Opportunity for Closing the Loop in the Lithium-ion Battery Supply Chain
June 17th, 2020
Presented To: CALEPA Lithium-Ion Battery Recycling Advisory Group
## Introduction and Macro Context

- Li-Cycle Introduction, Critical Material Supply and Demand
- Lithium-ion Batteries Available for Recycling
- Environmental Benefits and Supply Chain Dynamics

## Li-Cycle Overview

- Incumbent Options, Li-Cycle Technology
- What About Lithium-ion Battery Reuse?

## Li-Cycle Roadmap

## Supporting Lithium-ion Battery Recycling
**Year Founded:** 2016

**Service:** Closed-loop lithium-ion battery resource recovery

**Key Partners:**
- CALSTART
- MaRS
- Responsible Battery Coalition
- NAATBatt
- Suppliers Partnership for the Environment

**Key Investors:**
- TECHMET
- bdc
- DELPH25
- PELLA
- Bioindustrial Innovation Canada®

**Awards:**
- 2020 Global Cleantech 100
- 2016 Clean Energy Innovator Award
- Start Up Energy Transition
- CleanEquity Monaco 2018
To be the most sustainable, vertically integrated, and globally preeminent lithium-ion battery resource recovery company
# L i - C y c l e  E x e c u t i v e  T e a m ,  B o a r d  a n d  A d v i s o r s

## Leadership & Team

<table>
<thead>
<tr>
<th>Name</th>
<th>Title and Qualifications</th>
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</thead>
<tbody>
<tr>
<td>Ajay Kochhar</td>
<td>President &amp; CEO, Chem. Eng.</td>
</tr>
<tr>
<td>Kunal Phalpher</td>
<td>CCO, Elec. Eng., MBA</td>
</tr>
<tr>
<td>Bruce Maclnnis</td>
<td>CFO, CPA and CA</td>
</tr>
<tr>
<td>Ethan Callender</td>
<td>HSEQ Manager, HSE, Quality Expert</td>
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</tbody>
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## Board of Directors

<table>
<thead>
<tr>
<th>Name</th>
<th>Title and Qualifications</th>
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</thead>
<tbody>
<tr>
<td>Tim Johnston</td>
<td>Exec. Chairman, Co-Founder</td>
</tr>
<tr>
<td>Ajay Kochhar</td>
<td>Exec. Director, Co-Founder</td>
</tr>
<tr>
<td>Anthony Tse</td>
<td>Non-Exec. Director, Critical Materials</td>
</tr>
<tr>
<td>Mark Wellings</td>
<td>Non-Exec. Director, Capital Raising</td>
</tr>
<tr>
<td>Rick Findlay</td>
<td>Non-Exec. Director, Business Ops. &amp; Scaling</td>
</tr>
<tr>
<td>Alex Lowrie</td>
<td>Non-Exec. Director, Financial Mgt.</td>
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<tr>
<td>Brian Menell</td>
<td>Non-Exec. Director, Strategic Growth</td>
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</tbody>
</table>

## Advisory Board

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>Adonis Pouroulis</td>
<td>Senior Advisor, Mining &amp; Metals</td>
</tr>
<tr>
<td>Yuan Gao</td>
<td>Technical Advisor, Li-ion Battery Expert</td>
</tr>
<tr>
<td>Ahmad Ghahreman</td>
<td>Technical Advisor, Ph.D. Hydromet.</td>
</tr>
<tr>
<td>Chris Berry</td>
<td>Energy Metals Advisor, Leading Co &amp; Li Analyst</td>
</tr>
</tbody>
</table>
Lithium-ion battery demand globally has risen dramatically over the last 10 years, and is only beginning. Global demand depicted below with accurate relative scale.

