

# A Comparative Study of Recycling Lithium-ion and Lead-Acid Batteries

Ben Geller- Teacher Researcher for REU Program; Dr. Timothy Ohno-Associate Professor of Physics; Dr. Cynthia Howell- Energy and Outreach manager, Critical Materials Institute

## Background/Abstract

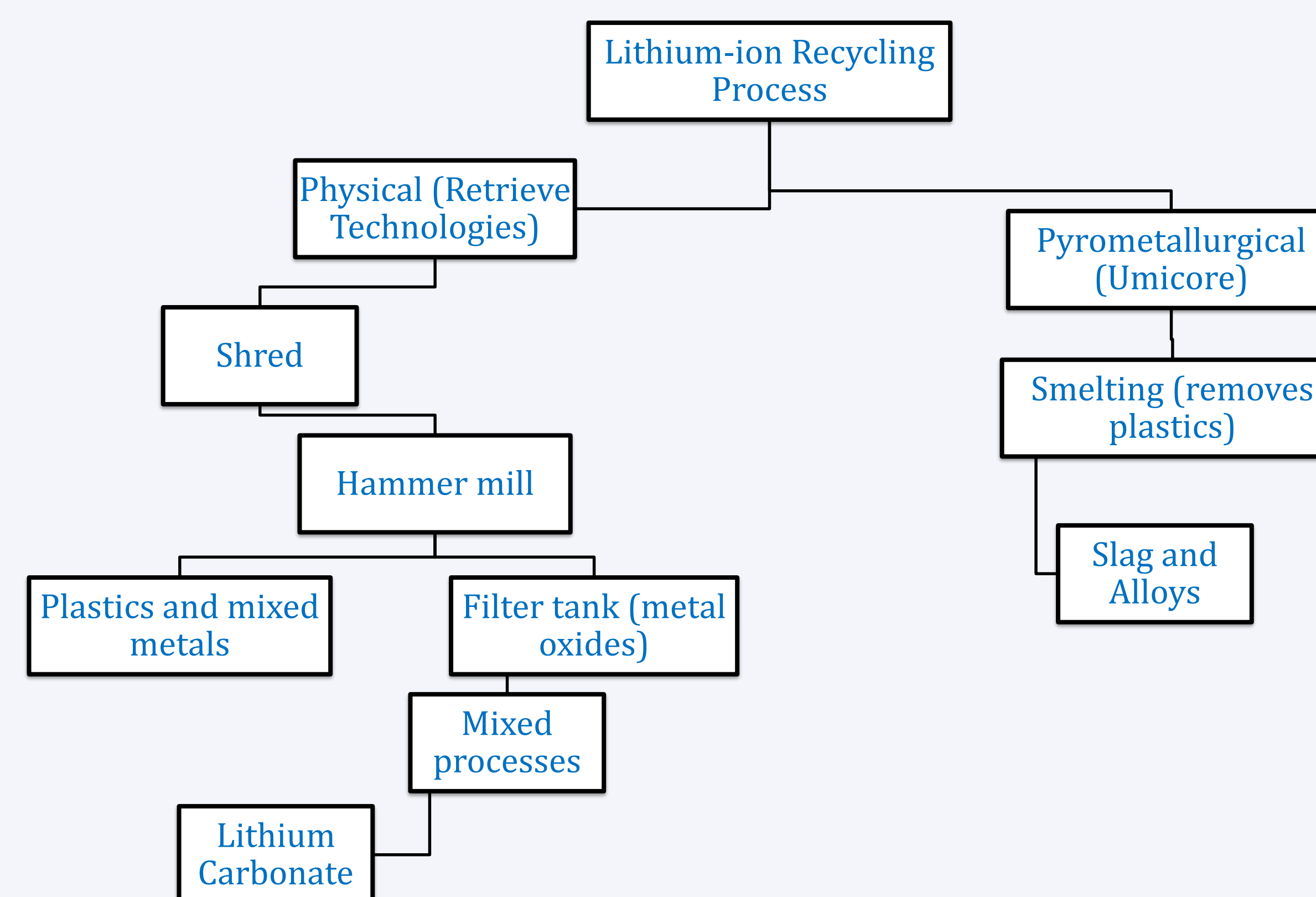
The purpose of this literature review was to research and compare recycling techniques in lithium-ion batteries with lead-acid batteries. Lead-acid battery technology has been around since the late 1800s and has been used for many years in the automotive industry where they are the main batteries in cars and trucks. Much of the chemical composition of a lead-acid battery has not changed for over 100 years. Lithium-ion batteries on the other hand, have been around since the late 1970s, and in full production since 1991. Uses for lithium-ion batteries vary, from cell-phones to photovoltaic storage and electronics in-between. Lithium is an important commodity that is considered a near-critical material by the Critical Materials Institute (CMI) so it is vital that it is understood the process for recycling lithium-ion batteries is considered and understood.

