Resources, Recycling and Circular Economy
The case of (battery) metals

Rotary Overijse-Zoniën

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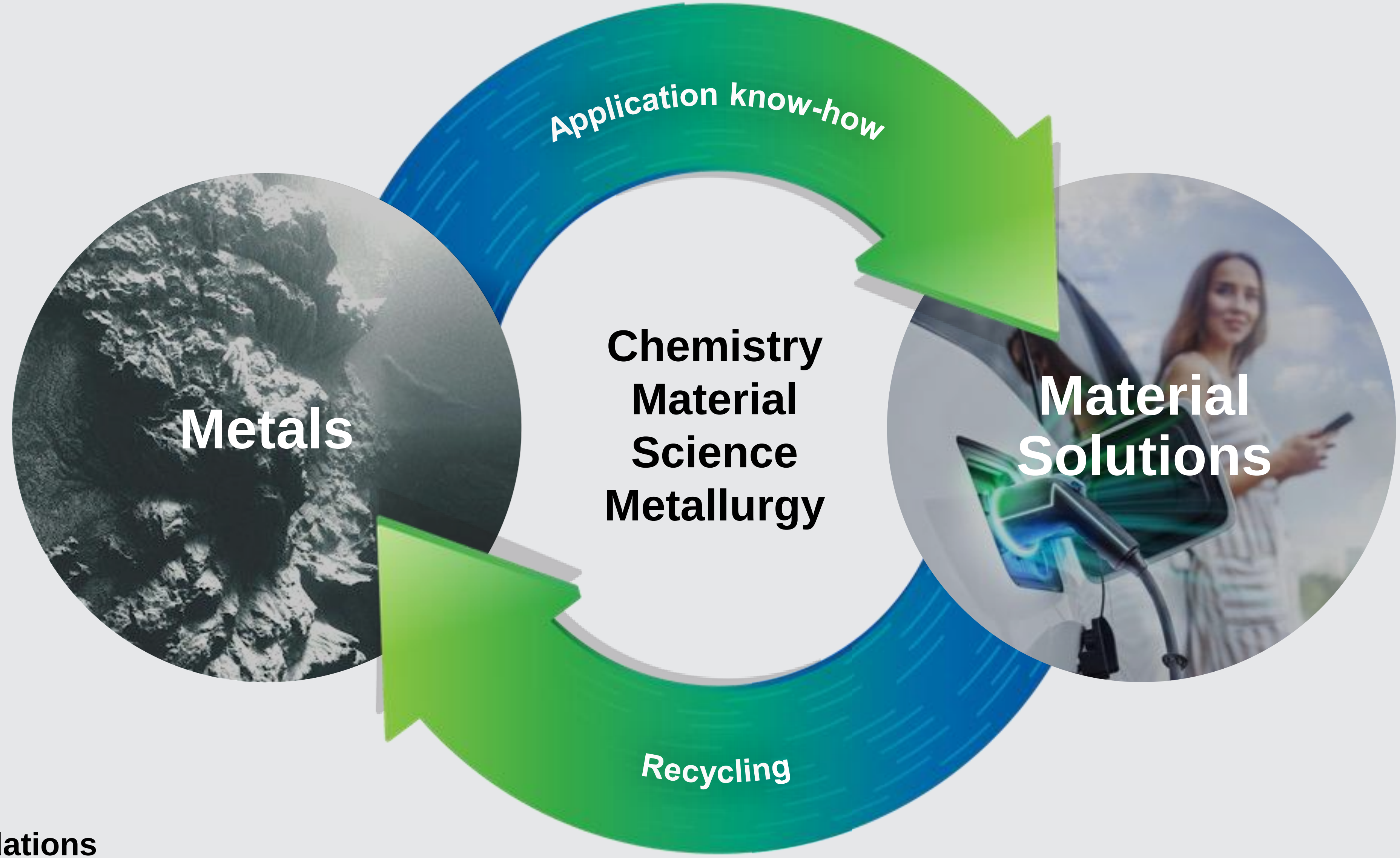
Who we are

We believe in the power of materials technology to create positive impact on people, planet and industry.

We accelerate the transformation to carbon free mobility, deliver the next-generation of advanced materials and drive the world towards a circular economy.

We are the **circular materials technology** company fulfilling our mission to create **materials for a better life.**

Unique Business Model



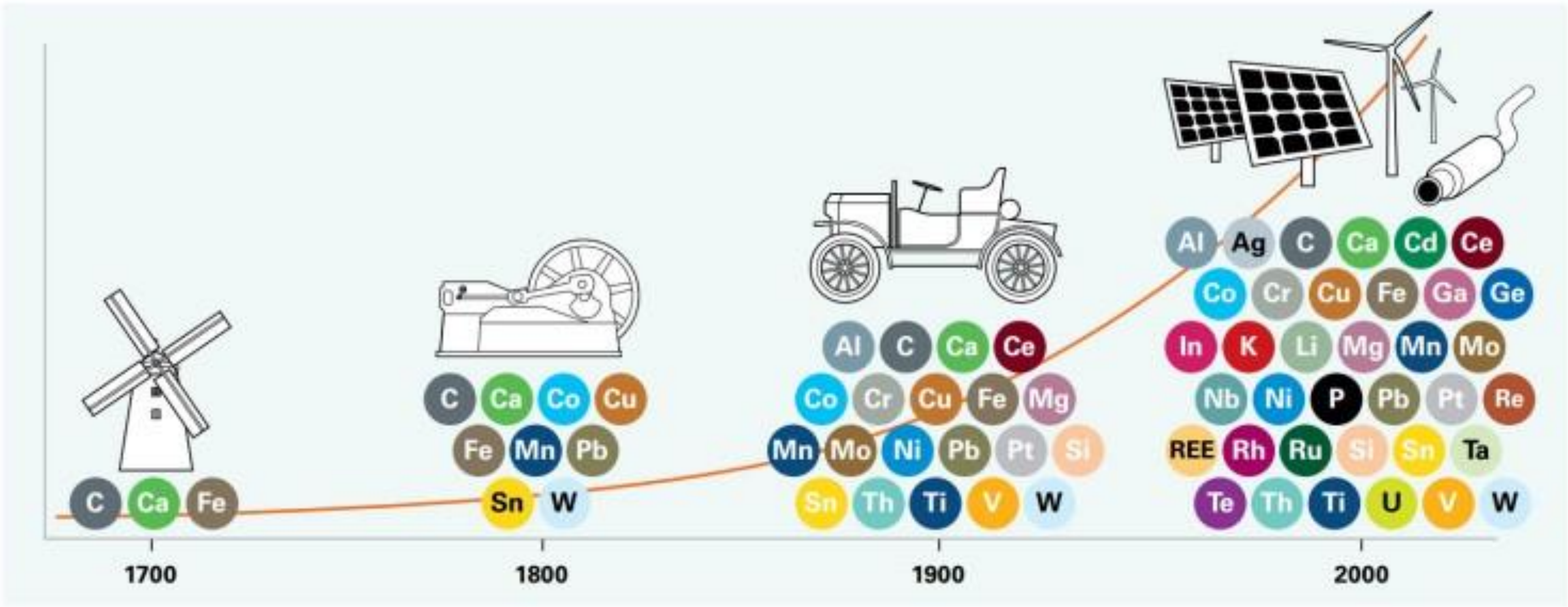
Our strongly rooted foundations

Chapter 1: Metals for clean technologies – fundamentals of metal markets and recycling

- Metals in modern society – on product complexity, resource scarcity, footprint, critical metals & related EU Initiatives
- Recycling of technology metals & the circular economy

Increasing product complexity

- making use of almost the entire periodic table of elements



Elements widely used in energy pathways

Achzet et al., Materials critical to the energy industry, Augsburg, 2011 umicore

The continuing need for mobility…

… creates significant needs for new metals

1900s

Mobility

1920s

Power

1950s

Style

+ steel alloys & decoration

1980s

Clean air

+ catalyst

2000s

Intelligence

+ electronics
+ aux. electric motors
+ lightweighting

> 2010

Low carbon

+ NiMH/Li-Ion battery
+ FC stacks
+ e-drives

Metals*

Fe Pb Cu Cr
Al Zn Pt Pd
Rh Ce La Au
Ag Sb Sn Ge
In Ga Nd Pr
Sm Tb Dy Mg
Li Co Ni Mn

*list only indicative

+ creation of a significant "urban mine"

- Recycling needs to cope with increasing product complexity

Precious & special metals – competing use for many high tech and clean tech applications

