

Closing the Loop
Electronics Design to Enhance
Reuse/Recycling Value
Final Report

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1.0 Introduction

The end-of-life (EOL) management of electronic products has traditionally been an externality for those who design and sell the products. An environmental standard to which manufacturers pay serious attention could provide an effective incentive to improve design for EOL. And that is the intent, and strength, of the Electronic Product Environmental Assessment Tool (EPEAT)¹. To achieve that potential fully, the EPEAT Standard² must reflect the best and most effective design features that speak to the real EOL world of electronics refurbishers and recyclers.

This project, Closing the Product Design – End-of-Life Loop (“Closing the Loop”), conducted by the Green Electronics Council (GEC), in collaboration with the National Center for Electronics Recycling (NCER) and Resource Recycling, Inc., explores the following questions:

1. What are the greatest challenges and obstacles facing electronics refurbishers and recyclers that are caused by the design of consumer electronic products?
2. How could the design of these products be changed to enhance the EOL value proposition?
3. What kind of information from manufacturers, and in what form, would expedite the most efficient management of electronics at EOL?

To address questions #1 and #2 above, the research team sought out a diverse set of North American EOL managers and talked to them in depth, both in individual interviews and at larger symposium events. EOL managers across the electronics EOL industry spectrum were interviewed: recyclers, for-profit and non-profit reuse operations, asset recovery businesses, resellers of both whole units and components, shredding recyclers, smelters, plastics reclaimers, and industry specialists. We asked for input on needed changes in electronic product design elements, focusing primarily, but not exclusively, on computers (both desktop and notebook) and monitors, that could enhance the value at EOL – and received thoughtful insights and ideas. EOL managers told us a number of product design element changes that could:

- Increase EOL process efficiency, and/or
- Enhance the market value or resource conservation value of commodities within each category of activity.

Because purchasing power drives the marketplace for product design, the research team will seek to have findings incorporated into purchasing and related programs intended to promote design for end-of-life (DfEOL), including EPEAT.

EOL managers were also asked about question #3 above – opportunities for information exchange between manufacturers and EOL managers. Manufacturers are required to provide information on product design features of EPEAT-registered products that are relevant to end-of-life managers. Because a tool to make this information easily accessible for recyclers does not exist, manufacturers are meeting this requirement of EPEAT on their own, in an uncoordinated

¹ For background on EPEAT see www.epeat.net.

² The ANSI-accredited IEEE 1680-2006 Standard.



fashion. This is likely of marginal utility to EOL managers. Additionally, states (such as Washington) and provinces are beginning to include information requirements of manufacturers in their takeback laws. Given this need, this project examines frameworks for an information resource, and develops a prototype and conceptual business plan for its sustainability on a long-term basis.

2.0 Processing Activities Used in the North American Electronics EOL Industry

The electronics EOL management industry is comprised of many different activities, which include practices and technologies ranging from very simple to very high-tech. The categories of activities below were defined because they identify processing steps that can be enhanced by either product design elements or the availability of information about the product and its components. With this project's specific focus on computers and monitors, the following nine categories of activities are explored:

1. Triage
2. Data Destruction
3. Refurbishment, Reuse and Resale
4. Demanufacturing into Subassemblies and Components (including resale of these items)
5. Depollution
6. Materials Separation
7. Mechanical Processing of Similar Materials
8. Mechanical Processing of Mixed Materials
9. Refining/Smelting of metals

These categories include both activities geared towards recycling (material sales) and those geared toward redeployment, refurbishment and resale of both whole units and working parts. Note that these activities are generally consistent with the categories used in research by *E-Scrap News* and in the International Association of Electronics Recyclers' report.³

Individual EOL businesses will likely perform more than one of these activities. There is a wide range of business models within the electronics EOL management industry, utilizing an array of different combinations of these activities. Some organizations focus on a single activity such as refurbishment and resale (e.g., an asset recovery business model) or mechanical processing (shredding – e.g., a recycling business model), whereas other organizations engage in many of these activities in their business. This is germane to this research because the various business models respond better to differing design-for-EOL imperatives.

Each of these activities is described briefly in the sections below.

³ IAER Electronics Recycling Industry Report, International Association of Electronics Recyclers, 2006, Albany, NY



2.1 Triage

Triage is the inventorying, sorting and, as appropriate, the testing, of incoming material in order to route into the selected business activities. Triage may include:

- Intake and inventory
- Visual inspection for identification of specific items (based on business model)
- Sorting and/or testing for working versus non-working
- Sorting equipment/component by age, functionality, or type, and less frequently, by brand
- Sorting by disassembly strategy (e.g., into equipment type for manual deep disassembly prior to resale of components versus into equipment type for manual and/or automated disassembly prior to preparation of similar materials to flow into recycle markets)
- Sorting and/or testing for whole units for resale and/or refurbishment

Each organization or company has a different set of criteria that used in triage and sorting based on business model, customer requirements, expertise, equipment and outlets or markets. Organizations prioritize different kinds of products and components that are then selected for the appropriate type of processing.

Virtually all EOL management organizations conduct some type of triage unless they are collection-only entities, simply collecting, packaging, and transporting material to another EOL management organization for necessary triage.

Performing in-depth and accurate triage allows product to be sorted into the highest value activity and enhances both the process efficiency and value of EOL electronics.

2.2 Data Destruction

Data destruction has become an increasingly important step in the EOL management of electronics, driven by an array of privacy and security laws and policies at both the national and corporate level. Many EOL operations offer data destruction services, either via hard drive wipes or physical destruction of the hard drives. However, ITAD companies usually offer the highest level of service such as locked and monitored transport and storage areas, and/or real-time video or in-person monitoring of customers' equipment moving through secure data and/or product destruction.

Data destruction is also conducted by refurbishment organizations whose intention is primarily to make memory devices reusable, while meeting customer data destruction requirements. Both these aims can be met in one organization however.

The demand for data destruction services continues to grow in the EOL electronics management industry.

2.3 Refurbishment and Resale (whole units)

Refurbishment and resale of consumer electronics comprises a significant portion of the EOL electronics management industry. ITAD companies service large businesses and institutions,



typically with access to newer equipment to refurbish, if needed, and resell. Non-profits and other smaller scale recyclers generally refurbish equipment from residential and small business returns.

Reuse of electronic products is vital and substantially more resource efficient than recycling. A majority (estimated to be approximately 80% in Computers and the Environment by Ruediger Kuehr and Eric Williams, UN University⁴) of the life cycle energy for computers is used in the manufacturing phase. Thus, extension of the reuse cycle yields greater environmental benefits than recycling earlier in a product's life.

Based on conversations with a variety of EOL managers, the percent of e-scrap coming from businesses versus residents that has resale value varies considerably. Generally, large ITAD businesses reported that about 90% of the commercially generated equipment they received had resale value. One EOL manager noted that although 90% had resale value, they refurbished and resold less than 50% due to customer requirements that equipment be destroyed. The same manager indicated that the amount resold (less than 50%) generated 90% of its revenue.

Residential e-scrap is typically much older and more heterogeneous than commercial e-scrap and consequently has a much lower percentage of units with resale value. EOL managers indicated only about 10 to 15% of residential e-scrap has resale value.

Interestingly, research during this project revealed small, but growing, skill sets for the repair and refurbishment of smaller IT products – laptops, PDAs, and other small devices. These skill sets are being added to a variety of EOL businesses – asset managers, recyclers adding a resale outlet, and expansion of skills in reuse operations. Several years ago small products were not considered viable for repair; in late 2008, growing skills and economic realities have made sale of refurbished laptops – along with other IT products – a growing segment of the computer industry, much like the mature used-car aftermarket that accompanies the new car industry. However, the volume of these products can be captured by this niche repair and refurbishment sector is not clear.

The refurbishment process can include:

- Testing to verify working status of both entire units and components therein
- Upgrade of processor, memory or other components
- Repairs as necessary
- Cosmetic treatments

One of the critical components of resale for desktops and laptops is an operating system – a unit can be resold having no system, using an open-source operating system, or using a Microsoft system⁵.

⁴ Computers and the Environment: Understanding and Managing their Impacts, Ruediger Kuehr and Eric Williams (Eds.), Lkuwer Academic Publishers, United Nations University, 2003.

⁵ Microsoft has two Microsoft Authorized Refurbisher (MAR) programs to provide Microsoft operating system software to refurbishers:

1. The Community MAR program, a partnership between Microsoft and [TechSoup](#), provides software to non-profit refurbishers. This program was created to increase the number of usable PCs available to nonprofits,



2.4 Demanufacturing into Subassemblies and Components

Many EOL management organizations recover value from working and/or non-working components/sub-assemblies.

