Electronics Waste Management Challenges and Opportunities

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Disclaimer

- The views expressed in this presentation are those of the author[s] and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency.

Global Rise of Information and Communication Technology

- Global cellphone sell, 17B, for population of 7.38B.
- 6B mobile subscriptions worldwide in 2011 – *78/100* people in developing countries.
- US mobile phone subscription 218 m (2015).
- US e-waste generated 3.2 M tons/yr. (2013).
- Recycling less than 40 % (2015).
- EOL-management – landfills, incinerators or export overseas.

Electronic Waste is Piling Up in U.S.

- Americans discard hundreds of millions of electronic items each year.
- The quantity and the variety of electronic technologies continues to grow; the average life cycle has continued to decrease.
- Very rapidly growing waste stream.
- Used-electronics end up cluttering homes, shipped abroad for reuse, disposed of in landfills, or incinerated.

Sales by Number

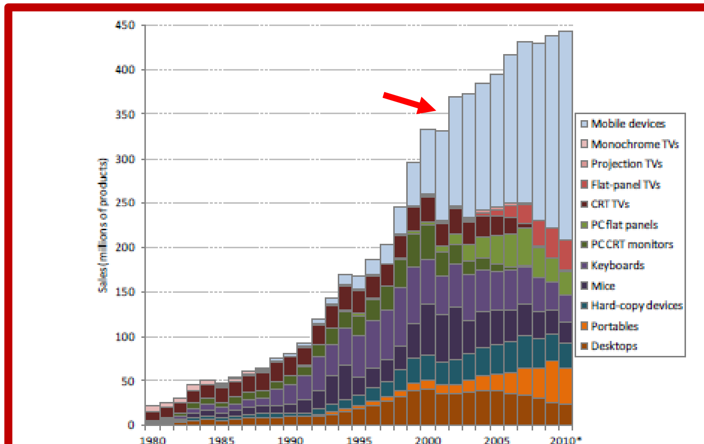


Figure 2: Sales of electronic products by model year, in number of units sold. *Results for 2010 are projected based on estimates from previous years.

Sales by weight

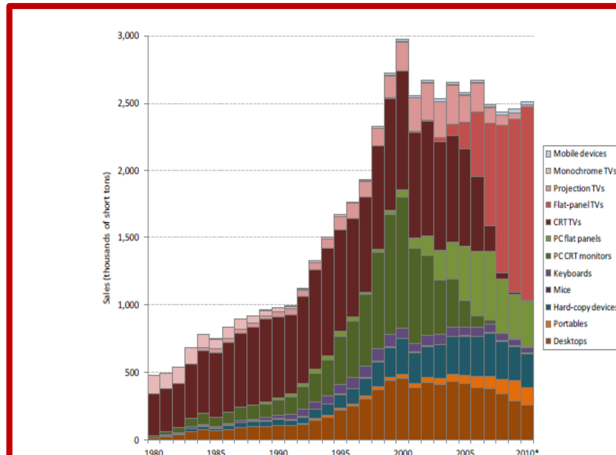


Figure 3: Sales of electronic products by model year, short tons of products sold. *Results for 2010 are projected based on estimates from previous years.

E-Waste is Hazardous

Sources: Lim & Schoenung, 2010; USEPA, 2009

- E-waste is a threat to ecological integrity and public health when improperly disposed of.
- E-Waste contains
  - lead (Pb),
  - cadmium (Cd),
  - Mercury (Hg),
  - Brominated flame retardants.

Health hazards:

- **acute toxicity.**
- **carcinogenicity.**
- **reproductive toxicology.**
- **skin corrosion, irritation.**
- **target organ systemic toxicity.**
- **germ cell mutagenicity.**
- **aspiration toxicity.**

Environmental hazards:

- acute & chronic aquatic toxicity.
  - rapid degradability.
  - bioaccumulation potential.

E-waste is a resource

E-waste contains:

- **Precious metals (Ag, Au, Pd).**
- **Critical materials (e.g., rear earth elements).**
- **Base and special metals (Cu, Al, Zn, In).**
- **Technology metals (Ga, In, La, Ru).**

Recycling reduces greenhouse gas compared to processing ores.

Primary mining

- ~ 5 g/t Au in ore
- ~ similar to other PGMs

Sources: UNEP, 2011; USDOR, 2011; Hageluken & Corti, 2010

"Urban" mining

- 300-350 g/t AU in cell phones
- 200-250 g/t AU in PC circuit boards

E-Waste Exported and Disposed Around the World → Environmental Justice

Accra, Ghana, 2009

Market scavenger boy, Alaba market, Lagos, Nigeria. ©2006 Basel Action Network (BAN)

Accra, Ghana, 2009

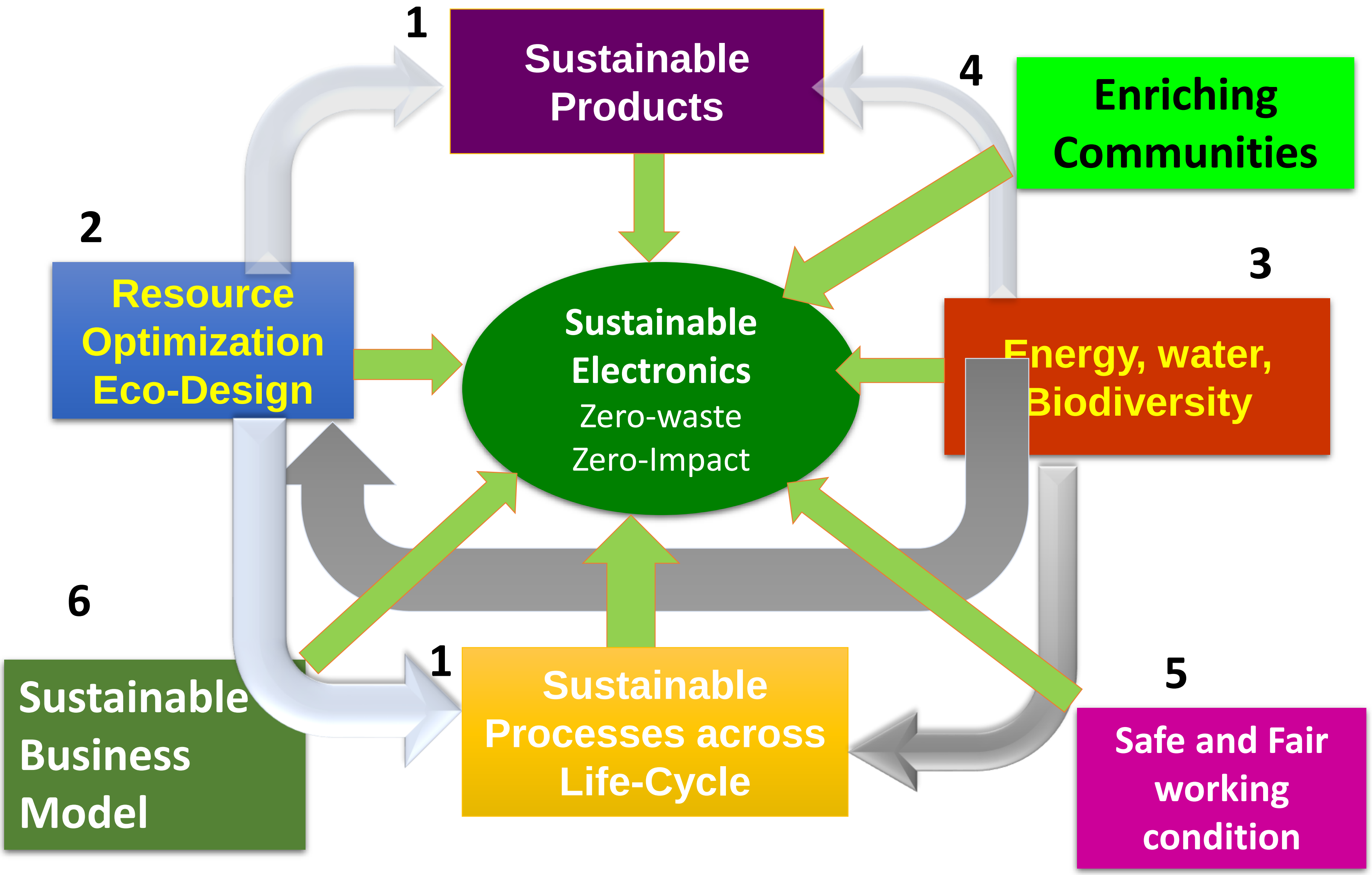
Migrant workers cracking piles of burned computer components to remove the copper in the burn village. Guiyu, China. May 2008. ©2008 Basel Action Network (BAN)

