RECELL–BATTERY DESIGN FOR RECYCLING

Project ID: bat467

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2021 DOE Vehicle Technologies Office
Annual Merit Review

PROJECT OVERVIEW

Timeline

- Project start: October 2018
- Project end: September 2021
- Percent complete: ~90%

Budget

FY19	$4,615k
FY20	$5,150k
FY21	$4,915k

Barriers

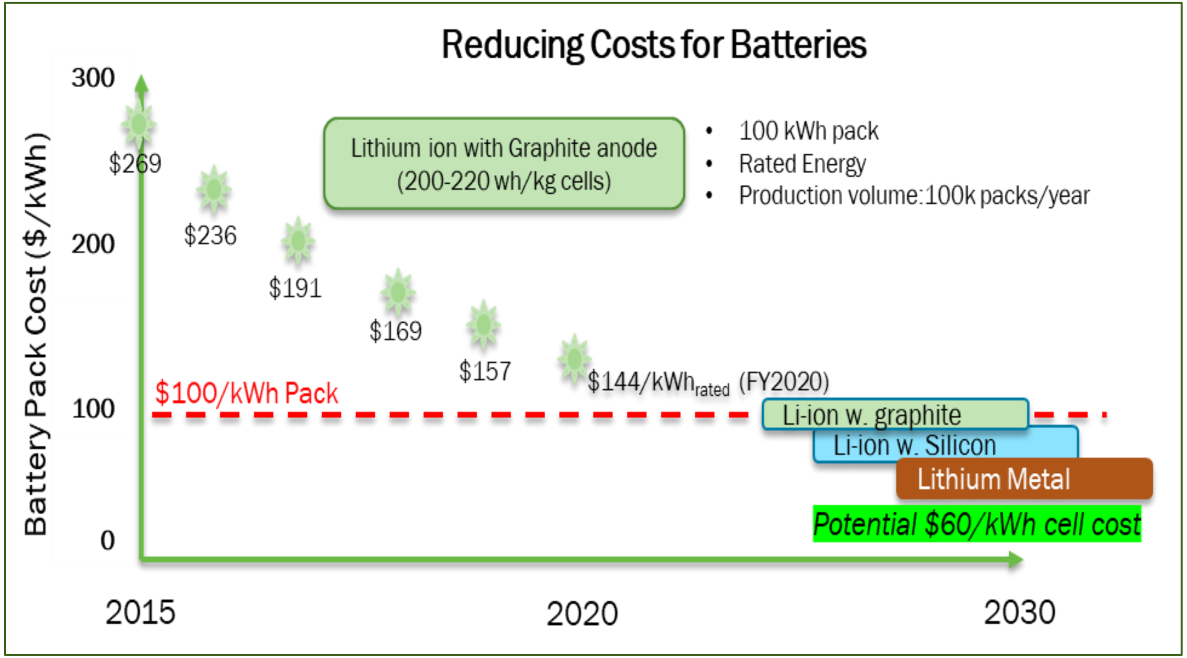
- Recycling and Sustainability
  - Cost to recycle is currently 5-15% of battery cost
  - Material shortage (Li, Co, and Ni)
  - Varying chemistries result in variable backend value

Partners

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

RELEVANCE

By 2025, reduce the cost of EV battery packs to less than $100/kWh with technologies that significantly reduce or eliminate the dependency on critical materials (such as cobalt) and utilize recycled material feedstocks.



