Umicore Precious Metals Refining

A key partner in closing the life cycle of EEE (Electrical and Electronic Equipment)

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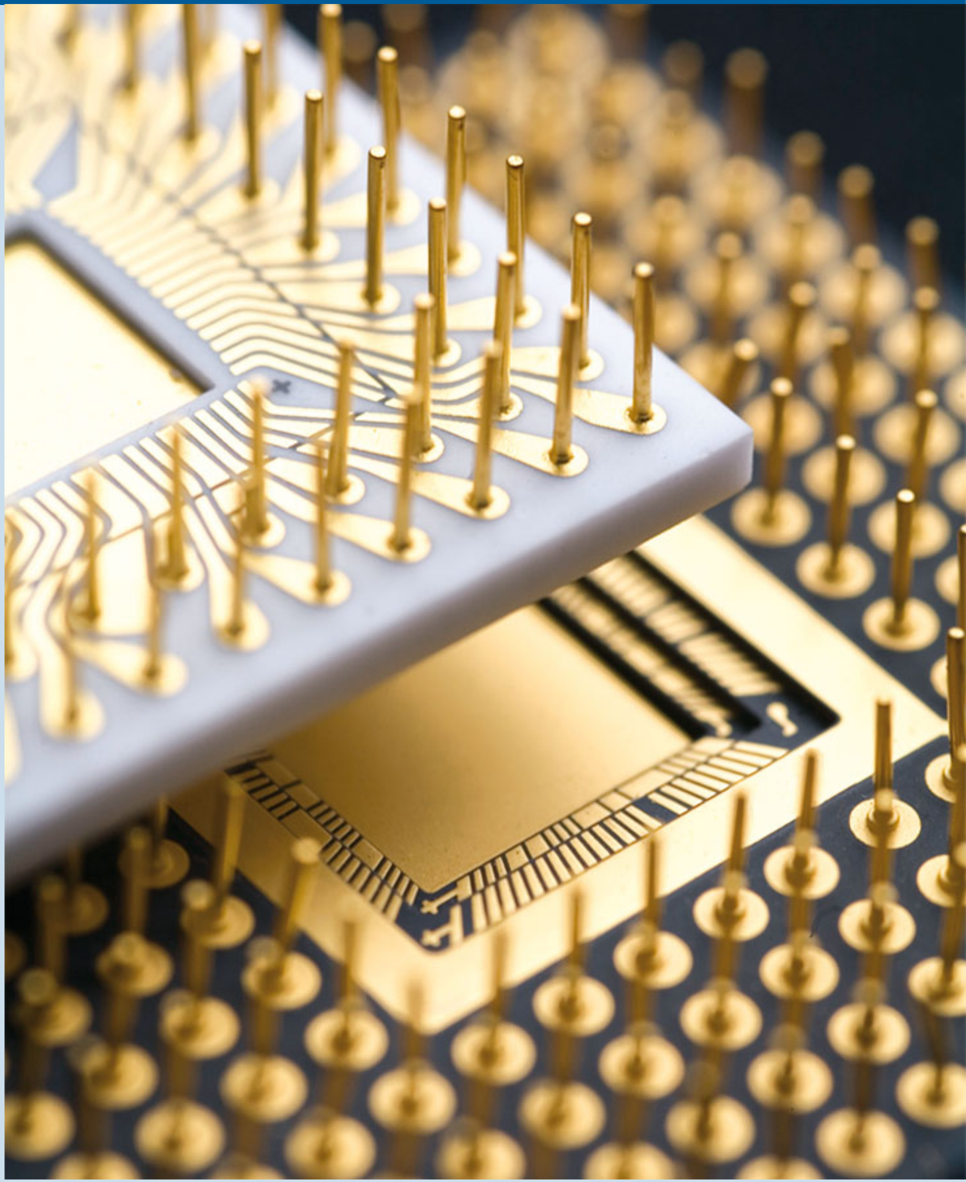
Umicore
USA

SERDC October 2012

Recycling Electronic End of Life Materials

- **Exploring Umicore**
- Metal Cycles & Markets
- Dimensions of e-scrap recycling
- e-Scrap recycling at Umicore
- Battery recycling at Umicore
- Modelling of e-waste recycling



Introduction to Umicore

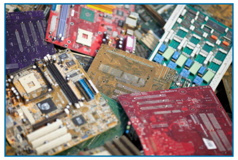
- We are a global materials technology company
- Our mission is to make “materials for a better life”
- The majority of our growth comes from clean technologies:
  - *technologies that are specifically designed to optimize the use of natural resources and to reduce environmental impact*
- We are listed on NYSE / Euronext Brussels with a market capitalization of some € 4.5 billion (~$5.6 billion)

Key megatrends for Umicore

Umicore fit with megatrends

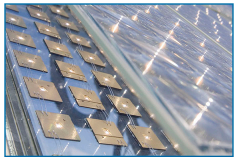
Electrification of the automobile → We are a leading producer of key materials for rechargeable batteries for laptops, mobile phones as well as electrified vehicles

Resource scarcity → We are the largest recycler of precious metals; we are able to recycle more than 20 different metals



More stringent emission control → We provide catalysts for 1 out of 3 cars in the world as well as for trucks & non-road vehicles

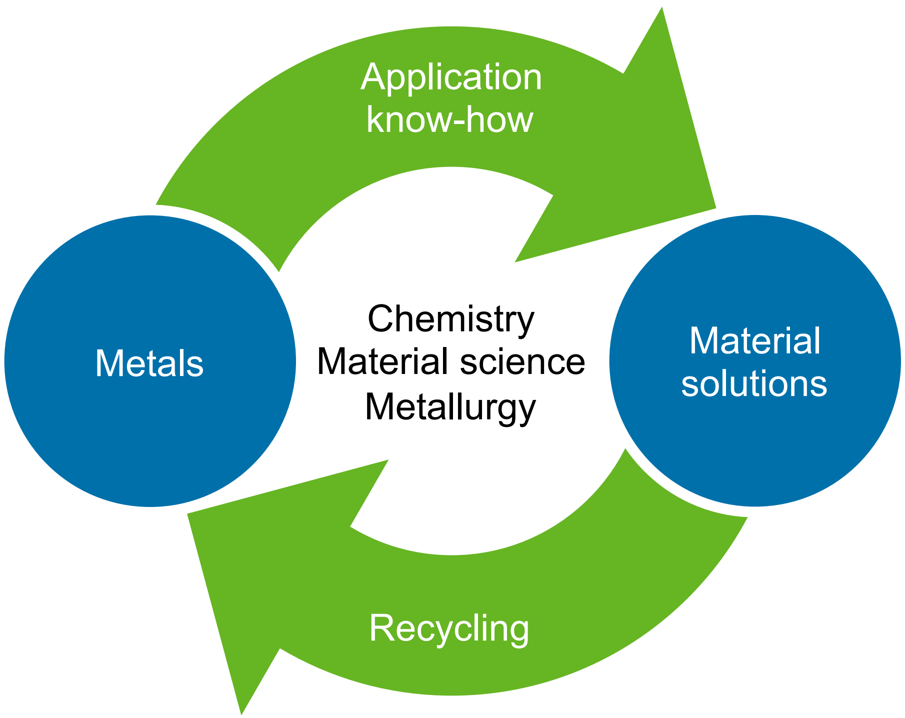
Renewable energy → We supply key innovative materials for high-efficiency solar cells and other photovoltaic applications



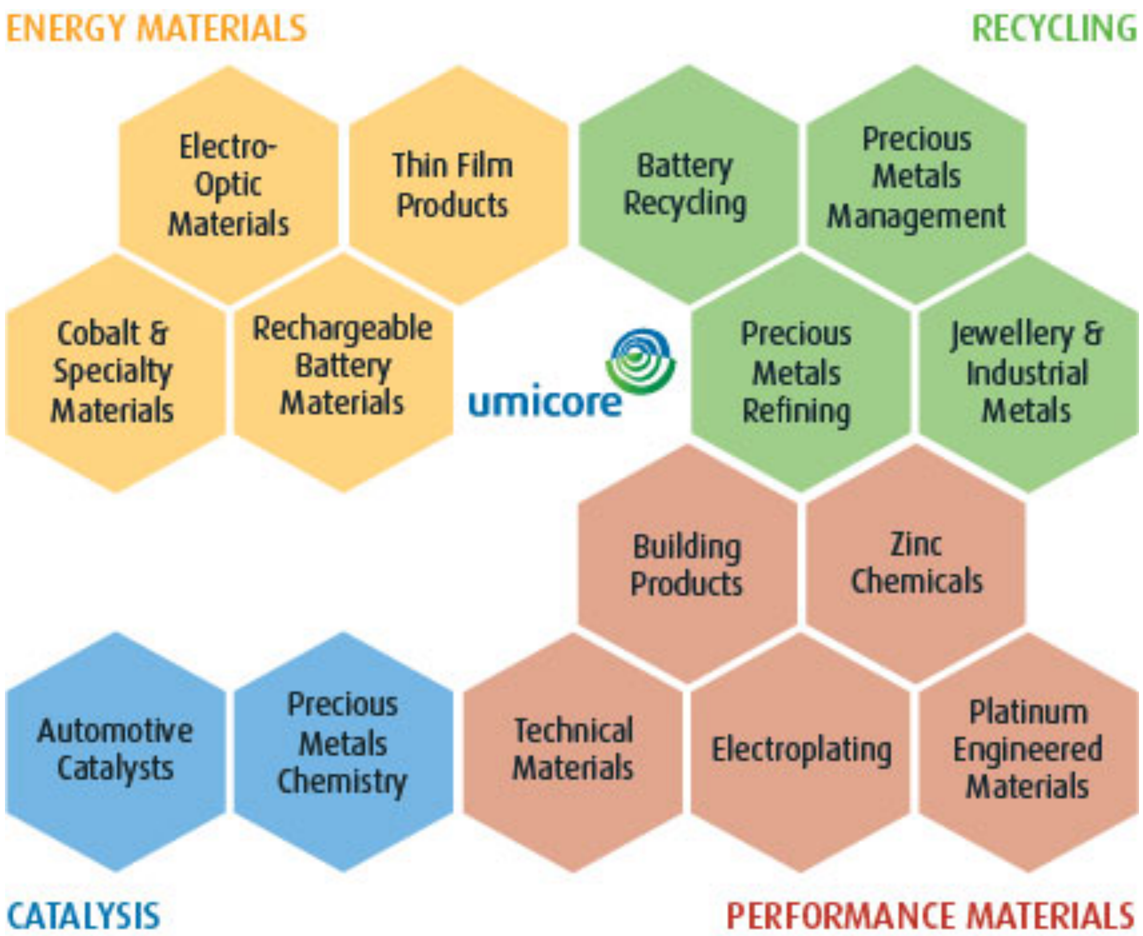
materials for a better life

Umicore's business approach

- We transform metals into hi-tech materials
- We use application know-how to create tailor-made solutions in close collaboration with our customers
- We close the loop and secure supply by recycling production scrap and end-of-life materials
- We aim to minimize our environmental impact and be the best employer and neighbour



Umicore's structure



materials for a better life

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External engagement and recognition

Engaging in external dialogue

World Business Council for Sustainable Development

MEMBER OF KAURI
Belgian meeting point for global sustainable action

Business & Society Belgium

Signing up for global agreements

ICEM

FIOM FITIM IMB FISM IMF

Receiving external recognition

BEST IN CLASS
environmental and social performance
STOREBRAND SRI

FTSE4Good Index Series

SRI

Prix pour le Meilleur Rapport de Développement Durable | Prijs voor het Beste Rapport Duurzaam Ondernemen

Precious Metals Refining

Largest and most complex precious metals recycling operation in the world

- Proprietary processes mastering a complex feed with the highest degree of flexibility
- Global customer base

Processes around 350,000 tonnes/year of more than 200 different types of raw materials

- Wide range of complex precious metals bearing materials
- Efficient recovery of 17 different metals
- Focus on high added value processes (throughput time, efficiency)

Applying world class environmental and quality standards

- Exploring Umicore
- **Metal Cycles & Markets**
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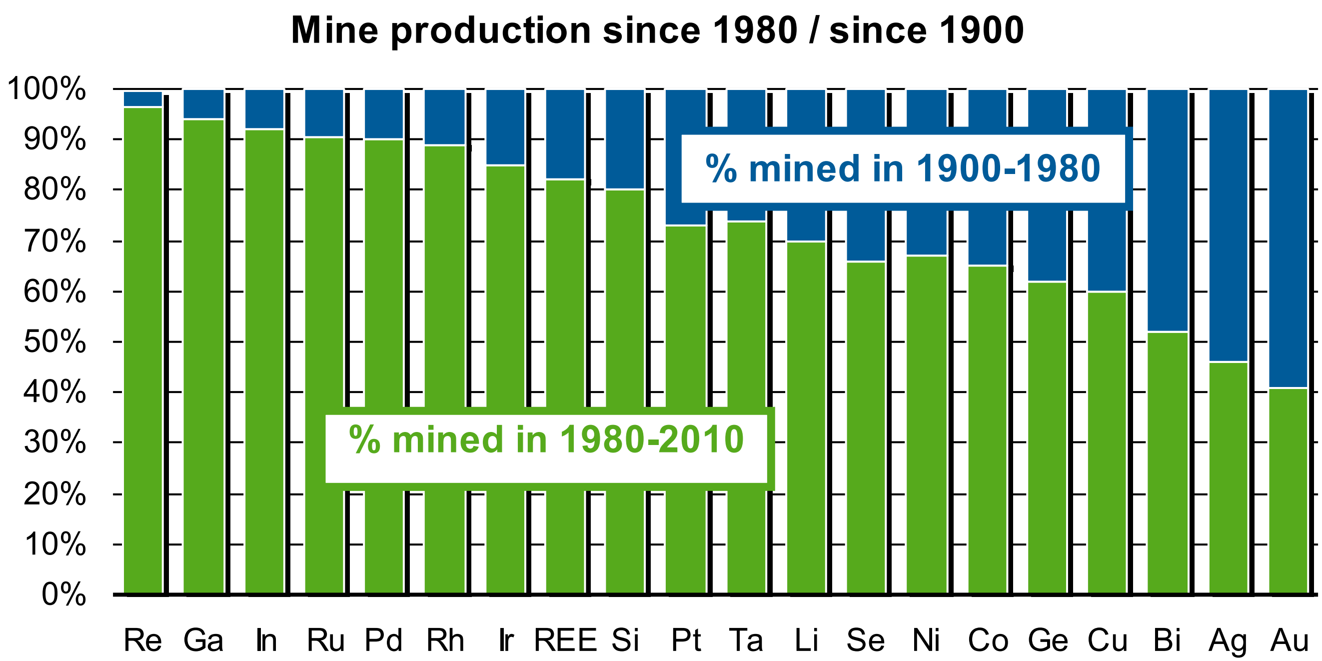
Recent boom in demand for most technology metals



