A processes-based approach to reduce the hazard of informal e-waste recycling

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Introduction and Overview

E-waste contains a mixture of approximately 1000 chemicals (Terada, 2012), some potentially valuable and some toxic. Consequently, e-waste recycling is associated with significant health hazards, which are exacerbated under the uncontrolled conditions prevalent in developing countries (Tsydenova & Bengtsson, 2011). Low labor cost and lax environmental standards make e-waste recycling more lucrative in developing countries, creating economic incentives for transnational e-waste trade (Terada, 2012). The global distribution of informal recycling and the uncontrolled nature of the e-waste trade pose significant challenges to tracing the fate of e-waste and implementing local solutions. Thus, mitigating the inherent hazard of the chemicals in electronics themselves is essential for effectively reducing the environmental and human health impacts of informal e-waste recycling. Here, we characterize organic and inorganic compounds found in electronic components and the post-recycling reaction products based on measurements in the environment and in humans as well as their inherent hazard. We then systematically evaluate the risk of these chemicals to the environment and human health within the context of informal recycling processes.

Approach

1) Researched which electronic components enter into the informal recycling processes
2) Described chemicals found in 10 electronic components using technical literature
3) Identified levels of environmental and human exposure at/near e-waste site from peer reviewed literature
4) Evaluated chemicals based on overall hazard and prevelance at e-waste site
5) Applied findings to case study: Assessed fate of Indium found in LCDs screens in the informal recycling disposal stream

Figure 1. Materials Recovered and Emissions of Informal Recycling

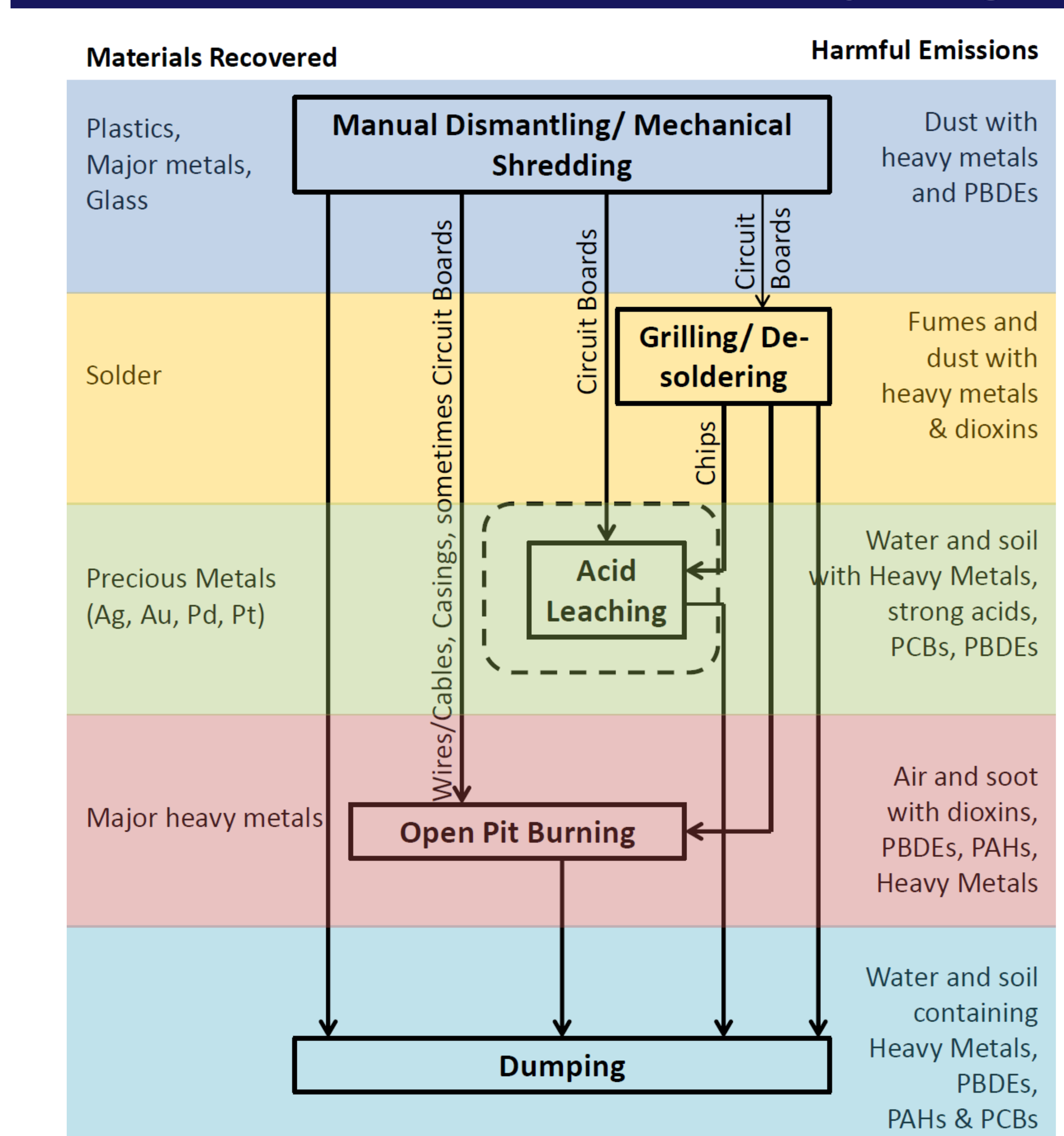
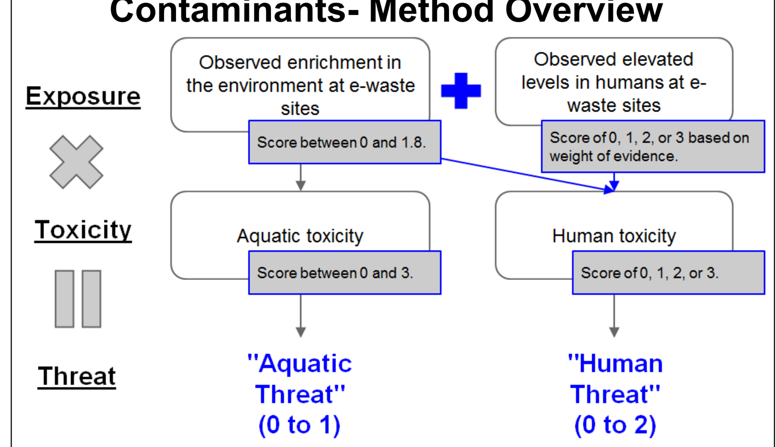