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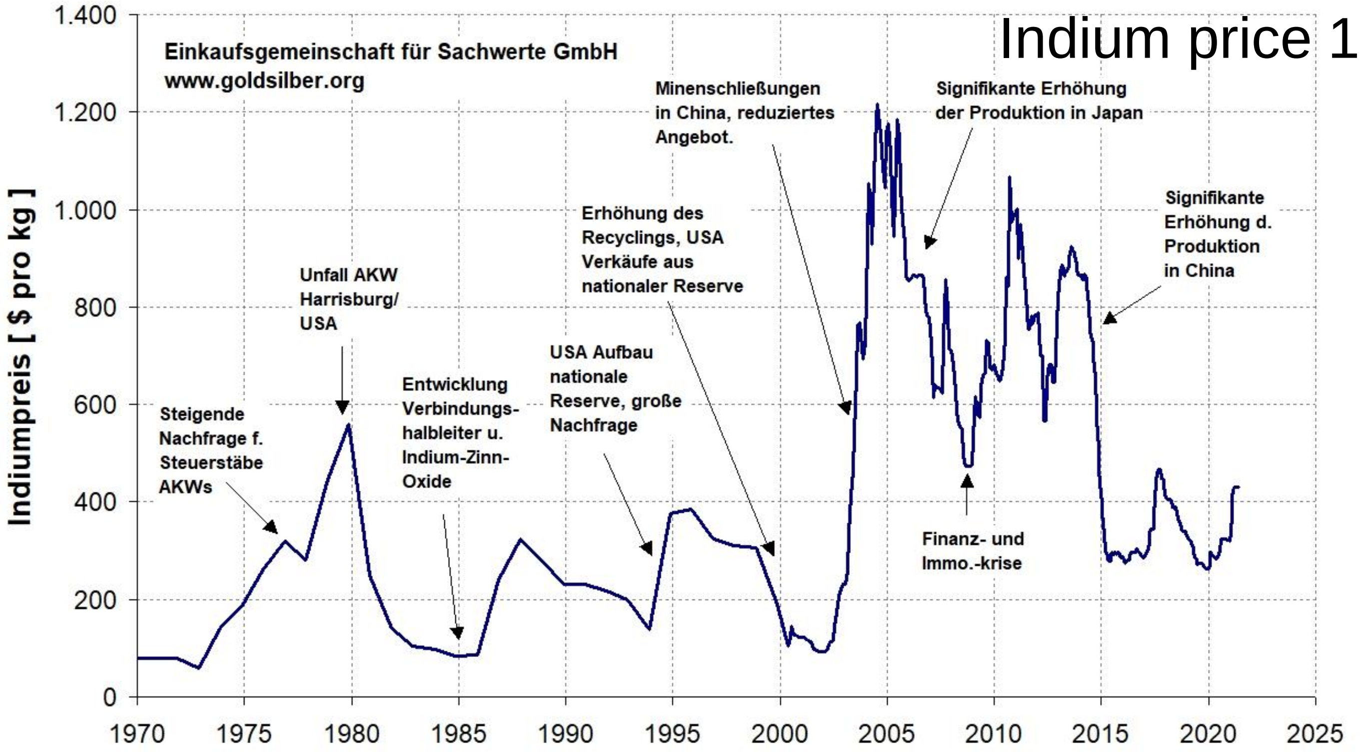
	Bi	Co	Ga	Ge	In	Li	REE	Re	Se	Si	Ta	Te	Ag	Au	Ir	Pd	Pt	Rh	Ru
Pharmaceuticals	■					■											■		■
Medical/dentistry		■	■	■	■			■	■		■	■	■	■		■	■		
Super alloys		■					■	■			■								■
Magnets		■					■		■			■							
Hard Alloys		■									■								
Other alloys					■	■		■	■	■		■							
Metallurgical*	■					■			■										
Glass, ceramics, pigments**	■	■			■	■			■			■	■			▒	■	■	
Photovoltaics			■	■	■				■	■		■	■						■
Batteries		■			▒	■	■			▒			■						
Fuel cells						■										▒	■	▒	■
Catalysts		■		■			■	■	■			■	■	■	■	■	■	■	■
Nuclear					■	■	■												
Solder	■				■								■						
Electronic		■	■	■	■		■	■		■	■	■	■	■		■	▒	▒	■
Opto-electric			■	■	■		■		■	■		■							
Grease, lubrication			■			■													

* additives in smelting, …, plating. ** includes Indium Tin Oxide (ITO) layers on glass

<u>Temporary</u> & structural scarcity

Indium price 1970 - 2024



Temporary scarcity = mismatch demand – supply

→ price volatility e.g. LCD impact on indium prices[1]

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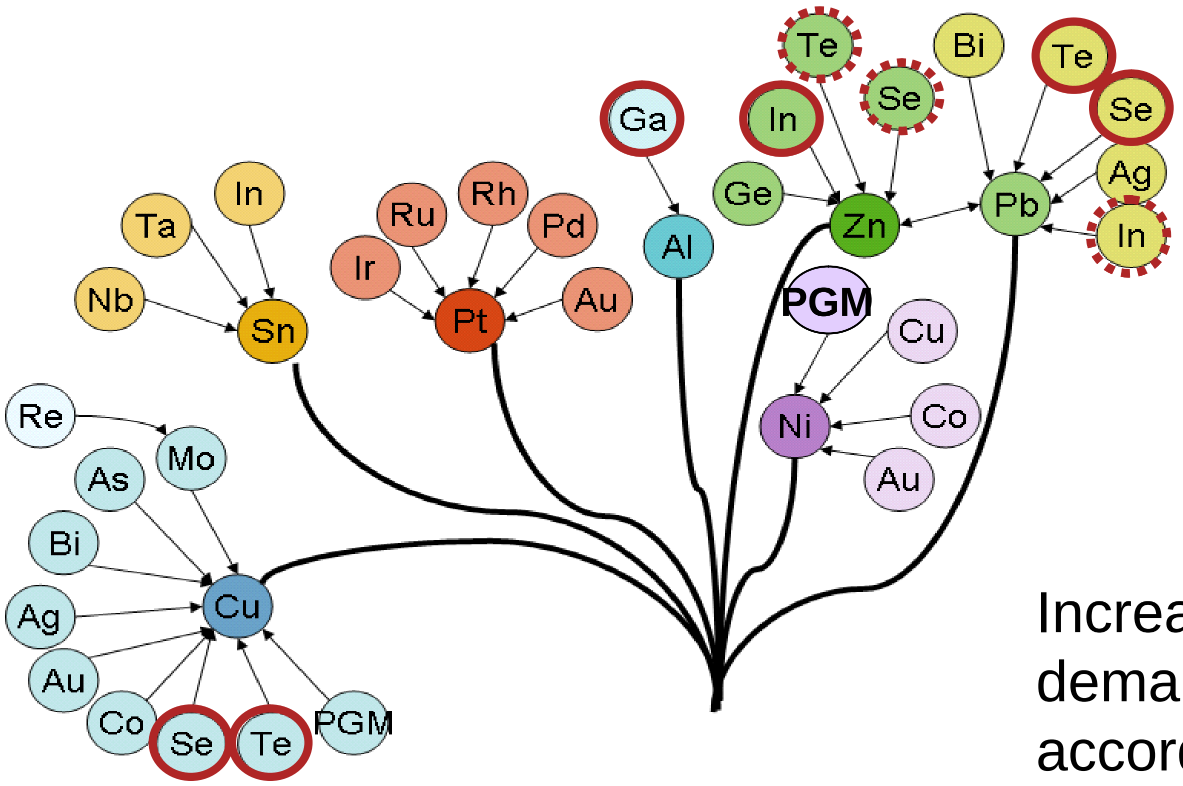
Drivers for temporary scarcity:

- Sudden demand increase
  → new applications, strong market growth, speculative, …
- Supply disruptions
  → Political unrest, war, natural disasters, …
- Time lag & investment risk for new mines and smelters
  → increased demand will lead to temporary price peaks during the lead time to install new capacities

[1] Price explosion by ITO boom for LCDs (2003-2006). Increased primary supply & recycling of production scrap drove prices down again (amplified by & economic crises)

Temporary & structural scarcity



Structural scarcity:
supply constraints by coupled production
(→ price inelasticity)

Increased demand can only be met if demand for main/carrier metals rises accordingly
→ places an absolute cap on availability

Critical Raw Material Act and Net Zero Industry Act

Situation and Motivation

Green Deal: EU C-neutral by 2050 (and -55% by 2030)

Green Deal Industrial Plan
1 Feb 2023

IRA

Ukraine war

Simplified regulatory environment:

- NZIA
- CRMA
- Reform electricity market

Faster access to Financing:

- Temporary State aid Crisis and Transition Framework
- Streamline and simplify IPCEI-projects
- European Sovereignty Fund

Enhancing Skills:

- Net-Zero Industry Academies
- foster and align public and private funding for skills development

Open trade for resilient supply chains:

- EU's network of Free Trade Agreements
- Clean Tech/Net-Zero Industrial Partnerships.
- protect the Single Market from unfair trade

