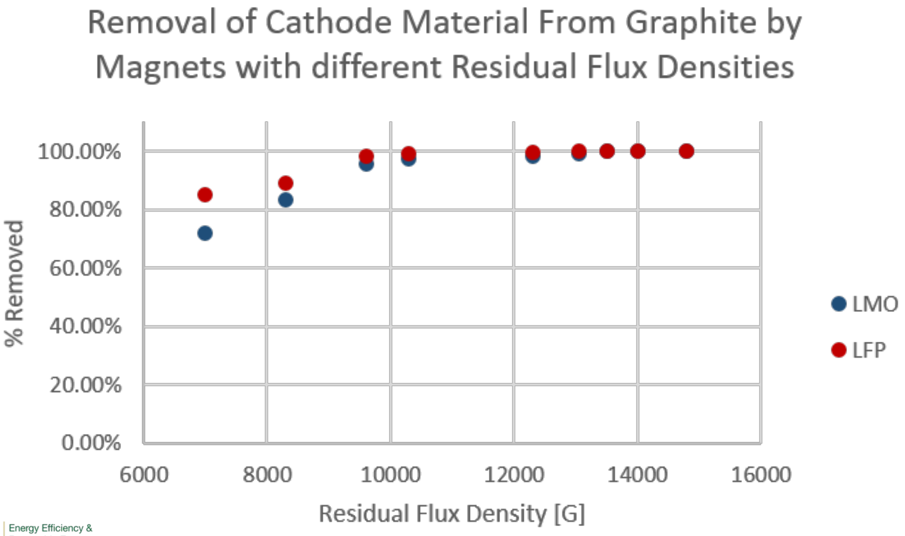


d50 : 24.54 µm	Average : 30.84 µm

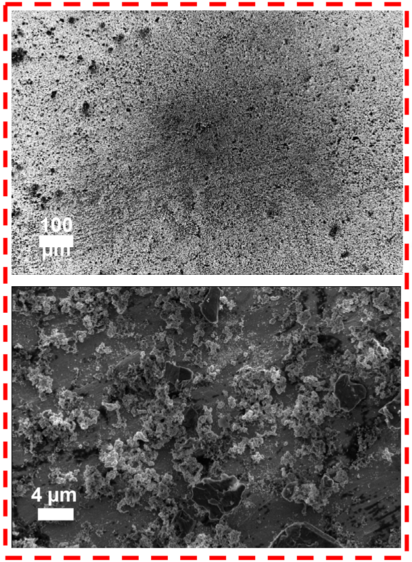
ANODE/CATHODE SEPARATION

Technical Accomplishments – Magnetic Separation

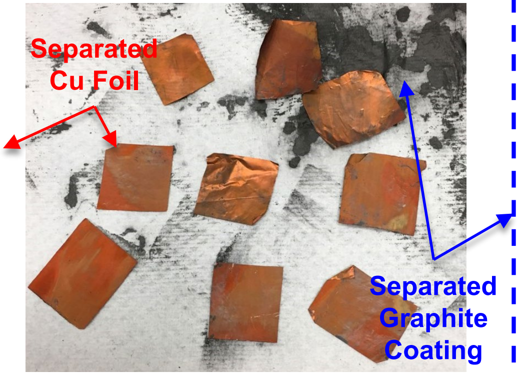
- Model black mass was created using 50/50 mixtures of LMO/graphite and LFP/graphite
- Test were conducted with various AlNiCo, SmCo and NdFeB magnets
- Separation quickly approaches 100% once neodymium based magnets are used.