Figure 2. Characterizing Metals in E-waste Based on Prevalence and Inherent Hazard

A. Risk Assessment of Inorganic Contaminants- Method Overview



B. Threat to Humans vs. Aquatic Organisms for Elements Measured at E-waste Sites

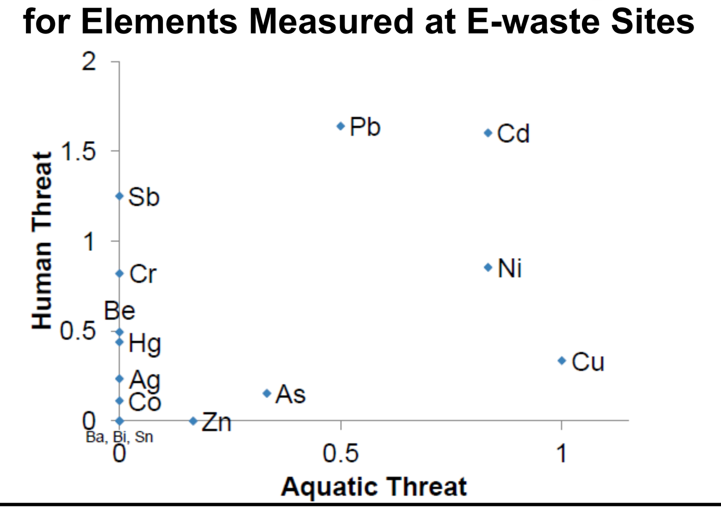
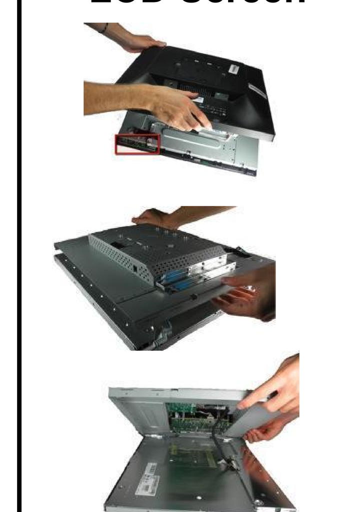


Figure 2A. Our risk assessment for inorganic contaminants is based on a review of the literature measuring contaminant levels in both humans and environmental media at informal e-waste recycling sites. **Elements were assigned scores based on various parameters:** (1) **"Environmental Enrichment Score" =** number of studies finding the element at levels 5 times or more above background levels **+** number of studies finding the element at levels 100 times or more above background, divided by the total number of studies that have measured the element at/near informal e-waste sites. (2) **A score of 1, 2, or 3 based on elevated levels in humans** at e-waste sites. (3) A **human toxicity score** of either **0, 1, 2, or 3** based on how established its human hazard was on authoritative lists (i.e. IARC, Prop 65). (4) **"Aquatic Threat"** was derived by comparing the dissolved elemental concentrations from studies conducted on surface waters near/at e-waste sites with aquatic wildlife criteria (US EPA, Can.).