REE = Rare Earth Elements

Source: C. Hagelüken, C.E.M. Meskes: Complex life cycles of precious and special metals. *In*: *Linkages of Sustainability*, T. Graedel, E. Van der Voet (eds.) MIT Press, 2010

Consumer products are increasingly complex

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- Ag, Au, Pd… (precious metals)
- Cu, Al, Ni, Sn, Zn, Fe, Bi, Sb, In… (base & special metals)
- Hg, Be, Pb, Cd, As… (metals of concern!)
- halogens (Br, F, Cl...)
- plastics & other organics
- Glass, ceramics

Cell phones*:

1300 Million units	x 250 mg Ag ≈	325 t Ag
	x 24 mg Au ≈	31 t Au
	x 9 mg Pd ≈	12 t Pd
	x 9 g Cu ≈	12,000 t Cu
	x 3.8 g Co[1] ≈	4900 t Co

PC & laptops*:

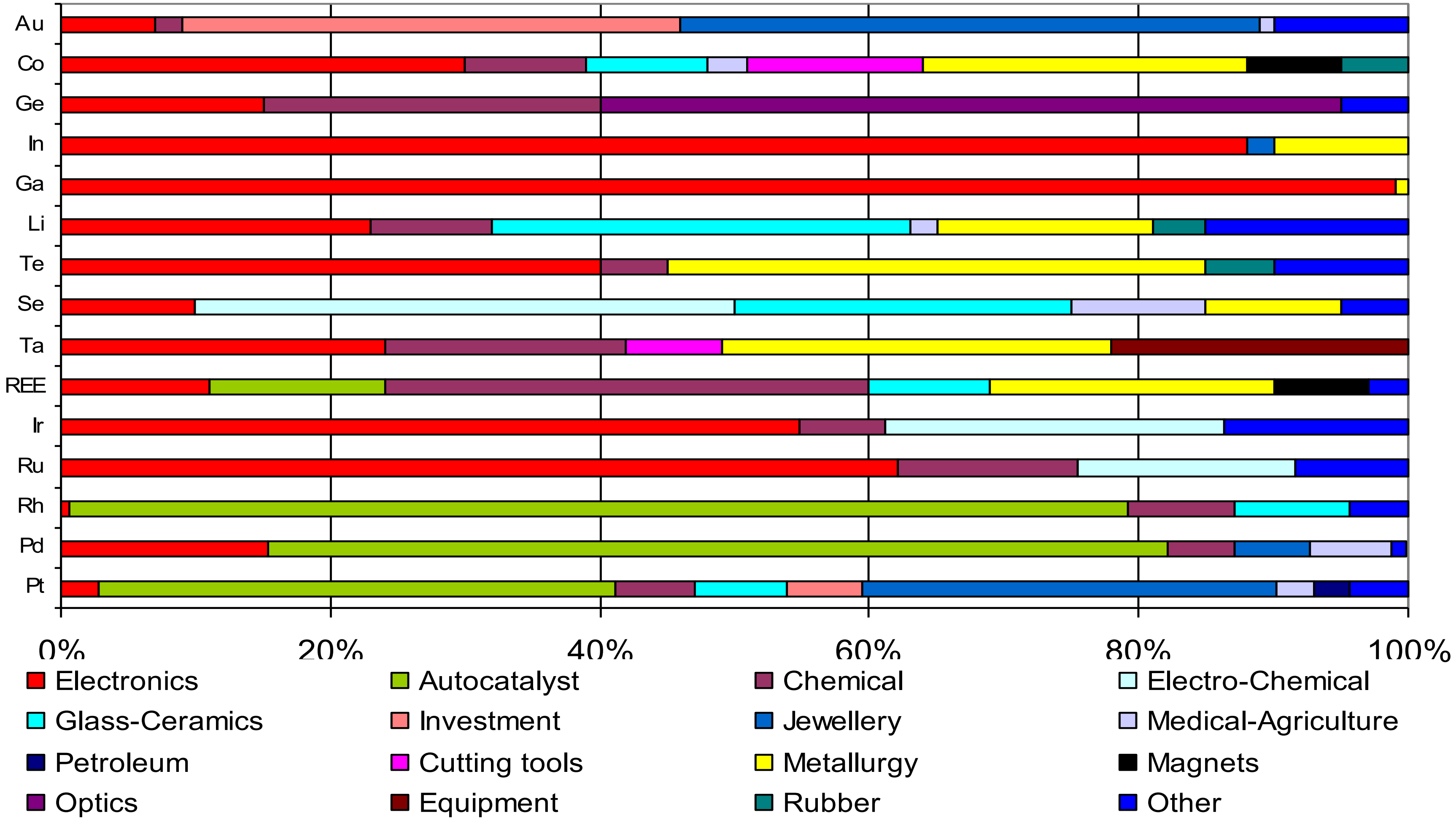
300 Million units	x 1000 mg Ag ≈	300 t Ag
	x 220 mg Au ≈	66 t Au
	x 80 mg Pd ≈	24 t Pd
	x ≈ 500 g Cu ≈	150,000 t Cu
≈140 M batteries[2]	x 65 g Co ≈	9100 t Co

* based on 2008 sales, Gartner 2.3.2009

[1] 20 g Li-ion battery

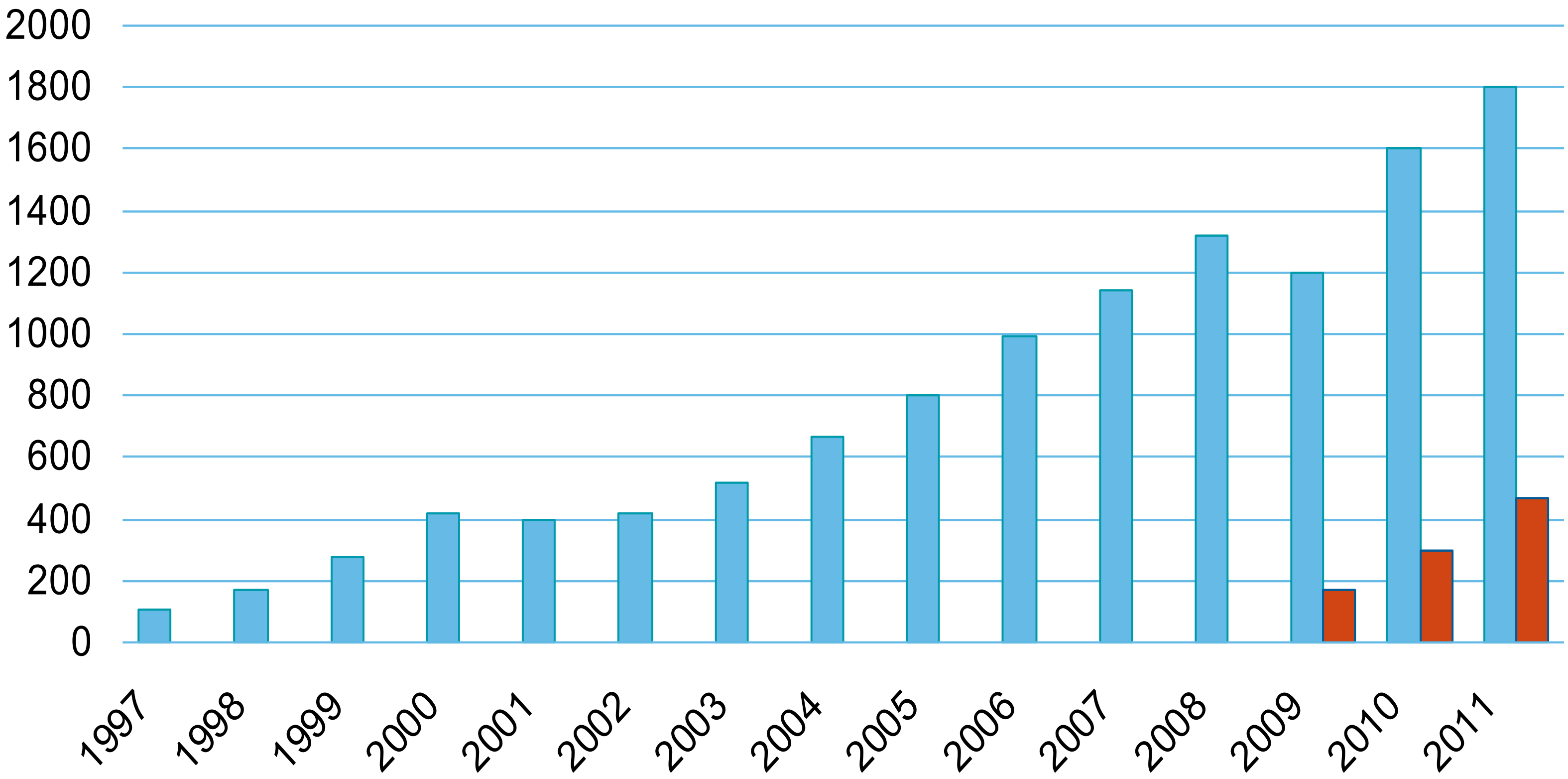
[2] Li-ion batteries is used in >90% of laptops

Impact of Electronics on metal usage



EEE are an increasing metal stock in society

Annual new mobile phone sales and smart phones [million pieces]



Source: based on sales figures from Gartner

Cumulated sales till 2010:	~10 billion units with 2,500 t Ag, 240t Au, 90t Pd, 38,000 t Co and 90,000 t Cu

Urban mining "deposits" can be much richer than primary mining ores

Primary mining

- ~5 g/t Au in ore
- Similar for PGMs

Urban mining

- 200-250 g/t Au in PC circuit boards
- 300-350 g/t Au in cell phones
- 2000 g/t PGM in automotive catalysts

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- Metal Cycles & Markets
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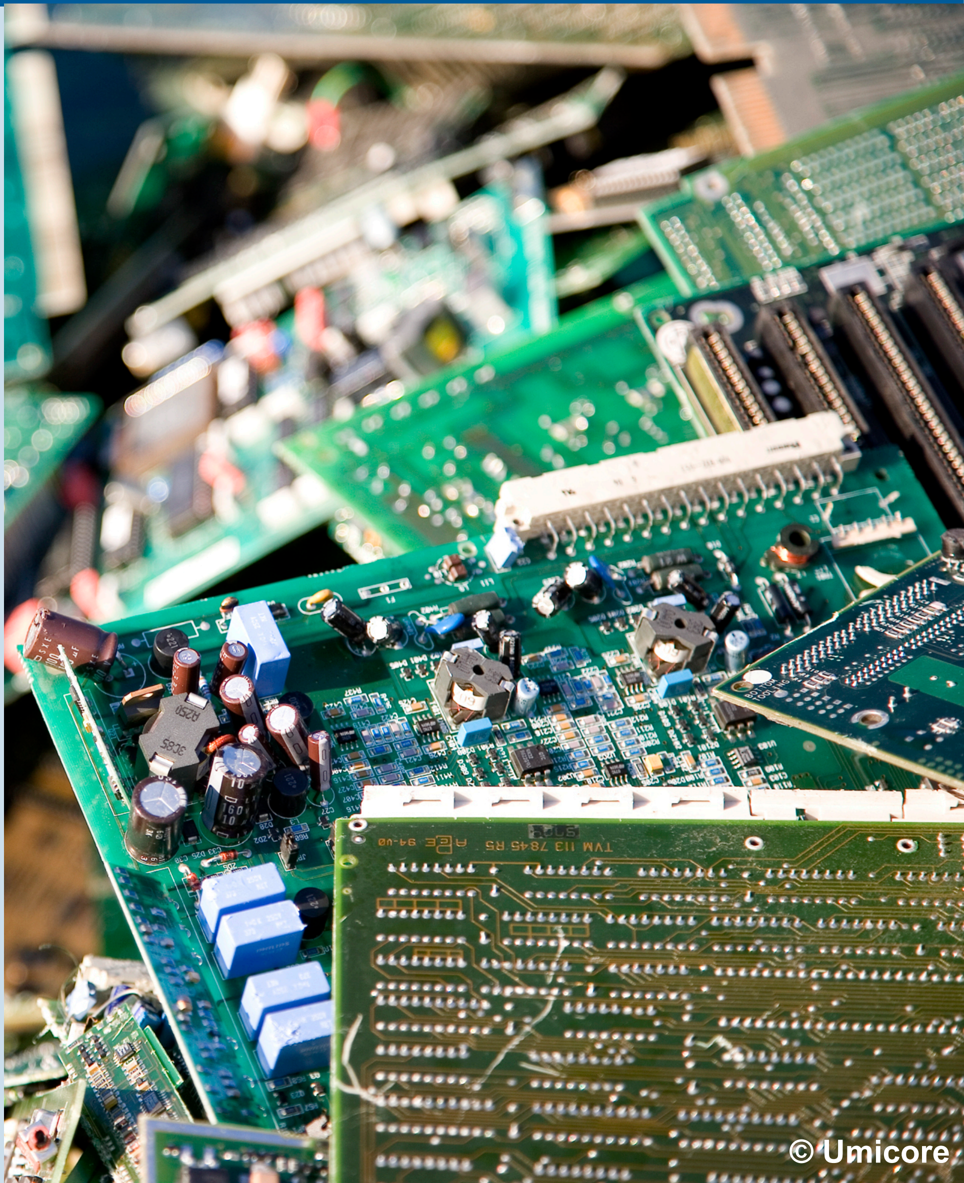
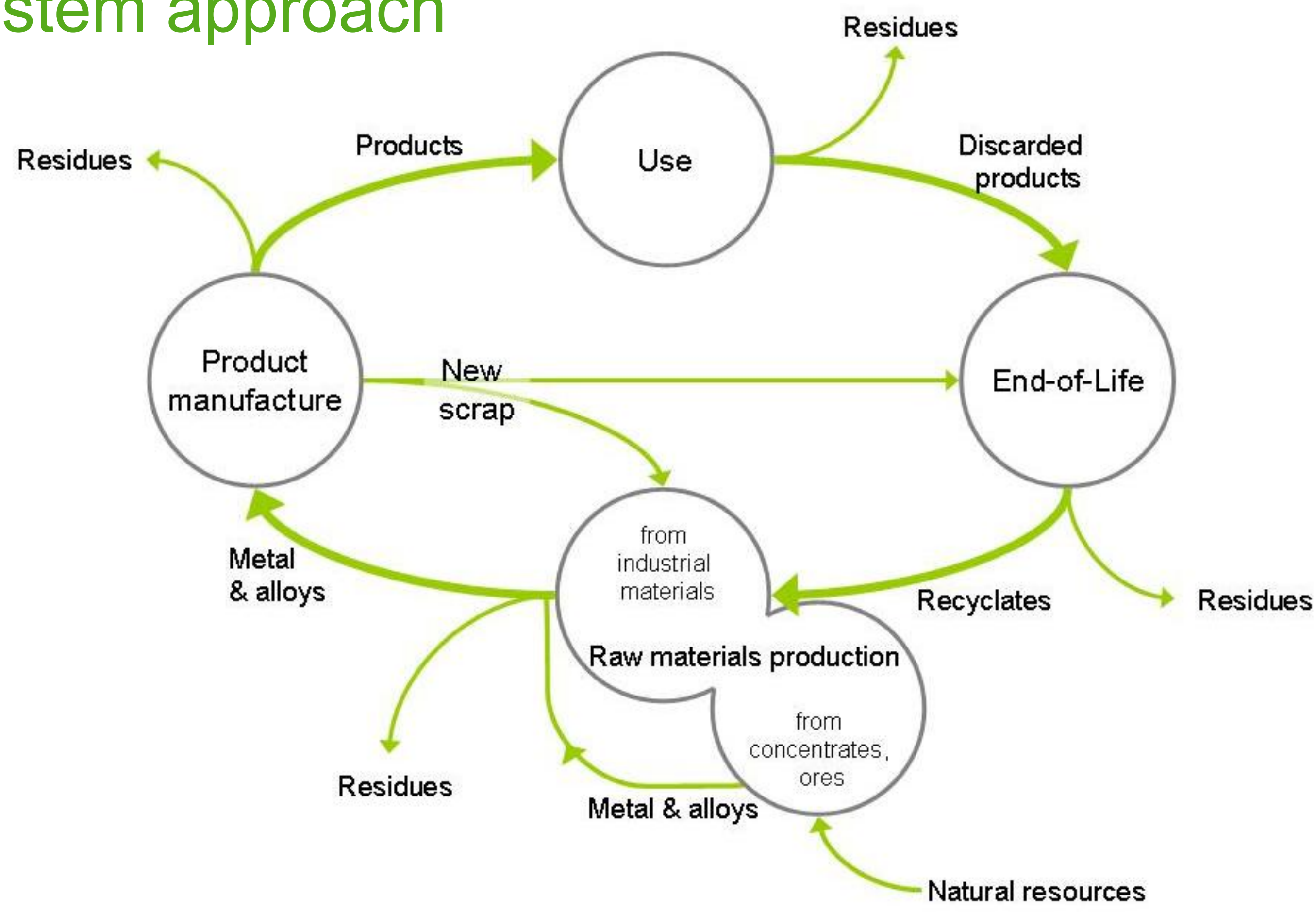