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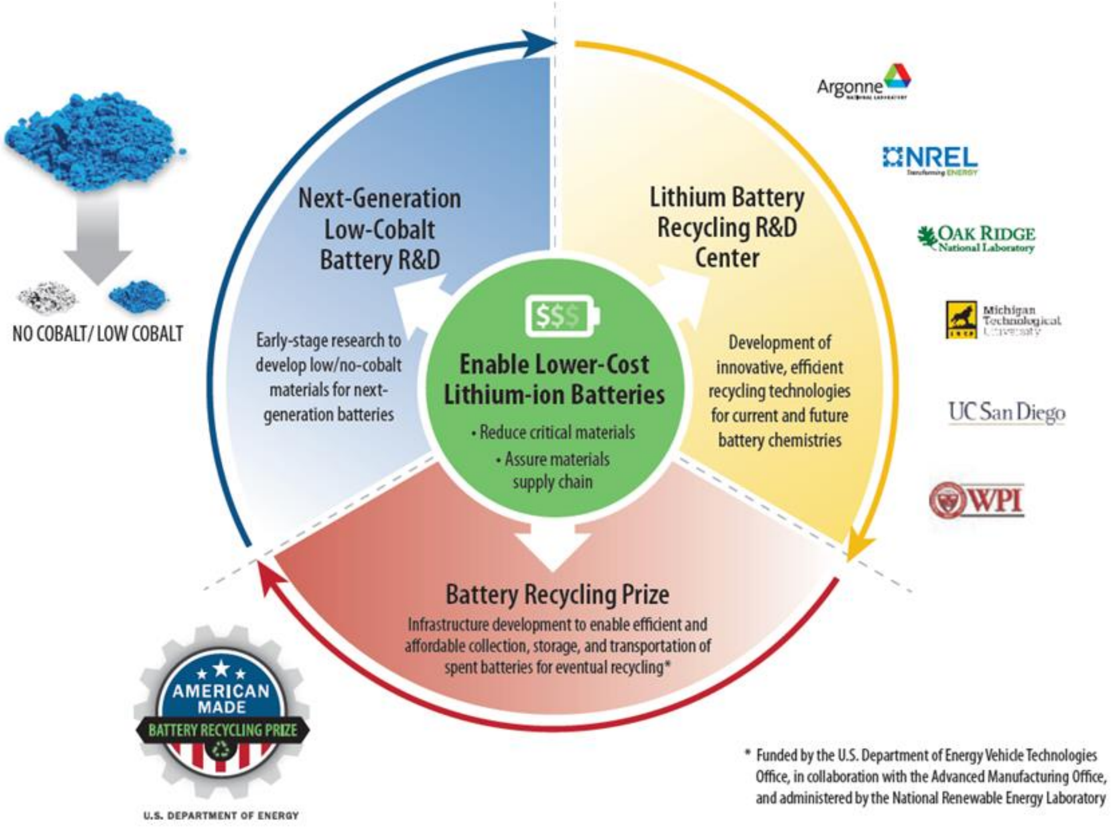
RELEVANCE

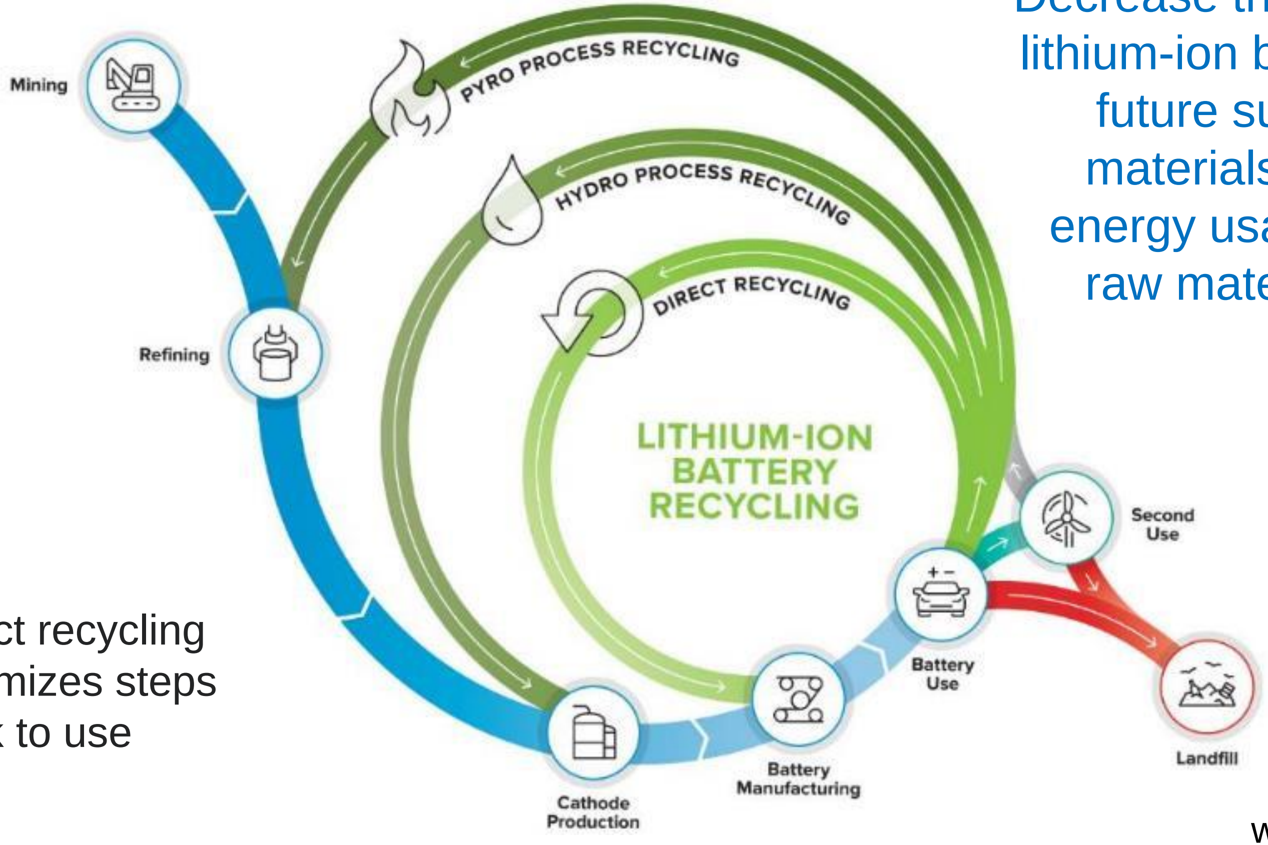
- Lower cost of batteries
- Enable lower environmental impacts
- Increase our country's energy security



