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Taking established zinc battery material recycling systems to a new dimension

Martin van Leeuwen

International Zinc Association

International Zinc Association

- 45 full members in zinc production
- >200 affiliate and associate members
- Offices in North Carolina, Brussels, Delhi, Shanghai
- www.zinc.org

IZA represents the global zinc industry in mining, production, first use production and recycling

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Zinc vs. Lithium Batteries

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

- Safer alternative – zinc batteries are water-based non-flammable
- Creates domestic jobs potential in manufacturing, mining and refining in many countries worldwide
- Improves energy security through ownership of a domestic supply chain in same countries
- Are easy to recycle and reuse, with a long track record of industrial-grade recyclability
- Have a significantly lower cost per tonne potential

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Zinc Batteries are Versatile

Silver Zinc | Nickel Zinc | Zinc Manganese | Zinc Ion | Zinc Halide Flow & Non | Zinc Air

High power density; Short duration storage

High energy capacity; Long duration storage

- Zinc has been developed across a wide range of chemistries and applications.
- Hybrid systems offer potential for zinc to meet the critical needs of the clean energy transition, meeting energy security needs and resiliency.

ZINC BATTERY INITIATIVE

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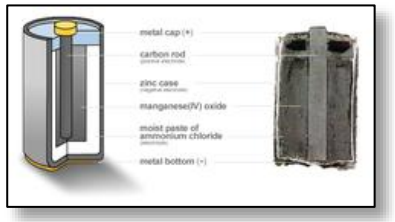
Single-use versus Rechargeable

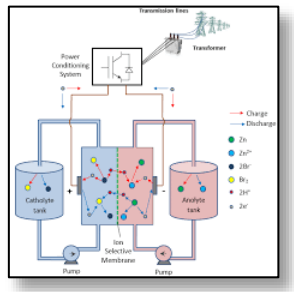
Single-use (primary)

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



Rechargeable (secondary)

- Zinc Manganese (alkaline electrolyte) – cell
- Zinc ion (sulphate electrolyte) – cell
- Silver Zinc – cell
- Nickel Zinc – cell
- Zinc Bromine – cell or flow
- Zinc air – cell or flow



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Single-use versus Rechargeable; starter materials

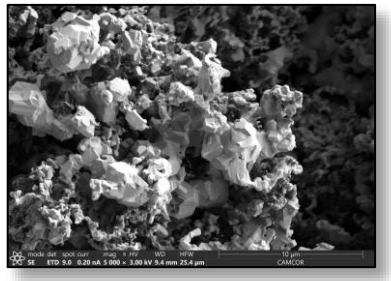
Single-use (primary)

- Alkaline:
  Zinc powder,
  doped with Bi, In, Al, Mg, and/or Ca (50-500ppm)

  Typical size 200-300µm
- ZnC:
  Zinc sheet, for battery case
- CAM: EMD, C

Rechargeable (secondary)

- Zinc powder, alloyed,
  finer than primary batt.
- Zinc oxide – ZnO
- Zinc hydroxide – $Zn(OH)_2$
- Zinc sponge
- Zinc sheet or foil
- Zinc bromide solution - $ZnBr_2$ (aq.)
- Mixtures of the above
- CAM: graphite, Ag, Ni, EMD
- Current collectors Cu, Al



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Recycling Paths of Primary Batteries

Zn	Fe	Mn	C	K	Cl
Zinc	Iron	Manganese	Carbon	Potassium	Chlorine
30 65.38	26 55.845	25 54.938	6 12.011	19 39.098	17 35.45

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, Mn are micro-nutrients)

