RECELL OVERVIEW AND UPDATE

Project ID: bat377

JEFF SPANGENBERGER
Argonne National Laboratory

2021 DOE Vehicle Technologies Office
Annual Merit Review
June 21-25, 2021

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

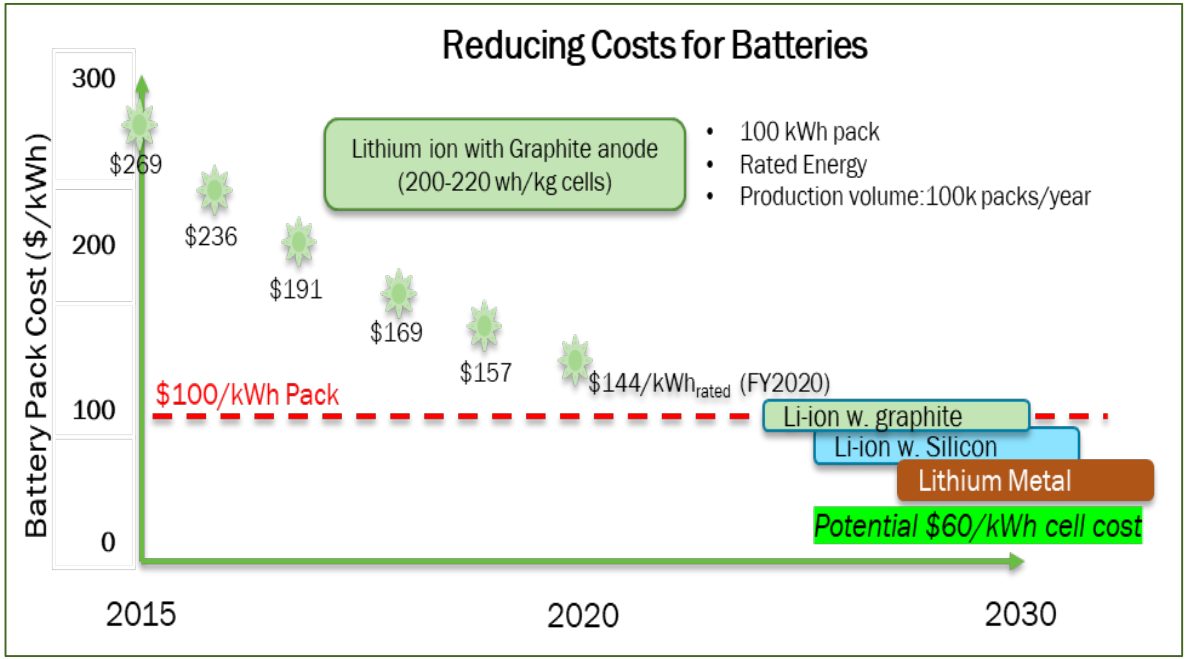
Partners

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

ReCell ADVANCED BATTERY RECYCLING

RELEVANCE

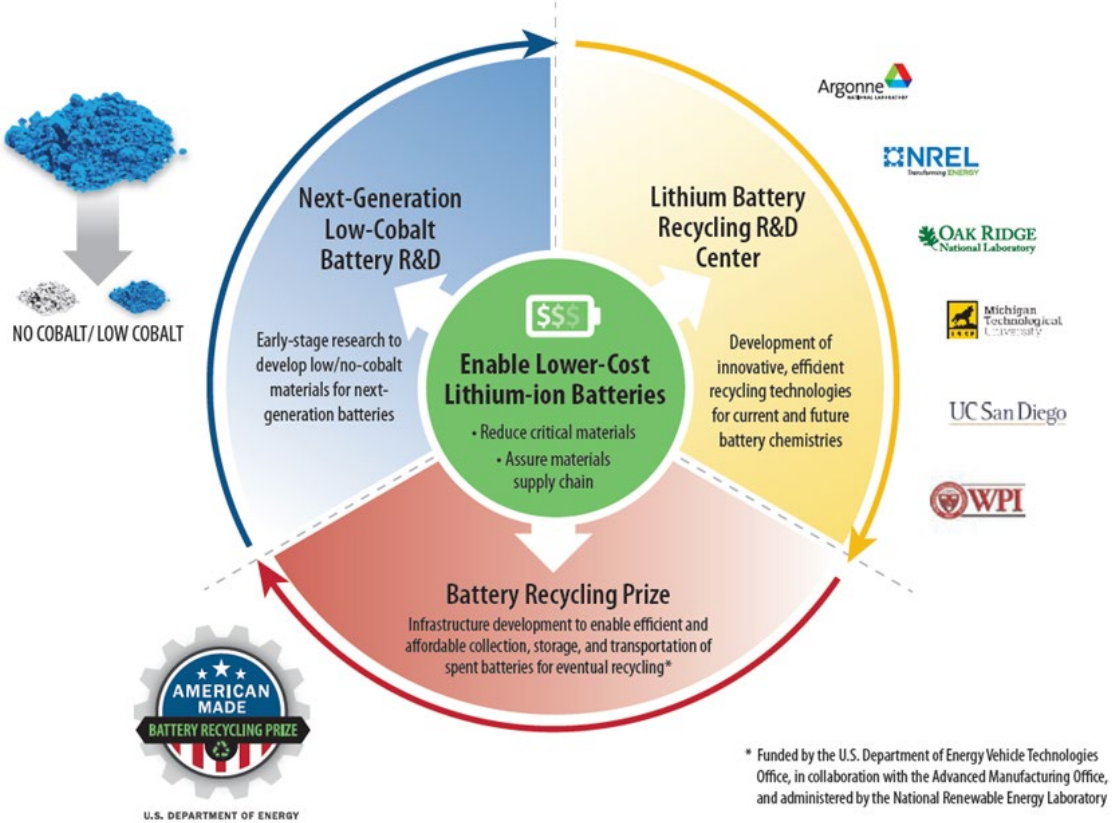
By 2025, reduce the cost of EV battery packs to less than $100/kWh with technologies that significantly reduce or eliminate the dependency on critical materials (such as cobalt) and utilize recycled material feedstocks.



