The Electronics Recycling Landscape

Report Summary

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CLOSED LOOP foundation

NCER National Center for Electronics Recycling

THE SUSTAINABILITY CONSORTIUM™

Electronics Recycling Landscape Report

Report Summary

Carole Mars
Christopher Nafe
The Sustainability Consortium
Arizona State University

Jason Linnell
National Center for Electronics Recycling

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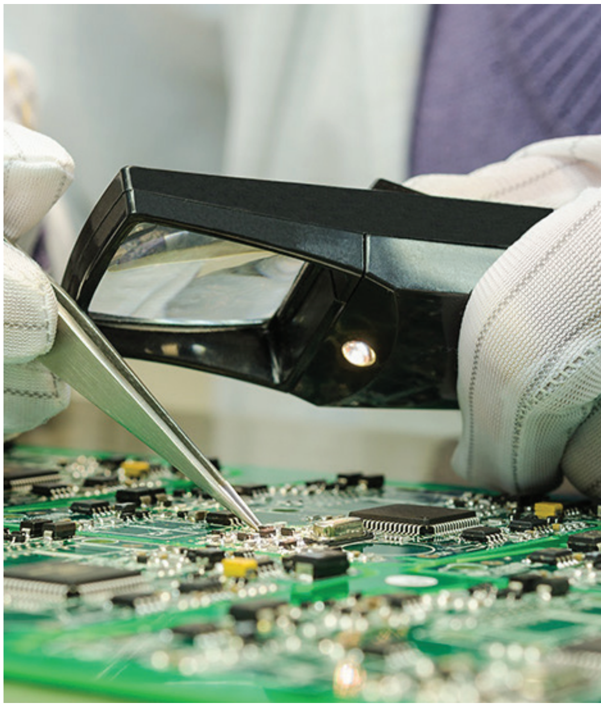
Report Summary



The rapid adoption and dissemination of new technologies and applications for consumer electrical and electronic equipment (EEE) creates opportunities for innovators in the used EEE industry to enable effective and efficient reuse and materials recovery. Reuse, refurbishment, and recycling activities capture the value of the devices and their components, protect human health and the environment by executing responsible used device management, and conserve the resources embedded in the devices so they are available tomorrow for new uses. The challenges to be faced in capitalizing on these opportunities, though, are not trivial. Challenges related to the sheer number of devices reaching end-of-life are compounded by the high degree of variation in material content (and, therefore, potential component and commodity streams), as well as the presence of potentially hazardous materials, which must be managed properly to protect human health and the environment. To meet these challenges and realize an effective

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used EEE management system in the United States, the industries that intersect in managing used equipment will need to modernize the system in place and prepare both technology and processes to manage the next wave of devices. To fail to do so is to lose the economic and material value of the devices and forfeit the environmental and societal benefits of a robust used EEE management system, both now and in the future.

This report, commissioned by the Closed Loop Foundation and written by The Sustainability Consortium and the National Center for Electronics Recycling, provides an overview of the current used EEE management landscape within the United States in order to understand 1) the types and quantities of materials that are currently and will be moving from the consumer market into the waste stream in the next 5 years; 2) the type of programs are in place currently and how effective they are; and 3) how changes in consumer desires and behavior, device technology, the governmental regulatory space, and practices in the electronics and recycling industries will impact the effectiveness of and demands on recycling programs in the next 5 years. This analysis is then used to identify the opportunities available and provide potential solutions to address the challenges identified to support the development of a resilient used EEE management system.

A combination of research and stakeholder surveys was used to collect the information for this report. In August and September of 2015, a series of stakeholder surveys were conducted in which 37 organizations participated, including representatives from the consumer electronics industry, NGOs, government agencies, refurbishers, recyclers, trade groups, and other organizations participating in this space. To address the primary questions for this study, analysis focused on the consumer electronics industry, the electronics reuse, refurbishment, and recycling industries in the United States and the used electronics management system that brings these industries together. The major findings from this work are outlined below, along with recommendations on how to participate in the improvement of used electronics management to the benefit of all stakeholders.

