U.S. DEPARTMENT OF ENERGY'S (DOE)
VEHICLE TECHNOLOGIES OFFICE (VTO)
2020 ANNUAL MERIT REVIEW (AMR)

ReCell
ADVANCED BATTERY RECYCLING

BATTERY DESIGN FOR RECYCLE

RECELL CENTER FOR ADVANCED BATTERY RECYCLING

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Oak Ridge National Laboratory

bat467
Virtual Poster
June 1-4, 2020

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

PROJECT OVERVIEW

Timeline

- Project start: October 2018
- Project end: September 2021
- Percent complete: ~50%

Budget

FY19	$4,615k
FY20	$5,150k

Barriers

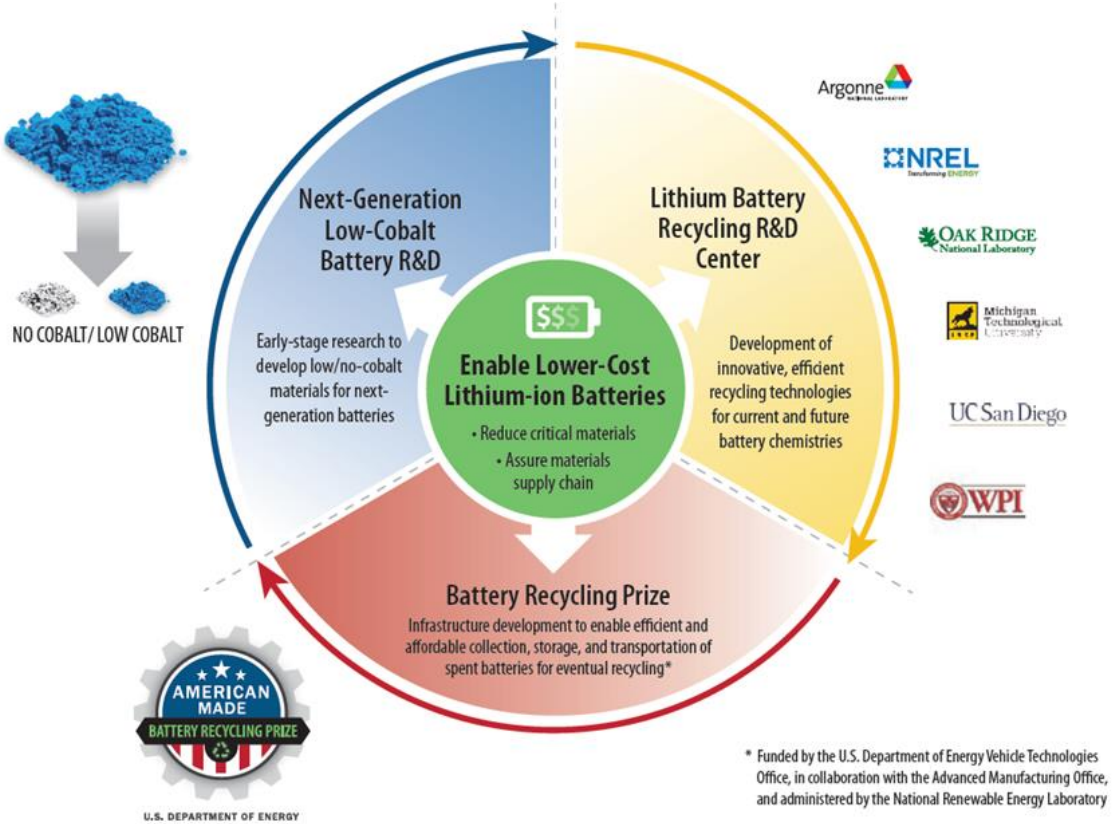
- Recycling and Sustainability
  - Cost to recycle is currently 5-15% of battery cost
  - Material shortage (Li, Co, and Ni)
  - Varying chemistries result in variable backend value

