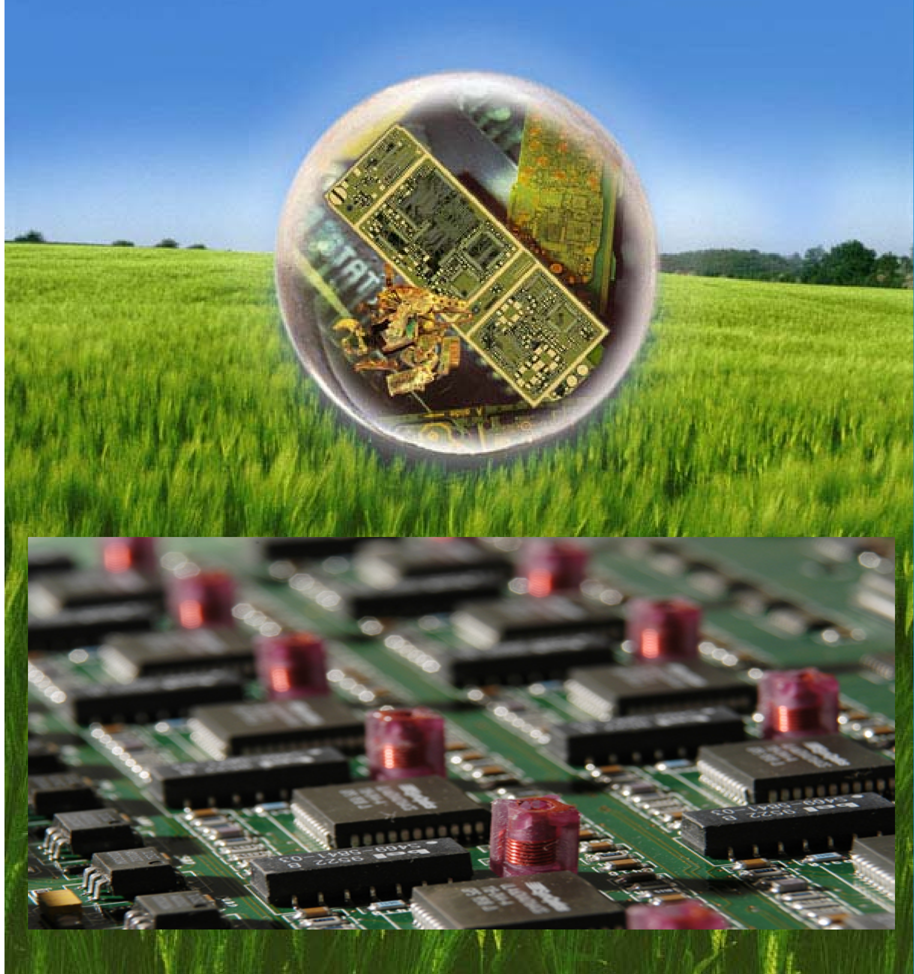
# The mine above ground – opportunities & challenges to recover scarce and valuable metals from EOL electronic devices




Christian Hagelüken
Umicore Precious Metals Refining

Matthias Buchert
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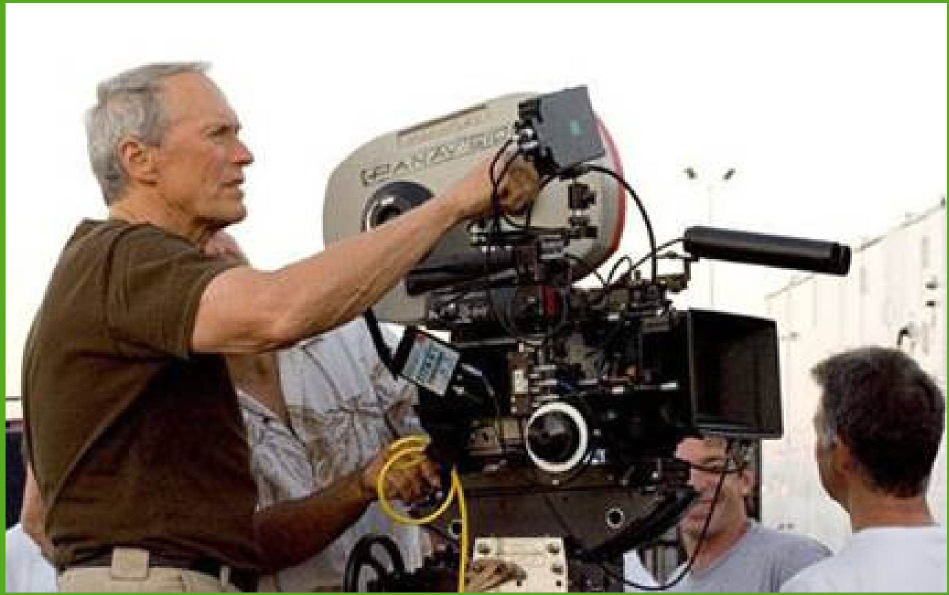
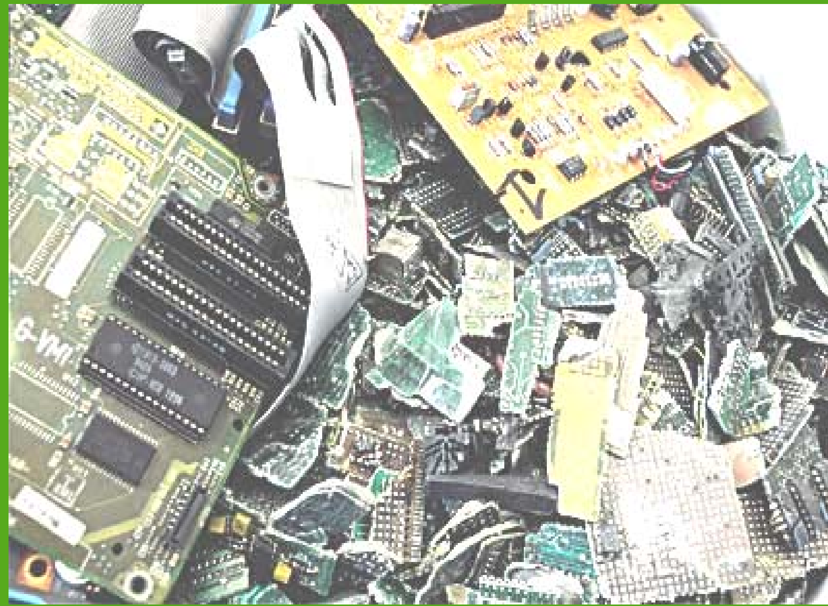
IERC Salzburg, 17. January 2008





