SCIENCE AND REGULATION

The Electronics Revolution: From E-Wonderland to E-Wasteland

Discarded electronics present serious threats to health and ecosystems, making e-waste regulations a policy priority.

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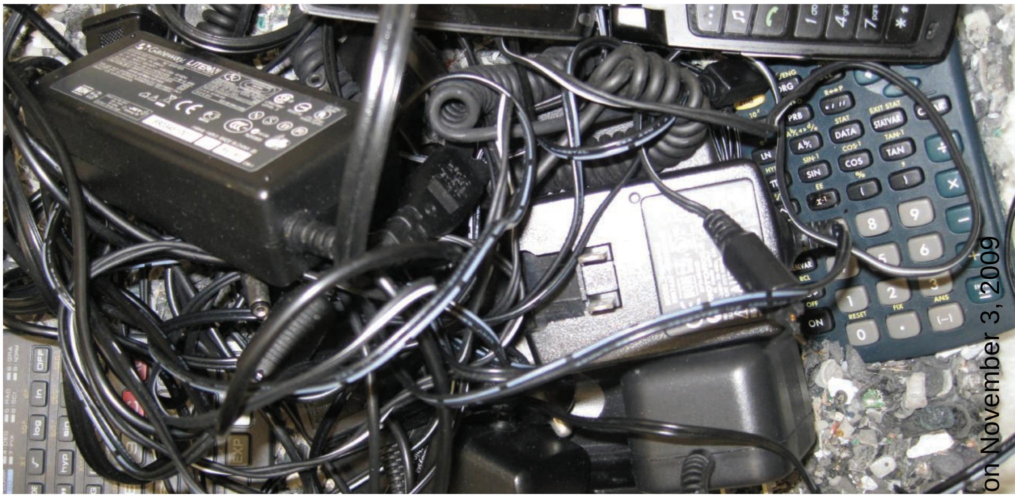

Since the mid-1990s, electronic waste (e-waste) has been recognized as the fastest-growing component of the solid-waste stream, as small consumer electronic products, such as cellular phones, have become ubiquitous in developed and developing countries (*1*). In the absence of adequate recycling policies, the small size, short useful life-span, and high costs of recycling these products mean they are routinely discarded without much concern for their adverse impacts on the environment and public health. These impacts occur throughout the product life cycle, from acquisition of raw materials (*2*) to manufacturing to disposal at the end of products' useful life.

This creates considerable toxicity risks worldwide (*3*, *4*). For example, the mean concentration of lead in the blood of children living in Guiyu, China, a notorious destination for improper e-waste recycling (*5*), is 15.3 µg/dl. There is no known safe level of exposure to lead; remedial action is recommended for children with levels above 10 µg/dl (*6*). Polybrominated diphenyl ethers used as flame-retardants in electronics have been detected in alarming quantities (up to 4.1 ppm lipid weight) in California's peregrine falcon eggs, raising the specter of species endangerment (*7*, *8*).

We recently estimated that each U.S. household has at least four small (≤4.5 kg) and between two and three large (>4.5 kg) e-waste items in storage (*9*); this represents 747 million e-waste items, weighing over 1.36 million metric tons. Moreover, most people (67%) in the United States are not aware of e-waste disposal restrictions or policies (*9*). The United States, one the largest generators of e-waste in the world (*4*), does not have legally enforceable federal policies that require comprehensive recycling of e-waste or elimination of hazardous substances from electronic products. Without a coherent U.S. policy, informed by challenges faced by similar efforts around the world, it will be difficult to reach a global consensus.

Patchwork of E-Waste Standards

The European Union (EU) adopted two comprehensive directives for managing e-waste: the Restriction on the Use of Hazardous Substances (RoHS), and the Waste Electrical and Electronic Equipment (WEEE) (*10*). China's own WEEE regulations will take effect in 2011. The Basel Convention (*11*), which regulates movement of hazardous wastes across international borders (and includes a technical working group on e-waste), has been ratified by 169 of the 192 United Nations (UN) member countries. Unfortunately, the United States is the only member country of the Organisation for Economic Co-operation and Development that has not ratified the convention. Within the United States, only 19 states have e-waste laws (14 others pending), although most do not provide sufficient infrastructure or dedicated revenue streams to enforce compliance and to promote public participation (*9*, *12*, *13*). This uneven patchwork of policies has created "risk holes." Poor communities and developing countries are disproportionately affected. Consequences are particularly troubling in Africa, China, and India (*4*, *14*, *15*). Markets for second-hand electronics thrive in such places, along with improper recycling of domestic and illegally imported e-waste to recover valuable materials.