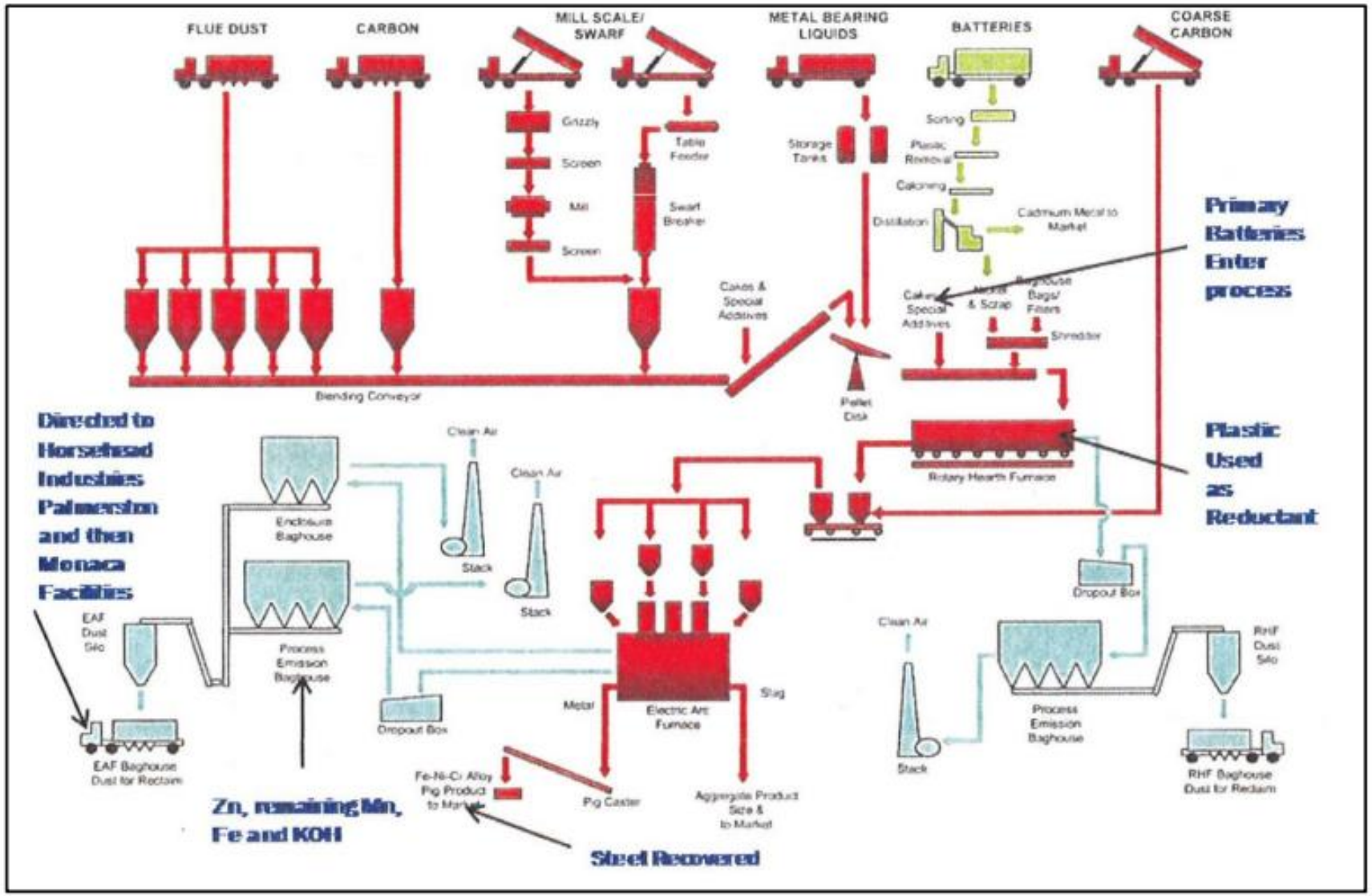
Hydrometallurgical

- Hydro treatment following mechanical separation
- Black mass is processed to Zn^0, ZnO, $Zn(OH)_2$ or other zinc compounds
- **Technically feasible, economic viability questionable**