APPROACH

ReCell's Mission:

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



Direct recycling minimizes steps back to use

www.ReCellCenter.org

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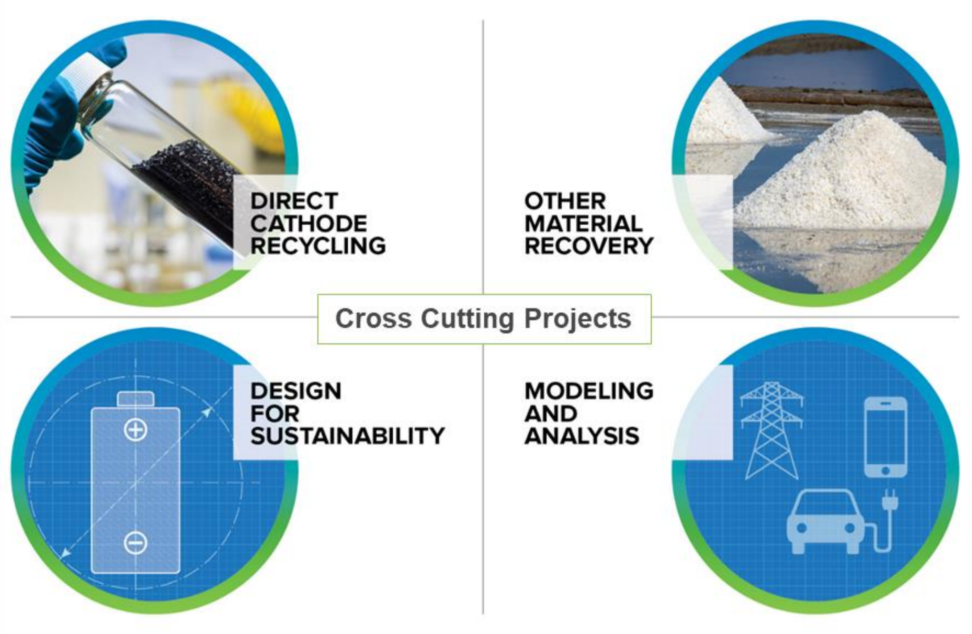
APPROACH

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

- Binder Removal
- Cathode/ Cathode Separation
- Relithiation
- Cathode Upcycling
- Impurity Impact

- Cell Design for Rejuvenation



- Cell Shredding
- Electrode Delamination
- Anode/ Cathode Separation
- Electrolyte Component Recovery

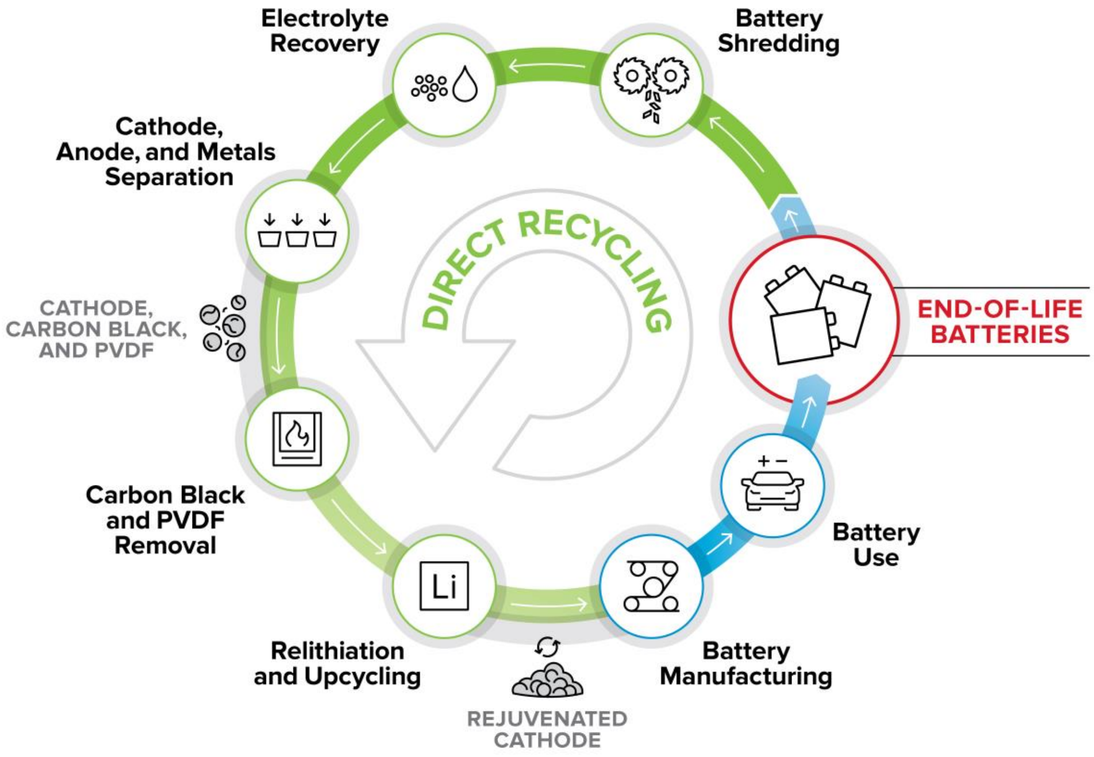
- EverBatt (TEA/LCA)
- LIBRA (Supply Chain Modeling)