ReCell
ADVANCED BATTERY RECYCLING

RELEVANCE

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

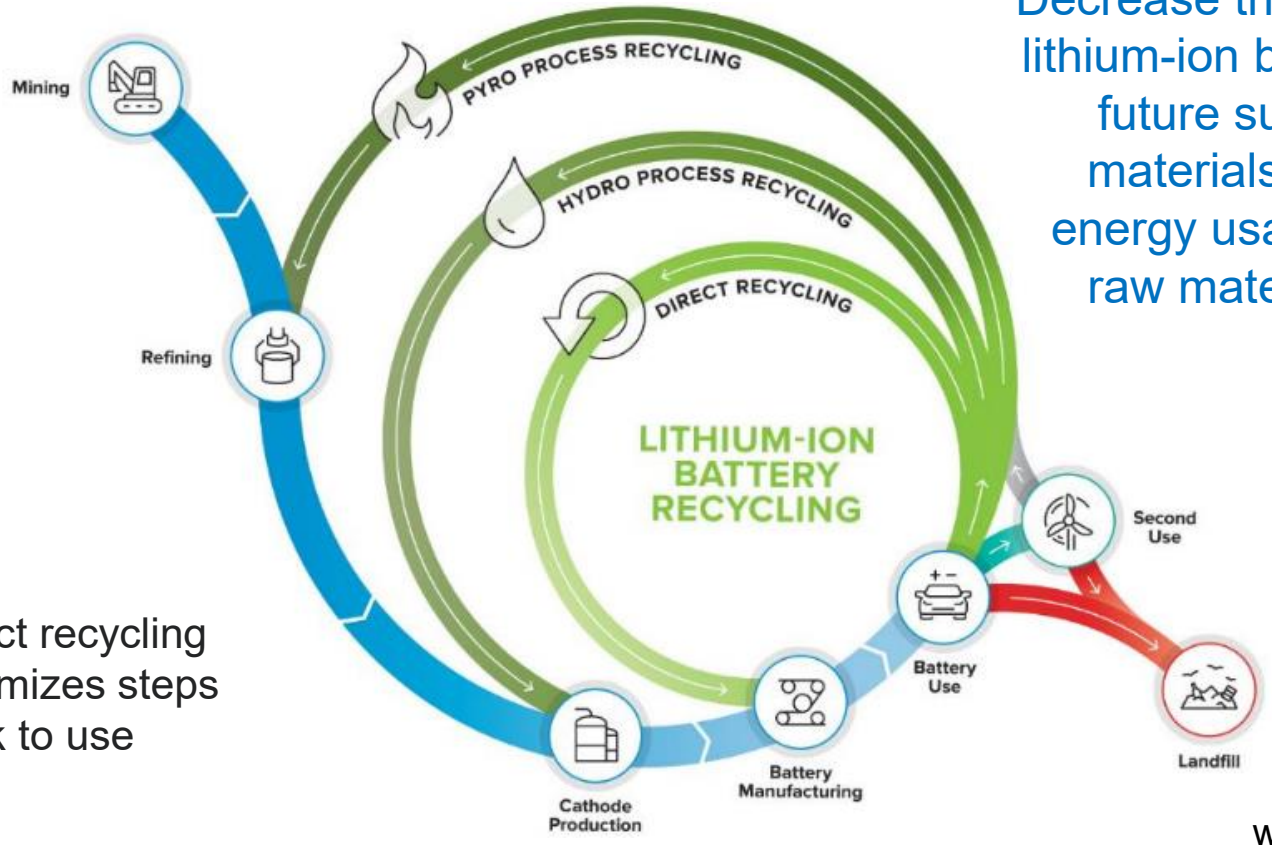


ReCell
ADVANCED BATTERY RECYCLING

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

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

DIRECT CATHODE RECYCLING

OTHER MATERIAL RECOVERY

