ReCell
ADVANCED
BATTERY RECYCLING

LCA FOR LI-ION BATTERY RECYCLING R&D

LINDA GAINES
lgaines@anl.gov
Energy Systems Division
Argonne National Laboratory

Life-Cycle Analysis for Transportation Symposium
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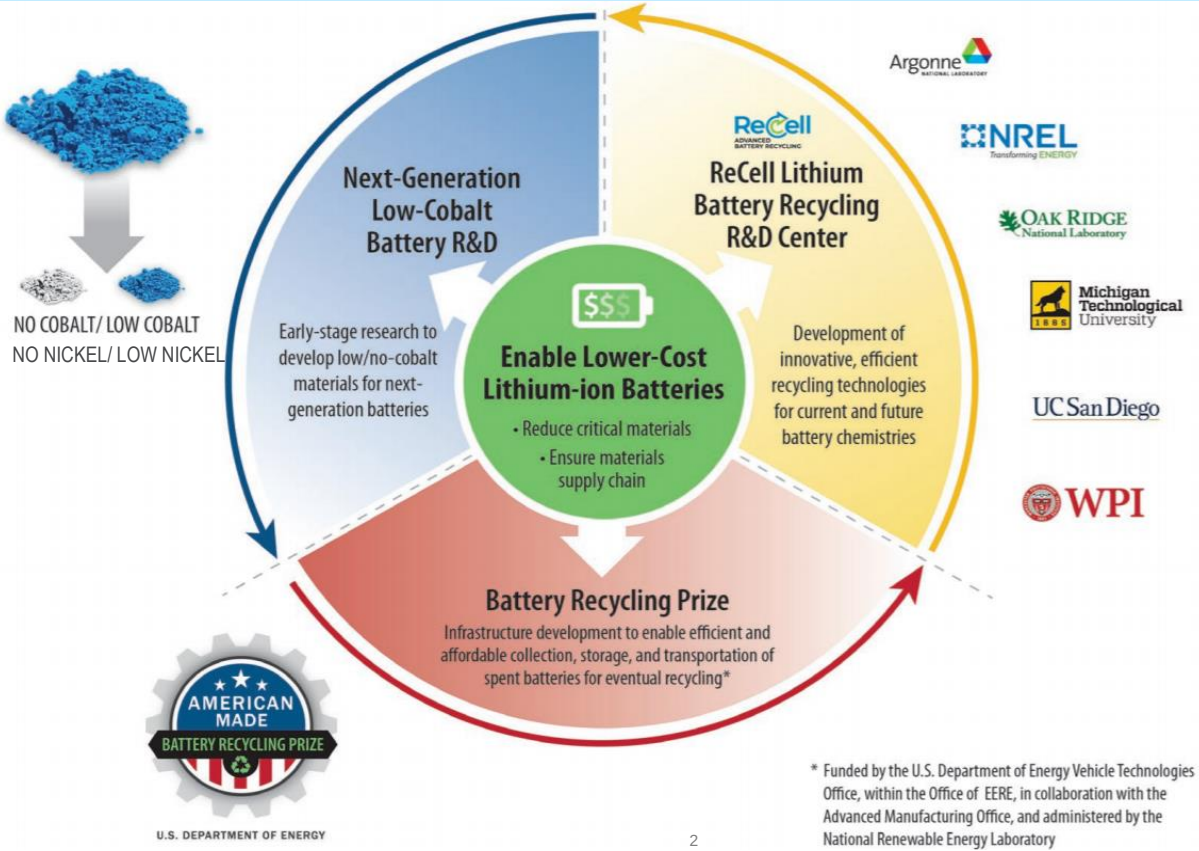
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
VEHICLE TECHNOLOGIES OFFICE

RECELL IS PART OF DOE'S CRITICAL MATERIALS PLAN

to reduce the cost of EV batteries while significantly reducing or eliminating dependency on critical materials (such as Co and Ni) and using recycled material feedstocks.



Argonne leads ReCell's $5+ million/y collaboration of 3 national labs and 3 universities, funded in 2019 by Vehicle Technology Office to develop a viable recycling process.

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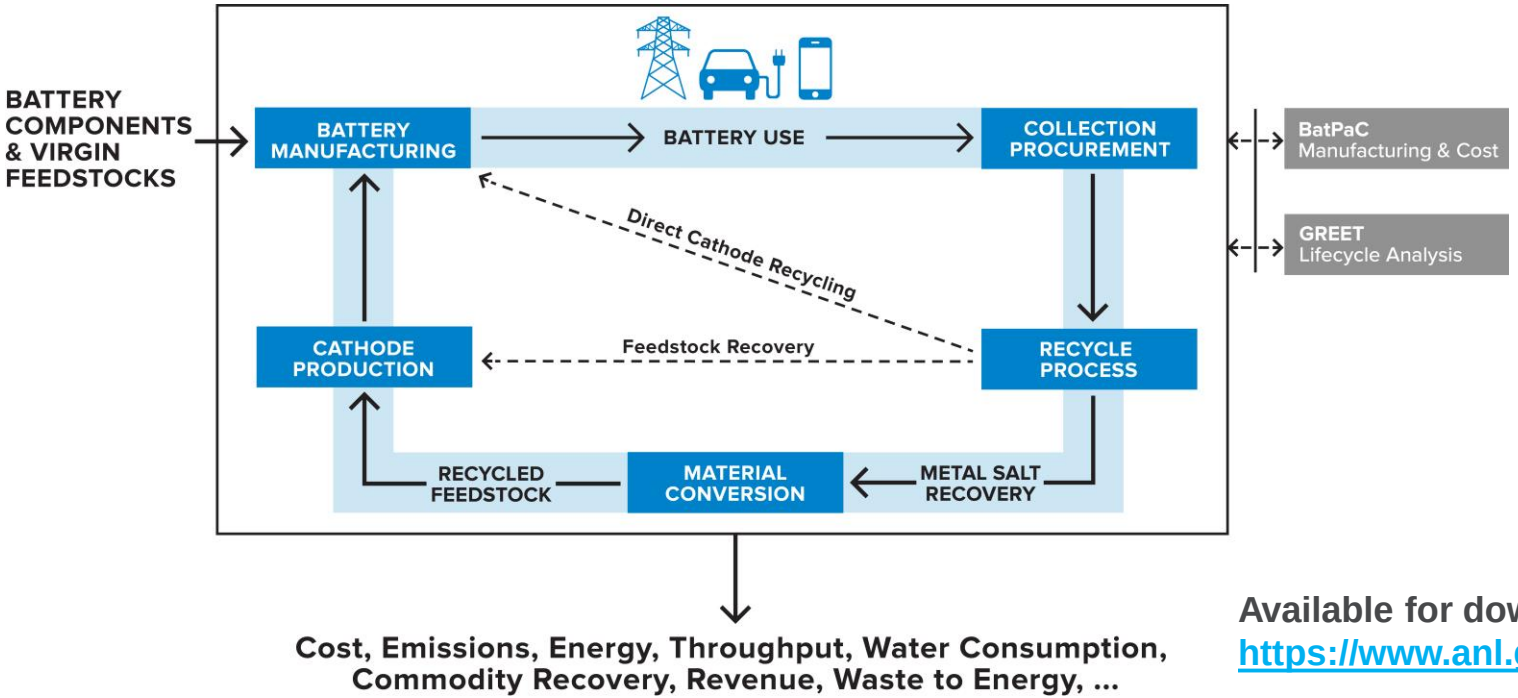
LIFECYCLE ANALYSIS EVALUATES PROCESS IMPACTS

of a product's life cycle, from raw material acquisition through production, use, end-of-life treatment, recycling, and final disposal if any.