Partners

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

RELEVANCE

- Lower cost of batteries
- Enable lower environmental impacts
- Increase our country's energy security



APPROACH

Year 1 – Bench scale testing: Powder-to-Cell → Year 2 – Start to scale up unit operations → Year 3 – Finish scale up and show cell-to-cell recycling

ReCell does not include battery dismantling, transportation, or 2nd use

PROGRAM MILESTONES

FY19 Q1 Complete Establish the battery recycling center's mission and include its targets and goals

FY19 Q2 Complete Provide an initial progress report on roll-to-roll relithiation

FY19 Q3 Complete Provide an initial progress report on design for recycle initiative

FY19 Q4 Complete Establish the ReCell Center's Battery Recycling Laboratory and Scale-up Facility

FY20 Q1 Complete Electron Backscatter Diffraction data comparison of various chemically delithiated NMC-111 versus pristine NMC-111

FY20 Q2 Complete All five relithiation processes added to EverBatt at lab scale and production scale

FY20 Q3 Ongoing Down-select solvent(s) to separate black mass from current collector and optimize the process conditions to achieve >90% recovery of black mass

FY20 Q4 Ongoing Demonstrate recovery of anode and cathode powders using the new pilot scale froth column

Each Individual project has its own milestones that are not listed here.

COVID-19 has reduced lab time and may cause delays in completing FY20 milestones

DESIGN FOR RECYCLE

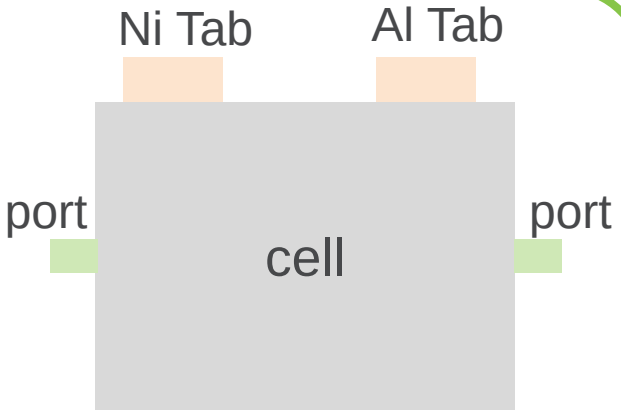
CELL DESIGN

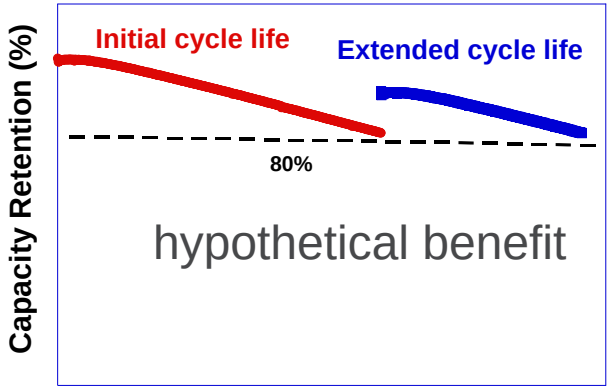
Project Goal:

- Create cell designs to enable rejuvenation of a spent cell that trade minimal loss in energy-density performance for the ability to use cheaper, new recycling processes at end of life
- Relithiate spent cathodes to extend battery cycle life and reduce the number of batteries to be recycled

Project Description:

- Develop new cell designs with ports that allow us to flush off some SEI components and reduce cell polarization
- Identify optimal rejuvenation conditions, including solvents, flushing times and period
- Demonstrate extended cycle life in rejuvenated cells





