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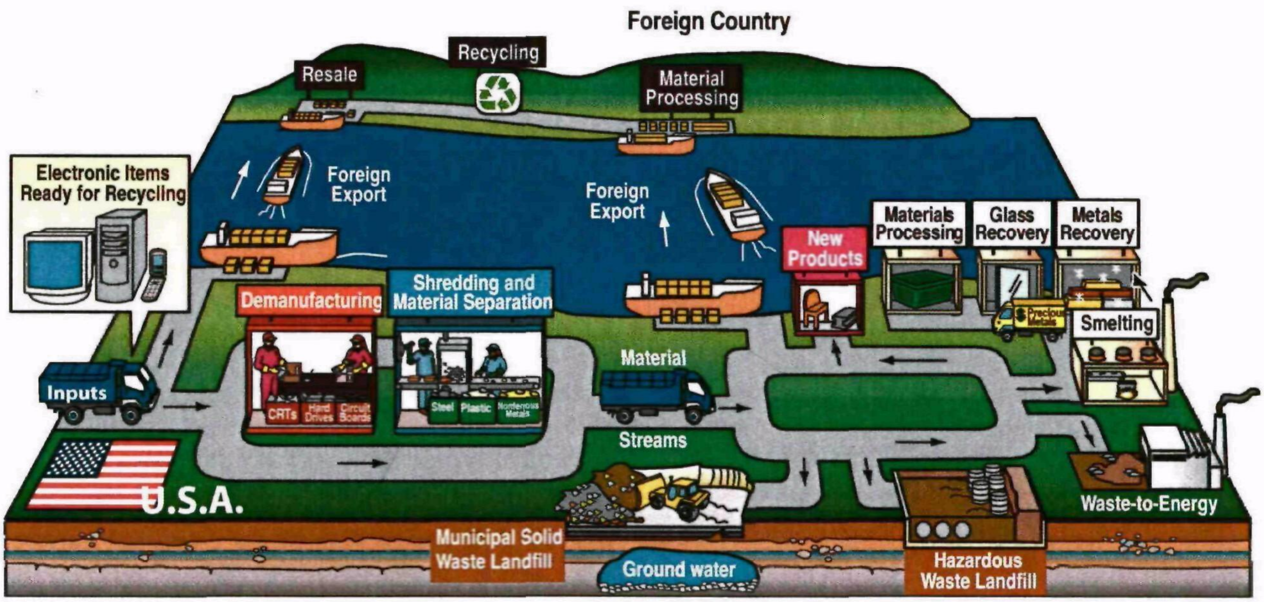
Report on the Panel Session: Emerging Electronics Issues – How Can We Minimize the Health and Environmental Impacts of Electronics Recycling?



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Report on the Panel Session: Emerging Electronics Issues – How Can We Minimize the Health and Environmental Impacts of Electronics Recycling?

Prepared for

Brian Schumacher
Office of Research and Development
U.S. Environmental Protection Agency
Las Vegas, Nevada

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Notice

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Prior to publication, a draft version of this report was sent to all members of the expert panel for review. Three panelists responded with comments and suggestions. The authors also received comments from Jeff van Ee and Kathy Osdoba of EPA, who both attended the panel session. All comments were considered, and revisions were made to strengthen the report.

Mention of trade names or commercial products in this report does not constitute endorsement by EPA. Likewise, the discussion of various state, international, and private-sector approaches to electronics recycling is intended to provide context, and does not constitute an endorsement or recommendation by EPA.

Contents

Acronyms and Abbreviations

ARF	advance recovery fee
BFR	brominated flame retardant
CBD	chronic beryllium disease
CDC	Centers for Disease Control and Prevention
CESQG	conditionally exempt small quantity generator
CRT	cathode ray tube
EPA	United States Environmental Protection Agency
EPEAT	Electronic Product Environmental Assessment Tool
EU	European Union
HAP	hazardous air pollutant
HP	Hewlett-Packard
IAER	International Association of Electronics Recyclers
IEEE	Institute of Electrical and Electronics Engineers
ISRI	Institute of Scrap Recycling Industries
LCD	liquid crystal display
MACT	maximum achievable control technology
MSDS	Material Safety Data Sheet
MSW	municipal solid waste
NIOSH	National Institute for Occupational Safety and Health
OECD	Organization for Economic Cooperation and Development
OEM	original equipment manufacturer
ORD	Office of Research and Development (EPA)
OSHA	Occupational Safety and Health Administration
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PCB	polychlorinated biphenyl
PEL	Permissible Exposure Limit
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
READ	Recycling Electronics and Asset Disposition (contract)
RFID	radio frequency identification
RIOS	Recycling Industry Operating Standards
RoHS	Restriction of Hazardous Substances (EU Directive)
SWANA	Solid Waste Association of North America
TCLP	Toxicity Characteristic Leaching Procedure
TSCA	Toxic Substances Control Act
WEEE	Waste Electrical and Electronic Equipment (EU Directive)

Executive Summary

Background

The production and use of electronic products is growing and the rapid pace at which the technology advances means that many electronic products become obsolete in a relatively short period of time. These factors are contributing to a growing challenge for waste management because electronic waste contains a vast array of materials, some of which are hazardous to human health or the environment. As state and local governments seek options other than disposal for properly handling electronic waste, the demand for electronics recycling services has increased dramatically. Today's electronics recycling industry includes businesses specializing in manual disassembly and parts recovery, automated shredding and material separation, and many other processes that break electronic waste into primary materials that can be reused or otherwise managed.

While EPA supports resource conservation and recycling, the agency also must confront the possibility that increased electronics recycling could pose its own risks to human health and the environment. To avoid unanticipated problems in the future, EPA wants to proactively identify and mitigate potential risks associated with electronics recycling. To this end, EPA's Office of Research and Development (ORD) convened a panel of experts to discuss the state of electronics recycling and identify key challenges and research needs. The panel met on May 19, 2005 in New Orleans at the 2005 Institute of Electrical and Electronics Engineers (IEEE) International Symposium on Electronics and the Environment, and included individuals from several sectors of the electronics recycling industry, academia, plastics industry, and the risk assessment community. Panelists are listed in Section 8 of this report.

This report summarizes the panel's discussions and recommendations. It is intended to serve as a reference for EPA and others in prioritizing research and other actions.

Current State of Electronics Recycling

The number of companies engaged in some form of electronics recycling is growing rapidly. Recycling firms vary in size and scope, ranging from small companies specializing in a single process (e.g., shredding circuit boards) to large companies that cover many parts of the recycling chain. These firms collectively process over a billion pounds of electronic equipment each year, producing many valuable commodity streams that can be used in new products.

The United States does not have a national electronics recycling program and EPA estimates suggest that a majority of the nation's electronic information products (computers, faxes, printers, and phones) are not currently recycled. However, a growing number of federal, state, local, and private-sector initiatives are in place to encourage electronics recycling. For example, the state of Maine recently enacted legislation requiring manufacturers to take back obsolete products and pay for recycling, while California has developed a system to fund collection and recycling of cathode ray tube (CRT) monitors and televisions with "advance recovery fees" charged to consumers. Other countries have also established mandates or guidelines for electronics recycling – particularly in Europe.

The discussions in the panel session underscored the fact that the expansion of electronics recycling is taking place with very limited regulatory oversight. In addition, the absence of widely accepted operating standards and best practices makes it difficult for recyclers who want to "do the right thing." Federal actions may be needed to help "level the playing field." Panelists also noted that the current maze of inconsistent state and international regulations makes it difficult to do business. Other challenges facing the industry include changing technology (e.g., flat screens and smaller devices), downstream accountability, and economic viability.

Exposure Concerns

Concerns about the human health and environmental impacts of electronics recycling are related to the composition of electronic waste. Computers and other electronic devices contain hundreds of chemical constituents, ranging from large quantities of metals and plastics to trace amounts of substances in circuit boards, batteries, bulbs, and flat screen displays. Several of these chemicals are known to be toxic, including lead, found in CRTs, and mercury, found in bulbs and switches. Other chemicals have not been studied well, but could be bioaccumulative (e.g., brominated flame retardants). A list of chemical constituents in electronics appears in Section 3.

Electronics recycling processes could potentially cause both occupational exposures and environmental exposures to toxic chemicals. The panelists identified the following potential exposure points:

- Occupational. Dermal or inhalation exposure to dusts or fumes from shredding, disassembly, or thermal processes could occur. Emissions could contain lead, mercury, beryllium or other metals, flame retardants, or other potentially toxic chemicals.
- Environmental. Inhalation emissions from recycling processes could potentially occur in the vicinity of recycling facilities. In addition, exposure to contaminated releases from downstream materials handling (e.g., landfill leachate and smelter emissions) may pose human health and environmental risks.

Needs Identified by Panelists

Members of the expert panel identified six key areas where further effort is needed in order to prevent electronics recycling from posing unanticipated risks to human health and the environment. These key areas, which Section 6 describes in further detail, are:

1. *Research needs*. Several parties have collected data that characterize health effects or exposures - including studies of specific recycling processes. An important first step will be to compile all the data available from different sources, including the government,

academia, and recyclers themselves. Once the existing data are assembled, it would be useful to identify critical data gaps, then conduct research to fill them.

2. *Best practices guidance*. The industry could benefit from clear guidance identifying practices that are most protective of worker health and the environment. Specific areas where best practices could be developed include exposure monitoring methods, actual operational processes (based on process-specific research), and auditing procedures.
3. *Standardization*. The current framework of state and international regulations is complicated. The industry could benefit from a clearer, more standardized regulatory approach.
4. *Communication*. Panelists identified a need for greater communication, both within the electronics recycling industry and with government and manufacturers. Recyclers and manufacturers could both benefit by collaborating to design products that are easier to recycle.
5. *Interagency collaboration*. Parts of the electronics recycling issue also fall under the jurisdiction of other federal agencies, most notably the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH), which are concerned with occupational exposure. It may be useful to collaborate with these agencies on research, education, and other related aspects.
6. *Informed decisions*. Panelists encouraged EPA and industry to remain mindful of economic and monetary realities as they continue their collaboration. For example, EPA will need to prioritize research efforts in order to make the best use of available funding. EPA and industry can also work together to develop economic incentives and approaches that consider all costs and benefits.

