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.

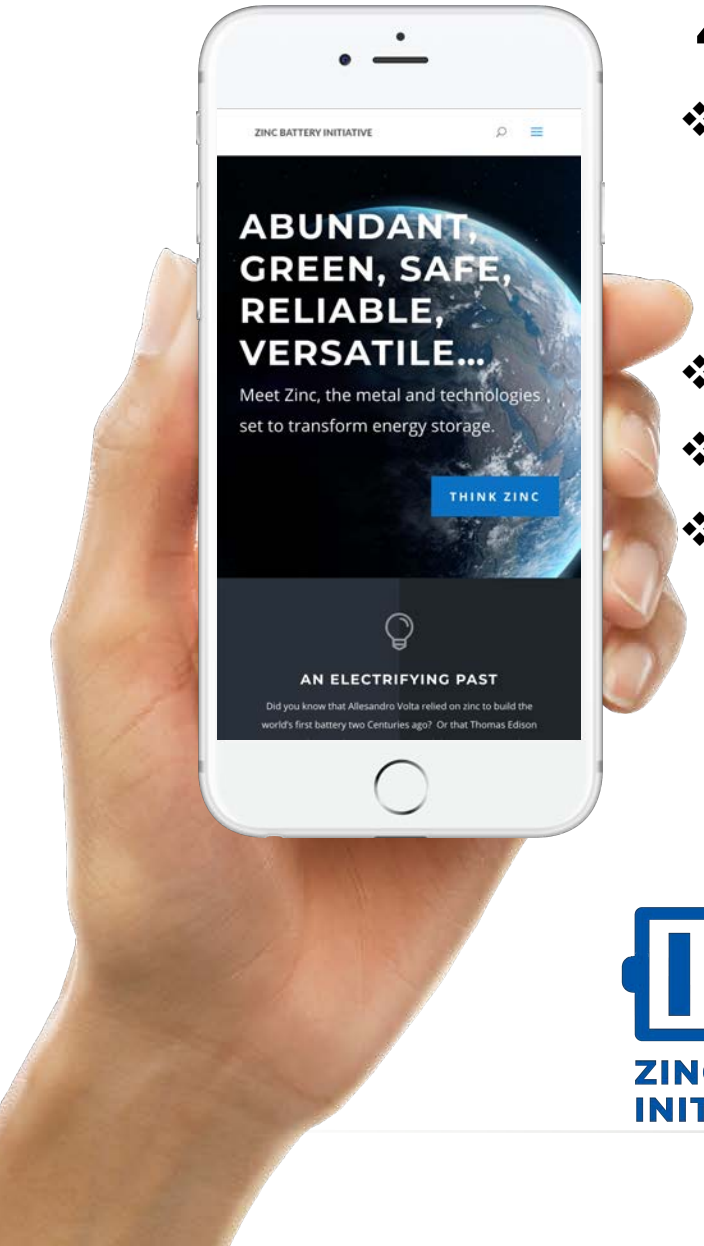
ZINC BATTERY INITIATIVE

ZINC | international zinc association



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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

ENERPOLY

e-ZINC

IMPRINT ENERGY

redflow

SALIENT ENERGY

URBAN ELECTRIC POWER

Energy Systems

Æsir Technologies, Inc.

ENZINC

ZincFive

ZINC BATTERY INITIATIVE

Silverline Communications

FORBES AGENCY COUNCIL Official Member | 2021

BULLDOG AWARD | BRONZE Most Innovative Agency

MARCOM AWARDS Multi-year award winner

ZELOS

ZINC8









Zinc Batteries are Versatile

ZINC BATTERY INITIATIVE

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

Hybrid systems offer potential for zinc to meet most critical needs.



High power density;
Short duration storage

High energy capacity;
Long duration storage

ZINC BATTERY INITIATIVE

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

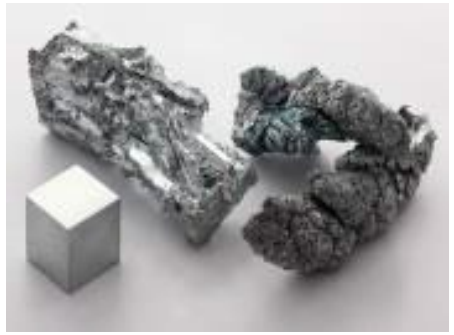
Mined in 50+ countries globally, fully integrated supply chains in major regions.

- 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

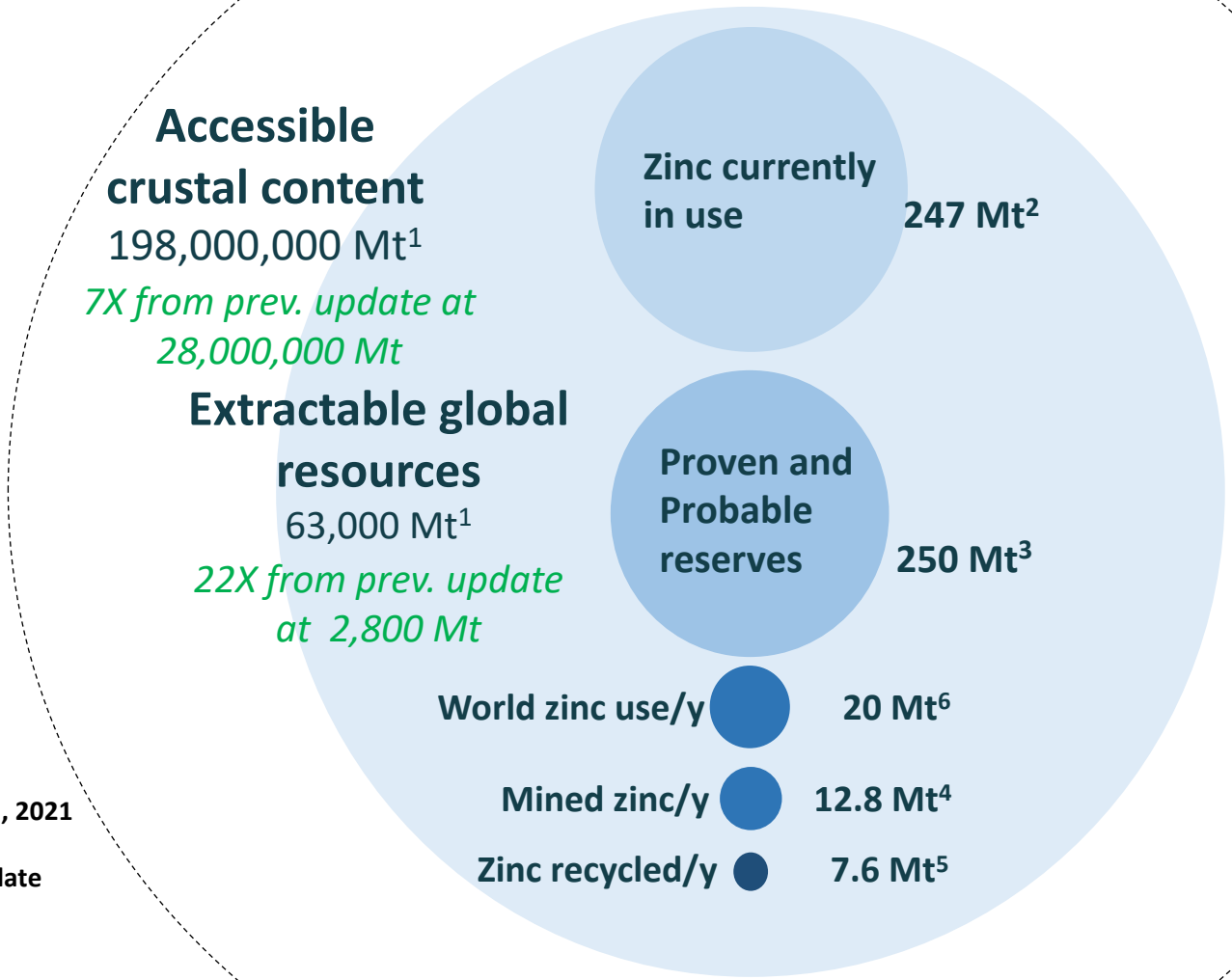






Accessible crustal content
198,000,000 Mt[1]
7X from prev. update at 28,000,000 Mt