– the art of metals recycling

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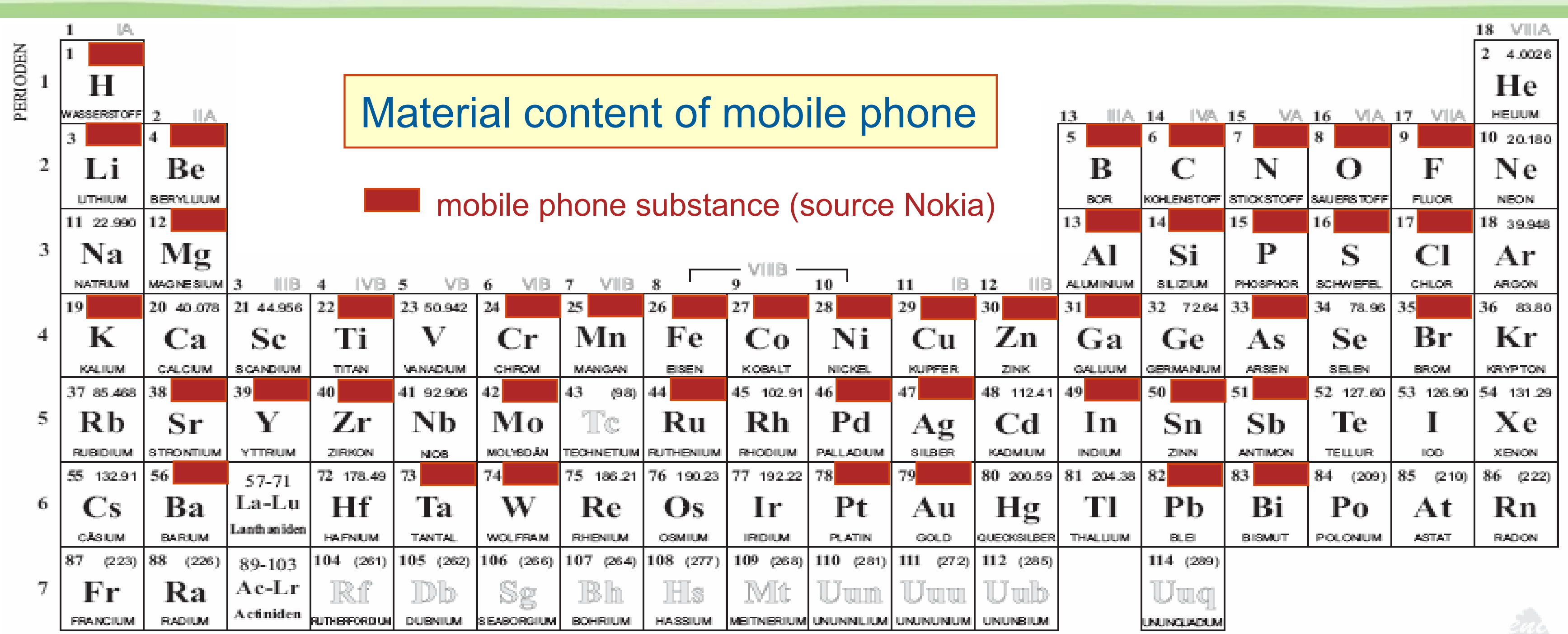
- **Introduction: The significance of electronics on metals demand and prices**
- **Data evaluation**
  - unit sales
  - metal use & metal value
  - recycling potential & reality
  - environmental impact
  - economic impact
- **What needs to be done**
  - technical
  - legislation & enforcement
  - global cooperation
- **Conclusion**

# Electronics contain up to 60 elements - a complex mix of valuables & hazards




- demand (and prices) of special & precious metals have increased significantly (specific metal properties are needed for more functionality )
- their primary production requires significant amounts of energy and resources
- "concentration" in specific components like circuit boards
- new material combinations compared to their natural occurrence & dissipation in final product (e.g. computers, cell phones, cars etc.) make recycling challenging

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# EEE have a significant impact on metals demand

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| important EEE metals | | world mine-production* | by-product from | demand for EEE | demand related to mine production | metal price** | value of EEE use | Main uses in electro/electronics |
|---|---|---|---|---|---|---|---|---|
| | | t/a | | t/a | | $/kg | billion $ | |
| **silver** | **Ag** | 20.000 | (Pb, Zn) | 6.000 | **30%** | 371 | 2,2 | contacts, switches, (leadfree) solders, conductors, MLCC, … |
| **gold** | **Au** | 2.500 | (Cu) | 300 | **12%** | 19.350 | 5,8 | bonding wire, contacts, IC |
| **palladium** | **Pd** | 230 | PGM | 32 | **14%** | 10.288 | 0,3 | Multilayer capacitors (MLCC), connectors, PWB plating, … |
| **platinum** | **Pt** | 220 | PGM | 13 | **6%** | 36.748 | 0,5 | hard disks, thermocouple wires, fuel cells |
| **ruthenium** | **Ru** | 30 | PGM | 6 | **20%** | 6.162 | 0,0 | hard disks, resistors, conductive pastes, plasma display panels |
| **copper** | **Cu** | 15.000.000 | | 4.500.000 | **30%** | 7 | 30,3 | cables, wires, connectors, conductors, transformers, e-motors |
| **tin** | **Sn** | 275.000 | | 90.000 | **33%** | 9 | 0,8 | (leadfree) solders |
| **antimony** | **Sb** | 130.000 | | *65.000* | **50%** | 5 | 0,3 | flame retardants, CRT glass |
| **cobalt** | **Co** | 58.000 | Ni, Cu | 11.000 | **19%** | 36 | 0,4 | rechargable batteries |
| **bismuth** | **Bi** | 5.600 | Pb,W,Zn | 900 | **16%** | 11 | 0,01 | leadfree solders, capacitors, heat sinks, electrostatic screening, … |
| **selenium** | **Se** | 1.400 | Cu | 240 | **17%** | 52 | 0,01 | electrooptic, copiers, solar cells, … |
| **indium** | **In** | 480 | Zn, (Pb) | 380 | **79%** | 822 | 0,3 | LCD glass, leadfree solders, semiconductors/LED, … |
| | | | | | | **total** | **41,0** | |

* rounded, source: USGS Mineral commodity summaries 2007; GFMS; JM-Platinum

** avg. 2006

By-product = coupled at ppm level to major metals Cu, Zn, Pb, etc, no own mines are existing.