In order to separate products into subassemblies and components, a manual disassembly process must be used. Usually this is a workbench-style operation, with pneumatic or sometimes simple hand tools to expedite the unscrewing, etc. that is central to this activity. The worker will sort into various subassemblies (e.g. a CPU) or components (e.g. motherboards, graphic cards, hard drives, PCBs by grade, etc.). This separation is by subassembly/component function, rather than material type, as in Section 2.6. Typically there will be bins or gaylords for circuit boards, hard drives, video cards, etc., as well as for other items that are not components such as the plastic or metal housings, cabling/wiring, etc.

At facilities where component reuse is part of the business model, working status of components can only be determined after disassembly. Special equipment is needed for testing of printed circuit boards, and consequently, there is little testing of circuit boards. They are typically separated and sometimes baled and sold for metals value.

2.5 Depollution

“Depollution” is a term used in Europe to mean the removal and the separate and appropriate handling of substances of concern that have been identified in the WEEE directive. This can be difficult to contain or control in certain EOL processes, such as whole-unit shredding. If depollution is not done, or done improperly, human health and the environment can be adversely impacted. Some examples include:

- Button cell batteries are removed from circuit boards prior to shredding, and are sent to a specialized battery processor
- Mercury-containing fluorescent lamps are separated from display devices and sent to a specialized processor
- CRTs containing phosphors are sent to specialized CRT processors after removal of the housing, copper yoke, and low-grade circuit boards.
- Removal of plastics embedded with brominated flame retardants (BFR) from the plastic recycle stream (common in Europe but not in North America)

All organizations that are involved in deep disassembly and/or mechanical processing should engage in depollution.

This necessary activity takes additional time in the recycling process, thereby reducing the efficiency of processing.

It is unclear how widespread the practice of depollution is in the EOL management industry in

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2. schools, and low-income families across the globe by reducing the cost of software to refurbishers.
 2. A commercial MAR program tailored to the needs of large refurbishers (who supply at least 5,000 refurbished PCs per month, on average) who want to deliver preinstalled Windows software licenses on refurbished PCs to be sold in the commercial market.



the U.S.; though virtually all the EOL managers we interviewed indicated that they were aware of the importance of depollution. In Europe it is driven by requirements of the WEEE Directive. In future years, with the development of recycler certification programs, depollution (and attendant worker protection) should become a universal best practice within the industry.

2.6 Materials Separation

A majority of EOL management organizations conduct some level of disassembly to separate materials and recover value from those material streams. These organizations may include manual disassembly operations, secondary recyclers, non-profits, some ITAD operations, etc. Generally, manual material separation generates a higher-grade commodity (cleaner fractions) than mechanical systems.

Materials separation involves manually separating and preparing materials for further processing. Disassembled equipment is sorted into material categories such as:

- Plastic housings/stands
- Ferrous/non-ferrous metal cases, strips
- Printed circuit boards of several grades
- CRTs
- Copper-rich components and subassemblies
- Other precious metal categories
- Cabling and wiring
- Batteries
- LCD panels/mercury lamps, or other mercury-containing devices
- Small peripherals (keyboards, mice)
- Sound/video cards
- Wood (from old console televisions)
- Miscellaneous packaging including Styrofoam, cardboard, etc.

One processor that was interviewed indicated that they manually separate into 55 discrete material streams; however, most processors manually separate into far fewer material streams.

2.7 Mechanical Processing of Similar Materials

This activity involves mechanical processing together of similar materials (such as compatible plastic resins, metals or CRT glass) by laser or wire cutting, shredding, grinding, pelletizing, and/or refining to generate market-grade commodities. Some examples include:

- A recycler has a relatively small metal shearer – all hard drives are shredded in it before being shipped to a metals recycler paying for the steel on a price-per-pound basis
- A recycler sorts the plastic housing from televisions, monitors, CPUs, and laptops into white versus black streams, and crushes and bales them before sending to a plastics recycler
- A plastics recycler uses optical sorting to separate grades of plastics into fairly pure grades of specific plastics, which are then put through a re-melt process that produces pellets of specific-grade plastics for the feedstock market
- A recycler bales all the cardboard and paper grades it receives (packaging for incoming e-



scrap), and sells to a paper recycler

- A recycler's automated CRT shredder (after the housing and copper yoke is removed) uses hot-wire, laser, or mechanical processing to separate face from funnel glass (these have different lead contents); it then crushes each stream to be sold into different markets
- A recycler shreds printed circuit boards for size reduction before shipment to a refiner
- A refiner receives loads of printed circuit boards and assays a small core sample of the PCBs; it then pays the e-cycler who shipped to the refiner. It then refines in a small furnace to remove some impurities, and sends materials to a larger smelter for final chemical reduction and metals separation.
- A smelter receives shipments of printed circuit boards and shreds them, conducts spot assays to determine potential value and pays the customer who shipped the load based on assay; the smelter then uses chemical reduction processes (electrolytic reduction involving use of flux such as limestone, for example) to extract the metals from the printed circuit boards, and sells the metals in the global metals markets

2.8 Mechanical Processing of Mixed Materials

Typically, mechanical processing of mixed materials, such as whole units (after depollution), is conducted by larger EOL management companies that have made significant capital investments in large-scale equipment.

This activity involves mechanical processing of mixed materials for recycling – usually by shredding followed by a series of separation technologies. For some mixed materials, a complex series of steps are needed to separate material into commodity-grade streams.

It is critical that adequate and compliant depollution occurs prior to this processing activity; however, it is not always done.

Mechanical processing, without any disassembly, is often driven by customer demand. Institutional/commercial/industrial (ICI) customers of processors frequently require product destruction for security or proprietary reasons. This can include product from electronics manufacturers.

These mechanical processing systems, if they handle large quantities, can be cost effective. Even though they forego revenue opportunities from recovered systems and components, they also avoid substantial labor costs involved with manual disassembly. They also may generate lower-value materials from a resource recovery perspective. They can effectively handle large quantities of old or lower-valued products or products that are not designed well for disassembly.

2.9 Refining/Smelting of Metals

After materials have been sorted into components (e.g., high-grade and low-grade circuit boards from demanufacturing) or into shredded streams (e.g., mostly copper, ferrous, or non-ferrous streams from mechanical processing), if being managed responsibly, they are sent to smelters or refiners. These final destination operations use sophisticated thermal and chemical management processes to extract metals of many types, which are then resold into the global metals markets.



Front-end processing to remove materials of concern is typically done. For example, at Boliden's smelter in Sweden, a separate metals management company, Kuusakoski, removes all batteries and certain other items from circuit boards before they are fed to Boliden's smelter. This results in a higher quality product and safe capture of hazardous substances.

3.0 Design for End-of-Life

There are two aspects of design for EOL: first the actual design elements, and secondly communication of those elements to the EOL industry. This section provides a summary of our findings on the challenges and recommendations on design elements themselves, based on what we heard is needed from EOL managers. A following section, Section 5.0, discusses how information about those design elements could be communicated to EOL management organizations.

As described in Section 1.0, the research for this project included interviewing EOL managers engaged in a range of different EOL activities both through individual interviews and at larger symposium events. The interviews sought to obtain insight and input on needed changes in electronic product design elements that could enhance the value at end-of-life.

The following sections (3.1 through 3.10) summarize the key design for EOL challenges and recommendations within each of the nine EOL activities addressed in this project. Please note that these findings are based on input from interviewees. It is recognized that some of the recommended product design changes may be extremely challenging, if not impossible, to achieve in the near term. The purpose of researching product design element changes from the EOL management industry perspective is to begin the dialogue with electronic product designers and close the communication loop.

3.1 DfEOL for Triage

We received much input in the area of inventorying and sorting of EOL electronics, particularly from reuse and asset recovery organizations, on both the information that would enhance process efficiency and methodologies for communicating the information.

Triage is a critical element in the EOL process. Products are often divided into different groups for different processing strategies.

For most operations, it is critical that this activity occur as quickly and accurately as possible. Challenges to streamlining this operation include getting adequate data, correctly identifying every aspect of incoming equipment – from make and model to component types - and accurately determining level of functionality.

