BATTERY RECYCLING MODELING

Project ID # bat342

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Argonne National Laboratory

2018 DOE Vehicle Technologies Office Annual Merit Review

June 19, 2018
Arlington, VA

OVERVIEW

Timeline

- Project start date: July 2017
- Project end date: to be added
- Percent complete to be added

Barriers

- Barriers addressed
  - To be added

Budget

- Total project funding: $250
  - DOE share: 100%
- Funding for FY 2017: $125
- Funding for FY 2018: $125

Partners/Interactions

- To be added

RELEVANCE

Objective of Argonne Battery Recycling (“ReCell” Model)

- Advancement of ANL’s baseline high-level, closed-loop battery recycling model that was developed in FY17 using internal LDRD funding
- ReCell quantifies energy, environmental, and economic impacts of battery manufacturing and close-loop recycling
- Addition of high nickel cathodes (NCA and NMC 811) to the baseline model
- Increase the accuracy of the model by working with battery recyclers to obtain more detailed process information.
- Compare virgin batteries to those with recycled content
  - For varied chemistry, design, plant size, utilization, etc.
  - Identify trade-offs
  - Enable customization for user-specific needs

RELEVANCE

Impact of ReCell Model

- Capability to guide battery manufacturers and OEMs in their decision making towards recycling
- Provides insight into impacts of LIB recycling and other process steps to allow stakeholders to simulate and visualize cost and environmental impacts
- Enable direction of battery recycling R&D towards optimization of both process specific, and overall, economic, energy, and environmental impacts
- Facilitates Design for Recycling (DFR) analyses.
- Other companies/organizations have shown interest in use/customization