Pyrometallurgical

- Pyro treatment of complete batteries, or following mechanical separation
- **Recovery of Fe, Mn (steel) and Zn at processing of complete batteries:**
  - Inmetco process
  - EAF process
  - Blast furnace
- **Black mass processing in Waelz Kiln for Zn recovery**

Pyrometallurgical Recycling in Ferrous Industry - Inmetco



Inmetco process

In:

- Flue dust
- Carbon / plastics
- Steel mill scales
- Metal bearing liquids
- **Primary Zinc Batteries and NiCd batteries**

Out:

- Fe-Ni-Cr(-Mn) steel alloys
- Zn-rich steel dust (feed for Waelz Kiln for Zn recovery)

Source: Salojee - Lithium Battery Recycling Process (2015)

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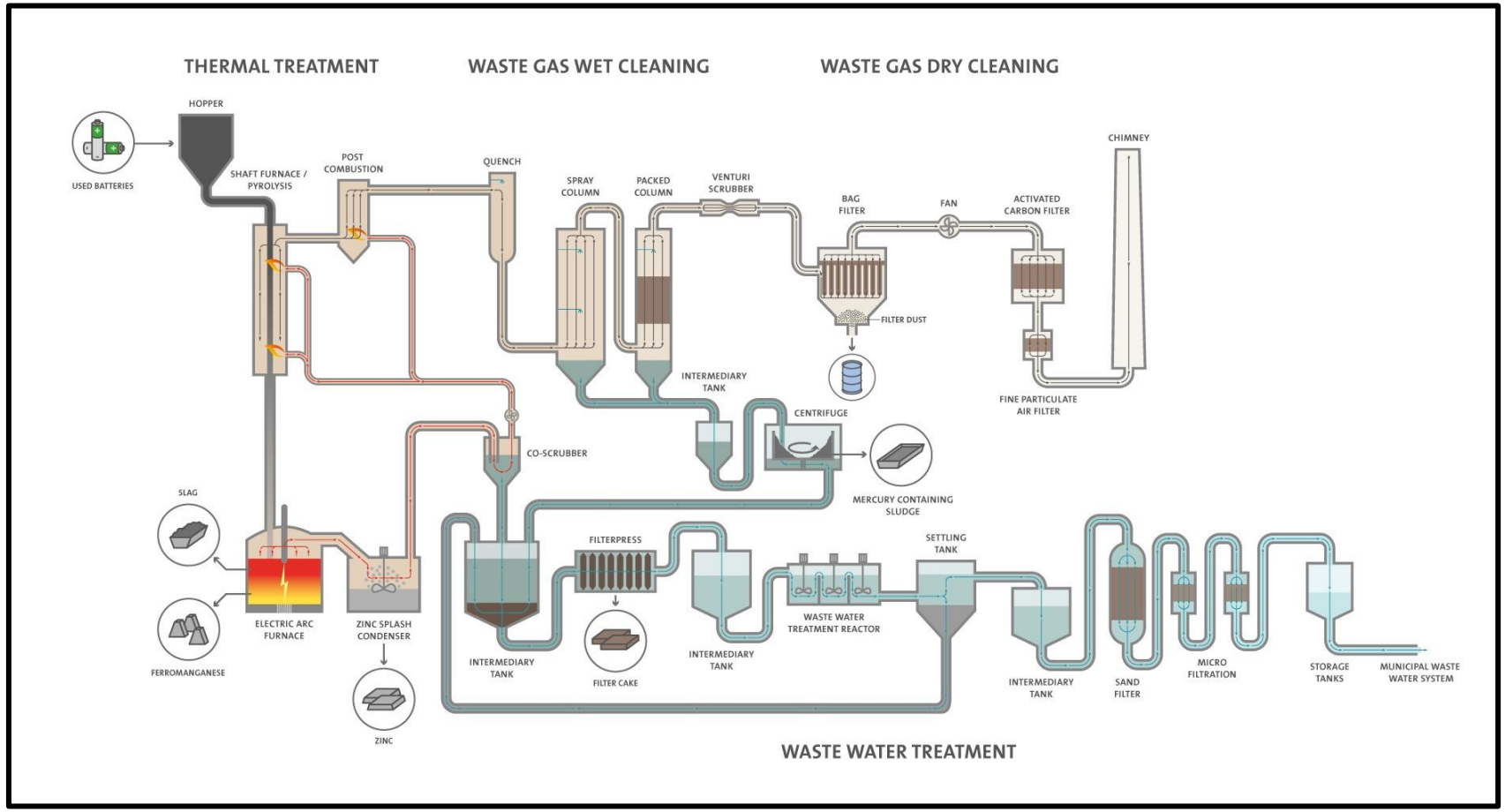
Pyrometallurgical Recycling in Ferrous Industry - EAF