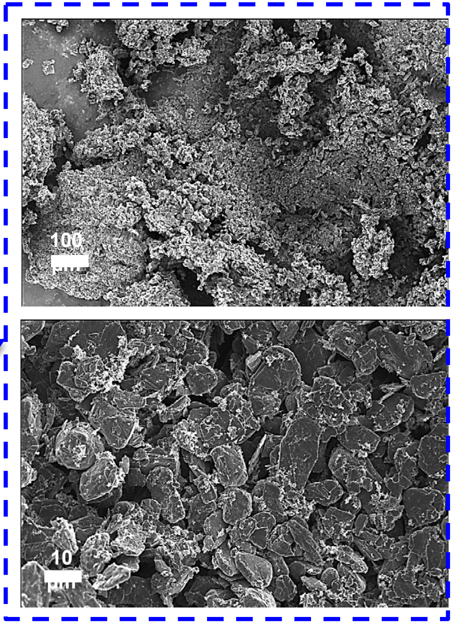


HYDROTHERMAL DELAMINATION OF ELECTRODES – ANODE



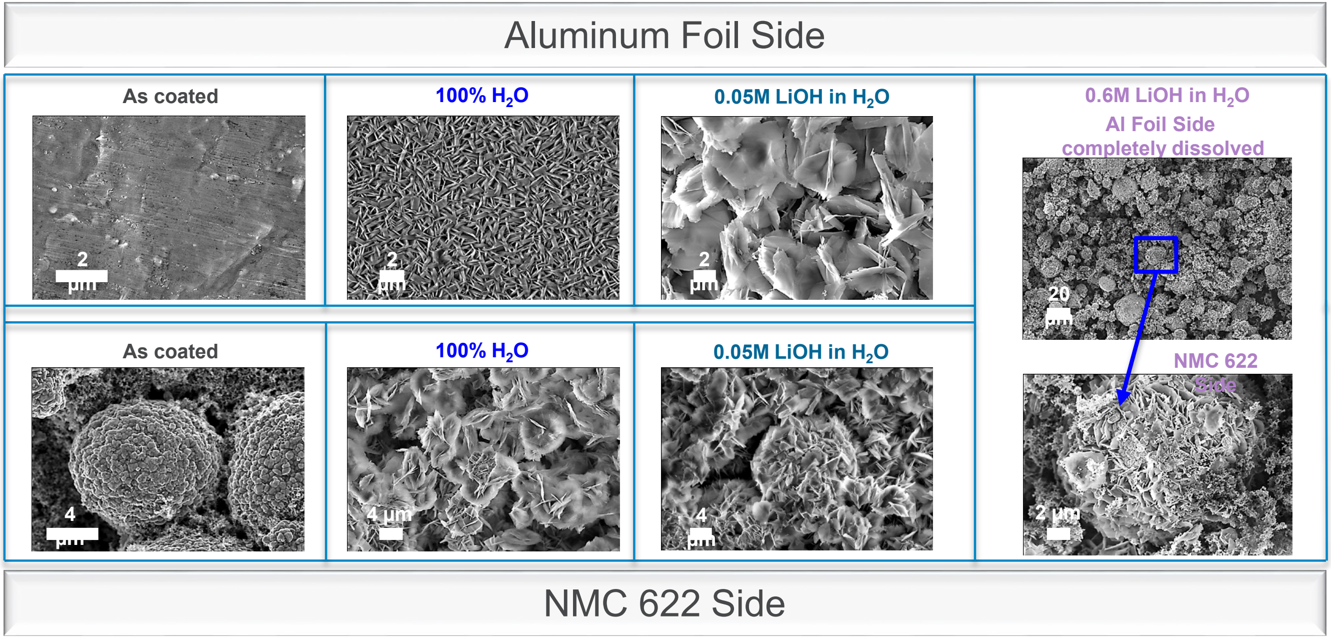
0.6g of Graphite coated on Cu foil in 20 mL H_2O (100% H_2O) at 170°C for 24h





Separation and recovery of anode (graphite coating and copper) was easily achieved through the hydrothermal treatment in DI water at 170 °C for 24 hrs