Within these six areas for further effort, panelists identified several key priorities for action. These suggestions, which are discussed further in Section 7, include the following:

- Analyze product content and key recycling processes to identify substances and exposure points of concern.
- Make a comprehensive effort to gather and review all relevant toxicology, exposure, and process-specific data from recyclers, federal agencies, and organizations in other countries.
- Conduct research to fill gaps in the existing data on effects, exposures, and processes. In particular, consider data needs for emerging chemicals, such as liquid crystal display (LCD) mixtures. To evaluate leaching potential, conduct lysimeter tests.
- Work to develop best practices guidance for processes, exposure monitoring, and auditing/verification.
- Develop a widely recognized certification program for electronics recyclers to help consumers of e-cycling services readily identify recyclers that are conducting activities in an environmentally sound manner.

- Ensure that existing protections are being enforced. For example, OSHA's lead standard applies to all workplaces, including some electronics recyclers that may not have met their obligation to demonstrate compliance. Also, RCRA prohibits disposal of hazardous waste in unpermitted facilities, yet panelists stated that they believe many recycling companies still dispose of hazardous electronic components in unpermitted solid waste landfills and incinerators.
- Improve communication within the industry and with government. Work toward a shared understanding and a shared vocabulary.
- Improve communication between recyclers and original equipment manufacturers (OEMs). In particular, find a way to give recyclers and their employees more information about the products and chemicals they are handling.

Although not specifically discussed at the meeting, individual panelists also suggested the following:

- Institute a nationwide solid waste disposal ban on e-scrap.
- Institute a national hazardous waste exemption for e-scrap that is recycled in accordance with environmentally sound management practices that are sanctioned by EPA.
- Maintain support for integrated resource management where different resource recovery technologies (i.e., mechanical, chemical, and thermal) are available to electronics recyclers to ensure that materials that cannot be recycled can be landfilled in an environmentally and economically sound manner.

EPA is well positioned to assist with several of these items, such as encouraging data sharing, facilitating communication, spearheading the effort to develop best practices guidance, and conducting research to fill some of the major gaps in health effects and exposure data.

Section 1

Introduction

The rapid growth in production and use of electronic products, coupled with the increasing rate at which these devices become obsolete, is posing new challenges for waste management. The demand for electronics recycling services to manage obsolete products has been increasing as state and local governments and others seek options other than disposal for properly handling these materials. EPA supports resource conservation, which is promoted through electronics recycling. At the same time, EPA seeks to proactively identify and mitigate any potential risks associated with the significant increase in electronics recycling activity.

The key question being asked is: How might the increased recycling of electronics potentially affect the environment and human health – particularly given the relatively unregulated state of the industry and the ever-changing composition of electronic products? On May 19, 2005, EPA's Office of Research and Development (ORD) convened a panel of experts to begin to discuss this question. The panel included individuals from several sectors of the electronics recycling industry, academia, the plastics industry, and the risk assessment community. The session was part of the 2005 Institute of Electrical and Electronics Engineers (IEEE) International Symposium on Electronics and the Environment in New Orleans. Panelists are listed in Section 8 of this report.

The panelists discussed the current state of electronics recycling and the electronics recycling industry and, with input from several members of the audience, identified some of the key challenges facing the industry. The panel then made recommendations for further research, communication, and other actions that would help ensure that increased recycling of electronics does not result in undesirable, unintended environmental and human health consequences. This report summarizes the panel's discussions and recommendations. It is intended to serve as a reference for EPA and others in prioritizing research and other actions.

1.1 Scope of the Issue

"Electronics" is a rather broad term: technically speaking, anything that has a circuit board could be considered an electronic product and eventually "electronic waste." However, this report will focus primarily on computers (both desktop and portable models), computer monitors, and peripheral devices (e.g., printers and scanners) because:

- The current electronics recycling infrastructure is largely focused on computer equipment.
- These products constitute the bulk of the material entering the electronics recycling stream, in part because they have a high turnover rate.

- Computer equipment is more complicated than most other household electronics, and it typically contains the broadest array of possible constituents of concern.
- Recent state regulatory efforts have specifically targeted computer recycling.

For the purposes of this report, electronics recycling is defined as demanufacturing or shredding and material separation of electronic products for purposes of recovering component parts and/or raw materials for other uses. When collecting electronic scrap from businesses or communities, electronics recyclers may segregate whole products for sale in reuse markets. "Reuse" can refer to either passing on a product to another user as is or passing it on after it is upgraded or repaired.

Electronics recycling is a global issue. Like the manufacture and sale of computer products, electronics recycling relies on global markets. For example, an obsolete computer collected in the United States could be resold as is in a developing nation, or it could leave the U.S. at some point further down the recycling chain in the form of scrap or raw materials. This means that a computer may be manufactured in one country, purchased and used in another, and recycled in several additional countries. Thus, a regulation in any single country has the potential to directly affect businesses in many other countries. Recent European standards provide a useful example, as they have forced U.S.-based manufacturers selling overseas to adopt new practices in dealing with their products as they become obsolete.

1.2 EPA's Objectives

EPA convened the May 2005 expert panel to focus on the environmental and human health ramifications of electronics recycling. The panel was charged with three specific objectives:

1. Identify materials of potential concern.
2. Identify research or action needs to assess potential risks.
3. Assist ORD in developing a plan for action.

Recognizing that the electronics recycling industry will continue to evolve as technology accelerates and more electronic devices are recycled, EPA is seeking to anticipate problems that could arise in the future, and to discuss ways in which government and industry might proactively address these potential problems through research and guidance rather than reach a point where regulation becomes necessary.

1.3 Industry Concerns

The electronics recycling industry faces a number of challenges, such as:

Changing technology. With the rapid pace of technological development, the electronics recycling industry constantly encounters new types of products in the waste stream. In some cases, the construction and composition of these products may require entirely new recycling processes, because existing technologies are not appropriate for new products or because new constituents interfere with processing equipment. For example, with the growth in laptop computers has come the challenge of handling the chemical mixtures used in liquid crystal displays (LCDs), the composition of which may be a protected trade secret. As products become smaller and more intricate, they may be more difficult to disassemble. This creates challenges for demanufacturing operations as well as shredding operations, which may require the prior removal of components containing hazardous materials. Also, as flat screen technology gains market share, more products with CRTs will become obsolete and enter the waste stream, while at the same time, markets for recovered CRT glass will shrink creating an added challenge for recyclers.

Lack of federal regulation. Compared with other industries, the electronics recycling industry is relatively unregulated by the federal government. Some large facilities may be required to comply with general permitting regulations related to air emissions or disposal, as discussed further in Section 5.2. However, there are currently no general standards or permit requirements specific to the electronics recycling industry. Where specific federal guidance and regulations exist, they tend to be slow to catch up with technological change. For example, EPA's CRT rule was still not final at the time of this publication even though CRTs are now increasingly being replaced by flat screen technology.

Variable international standards. In general, the global electronics recycling industry has adapted to take advantage of different levels of regulation in different countries. However, in some ways, different standards can lead to extra complications for recyclers. For example, Canada defines "hazardous" differently from the United States for circuit boards; thus, recyclers have to consider multiple sets of regulations when deciding on the most cost-effective ways to move materials across borders.

Variable standards within the United States. Individual states may differ in their definitions of waste classifications, which can complicate matters for recyclers trying to transport materials between states. Further, because of the relative lack of federal regulations, some states have adopted their own mandates governing electronic waste handling. Section 2.2 discusses some of these efforts in greater detail. Individual state efforts have begun to create a climate in which manufacturers and recyclers will have to learn and abide by many different sets of rules regarding what must be recycled and who is accountable for the cost.

Level playing field. Industry representatives are concerned that voluntary guidelines could put those who follow them at a competitive disadvantage against businesses seeking to cut costs by not following best practices.

Traceability. Most recyclers sell recovered materials and/or whole products to other downstream handlers. Without a legal requirement for material life cycle accountability, there is little incentive for recyclers to investigate whether these materials are being managed responsibly once they leave their facility. Only in some cases will customers (e.g., manufacturers, large institutions, and governments) ask for verification of responsible downstream handling.

Economic viability. Electronics recycling must be economically viable in order to keep recyclers in business. The industry originally focused on extracting value from the precious metals in computer equipment. However, it has shifted somewhat toward providing an environmental service to consumers and manufacturers, especially since newer products have smaller amounts of valuable materials (i.e., fewer metals and larger amounts of plastic). There are a limited number of processors for secondary plastics, and the markets for this material are less mature. Recyclers need a steady and reliable waste stream and viable end markets for recovered materials to stay profitable. Many need a large volume to operate at a capacity that allows them to recoup their investment in expensive processing equipment (e.g., automated shredders). Yet many consumers have not accepted that end-of-life services for products they have used are necessary and there is no direct regulatory mandate to provide the impetus that might change this thinking.

Section 2

Background

2.1 Electronics Recycling Processes

While exact step-wise processes involved in electronics recycling vary widely by recycling firm and type of product being processed, Figure 1 provides a general overview of some of the major steps and decision points in electronics recycling. Some recyclers perform several of these steps, while others specialize in a single step.

Electronic devices enter the recycling chain when the user decides a unit is obsolete or no longer needed and brings the unit to a collection point. In some cases, products are taken back by the original equipment manufacturer (OEM) or leasing company; in others, municipalities, retailers, nonprofit organizations, and others collect equipment directly from users.

Once electronic devices are in the recycling chain, they enter the "asset management" stage, in which each piece of equipment is evaluated to determine if it can be resold, easily repaired, easily upgraded, or if it has components or subassemblies with any resale value. Those products that can be reused or resold are directed to resellers, both domestic and international. Often, broken equipment that is not saleable in the United States is sold to markets in developing countries. Some products may be refurbished for sale using parts from other machines.

This report focuses on the stages of the recycling process that take place after the asset management stage. There are two main types of recycling operations: (1) demanufacturing and (2) shredding and material separation.

Electronic waste that goes to a demanufacturer is manually disassembled. Some components may be salvaged for resale, while the rest will be directed into resource recovery streams – e.g., sending CRTs to a glass recycler or smelter. Components that hold no value as recycled material may be disposed of as non-hazardous or hazardous waste, depending on the composition.

Shredding and material separation operations are automated. Shredders may shred whole pieces of equipment, but often there is some degree of demanufacturing prior to shredding to remove potentially hazardous bulbs or batteries. Shredders may also process secondary component streams from demanufacturers, such as CRTs. Generally after shredding, a series of magnets and other separation technologies are utilized to separate commodities.

