Think Zinc! Supply chain security and recycling options of emerging Zinc battery technologies

Dr. Josef Daniel-Ivad

MPSC NiZn Battery Symposium
14 April 2022
ZBI - Zinc Battery Initiative

A Partnership to Advance Zinc-based Battery Technologies

The ZBI aims to be the champion of zinc batteries and ensure that all potential customers and other stakeholders understand the value and advantages of these products.
**ZBI – Status**

- Formed in late 2020 to promote the new wave rechargeable zinc batteries’ remarkable story and encourage further adoption of these products.
- Principal sponsor is the Int’l Zinc Association.
- Grown to 11 members / battery producers.
- Engaged PR firm Silverline Communication to reach out to a variety of media channels in the clean energy / energy storage field
  - Secured press coverages and articles are publishing raising awareness for zinc-based batteries
  - More in pipeline
Zinc Batteries are Versatile

Zinc has been developed across a wide range of chemistries and applications.

Hybrid systems offer potential for zinc to meet most critical needs.
Advantages of Zinc Batteries go Beyond Performance

**SAFETY**
Zinc batteries are non-flammable and non-toxic.

**SUSTAINABLE**
Zinc is abundant, recyclable, and has the lowest GHG emissions.

**SECURE SUPPLY**
Mined in 50+ countries globally, fully integrated supply chains in major regions.

- Long life (15-20 years)
- Flexible operating temps (-35°C to +75°C)*
- Low operating cost
- Non-hazardous transport

*... Depending on Zn-tech used
Availability of Zinc

Accessible crustal content
198,000,000 Mt
7X from prev. update at 28,000,000 Mt

Extractable global resources
63,000 Mt
22X from prev. update at 2,800 Mt

Zinc currently in use
247 Mt

Proven and Probable reserves
250 Mt

World zinc use/y 20 Mt

Mined zinc/y 12.8 Mt

Zinc recycled/y 7.6 Mt

Mt = million tons
1. “Zinc resources – a state of knowledge” by Eric Pirard, 2021
   (5 km mineable depth scenario)
2. IZA and Fraunhofer ISI 2021 zinc stocks and flows update
   (based on 2019 data)
4. International Lead Zinc Study Group. 2019
5. IZA and Fraunhofer ISI 2021 update, post- and pre-consumer scrap
6. IZA and Fraunhofer ISI 2021, zinc entering first use stage

Source: International Zinc Association (2022)
Anthropogenic material life cycle of zinc

Source: Fraunhofer ISI, Karlsruhe (2022)
Global Zinc Stocks and Flows in 2019

Source: Fraunhofer ISI, Karlsruhe (2022)
Since 1960 over 60 countries have mined zinc ore.
In 2019, 51 countries were actively mining zinc.
Top 10 mining companies contributed to 41% of the world concentrate production capacity.

Source: International Lead and Zinc Study Group (2020)
Zinc Metal Producing Countries in 2019

- 27 countries had zinc metal smelting and/or refining activities
- Top 10 refined zinc metal producing countries contributed 81% of world total output

Source: International Lead and Zinc Study Group (2020)
Main zinc chemicals in current use include:

- ZnO, ZnCO₃, ZnCl₂, ZnSO₄, ZnS₂, ZnCO₃, ZnSeO₃, Zn borate,
- Zn powder and nanoform Zn compounds.

Source: International Lead and Zinc Study Group (2020)
Zinc Oxide Main Uses in 2020

Global demand: 1.7 million metric tons
- Rubber compounding remains major end use in all regions
- Ceramics & Glasses is second largest application in all regions but North America

Source: IHS Markit (2021)
Zinc Oxide Market Regional View in 2020

- China (mainland) 39%
- Other Asia & Oceania 16%
- North America 10%
- Central and South America 6%
- Europe/CIS 17%
- Africa / Middle East 4%
- Indian subcontinent 8%

Source: IHS Markit (2021)
Zinc Oxide Supply

Source: IHS Markit (2021)
Zinc Circularity - Recycling

Zinc recycling doubled between 2010 and 2019 while zinc mine production remained constant at 12-13 Mt; RIP: Recycling Input Rate, EoL RR: End-of-Life Recycling Rate

Zinc recycling from steel mill (EAF) dust increases with regulations being enforced (based on ILZSG statistics).

