Opportunities & challenges to recover scarce and valuable metals from electronic devices

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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
Impact on metals demand - 2 prominent examples

Global sales, 2006:

a) Cell phones:

1000 Million units
- $250 mg Ag ≈ 250 t Ag
- $24 mg Au ≈ 24 t Au
- $9 mg Pd ≈ 9 t Pd
- $9 g Cu ≈ 9000 t Cu

1000 M x 20 g/battery*
- $3.8 g Co ≈ 3800 t Co

b) PC & laptops:

225 M units
- $1000 mg Ag ≈ 225 t Ag
- $220 mg Au ≈ 50 t Au
- $80 mg Pd ≈ 18 t Pd
- ≈ 500 g Cu ≈ 113,000 t Cu
≈ 75 M laptop batteries*
- $65 g Co ≈ 4900 t Co

World Mine / a+b Production / 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-
- CO₂ burden for producing these metals (primary): 2.1 million t CO₂
- How much of this will finally be recycled?
Sales of electronic devices – a booming market

… with significant contributions from Europe

<table>
<thead>
<tr>
<th>million units 2006</th>
<th>world</th>
<th>EU 25</th>
<th>% EU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell phones</td>
<td>1000</td>
<td>200</td>
<td>20%</td>
</tr>
<tr>
<td>desktop computers</td>
<td>150</td>
<td>28</td>
<td>19%</td>
</tr>
<tr>
<td>laptop computers</td>
<td>75</td>
<td>28</td>
<td>37%</td>
</tr>
<tr>
<td>LCD Monitors</td>
<td>135</td>
<td>32</td>
<td>24%</td>
</tr>
<tr>
<td>CRT monitors</td>
<td>32</td>
<td>2</td>
<td>6%</td>
</tr>
<tr>
<td>Flat Panel TVs</td>
<td>45</td>
<td>20</td>
<td>44%</td>
</tr>
<tr>
<td>TV CRT</td>
<td>142</td>
<td>16</td>
<td>11%</td>
</tr>
<tr>
<td>DVD players/rec.</td>
<td>125</td>
<td>40</td>
<td>32%</td>
</tr>
<tr>
<td>MP3 players</td>
<td>180</td>
<td>35</td>
<td>19%</td>
</tr>
</tbody>
</table>

Sources:
- GFK 2007; Gartner 2007

metals demand for EEE will grow further
Environmental impact of metal production: CO₂

CO₂-emissions of Primary Production:

<table>
<thead>
<tr>
<th>Important EEE metals</th>
<th>demand for EEE t/a (2006)</th>
<th>data for primary production [t CO₂/t metal]</th>
<th>CO₂ emissions [Mt]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>4 500 000</td>
<td>3.4</td>
<td>15.30</td>
</tr>
<tr>
<td>Cobalt</td>
<td>11 000</td>
<td>7.6</td>
<td>0.08</td>
</tr>
<tr>
<td>Tin</td>
<td>90 000</td>
<td>16.1</td>
<td>1.45</td>
</tr>
<tr>
<td>Indium</td>
<td>380</td>
<td>142</td>
<td>0.05</td>
</tr>
<tr>
<td>Silver</td>
<td>6 000</td>
<td>144</td>
<td>0.86</td>
</tr>
<tr>
<td>Gold</td>
<td>300</td>
<td>16 991</td>
<td>5.10</td>
</tr>
<tr>
<td>Palladium</td>
<td>32</td>
<td>9 380</td>
<td>0.30</td>
</tr>
<tr>
<td>Platinum</td>
<td>13</td>
<td>13 954</td>
<td>0.18</td>
</tr>
<tr>
<td>Ruthenium</td>
<td>6</td>
<td>13 954</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>CO₂ total [t]</strong></td>
<td></td>
<td></td>
<td><strong>23.41</strong></td>
</tr>
</tbody>
</table>

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

additional impacts from SO₂, land use, waste-water etc.
Metals recycling creates a huge CO₂ benefit

Example:

**Umicore Precious Metals Refining**, Hoboken/Belgium (UPMR):
- recovered metals 2006: 75,000 t*
- total CO₂ impact of UPMR in 2006: 0.28 Mt
- total CO₂ impact primary production**: 1.28 Mt

► CO₂ 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 ecoinvent 2.0:

the unavoidable “black box approach” of the UPMR calculation mixes the CO₂ 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 CO₂ benefit compared to mining is even higher!
Example for “high-tech” metals recovery – a lot can be achieved

Umicore’s integrated metals smelter at Hoboken/Antwerp

- Unique flowsheet, focus on secondary materials with precious metals (PM)
- Recovering 17 metals: Au, Ag, Pd, Pt, Rh, Ir, Ru, Cu, Pb, Ni, Sn, Bi, Se, Te, Sb, As, In
- 300,000 t/a of complex PM bearing feed materials
- High purity metal output
- Global supply base
- Minimizing waste
- World class environmental standards (BAT) ISO 14001 & 9001
- > 1 billion € investment
Example “low tech”
– Gold recycling in Bangalore/India …

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

... this takes place in large parts of the world today!
Recycling potential vs reality

The potential: Value of electronics sales worldwide (2006)

- metals worth > 40 billion US-$ (EU > 10 billion $)
- CO₂ emissions of primary production: > 23 million t (EU > 6 M$)
- potential CO₂ 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)


Europe

- losing annually > 10 billion $ of metals value
- wasting a CO₂ saving potential of at least 4 million t CO₂
Conclusion

- Booming demand for precious & special metals (functionality)
  EEE as major driver for some metals. 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 structural, not technical → “open cycles” for consumer goods
- Efficient recycling & responsible mining are needed to meet future metals demand