Product Design Recommendations

Inventorying and Sorting

- EOL managers need products to be designed to improve access to key information for enhancing inventorying and sorting activities, such as:
 - Serial number
 - Manufacturer
 - Type of equipment (e.g., inkjet or laser printer; if it is a multi-function device



- (MFD) – information on what type)
 - Model
 - Date of manufacture
 - Component inventory (age, type, RoHS compliant, etc.)
 - Accurately identifying the customer’s required security level with regard to data destruction and equipment disposition
 - Type and location of hazardous materials (such as mercury lamps)
 - Type and location of new materials
 - Other information suggestions included:
 - Distribution and sales history of unit
 - Data that would assist states with return share allocation for producer responsibility takeback programs
- The suggested methodologies for communicating the above information, that should be incorporated in the product design include:
 - Markings and/or labeling on product, for example:
 - Identify products, their performance features and all internal components clearly on the outside of the unit, or
 - Print a uniform schematic format on the inside of product cases showing internal components and product information
 - See Section 3.4 for suggestions for items containing hazardous substances
 - Bar code identification to get component performance specifications
 - Consistency in serial numbers – so that the string of numbers and letters can provide information about the product to an EOL manager
 - RFID technology, particularly down to the component level to dramatically improve efficiency of the inventory process
 - Manufacturers providing “Bills of Materials” (BOM) which would identify key parts, sub-assemblies, and components, as well as those containing hazardous substances. These could be made available online, much as the automotive industry provides for automotive repair and body shops. As well, these BOMs should also identify any industrial hygiene or special treatment information related to how the items should be handled to protect worker health and safety.

For any of these communication methods, several interviewees emphasized the importance of creating a uniform and internationally readable format and information set.

More discussion on communication is provided in Section 5.0.

Testing for Working/Non-Working Units and/or Components

The following was also suggested:

- Mechanism for ease of testing for components (work/don't work)
- Development of an “indicator” on components showing amount of useful life remaining, like battery “charge indicators”
- Manufacturers provide test procedures for functionality online, for access by EOL managers



3.2 DfEOL for Data Destruction

Interviewees indicated that data destruction is gaining importance in the industry. Currently, different tools are required to wipe different types of memory devices. Some interviewees expressed a desire for developing industry harmonization, but it was also noted that the industry may be headed towards a change anyway with solid state drives and encryption of data. There are industry associations (including those for IT professionals, and the National Association for Information Destruction) addressing this, as well as the National Institute for Standards and Testing (NIST). As well, some OEMs are producing computers with Secure Erase features on the hard drives (allowing HDs to meet DOD security clearance levels) – EOL managers need to be able to identify and work to capture the maximum value from computers equipped with these features

Product Design Recommendations

- Information for consumers on how to erase and save data, including in operating manual or even links to such data directly on the product
- Hardware design that lends itself to thorough data destruction and reporting; etc. For example, personal computers with a Secure Erase feature (see above) may or may not be identifiable – use of pre-loaded features for data destruction can save EOL managers time using purchased data destruction products. Or, data storage device uniformity can lend itself to faster data destruction and thus faster re-deployment of storage media – thus enhancing the positive environmental impact by lengthening product life.
- A standard way to clear memory for smaller products, especially the handheld category. Clearing memory is different for each maker's products. Need standard way to plug in and reprogram.
- Need industry standards for drive formatting to ease data eraser (wiping hard drive).

3.3 DfEOL for Refurbishment and Resale

Critical for reuse and asset recovery organizations' efficiency is the quick and accurate (a) identification of product information (see Section 3.1); (b) differentiation between working and non-working units and components; and (c) efficient and safe disassembly (see Section 3.5).

Product Design Recommendations

Ease of Disassembly/Assembly

- Snap in/snap out components
- Use of consistent, limited and uniform set of screws and fasteners.
 - One recycler suggested that manufacturers use many different and uncommon screws to protect against customers disassembling products and voiding the warranties. This recycler suggested that manufacturers could put a simple seal in place saying "warranty void if seal is broken".
- Consistent placement of commonly used assembly features – e.g., how video displays are attached to stands; if it was always the same screw or attachment feature, damaged parts



could be quickly replaced

Longevity and Reparability

- Design for longer life span of components, including greater durability of components
- Eliminate or reduce painted plastics and proliferation of colors which precipitates cosmetic damages and unique models making it more challenging to refurbish
- Standardized test procedures for functionality of whole units and for components
- Manufacturers provide repair manuals within two years after first selling a product, in order to promote reuse and refurbishment of the products
- More easily transferable licenses for operating system licenses – e.g., some type of transferable certificate of authenticity that would survive a hard drive wipe of data, but leave core operating system software intact

Power Supplies

- Standardize power supplies, particularly for portable equipment. There is tremendous variation in voltage, amps, and plugs. Several interviewees noted that power supplies should be as universal as USB plugs. Uniformity of cords would enable much, much more reuse (cords and units often get separated in the multi-stop journey from use to an EOL facility).

Using RFID to Assess Reuse and Refurbishment Value

A particularly interesting concept that was brought up by a few EOL managers, and is being explored in academic circles, is the idea of a Radio-Frequency Identification (RFID) “blackbox” for each computer – essentially a chip that records operational data and can transmit it via RFID – which would periodically record the functionality of different subsystems. Essentially, the RFID would track data that could be used to estimate whether subsystems work or not, the remaining useful life of each component, whether a hard drive has been wiped correctly, or other pertinent information.

An RFID scan could extract the lifetime consumption data and provide an indicator of reuse and refurbishment potential. This information would be accessed off a unit by RFID and would simultaneously reference a central database, which could possibly also include real-time data on component resale prices or other information. When the data is combined with a component inventory of the unit, a highly valuable projection of the quality and value of the system for reuse and refurbishment could be rapidly secured upon the product’s entry to a processing facility.

Research in this arena is being conducted at the University of Limerick⁶, Arizona State University⁷ as well as in another EPA-funded project⁸ which includes assessing the use of RFID tags in electronic products and the environmental benefits at EOL.

⁶ “RFID Signaling to Stimulate Reuse of Personal Computers” by Eanna Cronin, Steward Hickey, and Colin Fitzpatrick, ISEE 2008

⁷ Eric Williams, Department of Civil and Environmental Engineering & School of Sustainability, Arizona State University

⁸ The PURE Project; managed by Elliot Maxwell emaxwell@emaxwell.net



3.4 DfEOL for Depollution

The primary challenges associated with depollution are 1) identification of the location of components containing hazardous materials, and 2) removal of components containing hazardous materials. Depollution is an essential activity for products that will be mechanically processed, if they contain hazardous substances, and involves shallow disassembly that is generally done before products are shredded. It may be a more natural and integrated part of a deep disassembly process.

Interviewees indicated that better identification mechanisms are needed for mercury lamps, batteries and toner cartridges – both on the specific component containing a hazardous material and on the exterior of a whole product. Manual removal of these items is necessary in large-scale shredding operations and it slows down processing considerably.

Many EOL managers expressed frustration at the difficulty of removing mercury lamps intact. One interviewee described a situation where the lamp in a laptop screen was “literally embedded into the screen with glues” and was “absolutely impossible to remove without breaking.” Another EOL manager of a large reputable company said that they had stockpiled laptop screens for a year because they were such a challenge to handle responsibly.

Interviewees indicated that large batteries were generally easy to locate and remove. However, small batteries, such as those affixed to circuit boards can be a challenge to identify and in some cases, are soldered onto the boards or embedded in clocks making them very difficult to remove.

Toner cartridges were recognized as universally easy to remove; however there was a concern that sometimes large imaging devices can have multiple toner cartridges and it can be hard to know whether all of the cartridges had been located and removed.

One interviewee discussed EOL worker health and safety issues associated with beryllium. This interviewee described how beryllium, when melted or shredded at EOL, can release a fine particulate into the air which can cause a disease called berylliosis, a chronic allergic-type lung response and chronic lung disease caused by exposure to beryllium and its compounds.

Interviewees did not provide much input on management of liquid crystals in flat panel devices. One interviewee said that liquid crystals are adhered to the metal, can therefore just be shredded. Given that more and more flat panel devices will be entering the recycling stream in the years to come, more research should be conducted on DfEOL product design elements of flat panels.

This section deserves mention of the importance of upstream design that eliminates hazardous substances from electronic devices altogether. Under the influence of RoHS and REACH, this is an important and growing trend in the consumer electronics and IT industries; however, there needs to be continual improvement in this area – especially in finding safe alternatives to items such as intentionally-added mercury in light sources, brominated flame retardants in plastics, etc.