EVERBATT MODEL IDENTIFIES THE MOST EFFICIENT AND ECONOMIC PROCESSES

There are many potential recycling pathways for batteries. Modeling and analysis can guide process development without the need to actually try all options.



Available for download at:
https://www.anl.gov/egs/everbatt

EverBatt received a 2019 R&D100 award.

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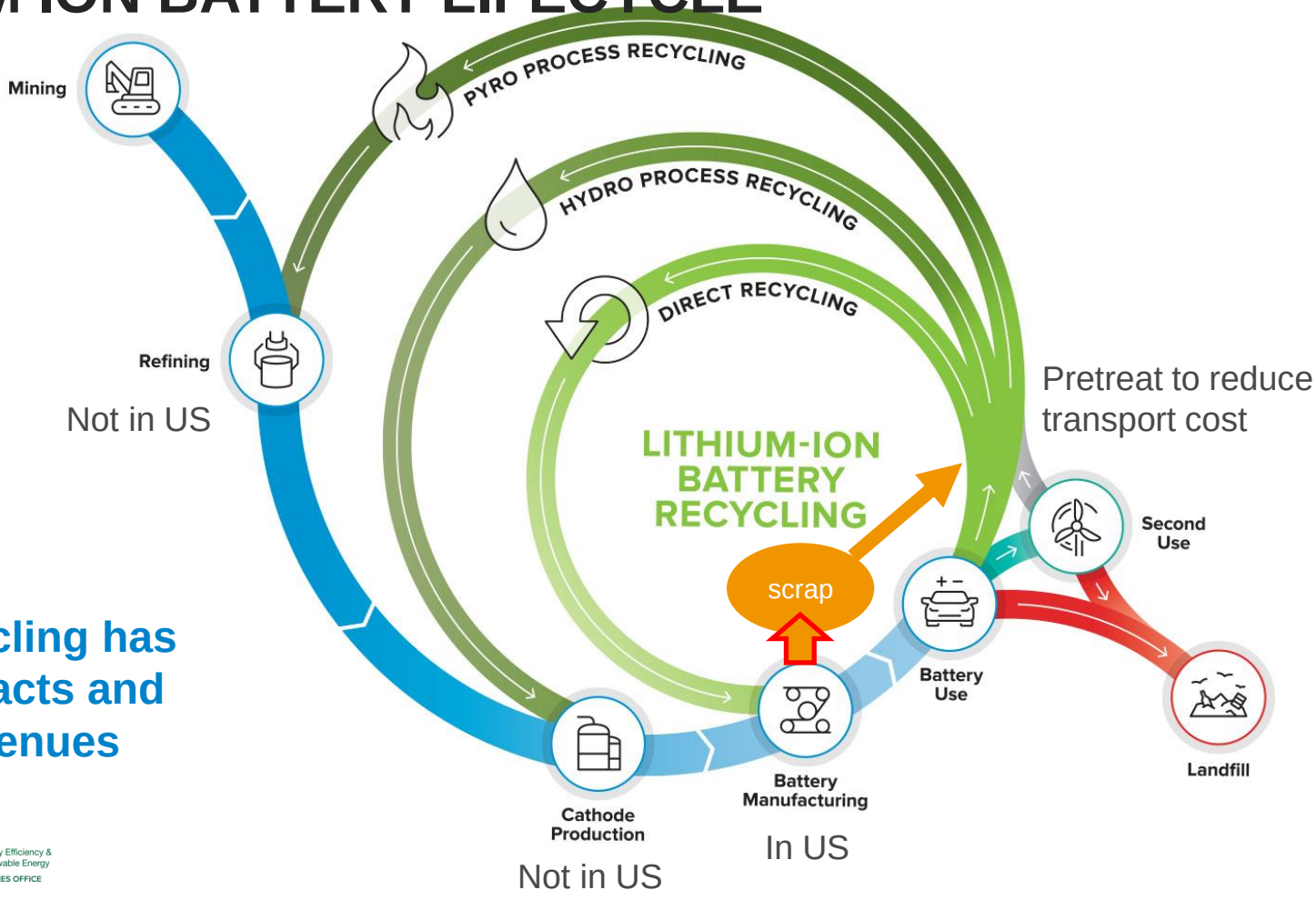
LITHIUM ION BATTERY LIFECYCLE