Extractable global resources
63,000 Mt[1]
22X from prev. update at 2,800 Mt

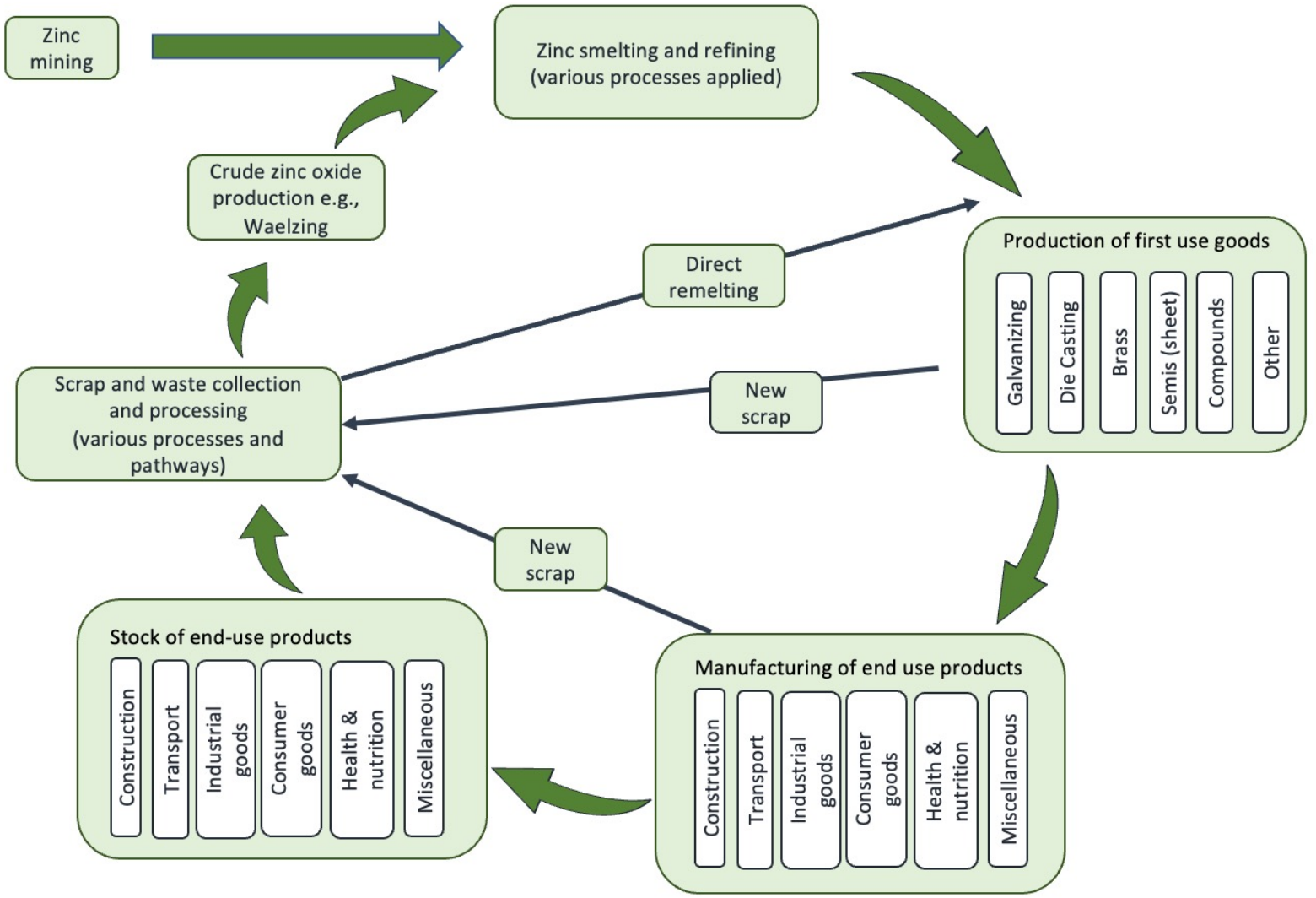


Mt = million tons

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)**
3. **U.S. Geological Survey, 2021**
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**

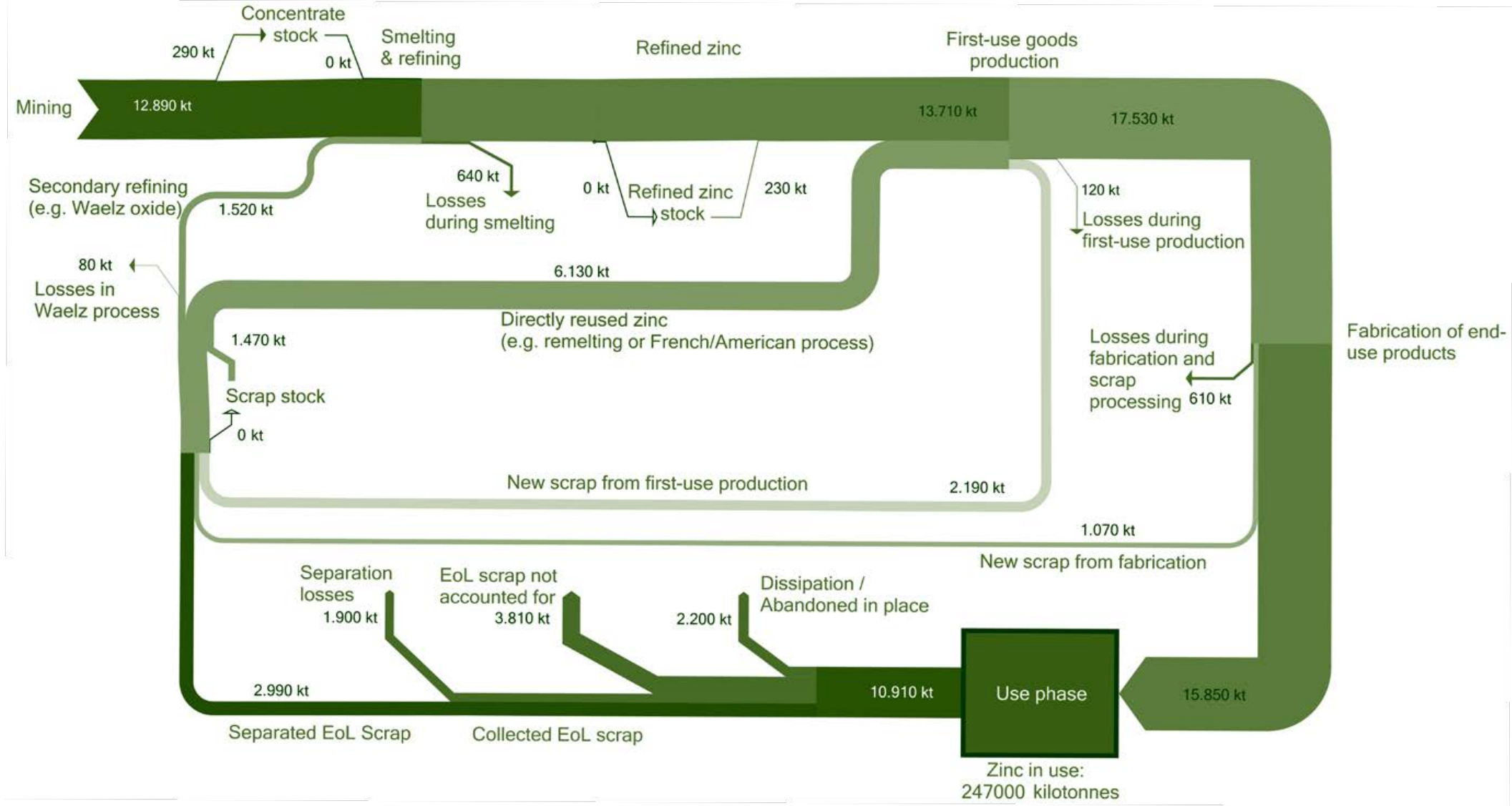
Source: International Zinc Association (2022)

Anthropogenic material life cycle of zinc



Source: Fraunhofer ISI, Karlsruhe (2022)

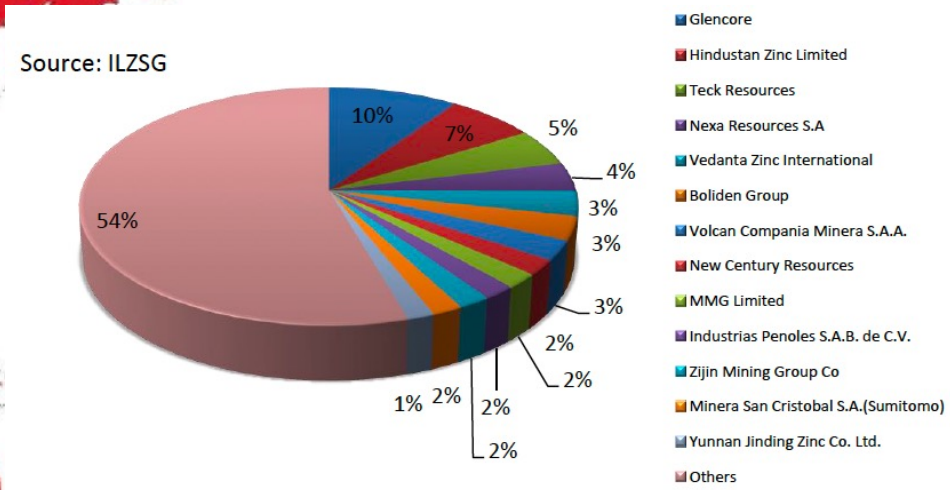
Global Zinc Stocks and Flows in 2019



Source: Fraunhofer ISI, Karlsruhe (2022)

Zinc Mining Countries in 2019



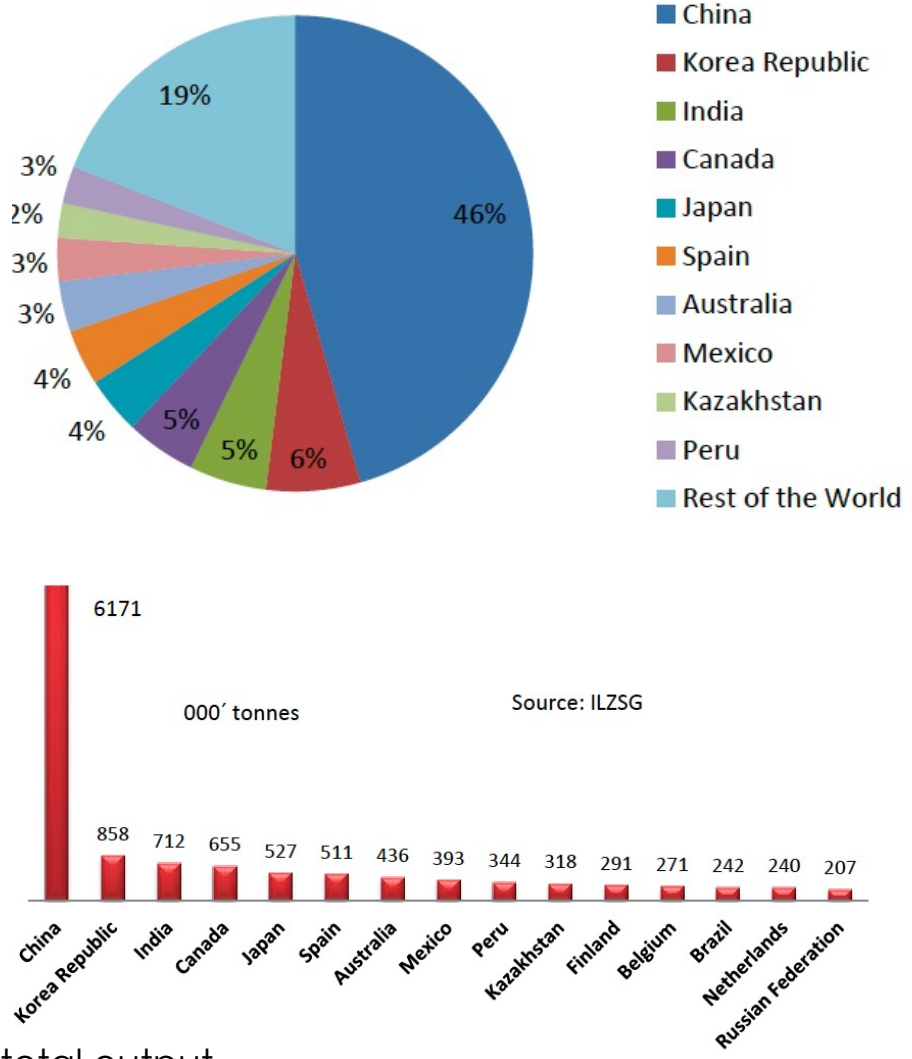


▷ Since 1960 over 60 countries have mined zinc ore.
▷ In 2019, 51 countries were actively mining zinc.
▷ Top 10 mining companies contributed to 41% of the world concentrate production capacity