BAN investigator Clement Lam taking a soil sample along riverside where circuit boards were treated with acid and burned openly. Massive amounts of dumping of imported computer waste takes place along the riverways. Guiyu, China. December 2001. ©2006 Basel Action Network (BAN)

The problem of Electronics waste

- Huge waste volumes, fastest growing.
- Cathode ray tube glass, batteries challenging to recycle economically.
- Landfilling of E-waste and informal recycling.
- Trans-boundary E-waste dumping.
- Deficit in closing the loop for consumer electronics.
- **Better collection**, tracing and tracking of material flows, transparency.
- **Recycling**: Requires economic incentives, corporate stewardship, education and legislation.
- Complex products require a systemic solution & interdisciplinary approaches:
  - ✓ product design, mechanical processing,
  - ✓ metallurgy, economics,
  - ✓ ecology, social sciences.

Sustainable Electronics Themes



THEME 1: Materials and Processes Cause No harm – Green Chemistry Principles

Goal: Limit the harm posed by all ICTs materials and process.

Objective

- *Complete inventory* and hazards of chemicals in production and electronic products.
- *Elimination of hazardous* toxics from electronic products and processes.
- Design tools fully populated with materials and product hazard problems.
- Virgin and recycled materials sources from certified facilities.
- Alternative assessment should be made prior to selection of materials and chemical.

THEME 2: Closing-the-Loop: Eco-Design and Resource Optimization

Goal

Better management of closed-loop

- Better design.
- Extended producer responsibility.
- Industrial ecology.
- Zero waste → Infinite recyclability of all products.

Objectives

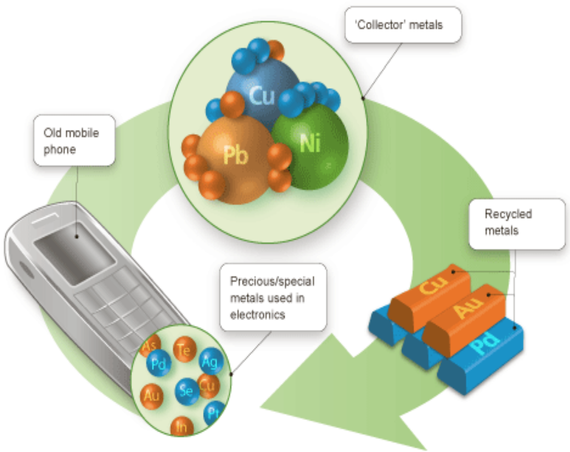
I. **Product design for recycling and life extension.**
   - Tracking & tracing of material flows / transparency creation.

II. **Research on recovery of rare earth elements.**
   - Recycling of Rare Earth elements such as Gallium, Germanium, Tantalum.

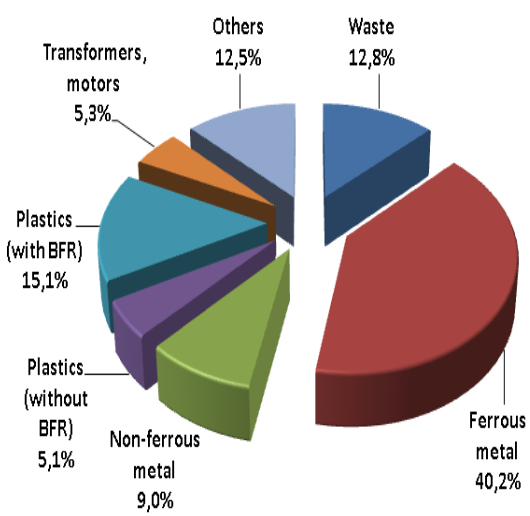
III. **Increase the recycled content of plastics.**

The Challenge: The good, the bad and the ugly

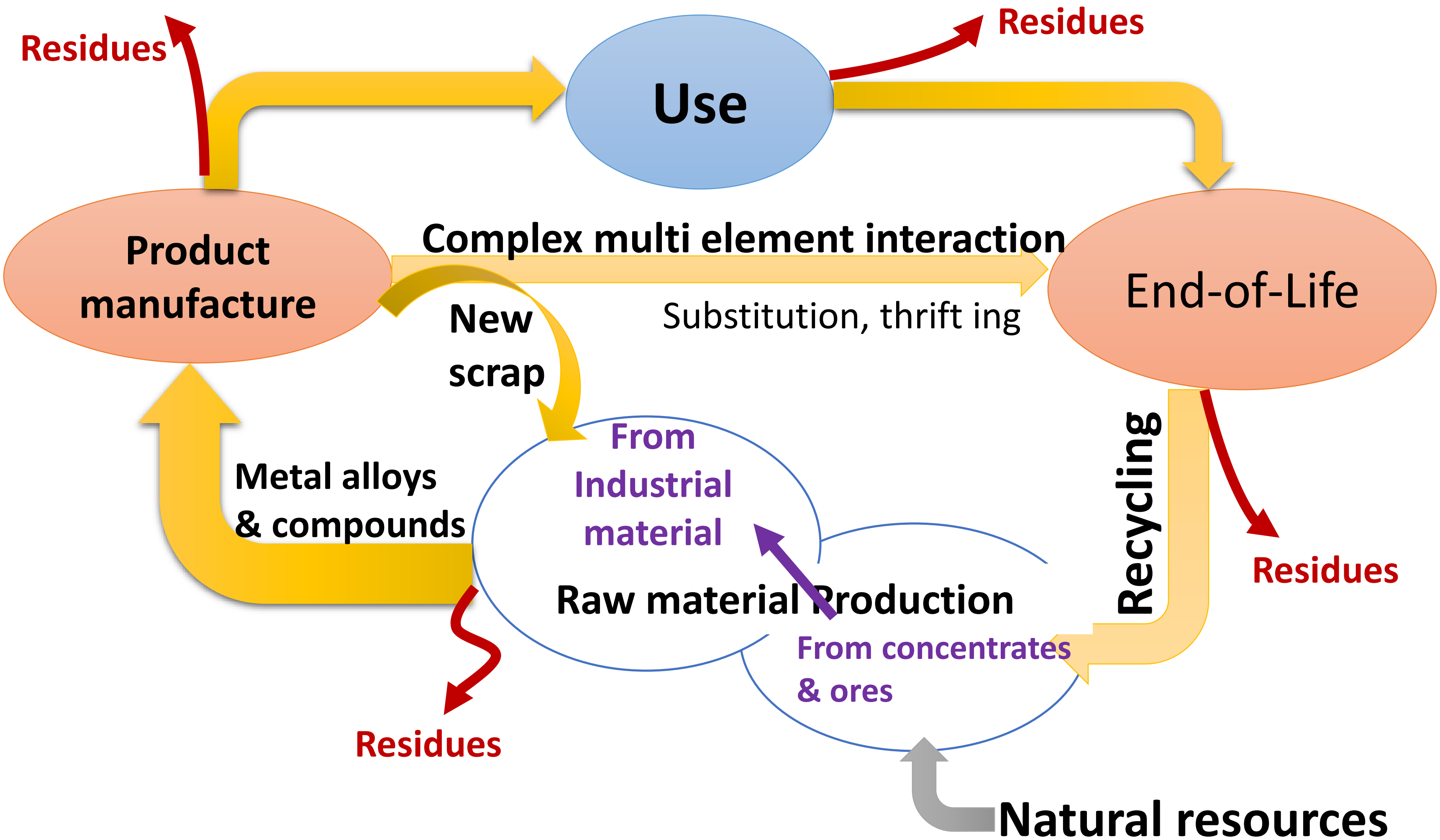
recovering valuables while taking care of hazards