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

APPROACH

Typical Direct Recycling Process Flow

- Multiple processes investigated to mitigate risk
- Continual review of new project ideas
- End projects that are not showing promise in cost and performance
- These processes can benefit other recycling processes



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MILESTONES

FY20 Q3	Complete	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	Complete	Demonstrate recovery of anode and cathode powders using the new pilot scale froth column
FY21 Q1	Complete	Preliminary report of sensitivity analysis of battery recycling in the LIBRA model focusing on outputs including the number of recycling plants built and the percentage of batteries recycled over time.
FY21 Q2	Complete	Demonstrate 30% graphene yield from spent anode using a Taylor Vortex Reactor
FY21 Q3	Ongoing	Final report on performance and cost modeling of directly recycled manufacturing scrap
FY21 Q4	Ongoing	Provide preliminary cost analysis, yield, and efficiency on the separation-relithiation conditions on NMC spent electrodes via solvent-based dual process

Each Individual project has its own milestones, though not listed here.

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COVID-19 has reduced lab time and may cause delays in completing FY22 milestones

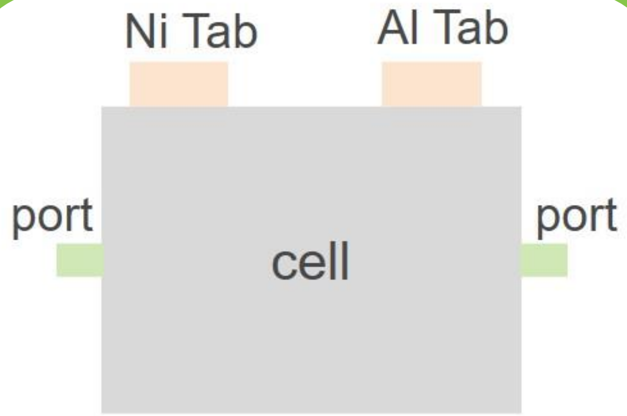
CELL DESIGN

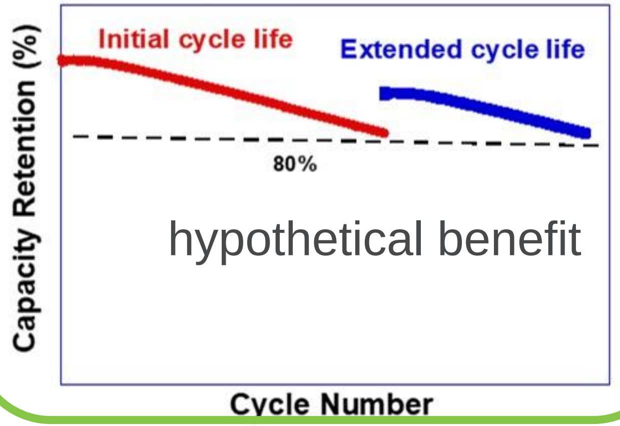
Project Goal:

- 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:

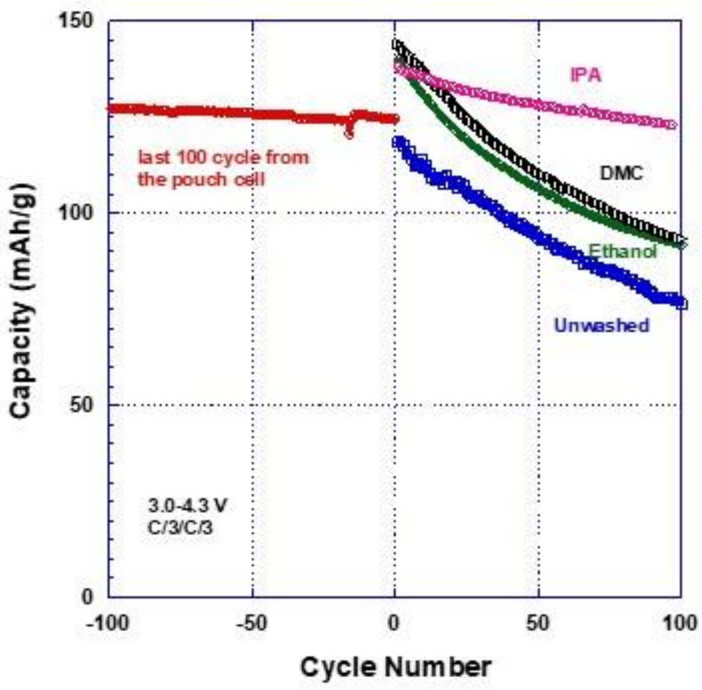
- Develop new cell designs with ports that allow us to flush off some SEI components and reduce cell polarization
- Identify optimal rejuvenation conditions, including solvents, flushing times and period
- Demonstrate extended cycle life in rejuvenated cells