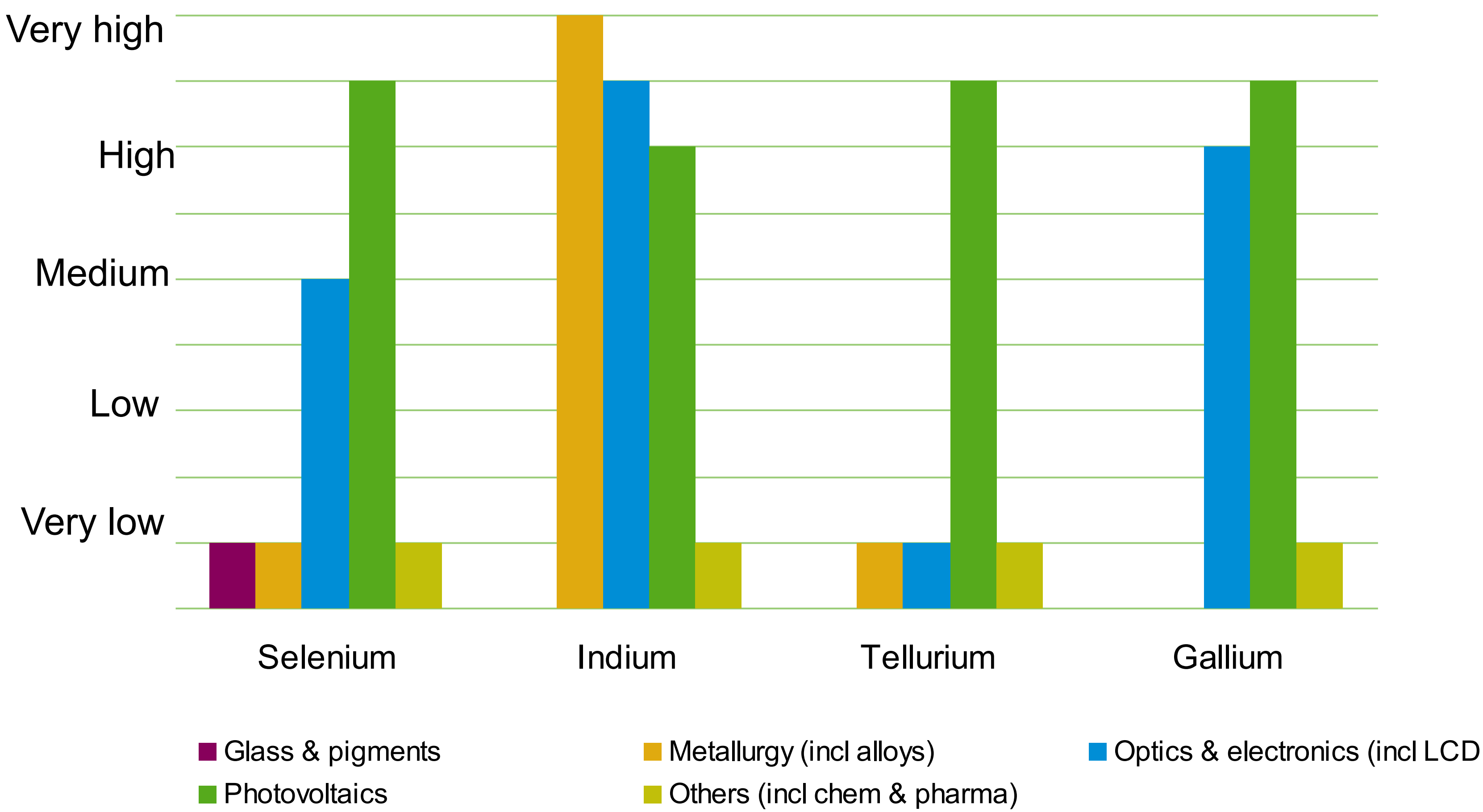
Materials cycle
system approach



Source: C.E.M. Meskes: *Coated magnesium, designed for sustainability?*, PhD thesis Delft University of Technology, 2008

Recycling of production waste

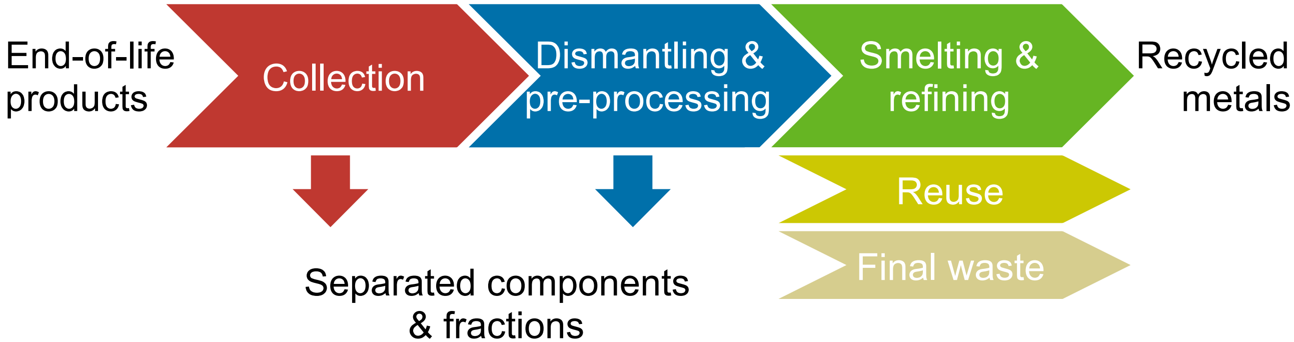
recycling potential in 2010



Source: K. Van den Broek *Exploring the challenges in closing the loop for special metals.* Minor Metals & Rare Earths 2010

Recycling of End-of-Life devices

System approach is key



- Consider the entire chain & its interdependences
- Precious metals dominate economic & environmental value ⇒ minimise PM losses
- Mass flows ≠ flows of technology metals
- Success factors ⇒ interface optimisation, specialisation, economies of scale

⇒

The total recycling efficiency is determined by the weakest step in the chain

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What are the reasons for the differences in gold recovery rate ?

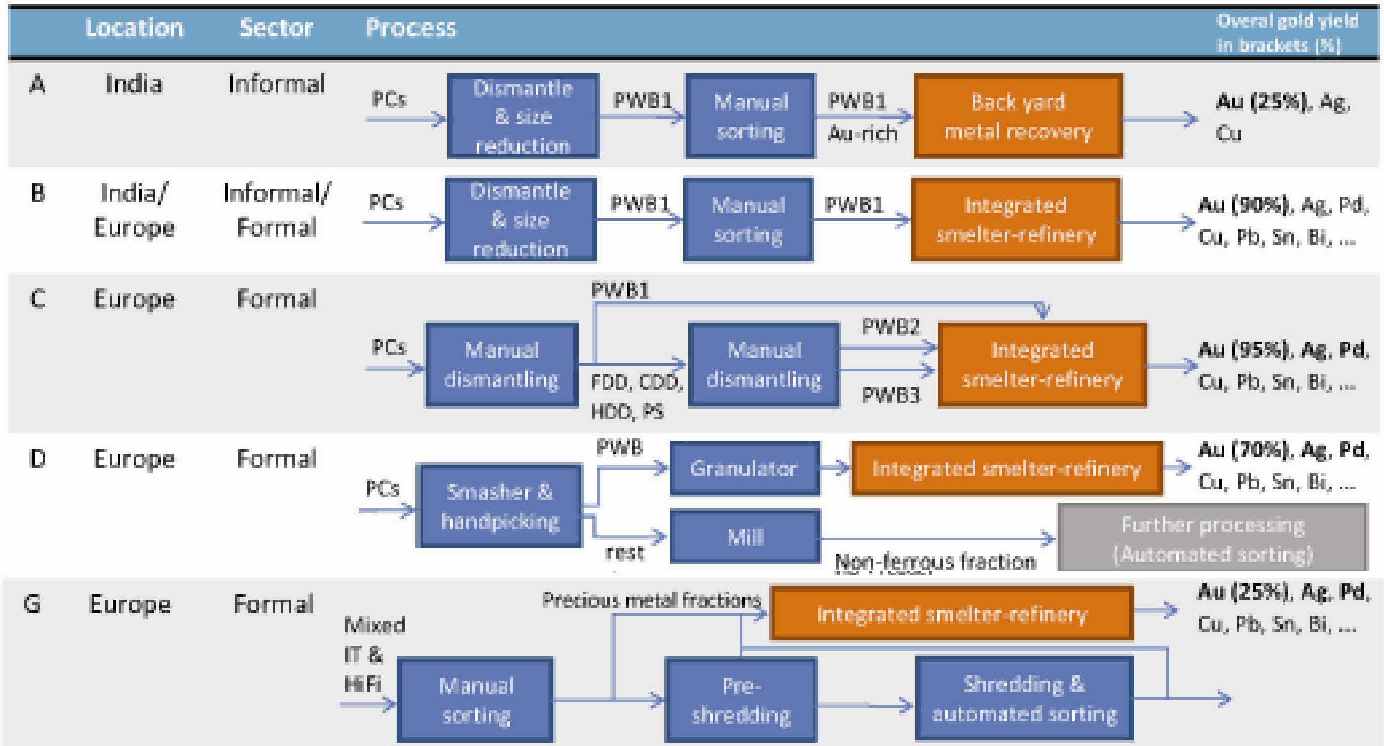
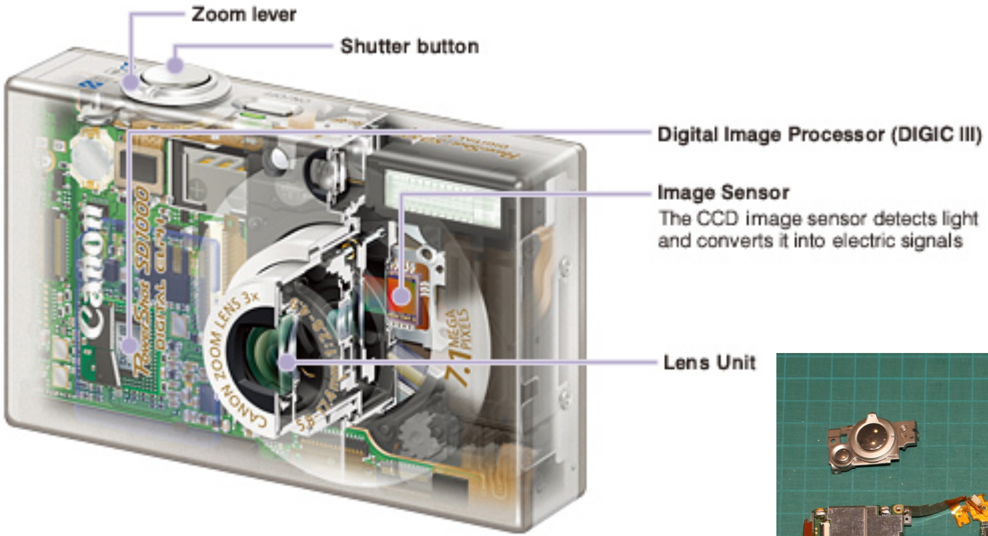
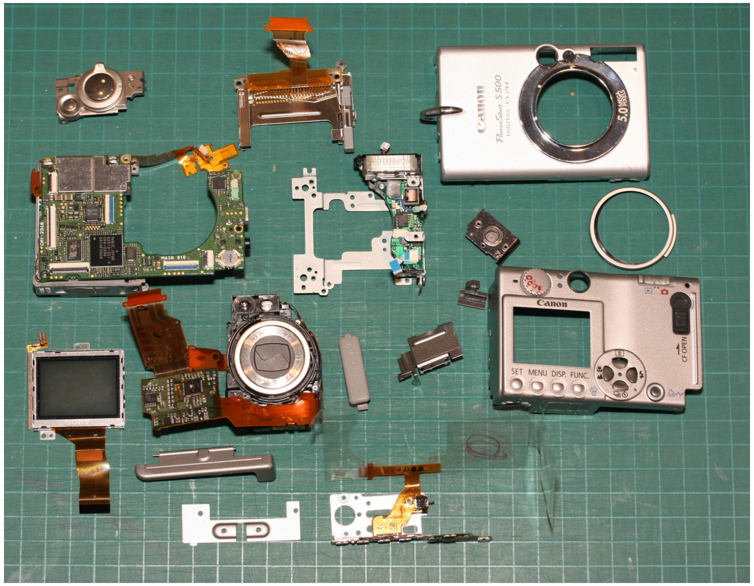


Figure 1: Pre-processing and end-processing routes investigated in the projects. PWB1 = motherboards, video cards. PWB2 = from floppy disk drive (FDD), hard disk (HDD) and CD/DVD drive (CDD). PWB3 = from power supply (PS). A and B: Rochat et al. 2007, Keller 2006. C and D: Salhofer 2009, Meskers et al. 2009. E and F: Gmünder 2007. G: Chancerel et al. 2008.