Source: International Lead and Zinc Study Group (2020)

Zinc Metal Producing Countries in 2019

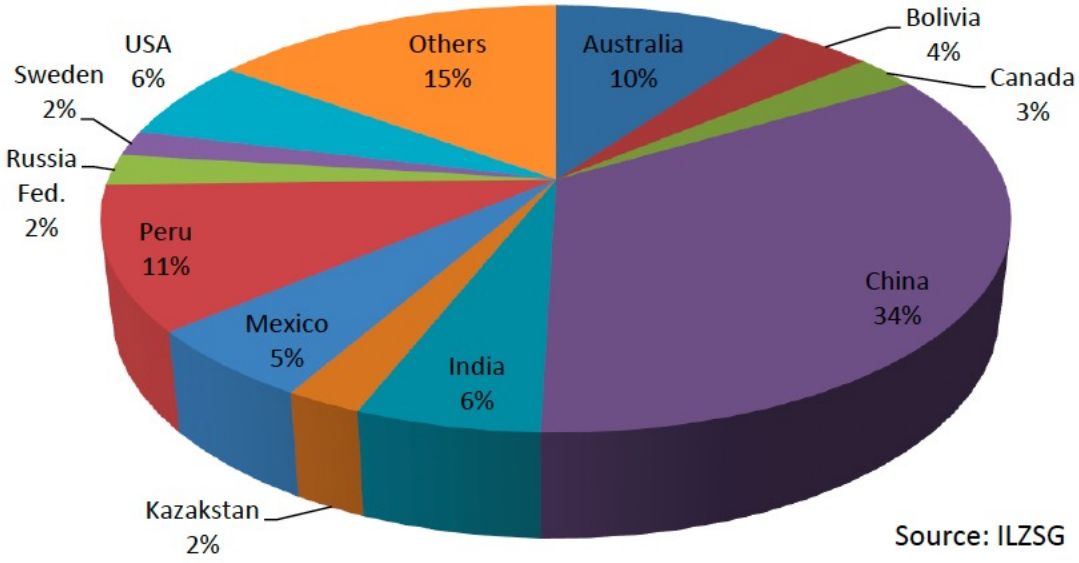


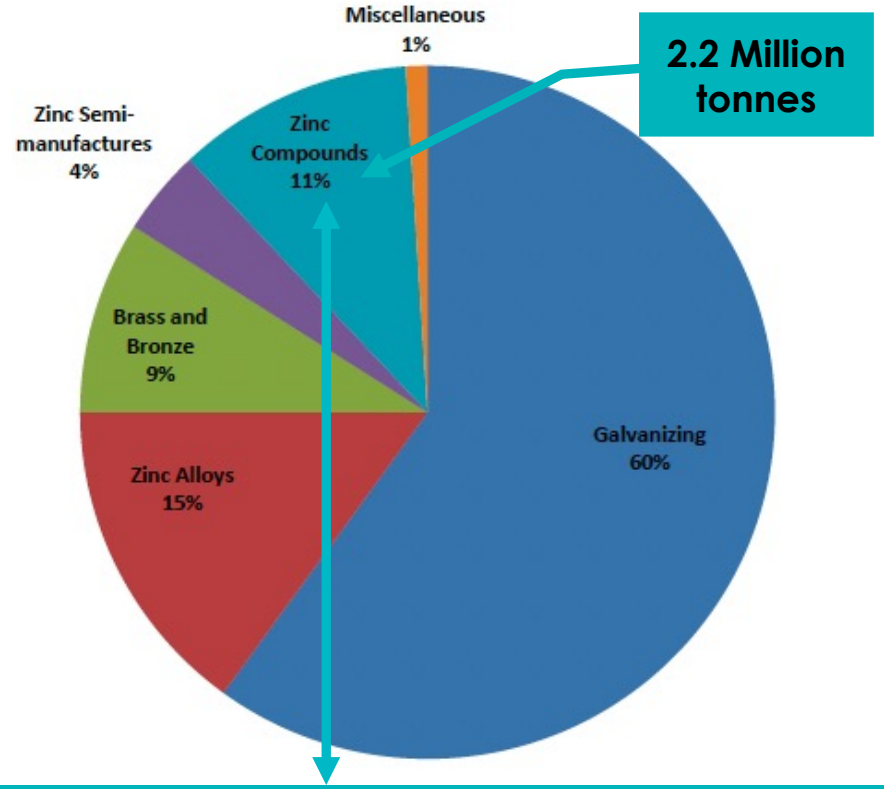


▷ 27 countries had zinc metal smelting and/or refining activities
▷ Top 10 refined zinc metal producing countries contributed 81% of world total output

Source: International Lead and Zinc Study Group (2020)

Zinc Production and First Use in 2019





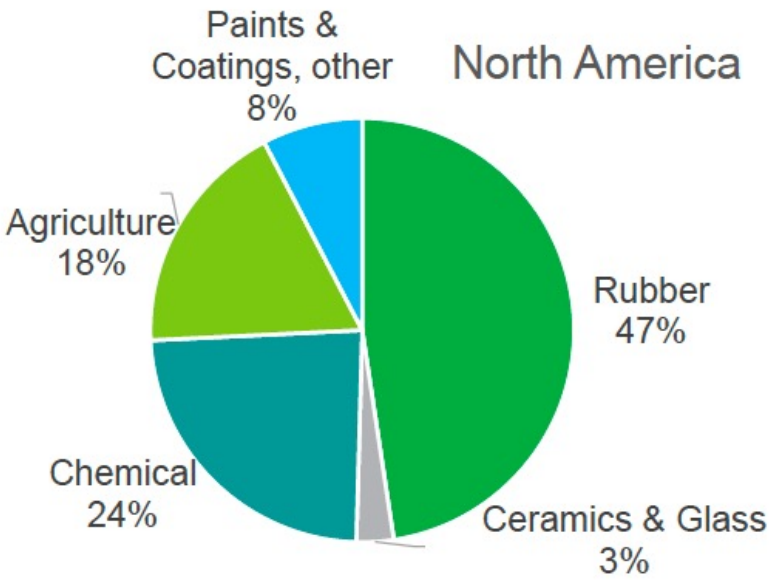
Main zinc chemicals in current use include:
- ▷ **ZnO**, $ZnCO_3$, **$ZnCl_2$**, **$ZnSO_4$**, ZnS_2, $ZnCO_3$, $ZnSeO_3$, Zn borate,
- ▷ **Zn powder** and nanoform Zn compounds.

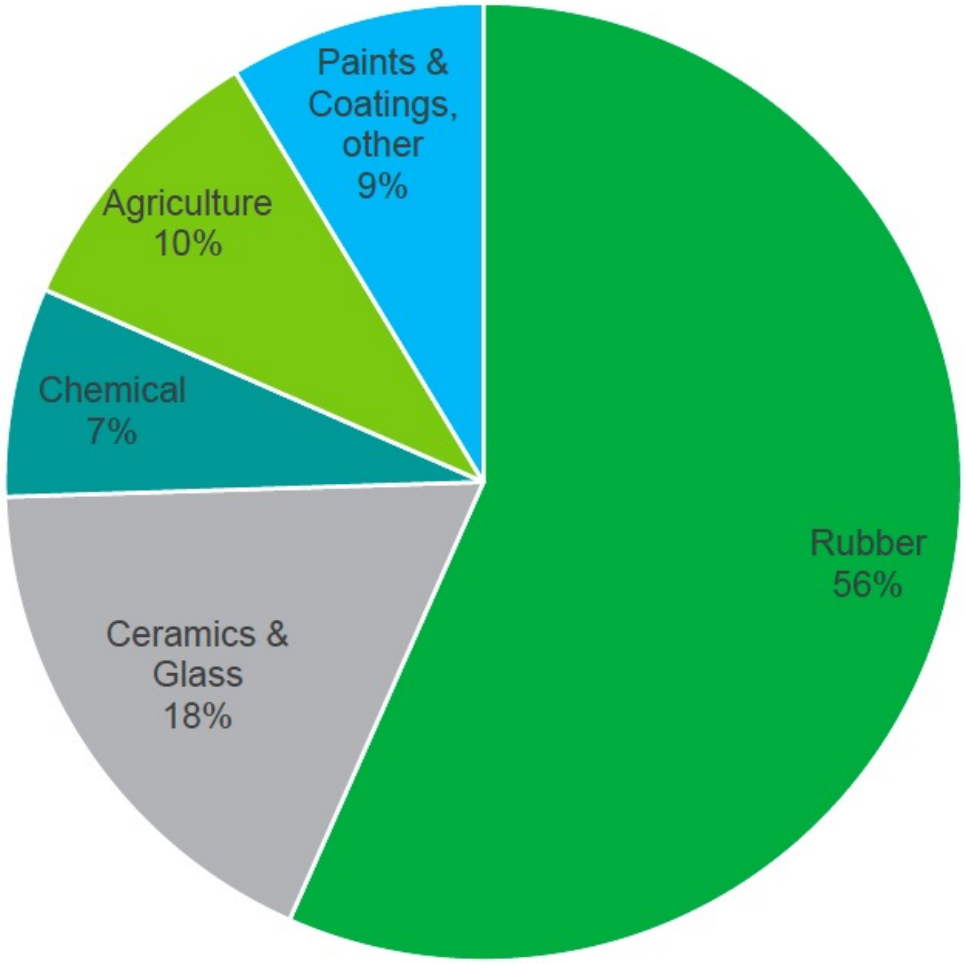
Source: International Lead and Zinc Study Group (2020)