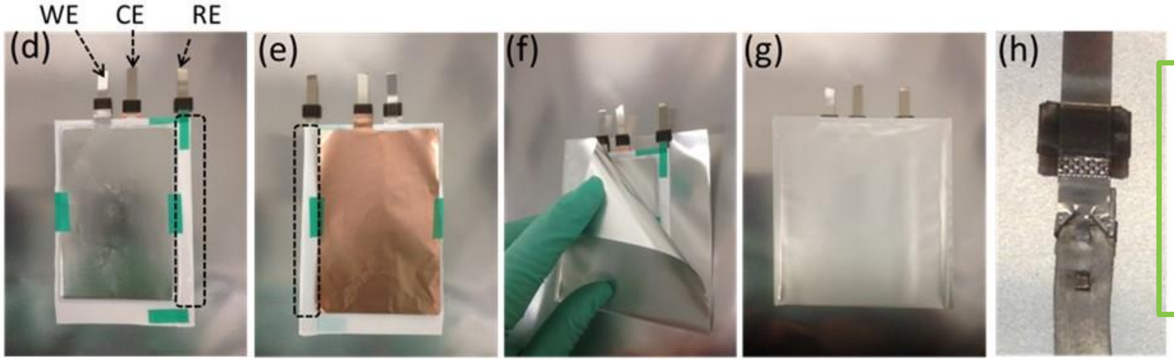
INITIAL CAPACITY RECOVERY DEMONSTRATED IN COIN CELLS IN FY20

- Cycled pouch cells till 20% capacity fade
- Disassembled the spent cells
- Rinsed and dried the spent electrodes in glove box
- Assembled the rinsed electrodes into full coin cells
- Continued cycling the coin cells with same protocols

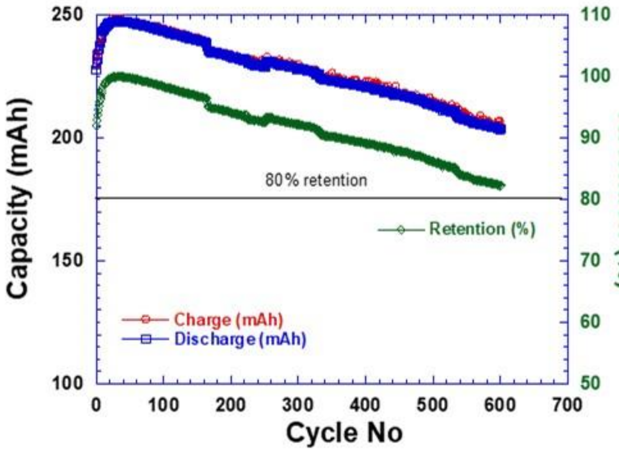


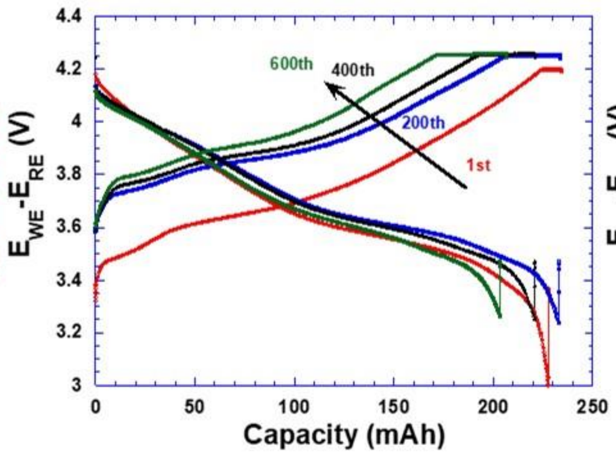
- Rinsing the spent electrode improved the capacity in the re-assembled cells albeit subsequent fast capacity degradation.
- The rinsed solution from the spent electrodes mainly consisted of POF_3, $C_5H_{10}O_3$, $C_7H_{14}O_5$ and $C_8H_{14}O_6$ esters while C_2H_6O was also found from the anode solution.