Source: Fraunhofer ISI, Karlsruhe (2022), : International Lead and Zinc Study Group (2020)
Zinc Circularity - Recycling

How Much Zinc is Recycled Today?

Source: Fraunhofer ISI, Karlsruhe (2022), : International Lead and Zinc Study Group (2020)
Battery Zinc Demand Forecast 2020-2050

- Zinc tonnage forecast for Primary Batteries based on 2020 estimate and a 4% annual growth rate.
- Energy storage demand based on BloombergNEF NEO 2020 GWh forecast for storage batteries, percentage of zinc market share estimates based on consultation from Avicenne Energy, and an average zinc intensity of use of 2.5mt Zn/MWh for ESS.

Most Relevant Recycling KPIs

- **End-of-Life (EoL) recycling rate (RR)** compares the amount of metals recovered from recycling of EoL scrap with the amount of metals contained in generated EoL scrap.

- **Recycled Content (RC)** looks specifically on a product level at how much recycled material is used in the production of a new product, e.g. refined SHG zinc.

- **Recycling input rate (RIR)** indicates the contribution of secondary material to total metal production and is therefore a measure of dependence on geological resources. The RIR represents the product specific Recycled Content (RC) but on a global scale and for all products.

Also Relevant for Zinc Batteries
Challenges to Close the Loop for Zinc

• **Zinc is versatile:** For all uses not one way of recycling is available but multiple ways that are tailormade for the uses.

• **Precondition of recycling is collection and sorting:** Zinc metal scrap and galvanized steel scrap are collected at good rates. In other cases, collection and sorting is incomplete or not material specific.

• **Recycling needs to be economic:** If this is not the case, only regulatory measures can lead to increased recycling rates (zinc in MSW incineration, or low zinc concentrations steel dust).

• **Closed-loop vs open-loop recycling:** Refining zinc metal scrap up to refined zinc of SHG quality vs. recycling zinc into zinc alloy or zinc oxide.

• **Metallurgy is never about one metal alone:** Zinc may be bound in complex products, recycled for the recovery of metals other than zinc, recycling technologies not being optimized for zinc recovery.
Single-use versus Rechargeable

**Primary (single-use):**
- Zinc Carbon – AAA, AA, C, D, 9V
- Zinc Manganese (alkaline) – AAA, AA, C, D, 9V
- Zinc air – button or coin cells

**Rechargeable (secondary):**
- Zinc Bromine – flow
- Nickel Zinc – cell
- Zinc ion (sulphate electrolyte) – cell
- Zinc Manganese (alkaline electrolyte) – cell
- Zinc air – cell or flow
Zinc Starter Materials for Batteries

Primary (single-use):

- Alkaline:
  Zinc powder, alloyed with Bi, In, Al, Mg, and/or Ca (50-500ppm)
  Typical size 200-300µm

- ZnC:
  Zinc sheet, for battery case

Rechargeable (secondary):

- Zinc bromide solution - ZnBr$_2$ (aq.)
- Zinc oxide – ZnO
- Zinc hydroxide – Zn(OH)$_2$
- Zinc powder, alloyed, finer than primary batt.
- Zinc sheet or foil
- Zinc sponge
- Mixtures of the above
In 2018, 191,000 tonnes of portable batteries were sold in the EU; 88,000 tonnes of used portable batteries were collected as waste to be recycled.
USA Battery Recycling in 2020
4.1 million pounds of primary batteries and 5.7 million pounds of rechargeable batteries were collected as waste to be recycled.
▷ ~4,500 tonnes vs. 88,000 tonnes EU