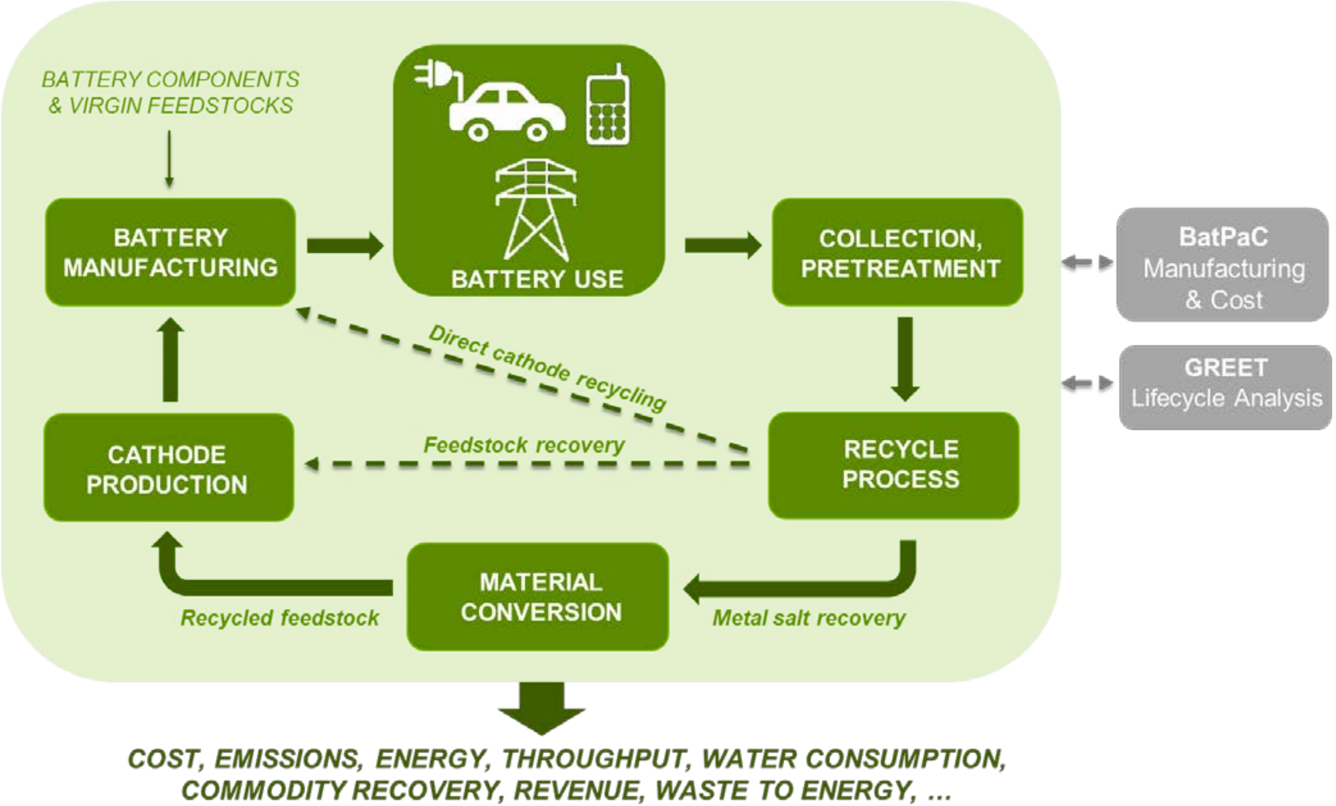
MILESTONES

ACTIVITY	PLAN START	PLAN DURATION	Jul 1	Aug 2	Sep 3	Oct 4	Nov 5	Dec 6	Jan 7	Feb 8	Mar 9	Apr 10	May 11	Jun 12
NMC/NCA Addition	1	2												
NMC/NCA added to current model	2	1												
Model Improvement	3	10												
Model completed	9	1												
Model documentation	10	1												
Demonstration Communication	12	1												
Stakeholder Interaction	1	12												
Documentation of all learnings	12	1												
Lithium-Sulfur Prelim. Investigation	4	3												
Report on prelim. Findings	6	1												

Plan Duration	Delivered

APPROACH

ReCell MODEL FLOW



APPROACH

- The ReCell model, linked to BatPaC and GREET, is designed with industry-wide generic recycling technology paths and unit process
- Provides flexibility for individual companies to modify the model to add company-specific technologies and processes.
- Format: Excel-based
- Input
  - As few as several high-level information (less than 10 input parameters to run the recycling module)
  - As many as detailed process/equipment specific information (hundreds of input parameters for the recycling module)
- Output
  - Cost
  - Environmental impacts: energy consumption, water consumption, air emissions

OUTPUTS FROM GREET AND BatPaC

Become inputs to ReCell

BatPaC and Process Models

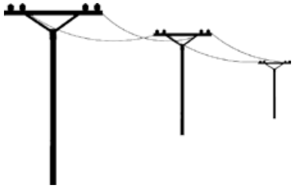
- Inventory of materials in battery pack
- Cost of cells, battery pack
- Cost contribution from processing steps in manufacturing plant
  - Material and energy needs and costs
  - Investment for capital equipment
  - Cost contributions to pack cost

GREET

- Life-cycle impacts from material production
  - Energy use, by type
  - CO_2 emissions
  - Criterial pollutant emissions
  - Water consumption
- Fuel production upstream burdens

MODEL INPUTS

Default inputs are used as a starting point



General

Labor cost
Material cost
Utility costs
Equipment
Plant Life

Battery Production

Throughput
Chemistry
Format
Location

Collection

Distance
Classification
Mode

Recycle

Process
Throughput
Chemistry
Location

Cathode Manufacture

Throughput
Chemistry
Location

MODEL INPUTS

Default inputs are easily changed

Basic Input		
Manufacture (click to link)		
Throughput	tonne/yr	6,650
Chemistry	N/A	NMC(811)
Format	N/A	Prismatic
Geographic location	N/A	U.S.
Collection & Transportation (click to link)		
From end use to collection	Miles	20
From collection to recycler	Miles	1,000
From manufacturer to recycler	Miles	500
From recycler to cathode producer	Miles	500
From cathode producer to manufacturer	Miles	500
Include shipping manufacturing scrap material to recycler	N/A	No
Include shipping rejected cells to recycler	N/A	No