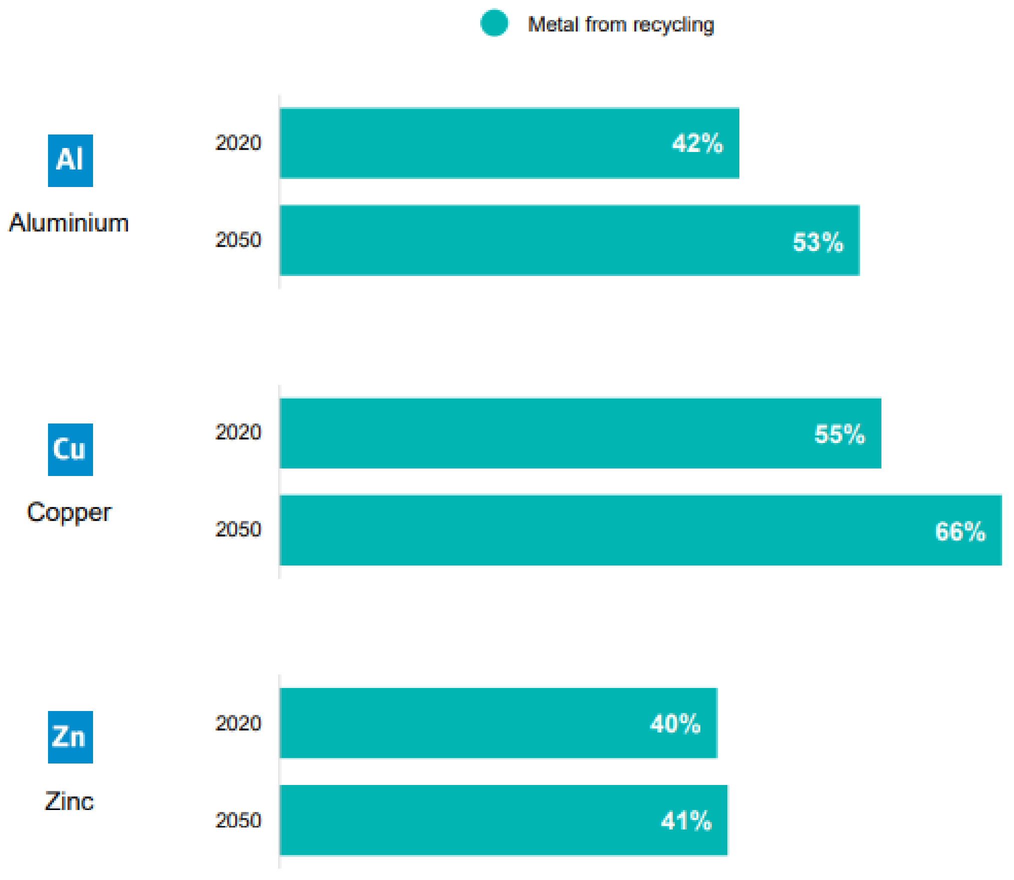
Image: European Parliament

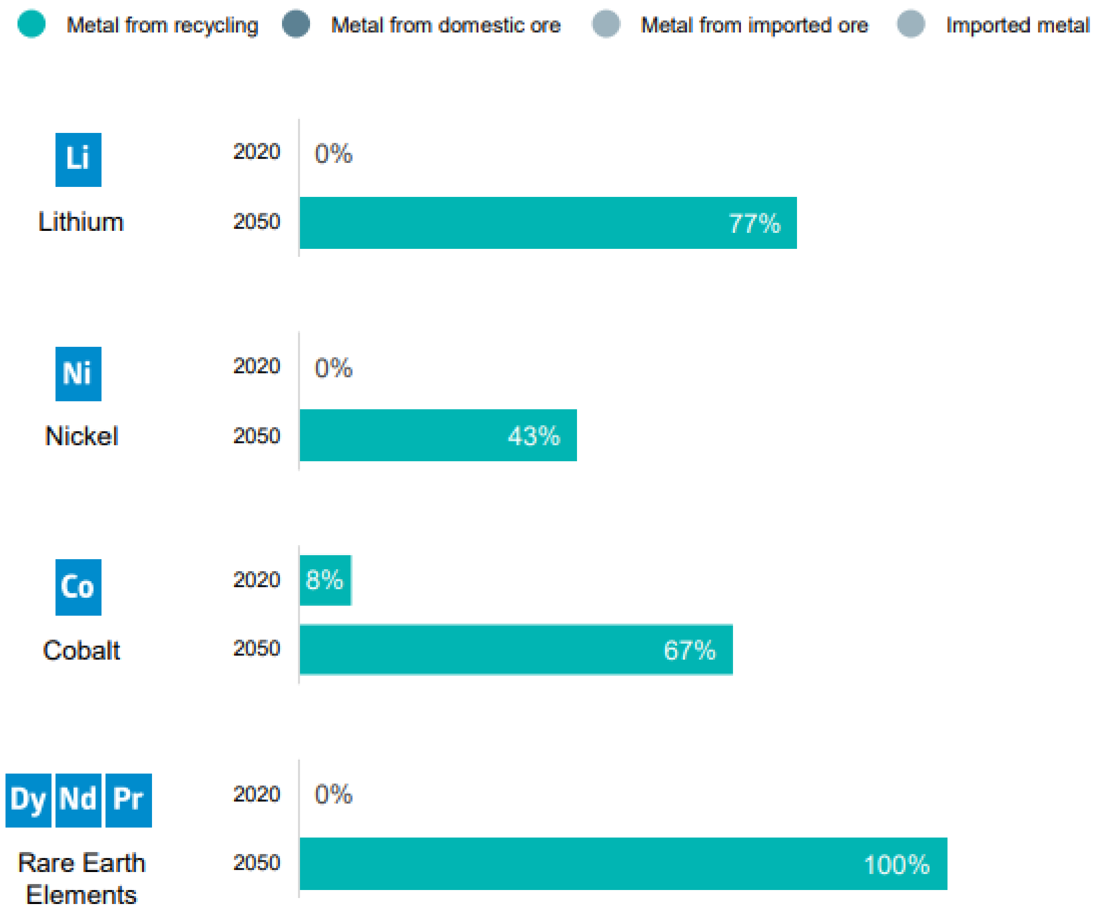
Chapter 2: Metals for clean technologies – fundamentals of metal markets and recycling

- Metals in modern society – on product complexity, resource scarcity, footprint, critical metals & related EU Initiatives
- ➔ Recycling of technology metals & the circular economy

Current level of recycling of metals

And potential by 2050





https://eurometaux.eu/media/jsfne00y/final-slides-ku-leuven-study-presentation-25-4.pdf

Urban mining “deposits” - much richer than primary ores

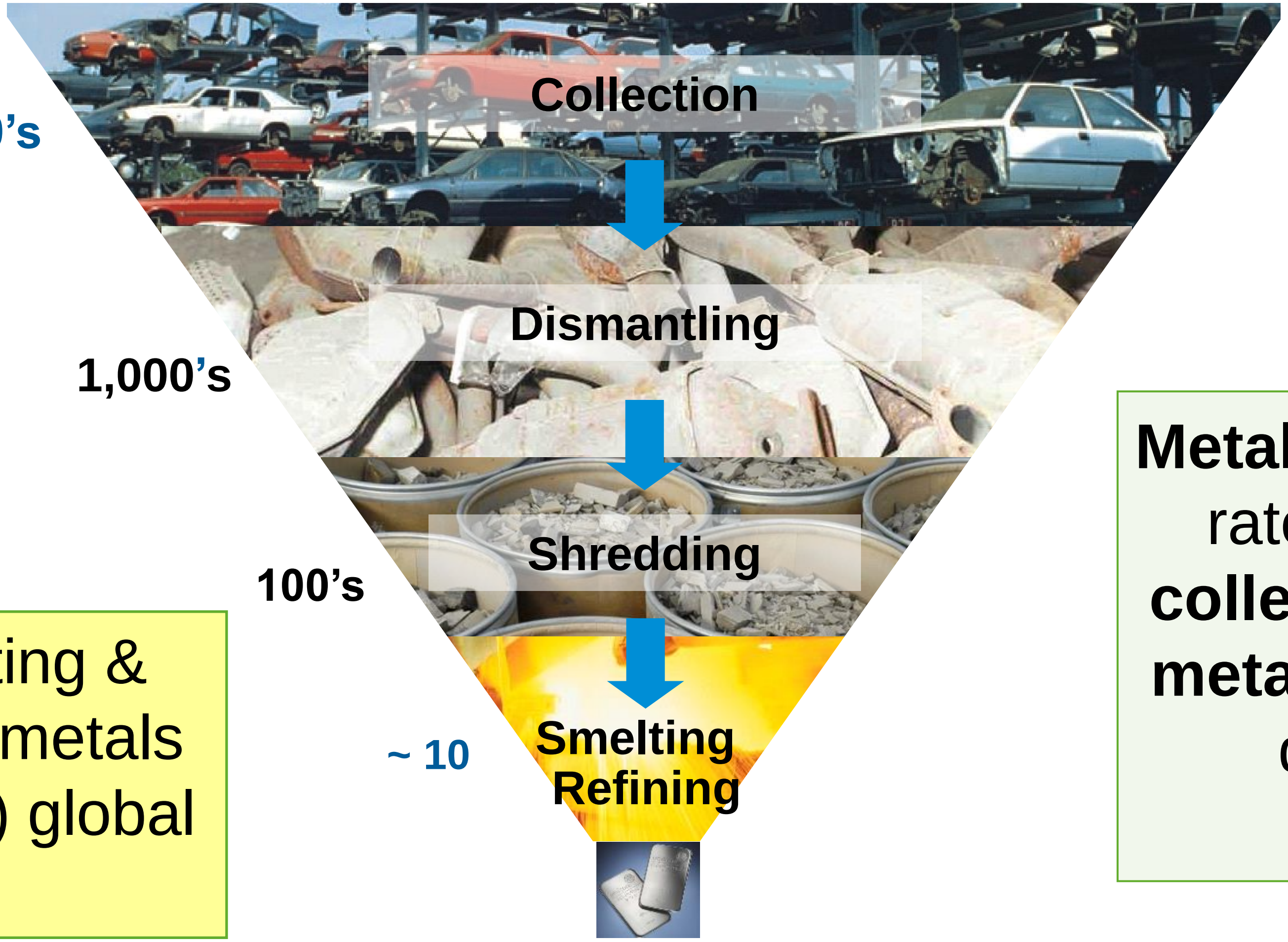
- **Primary mining**
  - << 5 g/t Au in ore
  - Similar for PGMs

- **“Urban mining”**
  - 100-150 g/t Au; Pd, Ag, Cu, Sn, Sb, … in PC motherboards
  - 200-300 g/t Au; Pd … in cell phones
  - 2000-3000 g/t PGM in automotive catalysts

factor 30
& more

How to accumulate millions of discarded EoL product into „urban mines”
of a reasonable (= economically viable) size?