~2% Primaries Collected

Canada Battery Recycling in 2020
3.4 million kilograms of primary batteries and 0.9 million kilograms of rechargeable batteries were collected as waste to be recycled.
▷ ~4,100 tonnes vs. 88,000 tonnes EU

~30% Primaries Collected

Source: Call2Recycle (2020 Annual Report)
# Recycling Paths of Single-use Batteries

## Mechanical
- Separation of steel and black mass
- **Steel scrap raw material for new steel**
- **Black mass raw material for agricultural use**, e.g. fertilizers (K, Zn and Mn are micro-nutrients)

## Hydrometallurgical
- Hydro treatment follows mechanical separation
- Black mass is processed to Zn\(^0\), ZnO, Zn(OH)\(_2\) or other zinc compounds

## Pyrometallurgical
- Treatment of complete spent batteries or after mech. separation
- **Recovery of Fe, Mn (steel) and Zn at processing of complete batteries:**
  - Sumitomo process
  - Inmetco process
  - Special blast furnace
  - EAF (dep. regulations)
- Black mass processed in Waelz Kiln for Zn rec.
## A Rechargeable Zinc Chemistry for Each Application

<table>
<thead>
<tr>
<th>Duration</th>
<th>Typical Size</th>
<th>Primary Applications</th>
<th>Technologies</th>
<th>Company</th>
<th>Stage of Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1 hour</td>
<td>50-100 kWh</td>
<td>UPS, hybrid systems for grid application</td>
<td>NiZn</td>
<td>ZincFive, Aesir Technologies</td>
<td>Commercialized, increasing manufacturing</td>
</tr>
<tr>
<td>2-6 hours</td>
<td>1kWh and up</td>
<td>Peak shaving, backup power</td>
<td>Zinc-ion</td>
<td>Salient Energy; Enerpoly</td>
<td>Commissioning pilot plant, looking for demonstration projects from 2022</td>
</tr>
<tr>
<td>4-12 hours</td>
<td>1kWh to 10MWh</td>
<td>Peak shaving, renewables integration</td>
<td>ZnMn; ZnBr</td>
<td>Urban Electric Power, Redflow</td>
<td>Redflow commercialized; UEP 5 demo projects and Series B funding complete</td>
</tr>
<tr>
<td>8-24 hours</td>
<td>1MWh and up</td>
<td>Renewables integration</td>
<td>Zinc air flow</td>
<td>Zinc8</td>
<td>Demonstration project commenced, commercial in 2023</td>
</tr>
<tr>
<td>24-72 hours</td>
<td>250kWh to 1MWh</td>
<td>Renewables, remote power</td>
<td>Zinc air</td>
<td>E-Zinc</td>
<td>Series A funding, TRL 6</td>
</tr>
</tbody>
</table>
# Material Bill of Rechargeable Zinc Batteries