- **E-scrap, a complex mix…**
  - Ag, Au, Pd…(precious metals).
  - Cu, Al, Ni, Sn, Zn, Fe, Bi, Sb, In (base-and special metals).
  - Hg, Be, Pb, Cd, As,…(substances of concern).
  - Halogens (Br, F, Cl…).
  - Plastics and Other organics.
  - Glass, Ceramics.
- **Environmental Risk** in case of landfill and inappropriate recycling.
- **Valuable metal resource.**

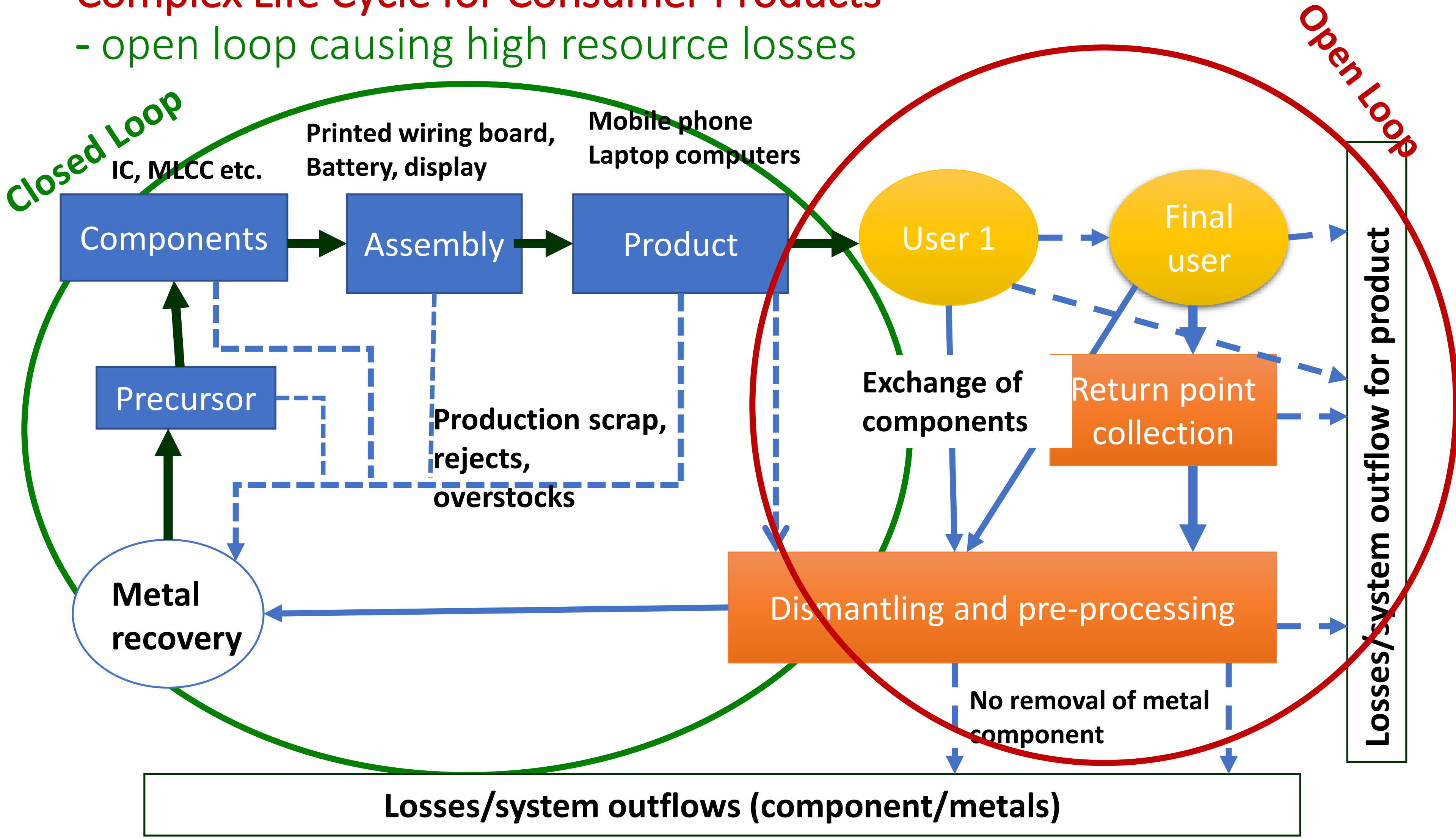


Creating Circular Economy:
Turing trash to treasure



Recycling, mining, substitution, product design &
use need to developed as interdependent tools in a holistic system approach.
Innovation needs all along the value chain.

Complex Life Cycle for Consumer Products
- open loop causing high resource losses



Multiple change of ownership, low transparency, High product mobility, global material flow.
High exports of EoL products in regions without appropriate recycling infrastructure.
Low consumer awareness on resource value and missing recycle incentives.
“Hibernating” good and inefficient .

Recycling example: Mobile Phone

Little recycling in spite of available hi-tech processes

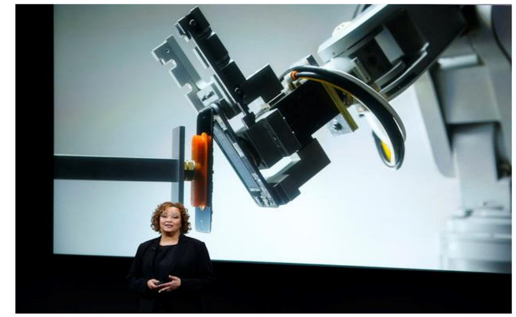
Recycling potential (2010, global): 800 M units/80,000 t

- Reality 2000 t.
- Most phones are not collected ("drawer & waste bin").
- Most collected phones are exported for "reuse" in developing / transition countries.
- Usually no recycling at final end-of-life.

