Testimony of
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Disposal or recycling of electronics can have significant human health and environmental impacts. Electronics can contain lead, brominated flame retardants, cadmium, mercury, arsenic and a wide range of other metals and chemical compounds. The recycling rate is, at best, about 18%, and most electronics collected in the U.S. for recycling have been sent to other countries for processing (US EPA 2008). In a 2008 report, the GAO found that a substantial fraction of these end up in countries where disposal practices are unsafe to workers and dangerous to the environment. Used electronics exported from the United States to some Asian countries are dismantled under unsafe conditions, using methods like open-air incineration and acid baths to extract metals such as copper and gold (US GAO 2008; Williams et al. 2008).

If it is carried out correctly, electronics recycling can prevent pollution, create jobs and save resources. Keeping activities such as sorting and reprocessing of electronics in the urban areas where they have been used and collected can provide significant economic and social benefits (Leigh et al. 2007a, 2007b). These benefits could be significantly enhanced if plans for recycling and refurbishment were incorporated into the design of the product and its supply chain.

It is widely recognized that electronics have not been designed for recycling: the valuable components are hard to extract and difficult to reuse, and the valuable constituents are mixed with a complex set of low value and potentially hazardous materials.

What is less well recognized is that the electronics supply chain also has not been designed for recycling. The existing supply chain for manufacturing, delivery, and retailing of electronics is a model of efficiency, managed with electronic data interchange, electronic manifests, radio-frequency tags on pallets and cartons, and UPC codes on individual product packages. These kinds of supply chain innovations, developed over the past thirty years, have saved money and allowed for the efficient production and retailing of tens of thousands of products. In stark contrast, the end-of-life supply chain is managed almost entirely by hand, with little record-keeping or even potential for monitoring or oversight. That the result has included unsafe, polluting, and illegal disposal activities should not be a surprise.

Electronics are just one example of the myriad products that consumers and businesses are increasingly expected to recycle. Recent major efforts to encourage electronics recycling have brought the recycling rate up to about 18%. Major efforts to encourage recycling of batteries – including passage of the 1996 Mercury-Containing and Rechargeable Battery Recycling Act – have been even less successful. The draft E-Waste R&D Act proposes to address low recycling rates by "studying factors that influence behavior and educating consumers about electronic waste." This will not be nearly enough. To achieve high collection rates, recycling programs for consumer products such as electronics and batteries will need a different approach to collection.

If electronics – or any other complex or hazardous product – are going to be recycled as part of a planned and well managed system, supply chain innovation is needed. Use of information technology to manage the end-of-life supply chain will be especially important because there are thousands of different makes and models of electronics products that enter the waste stream every year.

Electronics – and other complex products that need to be recycled – could have a standardized label that would allow recyclers to identify the make and model of the product and manage its recycling or refurbishment. These labels could be something like a standard UPC bar code (Saar et al. 2004). Alternatively, a radio-frequency identification code (RFID) could be installed inside the product and serve the same function while being easier to read and providing more information (Thomas 2008, 2009).

In a small project sponsored by the US EPA and convened by the RFID standards organization, EPCglobal, recyclers, electronics manufacturers, and retailers are beginning to think through how electronics recycling could be improved by use of RFID tags. This is an ongoing project, but in our preliminary report (Maxwell 2008), the group has concluded that potential benefits for manufacturers and retailers include:

- increased efficiency and lower cost for recycling,
- opportunities for recycling incentives, rebates, coupons and trade-ins,
- improved warranty management, and
- better after-sale services.

Potential benefits for recyclers include

- improved inventory control,
- more efficient product sorting and management,
- improved audit capabilities,
- integration of product data into online markets, and
- easier and less costly reporting to regulators and clients.

Better management of today's recycling programs is only the beginning of what could be accomplished. The end-of-life management of electronics and other products could be transformed by a combination of improved product design, innovative online markets, integration of information technology into product management, and supply chain innovations. Already, online markets such as eBay, Craig's List, and Freecycle have made the reuse and refurbishment of electronics easier and more common. Already, companies like Recycle Bank use RFID codes on recycling bins to reward consumers for recycling.

In the future, consumers could start the process of recycling, reuse or resale simply by putting their unwanted item in their own "smart" recycling bin: the bin would automatically read the label on the product, and automatically arrange for recycling pick-up; the recycler, receiving information in advance about the items in the bin, would be able to automatically arrange for sorting and resale or recycling, and the consumer would receive a rebate for recycling that specific item, based on its value or hazard. This kind of system places the capability to enter the collection system within the product itself. Rather than having to continue to work so hard to educate consumers about how to recycle each and every one of their purchases, consumer products could, almost, manage themselves (Saar and Thomas 2002; Thomas 2003).

Today, recycling programs for electronics and other consumer products have low recycling rates both because collection programs are difficult for consumers to use and because the products are difficult to recycle. To achieve high recycling rates, products need to be designed for recycling, and collection programs need to be designed to be very easy, almost automatic, regardless of the complexity of the product. Currently, *consumers* are mainly responsible for managing the recycling or disposal of their products. In some locations there have been efforts to make *producers* responsible for managing the recycling or disposal of their products. A third approach might work better: improve both product design and collection systems so that *products* can increasing manage their own entry into the collection and recycling system.

With respect to the specifics of the legislation: The draft E-Waste R&D Act will be most effective if it takes into account the entire lifecycle of electronics products. Electronics can have environmental impacts in manufacturing and in use as well as in disposal. Use of recycled materials or components can reduce the environmental impact of electronics production. In some cases reusing or refurbishing electronics will result in more energy use than would purchase of a new model; in other cases used or refurbished electronic devices can provide more environmental, economic and social benefit than recycling. A research program that focuses only on end-of-life has the potential to overlook major opportunities for reducing the environmental impacts of electronics, and could be counter-productive. The research program should consider the full lifecycle of electronics.

With respect to engineering education: The Engineering 2020 study from the National Academy of Engineering has identified environmental issues as one of the key challenges facing the world and the engineering profession now and in the coming decades (NRC 2002). Equally importantly, students realize that this important, and courses related to energy, environment, and sustainability can draw students in to the field of engineering. Section 6 of the draft E-Waste R&D Act supports the consideration of environmental consequences in undergraduate and graduate-level engineering curriculum. Many institutions of higher education have already made substantial progress in this area. A recent survey shows that teaching and research in sustainable engineering are part of the activities of most of the top 100 engineering programs in the United States (Murphy et al. 2009). At my own institution, the Georgia Institute of Technology, almost every school in the College of Engineering has environmental offerings at both the undergraduate and graduate level. Yet there is much to be done. By and large, the environmental aspects of the engineering curricula are at an introductory level. The next step is to develop the depth and rigor that engineers will need, and that engineering departments will require for environmental material to be adopted into their core curricula. Engineering schools are well-prepared to take the next steps, and support for this work would be welcomed.

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