Managing Used Electronics

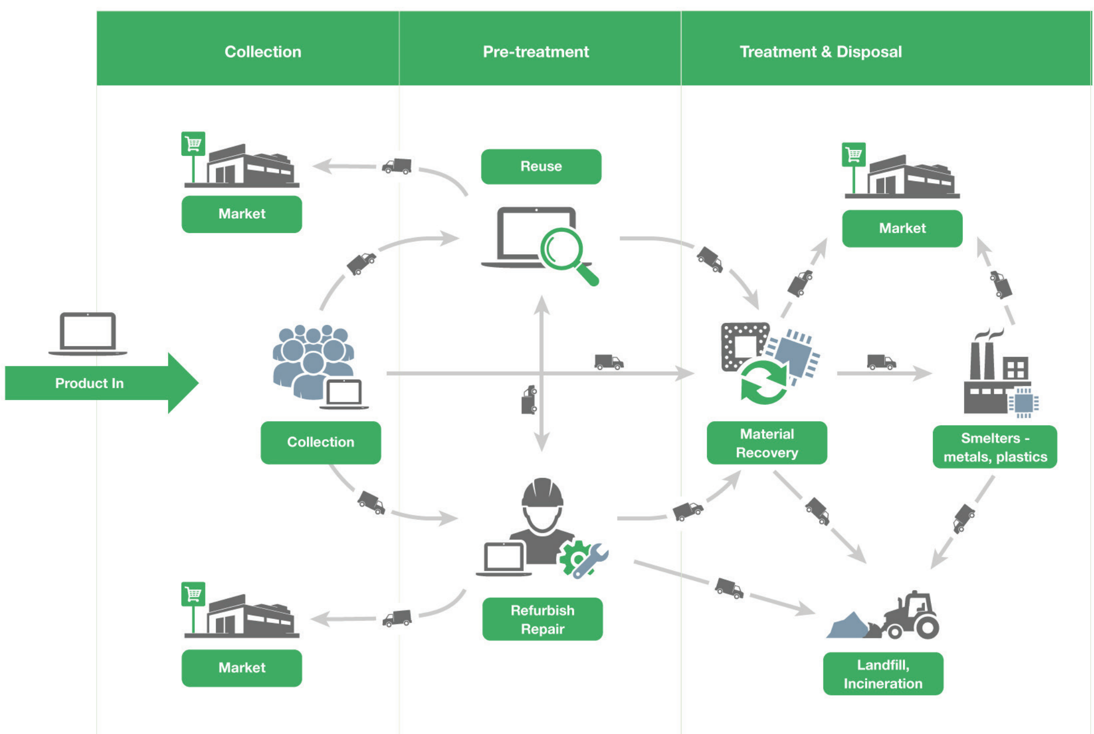


Figure 1: Stages of used electronics management

Used EEE Issues

Hazardous Materials

- Electronics can contain lead, mercury, cadmium, PVC, and plastics with brominated flame retardants that can present risks to human health and the environment if handled improperly.
- Even though many of the most hazardous materials are no longer used in EEE manufacturing, devices with these materials will still be in the waste stream for the foreseeable future.
- Irresponsible handling at device end of life compounds worker exposure, especially when devices are burned.

Environmental Impacts

- Irresponsible treatment of used devices also leads to contaminated land and water around material recovery facilities.
- Illegal dumping of equipment in the environment, especially lead-containing CRT displays, leads to expensive clean-up and environmental contamination.
- The energy and material resources that went into creating a device are lost when devices are thrown away. There is no opportunity to recapture the energy or offset mining impacts without repair and recycling.

Economic Impacts

- Disposal costs money. Even if used devices are included in regular municipal waste streams, communities still pay for dumping this equipment in landfills.
- Landfilling rather than recycling or repair costs jobs.
    - According to the Institute of Scrap Recycling Industries (ISRI), the electronics recycling industry employs more than 45,000 workers as of 2012.[1]
    - According to iFixit, 200 repair jobs can be created for every 1000 tons of used electronics, which equates to approximately 45,000 jobs for the estimated 455 million tons of devices collected in 2015.[2]
    - Repair and refurbishment organizations provide jobs to under served populations, such as individuals with criminal records and disabled and disadvantaged adults—opportunities lost without robust repair and recycling industries.

Personally Identifiable Information

- Devices today, especially mobile and wearable devices designed to collect information about their owner, contain a great deal of personal information that must be removed before a device is repaired or recycled to avoid data breeches.
- Information can be erased and devices reused rather than destroyed if handled by a responsible and qualified refurbisher or recycler.
- For equipment coming from commercial enterprises, an additional risk of the loss of proprietary information is present when used equipment is not handled responsibly.

Figure 1 illustrates the stages used electronics move through once they've reached the end of their first useful life and move into the used device space. Devices are collected by a wide range of organizations – not-for-profits, charities, government entities, retailers, independent recyclers, and manufacturer takeback programs all provide routes for consumers to turn in used equipment. Collected equipment is then triaged in the pre-treatment step, where the determination is made whether a whole device can go back onto the market, whether the device can be repaired or refurbished for resale or components can be harvested and reused or resold, or whether the device is too old or broken for those options and should move into material recovery. When a device heads to material recovery, potentially hazardous components that cannot enter the treatment phase are removed. Batteries, ink and toner cartridges, and mercury lamps are moved into their own management flows so that they can be treated appropriately. In treatment, further disassembly of the device may take place, and the device is then treated through shredding or other size reduction processes so that the metals and plastics can be sorted and separated for the commodity market. Materials with commodity value then move to smelters or other recovery facilities to be converted to a form that can re-enter manufacturing processes, and any residual materials are then landfilled or incinerated. This report covers the variety of challenges that face organizations working in one or more of these stages and considers potential solutions to these challenges.