⇒ increase of supply only in parallel with major metals

⇒ No price elasticity of minor metal



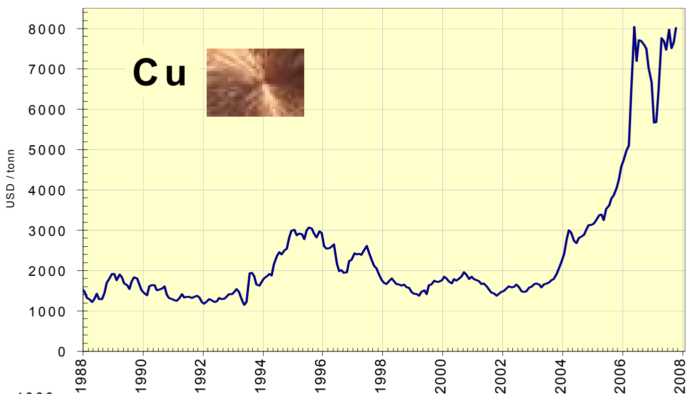


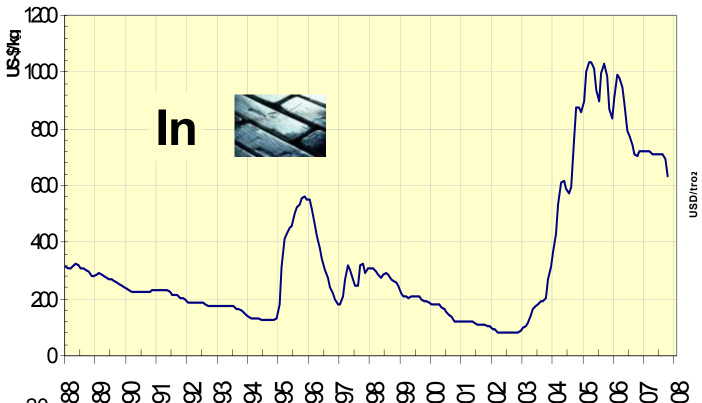


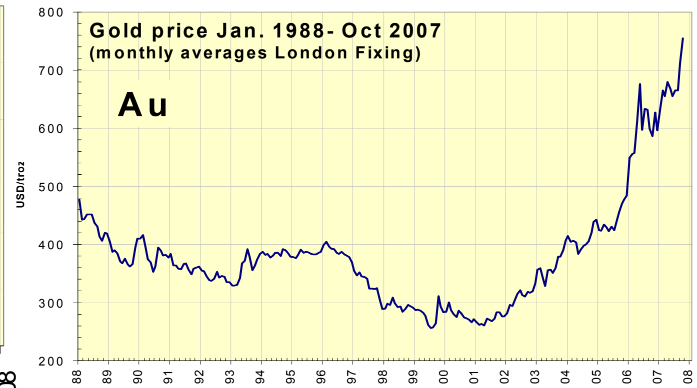

# Increasing prices put new attention on potential metal scarcities

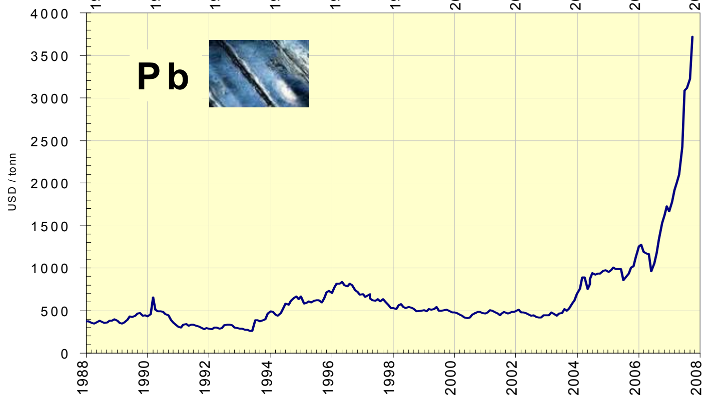
"Providing today's developed-country level of services for Cu worldwide (as well as for Zn and, perhaps, Pt) would appear to require conversion of essentially all of the ore in the lithosphere to stock-in-use plus near-complete recycling of the metals from that point forward."

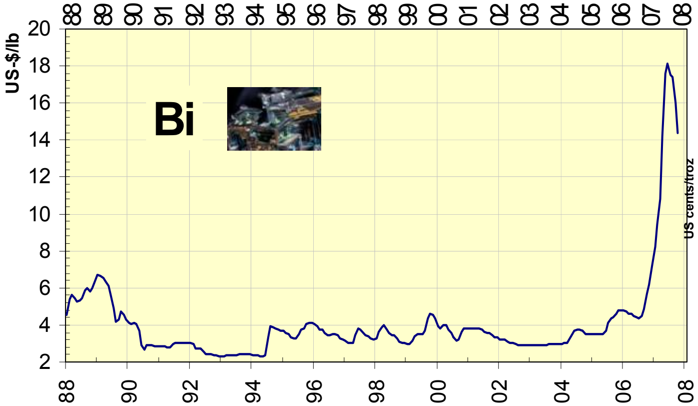
PNAS, Jan. 2006: Metal stocks & sustainability, R. Gordon, M. Bertram, T. Graedel, Yale

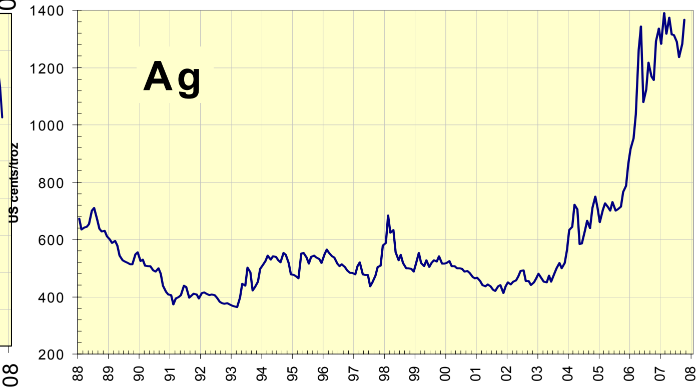


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# Impact on metals demand - 2 prominent examples

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## Global sales, 2006:

### a) Cell phones:

1000 Million units

x 250 mg Ag ≈ 250 t Ag

x 24 mg Au ≈ 24 t Au

x 9 mg Pd ≈ 9 t Pd

x 9 g Cu ≈ 9000 t Cu

1000 M x 20 g/battery*

x 3.8 g Co ≈ 3800 t Co

* Li-Ion type

### b) PC & laptops:

225 M units

x 1000 mg Ag ≈ 225 t Ag

x 220 mg Au ≈ 50 t Au

x 80 mg Pd ≈ 18 t Pd

x ≈ 500 g Cu ≈ 113,000 t Cu

≈ 75 M laptop batteries*

x 65 g Co ≈ 4900 t Co

** Li-Ion type is > 90% used in modern laptops

### World Mine Production / a+b share

Ag: 20,000 t/a ► 2.5%

Au: 2,500 t/a ► 3%

Pd: 230 t/a ► 12%

Cu: 16 Mt/a ► 1%

Co: 58,000 t/a ► 15%

- Although "negligible" metal quantities per piece, the leverage of huge unit sales leads to significant total numbers !
- value of these five metals at 2006 prices: 2.8 billion US-$
- $CO_2$ burden for producing these metals (primary): 2.1 million t $CO_2$
- How much of this will finally be recycled ?

| 2006 | t | $/kg | Mio $ | 1000 t CO2 |
|---|---|---|---|---|
| Ag | 475 | 371 | 176 | 68 |
| Au | 74 | 19.355 | 1.432 | 1.257 |
| Pd | 27 | 10.288 | 278 | 253 |
| Cu | 122.000 | 6,73 | 821 | 415 |
| Co | 8.700 | 15,22 | 132 | 66 |
| | | | 2.840 | 2.060 |

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# Sales of electronic devices – a booming market