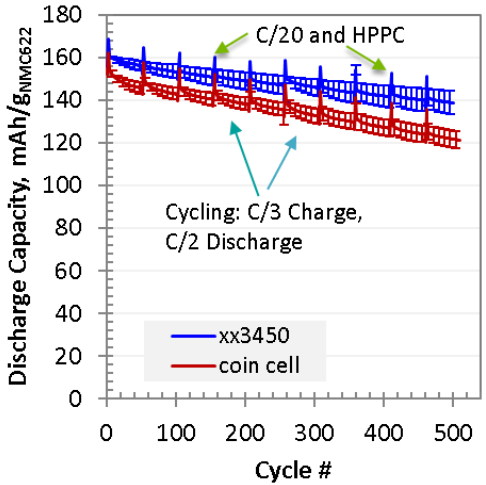
FABRICATED BASELINE ELECTRODES AND VALIDATED THEIR ELECTROCHEMICAL PERFORMANCE

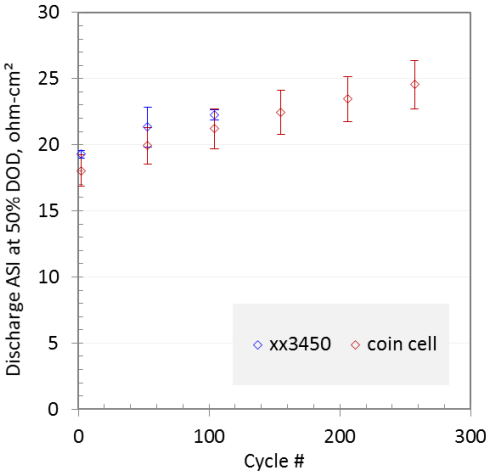
Anode: LN3174-63-1 (single-sided)
91.83 wt% Superior Graphite SLC1520P
2 wt% Timcal C-45
6 wt% Kureha 9300 PVDF Binder
0.17wt% Oxalic Acid
ReCell, 18650 cell build with cathode [LN3174-64-3&65-3]
Prod: SLC1520P, Lot#: Lot#: 022626-376-551
*"SS" = single sided -> **CALENDERED***
Cu Foil Thickness: 10 µm
Total Electrode Thickness: 98 µm (SS)
Coating Thickness: 88 µm (SS)
Porosity: 34.5 %
Total SS Coating Loading: 12.49 mg/cm^2
Total SS Coating Density: 1.42 g/cm^3
Estimated Areal Capacity: 3.78 mAh/cm^2
[Based on rev. C/10 of 330 mAh/g for 0.005 to 1.5 V vs. Li]
Made by CAMP Facility

Anode: LN3174-62-4 & 63-1 (double-sided)
91.83 wt% Superior Graphite SLC1520P
2 wt% Timcal C-45
6 wt% Kureha 9300 PVDF Binder
0.17wt% Oxalic Acid
ReCell, 18650 cell build with cathode [LN3174-64-3&65-3]
Prod: SLC1520P, Lot#: Lot#: 022626-376-551
*"SS" = single sided, "DS" = double sided -> **CALENDERED***
Cu Foil Thickness: 10 µm
Total Electrode Thickness: 180 µm (DS)
SS Coating Thickness: 85 µm (SS)
Porosity: 32.2 %
Total SS Coating Loading: 12.49 mg/cm^2
Total SS Coating Density: 1.47 g/cm^3
Estimated SS Areal Capacity: 3.78 mAh/cm^2
[Based on rev. C/10 of 330 mAh/g for 0.005 to 1.5 V vs. Li]
Made by CAMP Facility

Cathode: LN3174-65-3
(single-sided)
90 wt% Targray NMC622
5 wt% Timcal C-45
5 wt% Solvay 5130 PVDF Binder
ReCell, 18650 cell build with anode [LN3174-62-4&63-1]
Prod: Targray SNMC03006, Lot#: TBD
*"SS" = single sided -> **CALENDERED***
Al Foil Thickness: 20 µm
Total Electrode Thickness: 95 µm (SS)
SS Coating Thickness: 75 µm (SS)
Porosity: 33.5 %
Total SS Coating Loading: 20.43 mg/cm^2
Total SS Coating Density: 2.72 g/cm^3
Estimated SS Areal Capacity: 3.11(3.27) mAh/cm^2
[Based on rev. C/10 of 169(178) mAh/g for 3.0 to 4.2(4.3) V vs. Li]
Made by CAMP Facility