Consumer Electronics Industry

Smaller, lighter, faster – those are the trends expected for devices in the consumer electronics space. Several key facts and conclusions will shape the future of the electronics and electronics recycling industries in the coming years:

- The average U.S. household has 28 electronic devices, and estimates predict consumers will add over 1 billion more devices to this current count in 2015 alone.
- Estimates based on sales year and product life span of used electronics and electrical equipment ready for end-of-life treatment are nearly 700 million units in 2015.
- Assuming the average recycling rates for electronics have not changed from the values published by the US EPA for the year 2009, roughly 455 million tons of devices will be recycled in 2015.[3]
- The materials in EEE have not changed significantly over time – steel (which includes iron and manganese), aluminum, plastics, and precious metals. While

any one of these materials is recyclable, separating them from the device can be challenging and time-intensive, and recovering the trace amounts of some elements such as the rare earths or indium can be cost-prohibitive today.

Figure 2 shows the average material composition of selected products.

- With the advent of new materials, such as quantum dots, and the continued use of rare earth and other strategic minerals in batteries and for specialized functions in mobile devices, the possibility of material shortages tied to supply constraints is of concern to both governments and industries relying on these materials. Recycling these materials may provide a diverse and more stable supply for manufacturing, but the technology to do so is not widely available or cost-effective today.

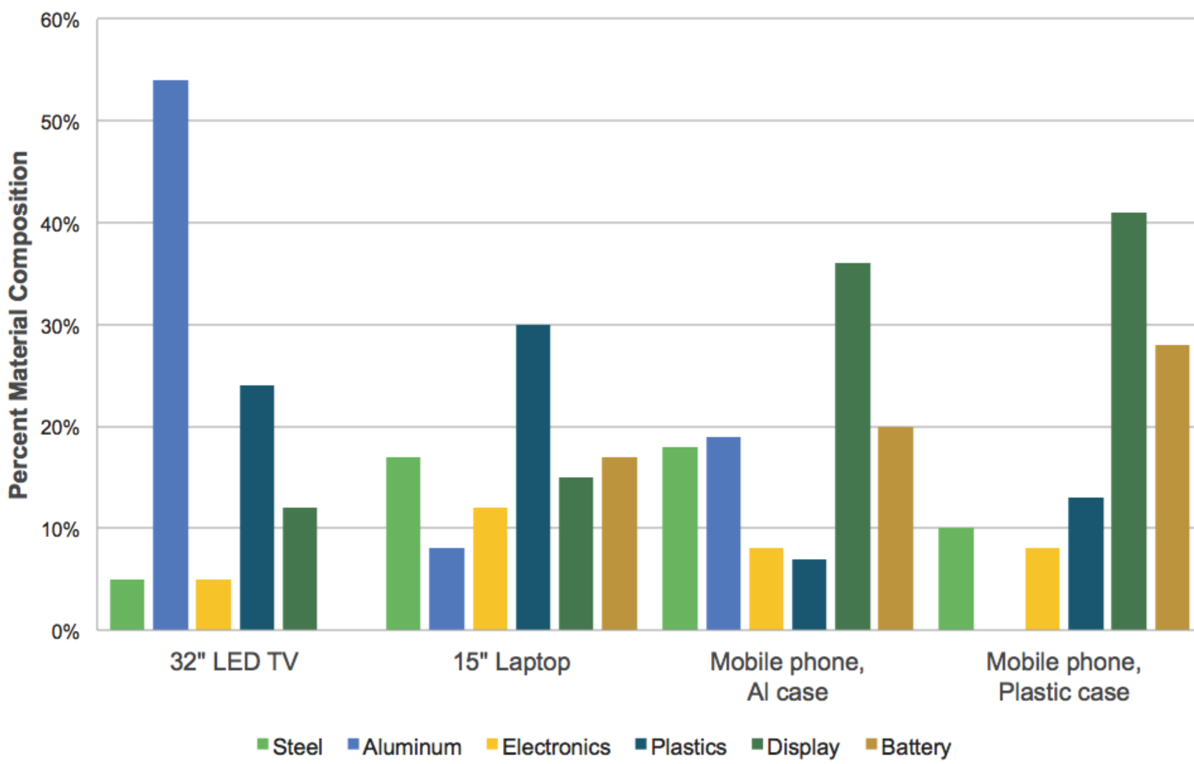


Figure 2: Average Material Composition

The Cautionary Tale of CRT Displays

Currently the largest portion of the used EEE stream by weight collected from households, cathode ray tube (CRT) displays have not always been the problem they are today. When the technology was dominant in the marketplace, many options existed for efficient, closed-loop material recycling. The leaded glass moved directly back into the manufacturing process to create new CRT displays. This process worked exceptionally well until CRT displays were eclipsed in the market by flat-panel technologies and became obsolete. At that point, the market for volumes of leaded glass disappeared, along with the vast majority of facilities that could safely manage this material.[8] This contraction left only a handful of outlets for glass available to recyclers at about the same time a larger number of displays started entering the recycling stream due to state-mandated producer responsibility laws.