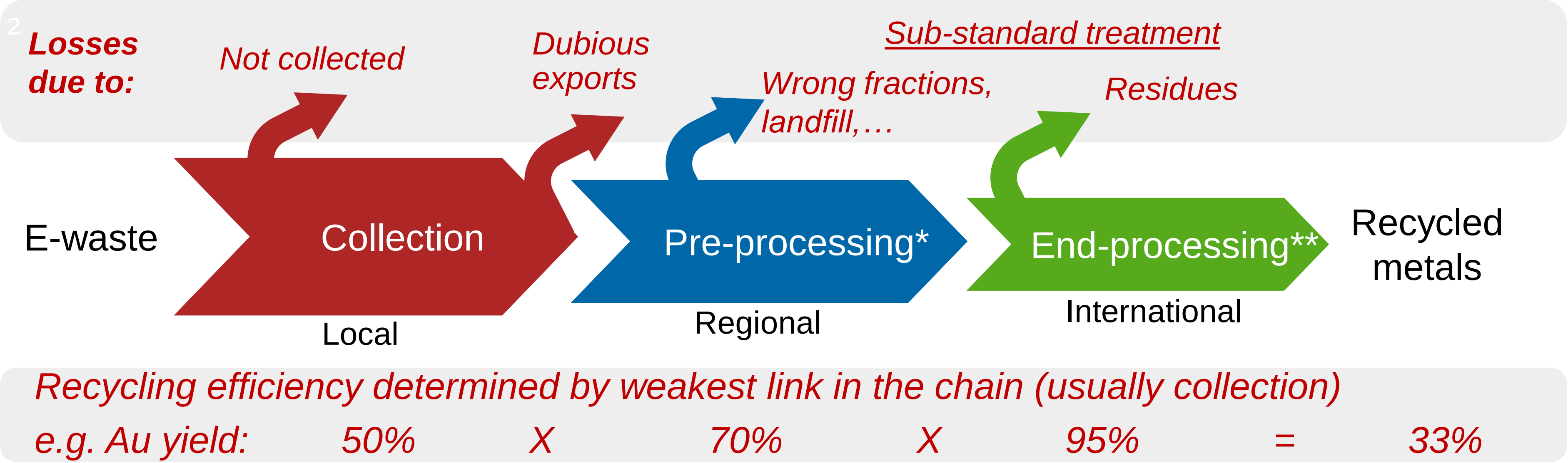
Recycling is a chain, not a single process



Final step: smelting & refining of scarce metals (PGMs, PMs, etc.) global market

Metallurgical recovery rates are **high**, but **collection** is **poor** and **metals are lost** during dismantling & shredding

Effective recycling requires optimised chains



* manual-mechanical
** chemical-metallurgical

Main recycling drivers:

- Economic value, business models & legislation (if well enforced)

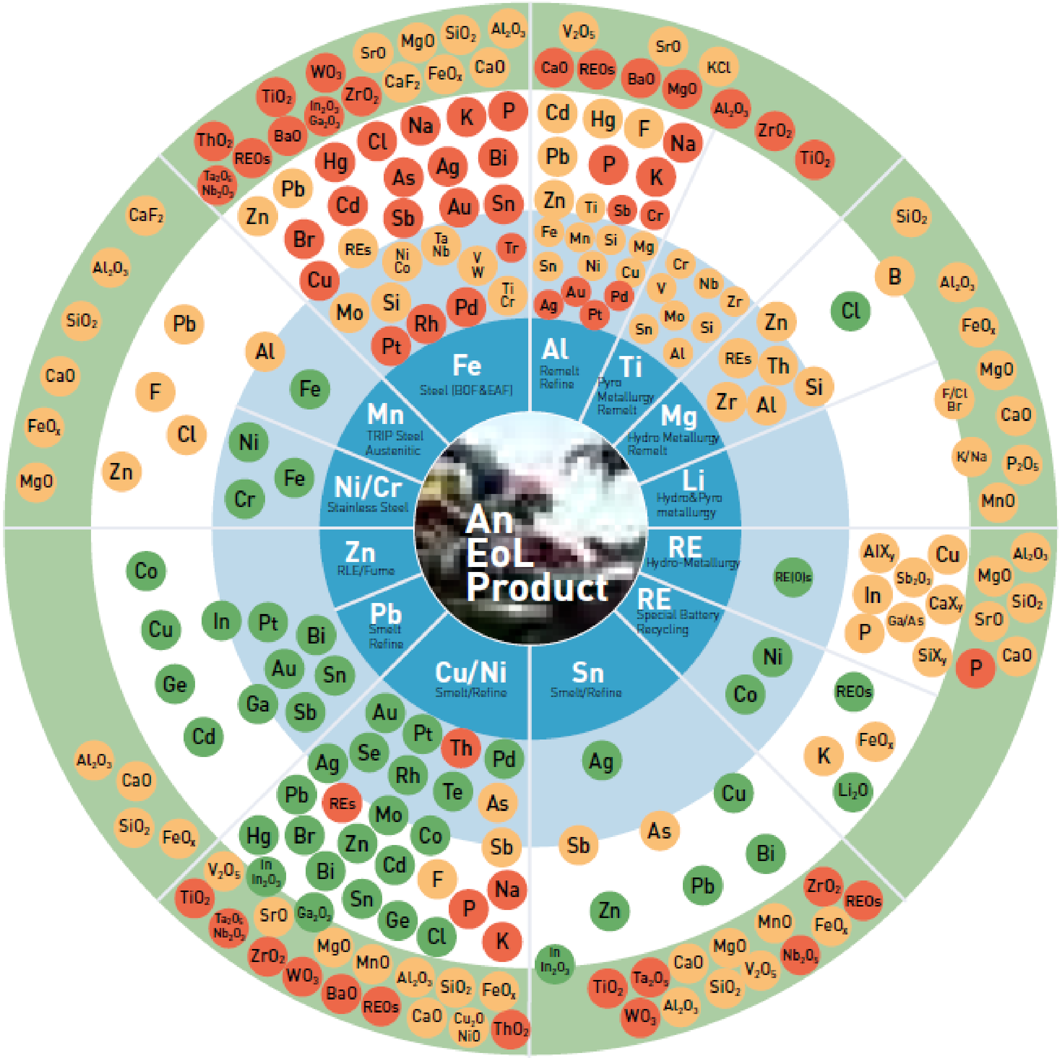
Main challenges:

- Insufficient collection, illegal waste exports, sub-standard treatment
  ⇒ high metal losses & environmental damage
- Reported „Recycling rates“ are rather collection rates, don’t reflect the physical truth

Recycling of technology-metals

Technology

A combined Pb/Cu flowsheet has the highest yield for recycling of technology elements and precious metals



Society's Essential Carrier Metals: Primary Product Extractive Metallurgy's Backbone (primary and recycling metallurgy). The metallurgy infrastructure makes a "closed" loop society and recycling possible.

Dissolves mainly in Carrier Metal if Metallic (Mainly to Pyrometallurgy) Valuable elements recovered from these or lost (metallic, speiss, compounds or alloy in EoL also determines destination as also the metallurgical conditions in reactor).

Compounds Mainly to Dust, Slime, Speiss, Slag (Mainly to Hydrometallurgy) Collector of valuable minor elements as oxides/sulphates etc. and mainly recovered in appropriate metallurgical infrastructure if economic (EoL material and reactor conditions also affect this).

Mainly to Benign Low Value Products Low value but inevitable part of society and materials processing. A sink for metals and loss from system as oxides and other compounds. Comply with strict environmental legislation.

El **Mainly Recovered Element** Compatible with Carrier Metal as alloying Element or that can be recovered in subsequent Processing.

El **Mainly Element in Alloy or Compound in Oxidic Product, probably Lost** With possible functionality, not detrimental to Carrier Metal or product (if refractory metals as oxidic in EoL product then to slag/slag also intermediate product for cement etc.).

El **Mainly Element Lost, not always compatible with Carrier Metal or Product** Detrimental to properties and cannot be economically recovered from e.g. slag unless e.g. iron is a collector and goes to further processing.

Metal Recycling, Opportunities, Limits, Infrastructure; report 2b of the Global Metal Flows Working Group of the International Resource Panel of UNEP

Metallurgical end-processing

Economies of scale & sophisticated processes needed for multi-metals recycling

Umicore’s integrated precious metals refining plant in Hoboken, Belgium

- Efficient recovery of 17 metals in main process: Au, Ag, Pt, Pd, Rh, Ru, Ir, Cu, Pb, Ni, Sn, Bi, Se, Te, In, Sb, As
- Treatment of catalysts, circuit boards, other e-scrap fractions, …, industrial wastes, smelter residues, complex mining concentrates, …
- Up to 500,000 t/y materials input, global sources
- In addition, specialized process for recycling of Li-Ion batteries recovering Co, Ni, Cu, Li
- Unique technology, high metal yields, high energy efficiency & EHS-standards

EoL materials need to reach such plants!