Product Design Recommendations

Identification of Components Containing Hazardous Materials

- External marking indicating the presence and location of components containing hazardous materials (mercury lamps, batteries, toner, brominated flame retardants,



perhaps beryllium, etc.)

- Identification of components containing hazardous substances, through use of technology such as RFID tags or other tags.

For example, an RFID, or other tags, could be affixed to a component requiring special handling, such as a battery. A mechanical processing system would be equipped with an RFID reader or other sensor that would sound an alert when a battery, or other components containing substances of concern, is detected. This would protect against crushing mercury lamps, explosions from crushing batteries, etc. It was noted it could be the equivalent of a radioactive detector used in scrap yards.

- Color coding all components containing hazardous materials, in particular small batteries. It was noted that many small batteries are hard to identify, and can easily inadvertently end up going through a shredder.
- Components containing hazardous materials located within “line-of-sight” spotting when external housing is removed.

Ease of Removal of Hazardous Substances/Components

- Design these components to be extremely easy to pull out, using cartridge-style housing that snaps, pulls or slides in and out readily.
 - For example, a mercury-containing lamp could be removed as easily as a battery from a laptop to protect from release of the hazardous material in handling. Interviewees indicated that it is currently an enormous challenge to get mercury lamps out intact – they are tiny and often deeply embedded.
 - Another example is batteries on circuit boards and embedded in clocks; it was suggested that these be affixed in a manner that allows for easy snap-off or pull-off.
- Use of consistent, limited and uniform methods of affixing components containing hazardous substances. This would greatly ease removal of these components.
- Manufacturer BOMs should be provided that identify new and hazardous substances, and any related industrial hygiene or special treatment information related to how items containing hazardous substances should be handled to protect worker health and safety during the entire recycling/reclamation process. An example is liquid crystal displays, where knowledge of handling requirements, exposure risks, and impact of various treatment methods is unknown by the EOL industry.

Elimination of Substances of Concern

- Elimination of intentionally added mercury used in light sources (this is already an optional EPEAT criterion, but is noted here because of the number of times this was mentioned by interviewees)
- Batteries free of lead, cadmium, mercury, and lithium
- Elimination of intentionally added cadmium in wires and cables



- Elimination of beryllium (often alloyed with copper) in connectors
- Elimination of brominated flame retardants, halogens, and polyvinyl chloride in plastics, due to concerns regarding dioxin formation if reclaimed plastics are subject to high-temperature treatments (see Section 3.9 for additional discussion)

3.5 DfEOL for Demanufacturing into Subassemblies and Components

The greatest challenge in demanufacturing or disassembly was universally identified as the number, diversity and variable locations of screws and fasteners. There was a strong desire amongst interviewees to enhance ease of disassembly and develop consistency in connection mechanisms.

Product Design Recommendations

- Use a consistent, limited and uniform set of screws and fasteners. One recycler suggested that manufacturer's use many different and uncommon screws to protect against customers disassembling products and voiding the warranties. This recycler suggested that manufacturers could put a simple seal in place saying "warranty void if seal is broken".
- Do not use hidden screws; if hidden screws must be used, have arrows showing location
- Screws should not be injection molded
- Use press-fit, not screw-fit connection mechanisms
- Snap, pull, slide-in/slide-out, or cartridge-style housing for components for ready removal
- The cartridge or slide-in/slide-out housing should protect items containing hazardous materials and the cartridge itself should be easy to disassemble (e.g., LCD mercury bulbs are fragile and the cartridge must keep them rigid so that they don't get broken on removal from a device)
- Manufacturer guide to quickest and safest disassembly

3.6 DfEOL for Materials Separation

Interviewees indicated that plastics are their greatest challenge with regard to materials separation: the proliferation of so many different plastic resins, flame retardant plastics, laminated plastics, plastics with paints or coatings, and lack of consistency in labeling plastics. A couple EOL managers expressed skepticism about the reliability of plastic markings, noting it is costly to change plastic molds.

Many EOL managers noted that an inability to effectively separate plastic resins prior to processing greatly decreases the value of the material. However, some plastics processors indicated that it is not a problem to process mixed plastic resins. One interviewee indicated that even facilities designed to separate plastics generate high percentages of waste. Another noted that the plastics regrinders have to remove trace contaminants from plastics such as stickers and labels (pervasive on certain electronic product categories). Currently the regrinders have to peel or "buff" them off.



The value of plastic resins and the downstream markets was also brought up as a concern. Some plastic resins have little secondary value, such as HIPS which, according to one interviewee, is only down-cycled currently. It should be noted, however, that plastic markets can evolve over time.

Molded-together, dissimilar materials, or bonded in some manner, was also mentioned as a barrier to materials separation.

Product Design Recommendations

- Develop a consistent and limited set of resins to be used, or at least a limited number of different resins per product category
- Consistent labeling of plastic resins (note that this is already an EPEAT criterion)
- Labeling to indicate the presence and type of flame retardant in the resin
- Eliminate laminated, bonded, glued, and/or molded-together dissimilar materials, including stickers and labels
- Inform the EOL industry when new materials or metals are being designed into products to enable better recovery of those materials
- Circuit boards, and/or other precious metal-containing components, should be easily removable using manual separation methods both from the product as a whole and from specific components (such as drives) that contain such boards to enhance recovery of high value material.
- Larger ferrous and aluminum parts should be easily separable from the precious metal-containing components.

3.7 DfEOL for Mechanical Processing of Similar Materials

Research findings for mechanical processing of similar materials centered on plastics. Specifically noted were the separation of plastic resins prior to processing greatly increasing the value of the material and elimination of laminated and affixed together materials. Some plastics processors indicated that it is not a problem to process mixed plastic resins. However, many of the EOL managers who are not solely processing plastics expressed that mixed plastics were of much lower value than separated plastics.

Separation of plastic resin types is discussed above in Section 3.6. Other product design recommendations for mechanical processing of similar materials are below.

Product Design Recommendations

- Ease of separation of affixed foams, glues, and metals
- Eliminate lamination of dissimilar materials, even two slightly different resins
- Reduce of number of resin types used



3.8 DfEOL Mechanical Processing of Mixed Materials

The mechanical processing of mixed materials, generally the shredding of whole units, involves some of the same challenges described above for other EOL activities. Most critical for this activity is depollution, described in Section 3.4.

The cleaner the material streams, the higher the value of the material. Barriers to separation into clean material streams include design elements such as materials laminated together that are incompatible for recycling. Interviewees also expressed a desire for ease of access and removal of high value materials cables and wires containing copper.

Product Design Recommendations

- All depollution recommendations in Section 3.4
- Minimize the variety of materials in any given product
- Ensure that items containing precious metals such as cables and wires containing copper can be removed easily (i.e. snap out)
- Eliminate lamination of dissimilar materials, even two slightly different resins, to maximize valuable materials recovery

3.9 Refining/Smelting of Metals

Refining and smelting of metals is an old and mature industry, often referenced as both a bedrock and bellwether of the global economy. Its role as an economic driver of the EOL industry should not be underestimated – therefore design to enhance value recovery from metals at the refining and smelting level should not be overlooked.

One large smelter contacted for this research noted that when OEMs add new metals, the EOL extractors of metals (i.e., refiners and smelters) need to be apprised of this. For example, ruthenium (Ru) is used in hard disks, but there are few Ru-recovery operations in the world. Once refiners and smelters are aware of the use of new metals, they can design assaying and extraction processes to recover valuable metals, such as Ru and improve recovery rates (thus keeping metals prices down).

This smelter called for easier removal of circuit boards: it reported that it now may take in two tons of "circuit board shred mix" (from a shredder of mixed materials; this mix includes plastics and metals from other items beyond circuit boards) to extract 200 grams of gold (Au). If the circuit boards were more easily and quickly separated from other materials then one ton of circuit boards alone would be enough to extract the same quantity of gold, using much less energy. etc.

Further, this smelter noted that smaller products, such as hand held devices, can contain "the whole periodic table of elements" – in tiny, closely interconnected bits and pieces. The valuable materials can be trapped between fiber layers, contained in tiny metallic pieces (e.g. pins or coated on copper in contacts), embedded in a ceramic matrix or plastic found in chips, and/or embedded in layers of the circuit board itself. Pyrometallurgical processes (smelting) can more



effectively extract precious metals or other valuable materials from such complex, interconnected materials.