The perfect storm raged during 2015, when multiple companies went out of business due to poorly managed stocks of CRT displays, and Videocon, the final glass-to-glass smelter in the world stopped accepting new displays.[9] The trend continued in 2016: more companies have gone out of business, some state programs have discontinued collection, and Best Buy began charging consumers to take these devices.[10] The small piece of good news is that Videocon has started accepting displays again from select vendors in the United States, with an expected demand for glass for another 3 years. The past year has illustrated the volatility in CRT glass management markets, and underscores the challenges and uncertainties that organizations responsible for managing these materials face.

Even in a robust system, this situation could happen again. For many years, it appeared that there would be a steady market for leaded glass, and the environmental and social ramifications of its disposal did not enter the conversation. Some are already pointing to mercury-containing liquid crystal display (LCD) flat screens as an example of the next potential challenge. New LCD devices have moved away from mercury backlighting to light emitting diodes (LEDs), so there are projections for large volumes of the older technology to enter recycling systems. Any system developed or redesigned to handle used EEE today needs to take into account where materials can go today and tomorrow, understand the risks to workers and the environment, and be flexible enough to change with changes in both incoming devices and outgoing materials. Reaching that point will require more thoughtfully designing devices with end of use in mind, creating effective forecasting tools and metrics to understand the current and potential landscape, and enabling use of this information by those managing used EEE.

US Estimates for Used Electronics[3-7]

US consumers are expected to purchase more than 1 billion devices in 2015, with sales reaching $285 billion.

Sales of mobile devices (including wearables) in 2015 will increase by 15% from sales in 2014.

In the US, approximately 3.8 billion devices are in use or stored in households.

Of devices sold since 1989, roughly 1.4 billion units will reach their expected life span and be ready for end-of-life treatment in 2015.

- 40% - 70% of these devices are expected to be recycled (computers, monitors, televisions, and mobile phones).
- This excludes small appliances, for which reliable US recycling rate data do not exist.

Electronics Recycling Industry

Electronics recycling is an umbrella term used to describe all activities that take place after the end of first use of EEE. This is misleading for electronics as there is an active reuse and refurbishment space that is not mirrored in other recycling streams, such as municipal recycling programs for packaging. While including only 10-15% of recovered devices today, reuse and refurbishment represents the highest value option for used electronics, and one that is expected to play an important role in managing the smaller and lighter devices that may not be of value for material recovery. Table 1 shows the relative values of refurbished devices, used devices, and materials recovered for a selection of devices. Figure 3 shows the decrease in retained value for two models of laptop computers and two models of mobile phones. Both product sets loose more than 50% of their original retail value within 2-4 years of their release date. This shows the danger of product storage: Products coming back into the secondary market after a few years do not retain value and will be sent for materials recovery instead, where the embedded energy and materials will get only cents on the dollar for the original investment.

Table 1: Average reuse and recycling prices for selected product categories[11, 12]

	FORMAT	REFURBISHED	USED	RECYCLED (PER UNIT)	LABOR COST (PER UNIT)
MOBILE DEVICES (2011)	ANDROID	$145	$122	< $2	-$0.07
	iOS	$180	$203	$1 ($3.30/lb scrap)	
TABLETS (2013)	ANDROID	$286	$225	$5	-0.78[1]
	iOS	$335	$315	$4	
LAPTOPS (2010)					
PC	15”	$450	$359	$17	-$0.42
APPLE	15”	$700	$600	$18 ($2-3/unit for non-functioning units)	
FLAT PANEL DISPLAY TELEVISIONS (2015)	1080P				
	32”	$260	$214	$5	-$2.11
	55”	$650	$600	< $10 (scrap LC display $3)	
CRT TELEVISIONS	ANY SIZE	N/A	$5	-$15 or higher depending on size and weight of display	-$0.98 (Excluding glass handling)
PRINTERS	LASER & INKJET	NONE LISTED	$60	< $1 ($0.04/lb scrap)	-$0.14