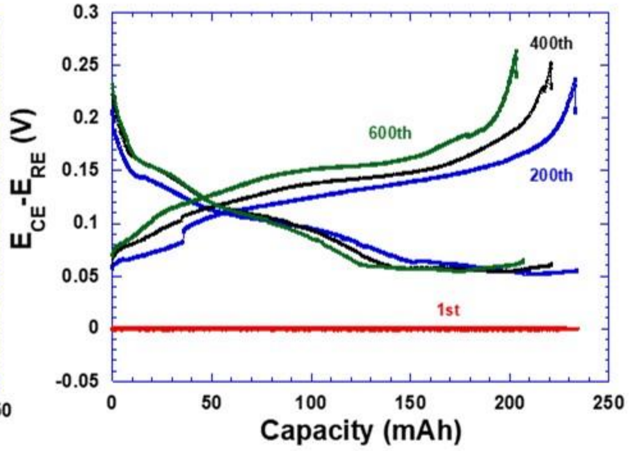
THREE-ELECTRODE POUCH CELLS VALIDATED CAPACITY FADE DUE TO LOSS OF LI



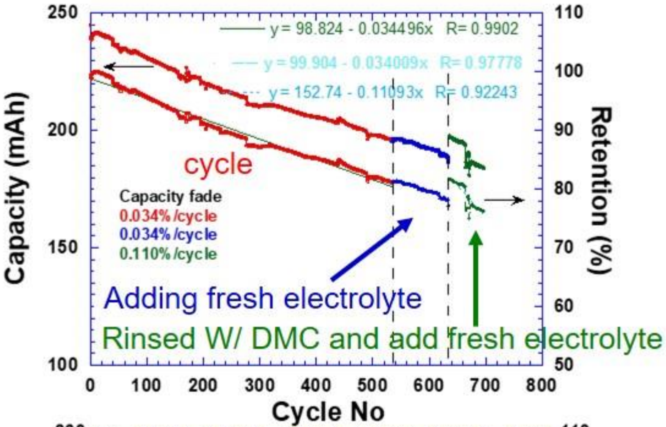
- Good cycle life
- Capacity fade due to Li loss and resistance increase

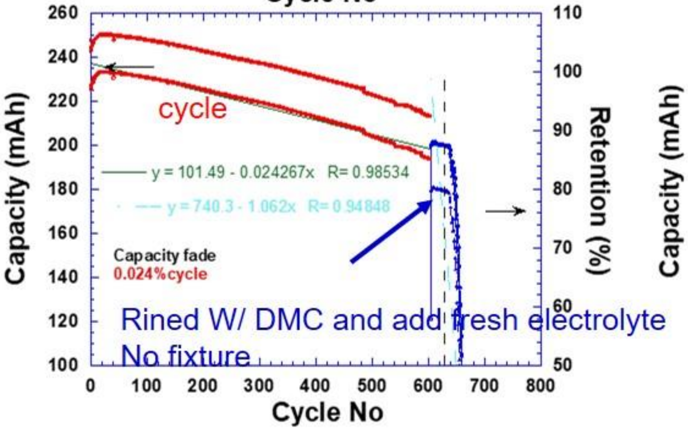


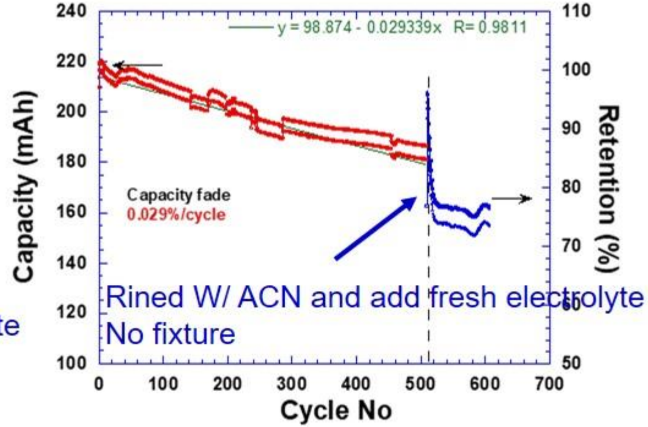




RINSING CELLS WITHIN TESTING FIXTURE ENABLE CAPACITY RECOVERY (SHORT TERM)







with the testing fixture:

- Adding more electrolyte has insignificant effect in capacity recover
- Rinsing the cells and add fresh electrolyte showed short term capacity recovery but capacity faded quicker.

