Development of a New Technology to Recycle Cobalt-Containing Cathode Materials from Spent Li-ion Batteries

AMERICAN MANGANESE
CATHODE RECYCLING TECHNOLOGY

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**Rough Estimates of Cathode Recycling Opportunity**

**GIGAFACTORIES**
- 2021 – 280 GWh per year production
- Assume NMC Chemistries
- 164,987 Tonnes per Year Li2CO3
- 87,370 Tonnes per Year Ni
- 81,780 Tonnes per Year Mn
- 87,727 Tonnes per Year Co
- Value: $8.89 USD Billion

**SMARTPHONES, TABLETS, NOTEBOOKS**
- 2017 – Data from [www.apple.com](http://www.apple.com)
- Apple Market Share is approx. 10%
- LCO Chemistries
- 22,450 Tonnes per Year Li2CO3,
- 35,820 Tonnes per Year Co
- Value: $2.49 USD Billion
Simplified American Manganese Flowsheet

Proprietary Operations Not Shown
HYDROMETALLURGICAL PROCESSING

USING SPENT CATHODES AS A RESOURCE FOR HYDROMETALLURGICAL PROCESSING

SELECTIVE PRECIPITATION OF METAL COMPOUNDS

PRECIPITATION OF LITHIUM CARBONATE
Manufacture of Test Battery from Recycled Cathode
## Estimates of Reagent Cost versus Output Value per Tonne of Cathode

### Input Reagents:
- 0.33 Tonnes SO2 value at $196 USD
- 1.00 Tonnes H2SO4 value at $200 USD
- 1.62 Tonnes Na2CO3 value at $487 USD

**TOTAL REAGENT COST = $883 USD**

### Output Values:

#### LCO
- 0.38 Tonnes Li2CO3 value at $5,662 USD
- 0.60 Tonnes Co (as metal) value at $36,129 USD

**TOTAL OUTPUT VALUE = $41,791 USD**

#### NMC
- 0.38 Tonnes Li2CO3 value at $5,745 USD
- 0.20 Tonnes Ni (as metal) value at $2,282 USD
- 0.19 Tonnes Mn (as metal) value at $391 USD
- 0.20 Tonnes Co (as metal) value at $12,219 USD

**TOTAL OUTPUT VALUE = $20,637 USD**

#### NCA
- 0.38 Tonnes Li2CO3 value at $5,768 USD
- 0.49 Tonnes Ni (as metal) value at $5,498 USD
- 0.09 Tonnes Co (as metal) value at $5,520 USD
- 0.01 Tonnes Al (as metal) value at $29 USD

**TOTAL OUTPUT VALUE = $16,815 USD**
LITHIUM ION BATTERY – CATHODE RECYCLING TECHNOLOGY

Mining and Processing

LITHIUM
Mining: South America
Processing: South America

ALUMINUM
Mining: Australia
Refining: Middle East, Canada

NICKEL & COBALT
Mining: DRC, Canada
Smelting: China, Canada, Europe
Refining: China, Canada, Europe

MANGANESE
Mining: Africa
Refining: USA/China/Europe
LITHIUM ION BATTERY – CATHODE RECYCLING TECHNOLOGY

Potential Future Packaged Processing Plants

Similar Chemistry to Cyanide Destruction Plant Delivered to Gold Mine in 2015

Packed Plant Fabrication and Shipping

Reagent Metering System

Reactors

Reagent Storage
The value propositions for advancing American Manganese’s technology for the treatment of spent cathode materials are:

1. **Creating a Higher Value Product**
   - The potential to process spent cathode materials to produce higher purity products that improve lithium-ion battery performance and safety.
   - Ability to tailor treatment process to precipitate cathode materials with tailored structures and chemistries for improved battery performance.

2. **Creating an Upcycling Industry for Spent Batteries**
   - Potential to recycle all lithium and base metal matrix compounds.
   - Applicable to multiple lithium ion battery chemistries including, LCO, NMC, NCA, LMO and other chemistries.

3. **Eliminating the Hazardous Waste Classification of Spent Lithium–Ion Batteries**
   - Creating an industry where spent batteries become a useful raw material rather than a waste.
   - Avoid costly and time consuming regulatory requirements to ship spent lithium-ion batteries for disposal.
AChievments to date

- **Laboratory scale recycling of cathode materials of the following chemistries:**
  - Lithium cobalt oxide (LCO)
  - Lithium manganese cobalt oxide (NMC)
  - Lithium cobalt aluminum oxide (NCA)
  - Lithium manganese oxide (LMO)

- **Metal recoveries achieved:**
  - 100% Cobalt
  - 100% Nickel
  - 100% Manganese
  - 100% Aluminum
  - 92% Lithium

- **Successful reformulation of the following batteries from recycled cathode materials:**
  - LCO
  - NMC
  - NCA
  - LMO

- **Developed a complete closed loop flowsheet tested on a laboratory scale to maximize metal recovery, minimize reagent usage and recycle water in a closed loop process.**

- **Filed US provisional patent application (November, 2016).**

- **PCT patent application to be filed in November, 2017.**