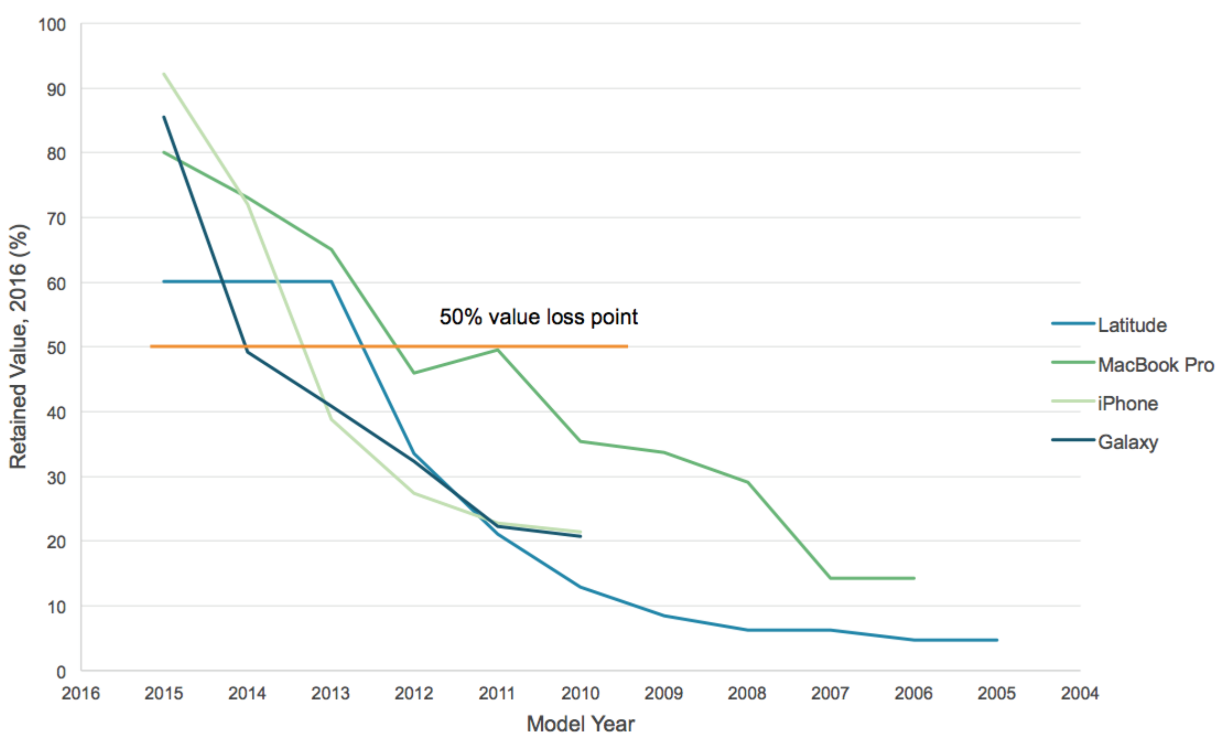
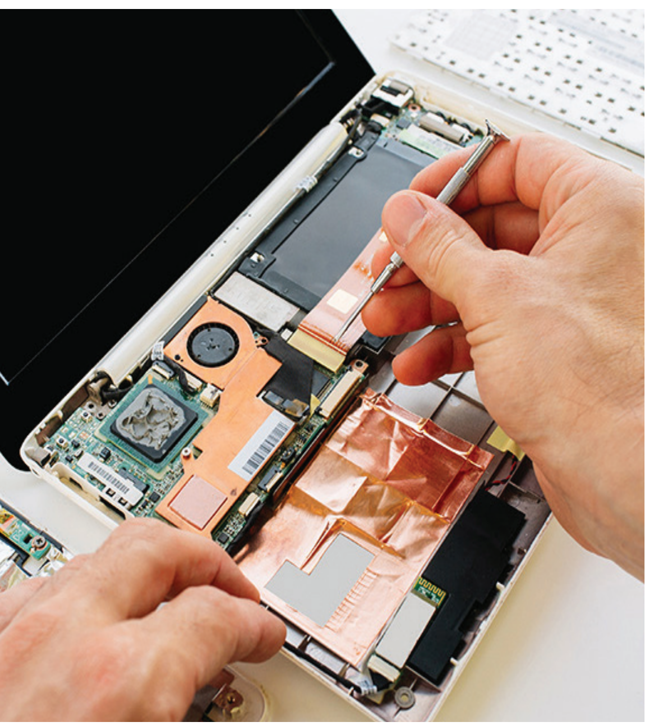


Figure 3: Retained value of select laptop computers and mobile phones in 2016.[11]

For those organizations that do focus on materials recovery rather than reuse and refurbishment, recycling electronics can be a challenging endeavor. Among the most significant challenges facing this space, as identified during the stakeholder interviews, are:

- **Record low commodity prices:** For an industry that depends on the sale of recovered materials into the commodity market, the low prices for materials make the majority of products cost-negative to handle.
- **Wide variety of product types and the rate of technological change:** This challenges the ability of recyclers to accurately forecast what they will receive today and to understand what they will be receiving in the future. The smaller, lighter products on the market today also have smaller percentages of valuable materials, such as precious metals, as well as less material overall to recover and sell into commodity markets.
- **Transportation costs:** Since the infrastructure for managing material is concentrated in the coastal states, the cost of moving recovered products or their components or materials the multiple times necessary to reach the appropriate facilities may be greater than the value of the material itself.



