Advances in Direct Recycling for Lithium-ion Batteries

OnTo Technology LLC
Steve Sloop

NDIA Event #7670 Joint Service Power Expo
Virgina Beach, VA May 1-4, 2017
OnTo Technology is in Bend, Oregon, which has flights to many US West Coast airports.
History and future for cost of Li-ion

Cost reduction due to improvements in battery chemistry, manufacturing processes, economies of scale...and commodities dip
What does recycling cost for Li-ion?

• Estimates $25-$60/kWh
  – Major part of the future cost goal of $100/kWh.

• Obviously, this has to decrease for a sustainable EV industry.
Existing Technologies
Smelting and hydrometallurgy

- Costly, uses a lot of energy.
- Li is lost.
- Co oriented.
- How does this work for NMC, LFP?
Sources of Li-ion for Recycle

Servable Market is limited by the Rate of
• Manufacturing seconds.
• Field faults.
• Managed battery lifetime.
There is a small market now, and a good opportunity to implement direct recycling.

Original Manufacturing

Fielded EV and Utility Batteries

EV or Utility Service

End-of-life Batteries For recycling

OnTo Technology LLC
OnTo Li-ion Up-cycling Development

• OnTo: US Based Feasibility and Technical Development.
• Business:
  – Consulting for EV and Large Format Industrial Products.
  – Development of manufacturing with recycled material.
• Pleased to announce “Upcycling of Lithium-ion Battery Materials”, Nissan North America.
• Upcycled Material Partner: CKE & Meekotech
Plan for Direct Recycling Early

Consider Recycle in the cathode material plan.

Plan for recycling to save money and resources.

We can help that process.

---

<table>
<thead>
<tr>
<th>EV Chem</th>
<th>% of Capacity Return in Recycling</th>
<th>Rate Capability Charge/Discarge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chem A</td>
<td>100%</td>
<td>Match</td>
</tr>
<tr>
<td>Chem B</td>
<td>100%</td>
<td>Match</td>
</tr>
<tr>
<td>Chem C</td>
<td>100%</td>
<td>Match</td>
</tr>
<tr>
<td>Chem D</td>
<td>80%</td>
<td>90%</td>
</tr>
<tr>
<td>LiCoO2</td>
<td>100%</td>
<td>Match</td>
</tr>
</tbody>
</table>

2Ah, 100% Recycled cell and New cell. Behave identically...the recycled cell is lower cost, higher purity electrode.

OnTo Technology LLC
Flexibility to Electrode Chemistry

**Recycled Li-Iron-Phosphate**

LFP vs. Lithium Metal

- Before Processing
- After Processing

**Recycled NMC**

- RNMC Ave Discharge Capacity % C/10
- NMC Ave Discharge Capacity % C/10

**Recycled Spinel-layered metal oxide-mix**

- Specific Capacity / mAh/g vs. Cycle Number

**Recycled LCO**

- Full Cell Cycling (mAh) vs. Cycle Number
- Specific Capacity / mAh/g vs. Cycle Number
Recent Results: Separation of (+) and (-) Electrodes

- Rapid process applicable whole-battery shredder residue.
- Industrially scalable.
- Feasible with use of patented process technology.
Innovative Processing for Up cycling of Nickel-rich NMC

NMC//Li button cells, 14-15mg pellet

Rate capability and capacity retention of recycled NMC (green) matches or exceeds standard NMC (gray)
Technology Features for EV & Large Battery Business

Features

• Low temperature process.
• Easy to use – no stoichiometric measurements – REQUIRED - by other processes.
• Flexible to Li-ion electrodes.
• Very high yield, essentially quantitative.
• Fast process to new-cathode.
• US and PCT Patented with priority.

Service

• License for direct recycling.
• Support in EV planning.
  – recycle value.
  – decrease lifetime costs.
  – Increase product marketability.
• Develop Industrial Scale EV Environmental Services.
• Already Serving a US Based EV Manufacturer!

OnTo Technology LLC
### Direct Recycling Patents

- **What it is:** Recovery of the entire electrode material from a battery for use as new electrode.

- **Innovative:** Patented Process Technologies reinstate electrochemical activity to “spent” battery materials.

- **OnTo Activities:** Demonstrate proof of concept, model and develop scale 10-100x in order to achieve commercial operation.

- **CKE:** Initial Industrial Scale Development site for Direct Recycling.

<table>
<thead>
<tr>
<th>Patent #</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 9,484,606 B1</td>
<td>Recycling and Reconditioning of Battery Electrode Materials (Sloop et al.)</td>
</tr>
<tr>
<td>US 8,846,225</td>
<td>Reintroduction of lithium into recycled battery materials (Sloop)</td>
</tr>
<tr>
<td>US 9,287,552</td>
<td>Reintroduction of lithium into recycled battery materials (Sloop)</td>
</tr>
<tr>
<td>Chinese # 2016109129500 Pending</td>
<td>Reintroduction of lithium into recycled battery materials (Sloop)</td>
</tr>
<tr>
<td>Chinese # 201580049244.1 Pending</td>
<td>Recycling Positive-Electrode Material of a Lithium-ion Battery (Sloop)</td>
</tr>
<tr>
<td>200980136414.4 Issued under Chinese Patent No. ZL200980136414.4</td>
<td>Recycling Batteries Having Basic Electrolytes</td>
</tr>
</tbody>
</table>
Battery Deactivation Prototype

- Liquid CO$_2$ at 700 psi and room temperature
- 2 x 89L (2 x 23.5 gallon).
- 55 lb. Capacity
  - Loose 18650 cells or battery packs.
- Extracts 90% of battery electrolyte with simple soak for 48 h.
- Yields battery shells with minimal flammability risk.
- Developed under NSF SBIR Award # 0750552.
- US Patents Issued:
  - #7,198,865
  - #8,497,030

1. Discharge
2. Extract
3. Pack & Ship

Electrolyte Neutralization/disposal or process for reuse
Minimized Risk of Fire
Commercial Scale Agricultural Processing with CO₂ (example)

• Design for extraction of oils from hops.
• Supercritical temperature and pressure.
• Stick-build, mobile, high volume.
• Example only: shows mobility, ease of construction and operation.
Acknowledgements

OnTo has received support from the following Federal Research Awards:

• **US Department of Energy (DOE):**
  – Small Business Innovation Research Award (SBIR) #DE-SC0006336

• **US National Science Foundation (NSF):**
  – SBIR Awards #0750552, and #1448061

• **Defense Logistics Agency (DLA):**
  – SBIR Contract # SP4701-15-C-0097
Contact information: Steve Sloop
ssloop@onto-technology.com
OnTo Technology LLC, 63221 Service Road
STE F, Bend Oregon 97703
Contact information:

Dr. Steve Sloop: ssloop@onto-technology.com  
OnTo Technology LLC, 63221 Service Road STE F, Bend, Oregon 97703

Dr. Tom Xu: tom@meecotech.com  
Meecotech Inc, 2734 Loker Ave West, Suite D, Carlsbad, CA 92010