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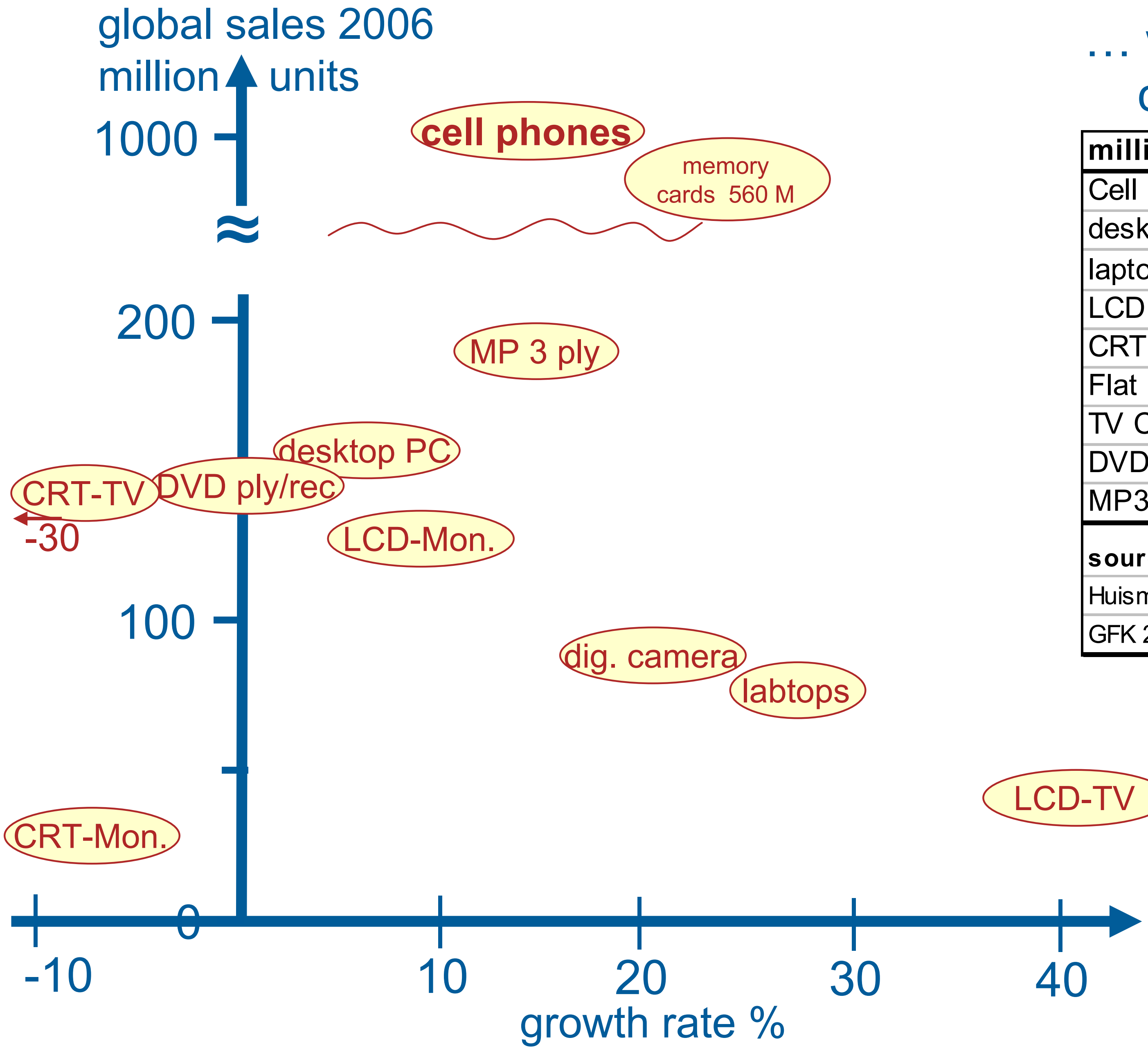
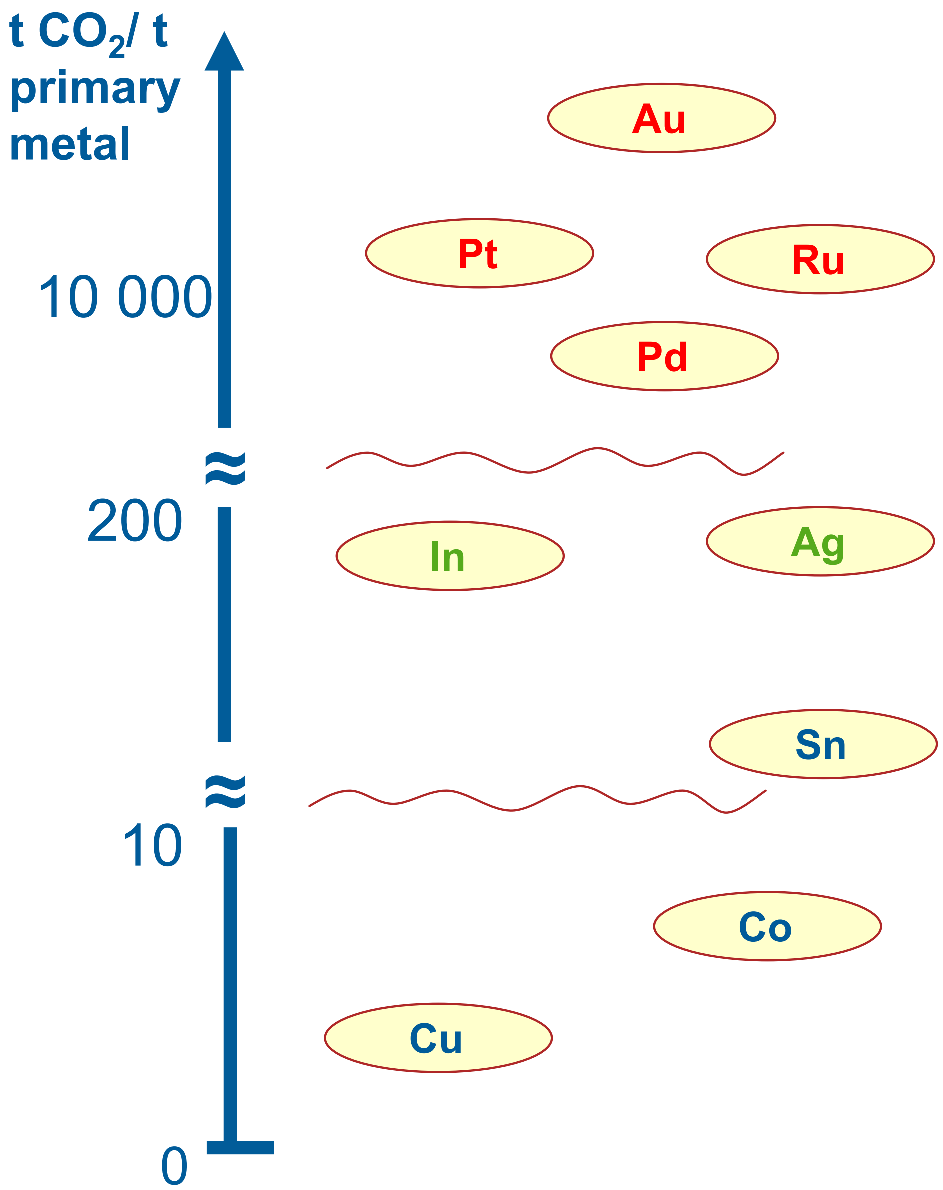



… with significant contributions from Europe

| million units 2006 | world | EU 25 | % EU |
|---|---|---|---|
| Cell phones | 1000 | *200* | 20% |
| desktop computers | 150 | 28 | 19% |
| laptop computers | 75 | 28 | 37% |
| LCD Monitors | 135 | 32 | 24% |
| CRT monitors | 32 | 2 | 6% |
| Flat Panel TVs | 45 | 20 | 44% |
| TV CRT | 142 | 16 | 11% |
| DVD players/rec. | 125 | *40* | 32% |
| MP3 players | 180 | 35 | 19% |
| **sources:** | | | ***25%*** |
| Huisman, Kühr et al: WEEE review , 2007 | | | |
| GFK 2007; Gartner 2007 | | | |

metals demand for EEE will grow further

# Environmental impact of metal production: $CO_2$




## $CO_2$-emissions of Primary Production:

| Important EEE metals | demand for EEE t / a (2006) | data for primary production [t $CO_2$ / t metal] | $CO_2$ emis-sions [Mt] |
|---|---|---|---|
| Copper | 4 500 000 | 3.4 | 15.30 |
| Cobalt | 11 000 | 7.6 | 0.08 |
| Tin | 90 000 | 16.1 | 1.45 |
| Indium | 380 | 142 | 0.05 |
| Silver | 6 000 | 144 | 0.86 |
| Gold | 300 | 16 991 | 5.10 |
| Palladium | 32 | 9 380 | 0.30 |
| Platinum | 13 | 13 954 | 0.18 |
| Ruthenium | 6 | *13 954* | 0.08 |
| **$CO_2$ total [t]** | | | **23.41** |

source: Ecoinvent 2.0, EMPA/ETH-Zürich, 2007

additional impacts from $SO_2$, land use, waste-water etc.