- **2010**: 4 GWh
- **2020**: 80 GWh
- **2030**: 760 GWh

*Samsung SDI*
GROWING NUMBER OF USES FOR LI-ION BATTERIES
INCREASING DEMAND FOR MATERIALS IN SHORT SUPPLY – LITHIUM

OCCASSION FOR NEW MATERIAL SOURCES

Source: Benchmark Mineral Intelligence Liithium Forecast
INCREASING DEMAND FOR MATERIALS IN SHORT SUPPLY - COBALT

Source: Benchmark Mineral Intelligence

OPPORTUNITY FOR NEW MATERIAL SOURCES

Cobalt market balance

Tonnnes


Benchmark Mineral Intelligence Cobalt forecast
INCREASING DEMAND FOR MATERIALS IN SHORT SUPPLY - NICKEL

Nickel market balance

Source: Benchmark Mineral Intelligence

OPPORTUNITY FOR NEW MATERIAL SOURCES
Critical Material Uses

Legend (USA)

Energy

HAFNIUM
RHENIUM
TANTALUM
URANIUM

Technology

GERMANIUM
INDIUM
GALLIUM
RARE EARTHS

Industrial

BERYLLIUM
ZIRCONIUM
TUNGSTEN
ALUMINUM
PGMs
BARITE
FLUORSPAR
ARSENIC
SCANDIUM
STRONTIUM
TITANIUM
POTASH

Steel

MAGNESIUM
CHROMIUM
TIN
TELLURIUM
MANGANESE
VANADIUM
NIOBrium

Batteries

LITHIUM
COBALT
ANTIMONY
GRAPHITE
NICKEL

Research

HELUM
RUBIDIUM
CESIUM
BISMUTH

Source: U.S. Department of the Interior, Bureau of Land Management
WHAT ARE THE SOURCES FOR BATTERY MATERIALS?

Mining

Recycling
Are there enough batteries for recycling?

Total Lithium-ion Batteries Available for Recycling by Region (tonnes/year)

- >15 million tonnes of lithium-ion batteries requiring recycling on a cumulative, global basis between 2019-2030

SOURCE: Li-Cycle Total Addressable Market forecasts (various sources therein)
ARE THERE ENOUGH BATTERIES FOR RECYCLING? (CONTD.)

Total Lithium-ion Batteries Available for Recycling by Application/Sector (tonnes/year)

Significantly larger volumes as EV and ESS batteries become spent (NMC, NCA, LFP, LMO chemistries) projected to be available for recycling.

SOURCE: Li-Cycle Total Addressable Market forecasts (various sources therein)
WHAT IS THE VALUE OF RECYCLED MATERIALS?

Total Recoverable Value by Region (US$/year)

>US$ 92 billion of residual recoverable value (associated with the >15 million cumulative tonnes globally, between 2020-2030

SOURCE: Li-Cycle Total Addressable Market forecasts (various sources therein)
WHAT IS THE VALUE OF RECYCLED MATERIALS? (CONTD.)

In the medium term, spent and defective xEV batteries contribute the greatest value towards the global recoverable value of any application/sector for lithium-ion batteries.

Total Recoverable Value by Application/Sector (US$/year)

SOURCE: Li-Cycle Total Addressable Market forecasts (various sources therein)
Third Party Life Cycle Analysis Results

GHG Emissions Reductions provided below are the emission reductions associated with recovering 1 tonne of each battery material using Li-Cycle Technology in comparison to mining and refining these materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Emission Reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li</td>
<td>8.9 t CO2</td>
</tr>
<tr>
<td>Mn</td>
<td>7.0 t CO2</td>
</tr>
<tr>
<td>Co</td>
<td>40.7 t CO2</td>
</tr>
<tr>
<td>Ni</td>
<td>8.1 t CO2</td>
</tr>
</tbody>
</table>
GAP IN SUPPLY CHAIN WILL PERSIST EVEN WITH RECYCLING

Cathode capacity update

Existing
- Asia (other): 19%
- S Korea: 22%
- Japan: 12%
- China: 64%

1,454,790 tpa

In construction
- S Korea: 9%
- Japan: 5%
- China: 81%

980,800 tpa

Planning
- S Korea: 3%
- Japan: 2%
- China: 90%

1,600,500 tpa

Source: Benchmark Mineral Intelligence
# Introduction and Macro Context

- Li-Cycle Introduction, Critical Material Supply and Demand
- Lithium-ion Batteries Available for Recycling
- Environmental Benefits and Supply Chain Dynamics

## Li-Cycle Overview

- Incumbent Options, Li-Cycle Technology
- What About Lithium-ion Battery Reuse?
- Li-Cycle Roadmap

## Supporting Lithium-ion Battery Recycling
END-OF-LIFE OPTIONS: BEFORE LI-CYCLE

Export it
Batteries are shipped blindly overseas and are often lost, landfilled abroad, or lead to fires.