- **Old and obsolete equipment:** Most old equipment does not have the resale value of newer equipment (less than 2 years from market date), and suffers from the same issues of low recovery value as other products. Of particular note are cathode ray tube (CRT) displays. These displays were common up to 10 years ago and were accompanied by a robust closed-loop system to recover and reuse the leaded glass that makes up the bulk of the display. With the advent of flat panel displays, these products became obsolete over time, and the demand for used CRT glass collapsed. The cost of responsibly managing these displays, the leaded glass in particular, well outweighs their commodity value, and mismanagement of CRTs has become a significant issue in the U.S. Unfortunately, this material is expected to be in the system for at least the next five years. How the situation is resolved will have significant ramifications for the electronics industry in the long run.
- **Material composition:** Batteries, mercury lamps, and other components may be hazardous to workers if they are not handled correctly and may damage equipment if not removed before processing. In addition, new products bring new materials, such as nanoparticles and multi-layer display panels, for which there is little to no understanding of how these materials will interact with the treatment systems in place today.

- **Labor market:** Manual disassembly of equipment is necessary not only to remove hazardous components, such as batteries, prior to shredding or other treatments, but to maximize device value through repair, refurbishment, or better materials recovery. These costs have been rising in a tightening labor market, and coupled with the precipitous decline in commodity prices, labor costs have added a significant challenge to electronics recyclers.
- **Inconsistent and unstable policies:** To address the challenge of collection of low value items, half of the States have passed mandated recycling laws. The patchwork of approaches creates challenges for manufacturers under producer responsibility laws. And even though recyclers see more volume as a result of the mandates, they are faced with challenges that come with contracting with different entities in different regions (e.g., manufacturers or their designees or government agencies) who can restrict what is collected, the volumes that are collected, and amount they are willing to pay for these services, as well as choose to work with a smaller set of large, national companies.

As mentioned previously, reuse through repair and refurbishment is seen as an important part of used electronics management, and one that will become increasingly important as devices on the market today make their way into the used electronics stream. This is not, however, without its own set of challenges. In addition to fundamental questions, such as when and how device ownership transfers from consumer to refurbisher and how protection of personally identifiable information (PII) can be ensured, challenges exist with respect to access to parts, schematics, and diagnostic tools for new devices, information regarding safe and effective repair, and products that are not designed for more than one life. Manufacturers are not comfortable with releasing this information due to potential liability if someone is injured during repair or brand damage from poorly or improperly repaired products on the market. How to enable a robust refurbishment and repair community while addressing concerns regarding the quality of those activities is an ongoing conversation that will shape the role of reuse in used electronics management.

The Used Electronics Management System in the United States

Our surveys suggest that all stakeholders viewed the "system" of managing used electronics in the U.S. as broken. The reasons for this ranged from the high degree of program variability between states to inadequate funding mechanisms to offset the costs of responsible recycling to the rapid evolution of the products themselves. On top of this, there was no clear direction on what the definition of a "working" or ideal system in the U.S. would be, as is illustrated in Figure 4.