Product Design Recommendations

- Manufacturers provide notification to recyclers – but especially to market players such as refiners and smelters who recover precious metals – of addition of new metals and materials to enhance metals recovery
- Ease of disassembly (see Sections 3.3 and 3.5)

3.10 Other Findings

As discussed above in Section 3.4, interviewees did not provide much input on management of liquid crystals in flat panel devices. However, given that more and more flat panel devices will be entering the EOL stream in the years to come, research should be conducted on DfEOL product design elements of flat panel devices.

Another important DfEOL concept, encountered during this project, is the issue of "closed loop" recycling – addressing whether the materials selected in manufacturing can be recycled back into new products in the same product category. Because end-of-life managers are not driving materials selection at the manufacturing level (as OEMs are), our interviewees did not have informed opinions about how to ensure that materials used in making electronics can be re-used again. They just think it is a good idea. For example, glass from LCD TVs and LCD monitors is not commercially viable to recycle at this time. If OEMs could design this glass to be reused or recycled back into the same material type, it would reduce the overall environmental footprint of display devices, thus providing an environmental benefit.

4.0 Suggested End-of-Life Management Concept – Two DfEOL Scenarios

It became clear to the research team as we discussed processing approaches with EOL managers that different electronic products, based on their inherent design, have greatly different potentials at EOL. This is especially notable given the evolution of increasingly smaller and lighter weight products, and products that are designed for particular functions or markets such that they are increasingly difficult to disassemble at EOL.

The intent of the two-scenario approach is to define design standards relative to the products management at EOL for different types of products. These design standards are intended to maximize the environmental benefits relative to resource use and conservation and environmentally safe EOL management. The key distinguishing design issue is whether the products can be readily and effectively disassembled through non-destructive processing at EOL. If so, systems and components can be recovered and reused, and pure streams of recyclable materials can be readily generated. The other scenario suggests design strategies for extended product life, dematerialization and smart material selection.

The Challenges

Some of the trends in product design and resulting challenges that we heard about that are facing the EOL management sector, and in particular in the reuse and asset recovery arena, include:



- Product distinctiveness and uniqueness is increasing as OEMs seek to distinguish their products in a market flooded with high technology. This results in:
 - Diminished adaptability of spare parts for repair or refurbishment
 - Increasing expense in sourcing spare parts for repair and/or refurbishment
 - A period of a steep learning curve while refurbishers learn how to repair product variants
- The race for faster and smaller processing power shows no sign of letting up. Moore's Law states that processing power of high technology products doubles every two years. This exponential growth in computing capability has held true for more than half a century and is expected to do so for some time to come. The result is not only smaller and smaller products, but also rapid obsolescence and short-lived generations of equipment.
- Increasingly unique external case designs, resulting in:
 - Increased difficulty in stacking and transporting equipment, particularly LCD monitors and televisions
 - Housings that damage easily cosmetically in transport and are increasingly difficult to cosmetically repair (e.g., materials that do not allow for painting, a great variety of colors, etc.)
 - Increased product returns for cosmetic reasons; returned but functional products are often directed by retailers into recycle streams
 - Difficulty in opening external cases without irreparably damaging internal components
- Incoming EOL equipment increasingly is arriving at recyclers' docks without data storage devices (due to data security concerns), while it is getting more difficult to source affordable compatible replacement drives.
- Incompatible power supplies across product and category types further hinders ease of reuse
- The trend toward more notebooks and fewer desktops exacerbates these problems since notebooks, especially as they are minimized in size, are more challenging to dismantle than the more generic desktop or tower computers.⁹

Most electronic product environmental standards that address design for EOL assume that the top environmental objective is deep disassembly for refurbishment and recycling. However, based on these technology trends, and the increasing efficiency and pervasiveness of automated

⁹ Note that there may be an environmental benefit through dematerialization in the trend towards smaller products, unless the smaller weight of materials used is offset by the use of more resource-intensive materials. An environmental life cycle assessment would be needed to assess those benefits.



recycling systems¹⁰ as well as new pyrometallurgical extraction processes tailored for EOL electronics, it may be that in the future only a portion of the electronics waste stream will be compatible with deep disassembly for refurbishment and recycling. If this turns out to be the case, the question, then, is what types of design standards can promote environmental improvement for products that are not suitable for deep disassembly?

Design Solution

We propose a potential concept of two scenarios, both of which can optimize product design and integrate EOL management methods. This two-scenario approach recognizes the realities of the marketplace and technology evolution and the need to maximize both reuse/refurbishment and the recovery of valuable resources at EOL through management systems that are tailored to the product design.

The *two scenarios* are:

	<u>Scenario #1</u>	<u>Scenario #2</u>
<u>Environmental Design Paradigm</u>	<i>Products designed for disassembly</i> including refurbishment, component and system reuse and recovery, removal of hazardous materials, and separation of materials into relatively pure streams for commodity recycle markets. Some mechanical processing may recover materials following disassembly. For example, a desktop or notebook computer with features that promote upgrading, disassembly and component recovery fits in this scenario.	<i>Products designed for whole unit processing for materials recovery</i> – these products are built with highly recoverable materials and the absence or easy removal of hazardous materials. This scenario may include some targeted shallow disassembly for necessary depollution. Ideally these products would be designed for longer life. For example, a compact fashionable notebook may present inherently difficult access to internal components and therefore is a better candidate for automated or pyrometallurgical processing.
<u>Product Characteristics</u>	Products without inherent and substantial constraints on design for disassembly.	Products designed for uses or markets that possess substantial constraints on size, weight or other design factors that present significant challenges for disassembly at EOL.

¹⁰ This trend toward automated, mass-processing systems, based on product shredding, is evidenced in Europe under various countries' producer responsibility systems. These producer-subsidized systems increase the flow of products substantially, and they increasingly draw products from the consumers. They appear to change the economics of EOL management in such a way that the efficiencies of mass, automated processing is favored.



	<u>Scenario #1</u>	<u>Scenario #2</u>
<u>Environmental Design Objectives</u>	Optimize the recovery and reuse of the system, its components or pure material streams through non-destructive disassembly.	Optimize long life, dematerialization and effective recovery of materials at EOL through smart design and material selection.
<u>EOL Handling</u>	<i>EOL management with a focus on demanufacturing</i> and an end goal of maximum reuse and asset recovery	<i>Recycling with a focus on whole unit materials recovery</i> and an end goal of depollution and efficient material recovery
<u>Design for EOL Objectives</u>	<ul style="list-style-type: none"> • Maximize hardware service life across software generations, perhaps with cascading functionality to enhance reuse • Increase demanufacturing process efficiency • Enhance the market value of the resulting material streams • Eliminate/minimize worker health and environmental impacts at EOL 	<ul style="list-style-type: none"> • Maximize product longevity (including design features which enhance whole product reuse) • Enhance dematerialization (minimize material usage) • Increase the generation of high-value material streams and materials recycling • Provide readily identifiable and removable hazardous components • Eliminate/minimize worker health and environmental impacts at EOL



	<u>Scenario #1</u>	<u>Scenario #2</u>
<u>Key Design Features</u>	<ul style="list-style-type: none"> • Ease of identifying and removing components containing hazardous materials • Use of consistent, limited and uniform set of screws and fasteners; elimination of hidden screws; increased use of press/snap fit connection mechanisms • Snap, pull or slide in and out components • Ease of plastics identification and separation • Increased standardization of components, such as power supplies, particularly for portable equipment • Easy access to product and component information to assess the resale value and refurbishment potential 	<ul style="list-style-type: none"> • Ease of identifying and removing components containing hazardous materials • Elimination of adhered-together (laminated, bonded, glued, etc.) materials that are not recyclable or compatible in recycling • Minimize the variety of materials in any given product, especially those that cannot be easily separated through mechanical systems such as different plastic resins • Ensure that items containing precious metals such as cables and wires containing copper can be removed easily (i.e., snap out) • Use of durable materials and robust power supplies/batteries that further product longevity • Offer warranties and training services for repair and refurbishment of products

As the electronics recycling industry matures, and more U.S. states and Canadian provinces adopt producer responsibility laws, there is likely to be increased use of mechanical processing. There are differing opinions on the merits and drawbacks of shredding versus demanufacturing as a primary processing approach from an environmental perspective. These opinions have been expressed in technical papers that take different stances, and are one of the major points of contention as the European WEEE system is under review. The question has also been posed to EPEAT as to whether products should be designed for disassembly or efficient shredding. This research is not to address the question of the merits and drawbacks of shredding versus demanufacturing, but to assess how best to design products for EOL, given that both processes are used, and mechanical processing may increase in the future.