Trash it
"Nationally we're losing a facility a month, burned to the ground by battery fires"
President, Derri-Con Waste Management

Reuse it
Costs circa $60/kWh to repurpose batteries. With new battery costs now <$100/kWh, the business case for reuse is rapidly eroding.

“Recycle” it
Current methods recover under 50% of raw battery materials, and only 30% of raw material costs.
Li-Cycle’s patented Spoke and Hub technologies recover 95% of all li-ion battery materials—extracting high-grade materials for battery production, at a cost competitive to mined and refined material.
### Incumbent Recycling Technologies
(i.e. pyrometallurgical processing/smelting)

- High cost resource recovery
- Not tailored for Li-ion batteries; old, inherited technology
- ≤50% recycling efficiency rate/recovery
- Manual dismantling with a high risk of thermal runaway
- Discharging of batteries necessary before processing
- Significant solid waste (slag)
- Effluent water
- Heavy metals in air emissions
- High energy consumption

### Li-Cycle Hub-and-Spoke Technologies

<table>
<thead>
<tr>
<th>Cost</th>
<th>Lowest cost resource recovery</th>
<th>'Fit-for-purpose'/tailored for all types of li-ion batteries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycling Efficiency and Recovery Rates</td>
<td>80-100% recycling efficiency rate</td>
<td>≥95% functional material recovery</td>
</tr>
<tr>
<td>Safety</td>
<td>Safe and automated size reduction of Li-ion batteries</td>
<td>Safely processes fully charged batteries</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>No solid waste; all end-products return to the economy, with various pathways being developed (e.g. for plastics)</td>
<td>Zero discharge facility Zero impact air emissions Low energy consumption</td>
</tr>
</tbody>
</table>
## Competitive Landscape - Recycling Technologies

<table>
<thead>
<tr>
<th>Technology Description</th>
<th>Li-Cycle Technology™</th>
<th>Cathode-to-Cathode</th>
<th>Smelting or Thermal Pre-Treatment &amp; Refining</th>
<th>Thermal or Mechanical Pre-Treatment only</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology Stage</strong></td>
<td>Commercial</td>
<td>Lab Scale, Pilot</td>
<td>Commercial</td>
<td>Commercial</td>
</tr>
<tr>
<td><strong>Input Material</strong></td>
<td>Complete battery, charge and state agnostic</td>
<td>Cathode only</td>
<td>Battery cells or modules, discharged or charge agnostic, chemistry specific</td>
<td>Predominantly battery cells only, must be discharged, chemistry specific</td>
</tr>
<tr>
<td><strong>Recovery Rate</strong></td>
<td>95%</td>
<td>30% (cathode proportion only)</td>
<td>≤ 50%</td>
<td>≤ 50%</td>
</tr>
<tr>
<td><strong>Li-ion families covered</strong></td>
<td>All, 14+</td>
<td>Select, 5</td>
<td>Select, 3</td>
<td>Select, 3</td>
</tr>
<tr>
<td><strong>‘Future Proofed’</strong></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Process Description</td>
<td>Li-Cycle®</td>
<td>Smelting/Pyrometallurgy</td>
<td>Artisanal/Small-Scale Recycling</td>
<td>Landfilling</td>
</tr>
<tr>
<td>--------------------------------------------</td>
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</tr>
<tr>
<td>Mechanical and ‘wet chemistry’/hydrometallurgical process</td>
<td>Low risk. Safe and automated battery dismantling. All products are safe and saleable</td>
<td>High temperature processing, typically &gt;1,100°C</td>
<td>Manual dismantling. Typically coupled with partial disposal</td>
<td>Disposal in the open and/or in landfills. Possible combustion</td>
</tr>
<tr>
<td>Low risk. Potential low safety standards in smelter</td>
<td>Medium risk. Effluent water streams could contain heavy metals</td>
<td>Very high risk. Toxic metal exposure and battery combustion</td>
<td>Very high risk. Battery combustion and/or explosion risk</td>
<td></td>
</tr>
<tr>
<td>Low risk. Water reused and recycled within the process</td>
<td>Medium risk. Effluent water streams could contain heavy metals</td>
<td>Very high risk. Toxic heavy metals leach into drinking water</td>
<td>Very high risk. Toxic heavy metals leach into drinking water</td>
<td></td>
</tr>
<tr>
<td>Low risk. Virtually no particulate matter (PM) and CO₂ emissions</td>
<td>High risk. Heavy metals in PM emissions, high level of CO₂ emissions</td>
<td>Very high risk. Heavy metals released as uncontrolled PM emissions</td>
<td>Very high risk. Heavy metals released as uncontrolled PM emissions</td>
<td></td>
</tr>
<tr>
<td>Low risk. No landfilled waste</td>
<td>Medium risk. Slag, waste streams are piled and/or landfilled</td>
<td>Very high risk. Heavy metals enter soil and contaminate plants</td>
<td>Very high risk. Heavy metals enter soil and contaminate plants</td>
<td></td>
</tr>
</tbody>
</table>
Reuse was traditionally a stopgap measure when economic recycling solutions were previously unavailable. Moreover, as new lithium-ion battery prices continue to fall, there ceases to be an economic case for the reuse of old lithium-ion batteries.