Zinc Oxide Main Uses in 2020

Global demand: 1.7 million metric tons

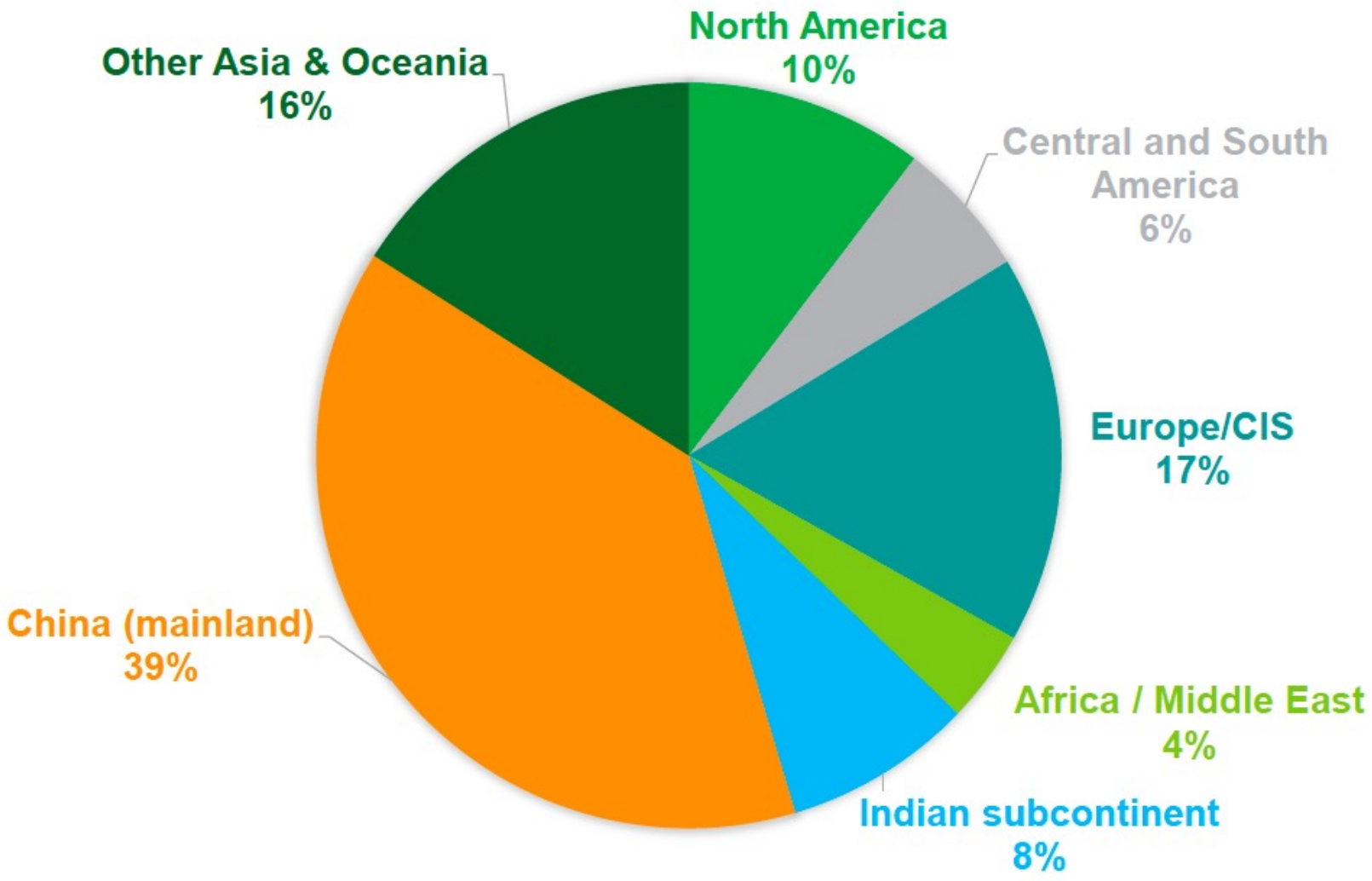
- Rubber compounding remains major end use in all regions
- Ceramics & Glasses is second largest application in all regions but North America





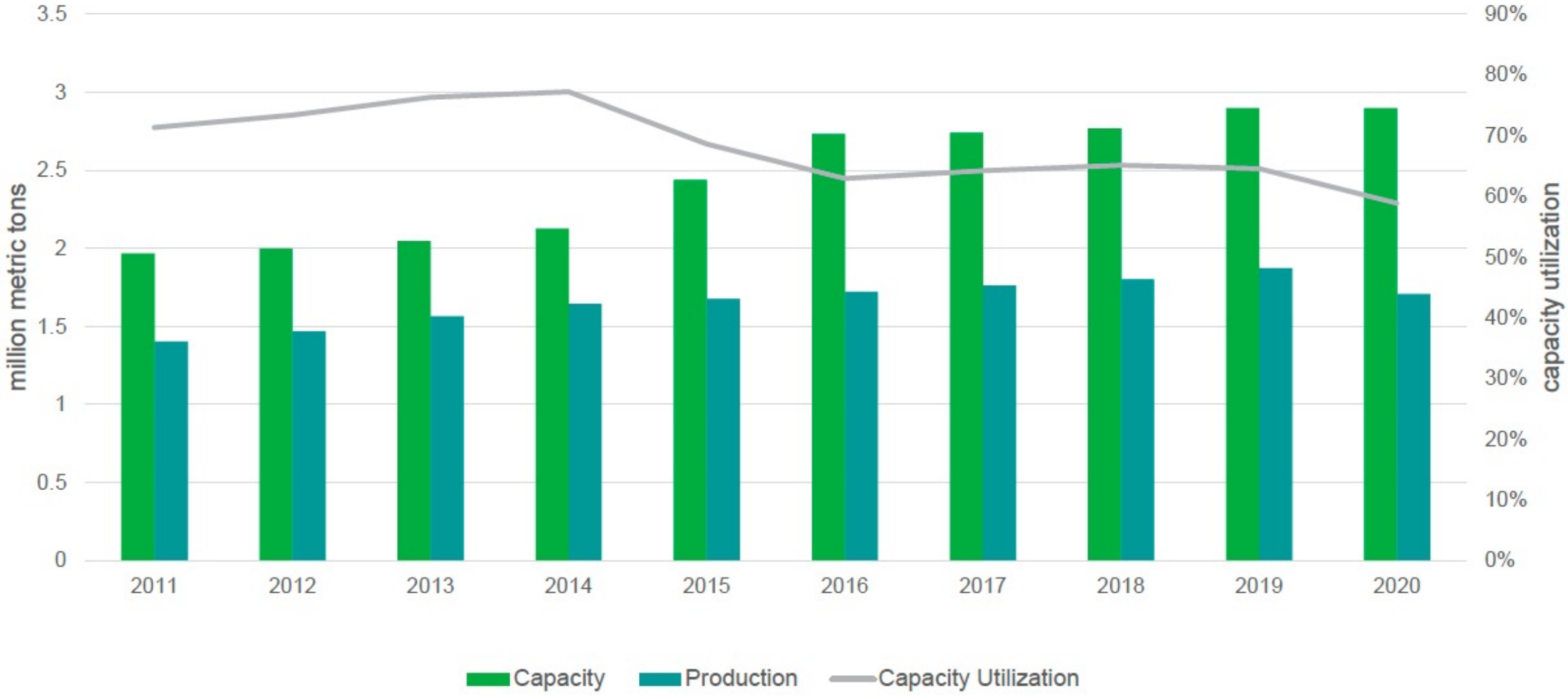
Source: IHS Markit (2021)