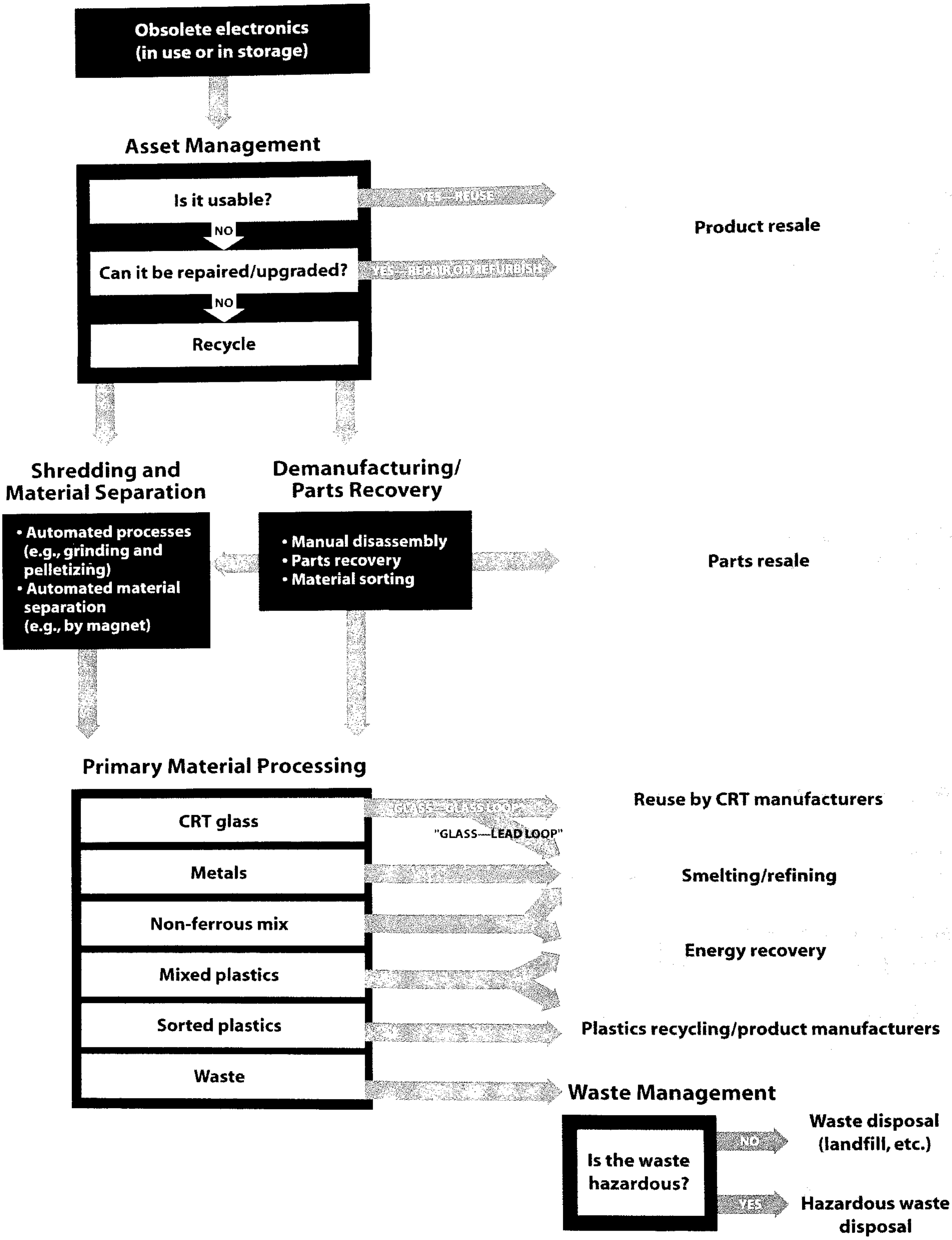

Figure 1. Key Steps in the Recycling Process

The final step in electronics recycling is "primary materials processing." At this stage, leaded glass from CRTs may be recycled directly into new CRTs (the "glass-to-glass loop") or smelted to separate the glass from the lead (the "glass-to-lead loop"). Metals can be recovered and reused through smelting and refining. These metals include aluminum, copper, steel, and precious metals. Sorted plastics may be directly reused by manufacturers of plastic goods or be sent to a plastics processor for additional purification. Mixed plastics may be reused in structural products (e.g., outdoor furniture, plastic lumber products, railroad ties) or road paving materials, but these outlets are limited to secondary plastics with low contamination. More contaminated mixed plastics are often burned for energy recovery. Mixed plastics can also be processed into various petrochemicals, but currently this is only done in Europe and Asia as it is not economically feasible in the United States. Like earlier steps, primary processing may generate some materials that cannot be reused or recycled safely or economically. These wastes may include unmarketable mixed plastics and hazardous materials such as heavy metals, and must be managed accordingly.

2.2 Existing Recycling Efforts

According to the International Association of Electronics Recyclers (IAER) 2003 Industry Report, more than 400 companies in the United States are considered to be electronics recyclers.[1] As of 2003, these firms collectively processed over 1.5 billion pounds of electronic equipment annually, yielding approximately 900 million pounds of recyclable materials and annual revenues in excess of $700 million. There are a few companies that process large volumes, but most companies in the industry are relatively small. The 400 companies include nonprofit organizations that collect and resell computer equipment, as well as for-profit brokers, resellers, and exporters who facilitate the movement of materials through the recycling chain. Since the 2003 IAER report was published, the number of recyclers has more than doubled, according to an IAER official.

EPA estimates that approximately 19 percent of the nation's obsolete electronic information products (computers, fax machines, printers, and phones) are being recovered for recycling or reuse.[2] The rest are either disposed of or stored (e.g., in attics or closets). Other estimates vary widely, but all suggest that the vast majority of electronic waste is not entering the reuse or recycling stream. The United States does not currently have a national electronics recycling program. However, the federal government is engaged in a number of efforts to promote the responsible recovery and recycling of electronics. These efforts include the following:

- Plug-In To eCycling, an EPA consumer electronics campaign launched in January 2003 as a component of EPA's Resource Conservation Challenge (see http://www.plugintoecycling.org/). The campaign focuses on the following three goals:
    - Providing the public with information about electronics recycling and increasing their opportunities to safely recycle old electronics.

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[1] International Association of Electronics Recyclers. 2003. *IAER Electronics Recycling Industry Report: 2003*. Albany, NY: IAER.

[2] U.S. EPA. 2003. *Municipal Solid Waste in the United States: 2001 Facts and Figures*. EPA530-R-03-011. Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response.

- Facilitating partnerships with communities, OEMs, and retailers to promote shared responsibility for safe electronics recycling. For example, Office Depot and Hewlett-Packard (HP) sponsored a 2½-month free electronics collection and recycling program.
- Establishing pilot projects to test innovative approaches to safe electronics recycling.

- The Recycling Electronics and Asset Disposition (READ) contract, a government-wide contract being used by EPA to promote and advance the disposition, reclamation, reuse, and recycling of electronic assets held throughout the federal sector. See http://www.epa.gov/oam/read.
- The Federal Electronics Challenge, a voluntary interagency partnership to better manage electronic assets. See http://www.federalelectronicschallenge.net/.
- The Electronic Product Environmental Assessment Tool (EPEAT), a tool for evaluating the environmental performance of electronic products throughout their life cycles. The tool was developed to meet the growing demand by large institutional purchasers – particularly state and federal government agencies – to buy "greener" electronic products. EPEAT uses criteria, developed using a multi-stakeholder consensus process, to assess products and assign ratings in several categories of product performance, such as materials selection and design for end-of-life. See http://www.epeat.net/.

In the absence of a national recycling infrastructure, several states have created their own programs to promote and fund recycling of electronics. For example, Maine passed a law that holds manufacturers responsible for the costs of handling and recycling all household-generated waste computers, monitors, and televisions once they are received at consolidation facilities in the state. Maryland recently legislated that manufacturers selling computers in the state must pay an annual registration fee to help pay for recycling CRTs, while California has established a program to reimburse authorized collectors and recyclers with money collected from an advance recovery fee (ARF) at the point of sale on television and computer CRT screens.

Bills on waste electronics management have been and are being considered in dozens of other states. California, Minnesota, Massachusetts, and Maine have banned CRTs from municipal solid waste landfills. Many states have created educational programs to promote reuse and proper recycling of electronics, and some have also provided financial assistance to municipalities to help pay for local collection and recycling programs.

Thus, at present, most recycling of consumer electronic waste in the United States takes place through state-sponsored initiatives and voluntary programs offered by the private sector. Some OEMs have taken steps toward creating their own recycling programs – in part due to state regulations and in part due to demands from customers who buy or lease large amounts of computer equipment and want to make sure it is disposed of properly. For example, HP and Dell both offer computer recycling services to their customers for a fee.

By comparison, many other countries have taken greater steps to promote electronics recycling. The European Union (EU) issued the Waste Electrical and Electronic Equipment (WEEE) Directive in January 2003, requiring OEMs to take responsibility for the end-of-life recovery of virtually all consumer electronic products ("anything with a plug") using the best available technology. EU member nations must use manufacturer funding to implement collection systems, and must collect annual data on the number of products marketed, collected, reused, and recovered. In Asia, South Korea has also mandated a take-back program, while Taiwan and Japan have officially mandated electronics recycling. In Japan, the take-back program is run through collection co-ops for manufacturers. In Canada, an industry-led coalition called Electronics Product Stewardship Canada is working on developing a national electronics end-of-life program (http://www.epsc.ca/); the province of Alberta has set up its own program, with an ARF on computers and televisions, to fund collection, transport, recycling, and education.

2.3 Existing Controls on Electronics Recycling Operations

As already mentioned, there are no industry-specific regulatory controls for electronics recyclers. Recyclers must comply with general regulations concerning occupational health and toxic releases to the environment, as is discussed further in Section 5. However, no specific system is in place to evaluate recycling processes or offer recyclers a standard for "compliance."