EAF process

In:

- **Primary Zinc Batteries**

Out:

- Fe-Mn alloys
- Zn metal
- Hg sludge

Source: Batrec, Switzerland

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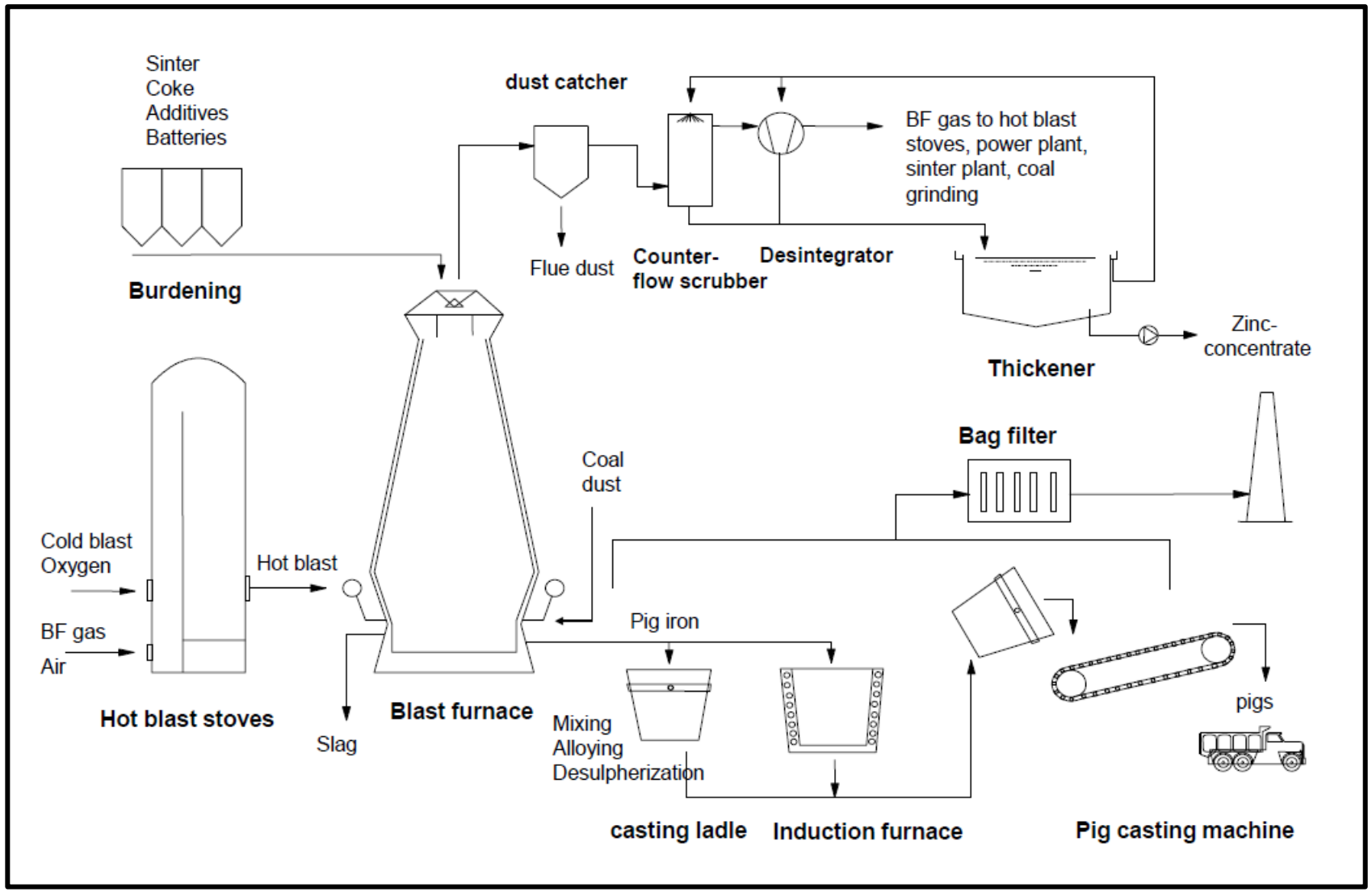
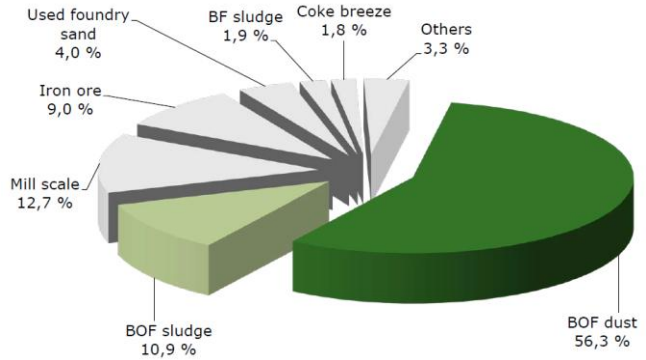
Pyrometallurgical Recycling in Ferrous Industry – Blast furnace