Direct recycling has lowest impacts and highest revenues

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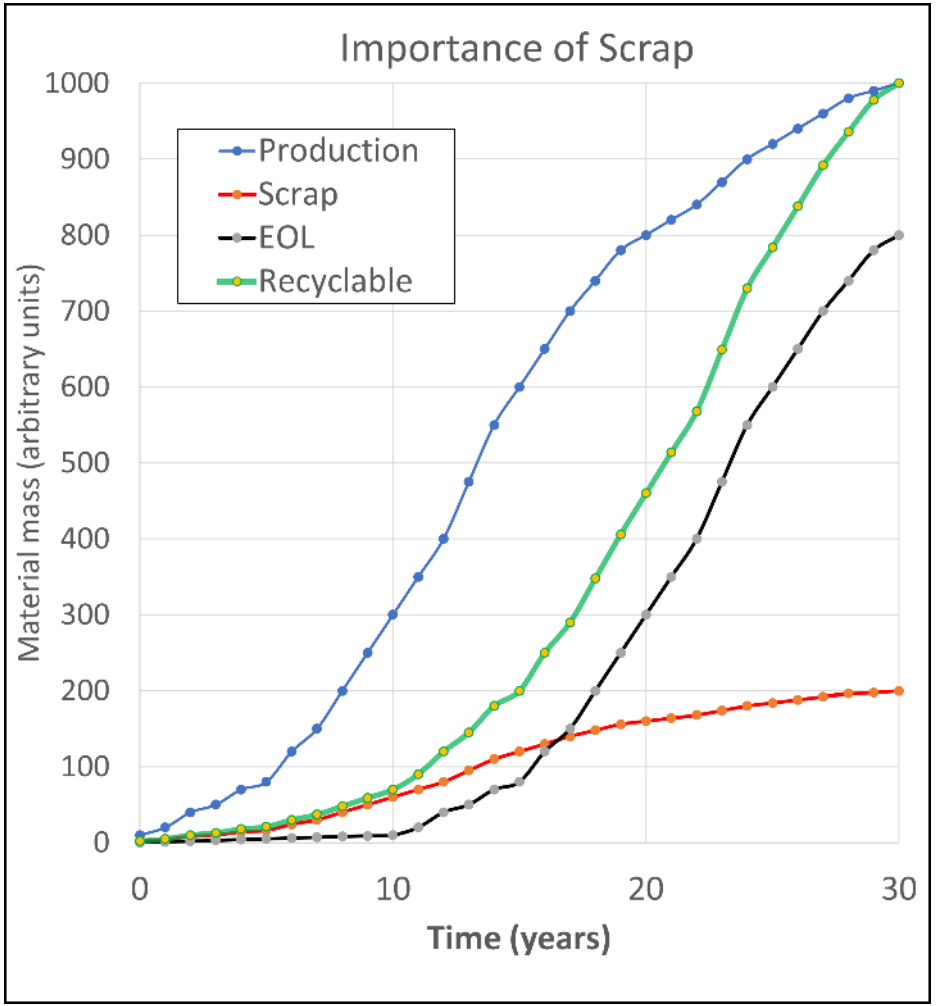
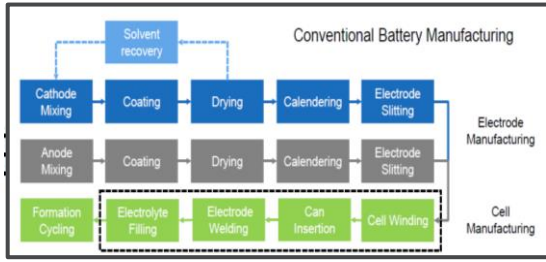
NEW RECYCLING PLANTS' MAIN FEED IS PRODUCTION SCRAP