Figure 2B. Results of risk assessment for inorganic contaminants at informal e-waste recycling sites. Certain elements, such as **Cd, Pb, and Ni** are likely to pose significant threats to both humans and aquatic ecosystems at informal e-waste recycling sites. **Cu**, is clearly the greatest "Aquatic Threat", while **Sb** may be a significant "Human Threat" without identifiable risks for aquatic ecosystems. **Threats posed by elements may change rapidly as the composition of the e-waste stream changes.**

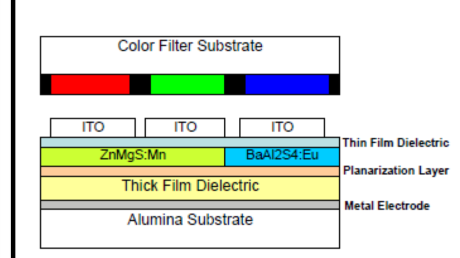
Figure 4. A Case Study: Indium in LCD Screens Entering in the E-Waste Stream Today

A. Disassembly of LCD Screen



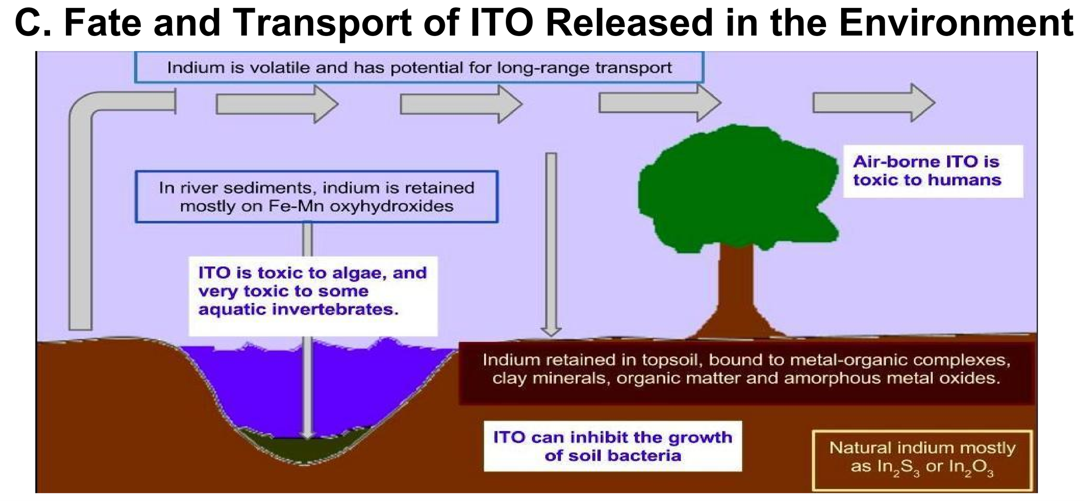
from http://www.ifixit.com/

B. Diagram of Indium Tin Oxide (ITO) in LCD Screen



from Technical Report by Planar Systems Inc.

C. Fate and Transport of ITO Released in the Environment



D. Studies Provide Evidence of Adverse Effects of ITO

	Reproduction	Respiration	Tumorigeness
Humans	not found	lung disease, pneumonia	not found
Animals (Rodents)	testicular damage	pulmonary lesions, pneumonia	Lung Tumors

Figure 4A. Modular design and disassembly of an LCD: First the back cover, then Printed Circuit Board (PCB) Mounting Frame with the PCBs, and finally Lightbox assembly (LCD screen package)
Figure 4B. Diagram showing location of ITO containing glass electrode layers in LCD screen
Figure 4C. Illustration of ITO's potential transport within different environmental media, given the LCD screen is burned at the e-waste site
Figure 4D. Table of limited human and animal studies examining chronic effects of ITO. All study endpoints described here were due to exposure via inhalation.