Several multilateral agreements and directives have been developed to address the electronics recycling issue from an international perspective. Significant examples include the following:

- *The Basel Convention on the Control of Transboundary Movements of Hazardous Waste* (adopted 1989). This framework requires a manifest and notification system to account for hazardous wastes – including discarded hazardous electronic equipment – that cross international borders. The Convention also prohibits parties to the Convention from trading hazardous wastes with countries that are not parties to the Convention, which includes many developing countries. Basel does not apply to U.S. recyclers because the United States is not a party to the convention.
- *Organization for Economic Cooperation and Development (OECD) technical guidance*. In February 2003, OECD published guidance on environmentally sound management for used and scrap personal computers (PCs). This guidance describes standards for refurbishment, disassembly, material recovery, component treatment, energy recovery, transport, and packaging. The United States is a member of OECD.
- *The EU's Restriction of Hazardous Substances (RoHS) Directive*. Issued in January 2003, this directive bans the use of lead, mercury, cadmium, hexavalent chromium, and certain brominated flame retardants in most electric and electronic products sold in the EU by July 1, 2006, with a few exceptions. This directive will indirectly affect electronics recyclers and the processes they use. In North America, the multinational Commission for Environmental Cooperation is currently meeting with the electronics industry to discuss a voluntary challenge to meet the RoHS Directive in the United States, Canada, and Mexico. U.S. manufacturers selling products in the EU will have to comply with these restrictions.

2.4 Projections for the Future: Changes and Challenges

Although it is impossible to predict exactly what the electronics recycling landscape will look like years from now, current trends suggest that numerous changes and challenges will confront government and industry in the future.

The amount of material designated for recycling will probably continue to rise as technology becomes cheaper, computers and cell phones become more widespread, and product life spans continue to be limited because of the fast pace of product innovations. The number of CRT TVs entering the recycling stream could also rise in the near future due to the pending switch to digital TV and flat panel technology.

The composition of electronic waste will also continue to change. Increasingly, consumers are choosing to replace CRT monitors and TVs with flat screen technologies such as LCDs and plasma screens, which pose their own unique challenges to recyclers. Electronics also appear to be trending toward smaller and more complicated devices, which may make it more difficult for recyclers to recover value from individual constituents or components. Other new technologies on the horizon include:

- Nanotechnology – developing materials at the molecular level.
- *Microelectromechanical sensors – tiny wireless monitors.*
- Interactive multimedia – electronic and interactive news delivery.
- Organic light-emitting diodes – display screens that directly emit light.
- 3-D displays – three-dimensionality built into the screen display.

In the future, some new technologies may be designed to facilitate recycling. For example, some researchers have proposed a system of radio frequency identification (RFID) tags that can be affixed to components within a computer. An RFID scanner at the recycling facility could link to a database containing information about the composition of each component.

To date, there have been some efforts to create a national recycling infrastructure in the United States, and it is likely that some of these efforts will continue into the future. In January 2005, a bill called the National Computer Recycling Act was introduced into the House of Representatives; this act would establish a grant program to fund collection and recycling of electronic waste, funded by a fee on new computers. In the Senate, a bill introduced in March 2005 (the Electronic Waste Recycling and Promotion and Consumer Protection Act of 2005) would create a national infrastructure to recycle computers, laptops, monitors, and televisions, with tax credits to reward companies and households that recycle.

Section 3

Composition of Electronics Scrap

3.1 Chemical Constituents

Electronic devices can contain hundreds of chemical substances. Table 1 lists some of the most significant constituents from a recycling perspective; these materials are notable because of their prevalence, value, or toxicity. Table 1 also describes where each substance is found within a typical product. By mass, the most prevalent materials tend to be plastics and ferrous metals (e.g., steel), which generally form the overall structure or housing of the device. Several other substances are present in small quantities yet play a critical role in complicated chips and circuitry; these include precious metals like gold, as well as toxic heavy metals like mercury. Table 1 is not a complete list. Many additional elements and compounds can be found in trace amounts in semiconductors, circuit boards, monitors, and LCD displays, and as functional additives in plastics.

Table 1. Notable Materials Found in Electronics

Material	Where Found
Aluminum/alloys	Structural; disk drives
Antimony	Flame-retardant; solder alloy in cabling; small amount in CRT glass
Arsenic	Integrated circuits (with silicon)
Barium	Contained in CRT glass
Beryllium	Switches, relays, and circuit board connectors (copper-beryllium alloy)
Brominated flame retardants	Added to plastic components, including housings, circuit boards, and cables
Cadmium	Batteries (nickel-cadmium); circuit board plating; small amount as coating on CRT monitor screen
Chromium	Metal plating (anti-corrosion treatment); small amount as hardener/stabilizer in plastic components (hexavalent)
Copper	Wires; connectors
Gold	Printed circuit boards
Lead	Radiation shielding in monitor CRT (frit is 70% lead; funnel glass is 22–25% lead oxide, by weight); solder on circuit boards; cable assemblies; batteries; paints; piezoelectric devices; sealing glasses
Lithium	Batteries
Mercury	Miniature switches; batteries; fluorescent back light for flat screen/LCD display

Table 1. *(Continued)*

Material	Where Found
Palladium	Printed circuit boards
PCBs (polychlorinated biphenyls)	Capacitors; transformers; cabling (production of PCBs ceased in 1977)
Pentachlorophenol	Capacitors
Phosphorus	Monitors
Plastics: ABS (acrylonitrile-butadiene-styrene) polycarbonate polyethylene polypropylene polystyrene PVC (see separate listing)	Structural (housing, etc.); circuit boards; wire coatings
Platinum	Printed circuit boards
PVC (polyvinyl chloride)	Housings; wire coatings
Silicon	Integrated circuits
Silver	Printed circuit boards
Steel	Structural
Zinc	Batteries

3.2 Material-Specific Challenges

At EPA's May 2005 meeting on electronics recycling, panelists and members of the audience identified a number of components and materials that pose a particular challenge to recyclers. Specific streams of concern include the following:

CRT glass. Recyclers noted that leaded CRT glass is heavy and costly to transport. Of particular concern are regulatory inconsistencies that increase processing costs. They expressed the need for clear direction on what constitutes hazardous waste, since definitions can vary among states and countries. Transportation costs are much higher if the cargo is deemed "hazardous." Other concerns about CRT glass relate to recycling practices. Common practices currently include removing CRT yokes with hammers and crushing the glass via "gravity drop." However, it is unclear whether further study would find these to be best practices. Finally, recyclers noted that in addition to the concern of lead exposure, workers handling CRT glass have suffered back injuries and cuts, even when wearing protective gloves.

Mercury. In flat panel displays of portable computers, the small fluorescent bulb used as a backlight typically contains 4 to 12 milligrams of mercury.[3] Mercury is also found in switches and relays in computers, medical equipment, and telecommunications devices. Recyclers agreed that identification and removal are primary concerns, noting that mercury-containing switches and bulbs are not labeled as such. Even if a switch or bulb can be identified, it may be hard to

[3] Williams, E. 2003. "Environmental impacts in the production of personal computers." In: Kuehr, R. and Williams, E., Eds. 2003. *Computers and the Environment*. Dordrecht, The Netherlands: Kluwer Academic Publishers, pp. 41-72.

remove, and breakage can be a problem. For example, to remove the mercury backlight in a laptop, the recycler may have to remove up to 27 screws. As a result, many recyclers do not remove mercury components (they are not required to do so). Because these bulbs are highly energy efficient and there is no adequate mercury-free alternative at this time, mercury use in lighting applications is exempted from the EU RoHS Directive's mercury ban.

Beryllium. Recyclers are concerned that parts containing this highly toxic metal can be hard to identify and handle appropriately. In general, recyclers need to ensure that their processes do not liberate beryllium dusts, and secondary smelters need to be particularly careful when handling copper alloys that contain beryllium. Dermal exposure is an additional concern.

Batteries. Electronic devices contain many different types of batteries; these include standard alkaline, nickel-cadmium, lithium ion, and lead-acid types. Batteries may not be labeled, yet some types are especially toxic and may need to be removed before shredding, both to protect worker health and to avoid contaminating commodity streams. As with mercury components, safe removal of batteries may be labor-intensive.

Plastics. Overall, plastics make up a significant proportion of the material handled by electronics recyclers. Plastic has good recovery potential, but for many applications, processors of plastic scrap require that plastics be sorted by type, and sometimes by color within a type. Sorting can be difficult for recyclers because plastics in electronics are not always labeled by type, and while the technology exists to physically separate by type, it is currently not always economically feasible at the end-of-life product demanufacturing stage. Color separation is even more difficult, given the multitude of different products that recyclers handle. Further, recyclers note that domestic markets for recycled plastics tend to be volatile and heavily dependent on the price of oil. Thus, most mixed plastics are currently landfilled, exported, or burned to produce energy if suitable energy recovery facilities exist. The technology to recycle mixed plastics into petrochemicals exists and is used in Europe and Asia, but it currently is not being used in the United States.

Brominated flame retardants (BFRs). This category includes polybrominated diphenyl ethers (PBDEs) and tetrabromobisphenol-A, which are among the additives most commonly embedded in circuit boards and plastics in electronic devices. BFRs are a concern because they are persistent and bioaccumulative and; therefore, could pose risks to human and ecosystem health. Studies have shown rapidly rising levels of PBDEs in human breast milk in Sweden and North America, as well as evidence of elevated levels of PBDE and other flame-retardant compounds in workers engaged in the demanufacturing of computers.[4] However, the toxicity and the exposure routes of many types of brominated flame retardants have not been extensively studied and are not well understood. Although PBDEs have been banned for use in electric and electronic products sold after July 1, 2006, in the European Union, and the chemical industry voluntarily agreed to stop production of penta- and octa-BDEs in the United States in 2004, older products coming into the waste stream will continue to contain these compounds for quite some time. Other concerns about brominated materials include their potential to generate certain halogenated

[4] Williams, E. 2003. "Environmental impacts in the production of personal computers." In: Kuehr, R. and Williams, E., Eds. 2003. *Computers and the Environment*. Dordrecht, The Netherlands: Kluwer Academic Publishers, pp. 41-72.

dioxins and furans during open burning and improper incineration.[5] As a practical matter, recyclers noted that it is often more difficult to find recycling markets for plastics with embedded BFRs.

Plasma screens and liquid crystal displays (LCDs). Recyclers expressed concern that these emerging technologies contain new or uncommon chemical mixtures, the exact composition of which is often known only to the OEM that holds the patent. In general, it is known that LCD screens contain a mixture of polycyclic aromatic hydrocarbons (PAHs) and halogenated aromatic hydrocarbons.[6] There have not been peer-reviewed scientific studies of the carcinogenic potential of LCD mixtures,[7] although there is evidence that some chemicals within these mixtures may be carcinogenic in humans (e.g., certain PAHs).[8] Recyclers need more information in order to design appropriate processes. For now, they generally shred plasma or LCD displays, since these cannot easily be demanufactured.