April 18, 2016

Apple Recovered More Than A Ton Of Gold From Recycled Devices

The company salvaged about $43.6 million worth of gold, reducing the need for future mining efforts.



STEPHEN LAM/REUTERS

Lisa Jackson, Apple vice president for environment, policy and social initiatives, introduces a robot named Liam that deconstructs iPhones for recycling.

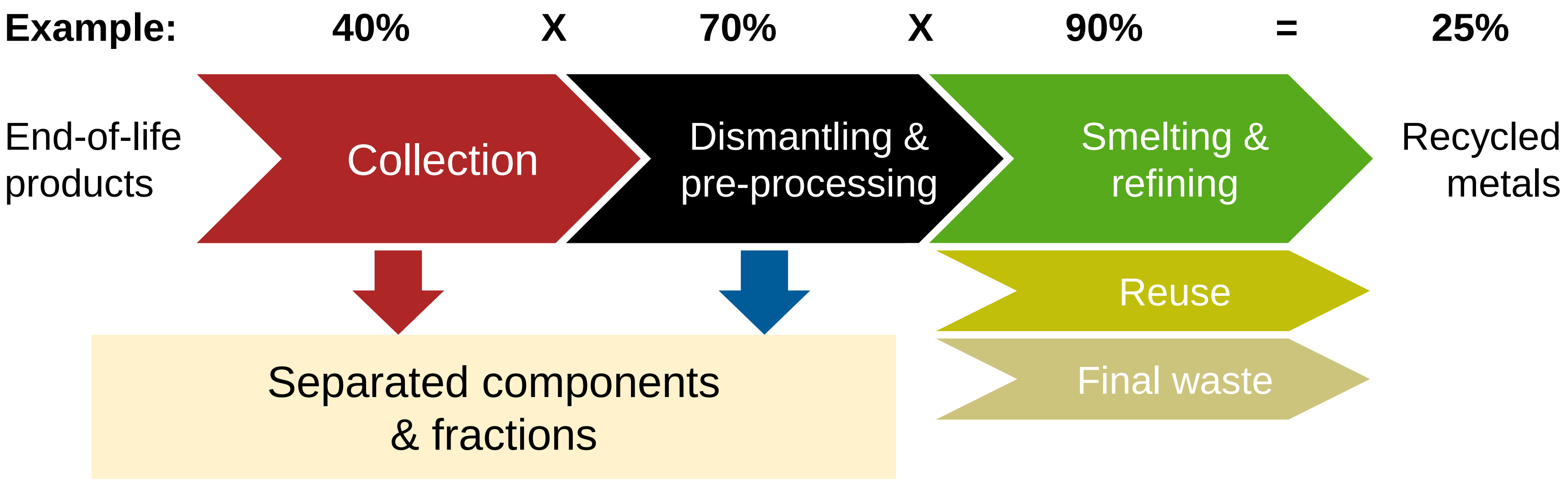
- Less than 30% of e-waste is currently recycled.
- Recycling 1 million laptops saves the energy equivalent to the electricity used by 3,657 U.S. homes in a year.
- For every 1 million cell phones that are recycled, 35,274 pounds of copper, 772 pounds of silver, 75 pounds of gold, and 33 pounds of palladium can be recovered.

Collection is the Challenge

In early 2006, an independent survey of 650 people for the Australian Mobile Telecommunications Association revealed that:

- 52% of Australians keep their old mobile phones (whether working or not)
- 23% give away their old mobile phones, either to family or friends, employer or retailer
- 5% throw them away
- 4% of people have lost or had their mobile phone stolen
- 4% still using them
- 4% recycle them
- 4% traded them in for a replacement handset
- 1% sold them
- 1% donated to charity
- 2% don't know

System Efficiency of the Recycling Chain



- 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.

Low loadings per unit, but volume counts
Example: Metal use in electronics

Global sales, 2009

a) Mobile phones

1300 million units/ year

X250	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

1300 million Li-Ion batteries

X 3.8	g	Co	≈	4900 t	Co

b) PCs & laptops

300 Million units/year

X1000	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 million Li-ion batteries

X 65	g	Co	≈	9100 t	Co

a+b) Urban mine

Mine production		/ share
Ag: 21,000	t/a	▶ 3%
Au: 2,400	t/a	▶ 4%
Pd: 220	t/a	▶ 16%
Cu: 16	Mt/a	▶ <1%
Co: 75,000	t/a	▶ 19%

- Tiny metal content per piece → Significant total demand.
- Other electronic devices add even more to these figures.

Recycling Chain Needs major Improvement

Gold recycling

Collection **Dismantling & pre-processing** **Smelting & refining**

Efficiency **80%** **X** **50%** **X** **50%** **=** **20%**

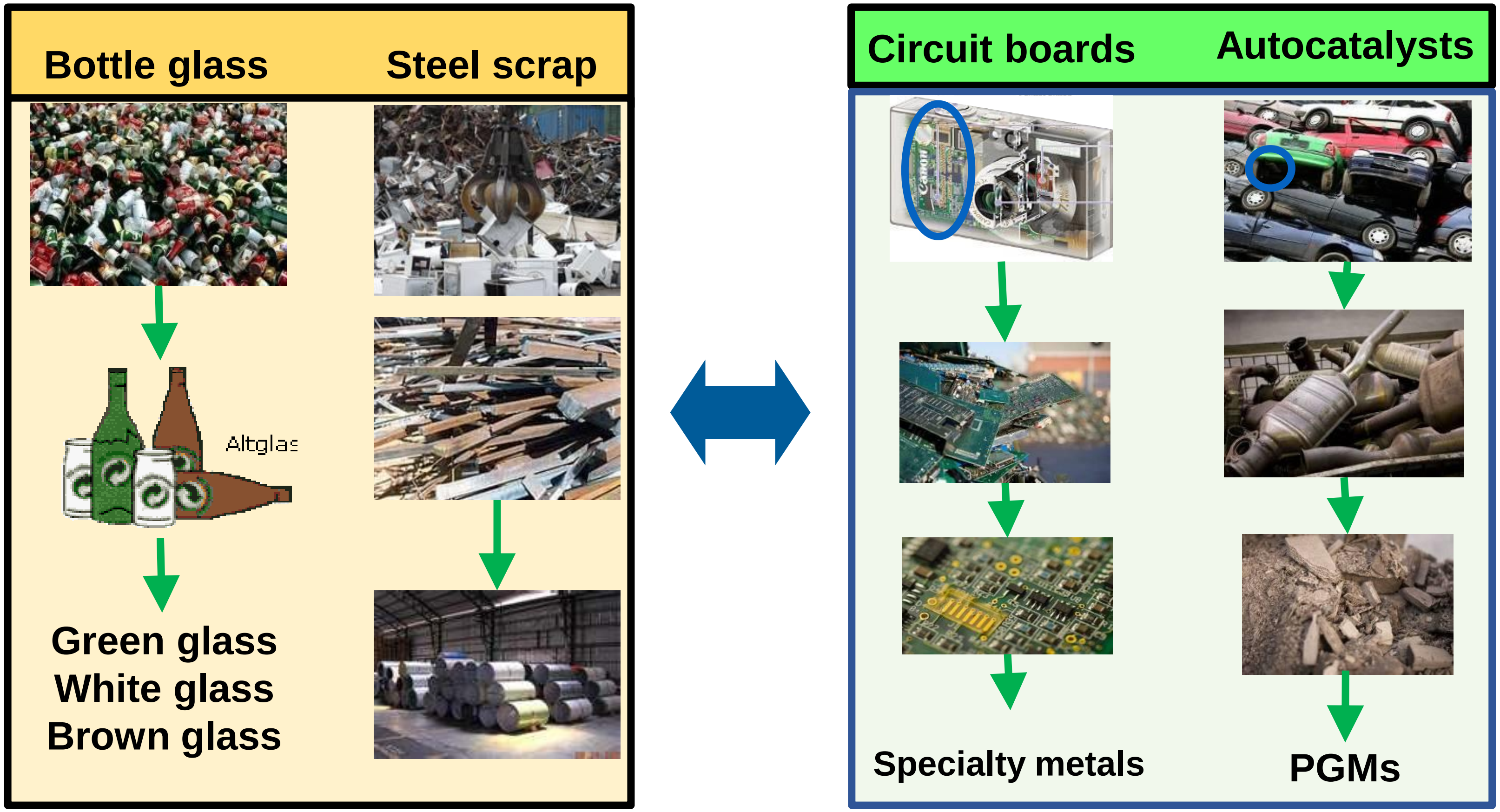
Efficiency **50%** **X** **25%** **X** **95%** **=** **12%**