Source: C.E.M. Meskers, C. Hagelüken *The impact of different pre-processing routes on the metal recovery from PCs.* R'09

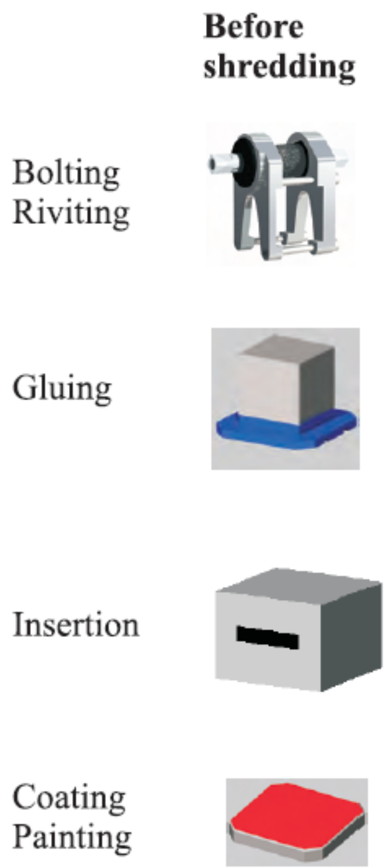
Product complexity





Material linkages in products

In devices the materials are connected in different ways



Source: M.A. Reuter, U. Boin, A. van Schaik, E. Verhoef, K. Heiskanen, Y.Yang, G. Georgalli: *The metrics of material and metal ecology*, Elsevier, Amsterdam, 2005

Metal linkages in consumer products

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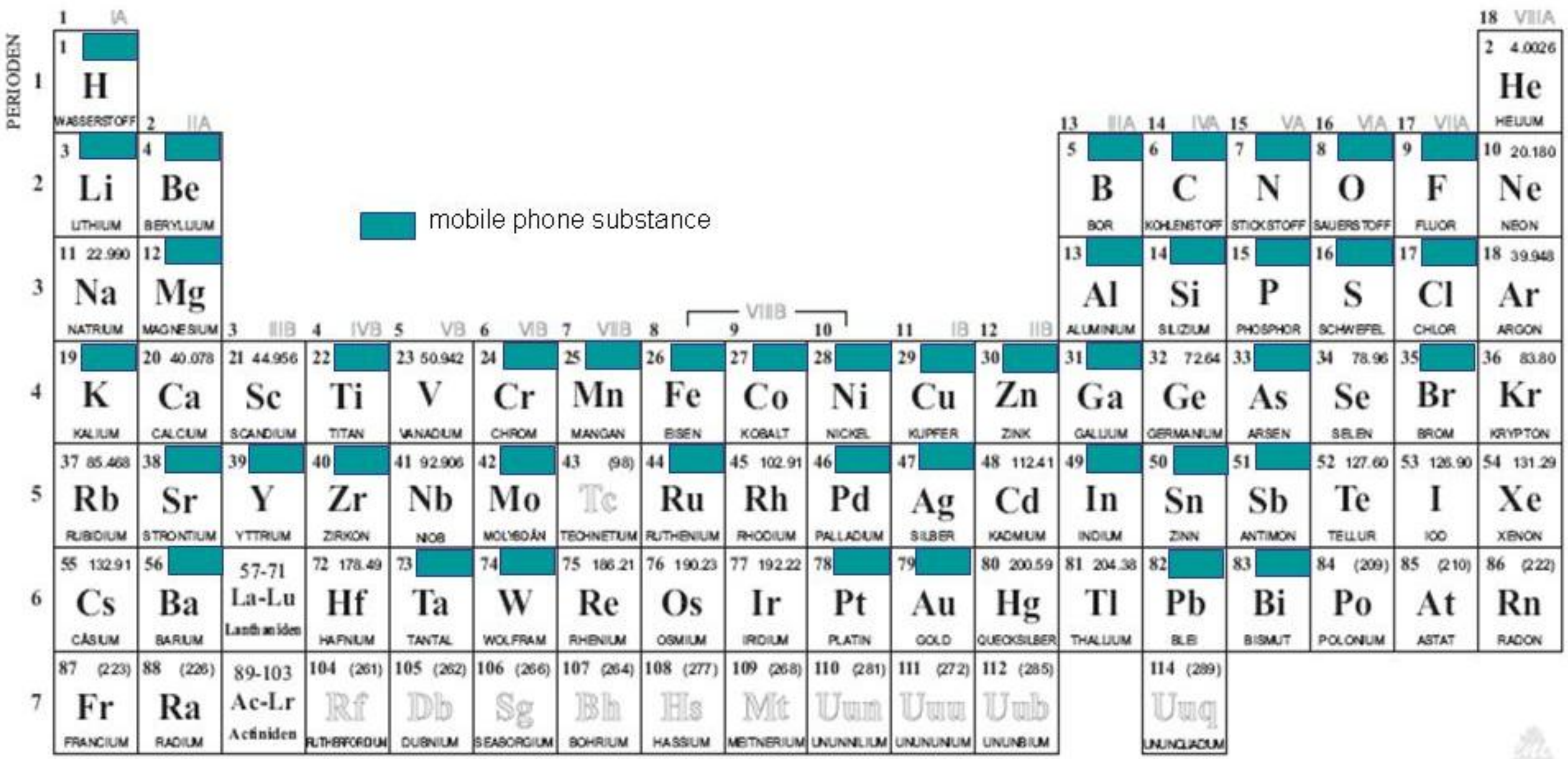

What is the objective of the processing of End-of-Life devices ?

To create recyclates that

- concentrate the metals in the ‘right’ recyclate for recovery in appropriate process
- meet the quality specifications for treatment in metal recovery processes !

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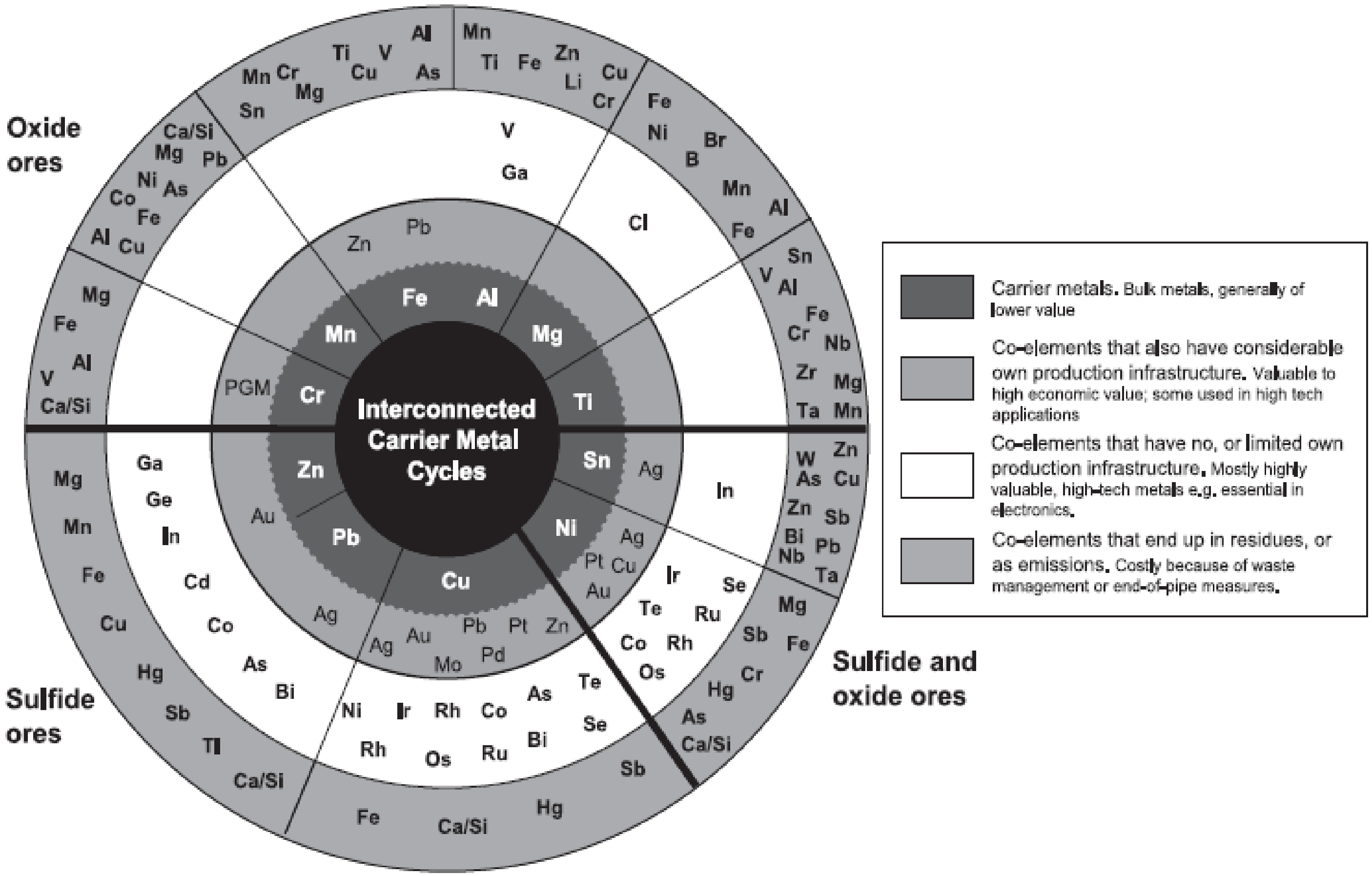
Metal linkages in nature

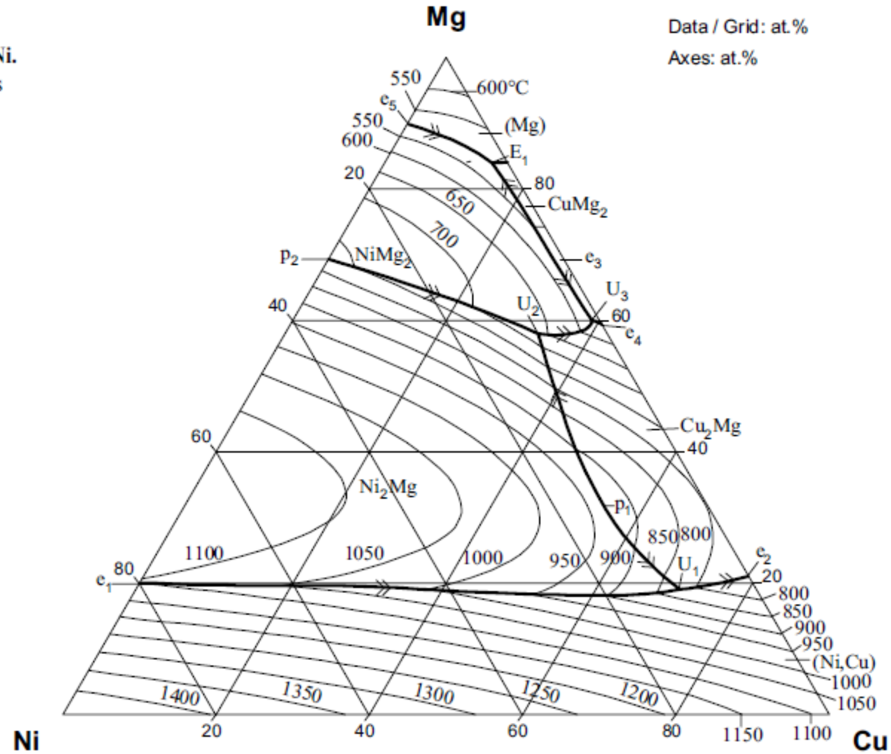
Metallurgical processes have their roots in nature (primary metal ores)

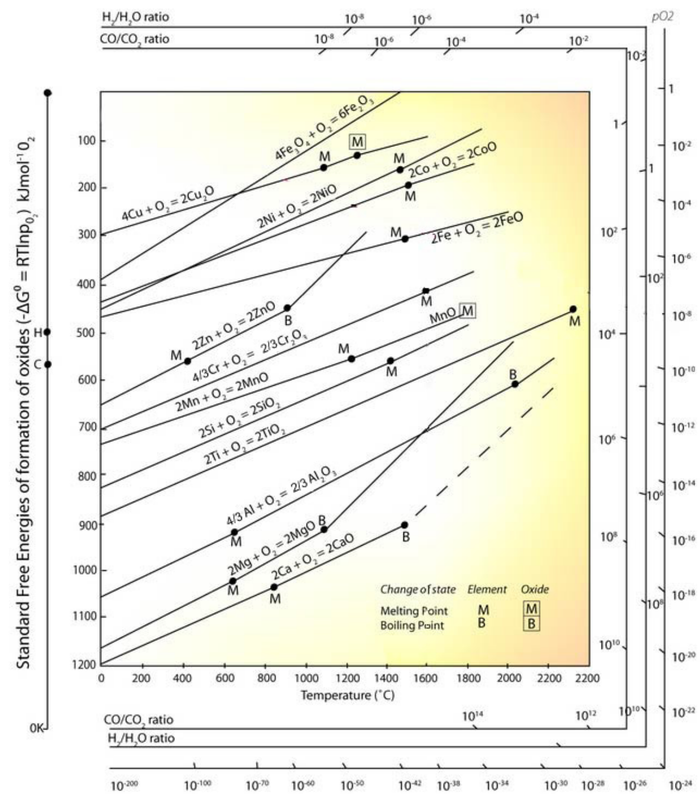


Source: M.A. Reuter, U. Boin, A. van Schaik, E. Verhoef, K. Heiskanen, Y.Yang, G. Georgalli: *The metrics of material and metal ecology*, Elsevier, Amsterdam, 2005

Thermodynamics is the basis

Fig. 4: Cu-Mg-Ni. Calculated liquidus surface





Phase diagrams (left) show which compounds and how much in the mix are present at a certain temperature. Ellingham diagrams (right) indicate which chemical reaction can take place at certain temperature.