Toners and inks. Some toners and inks are potentially carcinogenic. These materials also pose a potential explosion hazard, create a mess in shredding operations, and contaminate commodity streams. When recyclers remove whole ink and toner cartridges, they find few options for reuse. Manufacturers do not typically reuse inks and toners, and once products with different formulas are commingled, they cannot be reused for the same application. Further, while recovery is technically feasible, it is cheaper to landfill the cartridges (allowed in some jurisdictions) or use them for waste-to-energy.

Other materials. Members of the expert panel noted a few other materials that may present significant issues to recyclers. In some instances, metals and abrasives may damage processing equipment. For facilities handling computer chips, gallium-arsenide or other toxic blends may be a concern.

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5 INEMI, 2004. *2004 Roadmap: Environmentally Conscious Electronics.* International Electronics Manufacturing Initiative. December, 2004.

6 Williams, E. 2003. "Environmental impacts in the production of personal computers." In: Kuehr, R. and Williams, E., Eds. 2003. *Computers and the Environment.* Dordrecht, The Netherlands: Kluwer Academic Publishers, pp. 41-72.

7 Ibid.

8 U.S. EPA. 2005. *Integrated Risk Information System (IRIS).* Washington, DC: U.S. Environmental Protection Agency. Online at http://www.epa.gov/iris/.

Section 4

Potential Exposure Pathways

There are several potential routes of exposure to hazardous substances associated with the processing of electronic waste. For many of these chemicals, toxicologists have conducted ample research about the health effects caused by various levels of exposure. However, much less is known about the actual exposures associated with the handling of electronic waste at recycling facilities. To evaluate these exposures, it is important to know the level and duration of exposure (i.e., the dose) as well as the exposure route or pathway (e.g., inhalation). In addition, effects can be highly dependent on particle size and form. This section outlines what is known about exposures related to electronics recycling, while Section 6 addresses needs for additional research.

Potential exposures can be divided into two categories: occupational exposures (which occur within the recycling facility) and environmental exposures (which occur outside it).

4.1 Occupational Exposure

Occupational exposures to hazardous substances could occur in several ways over the course of the workday. Chief among these are recycling processes that produce dust. Processes of concern include shredding or grinding operations and processes used to crush leaded CRT glass. Crushing or shredding materials that contain heavy metals may liberate some of the metal into the air, where fine particulates can enter the body via inhalation. In cases of dust inhalation, the associated health effects may be highly dependent on the size of dust particle that the recycling process produces. A related hazard is the inhalation of vapors produced when hazardous components are broken, particularly mercury vapors from broken bulbs. Other potential inhalation exposures include hazardous fumes from smelting or other thermal processing operations.

In addition to inhalation exposure, dermal exposure may pose an occupational risk. Workers handling hazardous materials without gloves or other protection may absorb dust particles through the skin, provided the particles are sufficiently small. A particular concern is that workers who cut themselves while handling sharp CRT glass may risk dermal absorption of lead.

Government, corporations, and researchers have gathered some data on occupational exposures in the recycling industry. Available data include the following:

- A recent Swedish study analyzed exposure to PBDEs among a group of computer technicians, who spent much of their workday dismantling and rebuilding computers.[9] This study found elevated levels of PBDEs and other flame retardants in blood serum.
- Some companies actively monitor inhalation exposure by outfitting employees with personal monitoring devices. Data from personal monitors may be more valuable than data from blood tests because blood level results can be confounded by exposures to substances outside of the workplace. Some companies may have accumulated a substantial amount of exposure data by now and this information might help in assessing exposures across the industry.
- Research institutions such as the National Jewish Medical and Research Center in Denver, Colorado, have collected a great deal of data about beryllium exposure and the progressive lung disease it can cause (chronic beryllium disease, or CBD). CBD is believed to have led to several hundred deaths in the United States since the 1940s, including some associated with scrap metal recycling.[10] Although CBD has historically been associated with larger volumes of beryllium (e.g., military applications), inhalation exposure to even tiny amounts of this toxic metal during handling or smelting can put workers at risk. Thus, if there is even a trace of beryllium or beryllium alloys in electronic equipment, there could be risks associated with recycling processes. (Recent research suggests that sensitization to beryllium, which is a precursor to CBD, may occur as a result of dermal exposure.[11] Gloves are one simple way to reduce the risk of this exposure.)

4.2 Environmental Exposure

In addition to occupational exposure pathways, electronic waste management operations could expose people to hazardous substances even if they do not work in waste handling facilities. These non-occupational exposures could occur through a variety of environmental media, such as air, drinking water, or soil. The following scenarios highlight a few of the most plausible routes of environmental exposure.

Air emissions. Recycling facilities may emit hazardous substances to the outside air through point sources (vents and stacks) or fugitive releases (general releases not routed through a controlled exit point). Air emissions from electronics recycling could potentially include the venting of dust generated by demanufacturing, shredding, or compacting processes, as well as gaseous and particulate byproducts from thermal processing – e.g., refining or smelting. Thus, air emissions have the potential to expose nearby individuals to heavy metal particulates, harmful byproducts of combustion, and other hazardous substances associated with the processing of end-

[9] Jakobsson, K., Thurreson, K., Rylander, L., Sjodin, A., Hagmar, L., and Bergman, A. 2002. "Exposure to polybrominated diphenyl ethers and tetrabromobisphenol among computer technicians." *Chemosphere* 46: 709-716.

[10] Roe, S. 2001. "Deadly metal's use endangers workers: Employers often don't warn about risks from beryllium." *Chicago Tribune*. 29 July, 2001.

[11] Tinkle, S.S., Antonini, J.M., Rich, B.A., Roberts, J.R., Salmen, R., DePree, K., and Adkins, E.J. 2003. "Skin as a route of exposure and sensitization in chronic beryllium disease." *Environmental Health Perspectives* 111(9): 1202-1208.

of-life electronic devices. To assess these exposures would require either ambient air monitoring, a combination of stack testing and dispersion modeling, or engineering calculations.

Landfill leachate. When a material with hazardous constituents is landfilled, there is some risk that harmful substances can leach out of the material and enter the soil, groundwater, or nearby lakes and streams. Contaminated soil and water could lead to several different human exposure scenarios, including dermal exposure via water or soil, ingestion or inhalation of particles from soil, and ingestion via drinking water. Several tests have been designed to assess the risk that a given material will leach. EPA uses the Toxicity Characteristic Leaching Procedure (TCLP) to determine whether a material should be classified as hazardous under RCRA. TCLP studies of CRT monitors and circuit boards have indicated that the United States' regulated limit of 5.0 milligrams per liter for lead is exceeded.[12,13,14] However, in a review of several recent studies, the Solid Waste Association of North America (SWANA) found that leachate from existing municipal solid waste (MSW) landfills generally has relatively low levels of metals.[15] Recognizing the limitations of TCLP tests, researchers have developed lysimeter leaching tests, which more accurately simulate movement of chemicals through landfill waste.

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12 Townsend, T., Jang, Y., Tolaymat, T., and Jambeck, J. 2001. *Leaching Tests for Evaluating Risk in Solid Waste Management Decision Making.* Draft report. Gainesville, FL: Florida Center for Solid and Hazardous Waste Management.

13 Townsend, T., Musson, S., Jang, Y.C., and Chung, I.H. 1999. *Characterization of Lead Leachability from Cathode Ray Tubes Using the Toxicity Characteristic Leaching Procedure.* Report #99-5. Gainesville, FL: Florida Center for Solid and Hazardous Waste Management.

14 Yang, G. 1993. "Environmental threats of discarded picture tubes and printed circuit boards." *Journal of Hazardous Materials* 34(2):235-243.

15 O'Brien, J. 2005. "Recent studies indicate minimal heavy metal releases from MSW landfills: A summary of the SWANA Applied Research Foundation's findings." *MSW Management* 15(3). Online at http://www.mswmanagement.com/mw_0505_recent.html.

Section 5

Existing Controls: The Current Regulatory Framework

5.1 Occupational Standards

The Occupational Safety and Health Administration (OSHA) does not have any regulations directly targeted at the electronics recycling industry or at specific recycling processes. However, OSHA does have a number of general regulations in place to protect the health and safety of workers in any industry – including electronics recycling. Notable regulations include the following:

Substance-specific standards (29 CFR Part 1910 Subpart Z). For some toxic chemicals, OSHA has established detailed rules that limit all forms of occupational exposure. Among the chemicals potentially encountered in the context of electronics recycling, lead, cadmium, and inorganic arsenic each have a specific OSHA rule. A beryllium rule is currently in development. To comply with these rules, a facility handling the substance in question must first make an initial determination of the level of possible exposure – typically by measuring or estimating the concentration present in the air. If the level of exposure exceeds the "action level" outlined in the rule, further sampling, medical monitoring, or other protective or corrective action may be required. For electronics recycling, OSHA's substance-specific rules – particularly the lead rule – are critical for the protection of human health.

Permissible Exposure Limits (PELs) for air contaminants (29 CFR Part 1910 Subpart Z). For many other substances, OSHA has set maximum levels to which workers at any company may be exposed. In general, these PELs are for 8-hour time-weighted average airborne concentrations – reflective of exposure over the course of a workday – but for some contaminants, OSHA has also established limits on peak or ceiling concentrations that occur within the 8-hour averaging period. If concentrations exceed the PEL, the facility must either reduce them (e.g., by enclosing the process or by improving ventilation) or provide employees in the affected area with respiratory protection (e.g., a respirator). OSHA PELs are in effect for a number of substances associated with electronics recycling, including mercury, other metal dusts, and general "nuisance" dusts. No PELs have been established for BFRs or many of the more uncommon chemicals found in flat screen technology.

Hazard communication (29 CFR Part 1910.1200). OSHA requires that employees be informed of what substances they are handling and what hazards may be associated with exposure to these substances. Any workplace where employees are exposed to hazardous chemicals must have a written plan that describes how the hazard communication standard will be implemented in that facility. Unfortunately, recyclers may have a difficult time acting on these provisions because they are not always aware of the exact composition of the materials they are handling.

Manufacturers are required to make a "hazard determination" and communicate it via Material Safety Data Sheet (MSDS) to all downstream users of their products. However, the MSDS is often not passed on to the recycler and may be difficult to obtain from OEMs.

