

LITHIUM RECYCLING SYSTEMS

Introduction to the economics of Lithium battery recycling
Current processes
and Capabilities of the LRS-Engitec Team



Agenda



LIB Basics



Basic LIB recycling economics



Available processes



LRS-Engitec process and validation

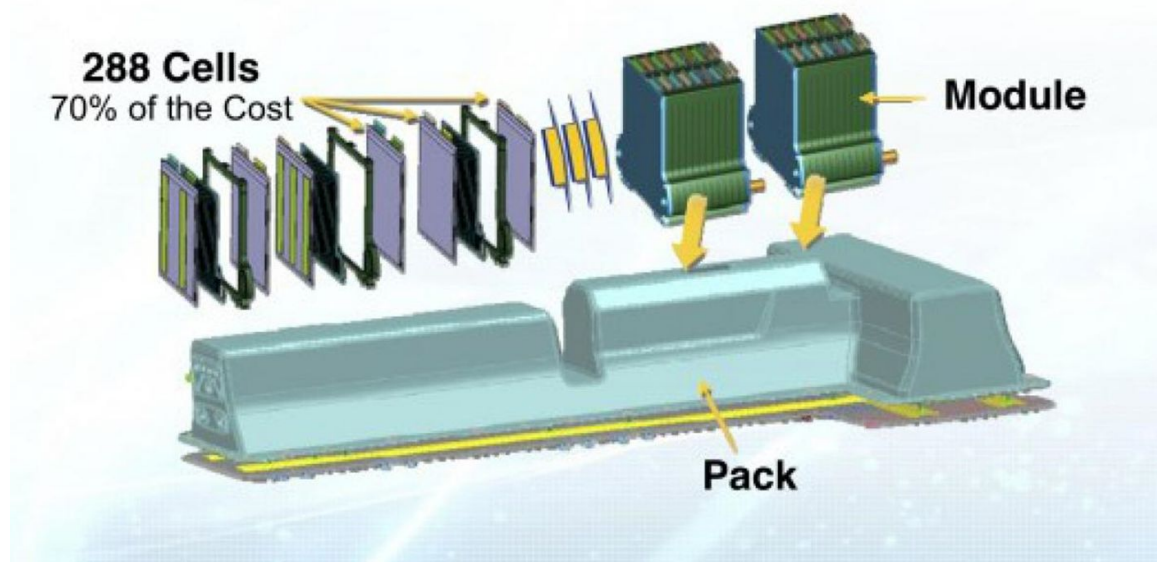


Definitions & Assumptions

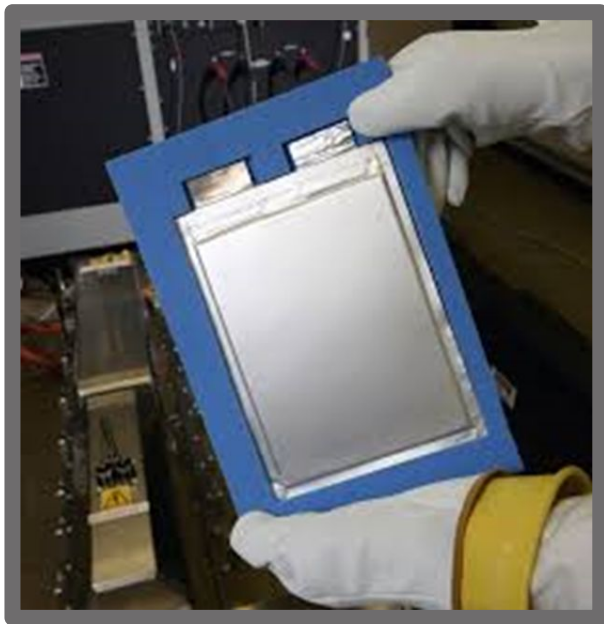
1. LIB – Lithium-ion battery
2. LAB – Lead acid battery
3. NMC – Nickel, Manganese, Cobalt
4. Black mass (BM) – mixture of nickel, manganese, and cobalt oxides with carbon.
5. Dirty black mass – black mass that contains some amount of metal and plastic pieces.
6. Plastic/separators – Plastic casings along with dielectric separators for anode/cathode.
7. Electrolyte – mixture of lithium based salt and organic electrolyte/solvent such as EC, DEC, PC, EMC (ethyl methyl carbonate).
8. Cells – Individual battery packs, pouches, or spiral wound batteries (see following pics).
9. Prismatic cell – flat pouch cell used by many companies like GM.
10. Cylindrical 18650 cell – Tesla LIB cell that looks like a double-A alkaline battery
11. Modules – Groups of cells.
12. Batteries – Groups of modules
13. Cathode – Aluminum Side that contains the Li, Ni, Mn, Co
14. Anode – Copper with graphite/carbon.
15. LME – London Metal Exchange
16. MT – metric ton, most common unit of recycling. 1 MT = 1,000 kg = 1.1 US tons = 2,205 lbs
17. LME pricing for metals: Co = 52,000/MT, Ni = 18,000/MT, Cu = 9,000/MT, Al = 2,200/MT
18. Pyro – Pyrometallurgical process, uses a ~ 1,000C furnace to melt/smelt metals and oxides.
19. Hydro – Hydrometallurgical process, uses water to separate BM from metals and plastic.



