# Advances in Direct Recycling for Lithium-ion Batteries

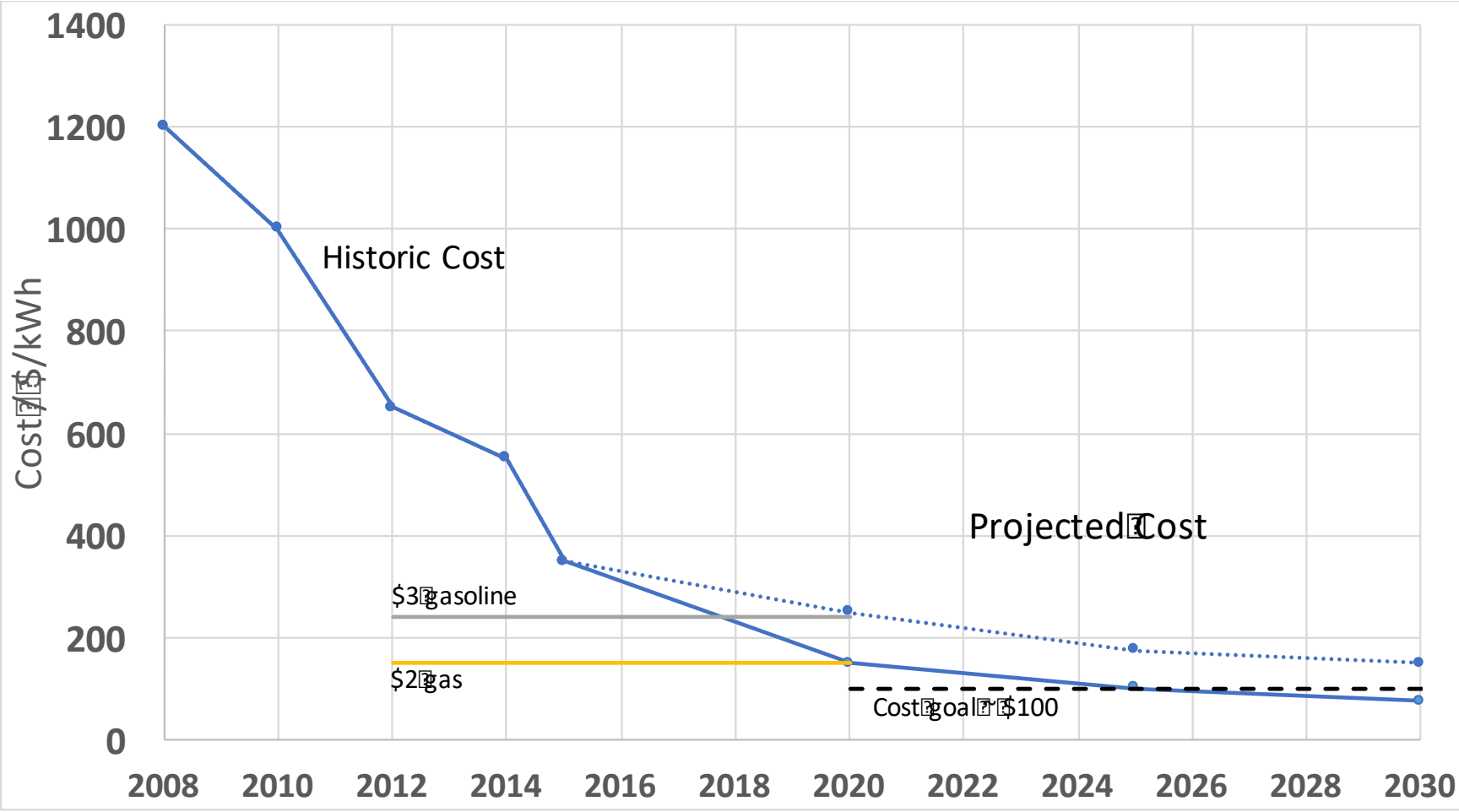
OnTo Technology LLC
**Steve Sloop**

NDIA Event #7670 Joint Service Power Expo
Virgina Beach, VA May 1-4, 2017