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# Metals recycling creates a huge $CO_2$ benefit

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Example:

**Umicore Precious Metals Refining**, Hoboken/Belgium (UPMR):

- recovered metals 2006: 75,000 t*
- total $CO_2$ impact of UPMR in 2006: 0.28 Mt
- total $CO_2$ impact primary production**: 1.28 Mt

**► $CO_2$ saved due to recycling*: 1.00 Mt**

*from treatment of 300,000 t of recyclables & smelter by-products.
Output: 1100 t Ag, 32 t Au, 32 t PGM, 70,000 t Cu/Pb/Ni, 4100 t Sn/Se/Te/In/Sb/Bi/As

**if these metals would have come from primary production, calculated with eco-invent 2.0:

the unavoidable "black box approach" of the UPMR calculation mixes the $CO_2$ impacts of very low grade materials (e.g. slags, flue dusts) with richer ones from recycling of consumer goods (e.g. circuit boards, catalysts)
► for recycling of electronics the $CO_2$ benefit compared to mining is even higher!

# Energy balance of circuit board treatment in the UPMR process


- mixed plastics from the feed substitute coke (reducing agent) & fuel (energy)
- 1 kg of boards contains 9.600 kJ of energy
- Smelting of boards asks for 1.500 kJ/kg
- Further treatment and refining of all metals contained in 1 kg of boards needs 6.500 kJ/kg
- Surplus replaces primary energy in the smelter
- Heat in smelter is recovered as steam and reused in the plant
- process layout & extensive offgas treatment safely prevent hazardous emissions
- all input & output streams are analysed, mass & energy balances are available (see annex)

Positive energy balance:
WEEE-feed contains more than enough energy for entire refining process, no extra $CO_2$ is generated!

# Example for "high-tech" metals recovery – a lot could be achieved


- Unique flowsheet, focus on secondary materials
- Recovering 17 metals:
  Au, Ag, Pd, Pt, Rh, Ir, Ru,
  Cu, Pb, Ni, Sn,
  Bi, Se, Te, Sb, As, In
- Wide range of complex precious metals bearing feed materials
- high purity metal output
- Global supply base
- Minimizing waste
- World class environ-mental standards (BAT) ISO 14001 & 9001
- > 1 billion € investment

# Example "low tech" – Gold recycling in Bangalore/India …



Total Au-recovery efficiency only ≈ 25%, while environmental & health damage is dramatic (Rochat, Keller, EMPA 2007)

foto: EMPA/CH

**… this takes place in large parts of the world today!**

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# In spite of all efforts - Mobile phone recycling largely fails today

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**Recycling potential 2006*: 400 million units per anno x 100 g = 40,000 t/a**

collected | Not collected

%? %?

Recy-cling¹ | reuse

**Stored "in drawer"**
(potential for recycling at later stage)

**Disposed with household waste**
(unrecoverable loss)

%?

Use in 2nd life

Exported to developing countries

Use in "2nd life"

Final end of life

EOL not collected

Collected | Not collected

%?

Local 'backyard recycling'³

Re-export to ESM-recycling

Recycling reality²:
< 1000 t
(< 10 M)
in 2006

¹ 25-35% of professionally collected phones are not fit for reuse and sent directly to recycling.

² global quantities treated for material recovery efficiently and environmentally sound

³ uncontrolled release of fumes, effluents and waste

Global Sales of new phones:
2001: 400 M
2003: 500 M
2004: 650 M
2005: 800 M
2006:1000 M
2007:1150 M estimate

Not to scale

# Recycling potential vs reality

**The potential: Value of electronics sales worldwide (2006)**

- metals worth > 40 billion US-$ (EU > 10 billion $)
- $CO_2$ emissions of primary production: > 23 million t (EU > 6 M$)
- potential $CO_2$ saving at 80% metals recycling: > 14 million t (EU 4 Mt)

**The reality for Europe*:**

> 60% are not properly recycled, metals are lost (exports, trash bin, …)

- 70% for IT &Telecom (3a), small household appliances (2, 5a, 8)
- 65% for CRT (3b, 4b)
- 60% for consumer electronics (4a)

*source: Huisman, Kühr et. al: WEEE review report, 2007

**Europe**

- **losing annually > 10 billion $ of metals value**
- **wasting a $CO_2$ saving potential of at least 4 million t $CO_2$**

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# What are the effects on …

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## European Recyclers

- lost revenues from missing WEEE arisings
- underutilization of plants
- missing investment security: preparing for future arisings would require plant expansions – but only if WEEE is not escaping

## Electronics Manufacturers

- are faced with increasing metal prices (more recycling would improve supply/demand balance and mitigate price development)
- might be faced with (temporary) supply security for certain metals
- are risking their image of sustainable production and proper EOL management

## Importing Countries of (illegal) WEEE shipments

- create severe & long-term environmental damage from dumping or backyard recycling
- expose their population to significant health risks
- are risking their image of becoming modern industrialising societies

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# Does the recycling society solve it all?


Brussels, 21 December 2005

*The European Commission today proposed a new strategy on the prevention and recycling of waste. This long-term strategy aims to help Europe become a recycling society that seeks to avoid waste and uses waste as a resource.* ...

**New EU waste strategy: Making Europe a recycling society**

**Impact factors on real recycling rates**

- Technology
- Society: awareness & legislation
- Economics
- Lifecycle structure

**► Status Quo in the EU**

- available, but often not used; weak interfaces
- frame conditions widely okay, but weak enforcement; low resource awareness
- high metal prices are good incentive
- ⚡ challenge of open cycles, exports of (used) WEEE, missing transparency, etc.

# Crucial remarks

- Consider WEEE as a valuable resource, not as waste.
- Weight based quotes ignore significance of trace elements (precious & special metals). Export losses are not considered in recycling quotes.
- Improve collection (all waste, not just 4 kg WEEE/capita) and ensure that (collected) WEEE does not escape as illegal export or in non-compliant recycling channels (enforcement).
- Improve treatment & stakeholder cooperation within recycling chain: use BAT processes, check input-output streams & real recovery rates achieved.
- IPR does not end at collection and first treatment plant: follow the material throughout the chain and ensure proper treatment. Report must focus on the recovered instead of on the collected material.
- Create a global recycling society: infrastructure in developing countries plus international cooperation in recycling. Promote re-export of critical waste fractions to certified environmentally sound recovery plants. Benefit from a division of labour & economies of scale.

# Requirements for a global recycling society

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- Set up local infrastructures in developing & transition countries, ensuring that (re-)used EEE finally is channelled into appropriate recycling chains.
- Local collection, dismantling and recycling of many components can be very effective if right structures are used → training! (consider also the social dimension)
- "Mining" complex WEEE fractions requires "high tech" processes & specialisation
- For these, economies of scale & adequate infrastructure are key to success. It does not make sense to replicate large and expensive plants in every country. ► International division of labour needed to treat critical e-scrap fractions.