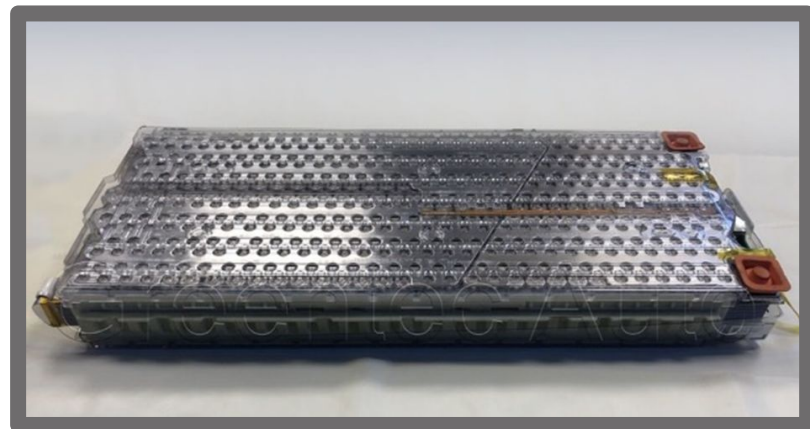
Typical Chevy Volt battery pack configuration



Chevy Volt prismatic cells and module



Tesla/Panasonic spiral cell and large module of cells





Market Projections

1. **Overall recycling market size (> 50% EV)**
 - a. 2019 – \$1.5 billion
 - b. 2020 – Project 460,000 MT available to be recycled.
 - c. 2025 est - \$12.2 billion
 - d. ~ 8.0% growth after that.

2. **Current EV recycling chain & sourcing**
 - a. Unspent cathode material – contract manufacturing for supplier (automotive companies).
 - b. Unspent batteries (cells, modules) – contract manufacturing for supplier (automotive companies)
 - c. Spent batteries - Contracts with battery brokers, dealers, & authorized replacement centers.

Some current LIB recyclers, processes, and products



1. Umicore (Full service Belgium recycler):
 - Large. Receives BM and metals, uses pyro then electro-refining. Produces refined metals and alloys.
2. Glencore International AG (Full service Swiss recycler):
 - Same as Umicore
3. Li-Cycle (Canadian recycler, only LIB).
 - Medium. Crushing then producing battery grade refined metals. Process not clear.
4. SungEel HiTech (US, South Korea, only LIB)
 - Large, 8,000 MT/yr, appears to be hydro.
5. Retrieval Technologies (US, black-mass) –
 - Small. Use aqueous crushing and separation, produce dirty black mass and metals for sale to companies like Umicore and Glencore.
6. International Metals Reclamation Company, LLC /INMETCO (US, disassembler)
 - Small. Only disassemble, sell cells, plastic, and metal connectors to companies like Retrieval, Umicore.
7. Raw Materials Company (Canada, disassembler) – Same as Inmetco.
8. Linico
 - Says they can recycle into separate metals



Agenda for presentation

1. **Understanding business model, path to profitability, supply and demand balance.**
 - a. Acquire LIB and sell byproducts on open market.
 - Facility: Either full service or LIB centric.
 - Acquisition: LIB (EV modules, cell), let's assume for free.
 - Processing: Either at LIB only factory or full-service recycler.
 - Products: BM, metallics (Al, Cu), and plastics.
 - Economics
 - Acquisition – Previously paid to take, now it appears to be free or slight charge.
 - Processing - ~ \$100/MT incoming (includes basic depreciation).
 - Revenue for sales - ~ \$300/MT for BM, should be able to get more. ~ \$500/MT for metallics.
 - Project gross profit of: ~ \$700/MT minimum acquisition cost.



Capital Cost, green field

1. Capital cost

- a. Typical small to medium size LIB setup is ~ 15MT/day of incoming batteries
- b. Approximate recycling capital cost is \$2 - \$4 million, depending on level of processing.
- c. Excludes facility acquisition, modifications, etc.



LIB recycling basics

1. Front end

- a. Acquire materials: spent/unspent batteries/modules/cells, cathode rolls, etc.
- b. Disassembly into modules/cells to feed recycling process.
- c. Crush and separate into dirty/clean black mass, polymers, aluminum, copper, etc.

2. Back end

- a. Sell black mass and metallics.
- b. Process black mass for reuse in batteries.
- c. Process black mass into individual metals.