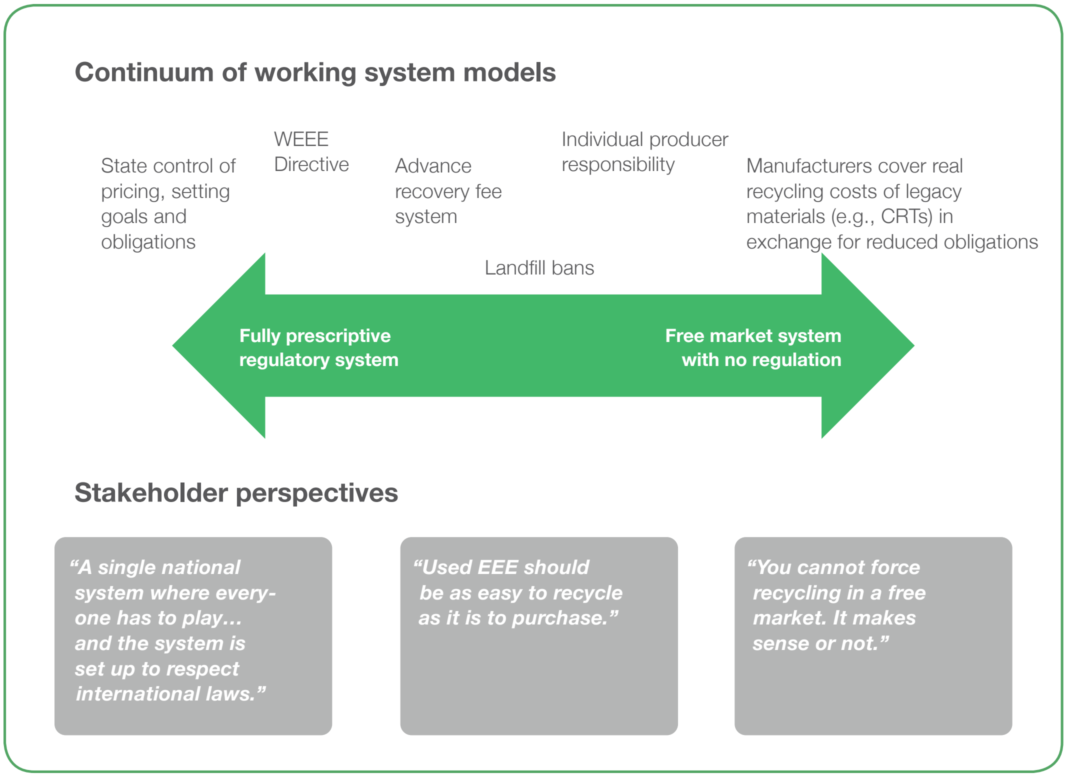


Figure 4: Overview of stakeholder opinions on a working used electronics management system

However, some consensus views on where improvement efforts should focus could be gleaned from the survey:

- From the stakeholder surveys, three major, interrelated themes emerged:
  - *Education:* Education and targeted messaging is needed for all actors involved in managing used electronics.
  - *Collection:* Increased and more systematic collection (e.g., permanent collection points rather than events) is needed to reduce the uncertainty of product volumes and product mix.
  - *Innovation:* Innovation is needed to improve the way used devices can be re-purposed, reused, or repaired to support the reuse market. The

challenge is to develop cost-effective systems that can produce purer streams of materials, which can reap higher prices in the commodity markets.

- There are other activities and initiatives that are necessary to support system improvements. Examples include developing a tool to forecast what material is going to be available when and in what volumes and creating key metrics for program success.

- Participants were slightly more optimistic about the chances that a national framework could be developed, possibly as an industry-led initiative that could better coordinate efforts at the national level and work with state agencies that have the regulatory flexibility to adjust program parameters.

Regulation also has a part to play in the effectiveness the used electronics management system. In the United States, a variety of programs have been implemented to offer consumers opportunities to offload their unwanted devices into the reuse and recycling ecosystem, but these are uncoordinated and have created a new set of challenges. For example, almost half of the U.S. States have adopted extended producer responsibility (EPR) legislation, which has led increasing volumes of e-waste collected from consumers. However, the largest percentage of this volume comprises CRT televisions and monitors, which are negative value and increase the risk of stockpiling and abandonment.

Recommendations Summary

The recommendations summarized in Figure 5 and presented below do not represent perfect solutions. Taken together, these recommendations are first steps toward building a more effective and responsible management system and providing resiliency for future changes.

Figure 5: Recommendation summary

Collection Solutions: Enable organizations to collect and handle more equipment and more types of equipment effectively. Additionally, minimize logistics costs through consolidation and more streamlined material management.

- Develop training materials based on existing work for collection sites. This may not decrease the variability of products turned in, but would help an organization get more recovery value from what they do receive.
- Support development of networks of small to medium collectors that can leverage each other to create steady volumes that would enable them to work directly with recyclers.

Innovation Solutions: Surface new technologies that address current issues related to device disassembly, automated materials sorting, and new business models for reuse.

- Refurbisher “bounty” on devices designed for reuse or end-of-life management.

- X-prize-style competition or event modeled on Recycling Innovators Forum, http://www.recyclinginnovators.com/, specifically for new technologies that address deficiencies in current processes or those on the near horizon.
- Create and support incubators to enable entrepreneurs to experiment with new business models and technologies for reuse, refurbishment, and materials recovery of future device streams and to facilitate the development of pilot projects for technology currently under development in universities.

System Support Solutions: Develop robust systems by focusing on collaborative initiatives that create better tools and processes throughout the supply chain.

- Convene the full supply chain to facilitate conversations around design and more effective cost-sharing mechanisms, and to create a forum for best practices and tool development. This would be especially effective if retailers or other entities with market influence led the effort.
- Support development of holistic metric sets that better assess effectiveness of management programs in dealing with the smaller and lighter products entering the recycling stream; forecasting tools for the industry to understand what is expected in the material stream and when that would happen; and recyclability calculators that accurately represent the economic reality of material recovery and the time and labor required for disassembly.