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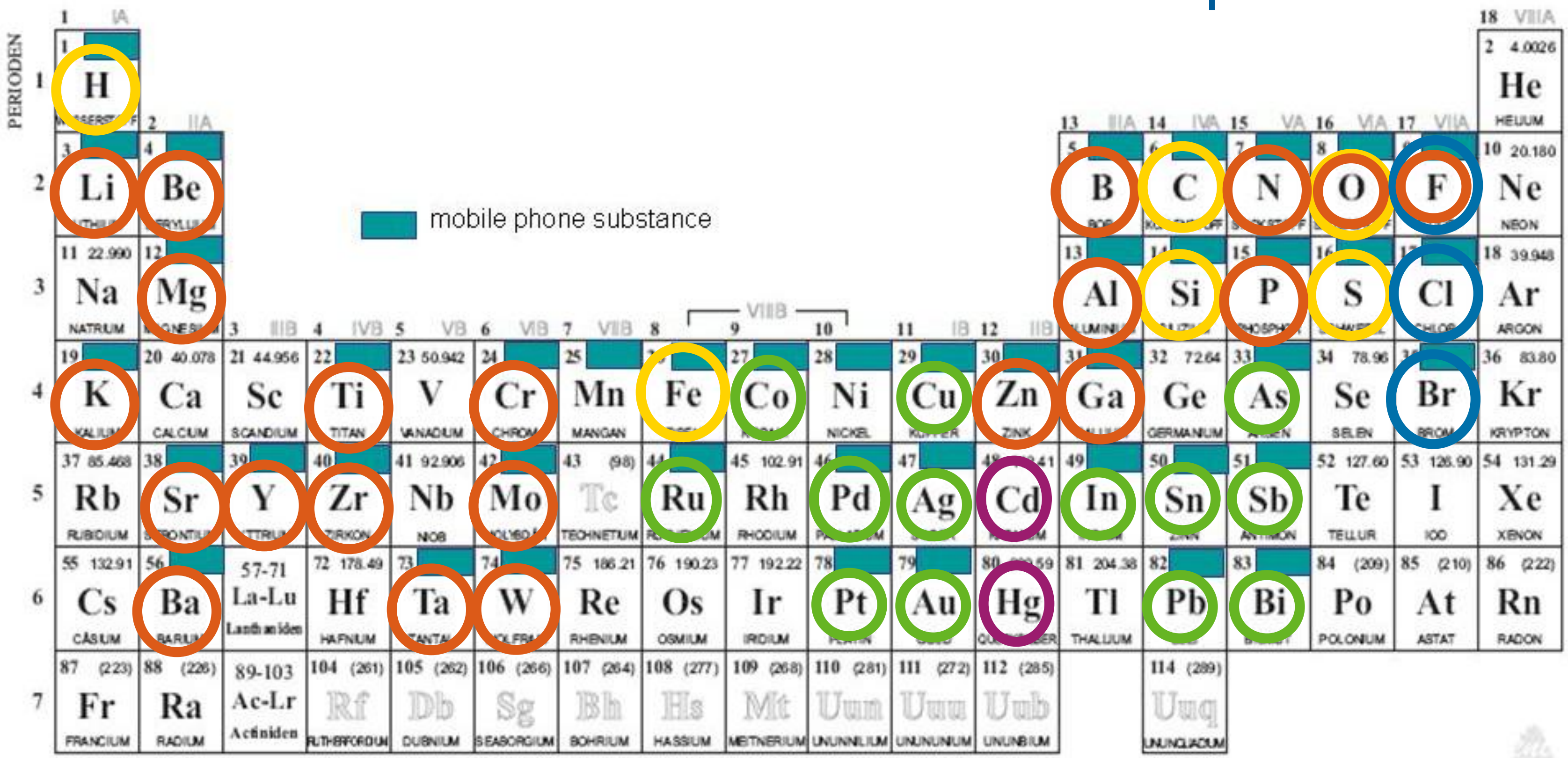
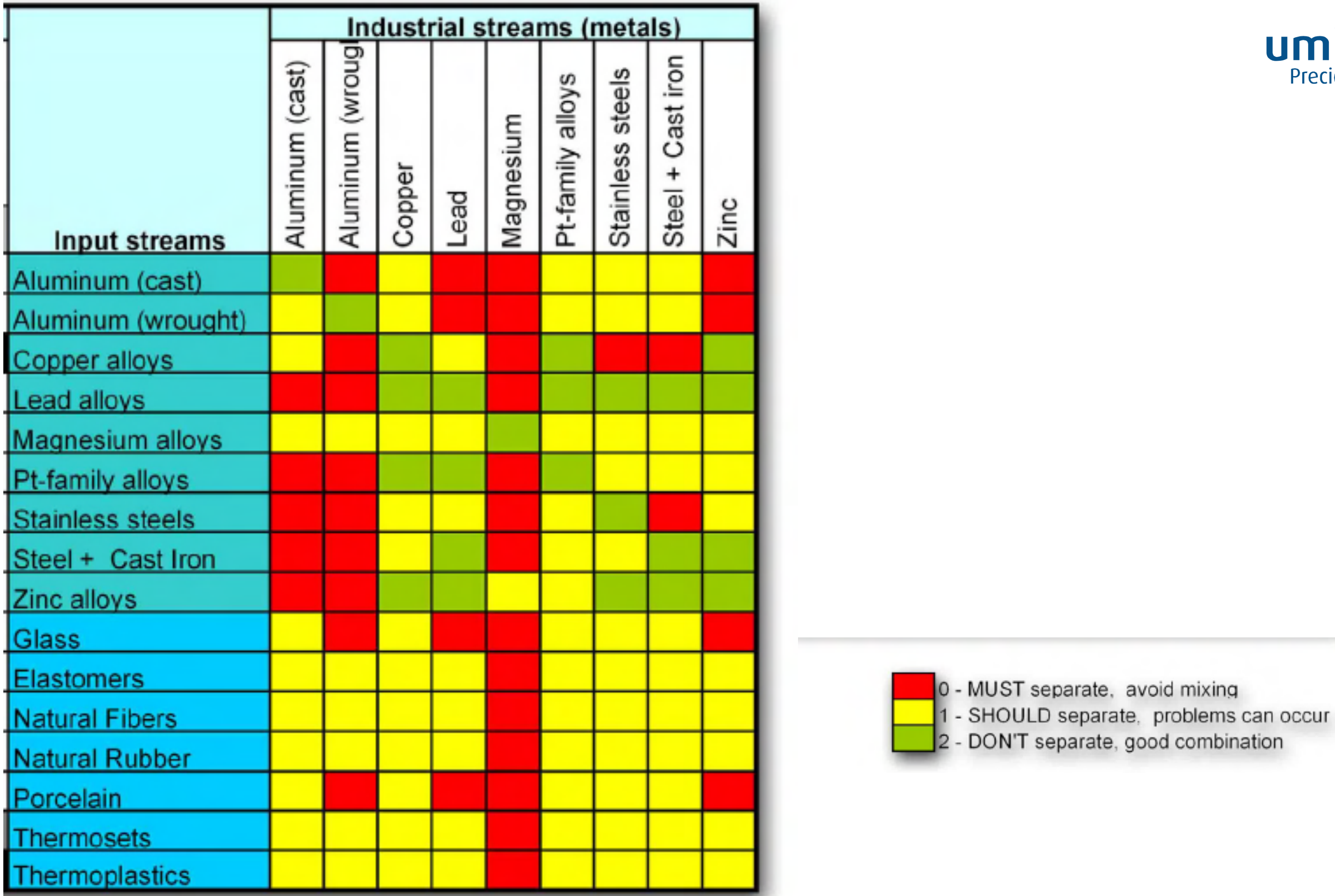
Destination of the elements in Umicore process



Umicore output

- Chemical use as process additive
- Transfer into an inert slag (product)
- Metal
- Isolation & safe deposit
- Neutralized in effluent



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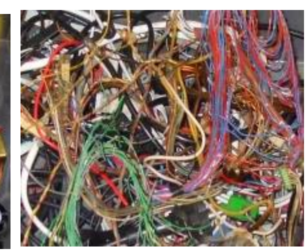
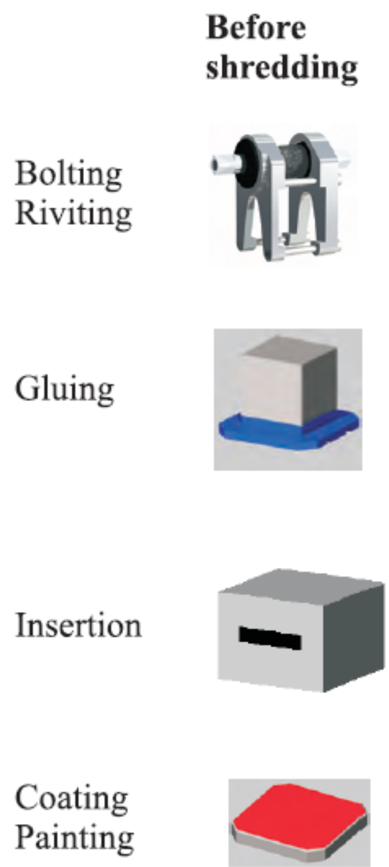
Manual dismantling generates fractions like these



Sufficient liberation to achieve recyclate quality?
Manual dismantling is labor intensive !

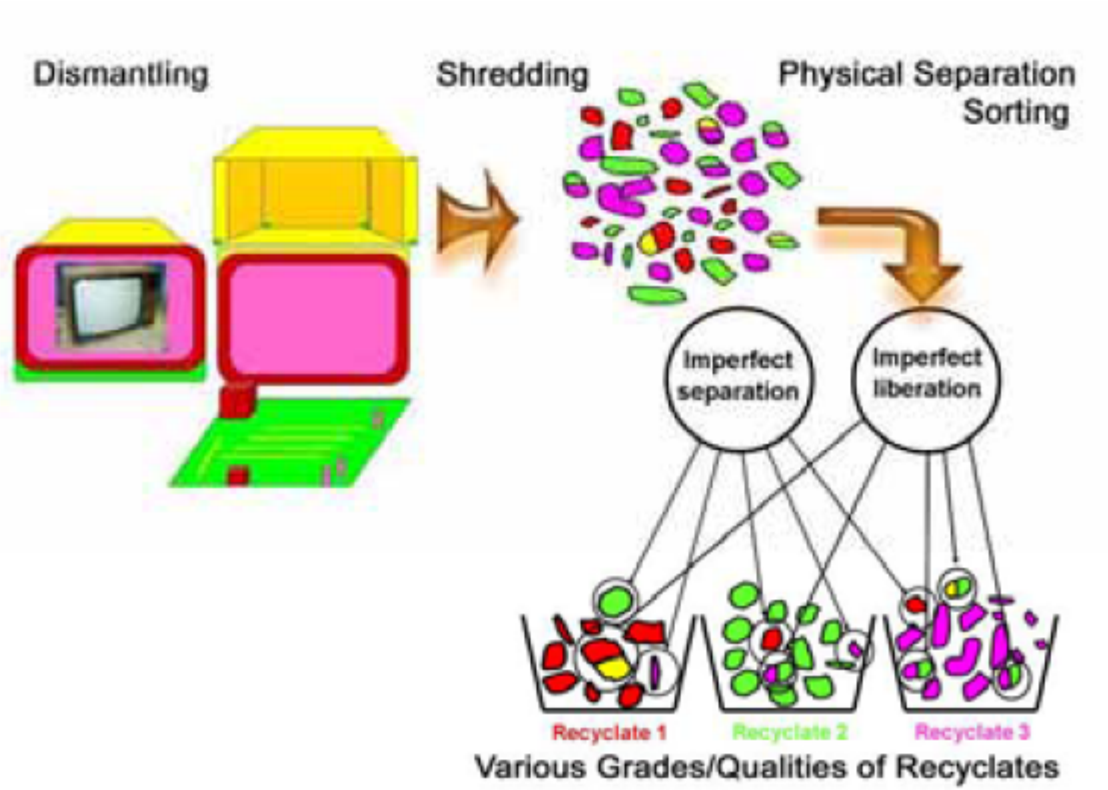
Mechanical pre-processing

- It requires good liberation to separate substances
- Separation efficiency influenced by used technology and type of material connections
- Full liberation of all particles is impossible to achieve *and*
- Becomes more difficult for complex materials like circuit boards



Source: M.A. Reuter, U. Boin, A. van Schaik, E. Verhoef, K. Heiskanen, Y.Yang, G. Georgalli: *The metrics of material and metal ecology*, Elsevier, Amsterdam, 2005

Product design and liberation in relation to physical separation efficiency



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Source: Slide from Antoinette Van Schaik - MARAS

Mechanical pre-processing

grade recovery curve

Liberation:

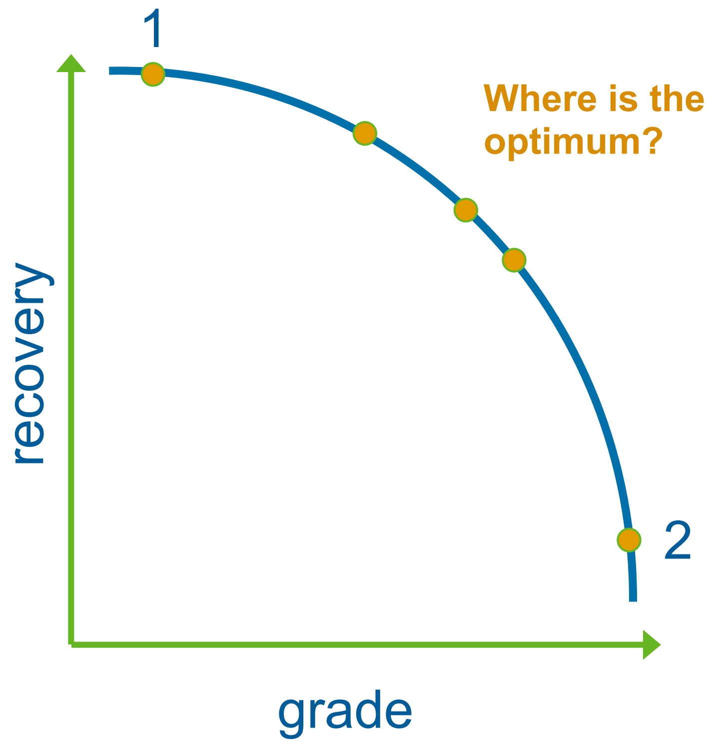
- Complete liberation of all particles is impossible and increasingly difficult for complex materials.