# Location

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

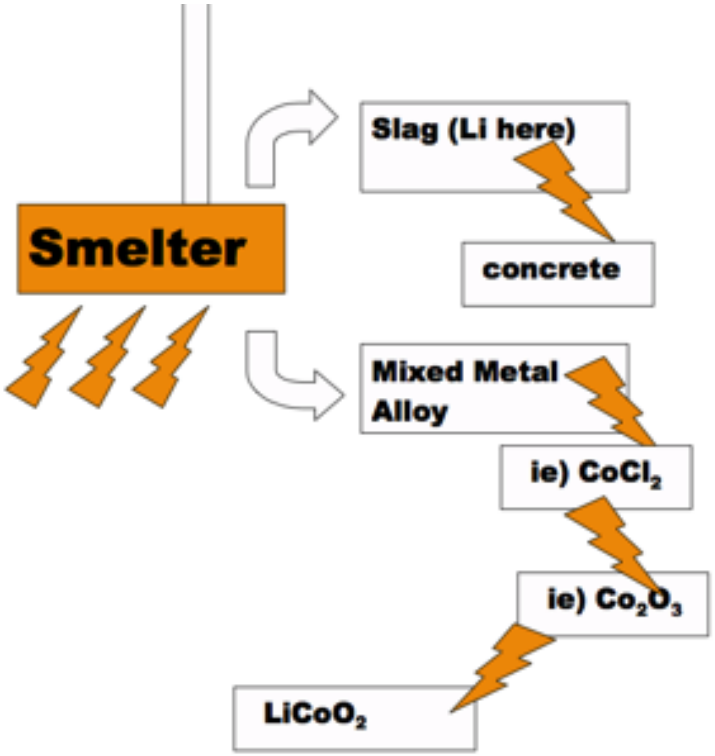
# What does recycling cost for Li-ion?

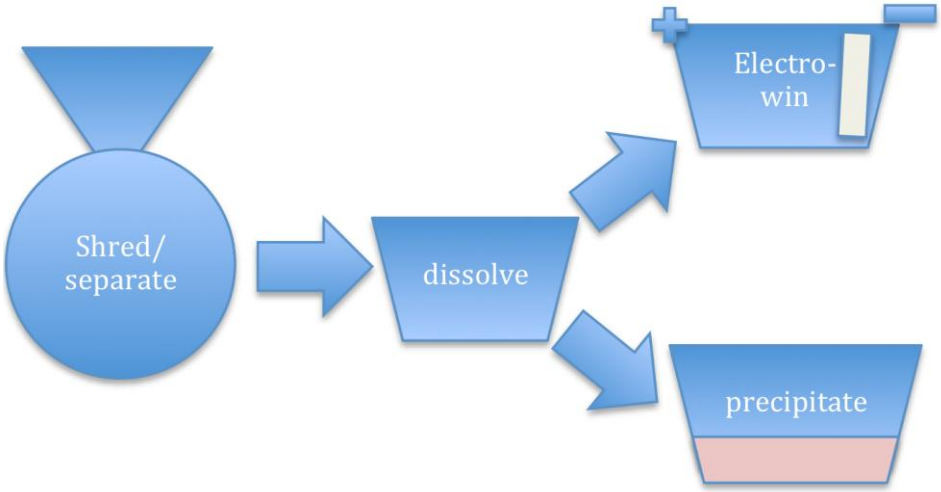
- **Estimates $25-$60/kWh**
  - Major part of the future cost goal of $100/kWh.