Future… 85% X 90% X 95% = 73%

➲ Huge opportunities by Improving the full system efficiency - so how to get there?

Figures are illustrative

Mass recycling vs technology metals recycling



- “Mono-substance” materials without hazards.
- Trace elements remain part of alloys/glass.
- **Recycling focus on <u>mass and costs.</u>**

- “Poly-substance” materials, incl. hazardous elements.
- Complex components as part of complex products .

Recycling focus on <u>value recovery from trace elements.</u>

THEME 1 - Research Questions: Electronic Products

I. Chemicals in Electronic Products

- Develop practical and multipurpose tools / methods to assess chemical found in electronic products,
- Develop a method for hazardous materials that need to be replaced. “White” and “black” list, ranked by risk,
- Transparency, sharing information.

II. Fate and transport of hazardous chemicals in products / processes

- Obtain better information on fate and transformation of chemicals through life cycle.
- Identify nanoscale materials, in electronic waste stream and their fate & transport.

III. Search for replacement of hazardous chemicals with safer one

- Elimination of toxics in products and processes over the life cycle, e.g.. BFR, PVC, phthalet DEHP, DBP, BBP.
- Replacement of hazardous and toxic chemicals with safer, biologically benign alternatives.

IV Integration of chemical information in electronics with OEDs/OEMs/ recyclers across the supply chain LC

- Integrate hazardous chemical information in the electronics process and product design.
- Create an EPA Green Star Program to direct purchasers to product standards that include these ideas in EPEAT.
- Create a register of preferred chemicals for various processes and make the accessible to stakeholders.

Theme 2: Closing-the-Loop:
Eco-Design and Resource Optimization-

Proactive eco-design that take into account

- Design for disassembly (reuse and refurbishment), Life extension and recycling.
- Design for recovery, avoid incompatible material mix if doesn't interfere with essential functionality.
- Design for tracking and detection.
- Design with less materials use.

- **Transparent material Flow**
  - Commonly accepted standards for scope, quality.

- **Optimize systems for priority devices**
  - Economic drivers.
  - Technical – interface and process technology.
  - Rules / incentive.

What are the Barriers

- ***Technical:***
  - Limited chemicals listed IEC 62474 - Material Declaration for Products of and for the Electrotechnical Industry - *eco-friendly and climate neutral.*
  - Lack of collaboration to collect chemical and process information.
  - Challenge in handling proprietary information.
  - Lack of transparency in the supply chain and fear of liability.
- ***Infrastructure:*** Lack of method to bring information on hazards and alternatives to designers.
- **Economical:** Lack of funding for developing effective alternative assessments.
- ***Standards*** : Lack of agreement on preferred materials.

Standards needed

- **Consensus on harmful / benign chemicals.**
- **Integrate a criterion for a full chemical inventory into Standards used by EPEAT®.**
- **Integrate a criterion for making information publicly available and verifiable.**

Challenges in Metal recycling from complex products
(source Christian Hagelüken)

1. Accessibility of relevant components/materials
   - ➢ Electronics in cars, REE magnets in electric motors,…
   - → "**Design for Disassembly**", mechanical processing, pre-shredding-technology.

2. Thermodynamic limits for multicomponent mixtures of "trace elements' – cost effective recovery challenging
   - ➢ Rare earth, Gallium/Germanium, Lithium, Tantalum, …
   - → "**Design for Recycling**," fundamental metallurgical research, pilot plants.

3. Severe deficits in closing the loop for consumer goods
   - ➢ Electronics, cars, batteries, lamps, …
   - → **Better collection**, tracing and tracking of material flows, transparency, economic incentives.

Complex products require a systemic solution & interdisciplinary approaches:
product design, mechanical processing, metallurgy, economics, ecology, social sciences.

THEME 3: Energy, Water and Biodiversity

Goal

- ICT manufacture and EoL process to realize zero net energy and water use while taking steps to maximize biodiversity.

Objective

- Maximize the benefits of ICT applications.
- Decrease manufacturing and supply chain energy use, with the goal of zero net energy and CO_2 from manufacturing.
- Decrease net water use.
- Increase biodiversity.

THEME 3: Energy, Water and Biodiversity Research Question

1. **Develop method for assessing lifecycle costs and environmental impacts electronics manufacturing and EOL processes.**
   - Simplified product and process LCA for key product segment.
   - Environment, health and safety protection throughout product lifecycle of REE.
   - Materials lifecycle optimization and what has highest risk?
   - **Demonstration case studies to model efficient water and energy use and simple cost-efficient measures.**

2. **Energy use for unit of production not known**
   - Energy STAR performance indicator takes 2-3 years to develop.
   - Need to measure energy use over time.

3. **Develop alternative assessment tools**
   - Proactive and timely evaluation of ESH impact of new materials.
   - How do can we integrate alternatives assessment into electronic process and product design tools.

4. **Maximize use of renewable energy**

Plastics and Steel Dominate Weight – Preciouses Metal Dominate Economical and Ecological Value

weight-%	plastics	Fe	Al	Cu	Ag [ppm]	Au [ppm]	Pd [ppm]
TV-board	28%	28%	10%	10%	280	20	10
PC-board	23%	7%	5%	20%	1000	250	110
mobile phone	56%	5%	2%	13%	3500	340	130
portable audio	47%	23%	1%	21%	150	10	4
DVD-player	24%	62%	2%	5%	115	15	4
calculator	61%	4%	5%	3%	260	50	5

value-share	Fe	Al	Cu	Ag	Au	Pd	sum PM
TV-board	4%	10%	50%	7%	22%	7%	36%
PC-board	0%	1%	18%	5%	61%	15%	81%
mobile phone	0%	0%	9%	13%	64%	14%	91%
portable audio	2%	0%	82%	3%	10%	2%	15%
DVD-player	13%	3%	42%	5%	32%	5%	42%
calculator	0%	5%	14%	7%	69%	4%	80%

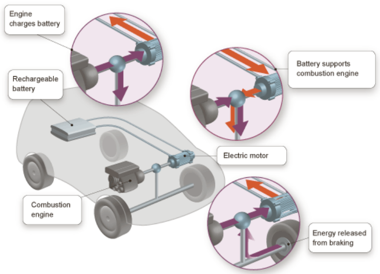
<1%	1-10%	10-20%	20-50%	50-70%	>70%

Prices of Oct. 2006

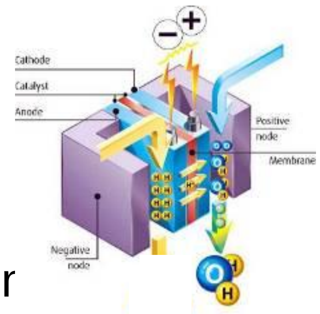
Note: indicative numbers only; value can differ significantly also within one category!