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

Cross Cutting Projects

- Cell Design for Rejuvenation

DESIGN FOR SUSTAINABILITY

MODELING AND ANALYSIS

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

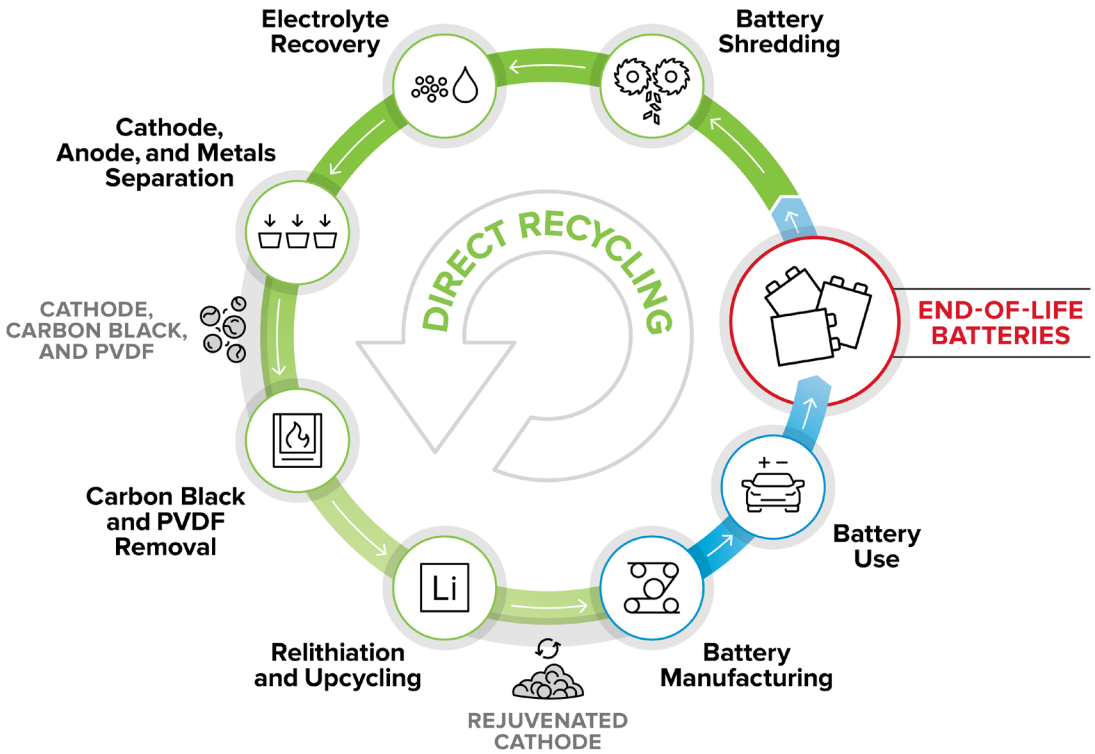
Program does not include battery dismantling, transportation, or 2nd use