## Comparison of Lithium-ion and lead-acid Batteries

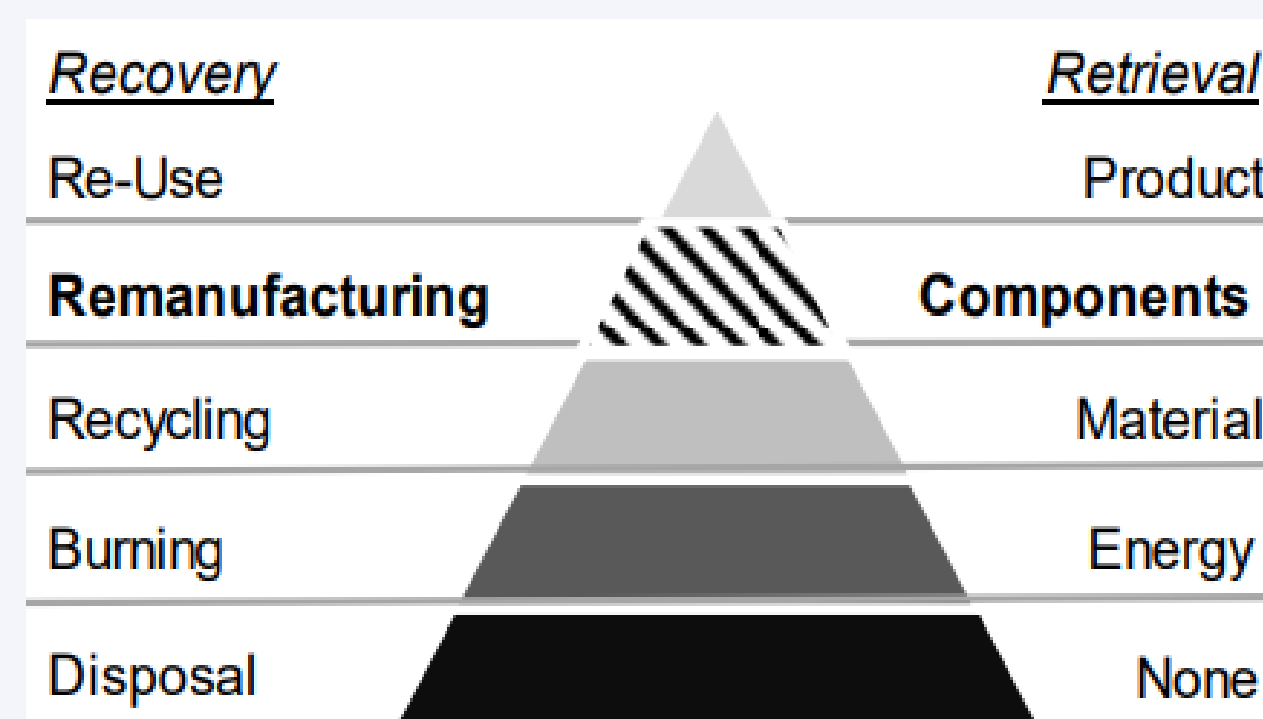
Properties	Lithium-ion Batteries	Lead-Acid Batteries
Average Composition	Varies: Lithium with combinations using: Co, Ni, Fe, Mn, Al, P, O, Ti	Pb, S, O
Major Components Recyclable	Cathode, anode	Cathode, anode, electrolyte
Near Critical Materials Present	Lithium, Cobalt	None
Voltage (single cell)	3.2-3.8V (can vary depending on composition)	2.1V
Capacity (Ah)	10(LiMn <sub>2</sub> O <sub>4</sub> ) to 60 (LiFePO <sub>4</sub> )	<10 to 100+ (depending on configuration)
Specific Energy (kJ/kg)	80 to >700	72 to 180 depending on study
Usage Temperatures	-20°C to +60°C	-20°C to +40°C (25°C is optimal)
Storage Temperatures	0°C to +40°C (at partial charge)	-40°C to +50°C (Battery University for Temperatures; at fully charged)
Cycles	500 (cobalt and manganese) to 2000 (phosphate at 80%DOD)	500-1000
Years Rated (life span)	Variable	6 years (although it varies)
Energy Efficiency	85-95%	70-84%+
Mechanical Recycling	Yes, but only as a first step (must freeze battery to prevent explosions)	Yes, but only as a first step
Average Recovery After Recycled	60%(Retrieve Technologies of which 10% usable, 93% Umicore (minimal re-usage after recycled))	99% recycling rate, 86% of all Pb recycled from batteries, 60-80% of new lead/acid batteries are from recycled materials (including casing, etc...)
Safety Concerns	Short circuit, thermal runaway, overheat, catch fire, explode	Corrosion (battery acid), shock hazard
Environmental Concerns	Not Landfill Friendly	Pb and H <sub>2</sub> SO <sub>4</sub> are toxic to environment
Pollution Produced	On average, more CO, NO <sub>x</sub> , VOC, and PM than PbA batteries during manufacturing and production	Much less CO <sub>2</sub> produced than Li-ion batteries along with less of the major pollutants (attributed to recycling during life cycle)
Use in PV system	Yes	Yes
Cost to Recycle Spent Batteries	Customer pays companies to recycle	Companies pay customer to recycle
Mines Tiny House System Usage	For AC System	For DC System
Example (picture)		