Sorting:

- Overlap of properties → loss of selectivity
- Incomplete liberation → unintended co-separation

Grade-recovery optimum →

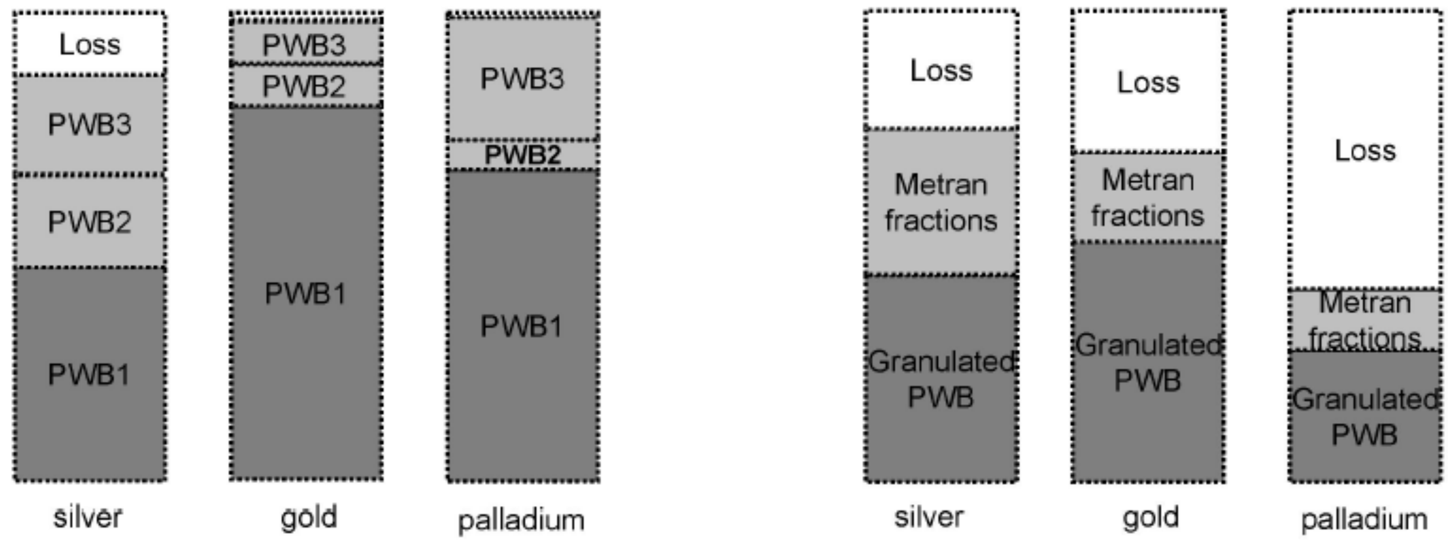
Its impact becomes larger with complex materials!



1. Low grade, high recovery = a lot of mixed material
2. High grade, low recovery = small amount of very pure material

Mechanical pre-processing

Do all metals behave in the same way?



Manual dismantling **Mechanical process** .

Silver about half is in power supply and drives PWB (PWB 2 & 3), which are not liberated during 1st dismantling or during smashing.

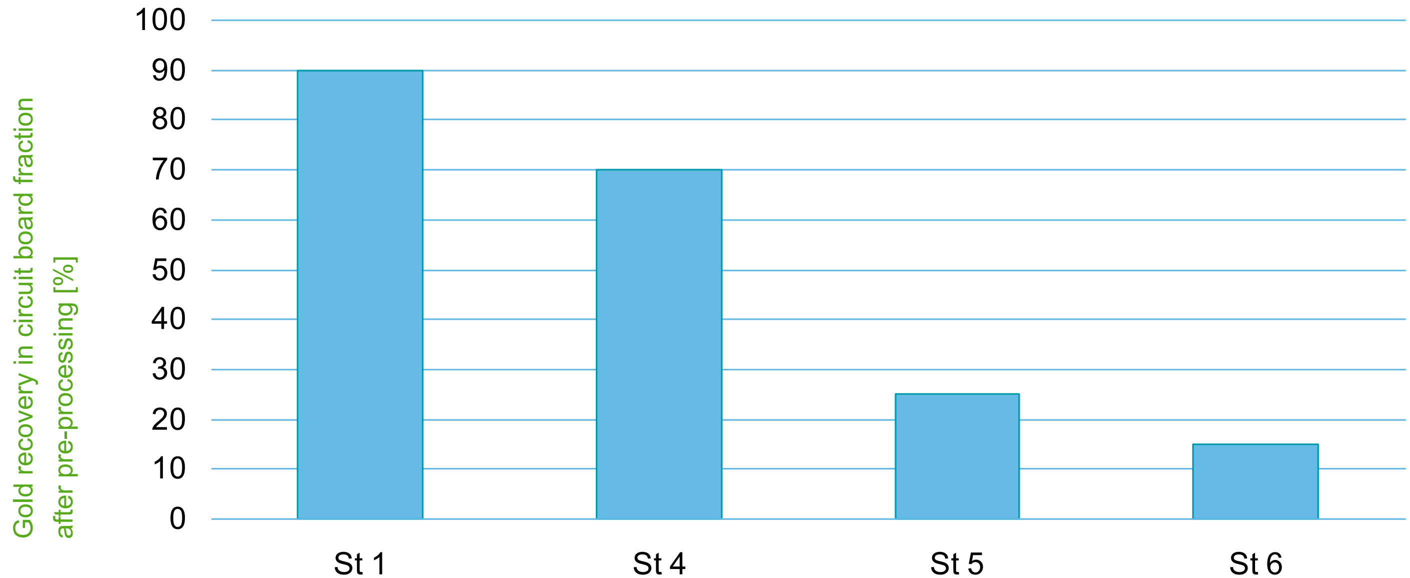
Gold used for plating, contacts and ceramic ICs (predominantly in motherboards PWB1), so could get lost during smashing and granulation.

Palladium used in ceramics is mostly influenced by the process, due to losses in dust fractions.

Source: C.E.M. Meskers et. Al: *Impact of pre-processing routes on precious metals recovery from PCs*. European Metallurgical Conference ‘09

Pre-processing

Choice of pre-processing technology strongly impacts Au recovery rates



Study	Reference	Process description	Input
St 1	Chancerel & Rotter 2008	Manual pre-processing	176 kg of IT & consumer eq.
St 4	Meskers et al. 2009	Low intensity mechanical pre-processing	1.4 tons of PC
St 5	Chancerel et al. 2009	High intensity mechanical pre-processing	27 tons of IT & consumer eq.
St 6	Van Schaik & Reuter 2009	High intensity mechanical pre-processing	Not indicated

Source: Rotter et al. Elektronik Ecodesign Congress München (Oct.2009)

Pre-processing

mass recovery focus or value recovery focus?

PC pwb	Plastics	Fe	Al	Cu	Ag	Au	Pd	Sum
Mass [% or ppm]	23%	7%	5%	18%	1000	250	100	
Value [%]		0%	1%	14%	5%	65%	14%	84%

Mobile Phone	Plastics	Fe	Al	Cu	Ag	Au	Pd	Sum
Mass [% or ppm]	56%	5%	2%	13%	3500	340	130	
Value [%]		0%	0%	7%	13%	67%	12%	92%

TV pwb	Plastics	Fe	Al	Cu	Ag	Au	Pd	Sum
Mass [% or ppm]	28%	28%	10%	10%	280	20	10	
Value [%]		9%	13%	37%	7%	27%	6%	40%

Calculator	Plastics	Fe	Al	Cu	Ag	Au	Pd	Sum
Mass [% or ppm]	61%	4%	5%	3%	260	50	5	
Value [%]		1%	7%	12%	7%	70%	3%	80%

End-processing

used technology has large impact on recovery efficiency

- Recovery of metals on g/t level is challenging
- Thermodynamics contraints determine what is possible in metallurgical processes.

Back yard recycling:

- Low efficiency: ~25% Au recovery
- Plus some Cu and Ag recovered
- High environmental impact
- Not environmentally sound
- Often in developing countries

Integrated smelter:

- High efficiency: >95% Au recovery
- Total 17 metals recovered
- Low environmental impact
- Environmentally sound
- Located in developed countries

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Technical factors
become environmental issues

Harmful substance emissions:

1. From the product itself:
   Pb in Printed Wiring Boards or CRT Glass,
   Hg in LCD backlights, …
2. Due to substandard processes:
   Dioxin formation during burning of halogenated plastics
   or use in smelting processes without suitable off gas treatment.
3. Of reagents used in the recycling process:
   Cyanide and other strong acids
   NOx gas from leaching processes
   Hg from amalgation

Even the perfect 'green' product can result in harmful substance emissions when it is recycled in an environmentally unsound process.

From pre-processing to end-processing

Described based on physical properties

Described based on chemical compounds/elements

Circuit boards & cables

Cu, Pb, Sn, Al, Ag, Au, Pd-oxide, Si, C_yH_x, Br, Sb_2O_3, $BaSO_4$, TiO_2

Mixed non-ferrous

Al, Si, Cu, Zn, Pb, Sn, …

Steel

Fe, Ni, Cr, …

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Room for improvement in the recycling chain

Example of gold recycling

Collection		Dismantling & pre-processing		Smelting & refining		
						
80%	X	50%	X	50%	=	20%
						
50%	X	25%	X	95%	=	12%

Are we doing much better in "the West" today?

Figures are illustrative

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Recycling is more complex than in the world of WALL-E.

Trade-offs will be necessary.

From: Disney/Pixar www.wall-e.com

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Integrated smelter-refinery

Best available technology focussed on secondary precious metal materials

Feed: 350 000 t complex PM-bearing materials
Output: 70,000 t of 17 different metals
of which >> 1000 t precious metals

Recovered metal value (2007):
$2,600 million precious metals,
others $400 million

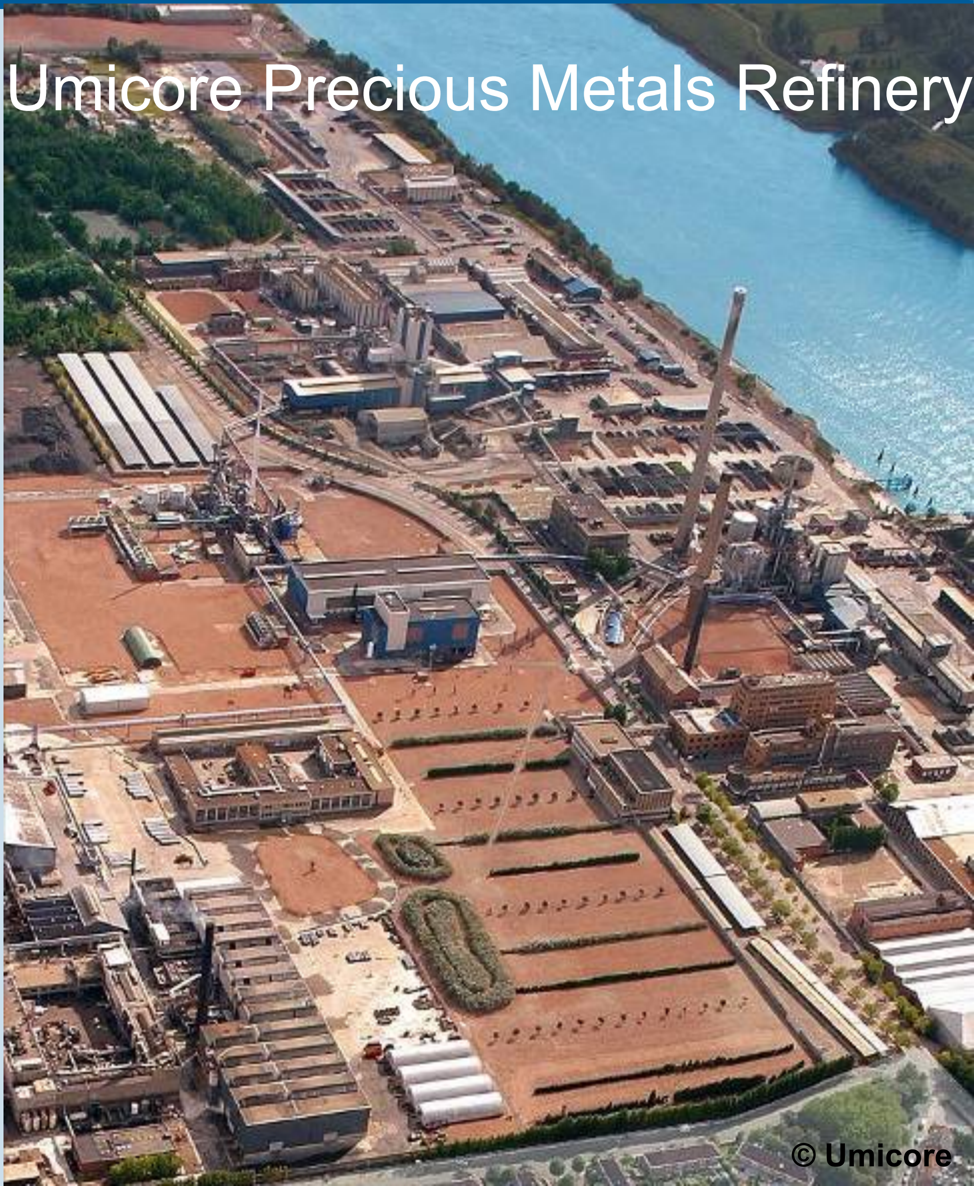
Precious metal recovery yield over 95%

Highest standards: ISO 14001 (environment), ISO 9001 (quality) & OHSAS 18001 (safety)

Minimizing waste (< 5%)

Land area: 116 ha

The integrated smelter-refinery represents an > € 1 billion investment, and over € 400 million has been invested in the last 12 years.