Metals Refining @ Umicore Hoboken
The process in a nutshell

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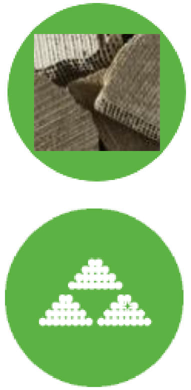
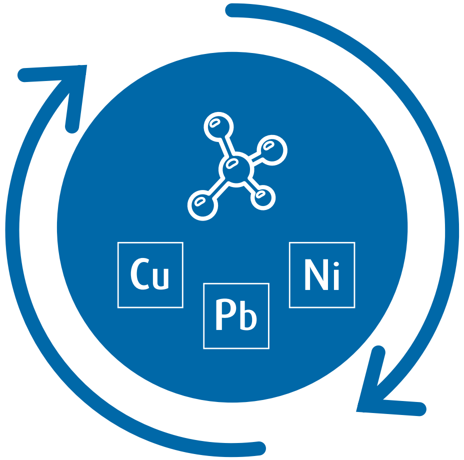
Recyclables:
catalysts, circuit boards, …



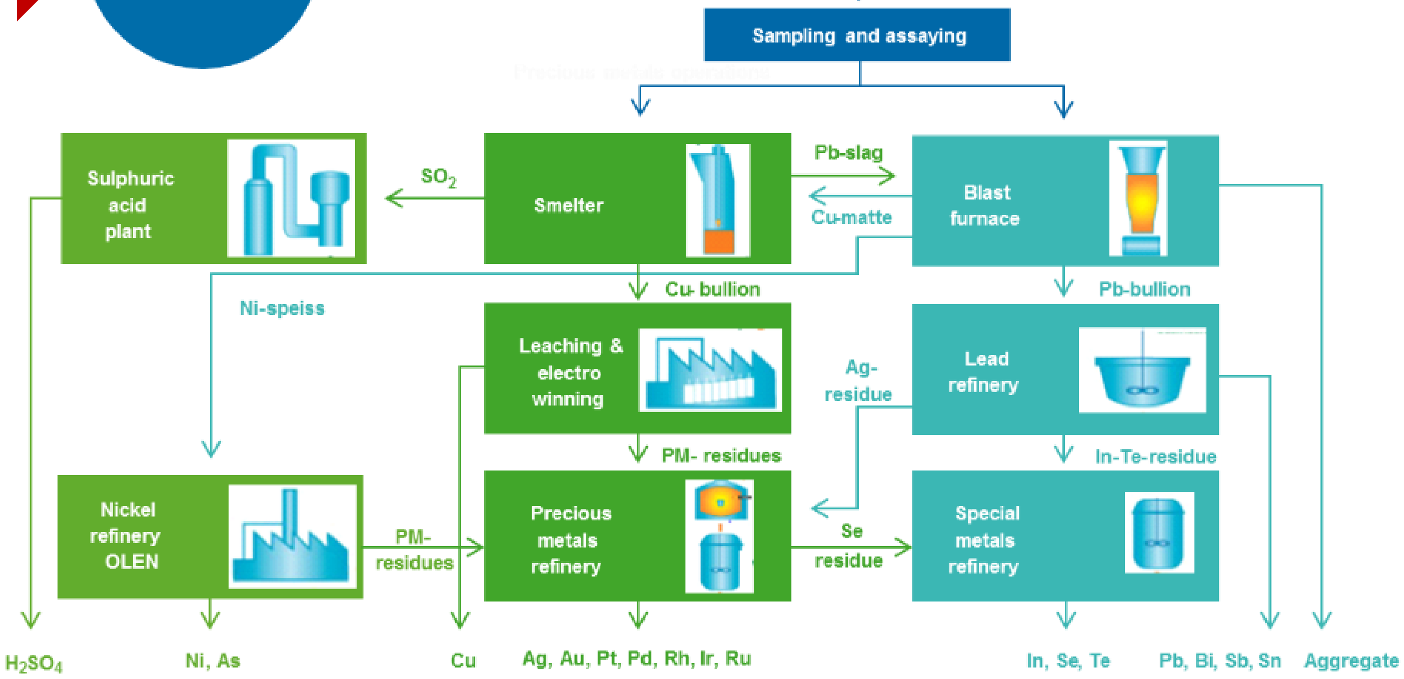
Industrial by-products:
smelter intermediates, slags, dusts, bottom ashes, …

Collector metals



17 different metals

- Highly flexible & robust process
- High performance due to optimised input mix
- >> 1000 t/d throughput of smelter process
- Accurate sampling & assaying of all feeds



Recycling economics: What's the right price for "waste"?

Waste price = recoverable material value - recycling chain costs

Recoverable material value:

$\sum$ material content x material price

product composition & market trends
(pollutants can have negative value)

Recycling chain costs:

Impacted by:

- Technical performance
- Process chain efficiency
- Factor costs (labour, energy, capital)

→ Recycling industry

- Available volumes/economies of scale
- EHS-performance (incl. reporting & hazardous emissions control)

→ Legislation & enforcement

- Shipping costs (incl. taxes, customs)
- Administrative costs (incl. time delays)

→ Trade regulations

The lack of level playing field for EHS-compliant, quality recyclers hampers the circular economy

Chapter 2: Sustainable metals management - case study on WEEE and EV-batteries

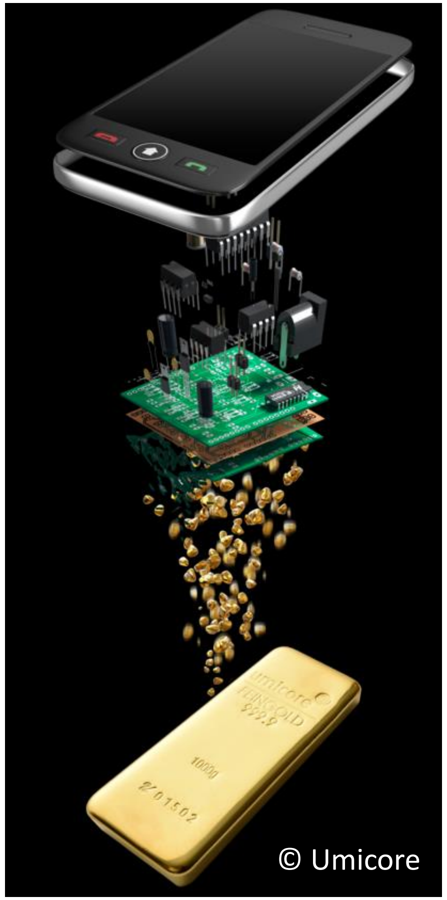
- Case study: Mobile phones & e-scrap – CE driving value creation
- Case study: Batteries for consumer electronics & electro-mobility – metal needs and business requirements

ENGINEERING
CHARACTERIZATION
SYNTHESIS
RECYCLING

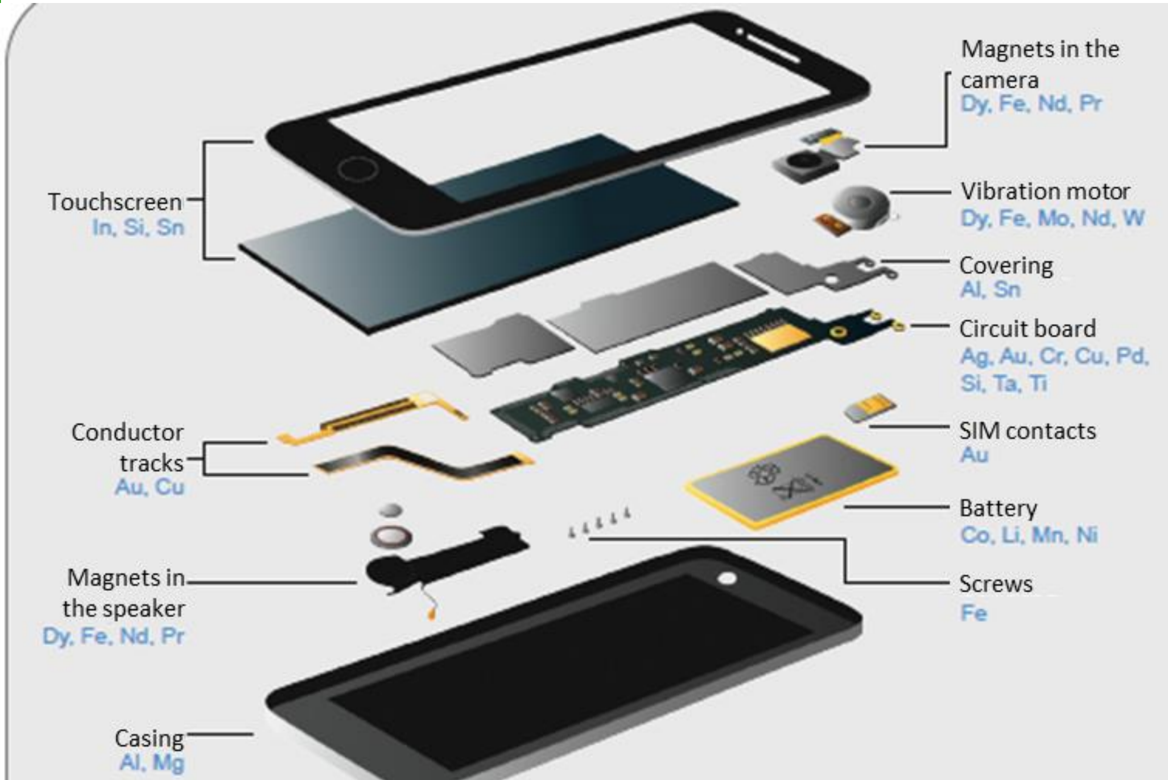
Example of an expensive product, containing gold …

Mobile phones & E-scrap, a complex mix …

- Precious metals: Ag, Au, Pd…
- Base & special metals: Cu, Al, Ni, Sn, Zn, Fe, Bi, Sb, In…
- Hazardous substances: Hg, Be, Pb, Cd, As, …
- Halogens (Br, F, Cl...)
- Plastics & other organic materials
- Glass, ceramics, wood, …

