Deactivation and Cathode-Healing™ to support the Low-Cost US Supply Chain

Military Power Sources Committee
Battery Recycling Symposium
May 6, 2021

Steve Sloop, OnTo Technology

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Challenges and Opportunities for Li-ion Cost Reduction

**Safe Transport**
- Deactivation
- Eliminate flammability and reactivity risks
- Reduce cost of shipping

**Efficient cathode recovery**
- High yield harvesting of electrode material
- Cathode-healing®
  - Flexible to cathode chemistry
- High quality, low cost cathodes
- Manufacturing scrap and end-of-life
Recycling Market

- Li-Ion battery use rapidly growing
  - EV sales increased by over 5X from 2015-2020*

- 2 million metric tons of Li-Ion battery scrap needs to be recycled in 2030.

- U.S. recycling rate currently ~5% (U.S. Dept. of Energy)

- Cobalt content decreasing

*Victor Irle, EV Volumes, Advanced Automotive Battery Conference (2021)
Safety
Battery Risk

The only part that is addressed in best-practices, discharging of cells

\[ \text{Risk} \sim \sum \text{State of charge} + \text{State of Health} + \text{XS Li} + \text{ely} + T + t \]

State of Health \sim \text{gas content, electrolyte aging, lithium dendrite, delaminated carbon, lithium, container corrosion, fuse-blown, etc.}

Risk reduction through discharge does not address potential SOH challenges

Recent explosion at Brunp recycling
Bolt cutter vs. fully charged battery - simulates shredding a charged cell

- Battery burst into flames instantly
- Temperature went over 600°C (Molten Al)
OnTo Patented Deactivation
A service to remove hazards from end-of-life Li-ion

- OnTo’s prototype uses CO$_2$ to transform Li-ion batteries to non-hazardous materials.
- Resolves reactivity and flammability.
- Can be practiced prior to transport. ($0.11/kg vs. $2.49/kg)

Any:
- State of charge
- State of health
- Chemistry
- Format

Patents: 8,497,030; CN102160220A; 7,198,865, and pending
Same battery deactivated and cut open
Safety Validation
The only way to guarantee safe EOL batteries
OnTo Decentralized Battery Deactivation and Harvesting Service

makes the spoke make sense

• Batteries deactivated at or near local collection sites.

• Safe, inexpensive transport to a destination recycling facility.

• Rail, highway, air, and seaport transportation.

• Reproducible concept world-wide.
Efficient materials recovery
Safe Deactivation

Cells, Modules, Packs → Deactivation

Disassembly (Shred, pulverize, etc.) → Sift/Float

Plastics, Metals → Mixed electrode material

Safe Inexpensive Transportation

Cathode-Healing™
Patented direct recycling method

Autoclave
Conc. Li solution & electrode material → Separation

Cathode → Graphite electrode

Heat

Healed Cathode

Upcycle to new chemistry
Cathode Precursors

Patents: 9,825,341 B2; 9,484,606 B1; 9,287,552 B2; EP2248220; 8,846,225 B2; 8,497,030 B2 ; 10,014,562; 8,832,329; 8,497,030; CN102160220A
Cathode-Healing® Direct Recycling

- Easily harvested electrode material and foils

End-of-life
Cu: 25ppm (UD: baseline)
Fe: 81ppm (50:baseline)

Healed
Cu: Undetected
Fe: 12ppm

Li_{(1-x)}Ni_{0.5}Mn_{0.3}Co_{0.2}O_2
LiNi_{0.5}Mn_{0.3}Co_{0.2}O_2

SEI and binder are removed after processing
OnTo cathode-healing® of Old-Scrap NCM622, 523

Cells made from healed material

Cathode-Healing® patents: 9,484,606; 10,333,183; 8,846,225; 9,825,341; 9,287,552; & PCTs
OnTo cathode-healing® of New Scrap NCM 811

NCM 811 produced from OnTo’s Cathode-healing® process

Cathode-Healing® patents: 9,484,606; 10,333,183; 8,846,225; 9,825,341; 9,287,552; & PCTs

OnTo Technology LLC
Cathode Healing Cost Performance Data for an NCM

- **Operating cost**: $2.00-5.00/kg for cathodes with value of $10-$90/kg.

- **Yield**: Essentially quantitative for cathode to cathode.

- **Scalable**: Simulated for large scale processes currently used industrially.

![Cost Breakdown Chart]

- Healed-Cathode: $3.60
- Precursor:
- Transportation:
- Deactivation:

![Cost Comparison]

- OnTo: $3.60
- Incumbent: $5.00
Market Size and Characteristics along the value chain

Metal-salt → Intermediate → Cathode → Slurry → Coating → Assembled Cell → Formed Cell → Package and use

New scrap
(3-7.5% of manufacturing)

Old scrap

$3-7.5 Billion

$24 Billion
Nissan Leaf Manufacturing Scrap

- **Cathode-Healing® patents**: 9,484,606; 10,333,183; 8,846,225; 9,825,341; 9,287,552; & PCTs
LFP from Cathode-Healing®
(the brave new world of recycling cobalt free lithium-ion)

Cathode-Healing® Patents: 9,484,606; 10,333,183; 8,846,225; 9,825,341; 9,287,552; & PCTs
## Competition: pyro / hydrometallurgy

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<thead>
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<th>Logistics Safety (Safe Spoke)</th>
<th>Cost</th>
<th>Flexibility to chemistry</th>
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<td>OnTo</td>
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### LFP Case Study

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<tr>
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<th>Pyro / Hydro</th>
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<td>Total Value</td>
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### OnTo Technology

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<th>$ / Ton Feed</th>
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<td>Case Study</td>
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Go To Market Operational View

- Pilot conception
  - End-to-end
  - Market Niches for sub-processes
- Modularly scalable

Pilot facility using OnTo Technology
Pilot Pro-forma

- **Capacity:** 1000 tons batteries/year
  - Operating at 50% capacity Y1
- **Battery Feedstock:** 50% NMC 622, 50% LFP
- **Labor:** 6 FTE
- **Cathode-Healing:** Healed cathodes sold at a deep discount, 75% market value
  - $0.11/kg shipping, paid by customer
- **For comparison, metal sulfate recovery:** Metals sold at March 2021 market prices with 100% metals recovery
  - CoSO₄
  - NiSO₄
  - MnSO₄
  - Li₂CO₃
  - Includes $7.00/kg-battery service fee
  - Operating cost based on incumbent hydrometallurgy, $21,590/ton-cathode
Patented Technical Capabilities:

- **Battery Deactivation**: Patented US 8,823,329; 7,198,865; 8,497,030; Pending 2019 & PCTs
- **Whole Battery Rejuvenation**: US 8,067,107
- **Materials Harvesting**: US 10,333,813 & PCTs
- **Cathode-Healing®**: 9,484,606; 10,333,183; 8,846,225; 9,825,341; 9,287,552; & PCTs
- **Materials Characterization**: XRD and electrochemical analysis, partners with OSU for microscopy, ICP,
- **Cell Building and Benchmarking**: Cell making and testing.
OnTo Partners & Customers

[Logos and brand names of various organizations]

OnTo Technology