Note: Cost es

Go

Go

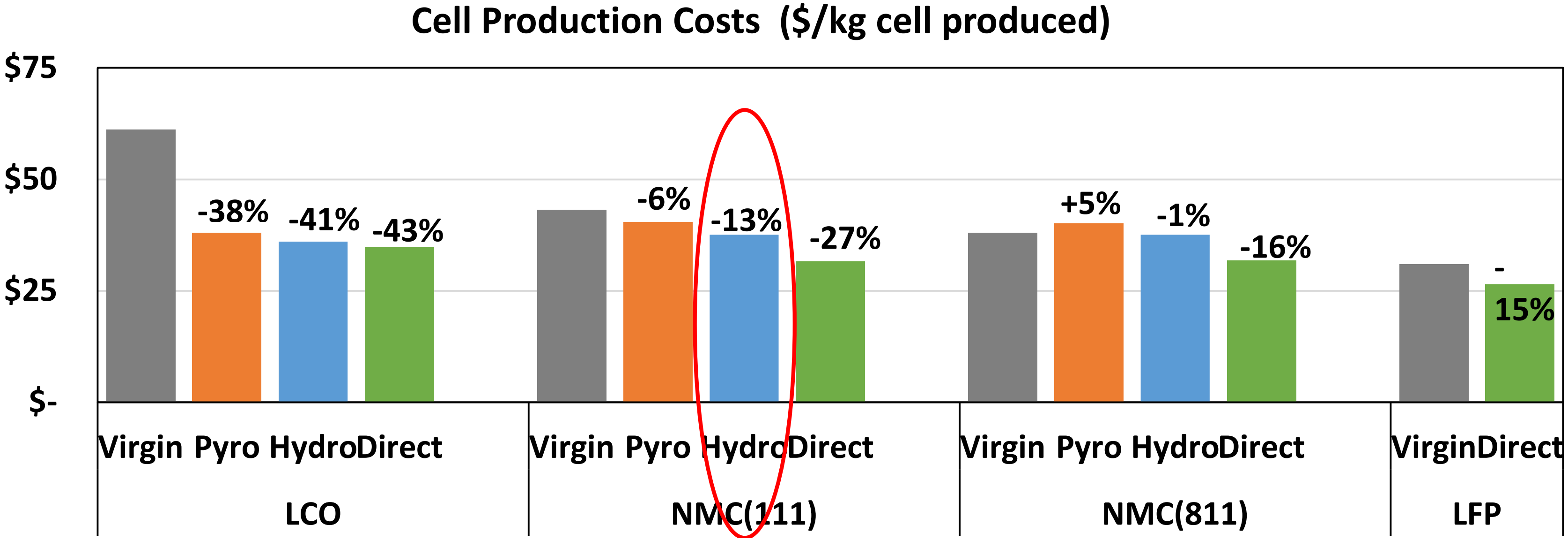
MODEL OUTPUTS

Output includes additional details and depends on assumptions

	Virgin Manufacture	Manufacture with recycled materials		
		Pyro	Hydro	Direct
Cost ($/kg cell produced)	43.18	40.40	37.60	31.63
Total Energy (MJ/kg cell produced)	152	135	140	91
Total Emissions (g/kg cell produced)				
VOC	1.8	1.8	1.8	1.0
NO_x	17.7	18.4	14.8	8.8
PM_{10}	5.3	3.2	3.0	2.3
SOx	295	88	92	56
CO_2	9457	13600	8702	5433