Without the testing fixture:

- adverse effect

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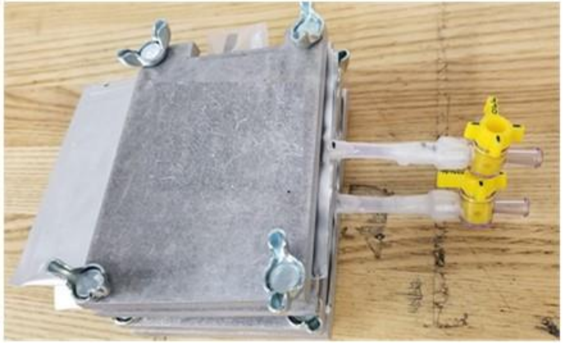
FABRICATION OF POUCH CELLS WITH PORTS

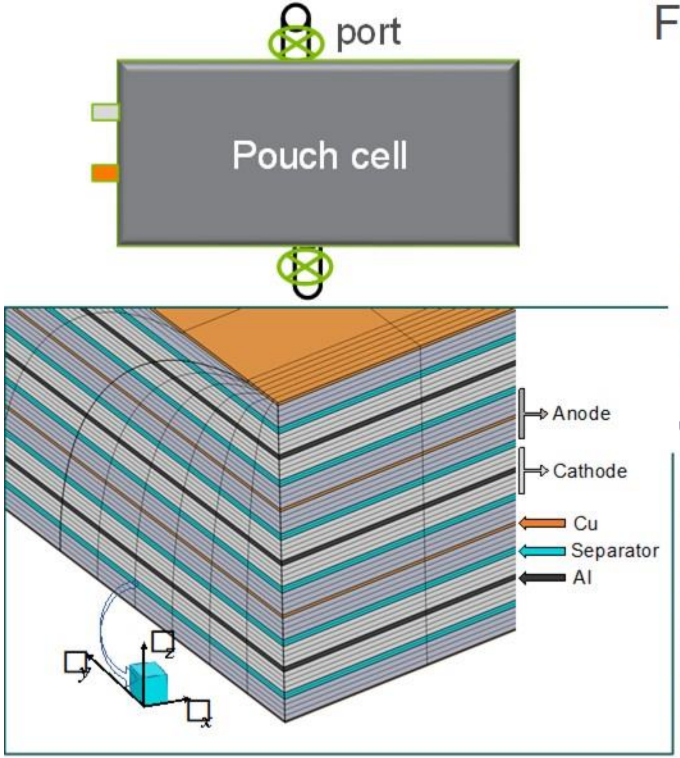




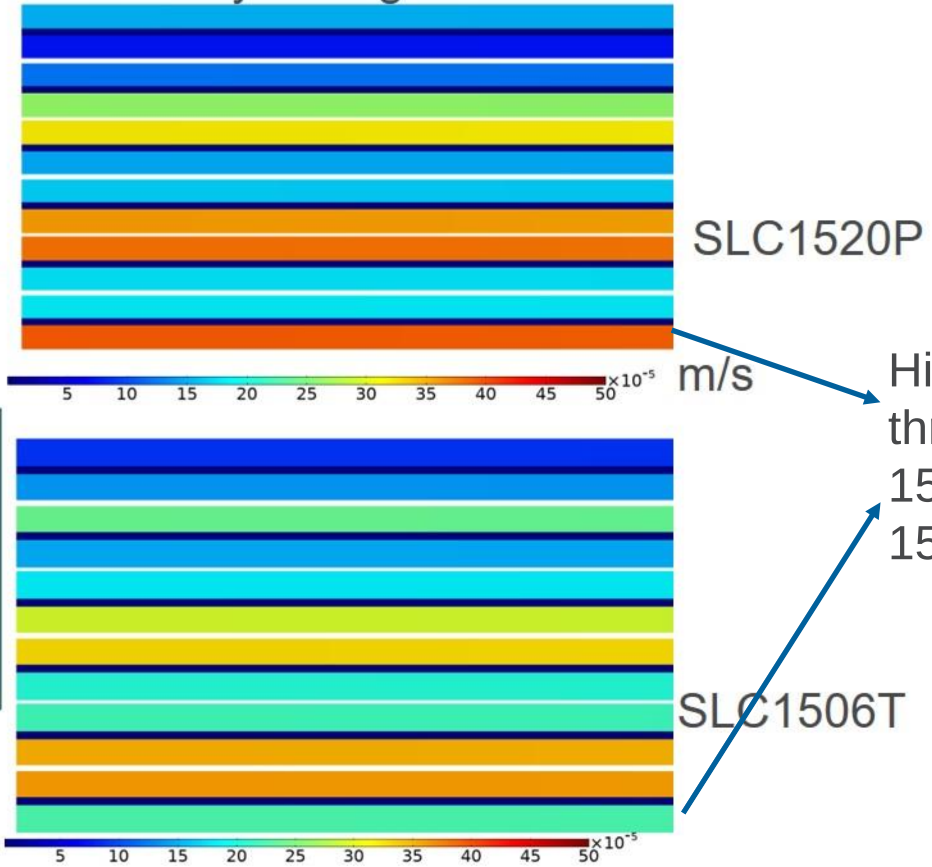




Challenge: difficult to maintain good sealing at the ports for long term, cells failed after a few days due to electrolyte loss