Zinc Oxide Market Regional View in 2020



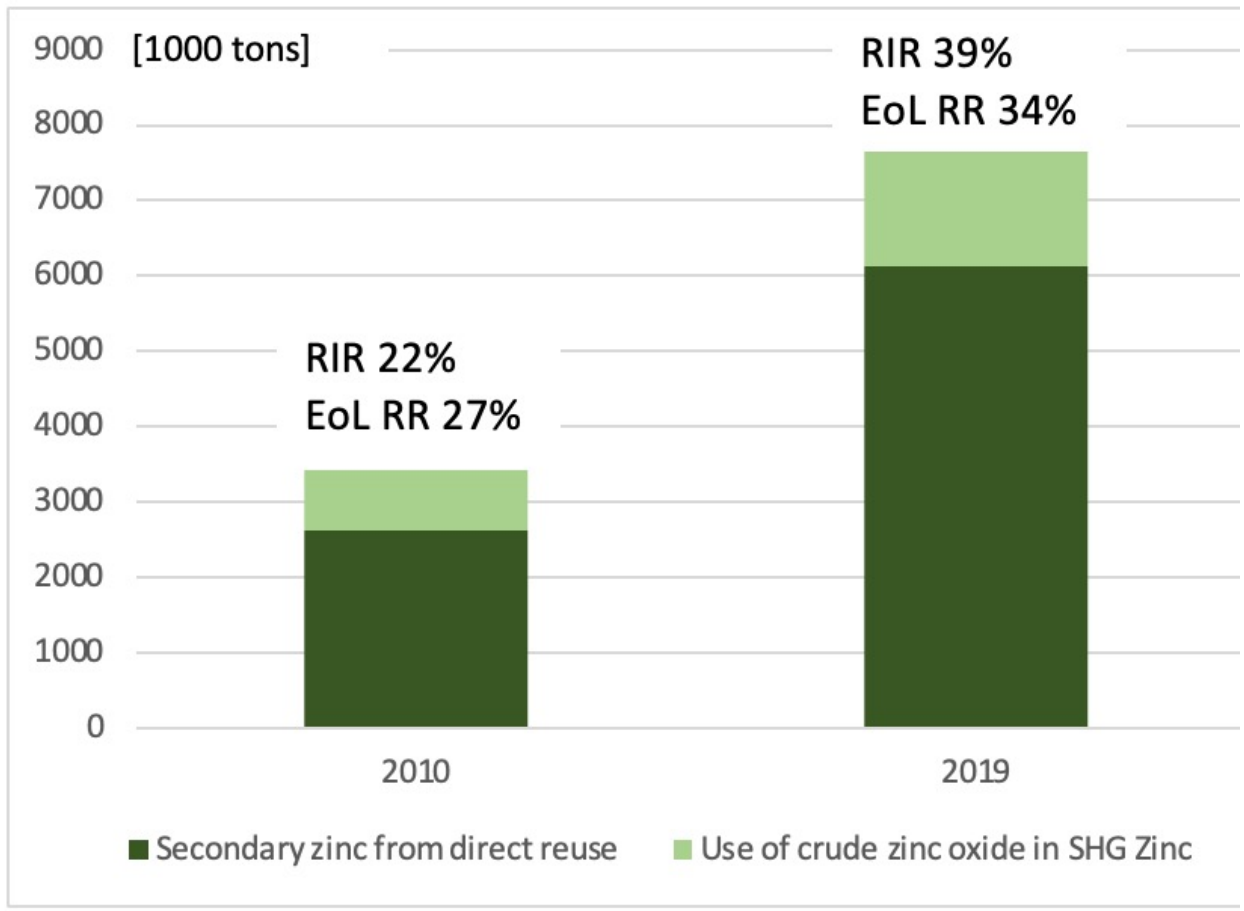
Source: IHS Markit (2021)

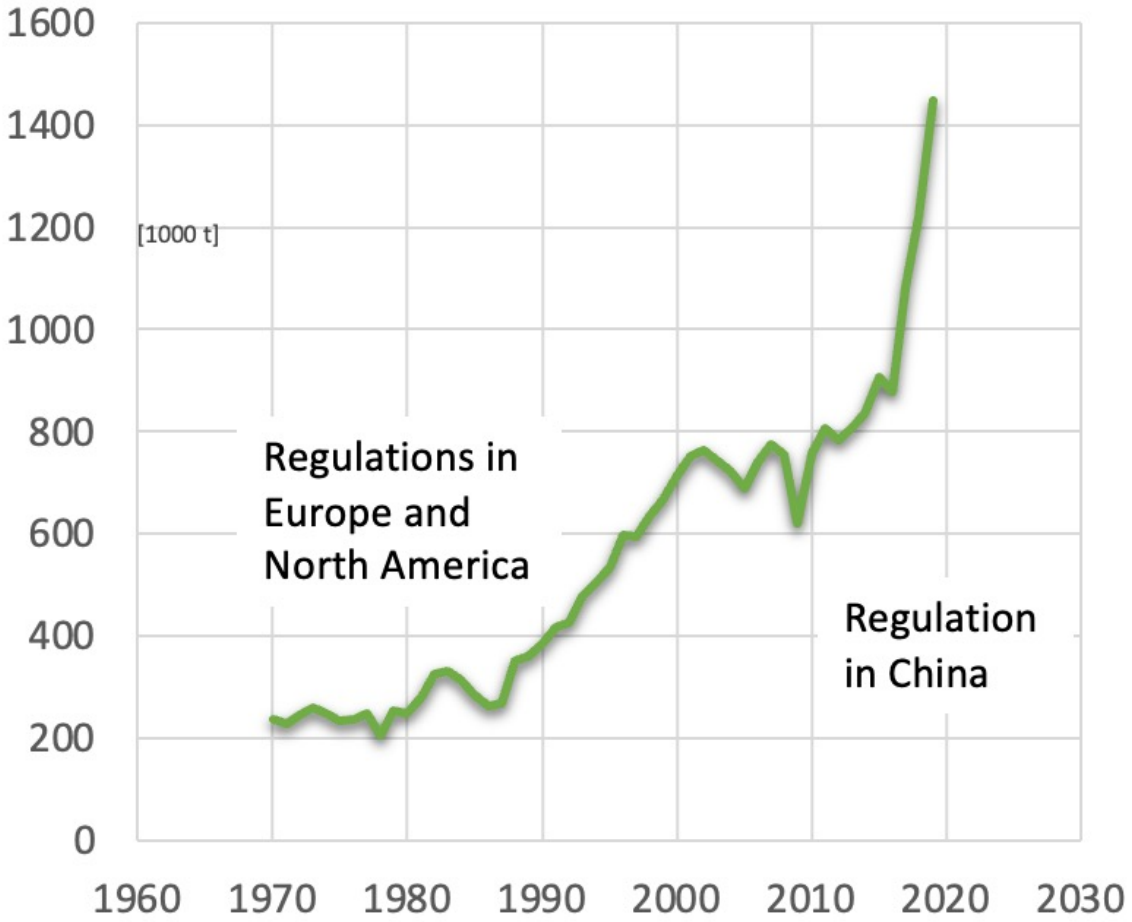
Zinc Oxide Supply



Source: IHS Markit (2021)

Zinc Circularity - Recycling



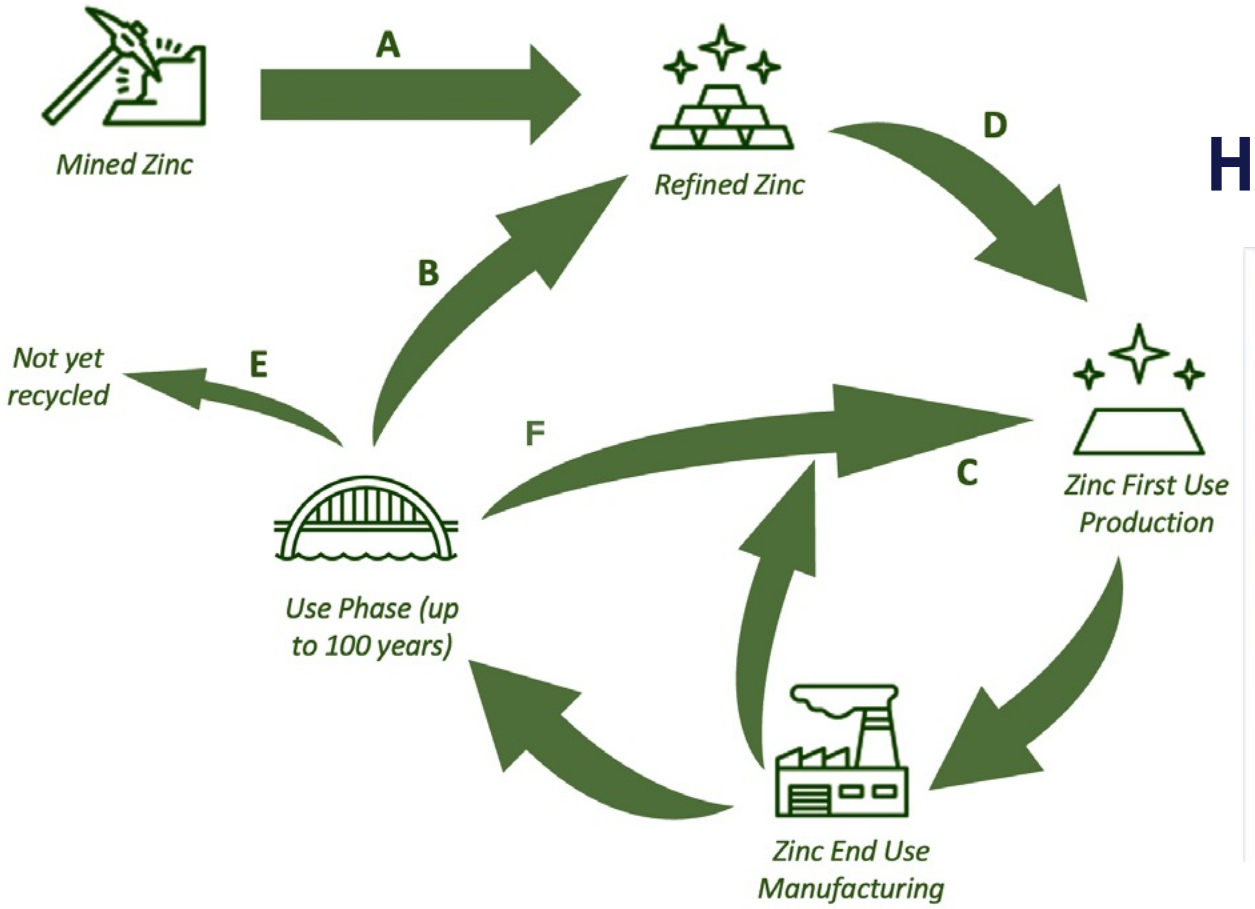


▷ Zinc recycling doubled between 2010 and 2019 while zinc mine production remained constant at 12-13 Mt; RIP: Recycling Input Rate, EoL RR: End-of-Life Recycling Rate