## Recycling Lithium-ion Batteries

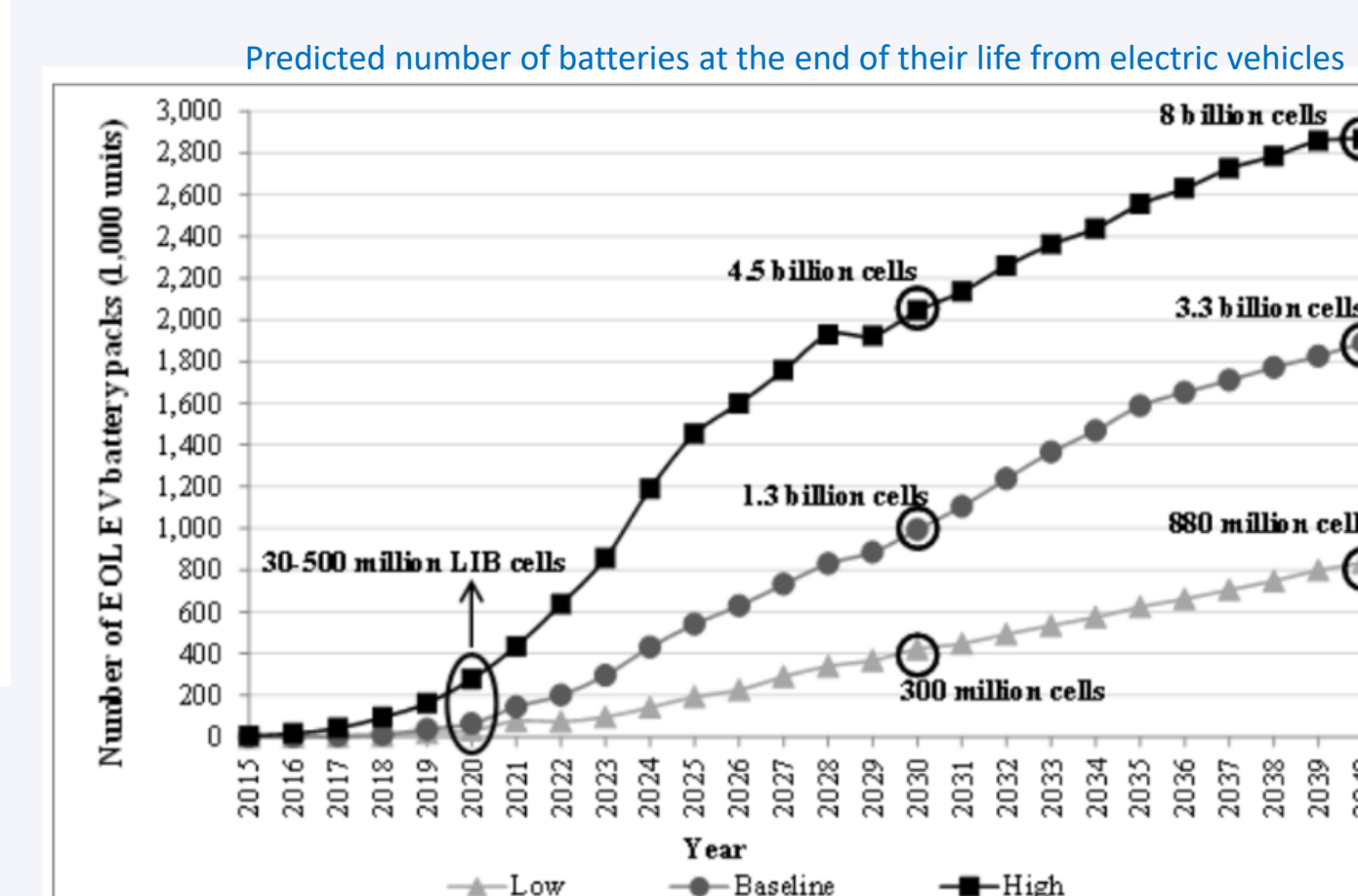
- Lithium is considered a near-critical element by the CMI, with reserves of only 14 million tons and resources of up to 46.9 million tons
- Lithium-ion batteries contain lithium (Li) in combination with several elements including: Co, Ni, Fe, Mn, Al, P, O, Ti
  - The most common combinations for batteries are: LiCoO<sub>2</sub>, LiFePO<sub>4</sub>, LiMn<sub>2</sub>O<sub>4</sub>, LiNi<sub>0.8</sub>Co<sub>0.15</sub>Al<sub>0.05</sub>O<sub>2</sub>, and LiCo<sub>1/3</sub>Ni<sub>1/3</sub>Mn<sub>1/3</sub>O<sub>2</sub>
- Hydrometallurgical or Pyrometallurgical processes both work to recycle lithium-ion batteries
- Two of the main companies involved in recycling lithium-ion batteries are Retrieve Technologies (Canada and Ohio) and Umicore (Europe)
  - Their processes are listed below:



- May become more cost effective due to amount of electric vehicles forecasted to be on roads in near future
- Currently, studies show additional more cost effective ideas other than recycling such as remanufacturing or repurposing of spent lithium-ion batteries from cars