New metals/elements appearing which are not used in primary batteries

## Table 1: Common zinc battery chemistries and formats

<table>
<thead>
<tr>
<th>Battery type</th>
<th>Anode</th>
<th>Cathode</th>
<th>Electrolyte</th>
<th>Formats</th>
<th>kWh/kg Zn</th>
<th>kg Zn/kg battery</th>
<th>Other metals</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZnBr&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Zn</td>
<td>Bromine (aqueous)</td>
<td>Water, complexing agents</td>
<td>Flow</td>
<td>0.5-0.6</td>
<td>7%</td>
<td>Titanium has been used in current collectors, but the market is trending to carbon current collectors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flooded Cell</td>
<td>0.06-0.47&lt;sup&gt;1&lt;/sup&gt;</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>ZnMnO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Zn</td>
<td>MnO&lt;sub&gt;2&lt;/sub&gt;, Bi,O, sometimes intercalated with Cu</td>
<td>KOH</td>
<td>Dry Cell</td>
<td>0.5-1.4&lt;sup&gt;2,3&lt;/sup&gt;</td>
<td>5-50%</td>
<td>Bismuth is typically used to stabilize cathodes (~2% or less), nickel mesh is common current collector</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ZnSO&lt;sub&gt;4&lt;/sub&gt;</td>
<td>Dry Cell</td>
<td>0.7-0.8&lt;sup&gt;4&lt;/sup&gt;</td>
<td>30-40%</td>
<td></td>
</tr>
<tr>
<td>NiZn</td>
<td>Zn</td>
<td>NiOOH</td>
<td>6M KOH (+ 1M LiOH, CaOH infused Zn sponge)</td>
<td>Dry Cell</td>
<td>0.4-1.2&lt;sup&gt;5&lt;/sup&gt;</td>
<td>7-15%</td>
<td>Ni: 1.34 kWh/kg Ni, 0.07-0.1 kg Ni/kg total, Bismuth is typically used as an anode stabilizer (~1% or less), Cobalt (~1% or less)</td>
</tr>
<tr>
<td>Zn-air</td>
<td>Zn</td>
<td>O, (Platinum catalyst)</td>
<td>KOH</td>
<td>Flow</td>
<td>0.9 kWh/kg Zn&lt;sup&gt;6&lt;/sup&gt;</td>
<td>8%</td>
<td>Platinum catalyst, usually Ni support to reduce Pt loading</td>
</tr>
</tbody>
</table>

Source: Ciez, Purdue University – White Paper Recycling Opportunities for Rechargeable Zinc Batteries (2021)
# Recycling Paths of Rechargeable Batteries

<table>
<thead>
<tr>
<th>Mechanical</th>
<th>Hydrometallurgical</th>
<th>Pyrometallurgical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow batteries easy to separate mechanically</td>
<td>Hydro treatment follows mechanical separation</td>
<td>Treatment of complete spent batteries vs. after mech. separation</td>
</tr>
<tr>
<td>Cell separation of steel and plastics from black mass or paste</td>
<td><strong>Recovery of high-value metals, pot. high recovery rates</strong></td>
<td>Complete batteries processed at Inmetco; Fe, Mn, Ni, Co, Zn rec.</td>
</tr>
<tr>
<td>Limited use of black mass or paste as micro-nutrients due to presence of other (eco-)toxic elements</td>
<td>Integration in <strong>recycling processes of other battery chemistries</strong> (e.g. Li-ion with Co &amp; Ni recovery)</td>
<td>Black mass processed in Waelz Kiln for Zn rec.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic materials (plastics, graphite) are lost eventually</td>
</tr>
</tbody>
</table>

**Table of Elements:**

- **Zn**: Zinc (65.38)
- **Fe**: Iron (55.845)
- **Mn**: Manganese (54.938)
- **C**: Carbon (12.011)
- **K**: Potassium (39.098)
- **Cl**: Chlorine (35.453)
- **N**: Nitrogen (14.007)
- **Ni**: Nickel (58.693)
- **Co**: Cobalt (58.933)
- **Br**: Bromine (79.904)
- **Bi**: Bismuth (209.0)
# Technical Potential for Adaptation for Rechargeable Zinc Battery Recycling in Existing Zinc Recycling Pathways

## Technical Potential, not Economical Potential

<table>
<thead>
<tr>
<th>Battery Chemistry</th>
<th>Cell Format</th>
<th>Hydrometallurgical</th>
<th>Pyrometallurgical</th>
<th>Scrap Steel Recycling</th>
<th>Chemistry-specific Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZnBr₂</td>
<td>Flow</td>
<td></td>
<td></td>
<td></td>
<td>Bromine solution</td>
</tr>
<tr>
<td></td>
<td>Flooded Cell</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZnMnO₂·KOH</td>
<td>Dry Cell</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZnMnO₂·ZnSO₄</td>
<td>Dry Cell</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NiZn</td>
<td>Dry Cell</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn-air</td>
<td>Flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Process Outputs