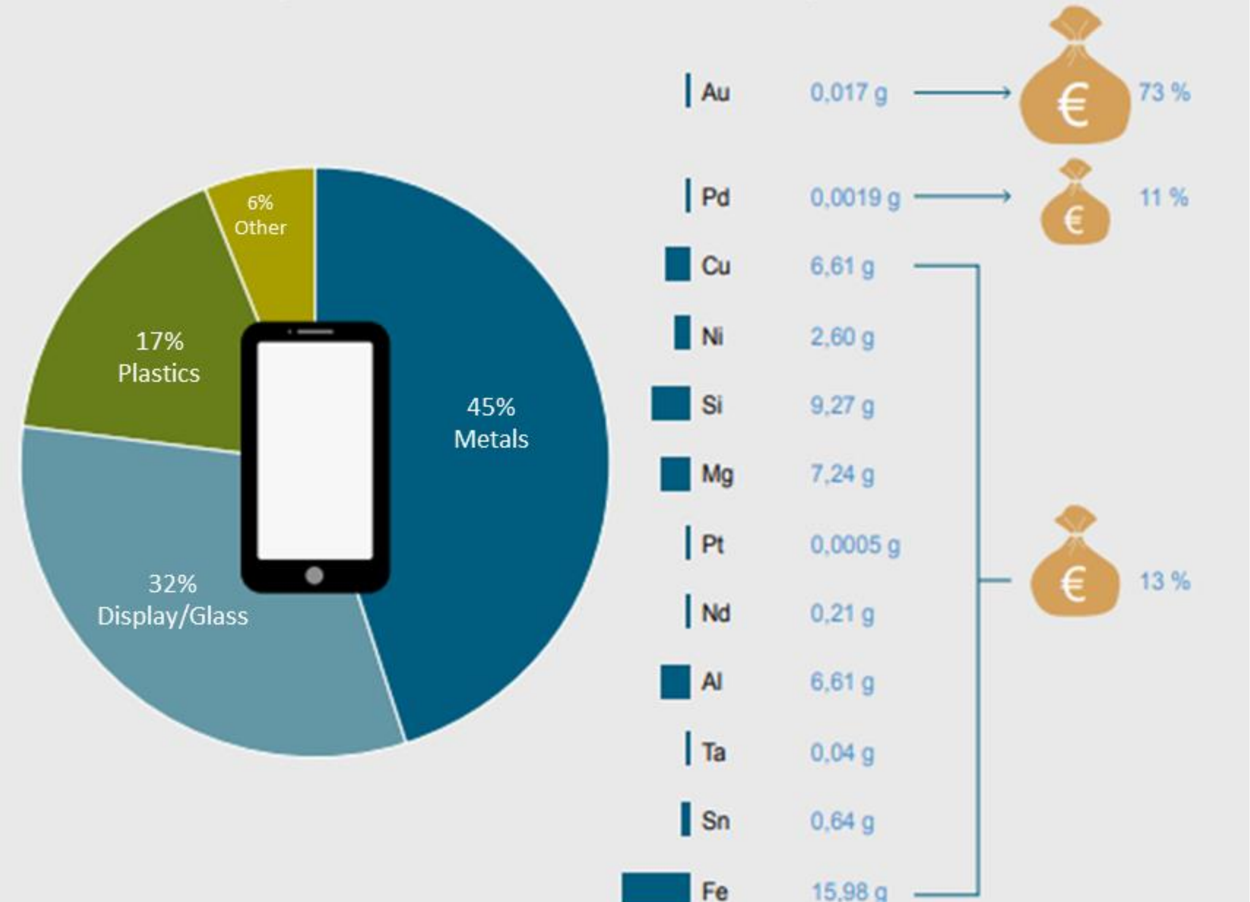


∅ Metal value in a smart phone ≈ 1.10 € (@ prices ∅ Jan-Jul 2020)



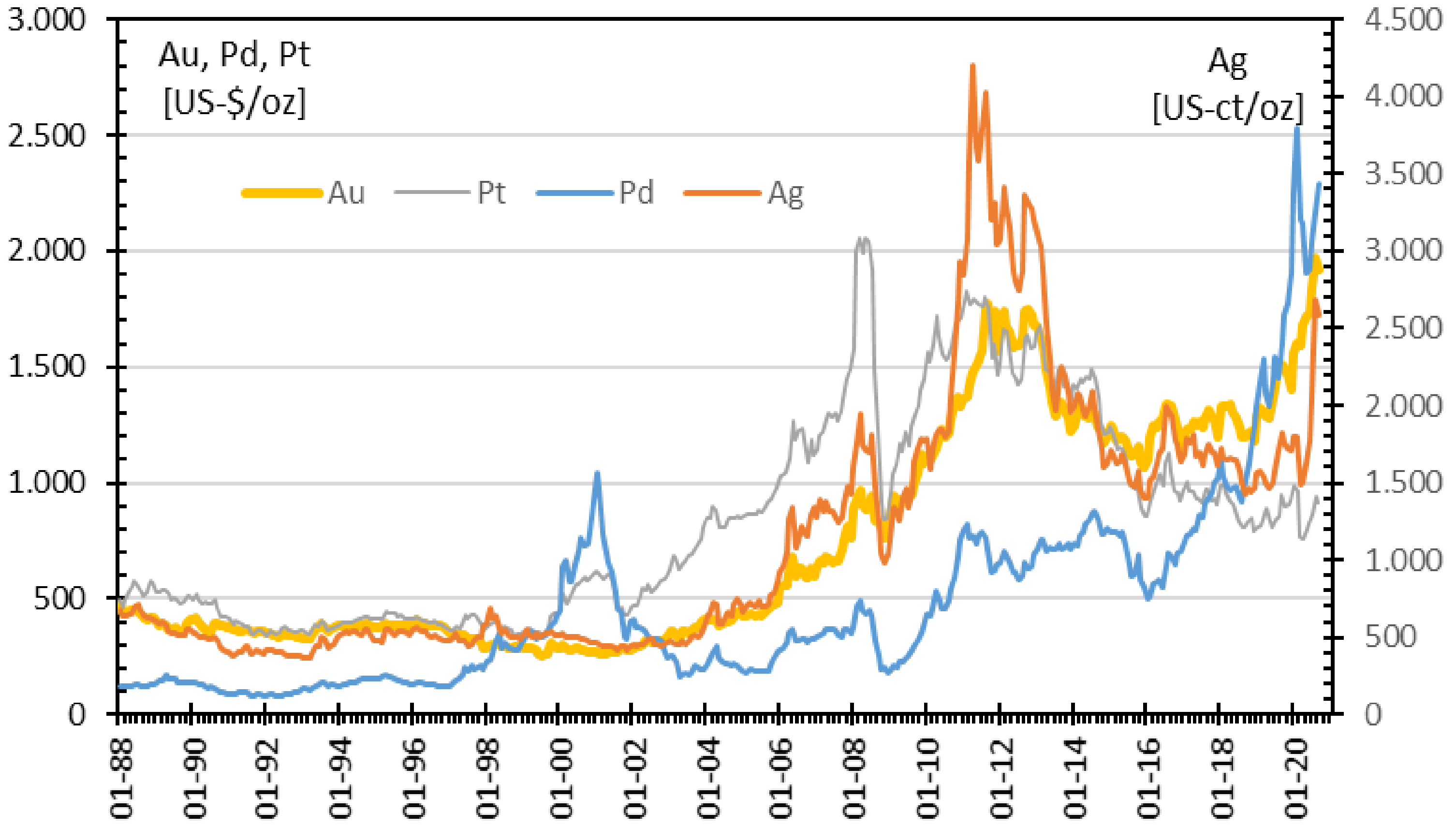
[Bookhagen, Bastien (2020)]

Composition [weight %] | Metal content | Metal value

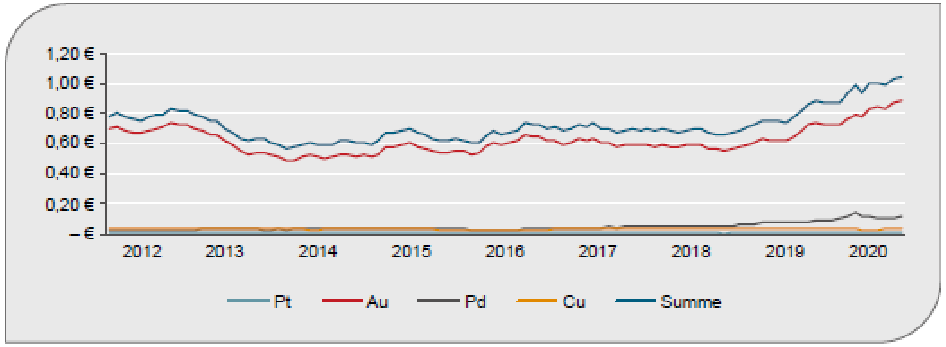


[Bookhagen, Bastien (2020)]

Volatile metal prices impact recoverable value



Price development Au, Ag, Pd & Pt 1988-2020/9



Metal values of Au, Cu, Pd, Pt in smart phones 2012-2020

Is it economically viable to recycle a smart phone???