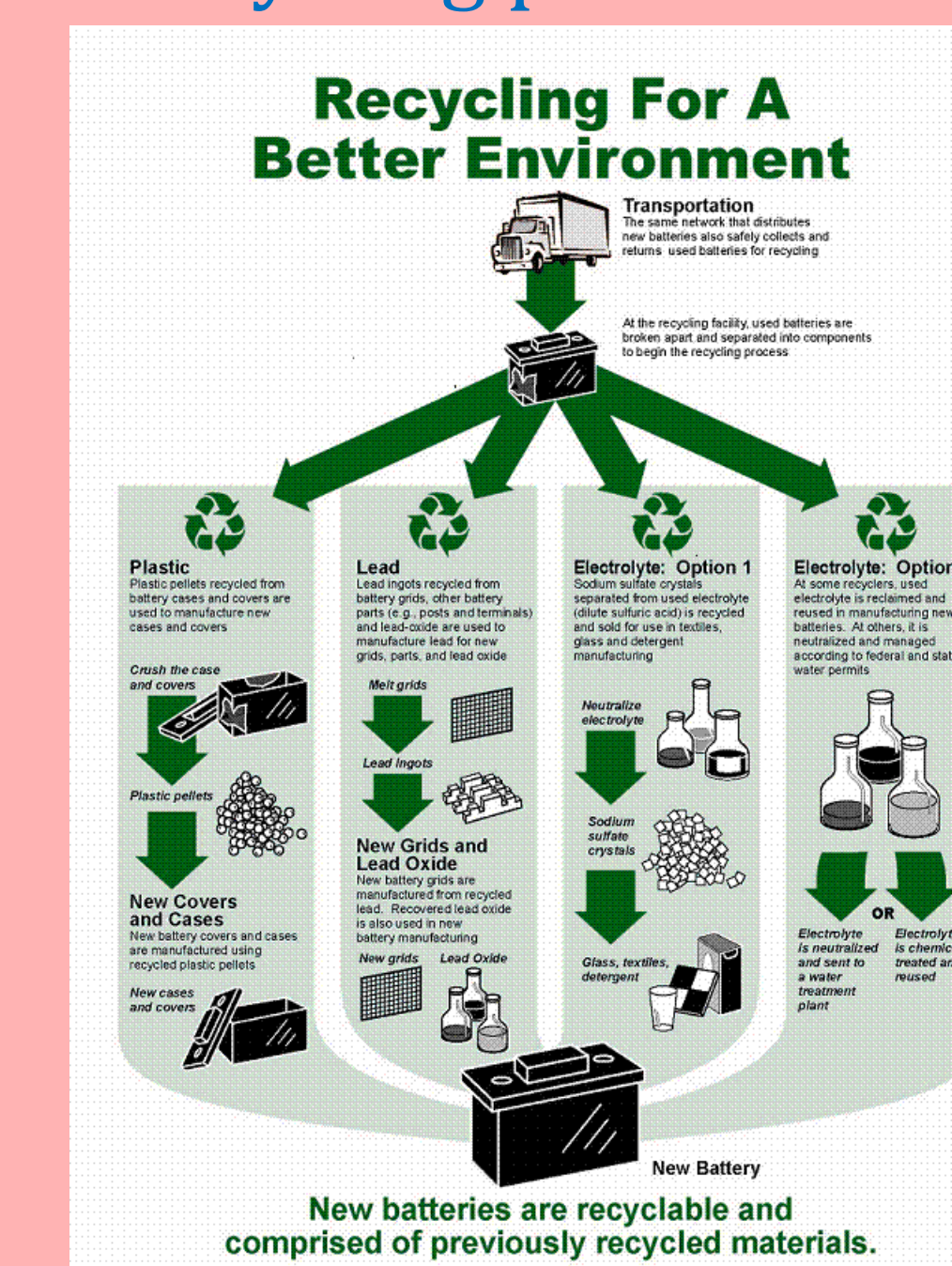
\*Adapted waste pyramid: higher level equals more recovery efficiency\* (Kampker et al) Kampker, Achim, et al. "Evaluation of a Remanufacturing for Lithium Ion Batteries from Electric Cars." Evaluation 1 (2016): 56023.