One critical question is that of reuse – is there is a place for design elements geared towards whole product reuse in the mechanical processing scenario? Reuse is much more environmentally beneficial than recycling, and for EOL scenarios to be fully environmentally responsible – whether driven by EPEAT ratings, manufacturer take-back programs, purchasing



specifications, state and provincial policies, or marketplace realities such as precious metals prices – they must include reuse. We suggest that for the Scenario #2 concept to maximize environmental benefit, it must include design elements for longevity and some shallow disassembly for whole-unit reuse.

5.0 Information Communication

The second important aspect of design for EOL is communication; communication of design elements from OEMs to EOL managers, as well as feedback from EOL managers to OEMs. As one EOL manager said, “what good is a magic button to release all connectors (screws, snap fits, etc.) if you don’t know that it exists on the unit and/or where it is located?”

This section provides:

- A summary of our interview findings on communication methods
- A description of a web-based information resource prototype for communicating design elements critical for EOL management
- A conceptual business plan for its continuation on a long-term basis

5.1 Interview Findings

Interviews with EOL managers included exploring communication needs and preferred methods. Interviewees were asked what information from manufacturers would enhance EOL process efficiency and/or material/commodity values, and how should that information be communicated to EOL managers. The findings of the interviewees were used to inform the development of the web-based information resource prototype described in Section 5.2.

Three primary categories of information were identified:

- 1) Product information for inventory and sorting purposes (see Section 3.1)
- 2) Identification, location and removal instructions of components containing hazardous substances (see Section 3.4)
- 3) Identification of plastic resins for separation for processing (see Sections 3.6 and 3.7)

The two communication methodologies that were highlighted as preferable by interviewees included:

- 1) Exterior labeling or marking on product
- 2) A web-based tool that could eventually be accessed in a semi-automatic fashion using technology such as RFID tags or bar codes

Many EOL managers were enthusiastic about RFID tags. It was pointed out that eventually an RFID tag could be affixed to every major component. This would enormously enhance inventory efficiency and identification of components containing hazardous substances. One interviewee indicated that from a shredding perspective, it was not a problem to have an RFID tag attached to the material at EOL. Another EPA project¹¹ is currently assessing the use of

¹¹ The PURE Project; managed by Elliot Maxwell emaxwell@emaxwell.net



RFID tags in electronic products and the environmental benefits at EOL.

Recent announcements in the electronics industry indicate that the ability to print RFID tags (as printed integrated circuits, as opposed to conventional silicon integrated circuits) is nearly market-ready – and can print at sizes ranging from 10 to 150 μm on initial test RFID tags, with prices expected to reach below \$.01/tag in high volumes in the foreseeable future.¹²

The research indicated that in the context of managing electronics at end of life, the cost of reading barcodes could be prohibitive. Additionally, barcodes must be in line-of-sight to be read, and therefore cannot be used at the component level.

5.2 Web-Based Information Resource Prototype

Following on the data gathered from EOL managers, the NCER led the development and launch of a prototype design for recycling web application, the “CTL Registry”, to house key information on product attributes that are useful for recycling purposes. The web application, known as the CTL Registry, will target EOL managers searching for information about a particular product (such as location of hazardous materials). The goal is to assist these EOL managers with proper breakdown and recycling by providing pertinent information on an array of electronic products. Users of this web application will be able to search products by the following categories: manufacturer, product type, model, date of manufacture, serial number, materials of concern and brand. Search results will net the user information such as the location of hazardous substances, information on identification and separation of plastics, and disassembly instructions, if available.

Providing such information by manufacturers is a requirement of EPEAT and of manufacturers covered by the Washington state electronics recycling law, but a place to make this information easily accessible for recyclers does not exist. Thus manufacturers are meeting this requirement of EPEAT on their own, in an uncoordinated fashion. This will be of marginal utility to recyclers. Moreover, the one-stop information source will be designed to house information for all products organized under easily recognizable categories, not only EPEAT-declared products. The conceptual business plan noted in Section 5.3 below proposes options for a sustainable funding model for the activity.

One of the major challenges in developing this web-based resource was to ensure that manufacturers can easily provide information on their products in a format they would be familiar with. After examining several options, the project team decided that integration with the back-end EPEAT data would be the most appropriate and logical method. Although this limits the data collection to EPEAT-covered products, it also allows manufacturers providing data on their products an easy method for including this additional information. EPEAT manufacturers can use their existing login information without duplication and input data in a format similar to data gathered for EPEAT registration purposes.

¹² “Kovio Demonstrates RFID Tags Using Printed Electronics,” David Lammers, Semiconductor International, October 16, 2008. Accessed 10/16/08 at www.semiconductor.net/article/CA6605965.html?nid=3572&rid=418790434.



5.3 Conceptual Business Plan

Introduction and Background

The CTL Registry prototype allows manufacturers who are already registered with EPEAT to use their existing registration to enter key data such as year of manufacture, number and location of materials of concern, and disassembly instructions. Previously, this type of information was not easily accessible for recyclers, and not centrally located. Recyclers desire this information to prevent operational accidents or pollutant releases and to make their disassembly, reuse or shredding operations more efficient. Manufacturers are incentivized to provide this information to due high environmental awareness among consumers, requirements of EPEAT, and requirements in a growing list of state statutes on electronics recycling. Instead of providing this information to recyclers in an uncoordinated fashion or on an as-requested basis, the registry aims to create a one-stop clearinghouse that allows manufacturers to satisfy their obligations and recyclers to obtain reliable data.

However, the prototype will not be able to fulfill its main goal without a sustainable source of funding. Therefore, this conceptual business plan described below offers several avenues for expanding and sustaining the work under the Closing the Loop project to date. While there are a few barriers to ensuring the registry develops into a robust information resource, the conceptual business plan articulates steps to overcome those barriers, target key potential customers, and market the registry to sustain its development over the long term.

Market for CTL Registry Services

There are two primary markets for the CTL Registry service. The first market is the recyclers and other end-of-life managers seeking information for their processes. This market is currently not served with the type of service offering of direct manufacturer data described below. The second primary market is manufacturers seeking compliance assistance in achieving additional EPEAT points and meeting state mandated requirements. Individual companies may be providing this information currently on an as-needed basis to individual recyclers, or on their corporate environmental websites, but there is currently no central information clearinghouse for these data. Other potential markets include consumers wanting info on potential materials in their products, and policy makers wanting to target key materials that could be in waste stream.

CTL Service Offering

The CTL Registry offers an easily accessible database of key product attributes that are valuable for end-of-life management. By incorporating the database into the widely used EPEAT database, the CTL Registry provides information directly from the primary source – the manufacturer. The database provides custom reports and is searchable based on any of the criteria the user selects. For example, users desiring information about which products contain batteries and where they are located can search the battery field. The CTL Registry will serve as a “one-stop shop” for recyclers seeking these data points, and for manufacturers looking to provide this information once rather than in several locations.



Near-Term CTL Registry Services

During the next six months to one year, the CTL Registry will focus on populating the database by reaching out the manufacturer market, initially for EPEAT registered products. The key messages to encourage the initial group of manufacturers to utilize the CTL Registry include:

- If you participate in EPEAT, you are already registered! By signing in to the CTL Registry, your basic contact information as well as all EPEAT-registered models will automatically be transferred without duplicative data entry.
- By supplying additional information on your currently registered EPEAT products, you are satisfying the following EPEAT Criterion:
 - 4.3.1.1 Identification of materials with special handling needs
For all covered products manufacturer shall provide *treatment information* to reuse and recycling facilities that identifies materials with special handling needs. This requirement addresses non-standard or new substances and technologies that would not be expected to be well-known to reuse and recycling operators.
- By utilizing the CTL Registry, your company is also responding to a requirement in the Washington Electronics Recycling law¹³ regarding communication of design for recycling information to recyclers:
 - **“Design for recycling:** A description of how the plan participants will communicate and work with processors used by the plan to promote and encourage the design of electronic products that are less toxic and contain components that are more recyclable.¹⁴”
- Use of the CTL Registry also demonstrates your commitment to proper end of life reuse and recycling, as well as your company’s willingness to go beyond compliance in providing information about the environmental attributes of your products.

A key group of manufacturers will be recruited to pilot the data entry system of the prototype, recommendation improvements, and be highlighted as the early adopters. Once a critical mass of manufacturers has entered data in the CTL Registry, it can be marketed to recyclers and other EOL managers.