Blast furnace

In:



- BOF steel dust & sludge
- Other Fe waste streams
- **Primary Zinc Batteries**

Out:

- Fe-Mn alloys
- Crude zinc oxide (67%Zn)
- Zn-rich BF dust (30%Zn)
  feed for Waelz Kiln for Zn-rec

Source: DK Recycling & Roheisen, Germany

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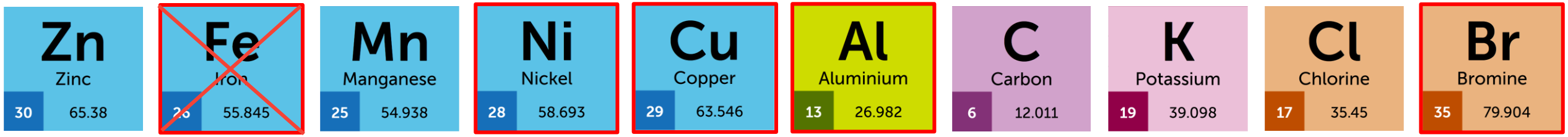
Recycling Paths of Rechargeable Batteries



Mechanical

- **Flow batteries easy to separate mechanically**
- Cell separation of plastics from electrodes and black mass
- Limited use of black mass as micro-nutrients due to **presence of other (eco-)toxic elements**

Hydrometallurgical

- Hydro treatment follows mechanical separation
- **Recovery of high-value metals**, potential high recovery rates
- **Integration in recycling of other battery chemistries** (e.g. Li-ion)

Pyrometallurgical

- Pyro treatment of complete batteries, or following mechanical separation
- **Recovery of Zn, Mn, Ni, and Cu at processing of complete batteries**
- **Black mass processing in Waelz Kiln for Zn recovery**
- **No steel to recycle**, organic materials are lost

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Hydro, Pyro or Combined Recycling