- **Obviously, this has to decrease for a sustainable EV industry.**

# Existing Technologies

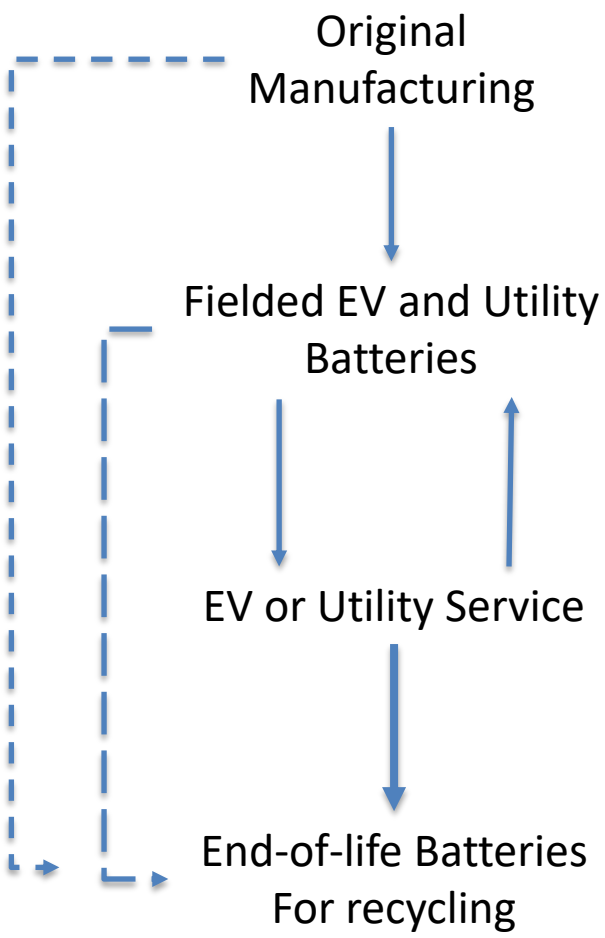
## Smelting and hydrometallurgy




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

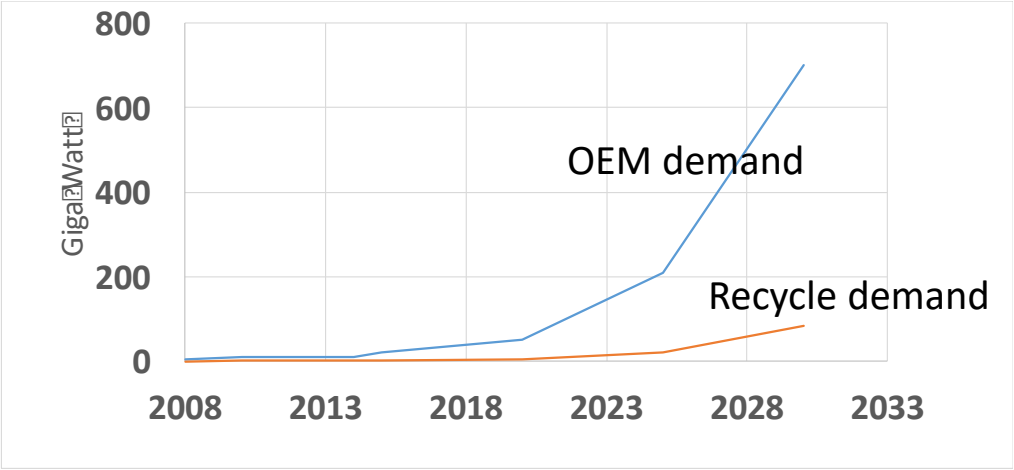
# Sources of Li-ion for Recycle




Servable Market is limited by the Rate of

- Manufacturing seconds.
- Field faults.
- Managed battery lifetime.

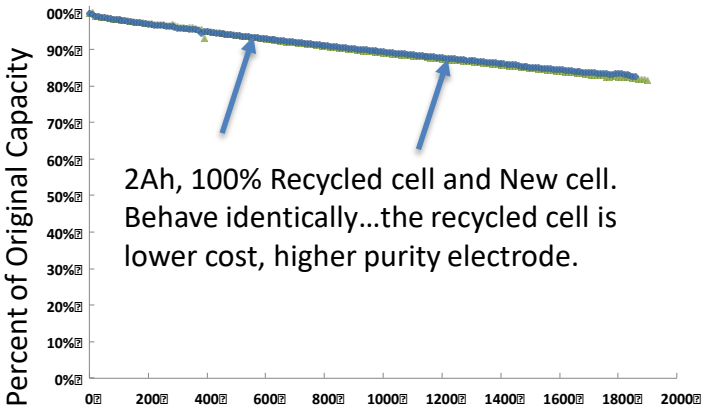
There is a small market now, and a good opportunity to implement direct recycling.