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

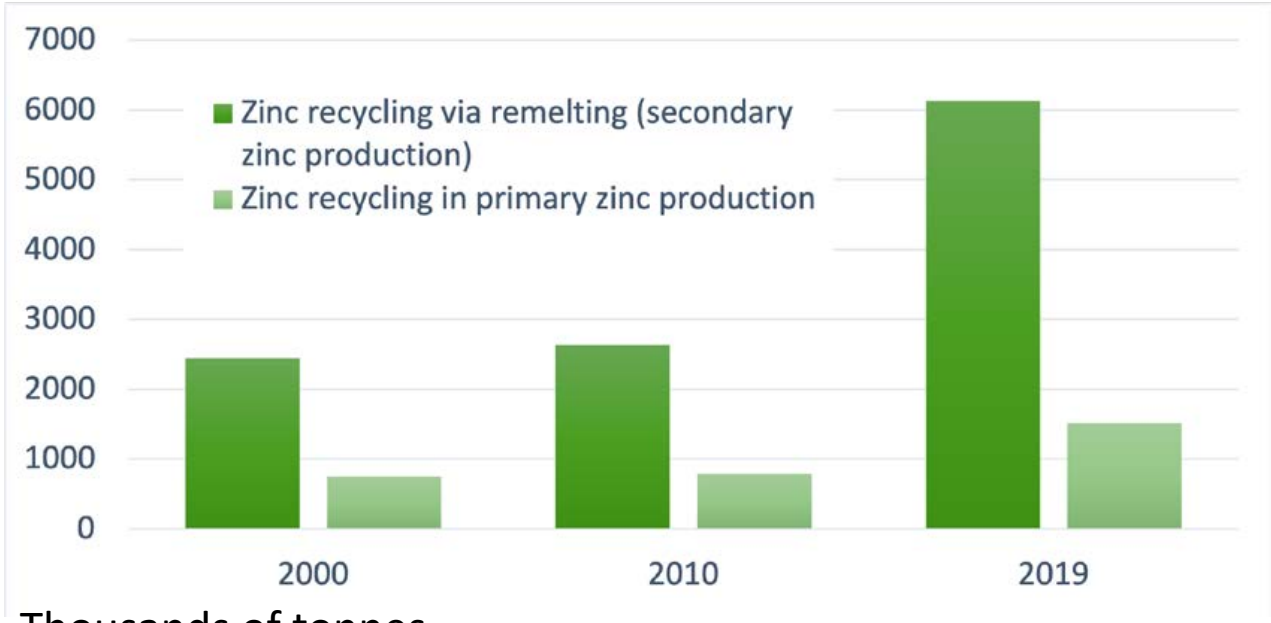
Source: Fraunhofer ISI, Karlsruhe (2022), : International Lead and Zinc Study Group (2020)

Zinc Circularity - Recycling



▷ Zinc recycling loops (simplified).

How Much Zinc is Recycled Today?

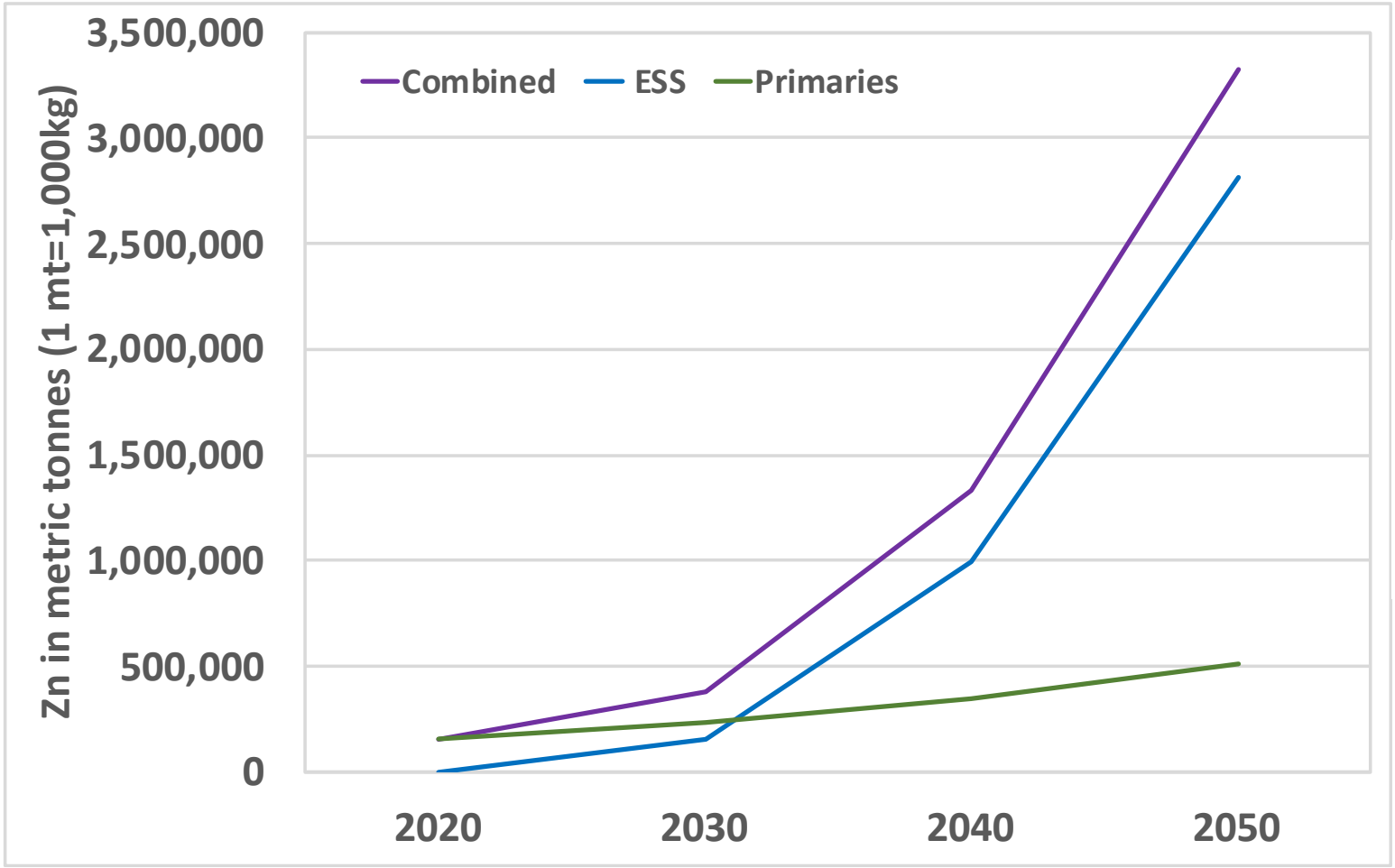


Thousands of tonnes

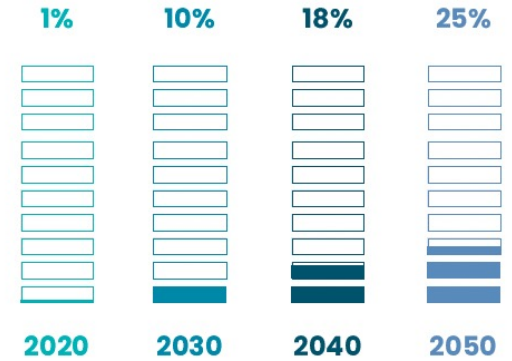
▷ Zinc recycling

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

Battery Zinc Demand Forecast 2020-2050



Zn Market Share Forecast in ESS'



▷ 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.

Source: BloombergNEF NEO (2020), Avicenne (2019), IZA (2021)

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

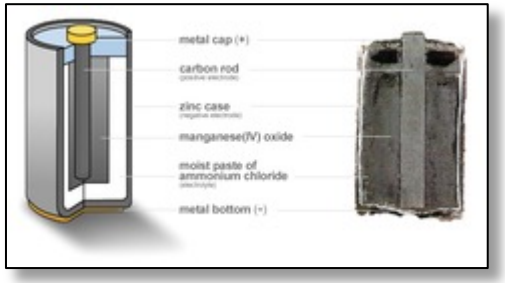
Challenges to Close the Loop for Zinc

- ***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

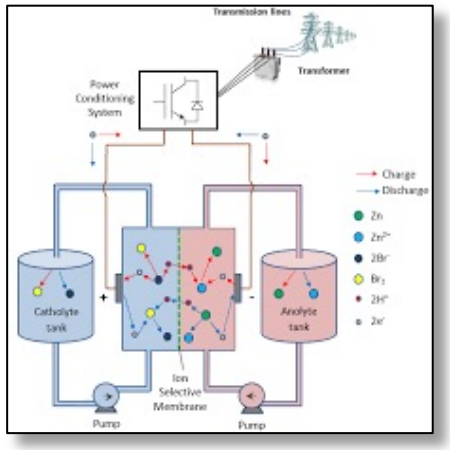


Zinc air – button or coin cells



Rechargeable (secondary):

Zinc Bromine – flow



Nickel Zinc – cell



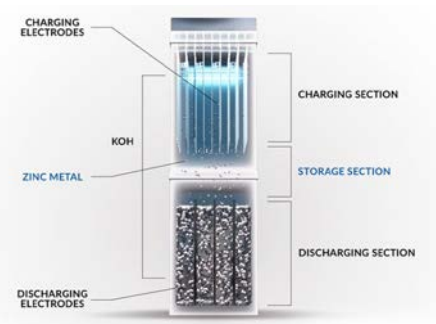


Zinc ion (sulphate electrolyte) – cell

Zinc Manganese (alkaline electrolyte) – cell







Zinc air – cell or flow

Zinc Starter Materials for Batteries

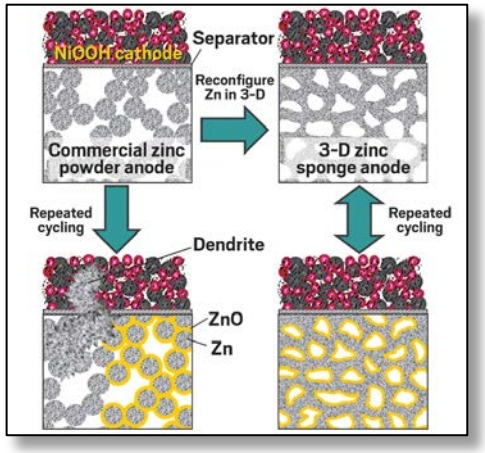
Primary (single-use):