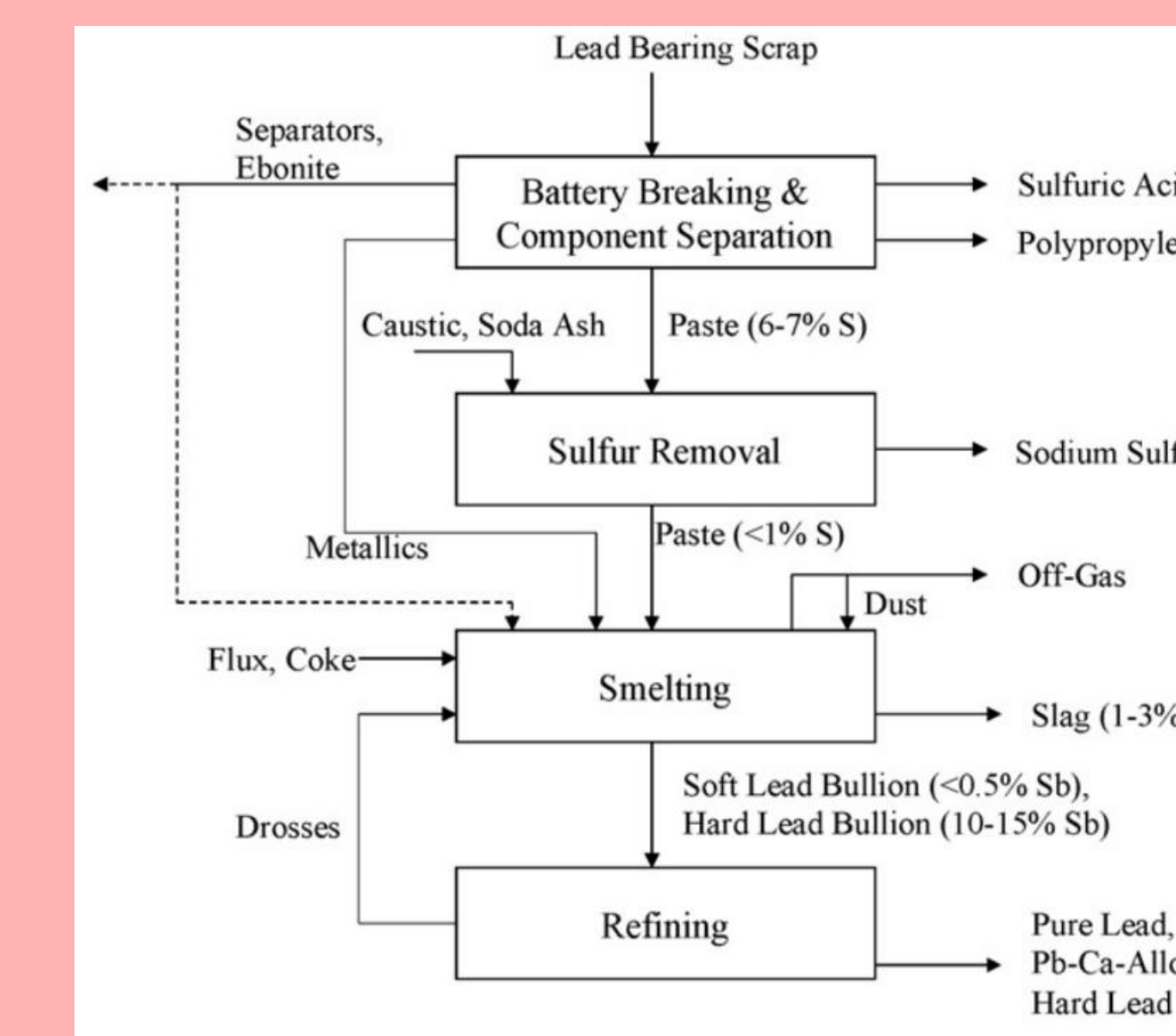
Richa, Kiril. Sustainable management of lithium-ion batteries after use in electric vehicles. Rochester Institute of Technology, 2016.

## Recycling Lead-Acid Batteries

- 3 main components of a lead-acid battery: lead, acid, and plastic
- Lead and plastic from the battery can be recycled for new batteries, acid cannot be recycled as easily for new batteries
- Established process has been run for over 100 years
- As of 2013, 86% of all lead production in the United States came from scrap (secondary) batteries
- Hydrometallurgical or Pyrometallurgical processes both work to recycle lead-acid batteries however, mixed processes might be best
- Recycled batteries currently indicated as PbA-30/70 with 30% new materials and 70% recycled materials
- Recycling lead-acid batteries reduces the energy to make new lead acid batteries by around 10%
- Recycling profitable due to low costs and closed loop process



Battery Council International (2017)



Typical lead-acid battery recycling process. (Ellis and Mirza)

## Conclusion/Further Steps

- At the present, production and demand of lithium with projected resources will last to the middle of the 20<sup>th</sup> century at which point demand may eclipse production globally
- Building facilities that can remanufacture or repurpose lithium-ion batteries will help curb demand for lithium such as the Tesla Gigafactory (which could lead to applications in PV or use in stand alone applications such as Mines Tiny House use of lithium batteries as storage for solar energy)
- At lead recycling rates, primary lead production will still be necessary due to growth of automotive manufacturing industry for electric, hybrid, and other vehicles
- Finally, lithium availability, production and supply may become non-issues if more efficient recycling entities come into place

## Acknowledgements/References

The National Science Foundation has generously supported this study through the award DMR-1461275 REU Site: Research Experiences for Undergraduates in Renewable Energy.  
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