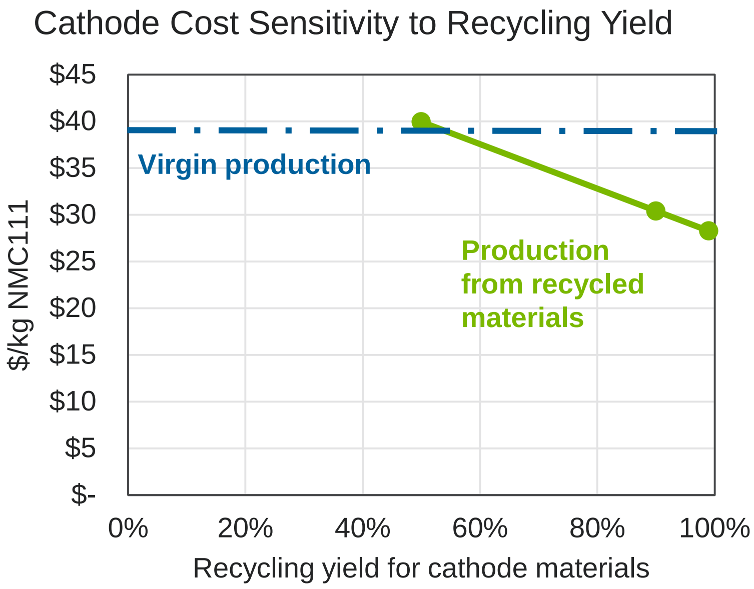
TECHNICAL ACCOMPLISHMENTS AND PROGRESS

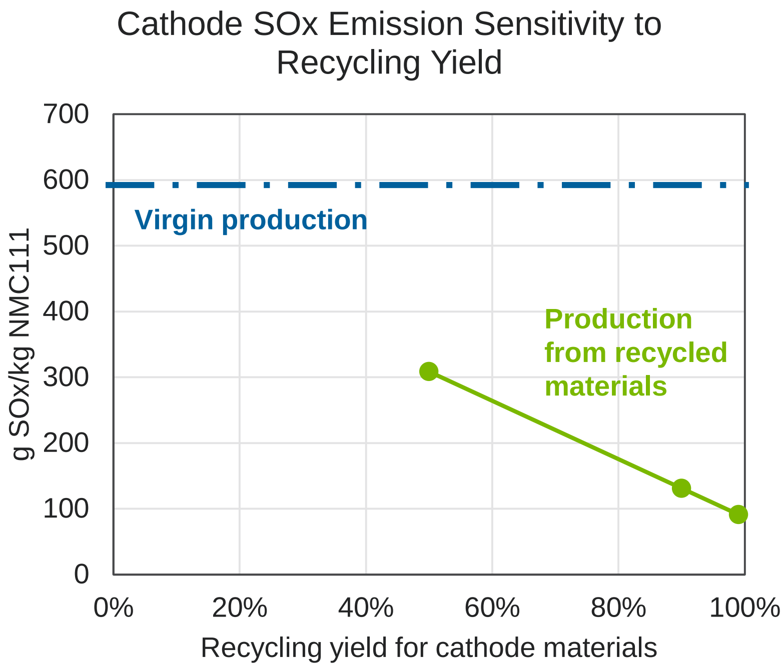
- Evaluated the economic benefit of cell produced from recycled cathode
  - for different lithium-ion battery chemistries
  - for different recycling technologies



TECHNICAL ACCOMPLISHMENTS AND PROGRESS (CONTD.)

- Translated technology parameters into cost and environmental impacts
  - Unit cost and environmental impact decreases as more material is recovered
  - Below 40% yield, recycled material costs more than virgin

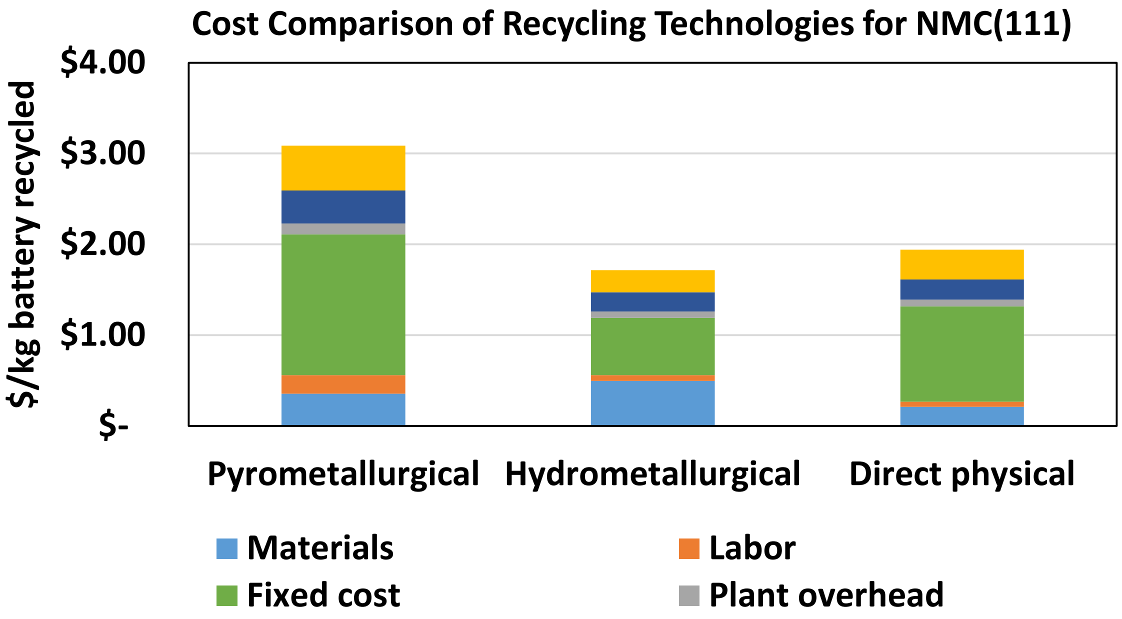




TECHNICAL ACCOMPLISHMENTS AND PROGRESS (CONTD.)