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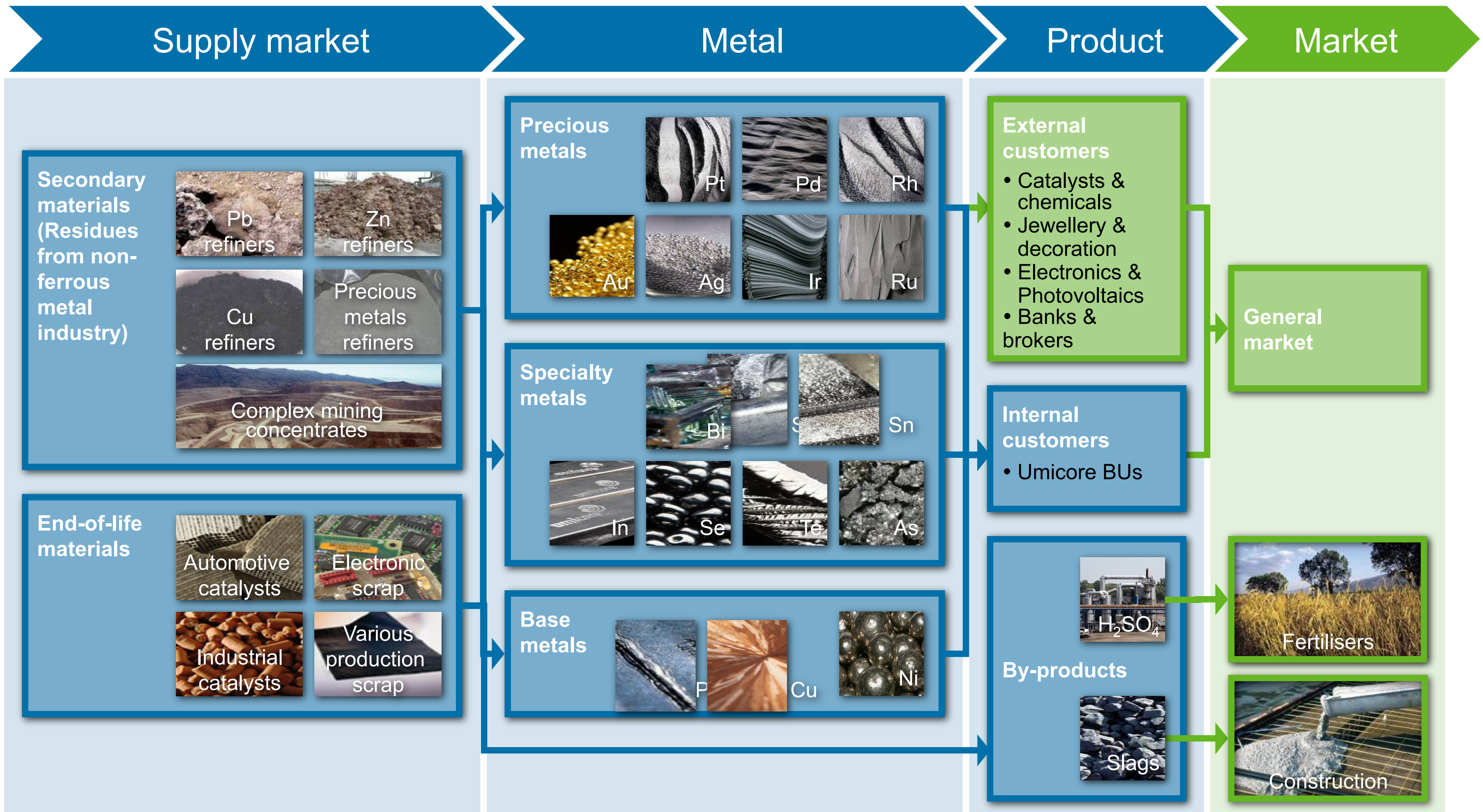
Supply streams and metal output



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Metal and derivated products

Silver (Ag)

2,400 t/y capacity

Gold (Au)

100 t/y capacity

Palladium (Pd)

25 t/y capacity

Platinum (Pt)

25 t/y capacity

Rhodium (Rh)

5 t/y capacity

Lead (Pb)

100,000 t/y capacity

Nickel (Ni)

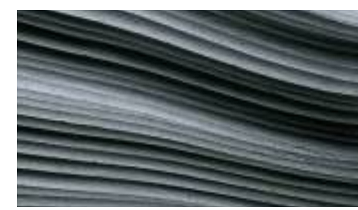
2,000 t/y capacity

Copper (Cu)

30,000 t/y capacity

Iridium (Ir)

Ruthenium (Ru)



Indium (In)

50 t/y capacity

Selenium (Se)

600 t/y capacity

Tellurium (Te)

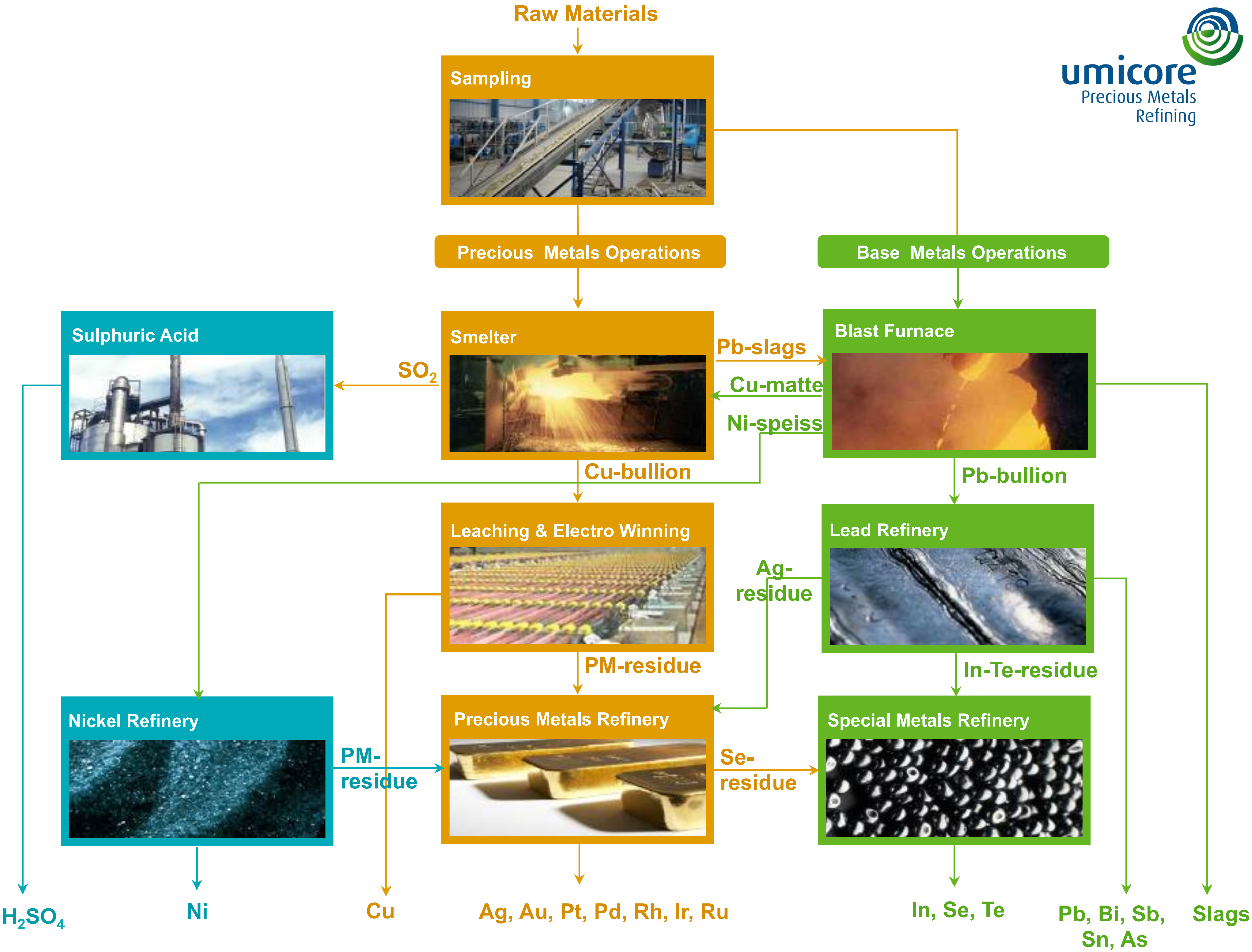
150 t/y capacity

Aggregate

140,000 t/y capacity

Sodium antimonate

6,000 t/y


Raw Materials
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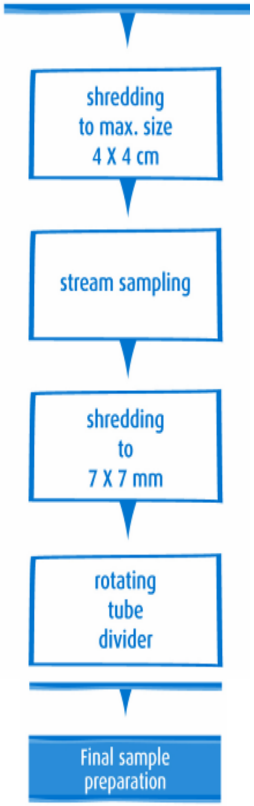
Precious Metals
Refining
Sampling
Precious Metals Operations
Base Metals Operations
Sulphuric Acid
SO_2
Smelter
Pb-slags
Cu-matte
Ni-speiss
Blast Furnace
Cu-bullion
Pb-bullion
Leaching & Electro Winning
Lead Refinery
Ag-
residue
PM-residue
In-Te-residue
Nickel Refinery
PM-
residue
Precious Metals Refinery
Se-
residue
Special Metals Refinery
H_2SO_4
Ni
Cu
Ag, Au, Pt, Pd, Rh, Ir, Ru
In, Se, Te
Pb, Bi, Sb,
Sn, As
Slags

Sampling and assaying

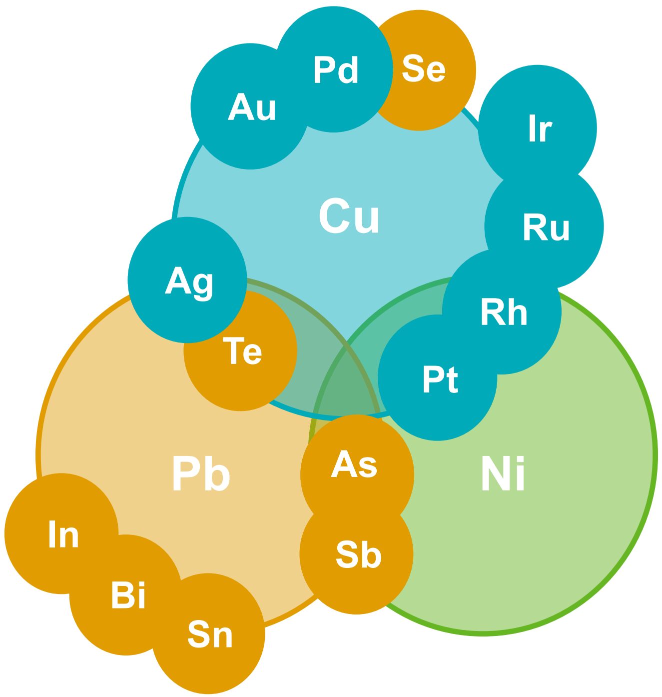
- Determination of exact composition by representative sampling is a key factor:
  - Leads to correct financial settlement with supplier of material.
    ► precious metals are present in small amount with high value.
  - Enables selection of optimum processing route for material.
    ► optimum metals recovery.
  - Monitoring of operations.
  - Automation where possible.
- State-of-the-art facilities and procedures processing ~ 8000 lots (350 000 t) per year.



Metallurgy is our toolbox

…for treating complex materials

- Pb, Cu & Ni are our collector metals.
- Using the specific chemical properties and affinities of metals, precious & other metals are separated and recovered with the greatest efficiency.
- The in-house developed Precious Metals Refinery is optimized to deal with complex materials like e-scrap.
- The share of End-of-Life materials in the feed is continuously increasing. The remainder is by-products of the non-ferrous industry.



a unique metallurgy

Copper smelter

Copper electrowinning

Silver, gold, rhodium

Copper smelter

- IsaSmelt technology
- Treats up to 1000 tons of material per day.
- Operating temperature ~ 1200 °C.
- Smelting and converting in one furnace.
- Good understanding, control and prediction of process parameters such as feed composition, metal composition, slag composition and properties, temperature etc. ensures optimum operation and efficiency.