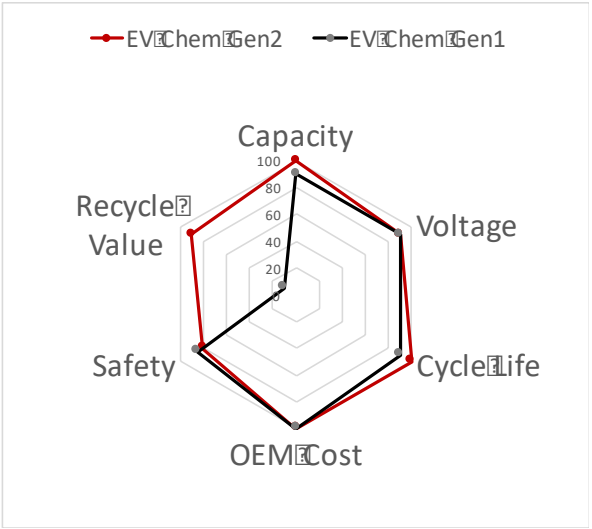


# OnTo Li-ion Up-cycling Development

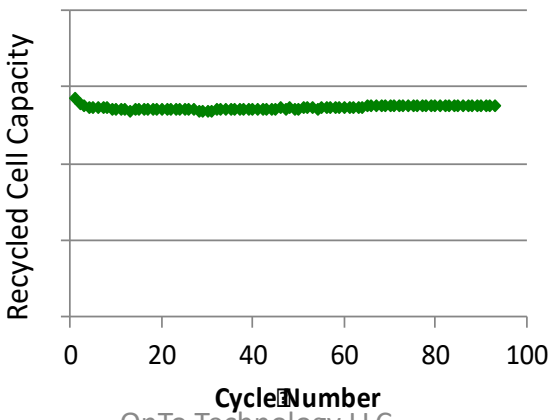
- OnTo: US Based Feasibility and Technical Development.
- Business:
  - Consulting for EV and Large Format Industrial Products.
  - Evaluation of products for recycle and performance.
  - Development of manufacturing with recycled material.
- Pleased to announce “Upcycling of Lithium-ion Battery Materials”,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

# Plan for Direct Recycling Early




| EV Chem | % of Capacity Return in Recycling | Rate Capability Charge/Discharge |
|---|---|---|
| Chem A | 100% | Match |
| Chem B | 100% | Match |
| Chem C | 100% | Match |
| Chem D | 80% | 90% |
| LiCoO2 | 100% | Match |



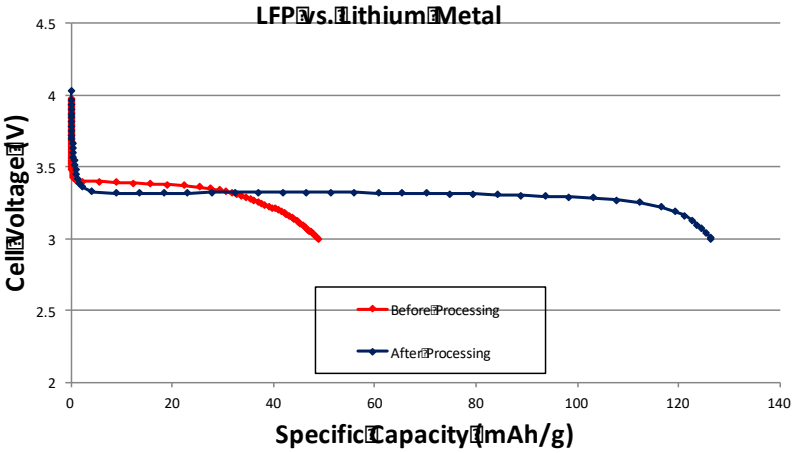

Consider Recycle in the cathode material plan.

Plan for recycling to save money and resources.