Longer-Term CTL Registry Services

Over the long term, the CTL Registry can be expanded to include more product categories and other data elements of interest. Initially, product scope will only expand as EPEAT adds categories to its list. Other product categories could be added in the future separately from incorporation into EPEAT, but this will involve restructuring the database to allow product model input. As explained below, the CTL Registry will be managed by an active stakeholder group that may provide suggestions on additional product categories and data elements.

¹³ <http://apps.leg.wa.gov/RCW/default.aspx?cite=70.95N&full=true>

¹⁴ Language on requirement for “plan participants,” or covered manufacturers under the Washington law, taken from final version of regulations found at: <http://www.ecy.wa.gov/pubs/0707042.pdf>



As became clear in interviews with EOL managers for the Closing the Loop project, many see the use of RFID as a key information communication tool in the future. RFID tags at the product, or even component, level would greatly enhance the ability to efficiently identify materials of concern and prevent inadvertent mishandling. Instead of relying on line-of-sight barcode identification, RFID tags could allow a recycling operation to scan all equipment in a Gaylord, for example, and determine if a hazardous substance is present. However, as RFID tags do not contain information embedded within the tag, they must point or refer to an external database. The utility of the RFID tags for design for recycling purposes will depend upon the quality of the database. The CTL Registry offers the opportunity to build a robust database of direct manufacturer information that can later be incorporated into larger RFID databases when this technology is incorporated at the product or component level.

Management Strategy

The core management team will consist of the NCER and GEC, and their respective staffs. The two organizations have experience in managing similar web-based databases and a manufacturer registration process. The two organizations will work cooperatively to develop a management strategy utilizing initially one primary IT services provider support database development and improvements.

Two potential scenarios exist for the future management of the CTL Registry. First, the CTL Registry could be made an official, but voluntary, extension of the EPEAT database. GEC would notify EPEAT manufacturers of its availability and purpose, and let manufacturers input data to fulfill one of their EPEAT requirements. Manufacturers would access the CTL Registry data input screen from the main EPEAT website without logging in to a separate site. An alternative second option is to keep the database separate from EPEAT, but functionally integrated at the back end. That is, the CTL Registry would be hosted on its own web page, and manufacturers would need to separately log in to input their data. Product information from the EPEAT database would be transferred to the CTL Registry to prevent duplicative data entry. NCER and GEC would work to engage stakeholders on the content and functionality of this database separately from the EPEAT standards development process.

Organizational Strategy

The CTL Registry will be managed cooperatively by two existing organizations, NCER and GEC.

Pricing Strategy

Customers of the CTL Registry would initially be manufacturers and EOL managers. The most likely source of revenue in the short term would be manufacturers looking for a compliance service for EPEAT and state requirements. As manufacturers are already paying annual subscription fees for EPEAT, the initial pricing strategy will be to charge manufacturers a separate, voluntary add-on fee for access to the CTL Registry service.

Over time, EOL managers could also be added as potential source of revenue with a unique pricing structure. The CTL Registry will always have a component of data that is publicly available, but a specific service of customized reports could be offered to recyclers and other EOL managers. Some flexibility may need to be incorporated as some EOL managers might



want to customize this service such that they can interface with their own proprietary in-house software.

Communications Strategy

The initial communications will be targeted towards individual manufacturer participants in EPEAT. It is critical that the CTL Registry gain their acceptance and participation first before marketing the Registry to other stakeholder groups. Once a critical mass of data has been provided by manufacturers, communications in the form of press releases and earned media news articles in trade publications will announce the availability of the CTL Registry to recyclers and other members of the public.

Timeline

- *1st Quarter 2009*: Identify and recruit 5-10 manufacturers for testing, improvements, and input of data into CTL Registry
- *2nd Quarter 2009*: Announce availability CTL Registry to all EPEAT-registered manufacturers, incorporate pricing for service
- *3rd Quarter 2009*: Implement communications strategy to EOL managers, enlist EOL manager input on potential services/reports to be derived from CTL Registry
- *4th Quarter 2009*: Evaluate feedback and usage of CTL Registry, plan for improvements in 2010, and changes to pricing structure

Financing

The initial rollout of the CTL Registry will require seed funding. Much of the work for the development of the prototype database has been funded by the CTL Project grant. The grant has enabled the creation of the database structure to incorporate feedback based on findings from the CTL research.

Financing will be required to support the maintenance and improvements to the database structure via an IT services vendor, and administrative support for outreach to the initial group of manufacturers. The seed funding is estimated to be \$50,000 for 2009. Options for the seed funding include additional government grants or “founding member” fees for the initial group of participating manufacturers.

Major Issues/Uncertainties and Planned Response

Issue: The data for EPEAT registered products will be of marginal utility to recyclers since it only applies to products placed on the market today.

Response: It is difficult obtain data directly from manufacturers on the location of these materials for current products, but nearly impossible for historic products coming into the recycling stream today. Since the initial focus is on IT products registered in the EPEAT database, and IT products have relatively shorter lifespans than consumer electronic products, this will be a temporary issue. Over time, recyclers will see more products from the CTL Registry entering their facilities.



Issue: Manufacturers provide extremely basic information, such as a boilerplate listing of mercury lamps in all LCD products. This

Response: While the input of all the data fields in the CTL Registry is voluntary, manufacturers who wish to use the CTL for compliance with EPEAT or state laws will need to prove that they are satisfying the requirements. Managers of the CTL Registry will be in contact with state and EPEAT officials regarding submissions that are incomplete or do not meet the intent of the CTL Registry mission.

6.0 Summary of Findings and Recommendations

6.1 Overview of Product Design-for-EOL Recommendations

This study yielded a great amount of information about product design from the perspectives of EOL managers. The research team will provide the product design findings and recommendations to upcoming EPEAT standard development working groups for their consideration in developing EPEAT criteria for new and revised standards.

The findings are applicable to EPEAT criteria in two primary environmental performance categories 1) design for EOL; and 2) product longevity and life cycle extension. The product design recommendations could be incorporated in EPEAT in two ways; either developed into new criteria or used to improve in existing criteria.

Based on the input of EOL managers, several product design recommendations were identified as most important for EOL management. These product design recommendations include:

- To make triage more efficient: Communications mechanisms that yield data “at the dock” for EOL managers to quickly identify key information about products such as age, power and functionality performance features, and internal components. The tools for accomplishing this should keep pace with advancing communications technology. In the near term, there could be systematic number sequences on product ID codes providing useful information based on pre-determined characters in each position. Bar code identification, or in the future RFID technology, can provide the same data more efficiently, using hand-held or other devices to read useful information directly into “at the dock” intake databases.
- To ease disassembly/assembly, refurbishment and resale, and demanufacturing into subassemblies and components: Use of consistent, limited and uniform set of screws and fasteners, no hidden screws and fasteners, no injection-molded screws. Note that this recommendation may require harmonization of design, and is therefore included in Section 6.2 below on initiating working groups to develop workable and agreeable voluntary harmonization.
- To enhance reuse, refurbishment and resale: Design for longer life span of components through more durable and interchangeable parts and other strategies.
- To enhance reuse, refurbishment and resale: Standardize power supplies, particularly for portable equipment; despite variation in voltage and amps, have consistent plugs and jacks; uniform cords would enable much more reuse. Note that this recommendation may



also require harmonization of design, and is therefore included in Section 6.2 below on initiating working groups to develop workable and agreeable voluntary harmonization.

- To reduce hazardous material impacts: Depollution was by far and away the highest priority product design area identified during this study. Specific design recommendations were highlighted in both identification and ease of removal of components containing hazardous materials, as well as elimination of hazardous substances including:
 - External marking indicating the presence and location of components containing hazardous materials
 - Color coding all components containing hazardous materials, in particular small batteries
 - Design these components to be extremely easy to pull out, using cartridge-style housing that snaps, pulls or slides in and out readily
 - Components containing hazardous materials located within “line-of-sight” spotting when external housing is removed
 - Elimination of intentionally added mercury used in light sources, beryllium in connectors, and BFRs and other halogenated substances

This recommendation is also included in Section 6.2 below; a working group could develop workable and agreeable voluntary harmonization design strategies and solutions in this area.