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

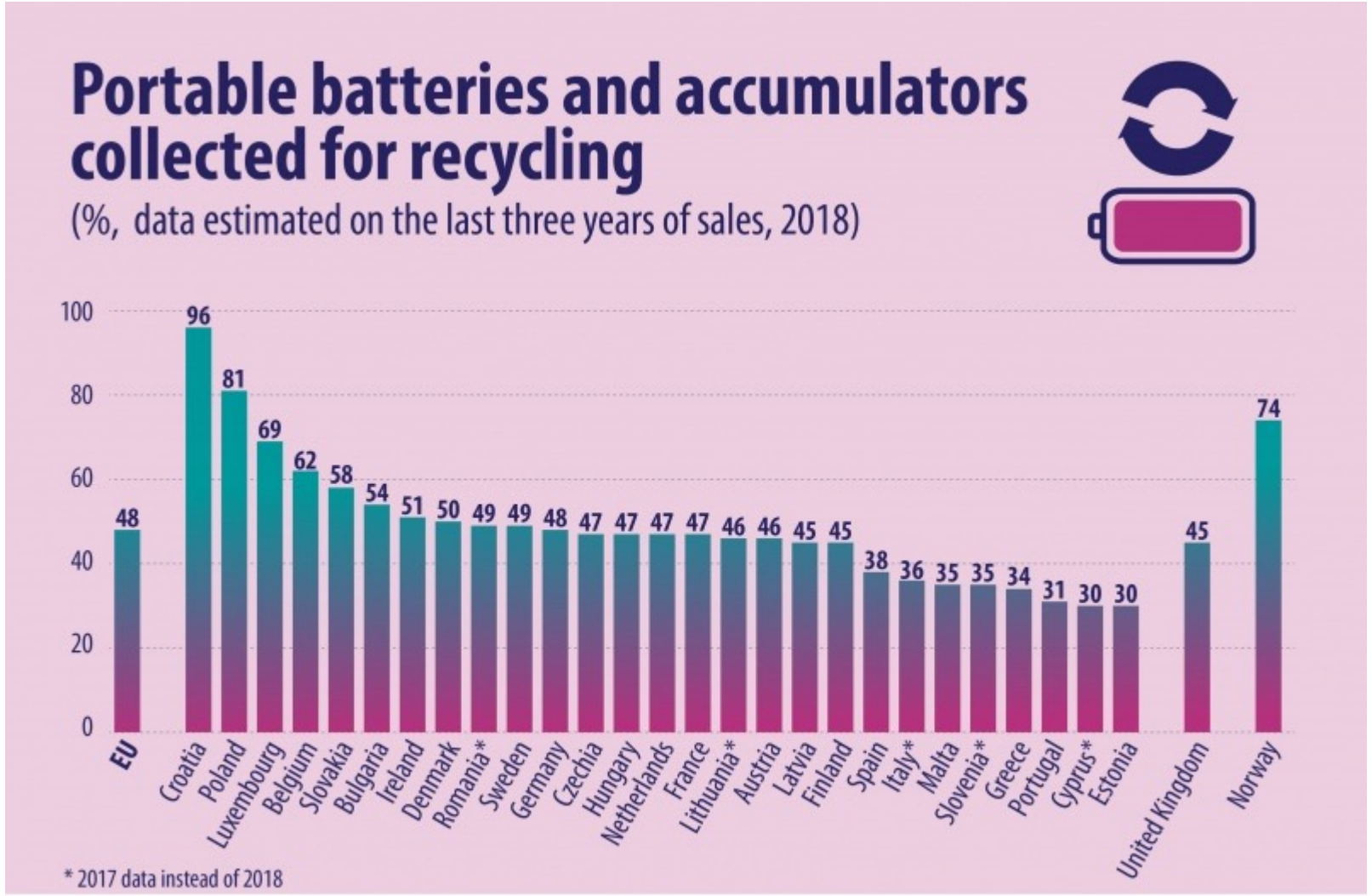


Rechargeable (secondary):

- 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

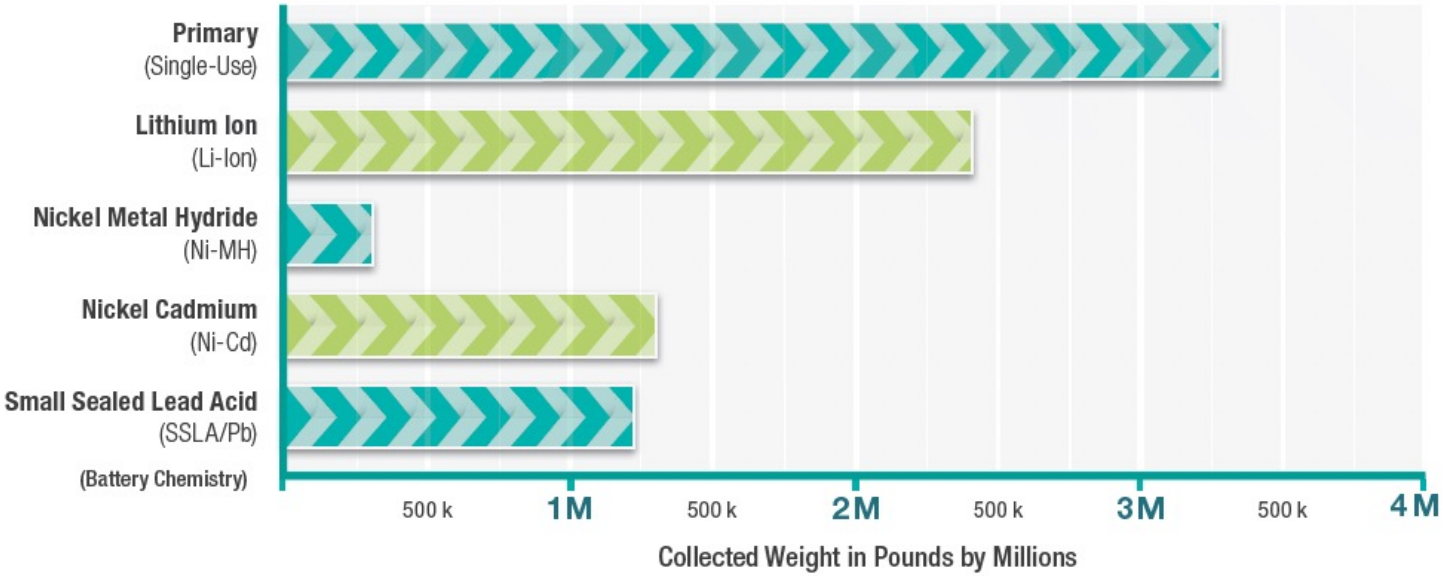


Collection is a Challenge - Europe



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.

Collection is a Challenge – North America

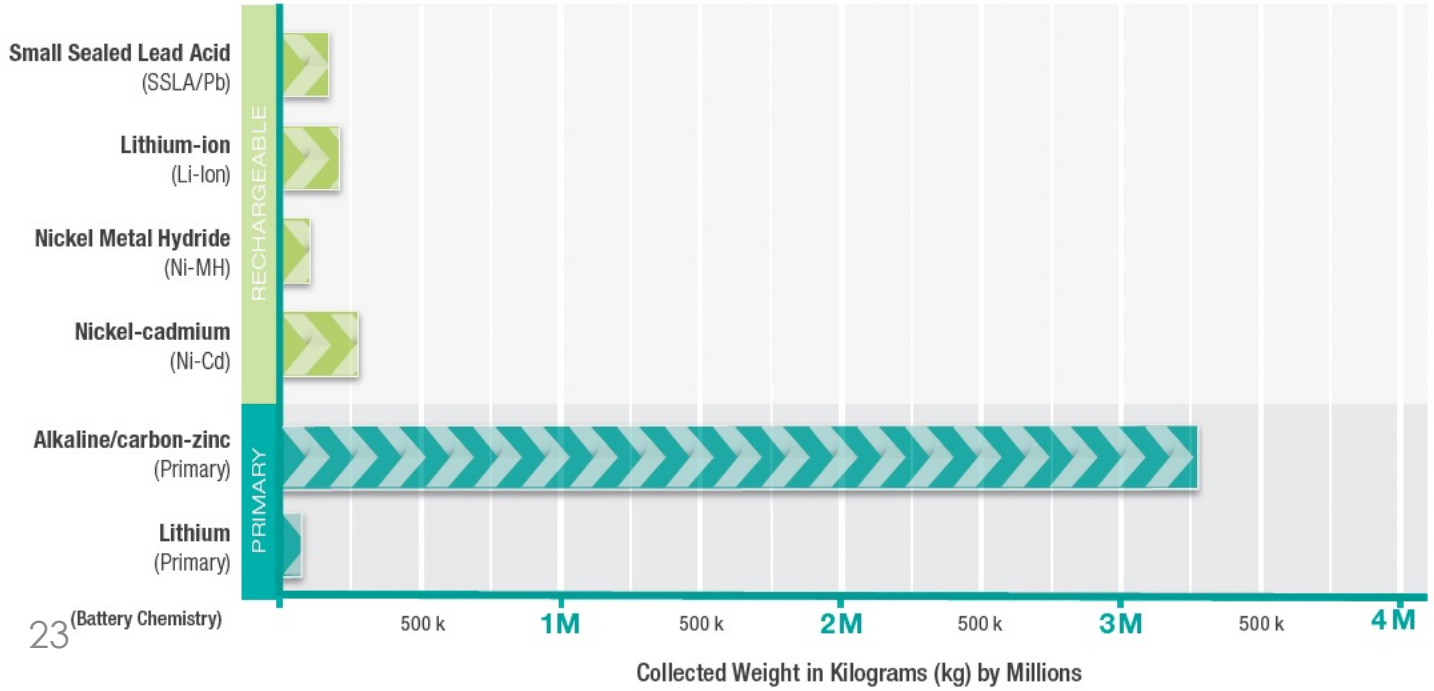


USA Battery Recycling in 2020

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)