Accumulation needed for economic viability

Gross metal value of 1 smart phone: **~ 1.1 €**

Net metal value of 5 t (~ 50,000 units) of mobile phones at gate of Umicore recycling plant: **≤ 50,000 €**

Gross metal value of 1.8 billion* mobile phones sold yearly (globally) : **~ 2 Billion €**

* https://www.sellcell.com/how-many-mobile-phones-are-sold-each-year/

Reality Check

Precious metals in a circular economy

Highly efficient recycling processes available

Umicore process yields: >> 95%

	Jewellery, ingots, coins	Chemical process catalysts	Automotive catalysts	Electronic products
EoL-recycling rates*	>> 90%	> 90%	~ 60%	~ 25%
Recycling drivers:	+ value	+ B2B, + value	- B2C, + value	- B2C, + legislation

= closed loop (B2B)

= open loop (mainly B2C)

But disappointingly low recycling rates for many consumer products (B2C), considering the entire product lifecycle

* of Au, Ag, Pt, Pd, Rh, global averages

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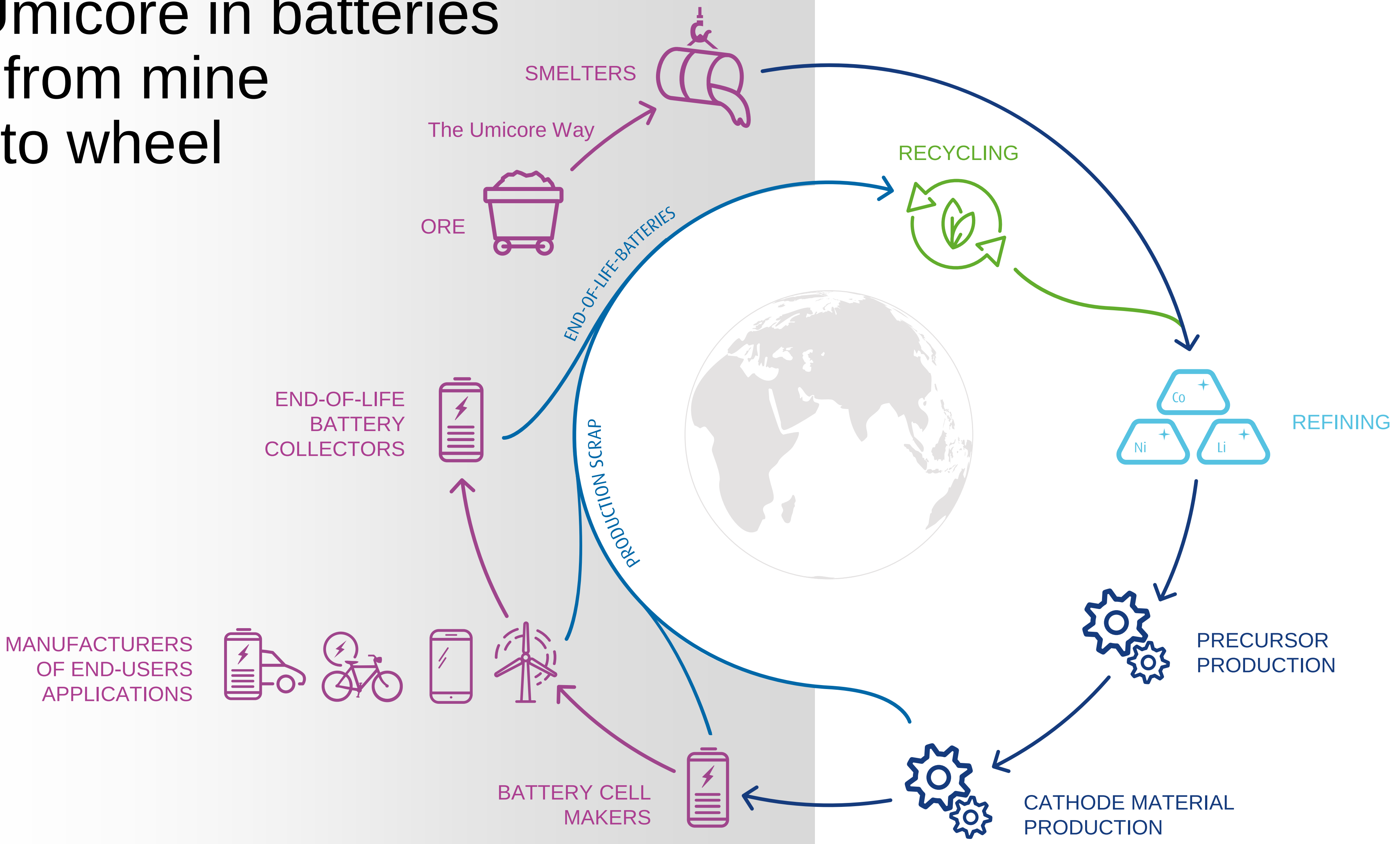
ENGINEERING
CHARACTERIZATION
SYNTHESIS
RECYCLING

Umicore in batteries - from mine to wheel



Umicore’s Battery materials production footprint

Kokkola
Refining, precursor

Hoboken
Battery recycling

Olen
Refining, precursor, battery lab, process competence centre

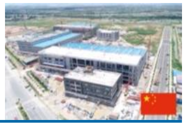
Hanau
Applied technology, end-of-life battery dismantling

Nysa
Cathode production

Cheonan
Precursor & cathode production, battery lab

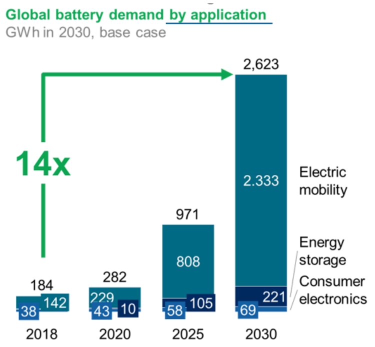
Ganzhou
Refining

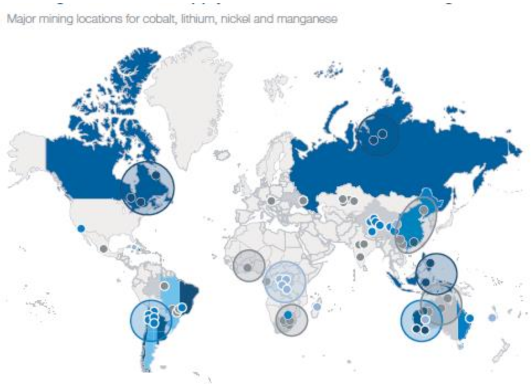
Jiangmen
Refining, Precursor & cathode production,



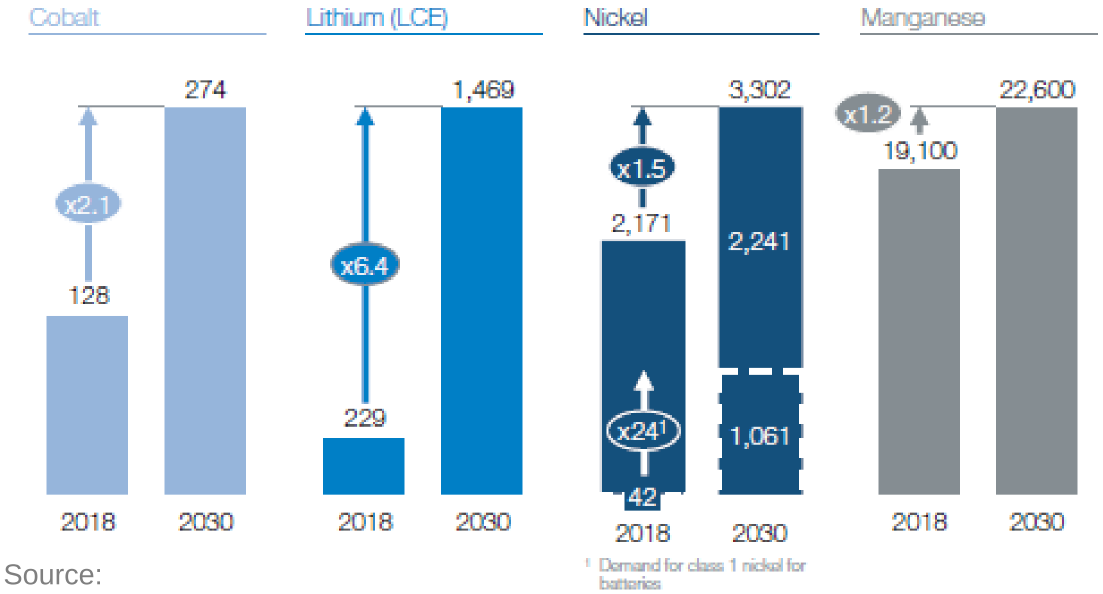
Electro-mobility boosting (critical) metals demand

Can we secure a (sustainable) supply?





Demand for Co, Li, Ni, Mn by 2030



Source:
Global Battery Alliance: A Vision for a Sustainable Battery Value Chain in 2030, Sep 2019.

e.g. for Co: Yes, but …

- Sufficient geological availability of Co for growing e-mobility
- DR Congo: ~ 60% of global mine production,~ 50% of reserves
  China: ~60% of global refined production
- ~ 80% of DRC production from industrial mines,
  ~ 20% from artisanal mining (responsible sourcing challenge!)
- > 95% of Co is by-product from Cu- & Ni-mining
  → Co mine supply depends on Cu & Ni demand & price development
- Mine capacity is expending but temporary bottlenecks and price surges possible
- Recycling offers a growing additional supply potential