- Recovered metals can be credited back to countries of origin ("toll refining") → no loss of resources from a country's perspective.
- No landfill, incineration, backyard recycling or treatment in plants without proper off-gas and waste water handling.

spot the difference

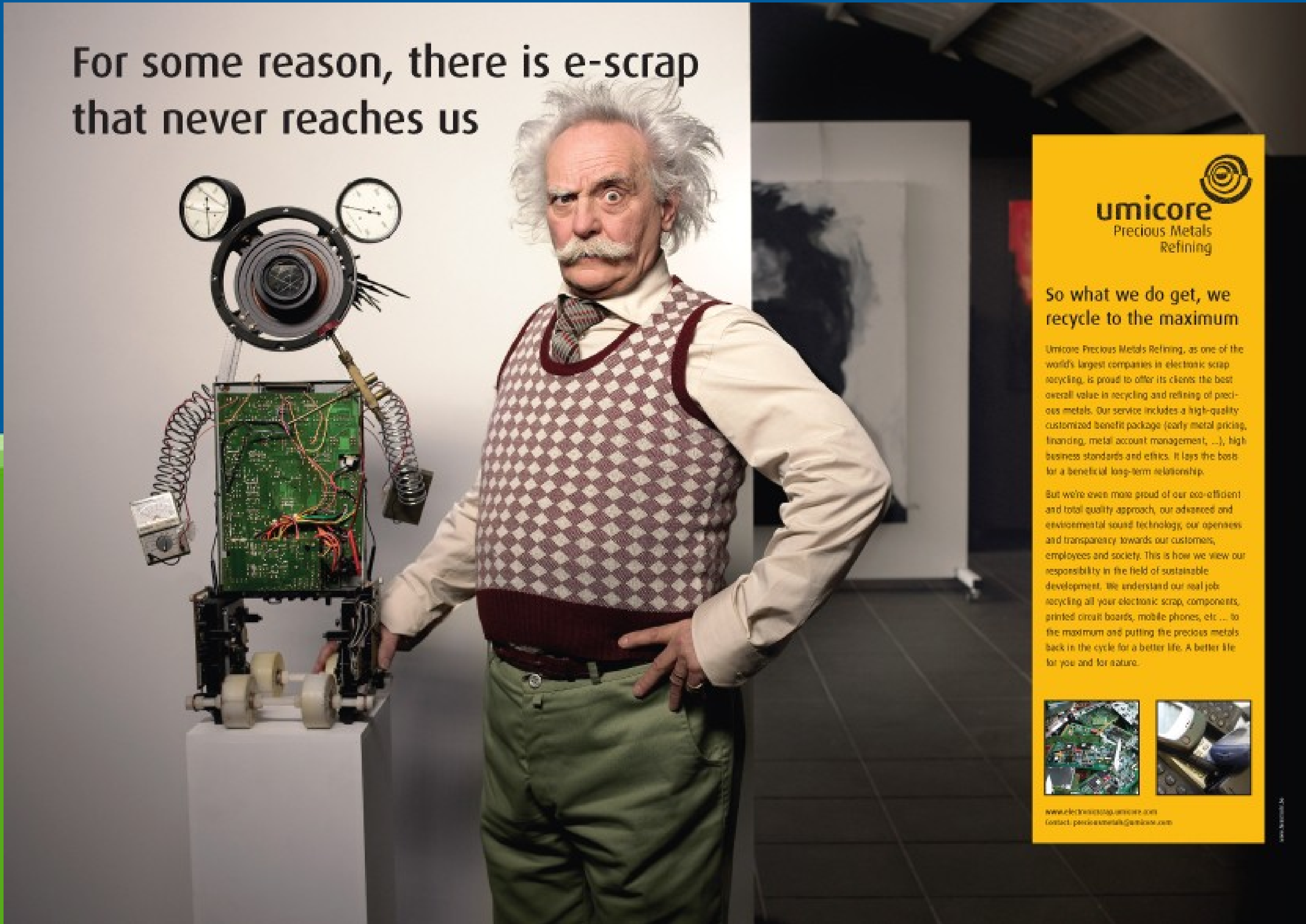
# Conclusion

- Demand for precious & special metals is booming (functionality), EEE are for some metals a major driver (also for prices). Mining those metals is energy intensive.
- Efficient recycling technologies exist but only smart interfaces & high tech processes can prevent losses of these trace elements.
- Main constraints are not technical but structural. Change open cycles for consumer goods gradually towards a closed cycle structure ?

- Current technosphere & EOL-products are Europe‘s largest resource stock (“mine above ground”).
- Effective recycling can play a key role to
  - conserve metal resources & enable a regionally more balanced access (supply security)
  - mitigate metal price increase / volatility
  - contribute significantly to a reduction of energy use & emissions
  - stimulate fair international co-operations along the added value chains

If things don‘t change, future secondary metals supply will be much lower than anticipated & the „recycling society“ will be just a nice buzzword. However, if we do it the right way, a lot can be achieved!

# Thanks for your attention

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# annex

Precious metals recycling isn't always about profits
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It's about life.
Of course, as one of the world's largest precious metals recycling companies, Umicore Precious Metals Refining is proud to offer its clients the best overall service in recycling and refining of precious metal bearing materials such as by-products from other non-ferrous industries, consumer and industrial recyclable products (e.g. electronic scrap, spent auto and industrial catalysts). This service includes a high-quality customized benefit package (early metal pricing, financing, metal account management, ...), high business standards and ethics.
It lays the basis for a beneficial long-term relationship.
But we are even more proud of our eco-efficient and total quality approach, our advanced and environmentally sound technology, our openness and transparency towards our customers, employees and society. This is how we view our responsibility in the field of sustainable development. We understand our real job: recycling precious metals to put them back in the cycle for a better life. A better life for you and for nature.
In fact, it's not even about precious metals

# Umicore structure

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Element Six Abrasives

**Advanced Materials**
- Electro-Optic Materials
- Electronic Materials
- Cobalt & Specialty Materials

Nystar

**Zinc Specialties**
- Zinc Chemicals
- Building Products
- Zinc Battery Materials

**Precious Metals Services**
- Precious Metals Management
- Precious Metals Refining

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- 14,000 people
- 50 industrial locations around the world
- 8.8 billion € turnover (2006)

**Precious Metals Products & Catalysts**
- Automotive Catalysts
- Catalyst Technologies
- Technical Materials
- Thin Film Products
- Jewellery & Electroplating
- Platinum Engineered Materials