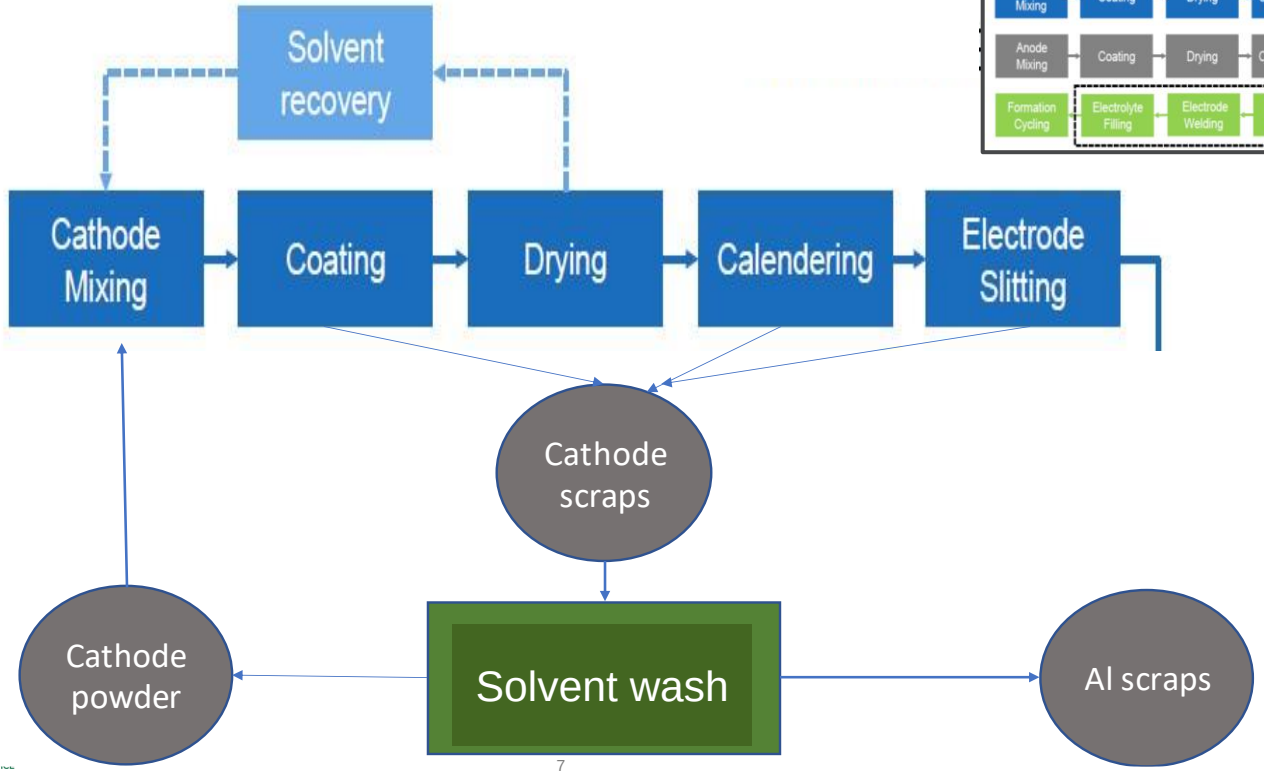
Artifact of rapid growth



AFTER SIMPLE PROCESSING, SCRAP CAN RETURN TO MANUFACTURING

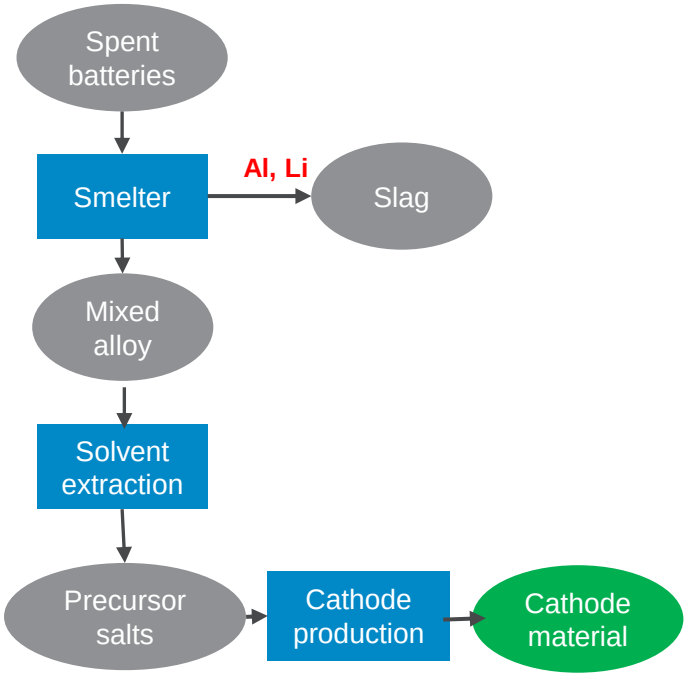
Need to compare to full recycle loop





PYROMETALLURGICAL PROCESSING IS HIGH TEMPERATURE AND LARGE SCALE

Umicore pilot plant is designed to process 7,000 tonnes per year



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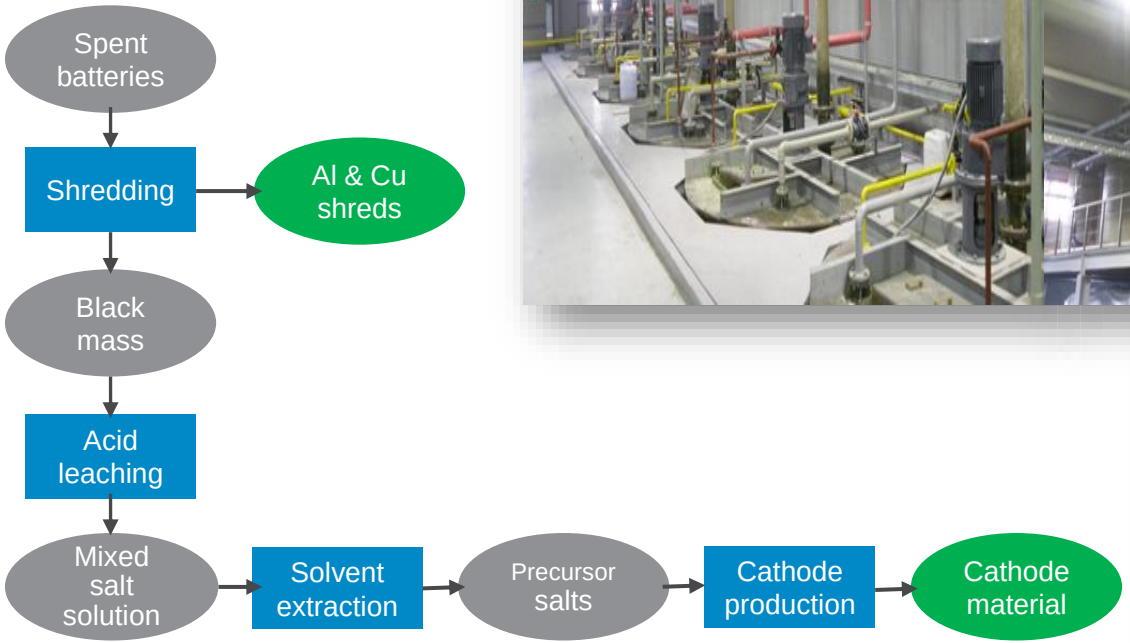
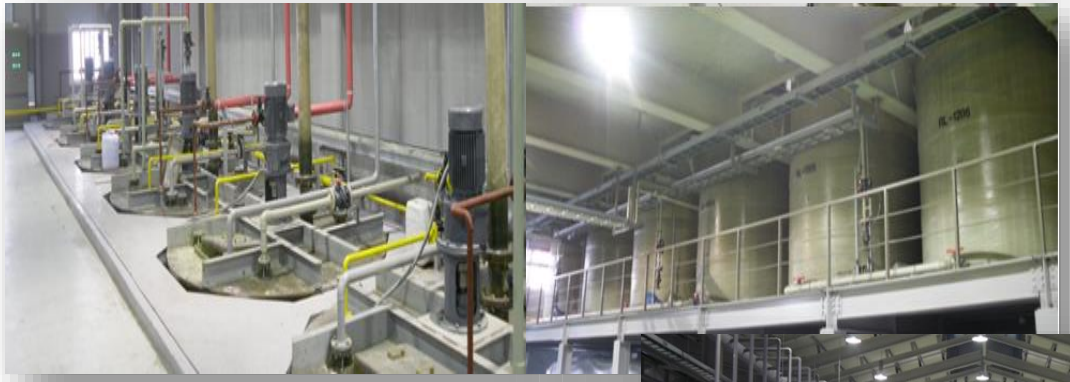
HYDROMETALLURGY

Materials are dissolved in acid and components are separated





Courtesy of SMCC

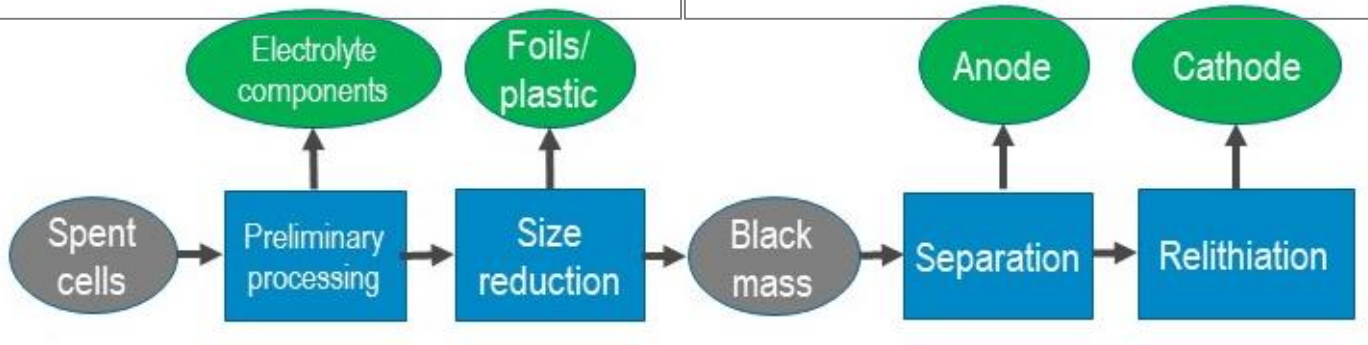
DIRECT RECYCLING is the recovery, regeneration, and reuse of battery components directly without breaking down the chemical structure.

BENEFITS

- **Retains valuable chemical structure**
- Enables economic recovery of more materials
- Could be used now for manufacturing scrap
- Low temperature, low energy
- Avoids most impacts of virgin material production

CHALLENGES

- Separating multiple cathode chemistry particles
- Product may be obsolete formulation
- Degradation may limit repeats
- Buyer must be assured of quality
- Not demonstrated on industrial scale