HIGHER FLUX THROUGH ANODE WHEN INCREASING GRAPHITE PARTICLE SIZE



Flow velocity through cell mid-section



Higher flux through SLC 1520P than 1506T

REMAINING CHALLENGES AND FUTURE WORK

- **Key Challenges**
  - Leakage at the connection
  - Low solubility of SEI in carbonate solvents
  - Difficult to rinse cells under high pressure

- **Future Work**
  - Explore appropriate materials to seal the port with pouches
  - Investigate liquid flow in electrodes with various microstructure

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

SUMMARY

- Validated loss of Li one main reason for capacity fade
- Demonstrated short term capacity recovery after cell rejuvenation in pouch cells
- Rinsing spent cells should be performed without releasing compression

We will complete the efforts in cell design for rejuvenation but will extend the efforts to design for sustainability.

- Reduce metal content in cell components
- Simplify pack design to access individual cells

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RESPONSE TO REVIEWERS

Not reviewed last year

COLLABORATION AND ACKNOWLEDGEMENTS

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)
Yaocai Bai (ORNL)
Jon Becker (NREL)
Ilias Belharouak (ORNL)
Ira Bloom (Argonne)
Anthony Burrell (NREL)
Zheng Chen (UCSD)
Andrew Colclasure (NREL)
Jaclyn Coyle (NREL)
Qiang Dai (Argonne)
Sheng Dai (ORNL)
Alison Dunlop (Argonne)
Jessica Durham (Argonne)
Rachid Essehli (ORNL)
Kae Fink (NREL)
Tinu Folayan (MTU)
Linda Gaines (Argonne)

Andy Jansen (Argonne)
Sergiy Kalnaus (ORNL)
Matt Keyser (NREL)
Greg Krumdick (Argonne)
Michael LeResche (Argonne)
Jianlin Li (ORNL)
Albert Lipson (Argonne)
Huimin Luo (ORNL)
Josh Major (NREL)
Margaret Mann (NREL)
Tony Montoya (Argonne)
Helio Moutinho (NREL)
Lei Pan (MTU)
Kyusung Park (NREL)
Haruka Pinegar (Argonne)
Bryant Polzin (Argonne)
Kris Pupek (Argonne)

Vicky Putsche (NREL)
Shriram Santhanagopalan (NREL)
Jeff Spangenberger (Argonne)
Venkat Srinivasan (Argonne)
Nathaniel Sunderlin (NREL)
Steve Trask (Argonne)
Jack Vaughey (Argonne)
Patrick Walker (NREL)
Tao Wang (ORNL)
Yan Wang (WPI)
Dustin Weigl (NREL)
Olumide Winjobi (Argonne)
Zhenzhen Yang (Argonne)
Jiuling Yu (NREL)
Xiaolu Yu (UCSD)
Ruiting Zhan (MTU)

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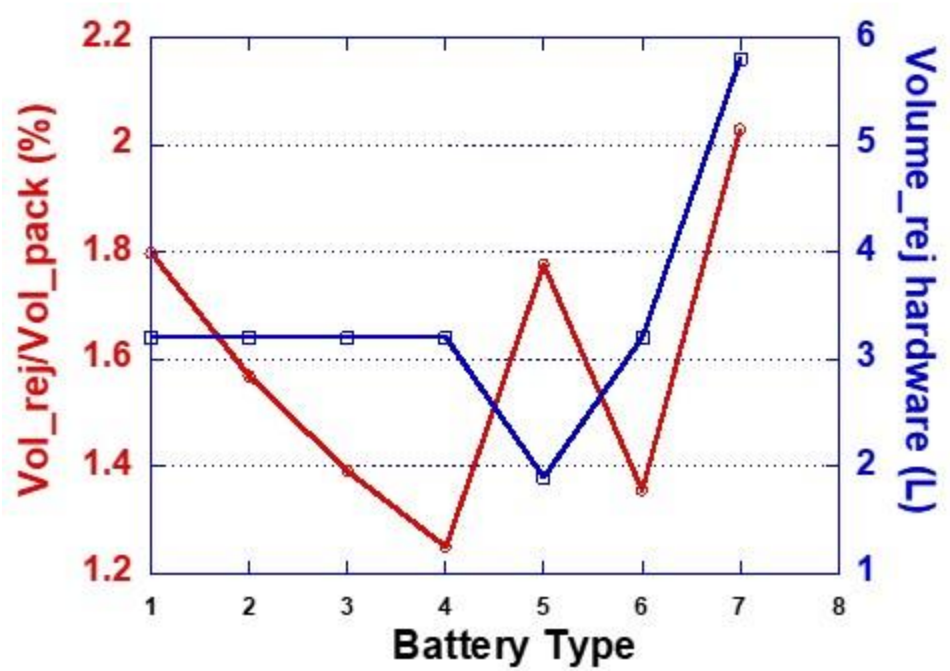
Technical backup slides

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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