Clean energy developments will further boost demand for technology metals

- **Electric vehicles & batteries**
  cobalt, lithium, rare earth elements, copper.

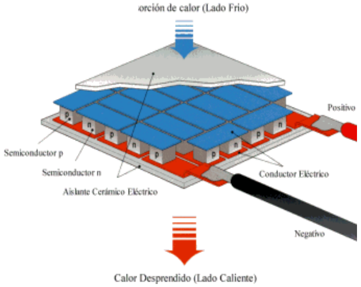


- **Fuel cells**
  platinum, (ruthenium, palladium, gold).



- **Photovoltaic (solar cells)**
  silicon, silver, indium, gallium, selenium, telluriur
  germanium, ruthenium.

- **Thermo-electrics, opto-electronics, LEDs, …**
  bismuth, tellurium, silicon, indium, gallium,
  arsenic, selenium, germanium, antimony, …



Technology Metals

Lanthanum

≅10 pounds of La in the Toyota Prius.

Europium

bright white LED lights.

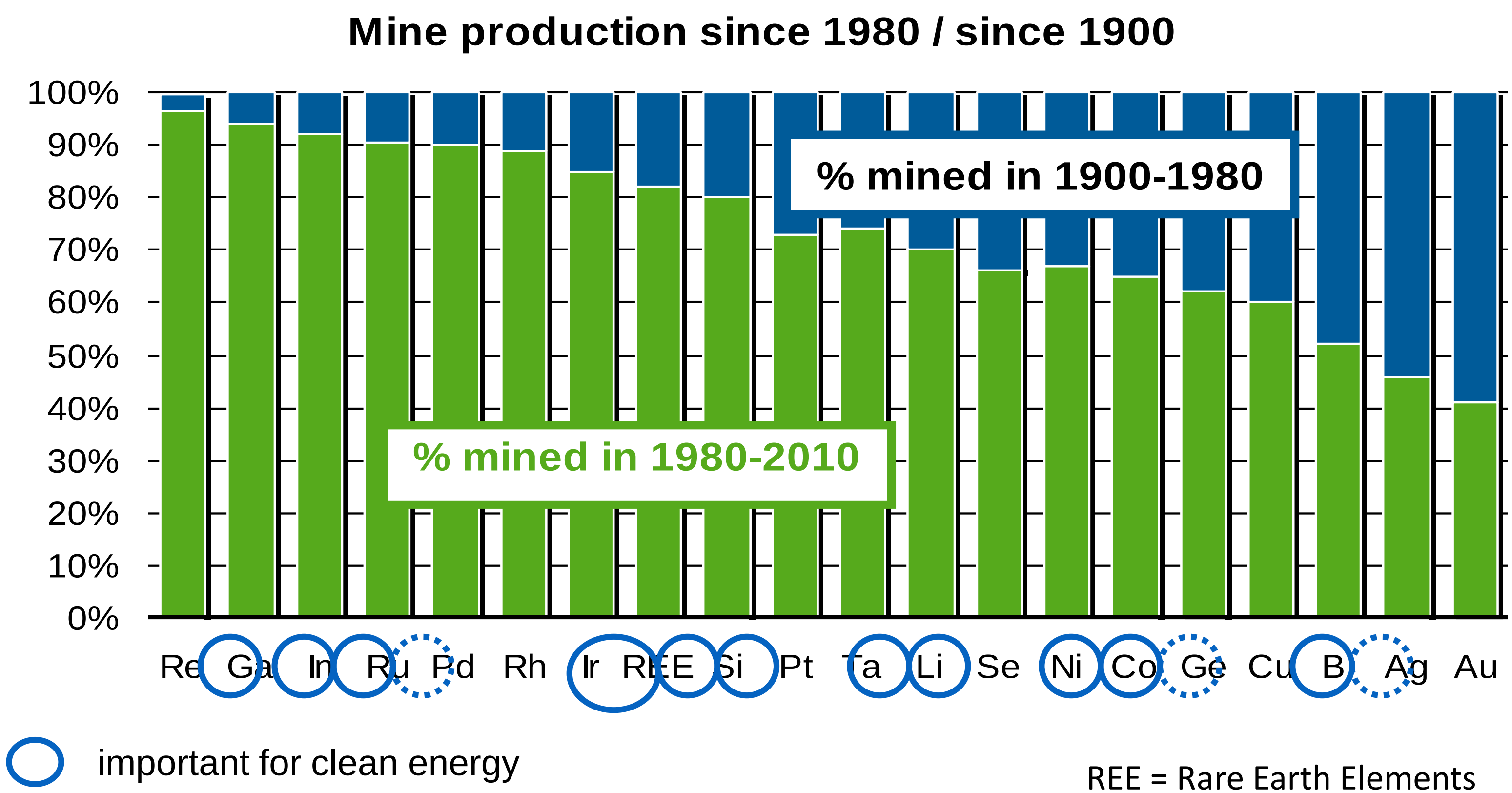
Erbium

Erbium is used to make lasers and super-fast fiber optics.

Neodymium

Neodymium is used to make tiny magnets to build miniature gadgets .

Demand for ‘technology metals’ is booming



➲ **Much more than Rare Earth Elements, but little significance of „mass metals“**

<u>Current Work</u>:
Hazardous Byproducts of Unsustainable management of used electronic