Conclusion

The clear consensus regarding the used EEE management system in the United States is that it is broken with few if any opportunities identified by stakeholders to improve the situation. There is no question that costs are involved in responsible materials management. The current CRT management crisis underscores this cost, and the potential for these materials to harm both human health and the environment. Unfortunately, without leadership or initiative from key parties, the path to a more sustainable solution appears far away from what is possible today. Because of increasing costs, bad actors will continue to optimize their economic gain at the expense of society and the environment, and responsible businesses will continue to leave the industry. The burden for this gain will be pushed up the value chain, where a continued need for new raw materials further degrades the environment and the health and well being of individuals interacting with EEE supply chains, and down the value chain

> *Working together, across organizations and industries, we can provide our best technology another legacy—one that continues to improve the standard of living of consumers, workers, and the environment long after reaching the end of its first useful life.*

to the communities, both domestic and international, who handle used electronics as waste. The very technology that has enabled a standard of living beyond that imagined by previous generations will be dumped, legally in landfills or illegally elsewhere, and its legacy will be one of lost opportunity, waste, and environmental degradation.

This vision of waste is avoidable. Today, many organizations are successfully navigating this continually changing space, and many examples of innovative management models exist. This point is also underscored in the current CRT display crisis—with good management practices, this material is being handled responsibly as part of profitable business. This is the story that does not make headlines. Getting the right tools, metrics, and processes to those who are committed to responsible materials management will ensure there is resiliency in the system for the next wave of devices that will arrive on loading docks. Engaging designers together with individuals responsible for product end-of-life management will help create devices that can be kept in use longer and enable efficient material recovery at the end of the device's useful life. Support is also needed for innovative, cost-effective technologies to improve material recovery processes. Working together, across organizations and industries, we can provide our best technology another legacy—one that continues to improve the standard of living of consumers, workers, and the environment long after reaching the end of its first useful life.

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    Best Buy – list price, refurbished and used
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Participating Organizations

Arizona Department of Environmental Quality (AzDEQ)
Basel Action Network (BAN)
BestBuy
Broadway Metals
Cisco
Consumer Electronics Association (CEA)
Dell
Dynamic Recycling
eGreenIT
EPRA
ER2
Electronics Recyclers International (ERI)
eStewards
Electronics Takeback Coalition
Green Electronics Council
iFixit
Independent
iNEMI
Lenovo
Minnesota Pollution Control Agency
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Panasonic
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Product Stewardship Institute
Resource Recycling
Samsung
Sustainable Electronics Recycling International (SERI)
SIMS
Sprint
State of Maine
Total Reclaim
Umicore
URT
US EPA /ENERGY STAR
US EPA Office of Resource Conservation and Recovery
Vintage Tech
Westech

About the National Center for Electronics Recycling

The National Center for Electronics Recycling (NCER) is a 501(c)(3) non-profit organization formed in 2005 that is dedicated to the development and enhancement of a national infrastructure for the recycling of used electronics in the U.S. through 1) the coordination of initiatives targeting the recycling of used electronics in the United States, 2) participation in pilot projects to advance and encourage electronics recycling, and 3) the development of programs that reduce the burden of government through private management of electronics recycling systems. At the local level, the NCER has spearheaded an electronics recycling initiative in the state of West Virginia, which has increased awareness in the state, prevented hundreds of thousands of pounds of electronics from entering state landfills, and helped spur the local recycling industry.

About The Sustainability Consortium

The Sustainability Consortium® (TSC®) is a global nonprofit organization working to transform the consumer goods industry to deliver more sustainable products. TSC creates change through the implementation of its science-based and by convening its more than 100 members, including manufacturers, retailers, NGOs, civil society and corporations that work collaboratively on innovation for a new generation of products and supply networks. The Sustainability Consortium is jointly administered by Arizona State University and the University of Arkansas, with additional operations at Wageningen UR in the Netherlands and in Tianjin China.
Learn more at www.sustainabilityconsortium.org

About Closed Loop Foundation

Closed Loop Foundation was created in 2013 to incubate and launch Closed Loop Fund, an independent and affiliated $100m social impact fund that invests in building municipal recycling infrastructure. The LP's in the Closed Loop Fund include Walmart and the Walmart Foundation, P&G, Unilever, J&J, Coke, Pepsi, and 3M.

Closed Loop Foundation researches and incubates business models that build markets and roadmaps to improve environmental outcomes. Its mission is to help communities improve the economic and environmental impact of waste management and recycling. The Foundation accomplishes these goals by (1) investing in and scaling early stage technologies; (2) providing funding to cities to improve recycling programs; and (3) acting as a center of excellence.