Other OSHA regulations (29 CFR Part 1910). OSHA has many other regulations that apply to all workplaces (including electronics recycling facilities). Additional health regulations include standards for respiratory protection (i.e., respirator selection and fit) and noise exposure. Major safety regulations include provisions for machine guarding and lockout/tagout, which are designed to protect workers from dangerous machines with many moving parts – e.g., automated shredders.

5.2 Environmental Regulations

On the federal level, no regulations have been developed specifically to address the environmental impacts of electronics recycling. However, there are a number of general environmental regulations that may apply to electronics recyclers if the size and scope of their operations meet certain criteria. Key environmental regulations include:

RCRA. Of all the current federal environmental regulations, the one that affects electronics recyclers most significantly is probably RCRA, which governs the handling and disposal of solid waste. RCRA establishes criteria (e.g., ignitability, corrosivity, reactivity, or toxicity) for determining whether a waste is officially "hazardous" and controls the generation, transportation, treatment, storage, and disposal of such wastes. RCRA also establishes a general framework for the management of non-hazardous wastes. Because RCRA follows a "cradle-to-grave" approach, electronics recyclers will find that the ultimate fate of any hazardous residuals will be regulated - e.g., through rules for the disposal of lead or mercury. However, RCRA contains exemptions that could exclude some recycling operations from strict regulation. Most notably:

- The Conditionally Exempt Small Quantity Generator (CESQG) exclusion, which covers any entity generating 220 pounds (100 kilograms) or less of hazardous waste per month (40 CFR Part 261.5(a)). Under RCRA, wastes from CESQG and household wastes (40 CFR Part 261.4(b)(1)) are not classified as "hazardous."
- Shredded circuit boards being recycled, which are not considered hazardous provided that they are containerized prior to recycling, and provided that all mercury switches, mercury relays, and nickel-cadmium or lithium batteries have been removed prior to shredding (40 CFR Part 261.4(a)(14)).

The disposal of non-hazardous wastes is governed by RCRA Subtitle D; this includes wastes exempted from hazardous waste requirements under the provisions above. Subtitle D provides technical requirements for any municipal solid waste (MSW) landfill, including criteria for location, design, and operation. These requirements are designed to protect human health and the environment by limiting potential exposure to contaminants from all pathways. Among other things, an MSW landfill is required to have a flexible membrane liner, a leachate collection system, and a groundwater monitoring program.

Technical requirements for hazardous waste disposal are outlined in RCRA Subtitle C, again with the intention of protecting human health and the environment. To minimize the toxicity and/or mobility of certain substances, Subtitle C provides standards for treatment that must occur before disposal. For some substances, the standards give a maximum allowable concentration; for others, they require that a specific technology be used to physically or chemically alter the substance. Subtitle C includes more stringent technical criteria for hazardous waste landfills; these include a double liner, a double leachate collection and removal system, and a leak detection system. If hazardous wastes are combusted instead of landfilled (e.g., waste-to-energy), the facility must comply with operation and control standards designed to ensure that hazardous constituents are sufficiently destroyed or contained.

Clean Air Act Amendments (Title V). Under Title V of the 1990 Clean Air Act Amendments, any stationary source releasing more than a certain mass of chemicals into the air is required to obtain an operating permit from the state in which it is located. For hazardous air pollutants (HAPs), the threshold for Title V permitting is 10 tons per year of any single HAP emitted to the air, or 25 tons per year of all HAPs combined. Smelters and waste-to-energy facilities in the United States would almost certainly be regulated under Title V, which specifies maximum achievable control technology (MACT) standards, as well as emission limits after controls have been installed. However, toxic releases from many smaller recycling operations are probably below the applicable thresholds.

Clean Water Act. The Clean Water Act authorizes EPA to regulate water pollution by requiring discharge permits and by setting wastewater standards for industry. Any company with wastewater or significant stormwater discharges would likely fall under these regulations. Electronics recyclers generally do not have industrial wastewater streams.

Toxic Substances Control Act (TSCA). Under section 4 of TSCA, EPA can place restrictions on the manufacture, processing, use, or disposal of certain chemicals to protect against "unreasonable risk to human health or the environment." In general, TSCA restrictions apply more to manufacturers than to disposal companies, since many provisions have to do with the contents of new products (e.g., lead-free paint). EPA has exercised TSCA authority over disposal of a few chemicals, including lead, and is working on similar provisions for mercury-containing products. However, RCRA is still the major regulatory framework governing waste management. Note that TSCA does have very specific requirements for the handling and disposal of polychlorinated biphenyls (PCBs), which an electronics recycler would probably only encounter if handling appliances sold before the late-1970s ban on PCBs.

State regulations. Because the federal regulations described above generally only set minimum standards, in many cases individual states are free to implement stricter controls. For example, states may choose to:

- Use lower thresholds in determining whether a facility must obtain permits.
- Regulate solid waste from CESQGs, which are ordinarily excluded from RCRA.

- Implement universal waste regulations in excess of the federal regulation, which currently does not include electronics.
- Further restrict the use or disposal of certain chemicals.

Individual states control many of the permitting processes established by federal regulations (e.g., Title V), which allows them to integrate their own requirements and restrictions. New York is one state that has specifically worked to highlight state regulations that may apply to the electronics industry; with a grant from EPA Region 2, the state has published a guide to help the industry understand and comply with the applicable state rules. See http://www.epa.gov/Region2/p2/electron.pdf.

5.3 Industry and Other Activities Related to Environmental Management

In the absence of federal standards for environmentally sound management in the electronics recycling industry, organizations within the industry have developed some standards of their own. Notable industry efforts include:

IAER certification. IAER, the major trade association for the electronics recycling industry, has developed a certification process for its members. The IAER framework focuses on management systems, including general business practices, environmental management (similar to ISO 14001), quality management (similar to ISO 9001), and health and safety. Through certification, IAER aims to:

- Support and promote high standards of environmental quality and regulatory compliance in the electronics recycling industry.
- Establish and maintain a formal process to certify that an electronics recycling company is using high-quality business practices.
- Provide a service to IAER member companies to help them improve their management systems and gain recognition as high-quality electronics recyclers.
- Recognize IAER member companies as "Certified Electronics Recyclers" if they are found to meet the IAER certification criteria as a result of a formal, objective certification process.
- Promote the fact that organizations seeking to dispose of electronics equipment will be able to have confidence in selecting Certified Electronics Recyclers as their service providers of choice.

To gain certification, a company must undergo a thorough professional audit. IAER has developed guidance to help member companies prepare for this audit. See http://www.iaer.org/.

ISRI standards. The Institute of Scrap Recycling Industries (ISRI), a trade organization representing over 1,000 companies that process, broker, and consume scrap commodities, has recently developed a set of environmental management standards for the industry. Called RIOS (Recycling Industry Operating Standards), these ISO-style standards are designed to help guide companies' quality, environmental, health, and safety management programs. ISRI aims to make RIOS an internationally recognized standard, as well as a domestic standard for certification. See http://www.isri.org/.

EPA's Guidelines for Materials Management. Through the "Plug-In To eCycling" partnership, EPA has worked with the electronics industry to develop general standards to:

- Maximize reuse, refurbishment, and recycling over disposal and incineration.
- Ensure that exported electronic products are being sent for legitimate reuse, recycling, or refurbishment, and provide for special handling of components that may contain substances of concern.
- Make sure that collection, recycling, refurbishing, and disposal facilities follow management practices that are consistent with the guidelines.

To be accepted as a partner in the "Plug-In" program, a company must demonstrate compliance with these standards. Although EPA currently limits the partnership to manufacturers and retailers (EPA has not yet developed standards to evaluate recyclers for membership), the guidelines encourage any company working with electronic products to make environmentally sound management decisions. See http://www.epa.gov/epaoswer/osw/conserve/plugin/guide.htm.

As an outcome of the EPA National Electronics Meeting in March 2005, EPA plans to convene a multi-stakeholder group to work on developing standards and a certification scheme for electronics recyclers.

Section 6

Needs Identified by the Panelists

In the course of their discussion on the environmental impacts of electronics recycling, members of the expert panel identified a number of needs that are currently unmet. Panelists offered several suggestions on how to improve the level of information, collaboration, and coordination between government and the recycling industry. Many of their suggestions include very clear "next steps" to direct future efforts.

6.1 Research Needs

Panelists identified several key areas where more information is needed in order to characterize potential human health and environmental impacts of electronics recycling. They specifically suggested the following areas of inquiry:

Consolidate existing data and identify gaps. Many different groups have evaluated the health effects of substances associated with electronics recycling; these include government agencies, international organizations, and manufacturers. To a somewhat lesser extent, researchers have also gathered information on exposures specifically related to electronics recycling processes. For example, the National Jewish Medical and Research Center has assembled a great deal of data on occupational exposures to beryllium.[16] It would be useful to gather all relevant data, not only to create a central information resource but also to show where data gaps remain. A particularly important first step would be to contact major recyclers who have already gathered some exposure data and ask if they will share what they have found.

Research to fill data gaps related to health effects. Once the existing data have been evaluated, future research should be directed toward filling key data gaps that remain. Risk assessors use toxicity benchmarks (e.g., RfDs, RfCs, cancer slope factors) to quantify both cancer risks and non-cancer hazards associated with exposure to certain contaminants. Such benchmarks have not been developed for some chemicals commonly found in electronic waste, such as BFRs.

Research to fill data gaps related to exposures. Recognizing the importance of dose in considering potential health effects, it is also critical to fill data gaps related to exposures in electronics recycling. Suggested next steps include:

[16] Newman, L.S., Maier, L.A., Martyny, J.W., Mroz, M.M., and Barker, E.A. 2003. *Response of National Jewish Medical and Research Center to OSHA Docket No. H005C, "Occupational Exposure to Beryllium: Request for Information."* Denver, CO: National Jewish Medical and Research Center. Online at http://dockets.osha.gov/vg001/V027B/00/78/61.PDF.

- Gather occupational data from related sources. For example, CRT manufacturers may have information about lead exposures among their employees; they may also have useful insights about the most effective methods of monitoring occupational exposures.
- Analyze the composition of materials being handled, as well as associated dusts. This information will help identify substances that are a priority for air sampling. Include sensitivity analyses that try to capture the potential impacts if certain components have not been removed (e.g., if a battery or mercury bulb failed to be identified and removed).
- Conduct area monitoring studies in recycling facilities. Sampling programs should be based on an analysis of material composition, with chemicals of concern selected according to toxicity and form (e.g., respirable).
- If necessary, conduct personal breathing zone monitoring studies in recycling facilities. As already stated, this type of study is generally preferred to assessing blood levels, since blood tests do not screen out the effects of possible exposures outside the workplace.
- If necessary, conduct stack testing or ambient air monitoring to evaluate potential ambient air quality impacts from recycling facilities.
- Conduct lysimeter tests on additional components to determine the extent to which landfilling could lead to leaching and environmental contamination. Of particular interest are inks and toners, which are often landfilled due to a lack of options for reuse.