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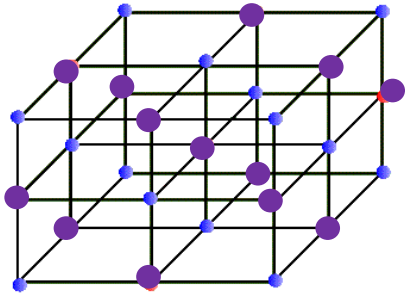
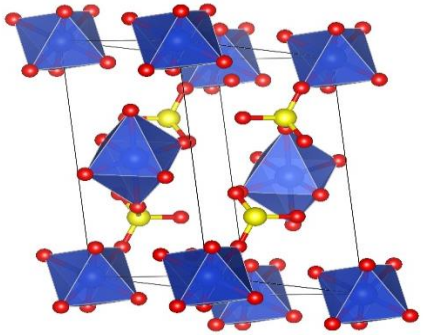
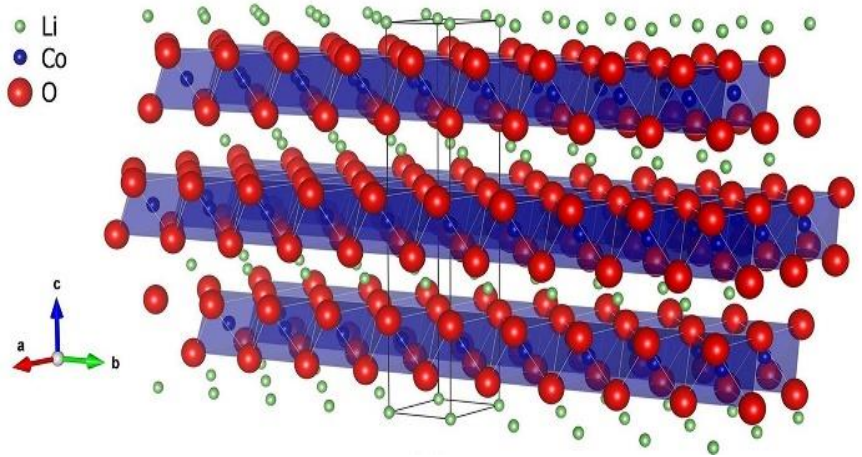
DIRECT RECYCLING RECOVERS HIGHLY STRUCTURED MATERIAL