ReCell ADVANCED BATTERY RECYCLING

APPROACH

- 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

Typical Direct Recycling Process Flow



ReCell
ADVANCED BATTERY RECYCLING

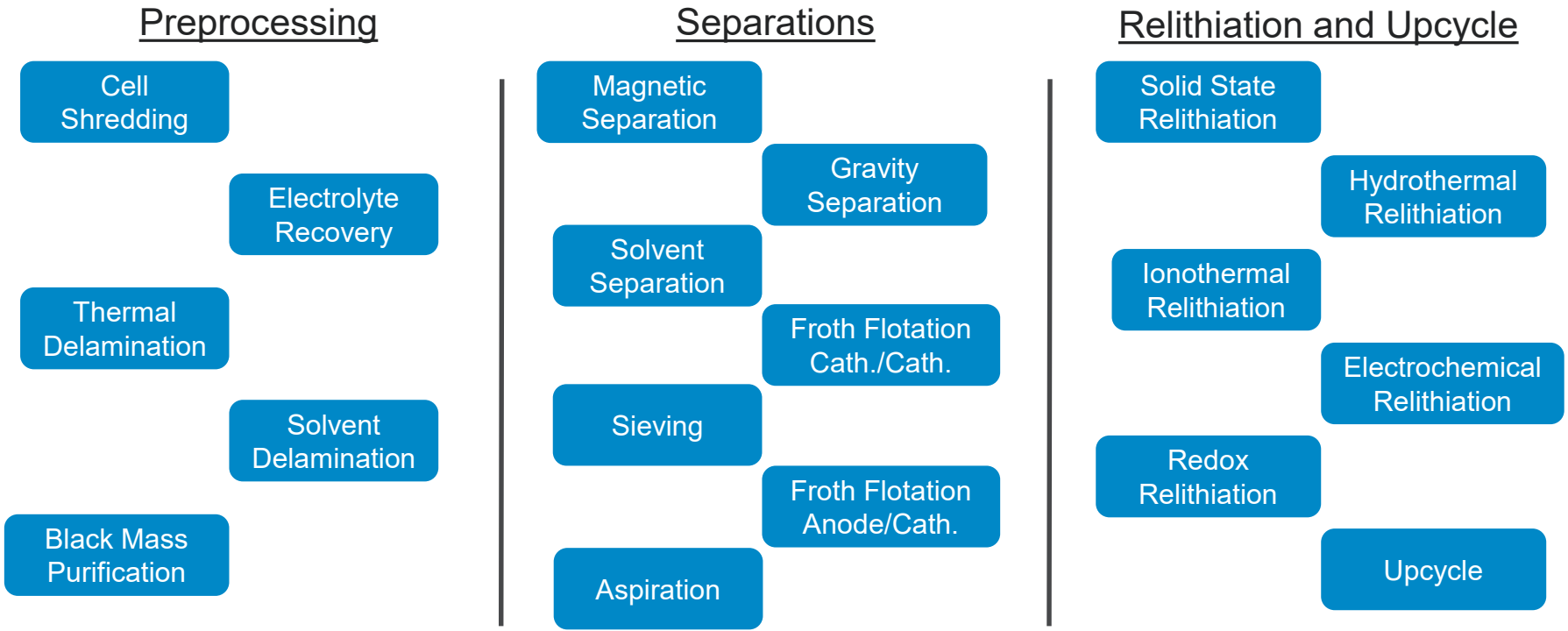
TECHNICAL ACCOMPLISHMENTS

Focus area and crosscut accomplishment examples

- Direct Recycling – Upcycling studies have identified pathways to modify NMC111 to NMC622
- Other Materials – Removal of copper and aluminum from black mass has been demonstrated
- Design for Sustainability – Initial capacity recovery in a pouch cell has been demonstrated
- Modeling and Analysis – LIBRA 1.0 is completed and scenarios are being analyzed
- Crosscut – Evaluated effects of low temperature on shredding safety
- The center has 28 published papers, with 10 more in process, and 17 inventions at various stages of being patented