Cathode: LN3174-64-3 & 65-3
(double-sided)
90 wt% Targray NMC622
5 wt% Timcal C-45
5 wt% Solvay 5130 PVDF Binder
ReCell, 18650 cell build with anode [LN3174-62-4&63-1]
Prod: Targray SNMC03006, Lot#: TBD
*"SS" = single sided, "DS" = double sided -> **CALENDERED***
Al Foil Thickness: 20 µm
Total Electrode Thickness: 165 µm (DS)
SS Coating Thickness: 73 µm (SS)
Porosity: 31.2 %
Total SS Coating Loading: 20.43 mg/cm^2
Total SS Coating Density: 2.82 g/cm^3
Estimated SS Areal Capacity: 3.11(3.27) mAh/cm^2
[Based on rev. C/10 of 169(178) mAh/g for 3.0 to 4.2(4.3) V vs. Li]
Made by CAMP Facility





- Validated excellent electrochemical performance from the baseline electrodes
- Fabricated cylindrical and pouch cells
- Created spent cells/electrodes for rejuvenation

Courtesy of Andy Jansen

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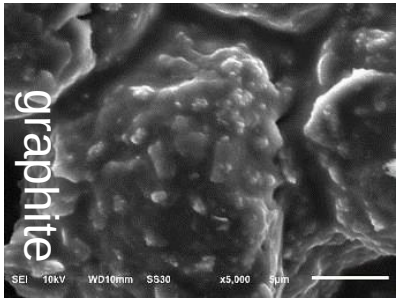
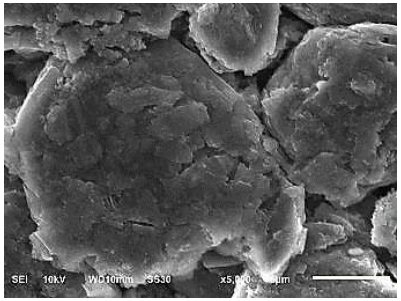
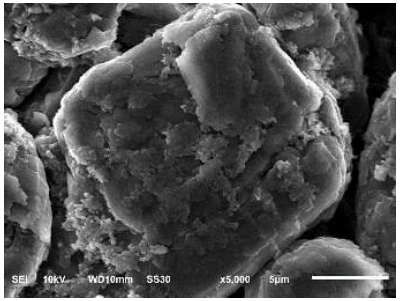
ELECTRODE RINSING REMOVED THE SURFACE LAYER FROM SPENT GRAPHITE ANODE BUT HAD LITTLE EFFECT ON THE SPENT CATHODE