- To enhance materials separation: Develop a consistent and limited set of resins to be used, or at least a limited number of different resins per product category. Managing plastics was identified as EOL manager’s greatest challenge with regard to materials separation. Using a limited number of different resins per product category and/or adhering to a limited set of resins would enhance EOL managers’ ability to separate and market plastic materials.
- To enhance materials separation: Eliminate laminated, bonded, glued, and/or molded-together dissimilar materials, including stickers and labels (materials separation).
- To enhance materials recovery and system efficiency: The study found that the case could be made for two different fundamental design/EOL management scenarios (discussed in detail in Section 4.0). The overall structure of EPEAT 1680 DfEOL criteria could be reconsidered in light of this two-scenario EOL paradigm, such that products could be designed to optimize EOL value through the two recovery scenarios, each with a corresponding set of EPEAT criteria.

6.2 Recommendations for Future Research

The Close the Loop Project has found very fertile ground in exploring the issue of how electronic product design, and the communication of design for EOL features, can enhance the economic viability and environmental sustainability of the EOL management of electronics. During the research, three areas have surfaced for further work that have substantial potential to increase the



life-cycle environmental profile of electronics by enhancing business opportunities for end-of-life managers.

- **Recommendation #1 – Refinement of Performance Measurement Parameters for Existing Eco-Label and EPEAT Criteria.** Several of the design-for-EOL recommendations developed in this project, and including criteria in existing eco-labels such as EPEAT, need to be refined and, in some cases quantified. The necessary refinement includes agreement on specific definitions and measurements that are critical in assuring that certain environmental criteria are meaningfully met.
- **Recommendation #2 – Development of Standards for Environmental Design Elements that could be Harmonized Across Products, Brands, and Even Generations.** This includes the development of technical industry standards that define, for electronics manufacturers, methods to harmonize specific design features of their products. The goal is to harmonize – across a broad range of products, brands and generations – design features that are especially critical for the environmental performance of the EOL system, including product life extension, refurbishment and reuse, and recycling. Once developed, stakeholders in future EPEAT work groups could choose to include criteria referencing these technical industry standards.
- **Recommendation #3 – CtL Registry Implementation and Expansion.** A web-based information resource that was designed and developed at a prototype level as part of this Close the Loop project. This tool needs to be expanded and implemented into a fully functioning information exchange system.

Recommendation #1 – Refinement of Performance Measurement Parameters for Existing Eco-Label and EPEAT Criteria

Several of the design-for-EOL recommendations developed in this project need to be further refined and, in some cases quantified for inclusion in design standards. It will require a small but diverse stakeholder group, with broader input from others, to develop some of these definitions/measurements. These differ from Recommendation #2, in that the necessary refinement includes agreement on definitions and measurements, as opposed to harmonization of design elements – and thus can likely be accomplished through a much more streamlined process.

Examples may include:

- Eco-label criteria often prescribe that certain items be “easily identifiable” (for hazardous items), “easily removable,” or “easily separable”. The important principle of “easily” needs to be quantified into a time measure, a disassembly step measure, a use of tool measure, or some other measurable and verifiable criterion.
- Eco-label criteria often prescribe that reference items that are above, or below, a certain size or mass have certain characteristics, such as removability, recyclability, marking of material type, made of a single resin, etc. The thresholds for each of these needs to be quantified into a mass or size measure that is both practical and environmentally responsible from a recyclers perspective.



- Eco-label criteria often prescribe a reduced number of plastic resins. This is a highly subjective measure and it is essential to define “reduced” for both advice to designers and for eco-label verification.
- Eco-label criteria often prescribe a percent “recyclability”. It will be important to quantify and further define all the measurable parameters of "recyclability" that can be used in eco-label criteria.

Recommendation #2 – Development of Standards for Environmental Design Elements that Could be Harmonized across Products, Brands, and even Generations

Whereas Recommendation #1 requires engagement of a fully diverse set of stakeholders, this project is more focused on design technicalities and would thus be more focused on industry representatives including product designers and stewards, while soliciting, of course, input from other key stakeholders especially EOL managers. Working groups would be convened, either directly by the team, or, more likely, through interested industry organizations and organizations. These groups would develop workable and technically sophisticated design standards to accomplish at least two of the four key challenges identified below. Some elements of this project may build on definitions and metrics established in Recommendation #1:

1) Harmonization of Power Supplies for Computers and Possibly Other Electronics

The customization of power supplies is a huge challenge for refurbishment and reuse organizations. Power cords often get separated from units and finding the correct power supply is often a time-consuming or costly effort, due to lack of harmonization and variation in voltage, amps, and plugs. The purpose of this working group would be to establish more uniformity, interchangeability, and/or adaptability in power supplies.

2) Enhancement of Cross-Brand and Cross-Generational Component Compatibility

The reuse and asset recovery sector is significantly hampered by the difficulty of obtaining replacement parts and the lack of component compatibility. Product uniqueness is increasing as OEMs seek to distinguish their products in a market flooded with high technology. This results in reduced availability of replacement parts, diminished adaptability of spare parts for repair or refurbishment, and increased cost to source spare parts for repair or refurbishment. A workgroup would explore the options for developing guidelines for components that could be used both cross-generationally and cross-brand.

3) Clearer Identification and Removal of Components and Parts containing Hazardous Substances

In all EOL management scenarios, it is critical to be able to safely but quickly identify and remove parts and components that contain hazardous substances, such as batteries, mercury-containing lamps, plastics with brominated flame retardants or polyvinyl chloride, and toners. Because RoHS allows exemptions for certain items, the need for depollution will continue. The first challenge facing an EOL manager is to identify components containing hazardous substances, which are often hidden or otherwise not obvious when the housing is removed. Color coding of items in highly visible colors,



markings to indicate presence of hazardous substances, and other strategies should be developed to ensure enhanced protection of human health and the environment during the EOL stage. Further, rapid and easy methods to remove such parts, without causing dispersion of the hazardous substances, are critical. The purpose of this working group would be to establish some basic principles and methods for how parts containing hazardous substances can be identified and removed from electronic products before intensive processing.

4) Harmonization of Connection Mechanisms

One of the most common complaints heard from EOL managers during this research is the use of an unnecessarily large variety of different types of screws and fasteners which greatly impacts the efficiency of EOL management. EOL managers expressed a strong desire for use of a consistent, limited and uniform set of screws and fasteners. The purpose of this working group would be to explore agreement on a consistent, limited and uniform set of screws and fasteners.

Recommendation #3 – CtL Registry Implementation and Expansion

The development of the prototype information system into a fully functioning information exchange would focus on implementation and expansion of the prototype web-based resource. Specifically:

1) Begin first phase of business plan by forming manufacturer committee for input, testing, and final integration into EPEAT

As the CTL Registry is currently in prototype form, there is still a need for manufacturers and others to test and modify the functionality before it is fully integrated as an extension of the EPEAT database. NCER will identify and recruit 5-10 manufacturers for testing, improvements, and input of data into CTL Registry.

2) Announce availability of CTL Registry to all EPEAT-registered manufacturers, populating database with manufacturer input, and then announcing availability of data to EOL managers

The next step after final integration is to populate the database with a critical mass of data points from manufacturers. The Registry can then be marketed as a useful tool to EOL managers.

3) Incorporate ability for direct communications between EOL managers and product designers

This activity will incorporate into the system a website for EOL managers to provide targeted feedback on design challenges can be directed to individual manufacturers anonymously.

6.3 Ideas for Future Research from StEP - for Discussion Purposes

Solving the E-Waste Problem (StEP) is an initiative of various United Nations organizations with the overall aim to solve the e-waste problem. Together with members from industry, governments, international organizations, NGOs and the science sector actively participating, StEP is working to initiate and facilitate approaches towards the sustainable handling of e-waste.



Following a review of the discussion draft of this report, StEP submitted the following ideas for future research:

- 1) Conduct a parallel study within the European Union. The composition of the EU EOL infrastructure is somewhat different from the infrastructure within U.S. The U.S. system may be headed more towards that of the EU, though it is much unknown. However, given that possibility, it would be beneficial to gain the insight of EU EOL managers. This effort could be conducted directly with the European StEP members.
- 2) Conduct a similar research project on DfEOL, focusing on the informal electronics recycling sector in geographies such as China, India and/or Africa. This research would assess how design could reduce impacts to human health and the environment during informal recycling.
- 3) Work with EOL managers to develop photo documentation on "Bad Design - Good Design". This would guide product developers on how to improve DfEOL. This effort could be expanded to a training for electronic product designers.
- 4) Engage with, or track, a soon to launch research project (ZeroWIN) in the EU with the University of Limerick, HP and others to investigate DfEoL criteria for LCD products.