Land Fill

Air pollution from Open combustion

Water Pollution

Fire Destroys Warehouse of Massachusetts E-waste Exporter

July 15, 2015

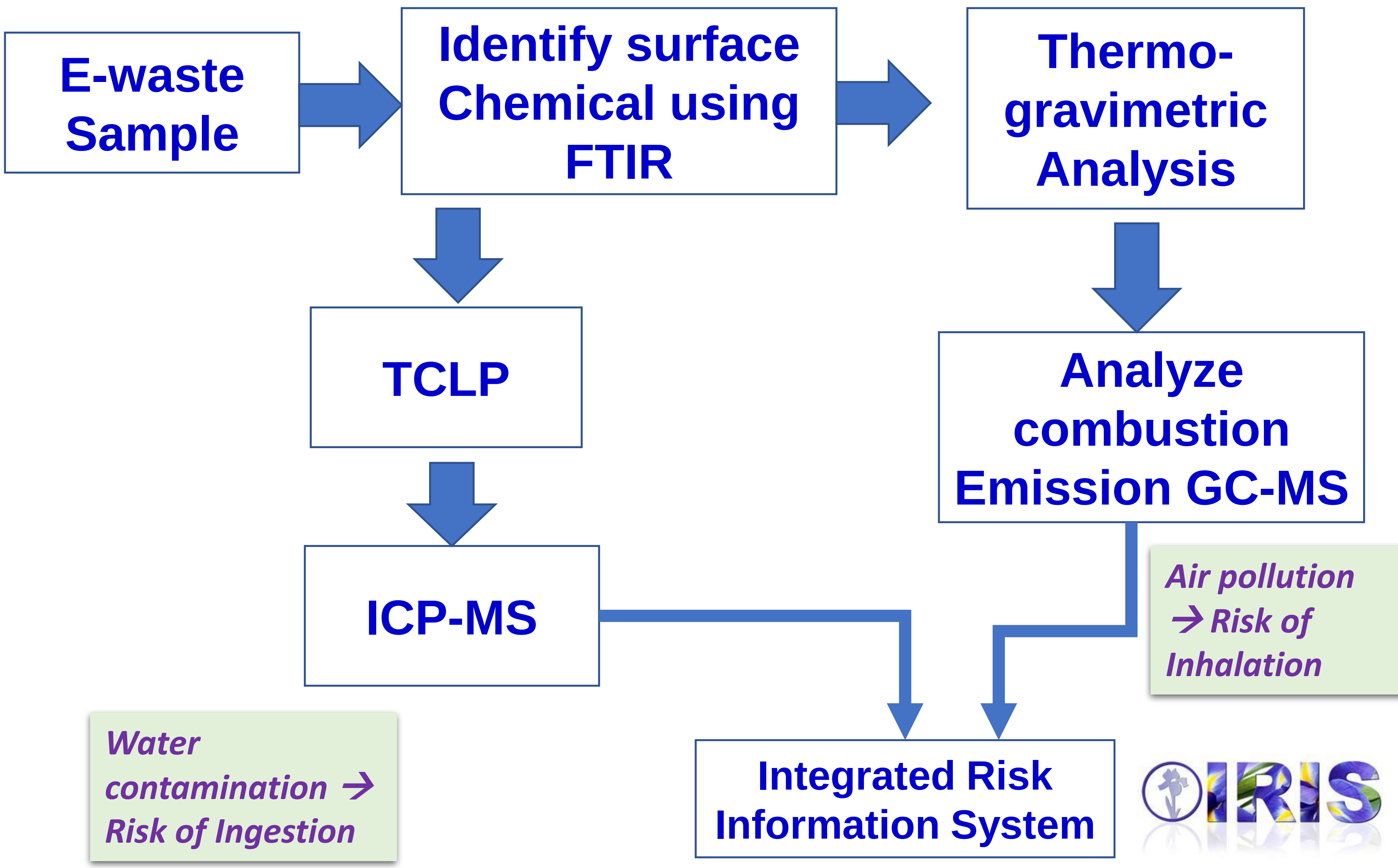
In the early evening of July 11, CRT Recycling Inc. (CRTR)[1], a Brockton, Massachusetts company well known for taking obsolete televisions and computer monitors from New England area businesses, residences, and schools, experienced a four-alarm fire in its warehouse. Consumed in the blaze were thousands of stockpiled Cathode Ray Tube (CRT) computer monitors and TVs[X] stored both outside and inside CRTR's warehouse. The State Fire Marshall's office has determined that the fire was ignited intentionally.

Authorities described the intense black smoke that billowed from the fire as being highly polluting and dangerous. The fire blew a wide plume of pollutants over nearby residential areas and a shopping center. The burning of TVs and monitors creates very toxic and **carcinogenic smoke and fumes containing brominated dioxins, and polycyclic aromatic hydrocarbons.**

http://www.enterprisenews.com/article/20150711/NEWS/150719156
http://archive.ban.org/2015/07/15/fire-destroys-warehouse-of-massachusetts-e-waste-exporter/

Current in-house study

Human health & environmental implication of improper management of e-waste



2e. TGA-Gas Chromatography-Mass Spectrometry

TGA

Sample heated to 800°C in presence of air

Gas is emitted and drawn through a hose to gas chromatography

Gas chromatography

Gas collected is then separated into different fractions

Each fraction is then fed into mass spectrometer

Mass spectrometer

Each fraction gives a mass spectrum

A library is used to search for matches to that spectrum

Each compound has a unique spectra, allowing the chemicals in the gas from the TGA to be identified

Health risk assessment

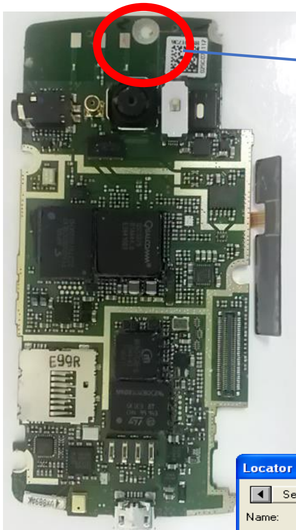
Investigate each compound identified from the mass spectrometer to see whether there are any health risks from exposure to it

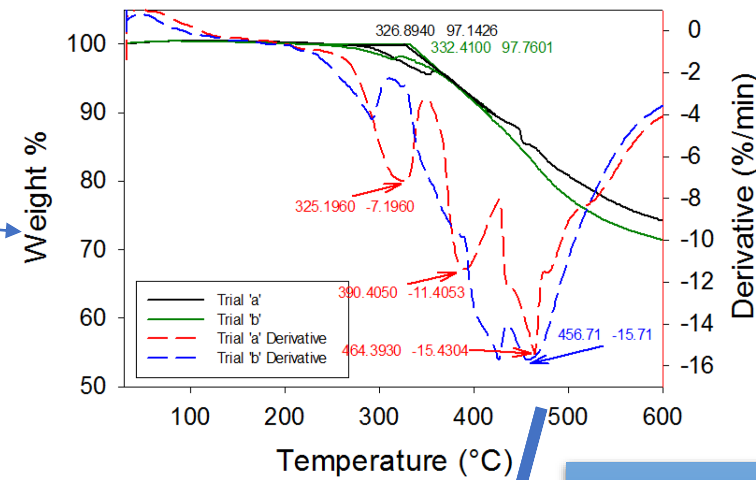
EPA's Integrated Risk Information System (IRIS)

IRIS

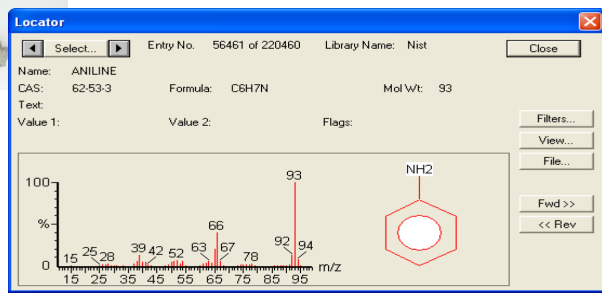
Emission analysis of Cellphone during open burning of Printed Circuit Board