Conduct additional research on processes and operations. It is not enough to evaluate exposures in one facility, because different processes can lead to very different levels of exposure. Researchers should familiarize themselves with common practices throughout the industry and evaluate all possible points of exposure. Common processes expected to cause elevated exposures should be thoroughly evaluated through air sampling and/or employee monitoring. Panelists identified several processes of particular concern:

- Processes for crushing CRT glass. Currently, the most common method of breaking CRTs is the "gravity drop," which essentially entails dropping the unit on the floor. While generally the most cost-effective technique, the gravity drop raises questions about dust generation and should be studied accordingly.
- Processes for handling mercury components, particularly the fluorescent backlight in laptops, which is sometimes not removed before the laptop is shredded.
- Processes that handle batteries. For example, it would be helpful to know what happens to different types of batteries if they are not removed before shredding.
- Processes that may expose workers to BFRs and other flame retardants commonly used in electrical and electronic products. (Not all plastics in these products contain flame retardants.)
- Processes for handling plasma and LCD screens. Some of these processes are still being developed; it is important to consider these new sources of potential exposure.

6.2 Best Practices Guidance

Panelists expressed the need for a comprehensive set of updated best practice guidelines. There are several potential benefits to establishing best practices, which could assist in:

- Promoting practices that are most protective of worker health and safety.
- Eliminating practices that pose unacceptable risks.
- Establishing a more level playing field for the industry (by setting standards for "compliance").
- Facilitating information sharing.

Panelists suggested that best practices be established in three key areas: exposure monitoring; technical processes; and auditing/verification.

Exposure monitoring. Panelists recommended that use of sampling and monitoring methods be evaluated in order to determine a set of best practices. Government and recyclers would benefit if they had clear guidance on determining when occupational exposure monitoring is required. If it is required, they could use guidance on how to properly conduct the monitoring.

Technical processes. The electronics recycling industry could benefit from technical guidelines for disassembly, shredding, and separation processes. In this case, best practices guidance would be a logical outgrowth of the process-specific research suggested in Section 6.1. Each process should be evaluated step by step to identify points that could generate hazardous forms of a substance of concern. For example, research can identify processes most likely to release beryllium from the beryllium-copper alloy. It is important to recognize that quality control of incoming feedstocks can be an important step in ensuring safe and environmentally sound recycling processing. Once processes have been evaluated, the results can be used to generate guidelines on which processes should be used and what procedures need to be in place to ensure that a given process will be safe (e.g., removal of batteries before a process that would liberate battery contents). Ultimately, guidance on best operational practices could serve not only to reduce risks to human health and the environment, but also to encourage a level playing field by allowing "good" recyclers to justify higher costs in the name of worker safety and environmental responsibility.

Auditing/verification. Although IAER has developed a general auditing system, it has yet to be endorsed by any government agency or OEM organization, or by the electronic recycling industry itself. Companies also could benefit from specific guidelines for auditing and verification procedures, particularly procedures to evaluate processes, which the IAER audit does not cover extensively. Best auditing practices could help recyclers whose clients (e.g., OEMs) require them to vouch for downstream handlers. Currently, companies conducting their own audits must put a lot of effort into developing and evaluating their own procedures. A set of guidelines would streamline the process.

6.3 Standardization

Companies in the electronics recycling industry need a clear understanding of the many state and international regulations that affect electronics recycling. A clear, concise presentation of this information could facilitate shared understanding, particularly in the complex areas of hazardous waste handling and interstate and international transport. Panelists noted that federal regulation could help standardize what is currently a fragmented regulatory landscape. A national effort to regulate electronics recycling would provide more thorough and consistent coverage than current state-by-state efforts.

6.4 Communication

Further effort by government and industry can facilitate communication in several key areas. Members of the expert panel suggested a number of opportunities for improvement, including the following:

Communication within the industry. As noted in previous sections, recyclers can contribute to the overall state of knowledge within the industry by sharing data they have gathered on exposures, processes, and monitoring methods. Greater communication will also help with developing best practices for monitoring, processes, and auditing. Essentially, an improved forum for communication can prevent everyone from having to "reinvent the wheel."

Communication with government. Industry and government should continue to work together to address issues of human health and environmental impact. Collaboration will help all stakeholders work toward a shared understanding and sustainable solutions.

Communication with OEMs. Recyclers and manufacturers can both benefit from improved two-way communication. The following are just a few of the many ways in which better communication between the two ends of the product lifespan can reduce potential hazards to human health and the environment:

- OEMs can provide recyclers with more information about the contents of their products. For example, the recycler might like to know the concentration of beryllium in a product, or whether a lithium battery is present. With the rising popularity of shredding, product-level information has become increasingly important. The EU requirements will likely give recyclers greater access to information about product contents, and the EPEAT program is currently developing a declaration resource that will cover at least those products that are EPEAT-certified. In the future, more extensive product information databases could be developed to assist recyclers. Another area for future development is the labeling of products or components, possibly with RFID tags that recyclers could scan and match against a database.
- OEMs can also provide recyclers with more detailed information about certain new or uncommon chemicals found in their products; most notably, the mixtures used in plasma

and LCD screens. Recyclers currently know little about the identity or health effects of these chemicals.

- OEMs and recyclers can work together to develop a consistent labeling scheme for hazardous constituents. For example, all mercury-containing components or lithium batteries could have a standard label or be color-coded for easy identification.
- Recyclers can help OEMs design products that are safer and easier to recycle. With improved communication, recyclers could make OEMs aware of difficulties that the latter could try to alleviate in the product design phase.

6.5 Interagency Collaboration

To address the potential human health and environmental impacts of electronics recycling, EPA should collaborate with other federal agencies whose work may be relevant to these issues. In particular, EPA should consider consulting or working with the following agencies:

- NIOSH. This branch of the Centers for Disease Control and Prevention (CDC) is responsible for conducting research and making recommendations for the prevention of work-related illnesses and injuries. NIOSH may have useful information on processes and exposures related to electronics handling. NIOSH also publishes its own set of chemical-specific exposure thresholds.
- OSHA. As noted in Section 5, OSHA has a number of general occupational health and safety regulations that apply to electronics recyclers. OSHA may also be able to assist with efforts to improve worker education, which panelists identified as a particular concern. Educational materials should be clear, simple, and available in multiple languages.

6.6 Informed Decisions

In general, members of the expert panel identified a need for informed decisions to move electronics recycling forward. Specific suggestions are as follows:

- Costs of data collection should be considered, and research efforts should be prioritized to make the most effective use of available funding.
- In promoting best practices, government and industry should ensure that recyclers can continue to develop and apply new technologies where they make sense from an environmental standpoint.
- Government can work to find ways to provide incentives for improvement in technology and environmental performance.
- In general, the parties involved in this collaboration should be mindful of all the costs and benefits of any proposed effort.

Section 7

The Path Forward

If a single theme can be gleaned from the input provided by electronics recyclers, it is that their industry is operating without standards and in a state of constant change. Product composition is changing with advances in technology; new processes are constantly being developed; the regulatory environment is growing more complex with every action by an individual state or local government; and through all of this, the industry is growing – which means that from a human health or environmental standpoint, the stakes are rising every day. Given the industry's limited federal oversight, it is important that government and industry work together *now* to anticipate and prevent dangers to human health and the environment.

Members of the expert panel convened by ORD identified several ways in which government and industry can move forward to address the human health and environmental impacts of electronics recycling; Section 7.1 presents a summary of these priorities for action. Section 7.2 outlines a number of specific activities EPA can undertake to address these priorities.

7.1 Priorities

Considering what is currently known about the possible human health and environmental impacts of electronics recycling, and considering the suggestions provided by various experts and stakeholders, key priorities for action include the following:

- Analyze product content and key recycling processes to identify substances and exposure points of concern.
- Make a comprehensive effort to gather and review all relevant toxicology, exposure, and process-specific data from recyclers, federal agencies, and organizations in other countries.
- Conduct research to fill gaps in the existing data on effects, exposures, and processes. In particular, consider data needs for emerging chemicals, such as LCD mixtures. To evaluate leaching potential, conduct lysimeter tests.
- Work to develop best practices guidance for processes, exposure monitoring, and auditing/verification.
- Develop a widely recognized certification program for electronics recyclers to help consumers of e-cycling services readily identify recyclers that are conducting activities in an environmentally sound manner.
- Ensure that existing protections are being enforced. For example, OSHA's lead standard applies to all workplaces, including some electronics recyclers that may not have met

their obligation to demonstrate compliance. Also, RCRA prohibits disposal of hazardous waste in unpermitted facilities, yet panelists stated that they believe many recycling companies still dispose of hazardous electronic components in unpermitted solid waste landfills and incinerators.

- Improve communication within the industry and with government. Work toward a shared understanding and a shared vocabulary.
- Improve communication between recyclers and OEMs. In particular, find a way to give recyclers and their employees more information about the products and chemicals they are handling.

Although not specifically discussed at the meeting, individual panelists also suggested the following:

- Institute a nationwide solid waste disposal ban on e-scrap.
- Institute a national hazardous waste exemption for e-scrap that is recycled in accordance with environmentally sound management practices that are sanctioned by EPA.
- Maintain support for integrated resource management where different resource recovery technologies (i.e., mechanical, chemical, and thermal) are available to electronics recyclers to ensure that materials that cannot be recycled can be landfilled in an environmentally and economically sound manner.

7.2 Roles EPA is Well Positioned to Play

EPA is well positioned to play a key role in the ongoing effort to address the potential human health and environmental impacts of electronics recycling. There are several specific ways in which EPA could assist the industry in achieving some of the action priorities outlined in the previous section:

- Investigating the potential levels of occupational and environmental exposure to heavy metals.
- Evaluating the potential human health effects of flame retardants where the existing data are deficient. ORD has expertise in establishing toxicity benchmarks (e.g., RfDs, RfCs, cancer slope factors).
- Encouraging recyclers to share data they have gathered on processes and exposures.
- Leading the effort to develop best practices guidelines, including possible standards for "compliance." In October 2005, EPA will "kick off" an effort to convene and facilitate a stakeholder process to develop a standard for environmentally responsible electronics recycling, as well as a system for certifying and verifying recyclers against this standard.
- Facilitating communication, particularly between OEMs and recyclers. EPA could conceivably provide an interface for product declaration, perhaps similar to the provisions in EPEAT, but with broader applications.