- Combining high temperature and wet chemical process steps can be effective to meet all recovery requirements
- Pyro-step efficiently reduces complexity in a unique way
- **Zinc, with its low melting point, is easily be fumed out of metal melts** and collected in furnace dust – can be recovered from these dust streams

Umicore

Pretreatment (optional)

Pyro metallurgy

Hydro metallurgy

Others

Pretreatment (optional)

Heat treatment (optional)

Shredding

Physical separation

Hydro metallurgy

Umicore 2030 RISE

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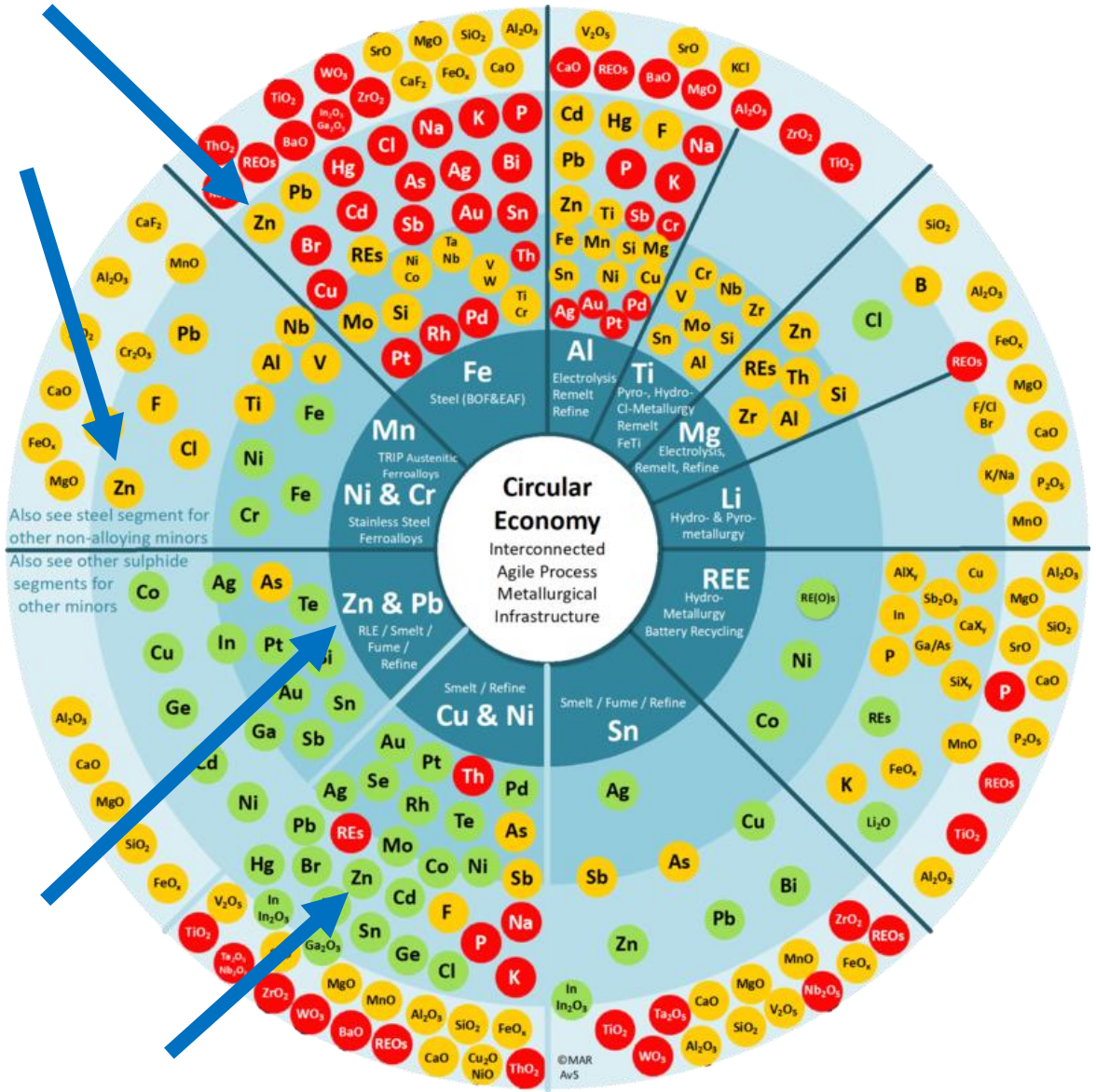
Pyrometallurgical Recycling and the Metal Wheel



The metal wheel organizes the periodic system of elements into divisions. Each division represents a **base metal industry**.