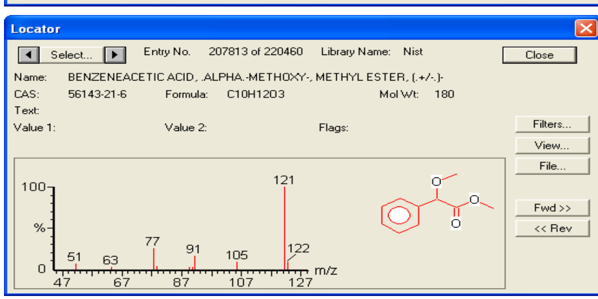
Thermal Analysis

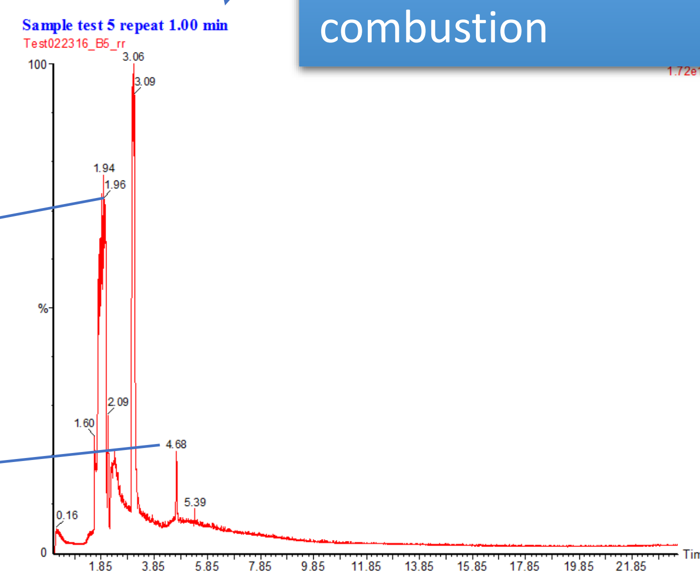




Chromatogram of emitted gas during combustion





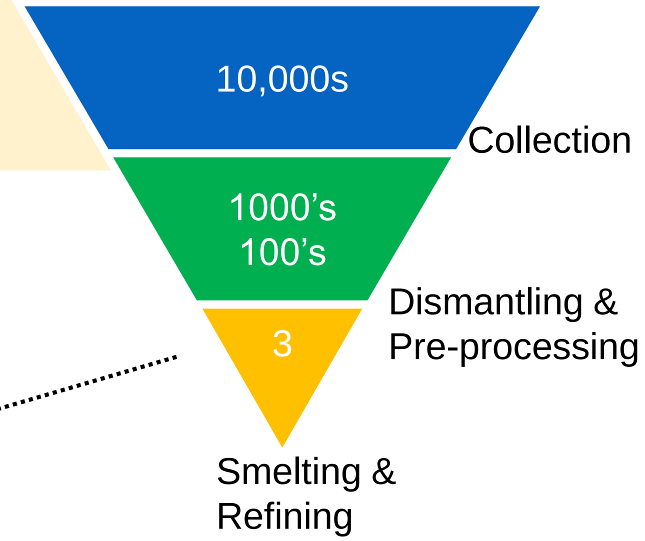


ACS Meeting, May 2016, August 2016.

Used Electronic Recycling Chain:
Many players but Limited Refiners for Technology metals

- Recovery capacity for technology metals available.
- Losses over supply chain is high .
- Ensure that critical fractions with technology metals are treated at best available processes.
- Innovation needed for:
  - High yields, minimal emissions.
  - Recovery of multiple metals.

Number of actors in Supply chain of e-scrap:



Main flaws in Current Used Electronics Management

Poor collection

Collection → Dismantling & pre-processing → Smelting & refining





Deviation of collected materials ⇨ dubious exports ⇨backyard treatment

Collection → Dismantling & pre-processing → Smelting & refining






Electronic Recycling in China

Improving Occupational Safety Standards at Production & Recycling Facilities

Taking yokes out of CRTs

Shredder

THEME 6: Business Model

Goal

Decision throughout the supply chain are aligned with sustainable objective.

Issues

1. **Quarterly earning matrix**

   How could investments in the electronics industry support requiring companies to report on their long-term strategy and how it makes the business more sustainable.

2. **Asses business models for optimization of product lifecycle**

   How do we incentivize companies to design and build products to be long lasting and upgradeable, easy to repair, and easy to refurbish for a significant reuse phase?

Theme 6: Sustainable Business Model

3. Determine ways for cost internalization

- Develop methods to assess the true costs for each phase of electronics in their lifecycle.
- Identify categories of externalized costs in each phase of the lifecycle?
- Develop appropriate methodology for itemizing costs in each category.

4. Lack of standards applicable per industry sector that can help companies establish best practices

5. Product longevity and ease of repair and upgrade

- What is the current rate of product turnover category?
- Would we pay more for the "Volvo" of laptops?
- Upgrade Vs. replacement – comparison between business and consumer
- How can a truly modular design enable upgrading?

EPA/ORD Electronics Research Topics

1. Life Cycle Assessment and Alternative Assessment Tools

- **Research to identifying potential environmental trade-offs for reuse and recycle of materials in electronics including rare earth elements and plastics (internal research and SBIR grants).**
- **Develop comprehensive methodology to evaluate the total impact of changes in products, materials, services.**
- **Developing a proactive tool for evaluation of ESH impact of new materials.**

2. Sustainable Electronic Products and Processes

- **Identify hazardous substances within the life cycle of electronic products.**
- **Information on fate, transformation and transport of chemicals used in electronic.**
- **Create Innovation Challenges: ORD & OSWER challenged industry to develop a system for tracking electronics devices as well as their chemical contents to advance recycling and recovery of valuable products.**

EPA/ORD Electronics Research Topics.

3. Green Chemicals and Cleaner Processes Replacement of hazardous chemicals with safer alternative

- Search for safer alternative substitutions for top toxic products.
- **Improve Standards and E-waste Tracking:** Support EPEAT on developing new standards for environmental preferred products/ Support funding for UN (StEP) E-Waste Tracking Study.

4. Develop Best Practice for Protecting Workers and Communities

EPA/NIOSH/OSHA will study to develop a best practice health scorecard/auditing tool that can be used to evaluate current performance worldwide for both manufacturing and recycling.

- Thank you !

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ICT Roadmap Major Needs

1. **Holistic impact studies of electronics industry:**

   Develop comprehensive methodology to evaluate the total impact of changes in products, materials, services.

2. **Recycling: Collect more, better and ensure smart recycling**
   - Holistic optimization of recycling chain, focus on interface management & product design.
   - Prevent dubious / illegal recycling.
   - Suitable economic incentives and legislative support for recycling critical metals.
   - Pre-shredder technology to remove magnets, circuit boards, batteries.

3. **Materials and their Replacements and Eco-Design for**
   - disassembly & recycling.
   - Detection and automated sorting with added information.
   - Safer substitutes – cross industry collaboration efforts.

4. **Transparency and data for product sale, EoL chemical content**
   - Composition, stocks & flows of secondary raw materials.

5. **Align business model with sustainable stewardship of electronics**
   - Cost internalization, consumer behavior, optimized product life.

Use electronics EOL management and data security

Used electronics contains critical personal, financial, legal, technical, operational, and classified information.

Sources

- Homes & Residences.
- Commercial Businesses, Professional Offices., Financial Institutions. Health Care Industry.
- Large Manufacturing Industry, Utilities & Public Services.
- Local, State, & Federal Government.

Laws

- HIPAA – Health Care Portability & Accountability Act.
- Gramm-Leach-Bliley Act – Financial Services Modernization Act of 1999.
- FERC CIP Standards – Utility Industry Critical Cyber Assets.
- DoD 5220.22-M – Department of Defense Standards.