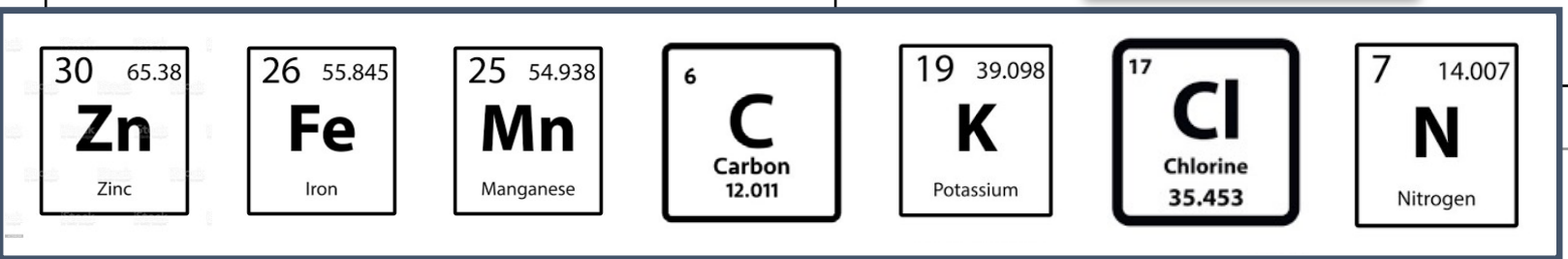
Hydrometallurgical

- 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

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

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

Battery type	Anode	Cathode	Electrolyte	Formats	kWh/kg Zn	kg Zn/kg battery	Other metals
$ZnBr_2$	Zn	Bromine (aqueous)	Water, complexing agents	Flow	0.5-0.6	7%	Titanium has been used in current collectors, but the market is trending to carbon current collectors
				Flooded Cell	0.06-0.47[1]	5%	
$ZnMnO_2$	Zn	MnO_2, Bi_2O_3, sometimes intercalated with Cu	KOH	Dry Cell	0.5-1.4[2,3]	5-50%	Bismuth is typically used to stabilize cathodes (~2% or less), nickel mesh is common current collector
			$ZnSO_4$	Dry Cell	0.7-0.8[4]	30-40%	
NiZn	Zn	NiOOH	6M KOH (+ 1M LiOH, CaOH infused Zn sponge	Dry Cell	0.4-1.2[5]	7-15%	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)
Zn-air	Zn	O_2 (Platinum catalyst)	KOH	Flow	0.9 kWh/kg Zn[6]	8%	Platinum catalyst, usually Ni support to reduce Pt loading

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

Recycling Paths of Rechargeable Batteries

Mechanical

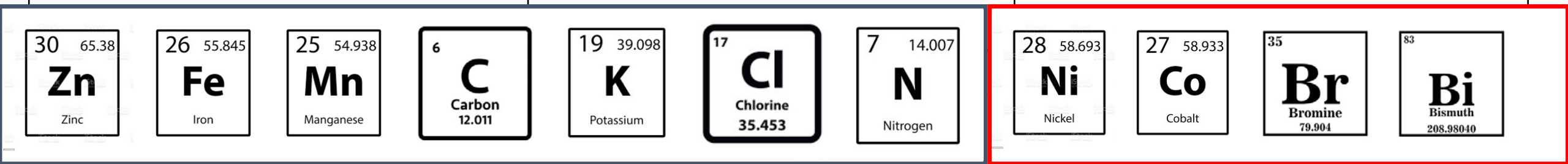
- Flow batteries easy to separate mechanically
- Cell separation of steel and plastics from black mass or paste
- Limited use of black mass or paste as micro-nutrients due to presence of other (eco-)toxic elements

Hydrometallurgical

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

Pyrometallurgical

- Treatment of complete spent batteries vs. after mech. separation
- **Complete batteries processed at Inmetco; Fe, Mn, Ni, Co, Zn rec.**
- Black mass processed in Waelz Kiln for Zn rec.
- Organic materials (plastics, graphite) are lost eventually



Technical Potential for Adaptation for Rechargeable Zinc Battery Recycling in Existing Zinc Recycling Pathways

		Processes	Mechanical Separation	Hydrometallurgical		Pyrometallurgical				
				Micronutrient Replacement	Metal Oxide Recovery	Waelz Kiln + Zincex	Sumitomo	Inmetco	Scrap Steel Recycling	
Battery Chemistry	Cell Format	Companies	*Raw Materials, Battery Solutions, Valdi*	Catalytic Innovations	Retriev, Revatech	AZR, WSP, HarzOxid	Batrec	Inmetco, Suez	Gerdau Steel	Chemistry-specific considerations
$ZnBr_2$	Flow									Bromine solution
	Flooded Cell									
$ZnMnO_2$-KOH	Dry Cell									
$ZnMnO_2$-$ZnSO_4$	Dry Cell									
NiZn	Dry Cell									
Zn-air	Flow									PtC on Ni scaffold catalyst is similar to PEM fuel cells.
Process Outputs			ZnO, MnO (if present) micronutrients		ZnO, MnO (if present)	ZnO, slag, metallic zinc	Metallic Zinc, ferromanganese, slag	Fe-Ni-Cr Pig, Slag, EAF dust (contains Zn)	Steel, slag, EAF dust (contains Zn)	

Technical potential, not economical potential

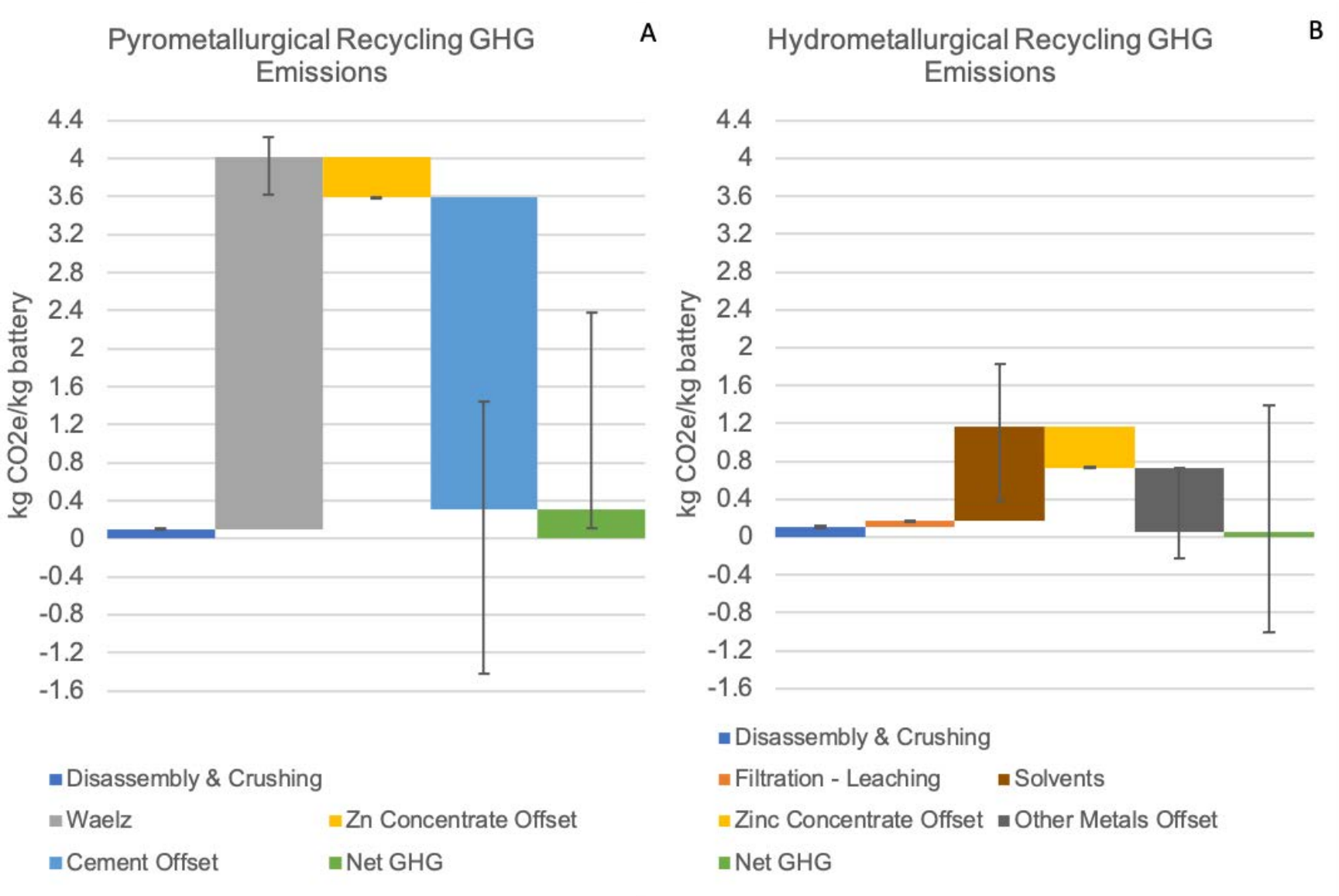
Source: Ciez, Purdue University – White Paper Recycling Opportunities for Rechargeable Zinc Batteries (2021)

Recycling needs to be Economic

Metal	USD price/mt	Exchange	USD price/mt	Exchange
Cobalt	$69,401	LME, 6Dec2021	$ 82,000	LME, 12Apr2022
$LiOH*H_20$	$31,000	LME, 6Dec2021	$80,750	LME, 12Apr2022
Nickel	$19,820	LME, 6Dec2021	$32,766	LME, 12Apr2022
Copper	$9,505	LME, 6Dec2021	$10,282	LME, 12Apr2022
MnO2 (EMD)	$2,628	SMM, 6Dec2021	$3,076	SMM, 31Mar2022
Zinc	$3,162	LME, 6Dec2021	$4,397	LME, 12Apr2022

Source: London Metal Exchange - LME, cash bid closing price; Shanghai Metals Market - SMM for Mn

Carbon Footprint of Zinc Battery Recycling



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

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

CALL FOR MEMBERSHIP!

Join IZA's ZBI – the voice of the zinc battery industry

Thank You!

PLEASE VISIT OUR WEBSITES

www.ZincBatteryInitiative.com

www.zinc.org

Josef DANIEL-IVAD

jdanielivad@zinc.org

ZINC BATTERY INITIATIVE