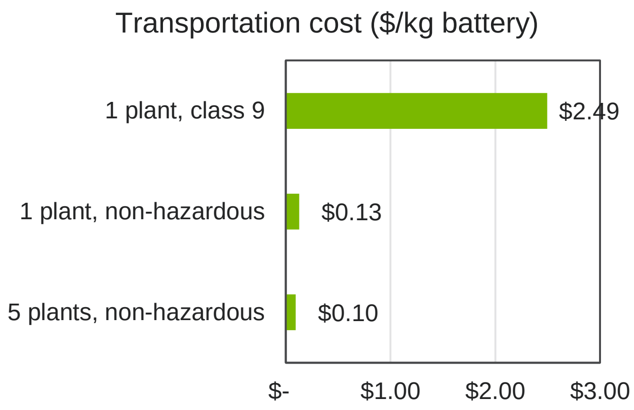
- Compared cost breakdown for various recycling processes

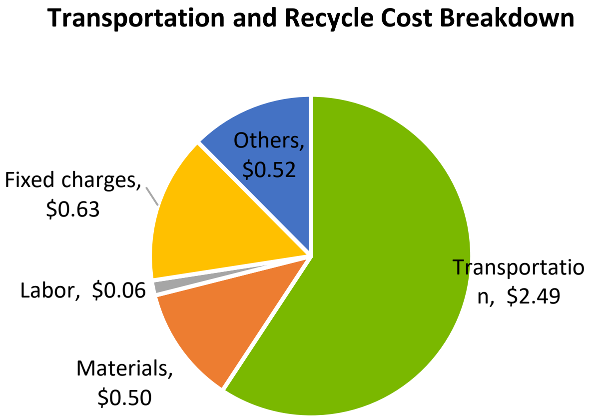
- High plant capital cost is largest contributor
- Materials are significant input for hydro
- Byproduct credits not included

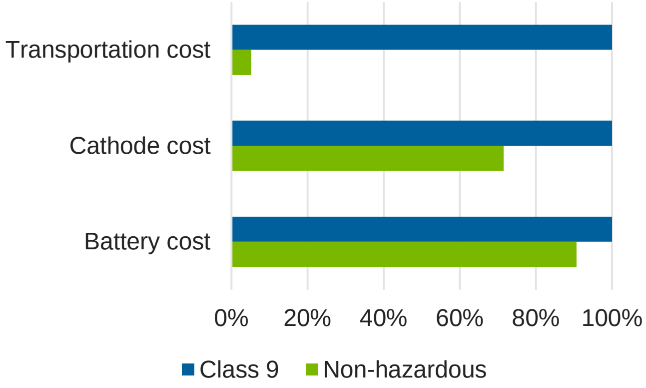


TECHNICAL ACCOMPLISHMENTS AND PROGRESS (CONTD.)

- Evaluated the impact of transportation cost on the overall cost of battery recycling
- Lithium-ion battery currently classified as Class 9 hazardous material in the U.S.
    - This classification increases the cost of recycling