# Umicore today provides …

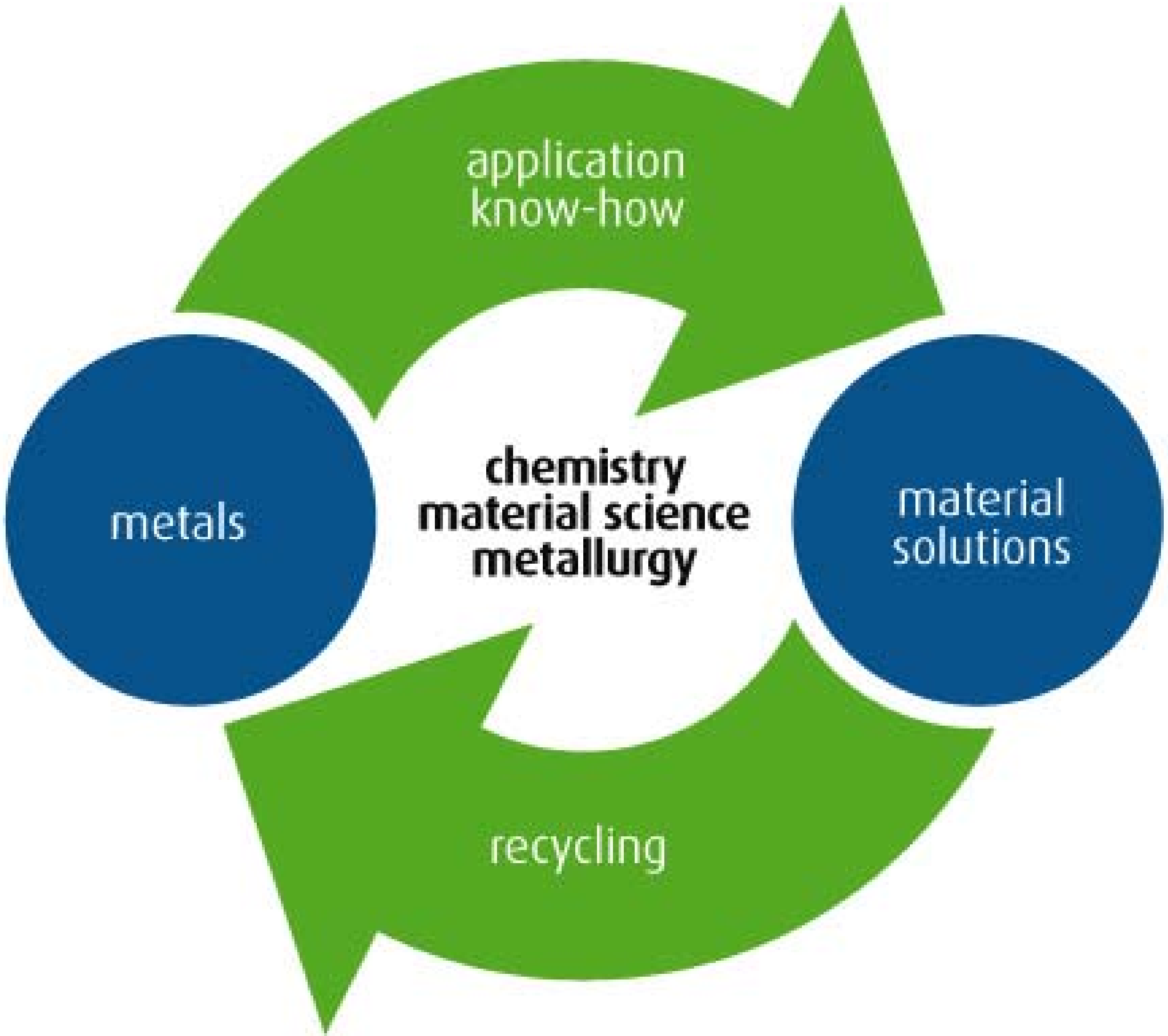
the automotive catalysts
for 1 in 4 cars produced in the world

key materials for the rechargeable batteries for more than 30% of all cell phones and laptops sold this year

the semiconductor substrates for more than 60% of all satellite solar cells in the last 2 years

recycling services for complex materials like electronic scrap, batteries and spent catalysts to gain more than 20 different metals

# The Umicore approach to materials technology

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# E-scrap treated at Umicore

## All parts, components, fractions that contain precious metals (PM):

- Printed circuit boards (from end-of-life scrap or production residues)
  - computer boards, cell phone boards, boards from hard disk drives, etc.
  - TV- / monitor boards, audio boards after removal of large iron and aluminum parts
  - unpopulated boards with PM

- PM bearing components: IC, multi layer capacitors (MLCC), contacts, etc.
- mobile phone handsets and other small devices with a relatively high PM content (after removal of battery)

- Fractions with a high circuit board content (e.g. after shredding and sorting)
- Other output-fractions from mechanical preprocessing with PMs
- Li-Ion & NiMH batteries (in dedicated business line)

**What do we not treat – examples:**

- entire devices if > 15 cm
- copper cables
- mere plastic scrap (casings, …)
- CRT-glass
- CRT yokes

# Composition of cell phone lots recycled at Umicore (examples)

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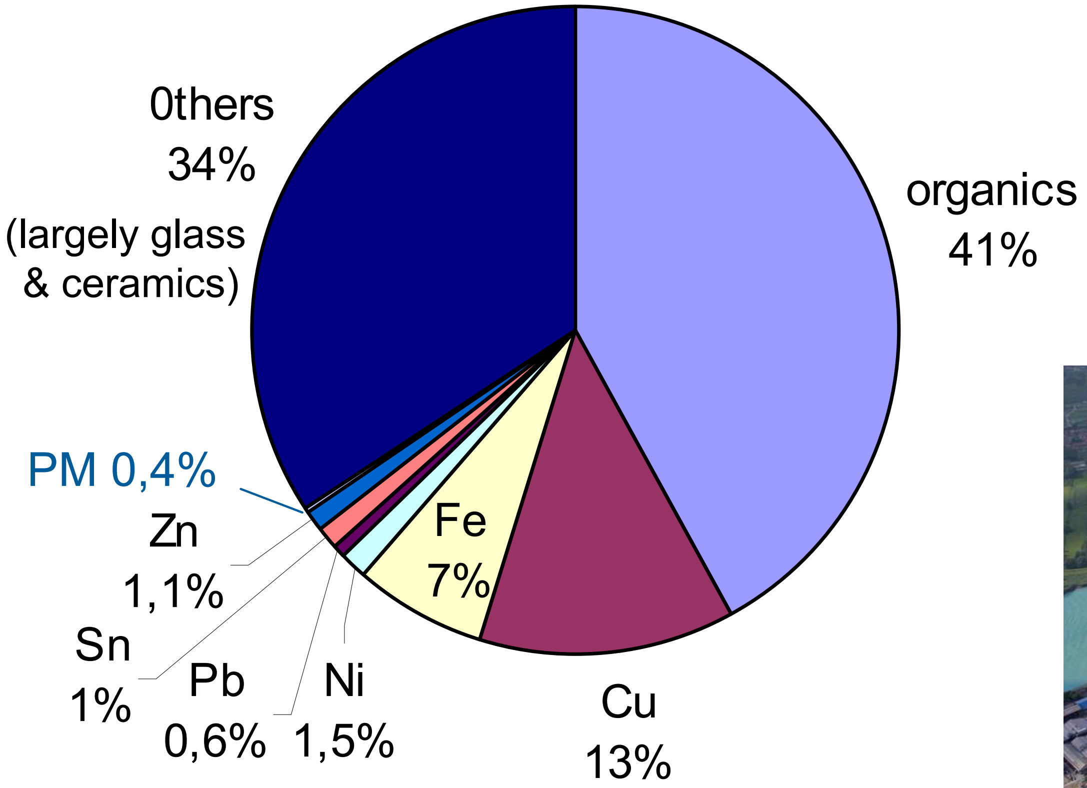
without batteries