Cobalt has a simple cubic structure; nickel impurities can substitute



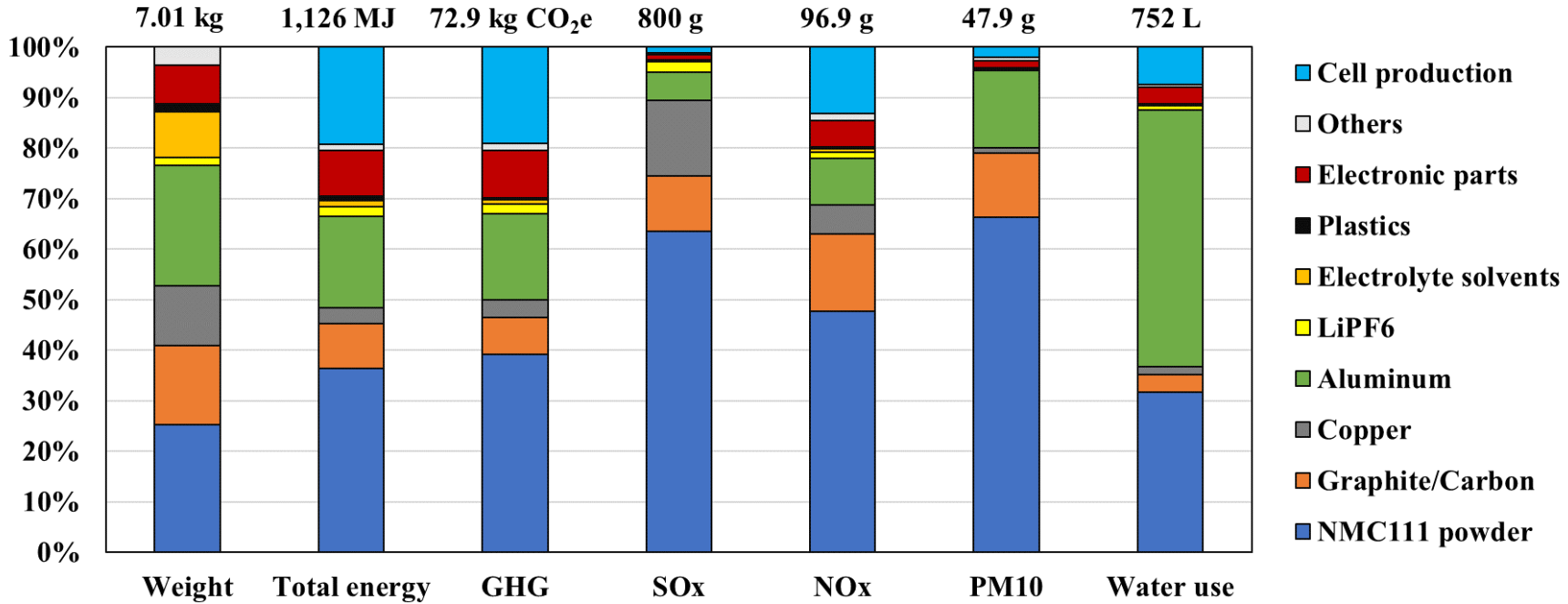
Cobalt sulfate is octahedral



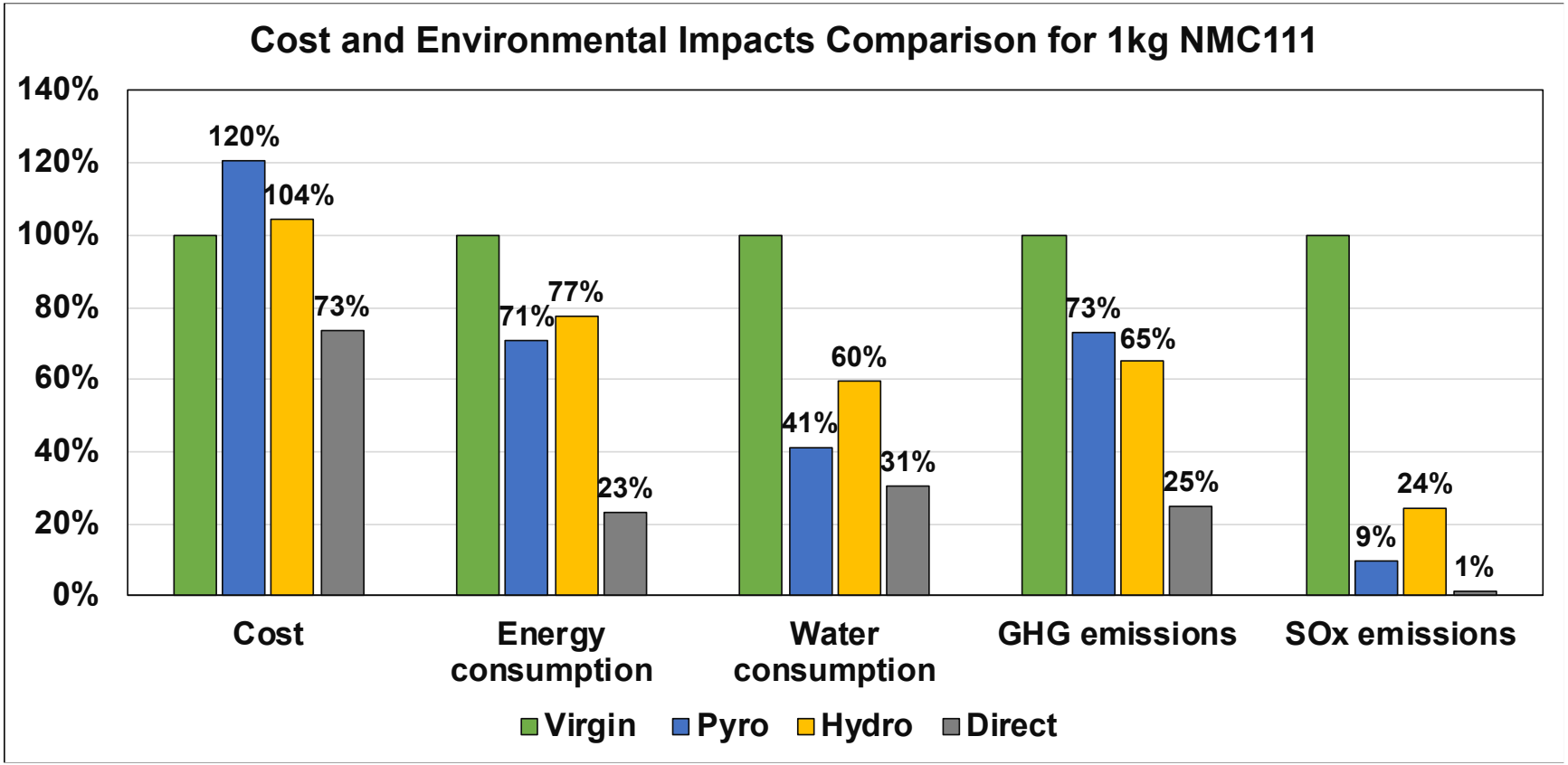
LCO has an ordered layered structure

CRADLE-TO-GATE ENVIRONMENTAL IMPACTS: 1KWH NMC111 CELLS

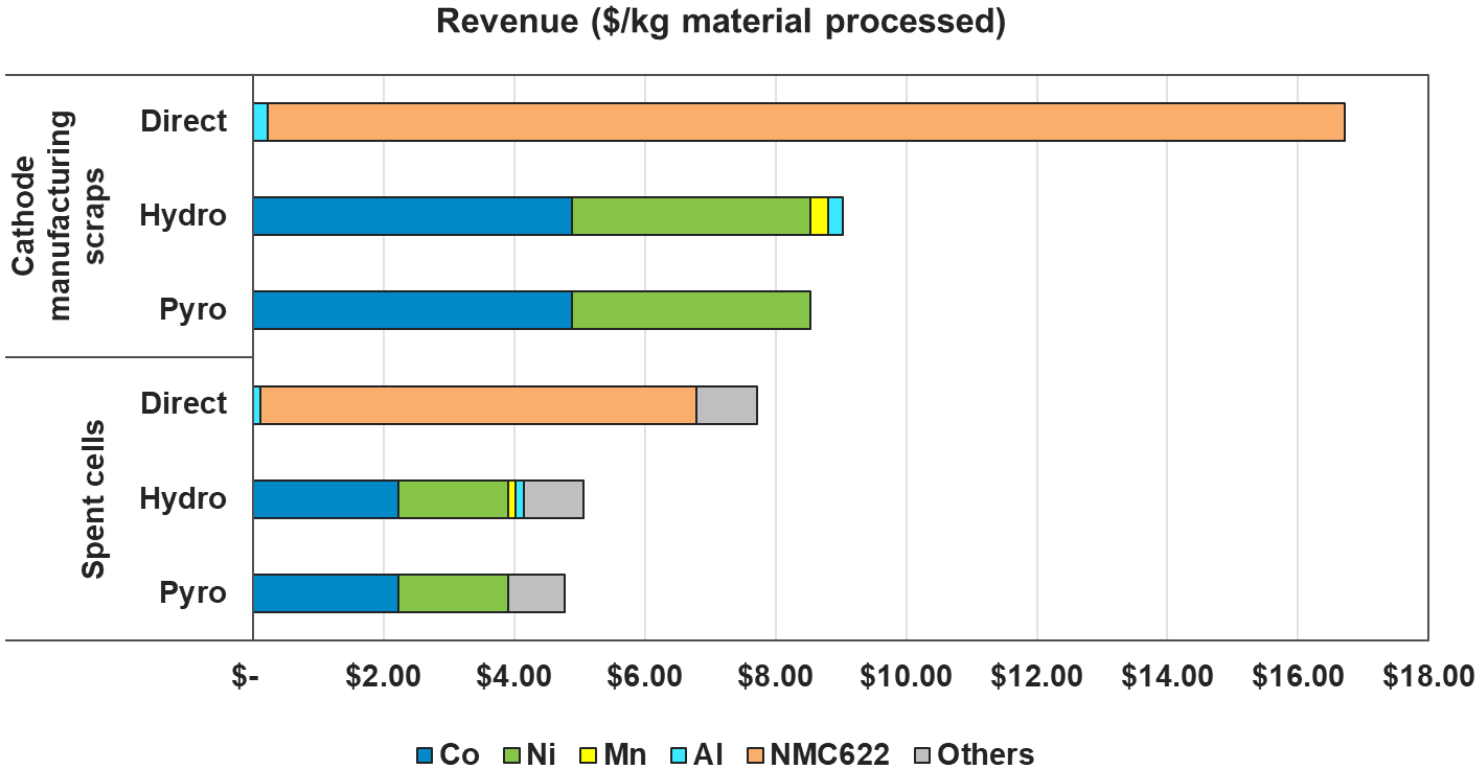
Cathode, production energy, and aluminum are notable contributors