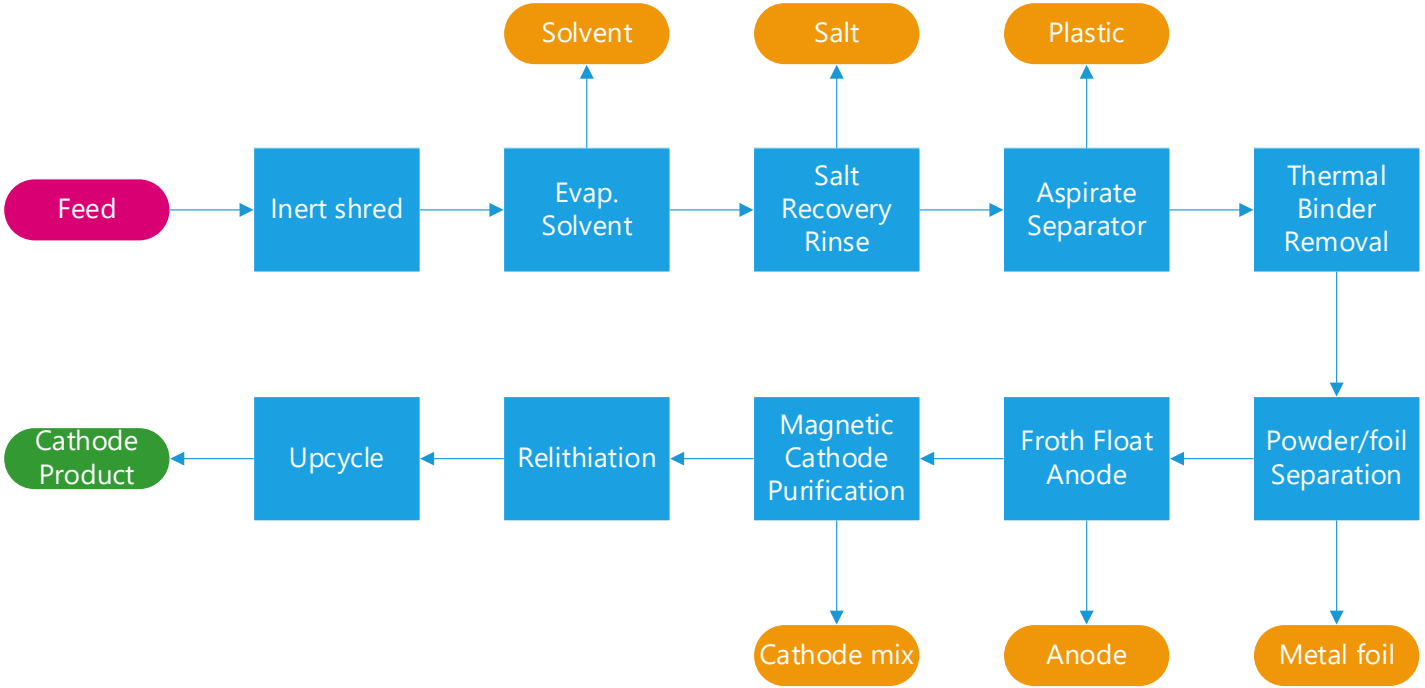
TECHNICAL ACCOMPLISHMENTS

The unit operation playground



TECHNICAL ACCOMPLISHMENTS

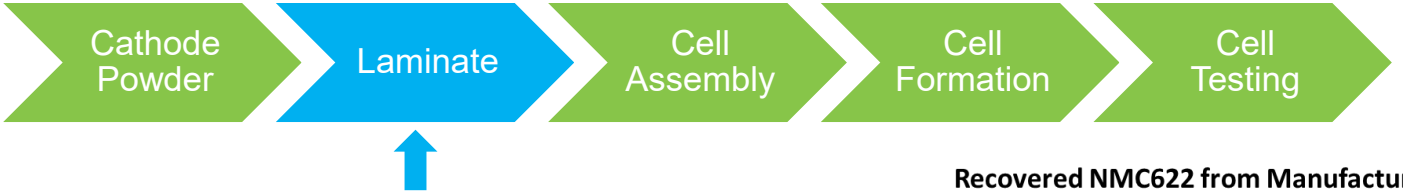
A direct recycling example



TECHNICAL ACCOMPLISHMENTS

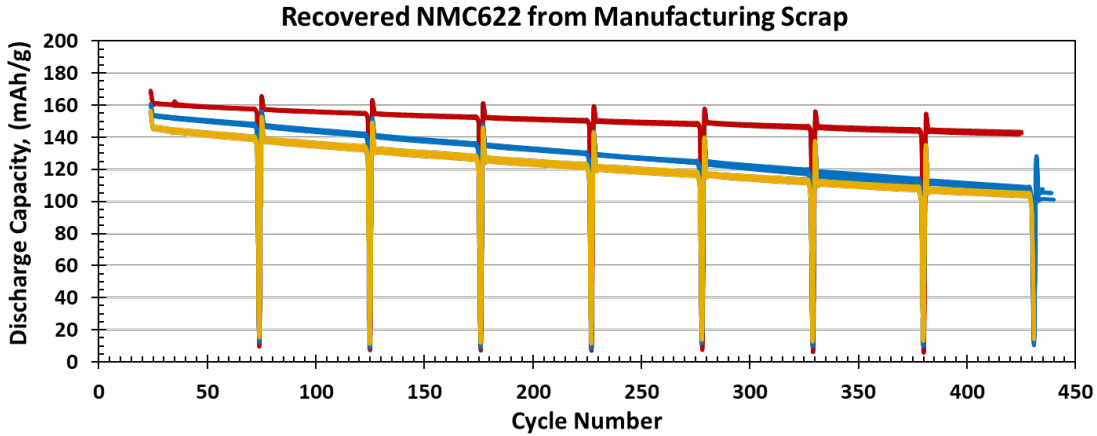
Manufacturing Scrap

Cathode manufacturing scrap is an entry point with less materials barriers while validating a partial list of unit operations being developed within ReCell



Demonstration point

Cycle 424 - C/2 Discharge Capacity Retention (%)	
ORNL Baseline NMC 622	88.5%
Thermally Delaminated Recovered NMC 622	69.9%
Solvent Y Recovered NMC 622	71.9%



ReCell ADVANCED BATTERY RECYCLING

COLLABORATIONS

Working with the Battery Recycling Prize and collaborating with others

- Team Portables
- Clarios
- Renewance
- Li Industries
- Smartville
- Titan Advanced Energy Solutions

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.

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

ReCell ADVANCED BATTERY RECYCLING

REMAINING CHALLENGES AND BARRIERS

- Ensuring recycled materials are reintroduced back into the domestic supply chain
- Achieving materials purity and performance (compared to virgin material)
- Detailed process/equipment information needed for accurate evaluation of technical and economic viability and a down-select process
- Industry buy-in for commercialization
- Battery recycling economics as chemistries move to low/no cobalt content
- The use of lithium metal anodes and solid state electrolytes will require new recycling processes
- Future battery chemistries (sulfur, sodium, magnesium, etc.) may introduce even more recycling challenges

PROPOSED FUTURE WORK

- Continue to research new technology concepts
- Joint projects and collaboration with industry to ensure relevant work scope and commercialization
- Demonstration of batteries made with recycled content in real applications