- Working with OSHA, the recycling industry, and other relevant parties to develop tools for worker education.
- Conducting research using TCLP and other approaches on e-scrap to determine what is and is not hazardous waste.
- Standardizing and enforcing regulations affecting electronics waste recycling.

Section 8

Participants and Attendees

The following individuals served as members of the expert panel on May 19, 2005:

Name	Affiliation	Expertise
Lauren Roman	MaSeR Corporation	Industry expert
Craig Boswell	Hobi International	Electronics demanufacturing
Michael Fisher	American Plastics Council	Value of recovered plastics in computers
Dale Johnson	MaSeR Corporation	Material separation and recovery
Cindy Thomas	Noranda Recycling	Material shredding and smelting
Tim Townsend	University of Florida	TCLP testing and landfills
John Wilhelmi	ERG	Risk and exposure assessment

The session was moderated by Lauren Roman of MaSeR Corporation. Jeff van Ee of EPA-ORD coordinated the session and provided an introduction to EPA's objectives.

The panel session was conducted in front of an audience that included representatives from the electronics recycling industry, electronics manufacturers, and government. Several attendees provided valuable comments and suggestions, many of which have been included in this report. A list of attendees is provided in Appendix A.

Some of the content in this report, particularly the background information in Section 2 and the description of current voluntary and regulatory actions and controls in Section 5, may not have been specifically discussed during the session, but is provided as supplemental information.

Section 9

Additional Resources

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Appendix A

Participant List

* ***Panelist*** ** ***Moderator***

Michael Alexander
National Recycling Coalition
P.O. Box 97
Brattleboro, VT 05301
802-254-3338
Email: michaela@nrc-recycle.org

Ian Bain
Citirya Inc./EWS USA
106 East Old Settlers Boulevard
Round Rock, TX 78664
512-238-1911
Fax: 512 238 1931
Email: ian.bain@citiraya-inc.com

***Craig Boswell**
HOBI International, Inc.
7601 Ambassador Row
Dallas, TX 75247
214-951-0143
Fax: 214-951-0144
Email: cboswell@hobi.com

Robert Busbice
U.S. Department of Defense
8900 Savage Road
Fort Meade, MD 20775

John Cianciarulo
Noranda Recycling, Inc.
80 Commercial Way
E. Providence, RI 02914
401-438-9220
Fax: 401-438-1237
Email: cianciaj@sampling.noranda.com

Jeffrey Dahmus
Massachusetts Institute of Technology
77 Massachusetts Avenue - Room 35-005
Cambridge, MA 02139
617-253-7530
Fax: 617-253-1556
Email: jdahmus@mit.edu

Joseph DeLorme
GE Advanced Materials
1 Plastics Avenue
Pittsfield, MA 01201
413-448-7491
Fax: 866-286-6625
Email: joseph.delorme@ge.com

Shashank Dubey
Teradyne, Inc.
44 Simon Street
Nashua, NH 03062
603-879-3788
Fax: 603-879-2788
Email: shashank.dubey@teradyne.com

Matthew Fischer
Gannon & Scott
33 Kenney Drive
Cranston, RI 02920
401-463-5550
Fax: 401-463-5971
Email: mattfischer@gannon-scott.com

***Michael Fisher**
American Plastics Council
1300 Wilson Boulevard
Arlington, VA 22209
703-741-5599
Fax: 703-741-6599
Email: mike_fisher@plastics.org

Staci Gatica
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460
202-564-2321
Email: gatica-hebert.staci@epa.gov

Kate Geraghty
Rohm and Haas
Herald Way
Coventry CV3 2RQ
United Kingdom
+44-(0)-247-665-4459
Fax: +44-(0)-247-644-8014
Email: kgeraghty@rohmhaas.com

Alfred Hambsch
Cable Recycling
220 John Street
Barrie, ON L4N 2L2
Canada
705-725-1919
Fax: 705-725-1920
Email: ahambsch@barriemetals.com

Joe Hennigan
U.S. Department of Defense
8900 Savage Road
Fort Meade, MD 20775

Lee Herriges
GE Healthcare
P.O. Box 414 (ED-91)
Milwaukee, WI 53129
414-747-6997
Fax: 414-747-6855
Email: lee.herriges@med.ge.com

Lloyd Hicks
INFORM
120 Wall Street - 14th Floor
New York, NY 10005
212-361-2400
Fax: 212-361-2412
Email: hicks@informinc.org

Jaco Huisman
Design Production & Contraction
TU Delft
Landbergstraat 15
Delft 2628CE
The Netherlands
+31-15-278-2738
Fax: +31-15-278-2756
Email: j.huisman@io.tudelft.nl

***Dale Johnson**
MaSeR Corporation
14 Schooner Ridge – Suite 200
Marblehead, MA 01945
617-290-2276
Fax: 617-687-9187
Email: djohnson@masercorp.com

Sandy Jones
U.S. General Services
401 West Peachtree Street - Suite 2300
Atlanta, GA 30308
404-331-1941
Fax: 404-730-9723
Email: sandy.jones@gsa.gov

Katharine Kaplan Osdoba
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW (5306W)
Washington, DC 20460
703-308-8659
Fax: 703-308-8686
Email: osdoba.katharine@epa.gov

Lynn Knight
Eastern Research Group, Inc.
110 Hartwell Avenue
Lexington, MA 02421
781-674 7313
Fax: 781-674-2851
Email: lynn.knight@erg.com

Jim Kozinski
GE HealthCare RR
2200 East College Avenue
Cudahy, WI 53110
414-747-6997
Fax: 414-747-6855
Email: james.kozinski@med.ge.com

Chris Lamie
Eastern Research Group, Inc.
110 Hartwell Avenue
Lexington, MA 02421
781-674-7247
Fax: 781-674-2851
Email: chris.lamie@erg.com

Jim Lynch
CompuMentor
1352 Acton Street
Berkeley, CA 94706
415-633-9308
Fax: 415-633-9400
Email: jimlynch@compumentor.org

Robert McKechnie
Citiraya Inc.
106 Old Settlers Boulevard
Round Rock, TX 78664
512-238-1911
Fax: 512-238-1931
Email: robert.mckechnie@citiraya-inc.com

Wayne Rifer
Rifer Environmental
1975 NW 113th Avenue
Portland, OR 97229
503-644-0294
Fax: 503-643-9705
Email: wrifer@concentric.net

****Lauren Roman**
MaSeR Corporation
22 Hatakawanna
Budd Lake, NJ 07828
973-426-0406
Fax: 973-426-0866
Email: Lroman@masercorp.com

Matthew Russell
Lexmark
740 New Circle Road
Lexington, KY 40511
859-232-7176
Fax: 859-232-3039
Email: mrussell@lexmark.com

Chris Ryan
Metech International
120 Mapleville Main Street
P.O. Box 500
Mapleville, RI 02839
978-772-4897
Fax: 978-772-5440
Email: cryan@metech-arm.com

Mark Sajbel
U.S. General Services Administration
7th and D Street
Washington, DC 20407
Email: mark.sajbel@gsa.gov

Greg Sampson
Earth Protection Services, Inc.
107 East Historic Columbia River Highway – Suite 208
Troutdale, OR 97060
503-667-1004
Fax: 503-667-1008
Email: g.sampson@earthpro.com

David Sanders
Great Lakes Chemical
1 Great Lakes Boulevard
West Lafayette, IN 47906
765-497-6319
Fax: 765-497-5411
Email: dsanders@glcc.com

Karsten Schischke
Fraunhofer IZM
Gustav-Meyer-Allee 25
Berlin 13355
Germany
+49-30-46403-156
Fax: +49-30-46403-131
Email: schischke@izm.fhg.de

J.M. Gideon Schroeder
Cisco Systems, Inc.
170 Tasman Drive
San Jose, CA 95134
773-444-5054
Email: gschroed@cisco.com

Douglas J Sellick
Industry Canada
155 Queen, 423
Ottawa, ON K1A 0H5
Canada
613-957-2857
Fax: 613-957-1201
Email: sellick.doug@ic.gc.ca

Sandford J. Selman
Asia West LLC
121 Post Road East
P.O. Box 5213
Westport, CT 06881
203-221-7455
Fax: 203-221-7457
Email: sandy@aswiawestfunds.com

Ingrid Sinclair
Noranda Recycling
3160 Vera Valley Road
Franklin, TN 37064
615-287-5945
Fax: 615-793-9959
Email: ingrid.sinclair@norandarecycling.com

Jorgen Svensson
Sony Ericsson
Torshamnsgatan 27
P.O. Box 64
Kista SE-164 94
Sweden
+46-8-404-2425
Fax: +46-8-404-8570
Email: jorgen.svensson@sonyericsson.com

***Cindy Thomas**
Noranda
Canada
905-874-6835
Email: cindy.thomas@toronto.norfalc.com

***Timothy Townsend**
University of Florida
352-392-0846
Email: ttown@ufl.edu

Dani Tsuda
WSP Environmental
405 Howard Street - Suite 500
San Francisco, CA 94105
415-298-0604
Email: dani.tsuda@wspgroup.com

Chris Turner
Sony Ericsson
7001 Development Drive
P.O. Box 13969
Research Triangle Park, NC 27709
919-472-6997
Fax: 919-472-1380
Email: chris.turner@sonyericsson.com

Jeff van Ee
U.S. Environmental Protection Agency
P.O. Box 93478
Las Vegas, NV 89119
702-798-2367
Fax: 702-798-2107
Email: vanee.jeff@epa.gov

Michael Vanderpol
Environment Canada
351 St Joseph Boulevard
Gatineau, QC J9J 1J5
Canada
819-953-9246
Email: michael.vanderpol@ec.gc.ca

***John Wilhelmi**
Eastern Research Group, Inc.
110 Hartwell Avenue
Lexington, MA 02421
781-674-7312
Fax: 781-674-2851
Email: john.wilhelmi@erg.com

Michael Williams
Inert Corporation
16 Swampscott Street
P.O. 146
Newfields, NH 03856
603-772-7236
Fax: 603-773-5643