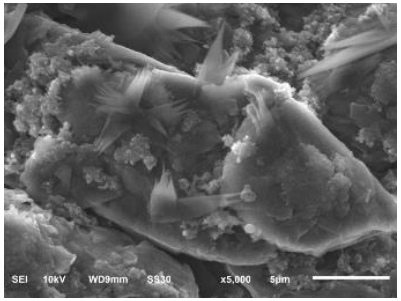
Unwashed | DMC | IPA | EtOH

graphite

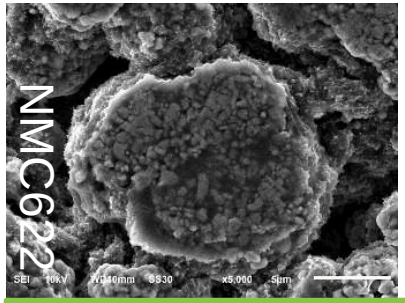


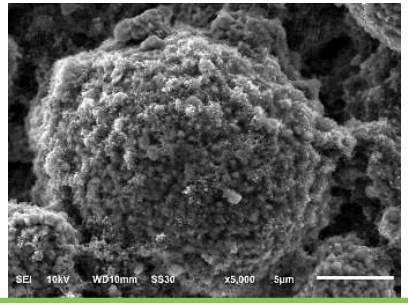


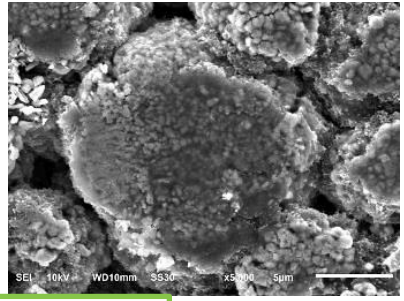


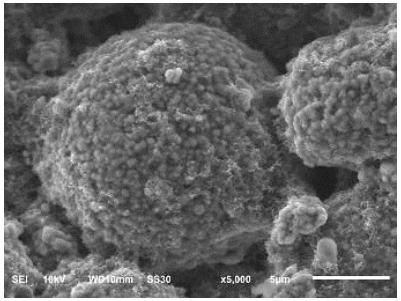


NMC622









XPS results indicated Li_2CO_3 was removed after rinsing.

Rinsing period: 5 min

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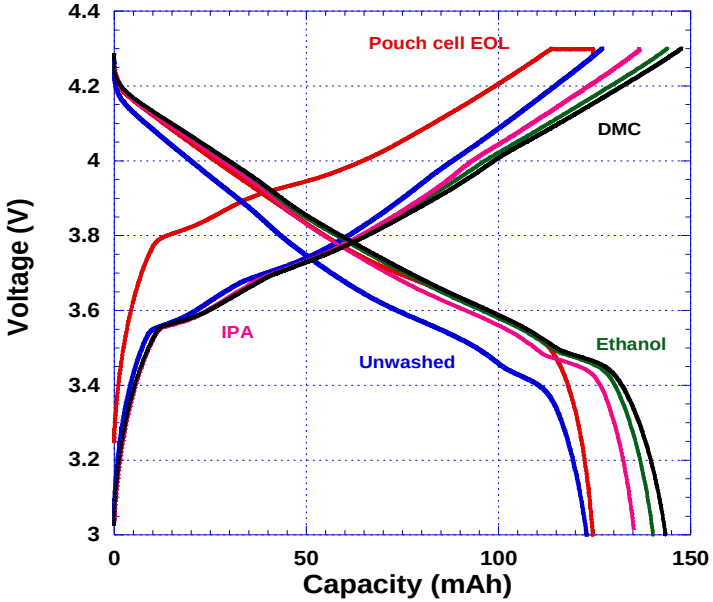
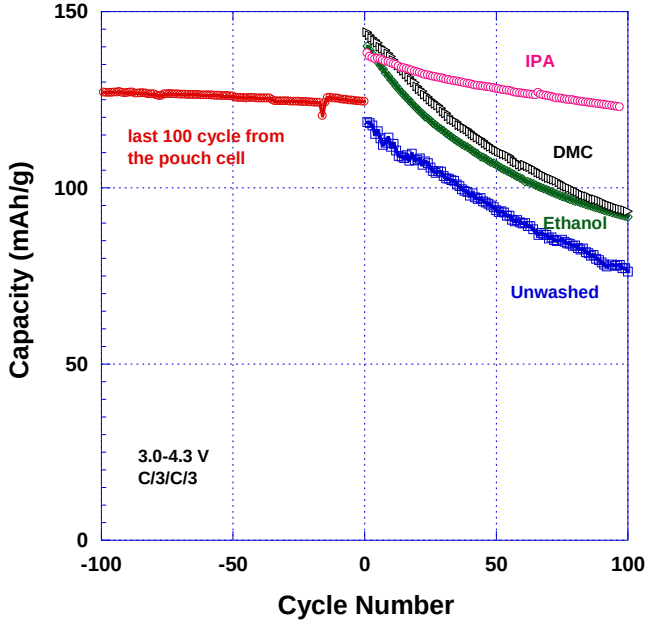
SEM images Courtesy of Zhenzhen Yang & Ira Bloom