The **carrier or base metals** are found in the inner ring.

The outer rings list the metals that are associated with the base metals, which dissolve in the carrier metal.

Zn — Metals obtained from intermediate or by-products in the base metal industry

Zn — Metals can be gained but can also be lost

Zn — Metals lost as residues in the circular economy

Source: Prof. Markus Reuter, SMS-Group (2021)

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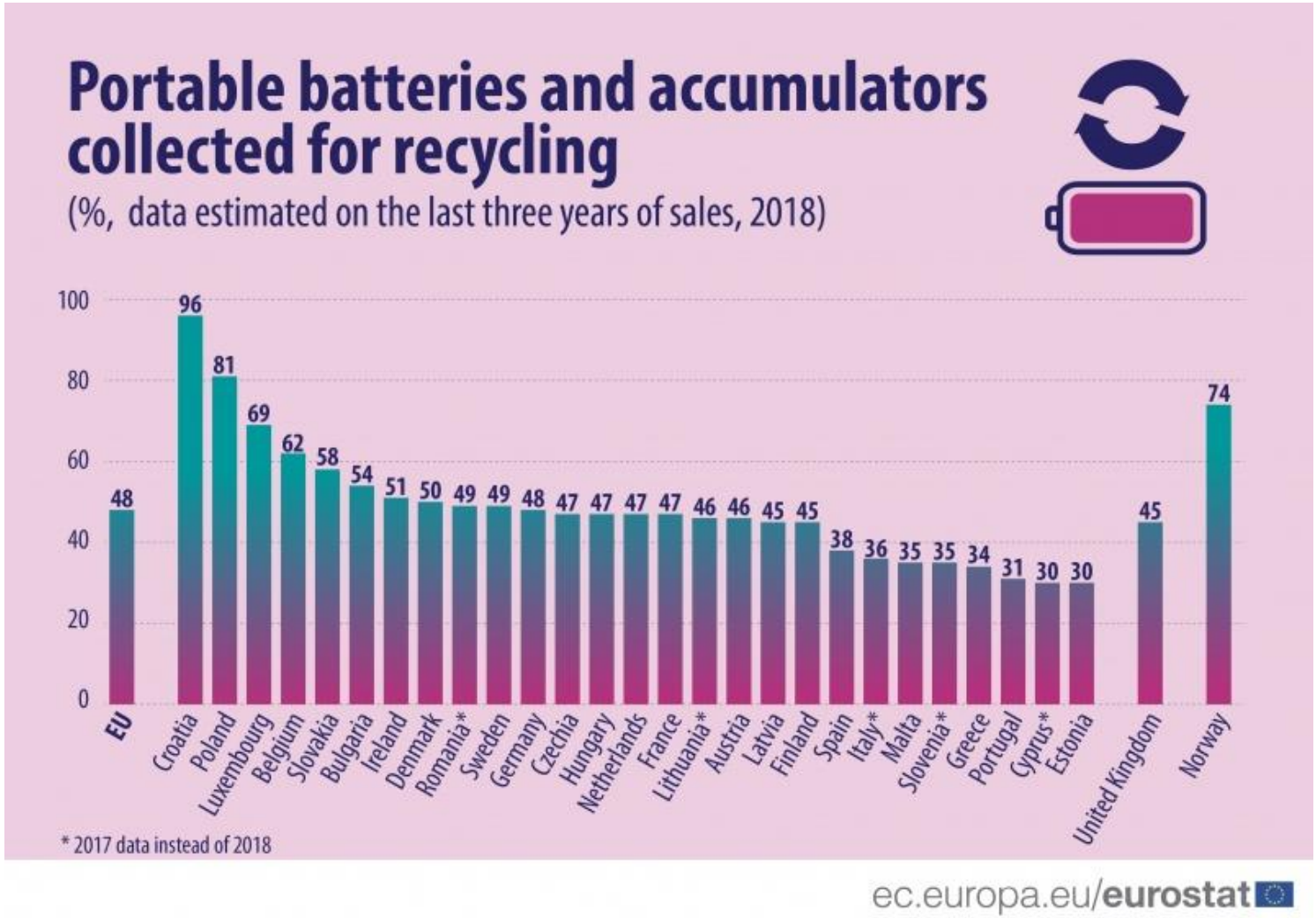
Recycling needs to be Economic