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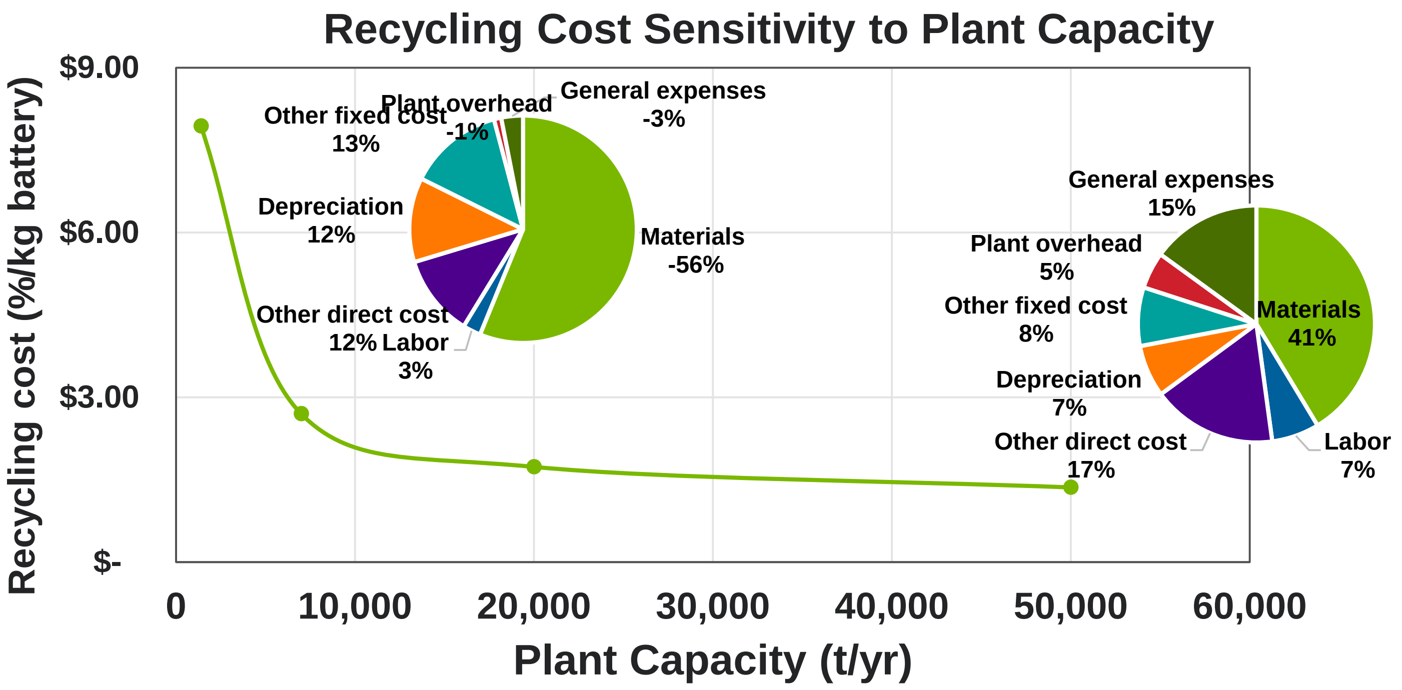
TECHNICAL ACCOMPLISHMENTS AND PROGRESS (CONTD.)

- Evaluated the impact of process scale-up on recycling cost
  - Recycling cost reduces as scale of recycling plant reduces
  - This will reduce the cost of battery production with recycled cathode



TECHNICAL ACCOMPLISHMENTS AND PROGRESS (CONTD.)

- Evaluated the consequences of business decisions and market dynamics
  - Geographic location, plant capacity, and battery chemistry will impact profitability of recycling

One 7,000 t/yr plant in U.S., recycling 100% NMC(111) via hydro

Battery feed changed to 50% NMC(111) and 50% NCA

Same new plant in China

Five 1,400 t/yr plant in U.S., recycling 100% NMC(111) via hydro

RESPONSES TO PREVIOUS YEAR'S REVIEWERS' COMMENTS

- This project has not been reviewed

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

- Collaboration with industry has been key to gaining accuracy of the model

REMAINING CHALLENGES AND BARRIERS

- Continued identification of real-life process data is very difficult to obtain due to company secrecy.

PROPOSED FUTURE RESEARCH

- Add lithium-sulfur battery manufacturing and recycling information to the recycling model for preliminary evaluations.
- Continue communications with industry/academia/government agencies
- Improve data accuracy
  - As detailed recycling process information is obtained, it will be included in GREET and linked to ReCell Model
- Characterize variants of hydrometallurgical processes (including direct recycling, using no acid or base)
  - Of interest are conditions under which the cathode crystal structure can be retained and possibly reused in rejuvenated cathode material
- Improve user experience of the Model
  - Stakeholder input will be used to make the model more user friendly and to help identify additional areas for improvement

SUMMARY

ReCell:

- Accelerates development of sustainable recycling processes
  - Enables direction of R&D to highest potential impact areas
- Evaluates cost and environmental impacts for each unit process
  - And aggregates to entire life-cycle
- Compares virgin batteries to those with recycled content
  - For varied chemistry, design, plant size, utilization, etc.
  - Identifies trade-offs
  - Can be customized for user-specific needs