DIRECT RECYCLING HAS LOWEST IMPACTS



ANALYSIS SHOWS SCRAP RECOVERY IS PROMISING

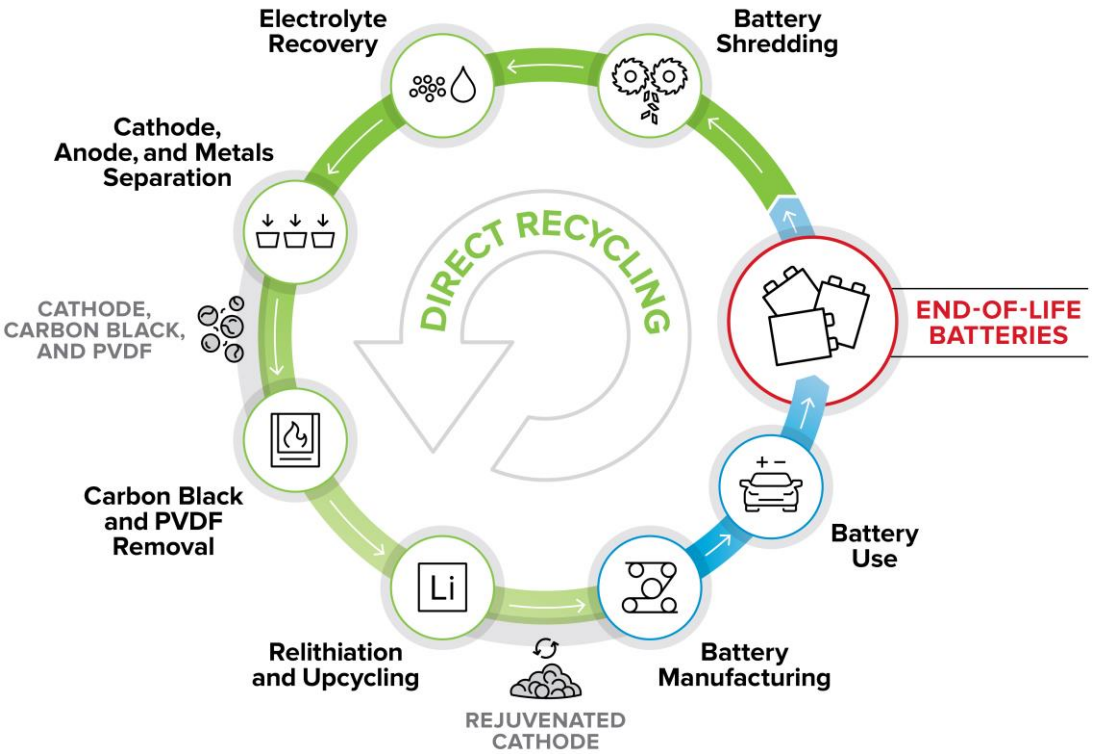


Results based on plants processing 10,000 t materials per year.

UNIT PROCESS ORDER WILL BE OPTIMIZED

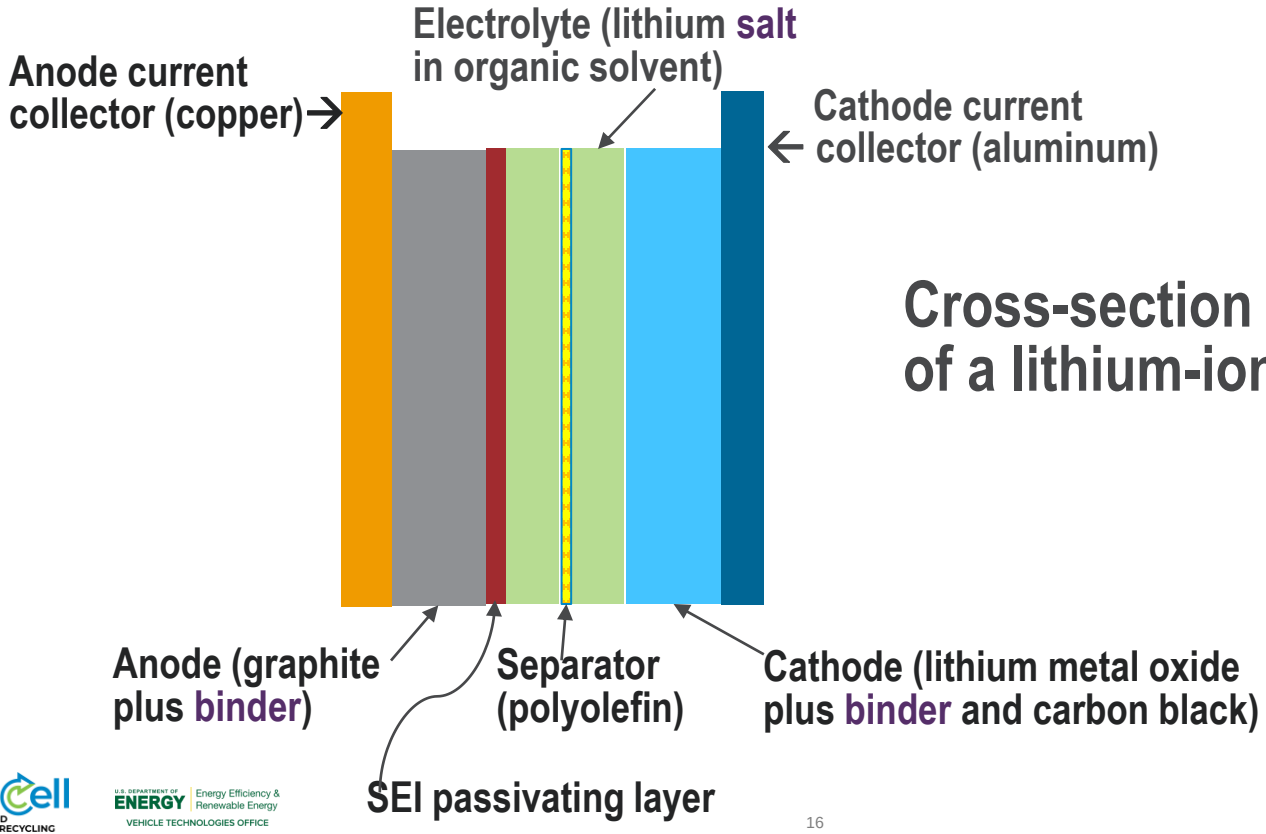
- Multiple processes investigated to mitigate risk
- Continual review of new project ideas
- End projects that are not showing promise in cost and performance
- These unit operations can benefit other recycling processes

Typical Direct Recycling Process Flow



PROCESSING REQUIRES MANY SEPARATIONS

Commercial technologies lose some of the materials



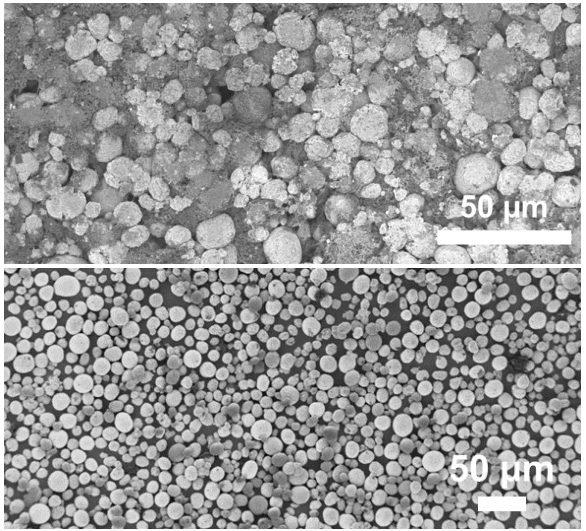
Cross-section of one layer of a lithium-ion cell

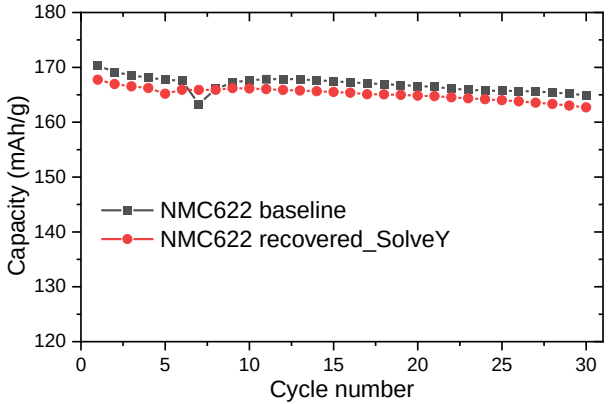
SOLVENT RECOVERS ELECTRODES AND BINDER

Al

Solvent Y

100 °C
1 h





Similar capacity retention at 1 C rate

- Developed a SolveY process to fully separate active electrode materials from current collectors and PVDF binder in a green solvent.
- Proved that the process does not damage the active materials or corrode the current collectors. Slight reduction in electrochemical performance.