| | | | recovered metals | | | | | | | | | Elements concentrated in end-slag (concrete additive/for dyke fortification) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | lot weight [t] | Organics % * | AG - /mt | AU - g/mt | PT - g/mt | PD - g/mt | PB - % | CU - % | NI - % | SB - % | SN - % | ZN - % | MGO - % | AL2O3 - % | CAO - % | SIO2 - % | FE - % | MN - % | TIO2 - % | BAO - % | BE - g/mt | ZRO2 - % | CEO2 - % |
| | **Cell phone handsets (11lots, avg. 9.5 t)** | | | | | | | | | | | | | | | | | | | | | | |
| min | 1 | 44 | 2792 | 276 | 3 | 98 | 0,5 | 11,7 | 1,1 | 0,1 | 0,8 | 0,7 | 0,6 | 2,7 | 1,3 | 10,3 | 5,4 | 0,3 | 1,3 | 0,7 | 6,0 | 0,1 | 0,1 |
| max | 18 | 43 | 5441 | 446 | 7 | 349 | 0,7 | 15,0 | 2,0 | 0,1 | 1,1 | 1,6 | 5,4 | 6,0 | 2,5 | 12,9 | 8,0 | 0,1 | 2,5 | 1,2 | 154,0 | 0,4 | 0,3 |
| **avg.** | **105** | **8** | **3630** | **347** | **5** | **151** | **0,6** | **12,8** | **1,5** | **0,1** | **1,0** | **1,1** | **3,4** | **4,7** | **1,9** | **11,6** | **6,5** | **0,2** | **1,8** | **0,9** | **88,2** | **0,2** | **0,1** |
| | **Shredded mobile phones (3 lots, avg. 4.7 t)** | | | | | | | | | | | | | | | | | | | | | | |
| min | 1 | 35 | 846 | 267 | 5 | 38 | 0,2 | 10,7 | 1,5 | 0,1 | 0,5 | 1,0 | 0,6 | 3,1 | 1,6 | 7,3 | 3,9 | 0,1 | 1,0 | 0,4 | 44,0 | 0,1 | 0,1 |
| max | 8 | 49 | 3459 | 425 | 143 | 173 | 0,8 | 15,2 | 2,0 | 0,1 | 1,0 | 1,6 | 9,3 | 8,7 | 1,9 | 12,7 | 7,6 | 0,2 | 1,7 | 0,9 | 95,0 | 1,9 | 0,1 |
| **avg.** | **14** | **44** | **2273** | **354** | **51** | **113** | **0,5** | **13,4** | **1,8** | **0,1** | **0,8** | **1,3** | **4,0** | **5,3** | **1,8** | **10,5** | **5,2** | **0,2** | **1,4** | **0,7** | **66,7** | **0,7** | **0,1** |
| | **Cell phone circuit boards (1 lot)** | | | | | | | | | | | | | | | | | | | | | | |
| | 10 | 26 | 5540 | 980 | 7 | 285 | 1,1 | 25,0 | 1,6 | 0,1 | 2,3 | 0,6 | 0,9 | 3,2 | 2,2 | 12,2 | 7,7 | 0,4 | 2,6 | 1,8 | 103,0 | 0,1 | 0,1 |

# Average composition from > 100 t of mobile phone handsets

umicore Precious Metals Refining




avg. content of precious metals (PM)

| | g/t |
|---|---|
| Ag | 3630 |
| Au | 347 |
| Pd | 151 |
| Pt | 5 |
| total | 4133 |

Ag, Au, Pd, Pt, Cu, Pb, Bi: recovered with > 95% yield in Umicore process

additionally recovered: Sn, Ni, In, Sb, As

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# Where do losses occur ?

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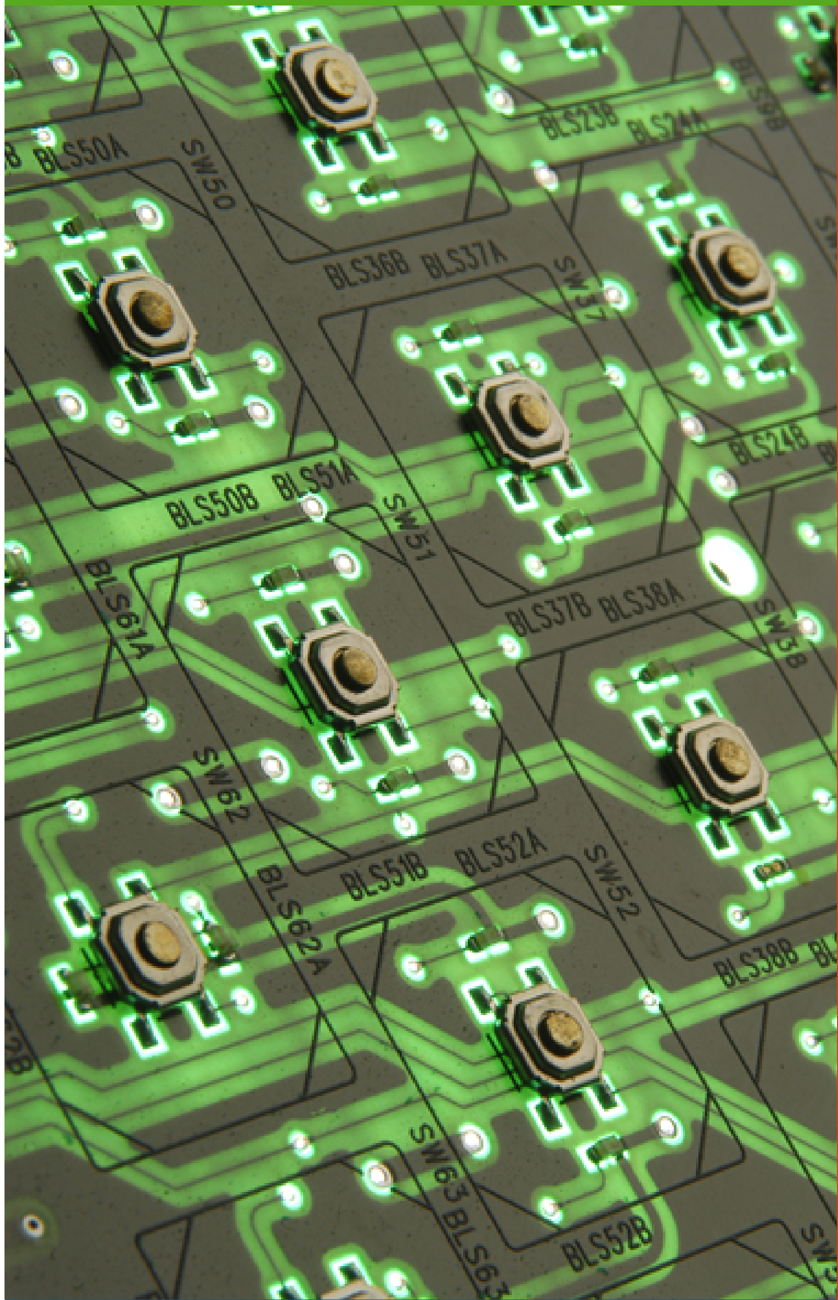


- EEE are not collected
- Collection but:
  - Export as legitimate “reuse” in region, where recycling fails at real EOL
  - Illegal export, disguised as reuse (sham reuse)
  - Removal of devices/components at municipal collection points or at subsequent steps in the recycling chain
- Losses within the recycling chain due to :
  - Wrong sorting („cell phones mixed with tools“)
  - Losses during mechanical processing (e.g. precious metals into dust, plastics, Fe- or Al-fraction)
  - Suboptimal interfaces to end processors
  - Losses at end-process

→ Dissipation of precious & special metals in end-products hampers recyclability

→ Thermodynamic constraints prevent recovering of “all” metals