Considerations for second life applications of lithium-ion batteries:

- Business case – reused versus a new lithium-ion battery?
- Issues with variability across lithium-ion battery packs and the need for a consistent ‘building block’ for the scalability of reuse
- Provenance and liability issues – who owns the issues with reused lithium-ion batteries if they arise?

Recycling and reuse will continue to co-exist. However, (i) economically viable recycling, and (ii) the need for secure supply of critical materials are driving a greater proportion of recycling now and into the future.
**Q4 2016:** Li-Cycle proof of concept  
**Capacity:** 5 tonne/year

**Q3 2017:** Mini-piloting complete in Canada  
**Capacity:** 50 tonne/year

**Q3 2018:** Spoke demo complete in Kingston, Ontario  
**Capacity:** 365 tonne/year

**Q4 2018:** Spoke demo complete in Kingston, Ontario  
**Capacity:** 50 tonne/year

**Q4 2019:** Hub Demo complete in Kingston, Ontario  
**Capacity:** 365 tonne/year

**Q4 2019:** First Commercial Spoke in Kingston, Ontario  
**Capacity:** 2,500 tonne/year

**Q3 2020:** Second Commercial Spoke established in Rochester, New York  
**Capacity:** 5,000 tonne/year

**Q4 2020:** Second Commercial Spoke established in Rochester, New York  
**Capacity:** 5,000 tonne/year

**Q4 2021:** Third Commercial Spoke established in Nevada  
**Capacity:** > 5,000 tonne/year

**Q4 2022:** First Commercial Hub established in North America  
**Capacity:** 60,000 tonne/year
Total resource recovery capacity in 2025 represents ~30% of the global Total Available Market (TAM)
LI - CYCLE GLOBAL ROLL OUT PLAN - END-PRODUCT PRODUCTION

North American Critical Material Production

<table>
<thead>
<tr>
<th>Year</th>
<th>Lithium Carbonate</th>
<th>Cobalt Sulphate</th>
<th>Nickel Sulphate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2023</td>
<td>5,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td>20,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td>30,000</td>
<td></td>
<td></td>
</tr>
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Li-Cycle Roadmap

Supporting Lithium-ion Battery Recycling
H O W  T O  S U P P O R T  L I - I O N  B A T T E R Y  R E C Y C L I N G  I N  C A L I F O R N I A

EDUCATE

“Unlike lead acid batteries, there is no practical way to recycle those made of lithium.” – PBS News Hour, July 8th, 2020

Problem to be Addressed:

Ensure the right information is in the public to generate the battery supply for recycling

INCENTIVIZE

Put in place incentives across the value chain from the battery consumer through to the battery producer

Problem to be Addressed:

Increase collection, increase local production and encourage recycled material use in new products

LOCALIZE

Attract critical pieces of the value chain to set up shop in California

Problem to be Addressed:

Gap in critical resource and cathode production in North America. Permitting often a gating factor for site selection