- ZnO, MnO (if present) micronutrients
- ZnO (if present)
- ZnO slag, metallic zinc
- Metallic Zinc, terraman ganese, slag
- Fe-Ni-Cr Pig, Slag, EAF dust (contains Zn)
- Steel, slag, EAF dust (contains Zn)

### Companies

- Raw Materials, Battery Solutions, Valor
- Catalytic Innovations: Retieve, Revatech
- AZR, WSP, HarzCoxid
- Batipec
- Inmetco, Suez
- Gerdau Steel

Source: Ciez, Purdue University – White Paper Recycling Opportunities for Rechargeable Zinc Batteries (2021)
## Recycling needs to be Economic

<table>
<thead>
<tr>
<th>Metal</th>
<th>USD price/mt</th>
<th>Exchange</th>
<th>USD price/mt</th>
<th>Exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt</td>
<td>$69,401</td>
<td>LME, 6Dec2021</td>
<td>$82,000</td>
<td>LME, 12Apr2022</td>
</tr>
<tr>
<td>LiOH*H₂O</td>
<td>$31,000</td>
<td>LME, 6Dec2021</td>
<td>$80,750</td>
<td>LME, 12Apr2022</td>
</tr>
<tr>
<td>Nickel</td>
<td>$19,820</td>
<td>LME, 6Dec2021</td>
<td>$32,766</td>
<td>LME, 12Apr2022</td>
</tr>
<tr>
<td>Copper</td>
<td>$9,505</td>
<td>LME, 6Dec2021</td>
<td>$10,282</td>
<td>LME, 12Apr2022</td>
</tr>
<tr>
<td>MnO₂ (EMD)</td>
<td>$2,628</td>
<td>SMM, 6Dec2021</td>
<td>$3,076</td>
<td>SMM, 31Mar2022</td>
</tr>
<tr>
<td>Zinc</td>
<td>$3,162</td>
<td>LME, 6Dec2021</td>
<td>$4,397</td>
<td>LME, 12Apr2022</td>
</tr>
</tbody>
</table>

Source: London Metal Exchange - LME, cash bid closing price; Shanghai Metals Market - SMM for Mn
Challenges to Close the Loop for Zinc Batteries

- **Zinc batteries are versatile:** For all battery chemistries, sizes and designs, not one way of recycling is available.

- **Precondition of recycling is collection and sorting:** Collection of consumer zinc batteries remains a challenge. Industrial battery collection schemes may become more effective.

- **Recycling needs to be economic:** Zinc is not always the most valuable metal in a battery, recycling may not always be economic (like Li in Li-ion)

- **Closed-loop vs open-loop recycling:** Zinc battery materials are likely to be recycled in a form and shape not always suitable for use as new starting materials.

- **Metallurgy is never about one metal alone:** Recycling of primary and rechargeable zinc batteries is often/will often be for the purpose of recovering many metals and materials, such as steel, Mn, Ni, Co and/or Cu – and of course zinc.

Yes, it is also Relevant for Zinc Batteries!!!
Summary

• **Zinc is a plentiful raw material with huge Extractable Global Reserves**
  - World EGR – 63,000 million tonnes
  - Economic reserves – 250 million tonnes
  - Demand estimate of 3.3 million tonnes by 2050 easily met

• **Zinc has a diverse, secure global supply chain**
  - Over 50 countries actively mining zinc
  - 27 countries actively smelting/refining zinc

• **Zinc recycling**
  - Zinc is versatile and multiple ways of recycling
  - Zinc Battery recycling choices will depend on battery type and other materials to be recycled alongside zinc
  - Recycling needs to be economic for widespread implementation
Thank You!

PLEASE VISIT OUR WEBSITES

www.ZincBatteryInitiative.com
www.zinc.org

Josef DANIEL-IVAD

jdanielivad@zinc.org

CALL FOR MEMBERSHIP!
Join IZA’s ZBI – the voice of the zinc battery industry