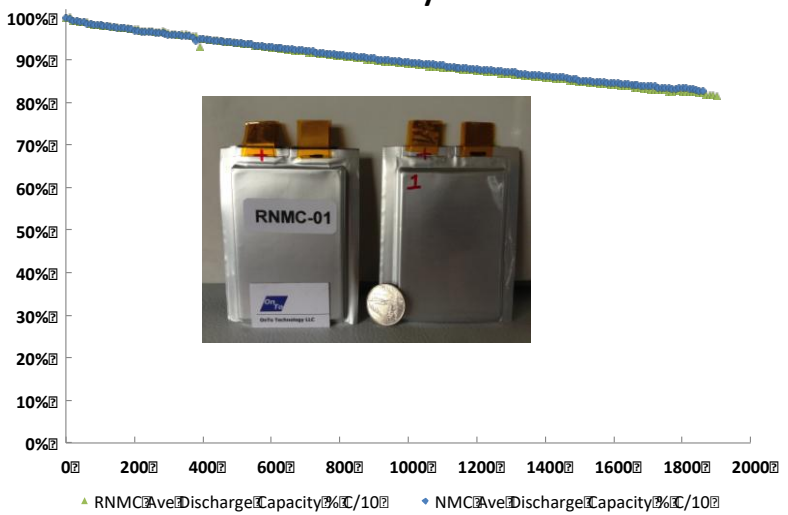
We can help that process.