Discussion

- Understanding the processes of informal recycling is essential for prioritizing chemicals in electronics based on overall hazard and prevalence of primary and secondary compounds in the environment and humans at e-waste sites
- Based on our inorganics assessment, Cu is clearly the biggest aquatic threat and not addressed on any authoritative lists for human toxicity
  - Copper emissions in the environment could be reduced by optimizing components for easy manual Cu removal
- Incomplete combustion due to open-pit burning lends to a heterogenous group of secondary organic products that are readily found in the environment and humans.
  - An assessment of organics in electronics must consider the formation of these harmful byproducts
- Organic compounds with low overall hazard still contain functional groups that have the potential to yield harmful byproducts via open-pit burning at e-waste sites
- Indium tin oxide (ITO) is an emerging threat as LCD screens enter the informal e-waste sector; however, the modular design of LCDs may reduce exposure to ITO
  - burning of LCDs could volatalize ITO, however valuable metals can be obtained without burning of the screens

Figure 3. Assessment of Organic Compounds in E-Waste Based on Potential to Form Hazardous Combustion Products

A. Organic Products Detected in the Environment and Humans from 3 Informal Recycling Processes

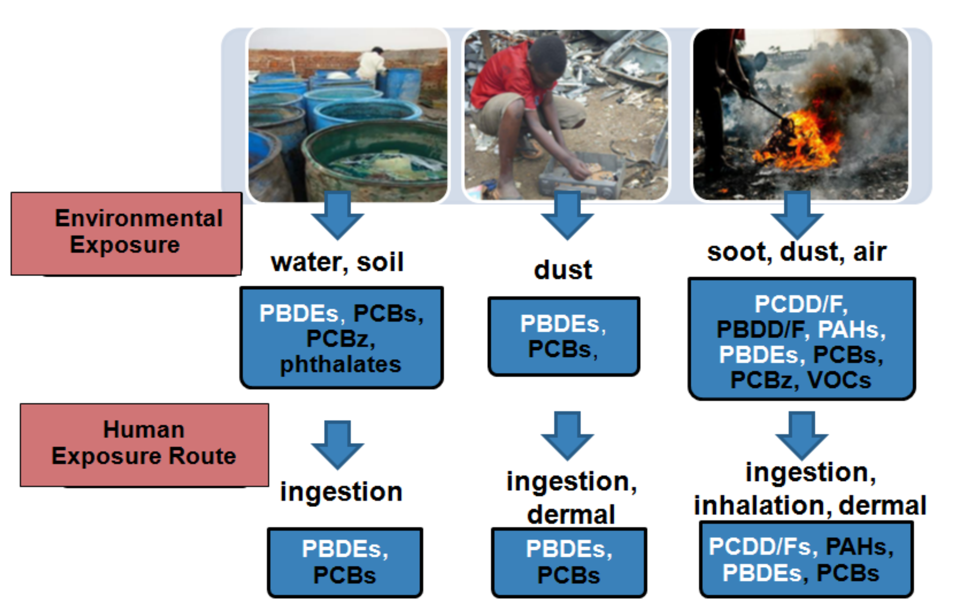


Figure 3A. Depiction of the top three informal e-waste processes: Acid leaching, manual dismantling and open-pit burning. Compounds highlighted in white were measured in the highest concentrations in both the environment and in humans relative to non e-waste sites. Open pit-burning releases the most heterogenous form of organic emissions into the environment—both primary and secondary products. Thus, we focused our organics assessment on the potential of parent compounds to form these byproducts via incomplete combustion during the burning of electronic components at e-waste sites.