- Demonstration of a cost effective continuous battery recycling pilot line to prove feasibility to industry
- Commercialize a cost effective direct cathode recycling process for manufacturing scrap
    - Then for end-of-life batteries
- Transfer ReCell technologies to recyclers outside of direct recycling (Hydro, pyro, beyond batteries)
- Work with Battery Recycling Prize winners to improve collection, transport and battery dismantling
- Work closer with other recycling organizations (NATTBatt, ISRI, etc)
- Work with relevant stakeholders to reintroduce recycled materials back into the domestic supply chain

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

SUMMARY

- ReCell's objective this third year is to finish scaling up the most promising technologies to the point that we can demonstrate going from an end-of-life cell to a new cell
- Economic and environmental evaluations are performed for all ReCell processes using EverBatt modeling
- Direct recycling process flow options are being optimized
- New ideas continue to be considered and tested when deemed appropriate
- Continue working with industry to ensure ReCell's work is relevant to their needs
- Work to demonstrate processing of manufacturing scrap with industry is underway
- Facility space is in place and equipment continues to fill that space
- Continue to work on maximizing the value of all materials in the battery
- Domestic battery recycling and materials reuse will ensure a robust domestic supply chain

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

Argonne NATIONAL LABORATORY

Michigan Technological University

NREL NATIONAL RENEWABLE ENERGY LABORATORY

WPI

OAK RIDGE National Laboratory

UC San Diego

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)

ReCell ADVANCED BATTERY RECYCLING

ReCell

ADVANCED
BATTERY RECYCLING

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

VEHICLE TECHNOLOGIES OFFICE

E-Mail: recell@anl.gov
Website: www.recellcenter.org