Potential Action in U.S. Congress

The U.S. Senate is considering the Electronic Device Recycling Research and Development Act (S. 1397, a version of bill H.R. 1580 passed by the House of Representatives) (*16*–*18*). If made law, the act could fund e-waste engineering research, development, and demonstration projects; engineering curriculum development; and research into nontoxic, environmentally responsible alternative products. The bill would also call for the U.S. National Academy of Sciences to investigate barriers and opportunities for reducing e-waste, decreasing the use of hazardous materials in electronic products, and enabling product design for efficient reuse and recycling. The act addresses an especially overdue need: It asks the National Institute of Standards and Technology to establish a database of physical properties of "green" alternative materials for use in electronic products. Yet it is unclear which properties will be available in this database, or whether human and ecological toxicity data, energy demand, and other socioeconomic indicators will be included.

While developing and implementing national policy in the United States, lessons could be learned from challenges faced by similar programs already under way. The European Commission in 2007 began phasing the REACH program (Registration, Evaluation, Authorization, and Restriction of Chemical Substances) into enforceable law. REACH addresses manufacturers' responsibilities to manage risks from chemicals in

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their products. There has been some confusion about the overlap of REACH and RoHS. They have different approaches to risk characterization and management, and they specify different processes by which they can be implemented by different EU members (*19*).

Also informative, from a major U.S. state-level effort, is the contentious intersection of California's RoHS-like Electronic Waste Recycling Act (EWRA), and the broader, REACH-like, California Green Chemistry Initiative (CGCI). EWRA focuses on very specific chemicals, but the same consumer electronics are covered by the CGCI, which focuses on more comprehensive assessment of toxic chemicals in consumer products and comparative assessment of alternative chemicals through the kind of database outlined in S. 1397. Had it been signed into law, California Assembly Bill 147 would have required manufacturers to declare hazardous materials content in consumer electronics, a specification that was not part of the original EWRA, but that is essential for the CGCI (*20*).

Research Needs

Technology is available to recover precious materials from e-waste, but the bottleneck is consumer participation, collection, dismantling, and sorting to separate the material components (e.g., plastics, different types of metals, and glass). So, to make a difference in confronting the global e-waste challenge, S. 1397 must call for policy research to characterize the factors that motivate consumers to recycle. For example, Californians are willing to pay extra for "green" electronics products (e.g., containing fewer toxic substances, capable of being economically recycled) and to drive up to 8 miles to drop-off products for environmentally sensitive recycling (*21*, *22*). In addition, political mandates and economic incentives are key tools for engaging manufacturers, who will need to assume greater responsibility for designing electronic products that contain safer materials and are easily managed after consumers no longer want them (*23*, *24*). Research to advance recycling technology, such as through improved sorting and labeling, and logistics of product take-back, are necessary to make e-waste recycling economically viable (*25*).

To have a larger impact, research must go beyond management. Solutions to the e-waste problem should not be developed as "end-of-the-pipeline" treatments of hazardous waste; the entire life cycle must be included in the solution. There is a promising collaboration between the UN Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry to produce guidelines for product social life-cycle assessment. Integrating the guidelines with human disease end points or ecotoxicological assessments remains problematic (*26*).

Research to identify alternatives to toxic materials and investments in smelter facilities to safely recycle e-waste sorely lag behind the pace at which new electronic devices are invented, which in turn supports consumers' habits of buying replacements for electronic products that are still functioning perfectly (*4*, *25*, *27*, *28*). Improved standards for materials testing could eliminate the need for exemptions to toxic-substance policies for sensitive industries (e.g., medical, military, and aerospace technologies) (*29*). Improved testing of materials and a robust toxics database may encourage manufacturers to consider toxicity early during product design rather than in retrospect, only after performance standards and economic considerations have first been satisfied.

Education

S. 1397 calls for e-waste education programs, but hurdles remain (*30*). The bill targets only undergraduate engineering students and industry professionals, but investigators in other disciplines, such as toxicology, need to be engaged. Efforts should include graduate programs, where opportunities for cross-disciplinary work are increased (*31*).

Conclusion

Bart Gordon, Chairman of the U.S. House Committee on Science and Technology, said that "we need our future engineers to understand that whatever they put together will eventually have to be taken apart (*32*)." They must also understand social, ecological, and public health consequences of their inventions. Manufacturers must adopt a cradle-to-cradle stewardship model for their products (*33*). S. 1397 will be most effective if its expected outcomes in research products, inventions, and workforce and public education are linked to regulatory policies that provide uniform guidance for nationwide e-waste management and "green" electronic product design in light of international, interdisciplinary dimensions of the problem.

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