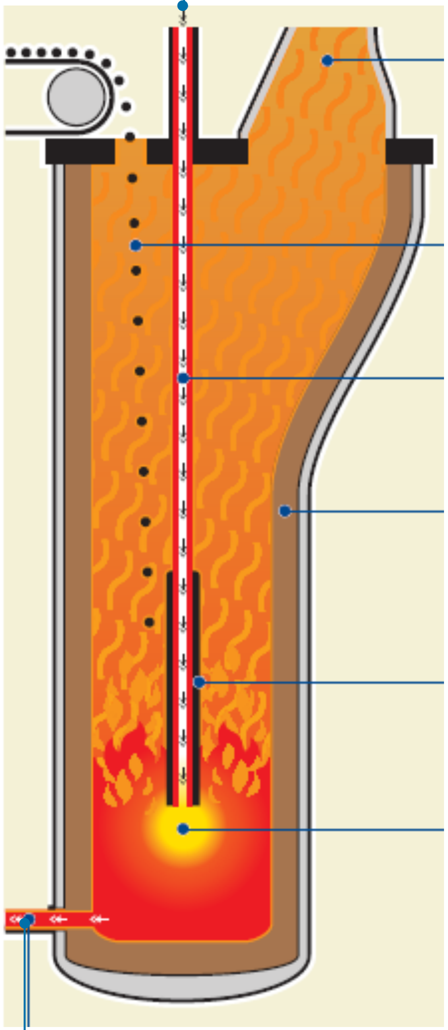
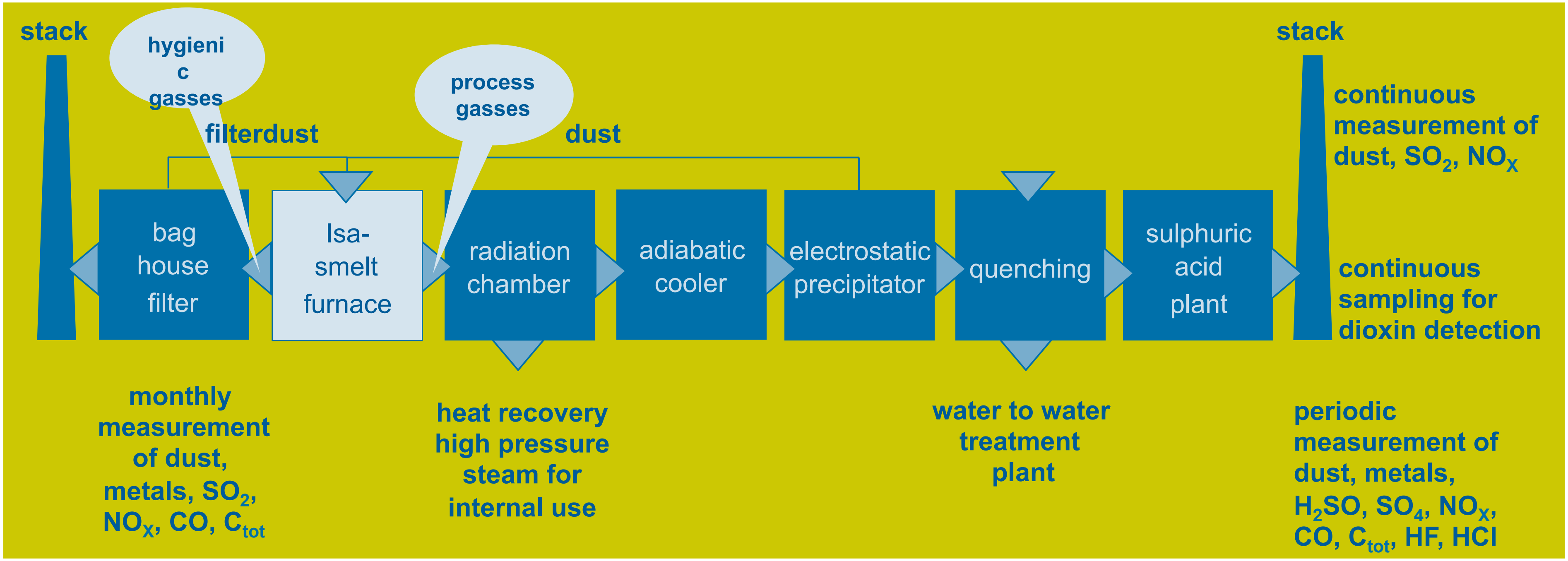


Image: Xstrata Technology About Isasmelt brochure

Smelter – off gas control & heat recovery

- Umicore's IsaSmelt process can efficiently cope with complex mixtures of metals and plastics as present in circuit boards.
- These plastics can partially substitute coke and fuel ▸ feed stock recycling.
- Formation and emission of dioxins is prevented by using appropriate smelter process conditions and presence of extensive offgas treatment.



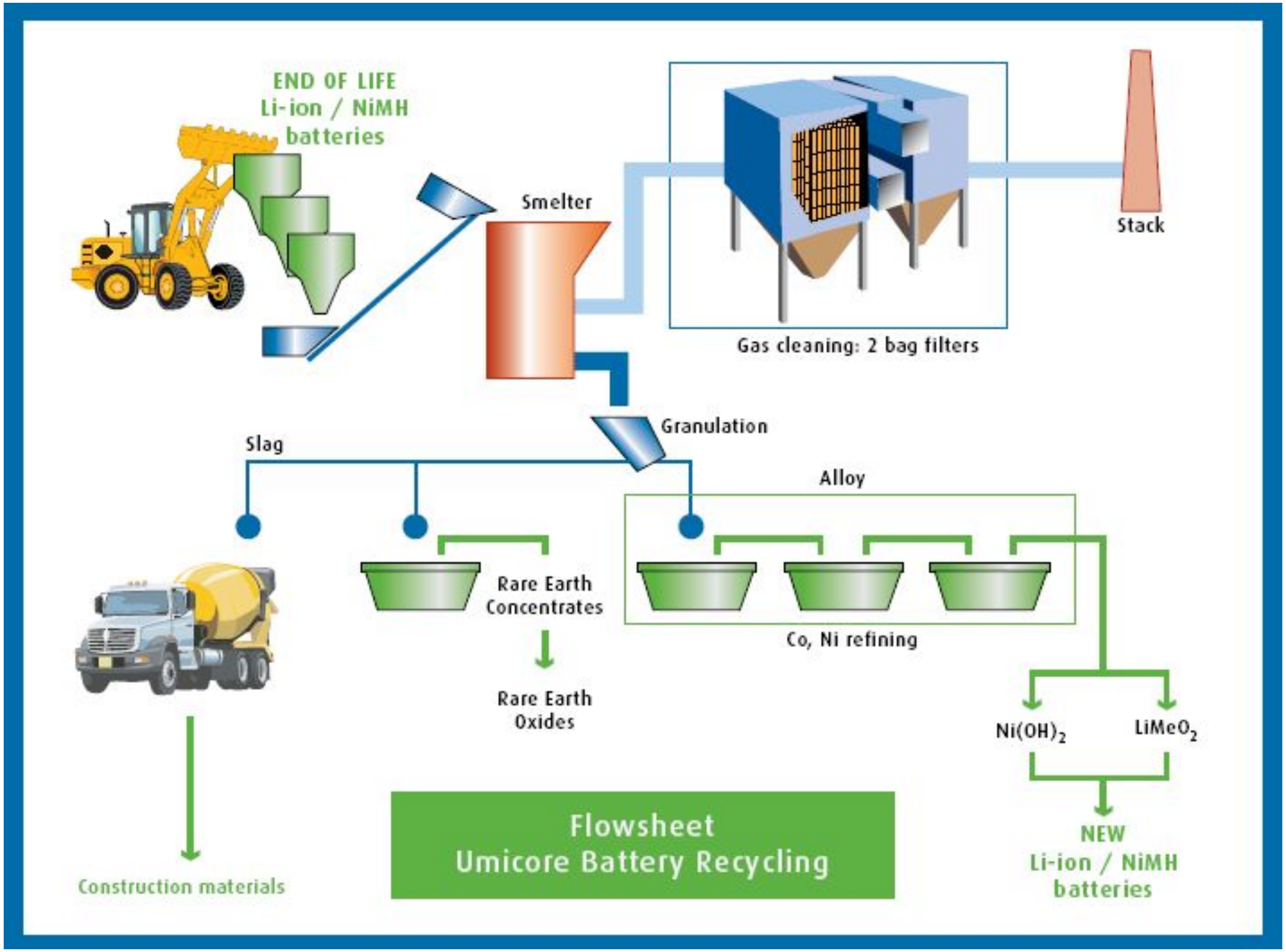
- Exploring Umicore
- Metal Cycles & Markets
- Dimensions of e-scrap recycling
- e-Scrap recycling at Umicore
- **Battery recycling at Umicore**
- Modelling of e-waste recycling

Umicore Battery Recycling

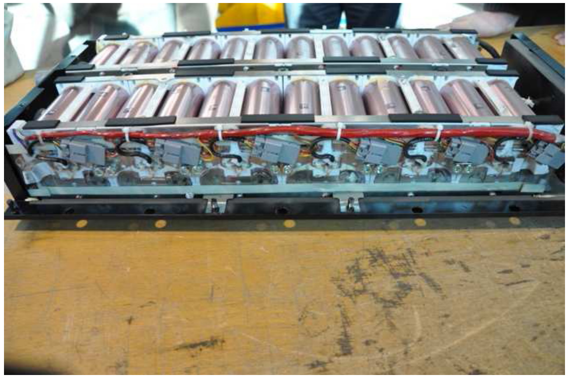
- Official inauguration: September 7, 2011
- Capacity: 7,000 ton/y
- Improved energy & CO_2-balance
- No dismantling, crushing…
  - Safe for workers
  - Safe for environment
- For any size of batteries
  - Small electronic appliances
  - Industrial batteries
  - HEV/ EV batteries
- Future volume is driven by the merging electrification of transport

http://www.batteryrecycling.umicore.com/UBR/

Closing the loop for rechargeable batteries



Dismantling lines at UBR Hanau, DE and Maxton, NC USA



- ❑ A manual job, today in Hanau, Germany and Maxton, NC, USA
- ❑ Dismantling avoids transport of parts which are ‘easy’ to recycle locally
- ❑ Creates valuable jobs for lower educated personnel in several locations

umicore
Precious Metals
Refining

Feed structure

Small applications | Industrial applications → xEV (ind. applications)

Recycling process
Feeding equipment / batteries handling

- No dismantling, crushing…
  - Safe for workers
  - Safe for Environment
  - Cost effective
- For any size of batteries
  - Small electronic appliances
  - Industrial batteries
  - HEV/ EV batteries

Recycling process
Smelting batteries

- Specially designed furnace
  - Intellectual property of Umicore
  - No explosion of batteries (safety)
  - No cell dismantling
- Products
  - Alloy
  - Slags

Recycling process
Smelting batteries

- Specially designed gas treatment
  - A unique Umicore design
  - No VOC formation
  - All dust removal
- Gas cleaning technology
  - Low volume gas
  - Low CO_2 footprint

- Exploring Umicore
- Metal Cycles & Markets
- Dimensions of e-scrap recycling
- e-Scrap recycling at Umicore
- Battery recycling at Umicore
- **Modelling of e-waste recycling**

Advanced dynamic e-waste recycling models

created by Reuter & Van Schaik

What does it do?

- control and prediction of recyclate quality as function of time-varying product design and product type
- and their impact on the efficiency of the applied recycling processes
- from an economic and environmental perspective
- creating a direct link between product design (CAD models) and recycling models

Source: A. van Schaik and M.A. Reuter: *Dynamic modelling of e-waste recycling system performance based on product design* in Minerals Engineering vol.23, 2010

Advanced dynamic e-waste recycling models

created by Reuter & Van Schaik

Fundamental aspects

- product design and liberation
- physical separation
- metallurgical, thermal and (in)organics processing
- dynamic feedback control

Application areas:

- prediction of mass flow, recyclate and output quality
- prediction of impact of different operating modes of technology on the total recycling of minor metals
- predicting recyclability & energy recovery as function of (distributed & time-changing) input of recycling systems

Source: A. van Schaik and M.A. Reuter: *Dynamic modelling of e-waste recycling system performance based on product design* in Minerals Engineering vol.23, 2010

Thank you

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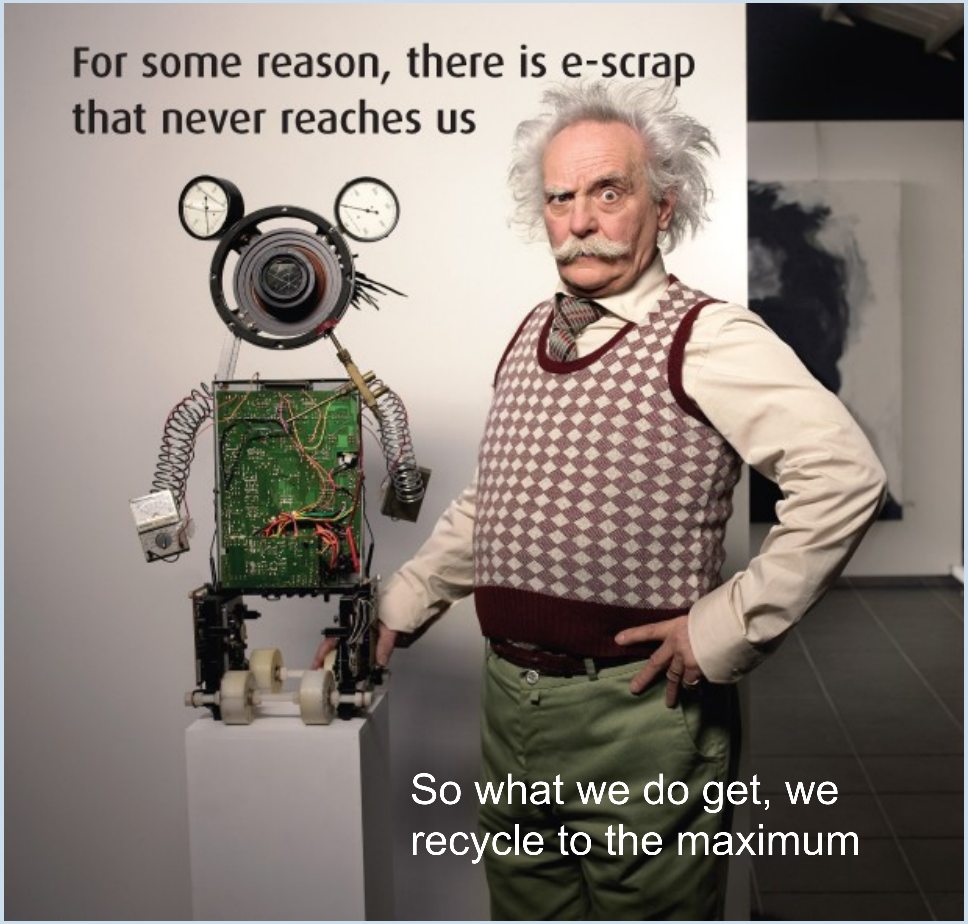

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