# Flexibility to Electrode Chemistry

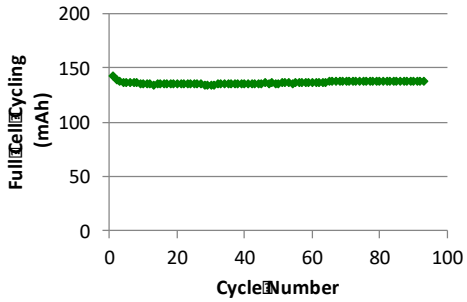
## Recycled Li-Iron-Phosphate



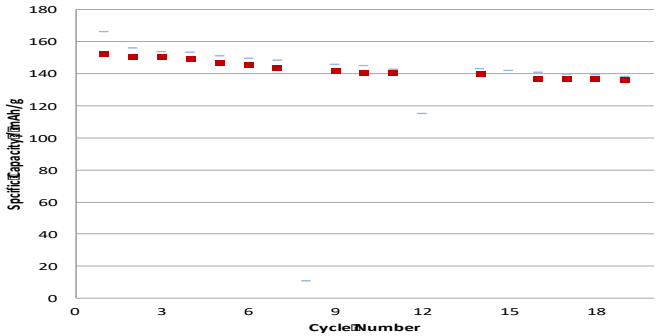

## Recycled NMC



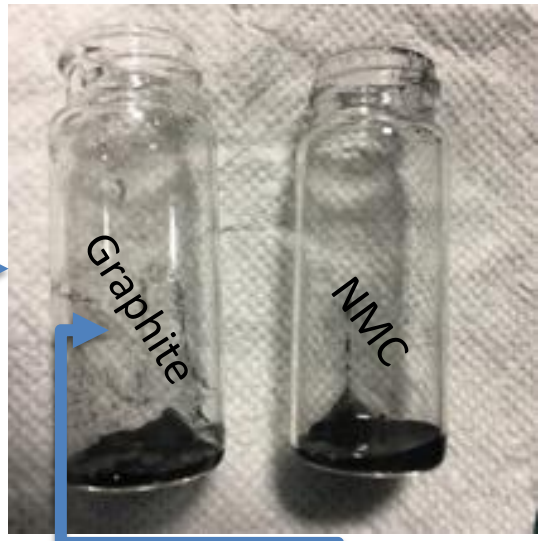

## Recycled Spinel-layered metal oxide-mix



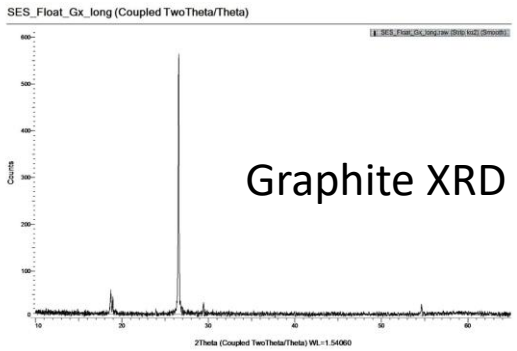

## Recycled LCO



# Recent Results: Separation of (+) and (-) Electrodes

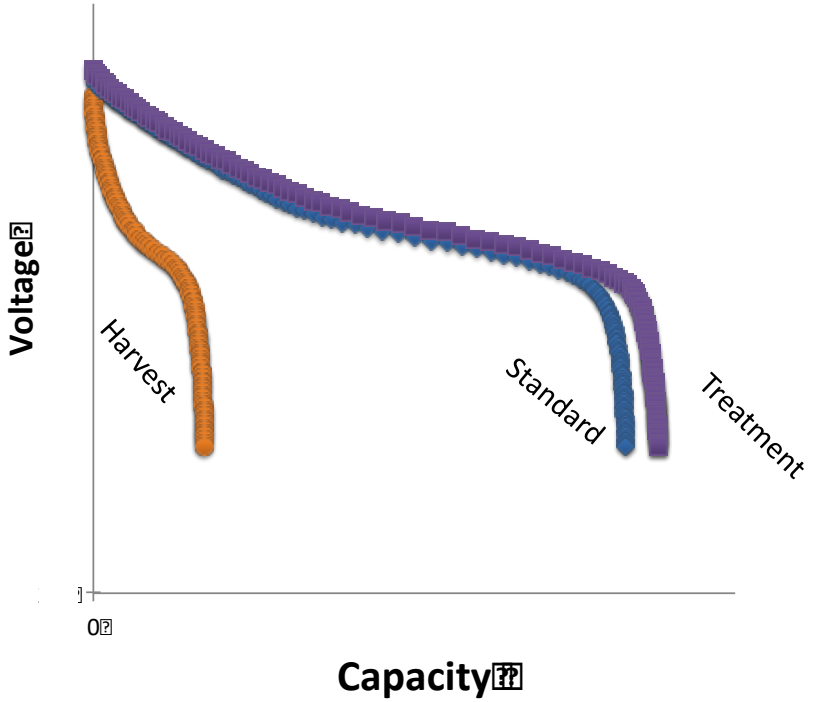



- Rapid process applicable whole-battery shredder residue.
- Industrially scalable.
- Feasible with use of patented process technology.

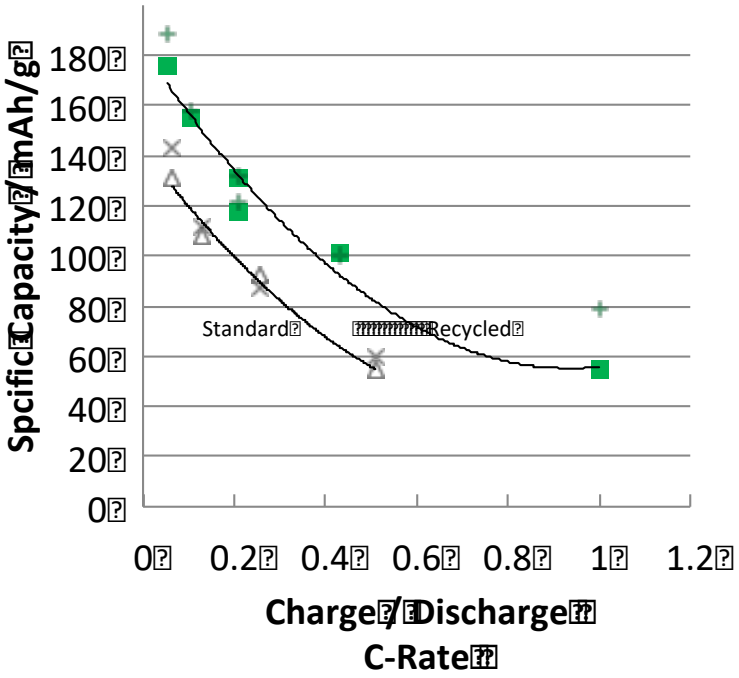



Graphite XRD

# 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 Environmnetal Services.
- Already Serving a US Based EV Manufacturer!