LIB processes

Company	Website	Dismantling	Discharge	Breaking	Separation	Hydrometallurgy	Chemicals	Byproducts	Electrolite
LRS	www.lithiumrs.com	Not required at module size	Not required	Wet hammer mill	Shakertable, Sinkfloat, Elution Column, Secondary Screen	Can produce clean black mass for smelting, clean unspent for reuse, or separate Li, Ni, Co, Mn for reuse	MSA, H ₂ O ₂ , NaOH, NaOCl at 1 percent	Black mass or NiO, CoO, MnO, LiOH, Carbon, metals Cu/Al	Disposed of with natural digestion by bacteria
American Manganese. Kemetco are working together, experimental stage now	https://americanmanganeseinc.com https://www.kemetco.com	Not required as they have not started breaking full spent batteries yet, nly cells. They specialize currently with scrap metal cathodes	Scrap cathodes does not need to be discharged as it never was a battery, method they use is unknown	Dry shredding and milling	Shakertable	Not required for reclaiming black mass. Kemetco is still in lab stage with their spent battery process	None that we know of	Ni, Co, Mn, Li (black mass) Cu/Al plastic	No electrolyte present in scrap materials
Dusenfeld	https://www.duesenfeld.com	Must disassemble batteries down to module level	They discharge modules but its not clear how. Likely just load banks	Dry shredding	Shaker screen	Low pH with H ₂ SO ₄ solids remain with only less than half dissolved filtrate precipitated out as black mass. It appears that their process only processes the monoxides of the metals. Does not appear that they are processing the spent versions of the metals which are sulfated	H ₂ SO ₄ , NaOH	NiSO ₄ , CoSO ₄ , MnSO ₄ (black mass)	Evaporation and condensing for recycling
Retriev	https://www.retrievtech.com/lithiumion	Dismantle by hand if full battery, usually receive modules	Not required	Hammer mill with very basic water addition	Shakertable, Sinkfloat. Produce black mass, plastic, and metals with plastic	None	No chemicals	Black mass, dirty Al/Cu contaminated with plastic and separators, dirty mix of plastics	Disposed of with natural digestion but very basic as far as we know. No pH adjustment.
LiNiCo	https://linicorp.com	Appear to only recycle cathode material, no battery disassembly	Scrap cathode does not need to be discharged as it never was a battery, method they use is unknown	None required for only cathode processing		Alleges to be able to separate into individual metals	None that we know of	Ni, Co, Mn, Li (black mass) Cu/Al plastic	No electrolyte present in scrap materials



LRS-Engitec Capabilities

1. Engitec (EGT)

- a. 43 years of experience.
- b. Plants in 40 countries
- c. Has built > 50% of the worlds lead acid battery recycling capacity
- d. World class engineering and manufacturing
- e. Investor in LRS
- f. Has exclusive rights to the LRS process technology.
- g. Conducted pilot tests of version 2.0 process (see below) with Chevy Volt cells
- h. Has contract to engineer and build first LIB plant in the US.

2. Lithium Recycling Systems (LRS)

- a. Technology and consulting company, designers of version 2.0 process.
- b. 3 team members with over 50 years of LAB recycling experience.
- c. Experience running basic commercial LIB recycling process (version 1.0) at 15MT/d
- d. Patents pending LIB recycling processes and technology for version 2.0.
- e. Processed samples for Tesla.



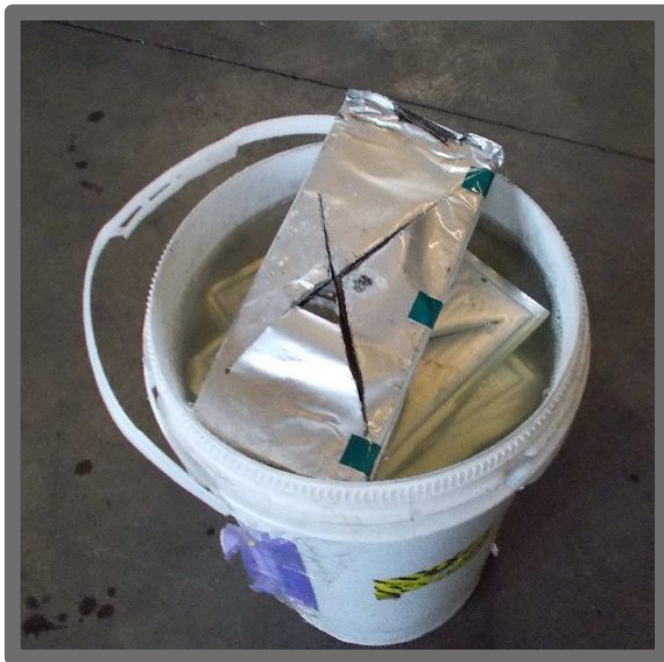
Example of Engitec Pilot Plant



Chevy Volt modules and cells



Chevy Volt modules and cells



Tesla 18650 Cells