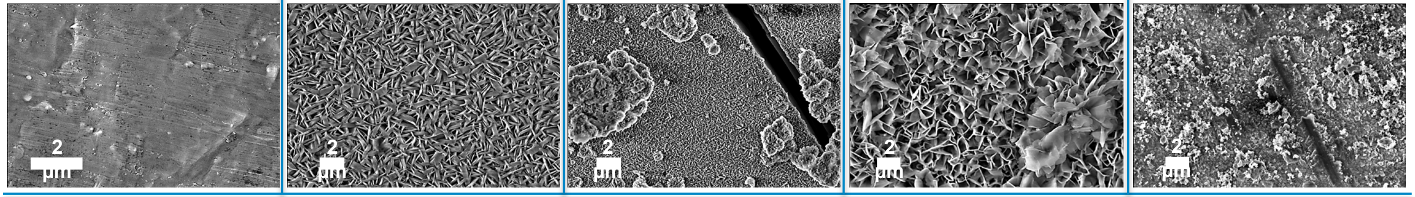
HYDROTHERMAL DELAMINATION OF ELECTRODES – CATHODE



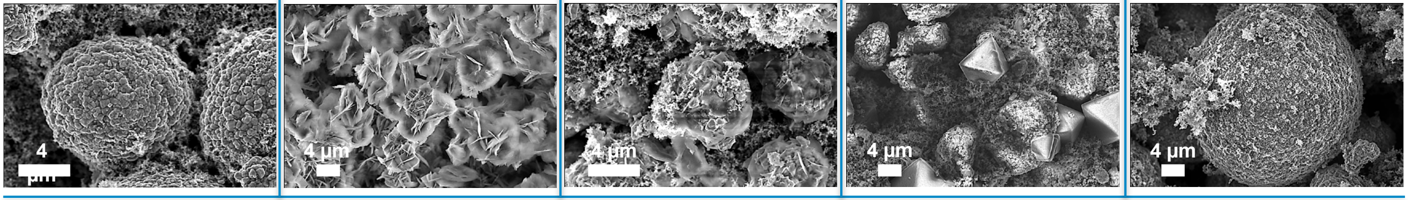
Black mass was recovered from NMC622 cathode and Al was dissolved in basic solution through hydrothermal treatment (170 ºC; 24h; 20 mL solvent; 0.6 g sample).

HYDROTHERMAL DELAMINATION OF ELECTRODES – CATHODE

Aluminum Foil Side


As coated | 100% H_2O | 10 wt% NMP in H_2O | 50 wt% NMP in H_2O | 100% NMP

NMC622 Side


As coated | 100% H_2O | 10 wt% NMP in H_2O | 50 wt% NMP in H_2O | 100% NMP

Corrosion in aluminum was observed in hydrothermal treatment owing to the presence of mild base (LiOH) when treated with DI water – NMP mixture (170 ºC; 24h; 20 mL solvent; 0.6 g sample).

REMAINING CHALLENGES AND BARRIERS

- In an actual industrial setting the composition of the feedstock will likely vary from day to day and change over time as battery technology changes
- The recycling technology must be robust enough to accommodate variable feedstock
- The processes developed to separate and purify each particular component of the cell must be compatible one another.
- Current generation electrolytes are formulated as a complex mixture of salt(s), carbonate solvents and various additives
- In order to create a reusable product the output electrolyte or salt needs to be a consistent product (composition, concentration, purity, impurity profile)
- Pre-processing (shredding and/or thermal treatment) may convert $LiPF_6$ into several different Li species, useless or harmful, if used in a new electrolyte
- Direct recycling of graphite from end of life cells will require separating many materials to achieve high purity products.

FUTURE WORK

- Determine the necessary level of purification for each electrolyte component recovered
- Investigate other methods of electrolyte component removal and recycling (thermal treatment for removal of volatile organics, supercritical CO2)
- Feasibility of water washing (anode fraction) to improve recovery of Li
- Impact of pre-processing (shredding, thermal treatment) method on recoverable electrolyte components quantity and purity
- Feasibility of a simple magnetic separation of additional cathode materials
- Separation of model black mass components using multiple methods (density, size, magnetism, conductivity)
- Electrochemical testing of recovered components (electrolyte, graphite)
- Optimize process parameter for hydrothermal delamination (anode and cathode)
- Design and investigate continuous process for hydrothermal delamination.
- Cost modeling of the processes to determine potential of profitability

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

SUMMARY

- We used actual EV battery cells to study multiple aspects of electrolyte components extraction from cathode and anode, qualitative and quantitative depend on the solvent used.
- We used various analytical techniques to investigate chemistry and purity of recovered electrolyte components.
- Cells (coin cell format) were assembled and cycled to assess usability of recovered materials as a new electrolyte.
- A hydro/solvothermal process for electrode delamination was investigated. We demonstrated that delamination can be cleanly achieved without using any auxiliary chemicals.
- Black mass from shredded, unsorted end of life lithium ion cells was analyzed using various analytical techniques.
- Model mixture of cathode and anode powders were used to successfully separate the materials based on their magnetic properties.
- Data collected during the process development are being added to the EverBatt model

ReCell
ADVANCED
BATTERY RECYCLING

www.recellcenter.org

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

VEHICLE TECHNOLOGIES OFFICE

RESPONSE TO REVIEWERS

- **New Project FY19**