Metal	USD price/mt	Source
Lithium Hydroxide	**$21,438**	SMM, 28/05/2026
Nickel	**$18,550**	LME cash, 22/05/2026
Copper	**$13,545**	LME cash, 22/05/2026
Zinc	$3,545	LME cash, 22/05/2026
MnO_2 (EMD)	$2,239	SMM, 22/05/2026



Collection is a Challenge

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.

~48% Primaries Collected

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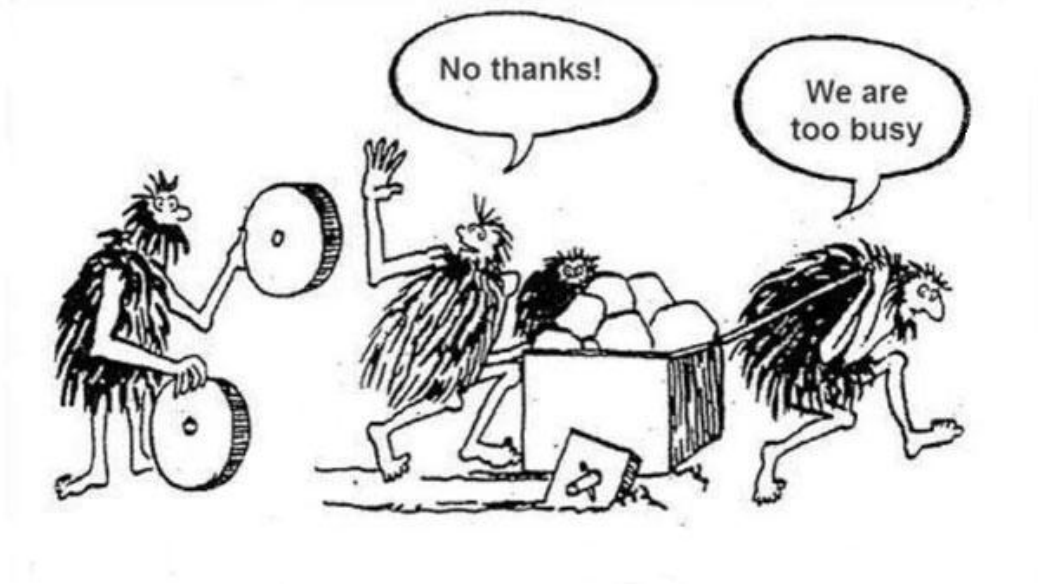
Challenges to Close the Loop for Zinc Batteries

- ***Zinc batteries are versatile:*** For all battery chemistries, sizes and designs, not one way of recycling is available.
- ***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, and/or Cu – and of course zinc.
- ***Recycling needs to be economic:*** Zinc is not always the most valuable metal in a battery, recycling may not always be economic.
- ***Precondition of recycling is collection and sorting:*** Collection of consumer zinc batteries remains a challenge. Industrial battery collection schemes may become more effective.



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