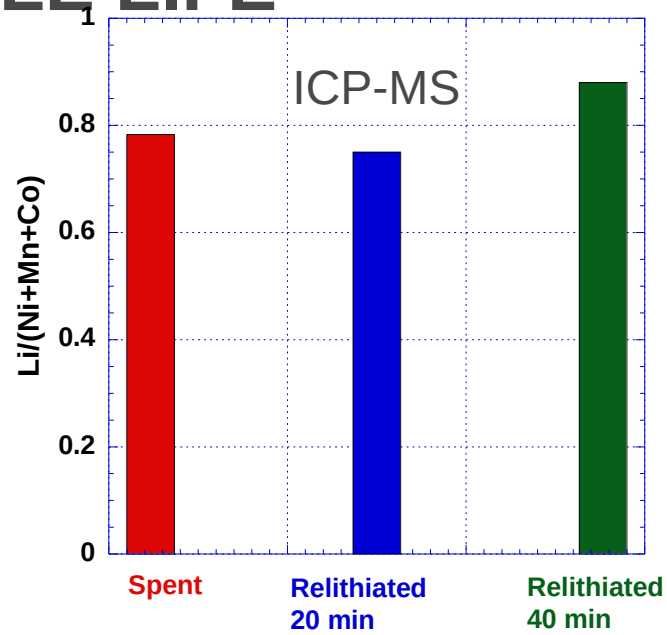
INITIAL RESULTS FROM RINSING SPENT ELECTRODES SHOWED CAPACITY RECOVERY

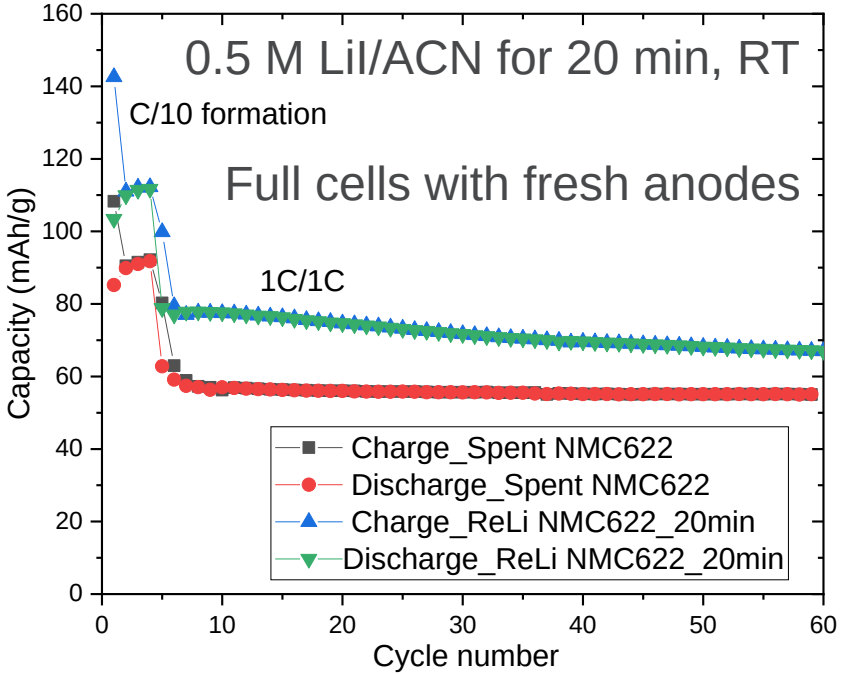




- Rinsing the spent electrode improved the capacity in the re-assembled cells albeit subsequent fast capacity degradation.
- The rinsed solution from the spent electrodes mainly consisted of POF_3, $C_5H_{10}O_3$, $C_7H_{14}O_5$ and $C_8H_{14}O_6$ esters while C_2H_6O was also found from the anode solution.