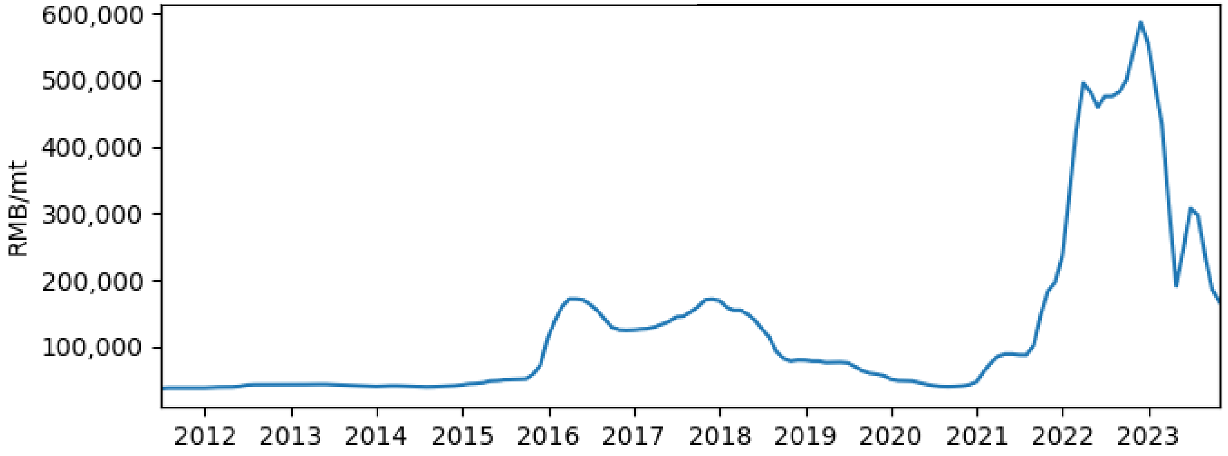
See also: DERA reports www.deutsche-rohstoffagentur.de

(partial) substitution of Co by Ni:
from NMC 111 → NMC 622 → NMC 811

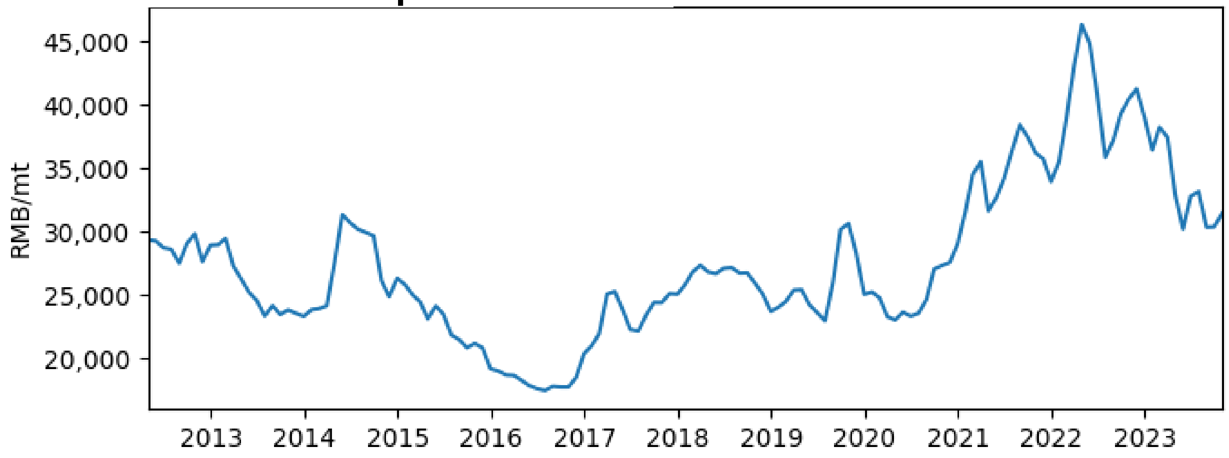
Price development of battery metals Co, Ni, Li

Source: Umicore Strategic Insights & Analysis

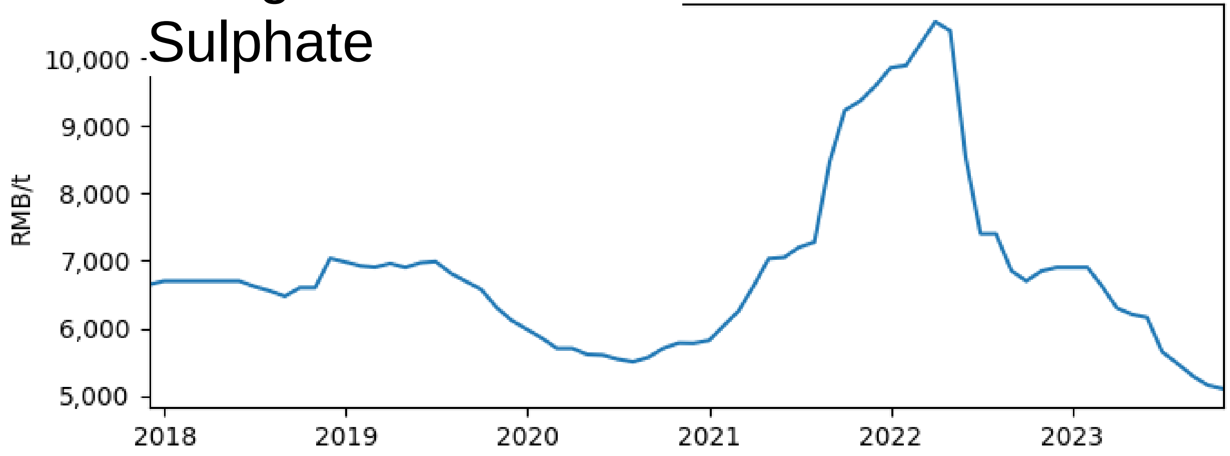
Lithium Carbonate



Nickel Sulphate

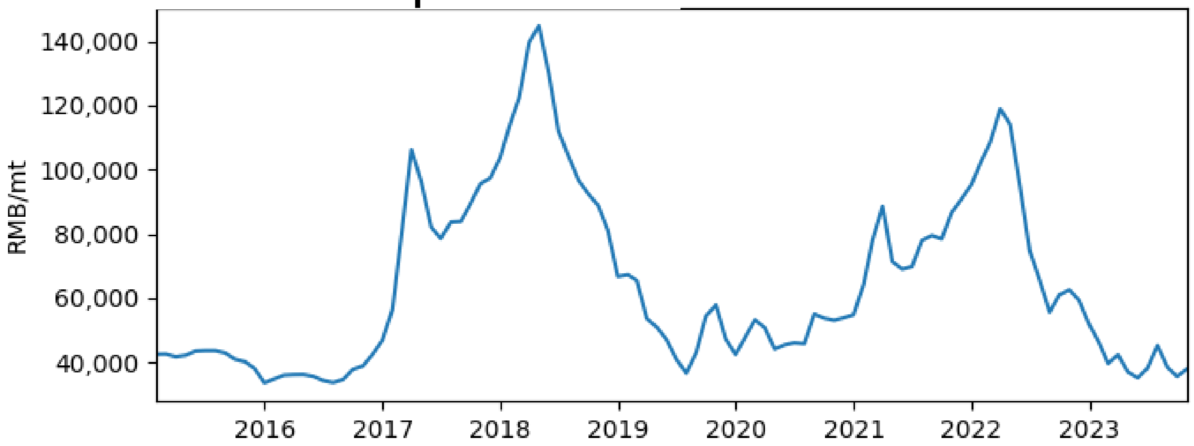


Manganese Sulphate



Last data: 13 Oct. 2023
Produced by Umicore SIA / Data source: Asian Metal

Cobalt Sulphate



Last data: 13 Oct. 2023
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Responsible sourcing becoming a key requirement

Umicore’s Procurement Framework <u>for Cobalt</u>

- Internal checks and Chain-of-custody systems implemented since 2004.
- Framework created to assure that the cobalt in Umicore’s supply chain is free of sustainability abuses:
  → human rights, environment, health & safety, bribery & corruption, artisanal mining
- Applied to all purchases of cobalt in Umicore, based on understanding of risks related to sourcing & handling of cobalt
- Third-party validated and OECD’s Due Diligence aligned Framework

Strong involvement in the **Global Battery Alliance** (World Economic Forum). Projects ongoing to promote a responsible battery value chain:

- **Battery Passport** (support data sharing on origin, chain of custody, chemistry, health & history of battery, ensure transparency on “battery fate” along entire lifecycle)
- **Standard for** responsible artisanal & small-scale mining (**ASM**)
- Increased attention for **traceability solutions with Blockchain**

http://www.umicore.com/en/cases/sustainable-procurement-framework-for-cobalt/

Closing the battery loop

Recycling is essential for <u>sustainable</u> e-mobility

- Resource conservation, complementing primary supply of Co, Li, Ni & Cu
- Responsible sourcing, „clean“ supply chains
- Supply security, urban mine as local EU source reduces (risky) import dependence
- Reducing CO_2 footprint & environmental impact of e-mobility
  → less use of energy-, water- & landscape vs mining (higher metal concentration)
  → batteries contain less impurities than ores
- Environmental protection → avoiding risks from landfill or sub-standard treatment (fire, emission of hazardous substances)

Reality Check

Europe is rich in resources if end-of-life products are utilized as „urban mine“

Significant unused recycling *potential*: Globally ~30 000 t/a Co used for portable Li-Ion batteries (electronics, power tools …) with very low recycling rates → Co would be sufficient for 3-4 million EVs

Battery recycling process requirements

Technical performance:

- High effective recycling rates of key metals **Co**, **Ni**, **Li, Cu** considering yields of entire recycling chain
  → output from recycling process must fit as input for new products! = suitable quality of recyclates
- Safe handling of battery systems during dismantling and recycling of battery cells
  (→ electric charge, electrolyte, process emissions, …)
- Environmentally sound & energy efficient recycling processes along chain (environmental footprint)

Economical performance:

- Cost efficiency → consider recyclate quality & impact on up-/downstream steps
- Scalability → handling of mass flows on industrial scale (economies of scale); access to EoL-batteries
- Flexibility in handling various (EoL) battery types and chemistries

Regulatory requirements:

- High collection rates, transparent flows, high-quality recycling (EU-standards!), level playing field, ambitious recycling rates based on clear, target oriented definitions & system boundaries

Umicore recycling process for Li-Ion batteries

industrial pilot plant with 7000 t/a capacity

target: Recovering metals in battery grade quality