B. Prioritization Scheme of Combustion Byproducts of Parent Organics Based on Functional Groups

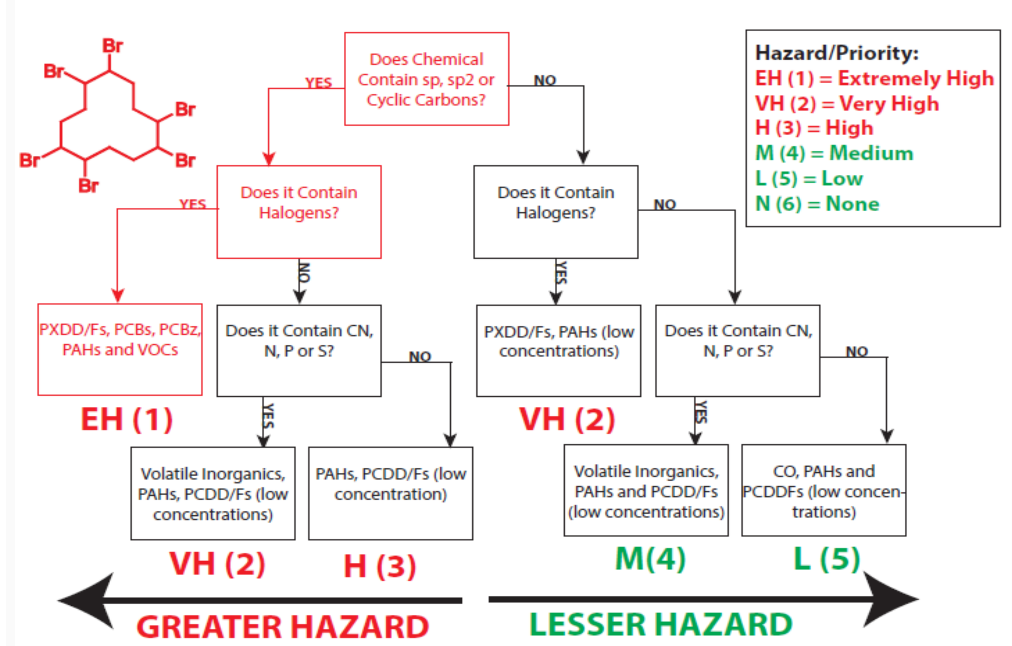


Figure 3B. Because open-air burning of electronic waste leads to additional byproducts, it is pertinent to analyze what byproducts might form. Accounting for the same conditions, the products that result from combustion of a specific organic compound strongly depends on the structure and the functional groups inherent to the molecule. This flowchart shows how the distribution of byproducts ranges from low to extreme hazard based on structure and functional groups.

C. Ranking of Organic Compounds in Electronic Components Based on Functional Groups

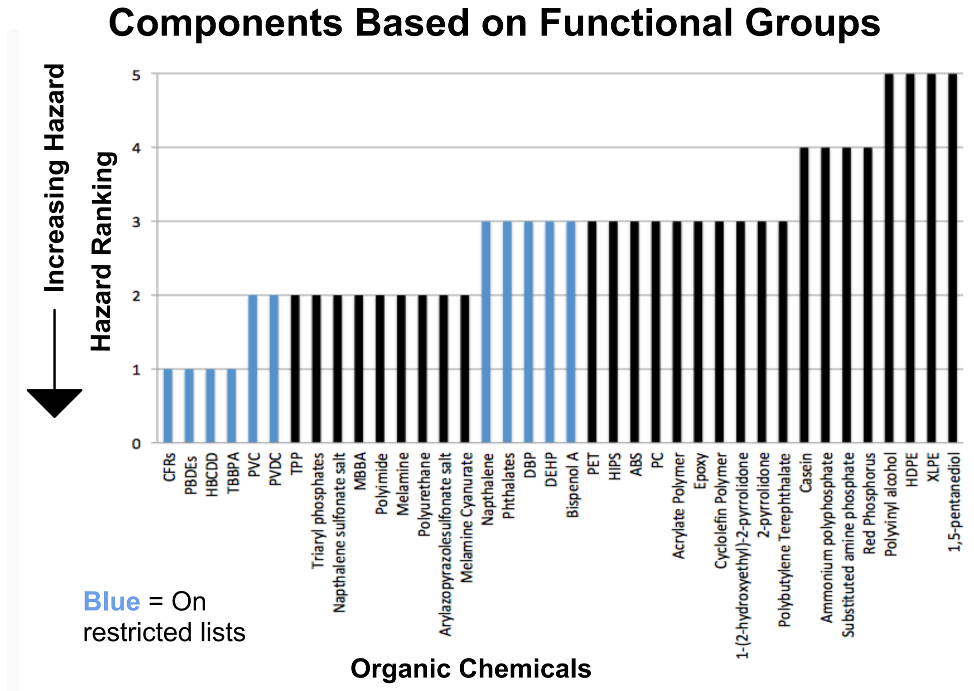


Figure 3C. This bar chart summarizes the hazard rankings, attributed by the analysis in the previous figure, of the known organic chemicals in electronic products. Many organic chemicals that are not on restricted lists for hazardous chemicals still have the second highest hazard ranking. This suggests that an approach analyzing the hazardous byproducts as a result of combustion is important in fully understanding the risk an organic chemical poses.

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