- Europe’s largest resource stock: our technosphere & EOL-products (“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

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

For some reason, there is e-scrap that never reaches us

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### EEE have a significant impact on metals demand

<table>
<thead>
<tr>
<th>Important EEE metals</th>
<th>World mine production*</th>
<th>By-product from</th>
<th>Demand for EEE</th>
<th>Demand related to mine production</th>
<th>Metal price**</th>
<th>Value of EEE use</th>
<th>Main uses in electro/electronics</th>
</tr>
</thead>
<tbody>
<tr>
<td>silver Ag</td>
<td>20.000 t/a (Pb, Zn)</td>
<td>6.000 t/a</td>
<td>30%</td>
<td>$371</td>
<td>2.2</td>
<td>contacts, switches, (leadfree) solders, conductors, MLCC, ...</td>
<td></td>
</tr>
<tr>
<td>gold Au</td>
<td>2.500 t/a (Cu)</td>
<td>300 t/a</td>
<td>12%</td>
<td>$19,350</td>
<td>5.8</td>
<td>bonding wire, contacts, IC</td>
<td></td>
</tr>
<tr>
<td>palladium Pd</td>
<td>230 PGM</td>
<td>32 t/a</td>
<td>14%</td>
<td>$10,288</td>
<td>0.3</td>
<td>Multilayer capacitors (MLCC), connectors, PWB plating, ...</td>
<td></td>
</tr>
<tr>
<td>platinum Pt</td>
<td>220 PGM</td>
<td>13 t/a</td>
<td>6%</td>
<td>$36,748</td>
<td>0.5</td>
<td>hard disks, thermocouple wires, fuel cells</td>
<td></td>
</tr>
<tr>
<td>ruthenium Ru</td>
<td>30 PGM</td>
<td>6 t/a</td>
<td>20%</td>
<td>$6,162</td>
<td>0.0</td>
<td>hard disks, resistors, conductive pastes, plasma display panels</td>
<td></td>
</tr>
<tr>
<td>copper Cu</td>
<td>15,000,000 t/a</td>
<td>4,500,000 t/a</td>
<td>30%</td>
<td>$7</td>
<td>30.3</td>
<td>cables, wires, connectors, conductors, transformers, e-motors</td>
<td></td>
</tr>
<tr>
<td>tin Sn</td>
<td>275,000 t/a</td>
<td>90,000 t/a</td>
<td>33%</td>
<td>$9</td>
<td>0.8</td>
<td>(leadfree) solders</td>
<td></td>
</tr>
<tr>
<td>antimony Sb</td>
<td>130,000 t/a</td>
<td>65,000 t/a</td>
<td>50%</td>
<td>$5</td>
<td>0.3</td>
<td>flame retardants, CRT glass</td>
<td></td>
</tr>
<tr>
<td>cobalt Co</td>
<td>58,000 Ni, Cu</td>
<td>11,000 t/a</td>
<td>19%</td>
<td>$36</td>
<td>0.4</td>
<td>rechargeable batteries</td>
<td></td>
</tr>
<tr>
<td>bismuth Bi</td>
<td>5,600 Pb, W, Zn</td>
<td>900 t/a</td>
<td>16%</td>
<td>$11</td>
<td>0.01</td>
<td>leadfree solders, capacitors, heat sinks, electrostatic screening, ...</td>
<td></td>
</tr>
<tr>
<td>selenium Se</td>
<td>1,400 Cu</td>
<td>240 t/a</td>
<td>17%</td>
<td>$52</td>
<td>0.01</td>
<td>electrooptic, copiers, solar cells, ...</td>
<td></td>
</tr>
<tr>
<td>indium In</td>
<td>480 Zn, (Pb)</td>
<td>380 t/a</td>
<td>79%</td>
<td>$822</td>
<td>0.3</td>
<td>LCD glass, leadfree solders, semiconductors/LED, ...</td>
<td></td>
</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>41,0</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 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
In spite of all efforts
- mobile phone recycling largely fails today

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

<table>
<thead>
<tr>
<th>Collected</th>
<th>Not Collected</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Reuse
- Stored “in drawer” (potential for recycling at later stage)

Disposing with household waste (unrecoverable loss)
- Exported to developing countries
- Re-export to ESM-recycling
- Local ‘backyard recycling’

Use in 2nd life
- Final end of life
- Collected
- Not collected

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

Global quantities treated for material recovery efficiently and environmentally sound

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

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:
- mere plastic scrap (casings, …)
- CRT-glass
- CRT yokes
Energy balance of circuit board treatment in the Umicore 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!
Average composition from 150 t of mobile phone handsets recovered at Umicore

- **Others**: 34% (largely glass & ceramics)
- **Organics**: 43%
- **PM**: 0.4%
- **Sn**: 1%
- **Pb**: 0.6%
- **Ni**: 1.4%
- **Fe**: 7%
- **Cu**: 13%

**Avg. content of precious metals (PM)**

<table>
<thead>
<tr>
<th>Precious Metals</th>
<th>g/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>3512</td>
</tr>
<tr>
<td>Au</td>
<td>341</td>
</tr>
<tr>
<td>Pd</td>
<td>144</td>
</tr>
<tr>
<td>Pt</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4001</td>
</tr>
</tbody>
</table>

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

Additionally recovered: Sn, Ni, In, Sb, As
New EU waste strategy: Making Europe a recycling society

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.

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.
Where do losses occur?

- 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
What are the effects on …

**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 problems 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
What needs to be done …

- 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

- 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.