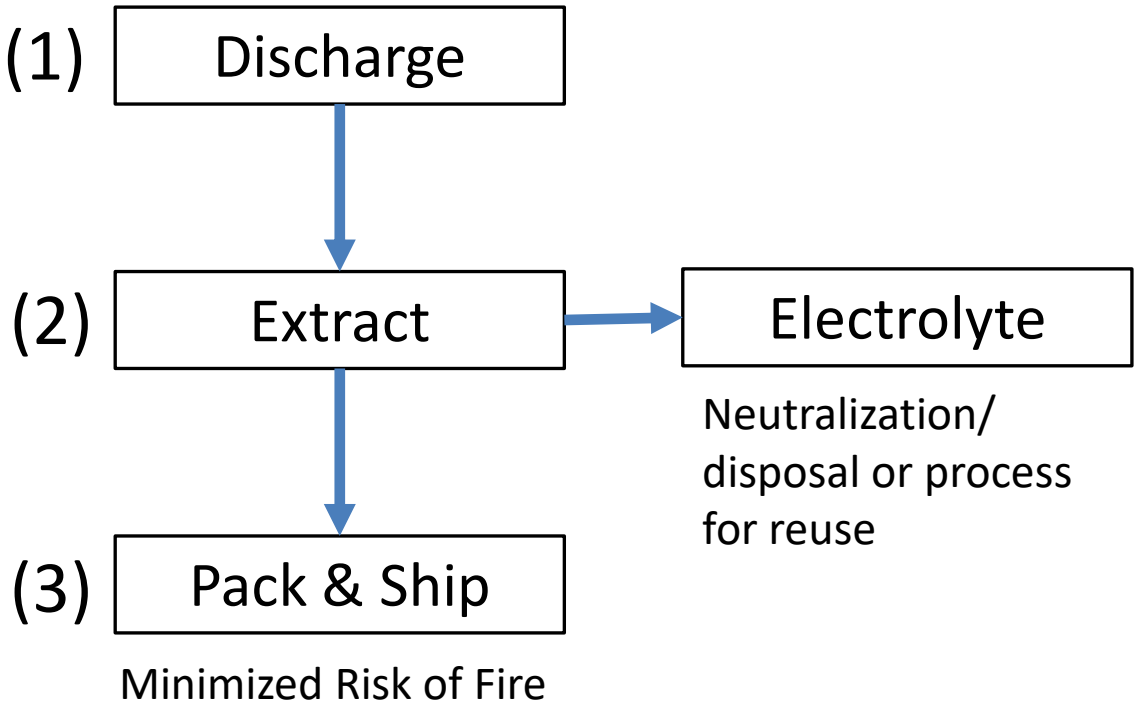
# Direct Recycling Patents

- *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.

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

# 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



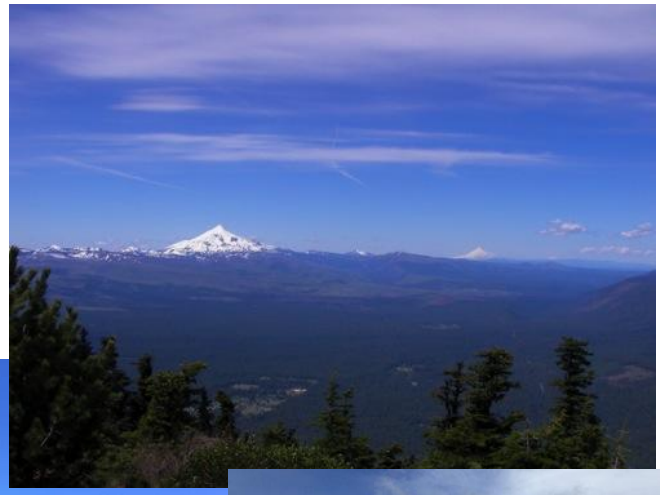
# Commercial Scale Agricultural Processing with $CO_2$ (example)

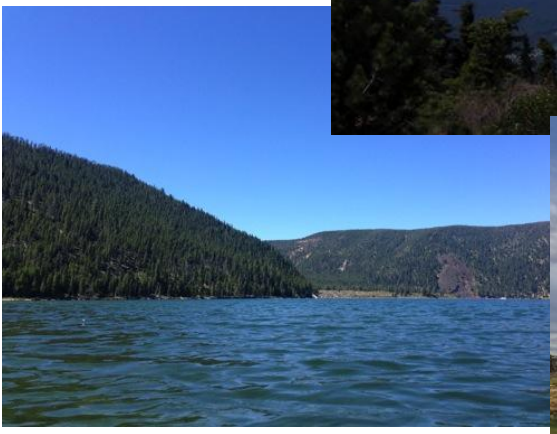
- Design for extraction of oils from hops.
- Supercritical temperature and pressure.
- Stick-build, mobile, high volume.
- Example only: shows mobility, ease of construction and operation.

# 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





CFO and CEO hard at work

**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