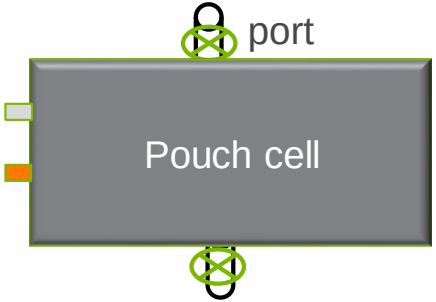
RINSING AND RELITHIATING SPENT NMC622 SHOWED RECOVERY IN CAPACITY AND EXTENDED CYCLE LIFE

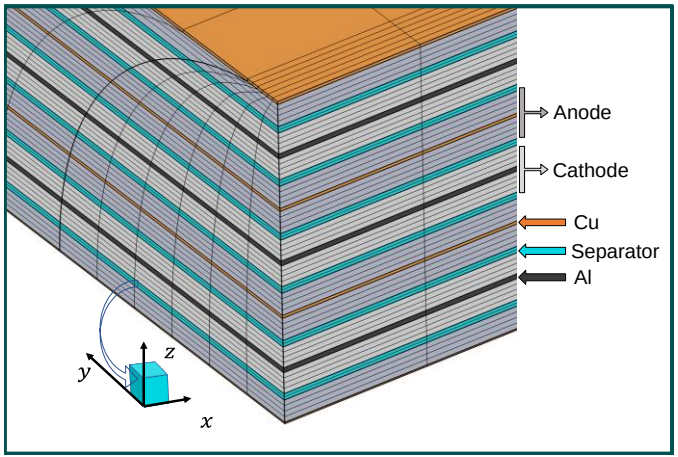


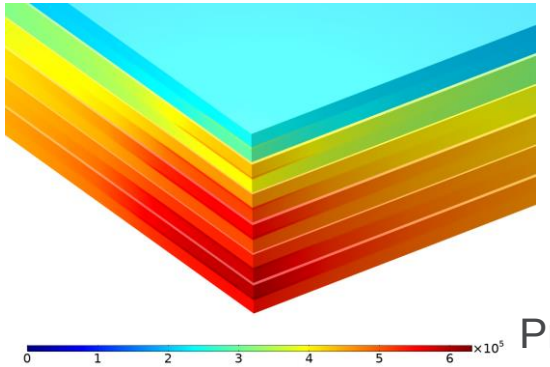


- Li content in spent NMC622 increased after relithiation for 40 min
- Relithiated electrodes showed higher capacity.