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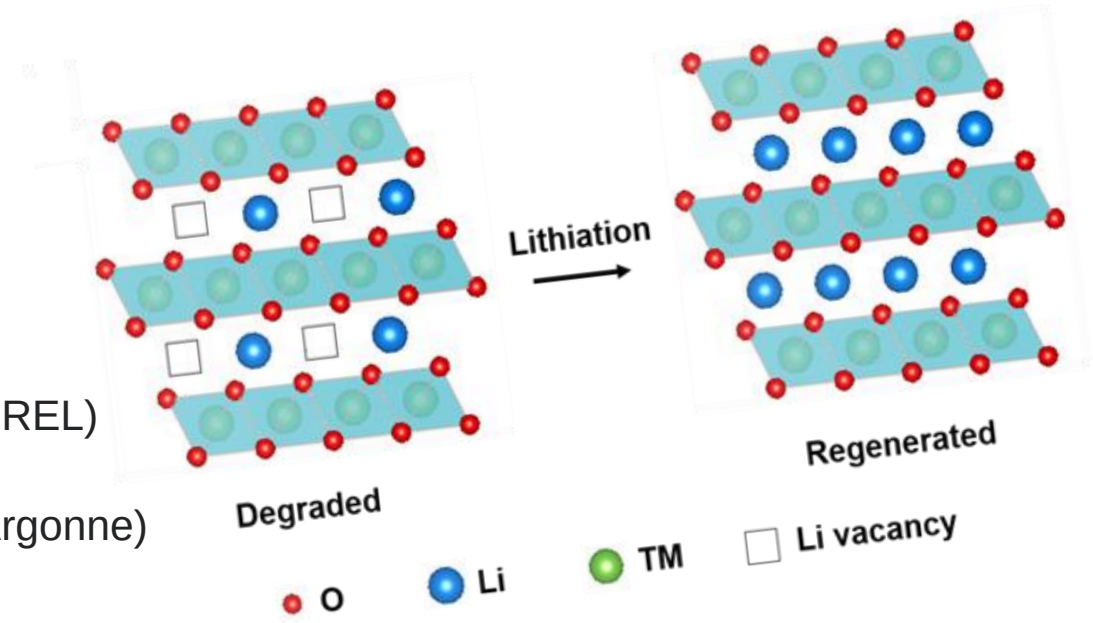
DIRECT RECYCLING UPGRADES CATHODE

Product must be as good as new… or better

Several phenomena contribute to the gradual drop 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.

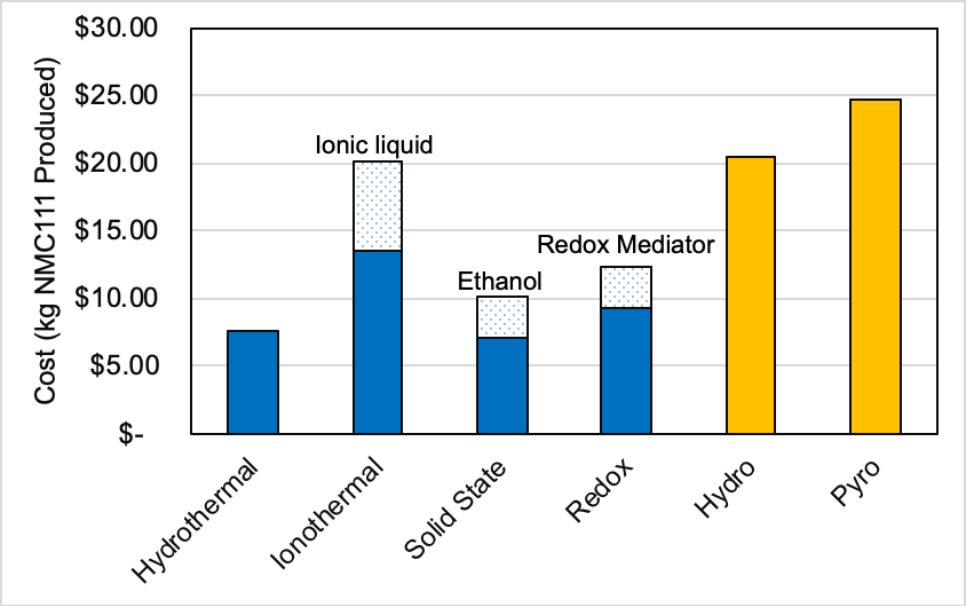
- **Relithiation**
  - Electrochemical (NREL)
  - Solid State (Argonne)
  - Hydrothermal (UCSD)
  - Ionothermal (ORNL)
  - Redox Mediated NREL)
  - Roll to Roll Processing (NREL)
- **Upcycling**
  - Compositional Change (Argonne)



MATERIALS ARE KEY TO RELITHIATION COSTS

Further research targeted at reducing high material costs

- Replace or reduce use:
  - Ionic liquid (ionothermal)
  - Redox mediator (redox)
  - Ethanol (solid state)
- Hydrothermal lowest cost
- Solid state could potentially be lower
- Results for commercial-scale plant; scaling will not change ordering



Dashed bars represent potential cost reductions by closed-loop recycling of key materials; blue bars represent other costs for 10,000 T/y direct recycling plants; yellow bars represent costs for 10,000 T/y pyrometallurgical (pyro)/hydrometallurgical (hydro) recycling plants plus costs to convert recovered materials into cathode powder.

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TECHNICAL ACCOMPLISHMENTS

- Recovered usable cathode from spent cells and scrap
- ~40 papers, ~20 patents in process
- Dedicated ReCell laboratory space ready for collaboration
- Industry meeting provided an opportunity for ReCell and industry stakeholders to exchange challenges and ideas.

REMAINING CHALLENGES AND BARRIERS

- Getting the most life out of batteries
- Keeping used batteries in the US for material recovery
- Recovering materials that perform as well as new ones
- Getting industry buy-in for commercialization
- Developing new recycling processes for future batteries
  - Sodium or magnesium-based cathodes
  - Lithium metal anodes and solid-state electrolytes

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Thanks to:
Samm Gillard and Dave Howell

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