HIGHER PRESSURE AND HIGH FLUX AT THE COMPONENTS WITH HIGHER PERMEABILITY



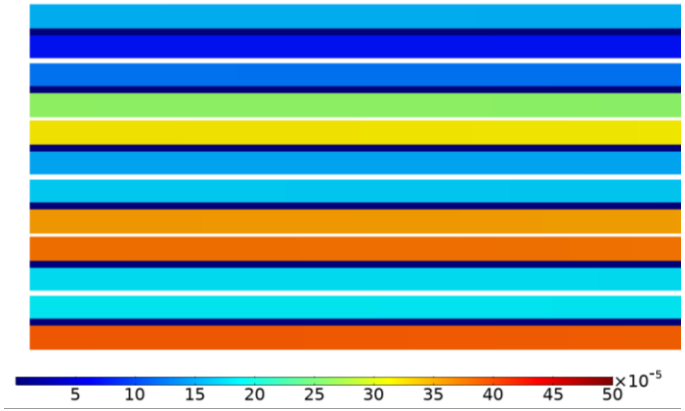




Pressure, Pa

- NMC622
- SLC1520P
- Celgard separator

Flow velocity through cell mid-section



Flow rate m/s

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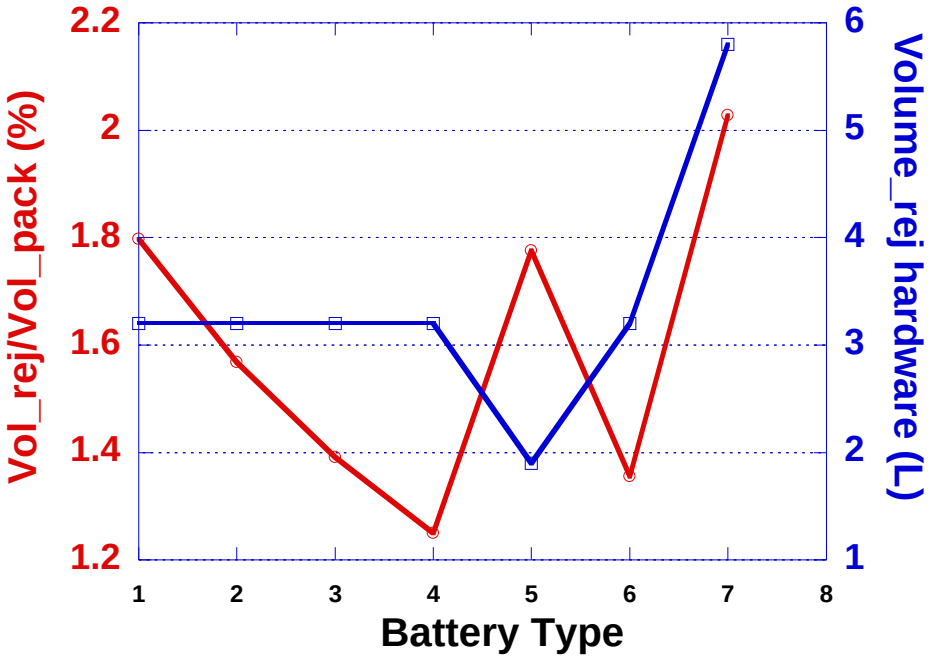
REJUVENATION HARDWARE WOULD COMPROMISE ENERGY DENSITY BY 1-2%



- Estimation using BatPac
- Assume: 2 tubes per cell, each 30 cm long & 0.4 cm OD (~4 mL each)
- Assume: 2 valves per module (30 cells per module), ~60 mL each
- Assume: 2 ganged tubing ports per module, ~15 mL each
- Implied total of 400 mL per module *if no wasted volume*
- Volume of the dardware for rejuvenation is 1.9 to 5.8 L.

- The additional rejuvenation hardware would increase the pack volume by 1-2%.

Courtesy of Andy Jansen

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DESIGN FOR RECYCLE – ACCOMPLISHMENTS AND RESULTS

- Created new cell design for cell rejuvenation
- Created spent cells and electrodes with NMC622 and SLC1520 P graphite
- Demonstrated capacity recovery after rinsing the spent electrodes in coin cells
- Demonstrated capacity recovery from relithiating the spent NMC622 cathodes
- Simulated flow rate and pressure distribution in pouch cells during electrode rinsing
- Estimated penalty in energy density with the new cell design using BatPac

For more information please see www.recellcenter.org, where our Quarterly Reports are posted.

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Michigan Technological University

NREL NATIONAL RENEWABLE ENERGY LABORATORY

WPI

OAK RIDGE National Laboratory

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RECELL RECYCLING TOWN HALL

FRIDAY, JUNE 5, 2020 FROM 1:00 TO 3:00 (CENTRAL)

To continue the discussion the ReCell team will hold an interactive town hall meeting.

Please join us at the BlueJeans session shown below and ask questions through Slido

Take a picture of this slide

For Information about ReCell

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https://bluejeans.com/749203749/9534?src=htmlEmail

Phone
(866) 226-4650
Meeting ID: 749 203 749

Slido Q/A website

Computer or Smart Phone
www.Slido.com

Event Code
“recell”

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