End-of-Life Phase of Consumer Electronics - Methods and Tools to Improve Product Design and Material Recovery

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The focus of research in the LMAS is on the analysis and improvement of manufacturing processes, systems and enterprises and the development of tools to analyze their sustainability.

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Green Manufacturing

Impact of manufacturing strategy on product life cycle, including:

- Environmental (e.g., resource consumption)
- Economic (e.g., payback periods, productivity, quality)
- Social (e.g., fair labor standards, employee health and safety)

Source: Microsoft
Scope of Analysis

Enterprise

Factory/Facility

Machining Cell or Line

Machine Tool

Machining Process

Tool-chip interface

www.remmele.com/flash/contractManu/pca.html
<table>
<thead>
<tr>
<th>Research focus</th>
<th>Current projects</th>
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<tbody>
<tr>
<td>- Sustainable products and systems</td>
<td>- Smart manufacturing, data analytics, and machine learning</td>
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<td>- Impact and life cycle assessment tools for manufacturing</td>
<td>- Appropriate technologies for improving manufacturing productivity in developing economies</td>
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<td>- Manufacturing technology for reduced impact and green machine tools</td>
<td>- Develop total cost of ownership for design and manufacturing optimization of fuel cell stationary and</td>
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<td>artificial photosynthesis applications</td>
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<td>- Manufacturing technology for producing advanced energy sources or storage, Cleantech</td>
<td>- Tools and methods to inform design of electronics for end-of-life recovery</td>
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<td>- Design for sustainability, Material selection, Design for the Environment, the Circular</td>
<td>- Sustainable material selection for consumer electronics</td>
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<td>Economy</td>
<td>- Trade-off analysis of manufacturing process chains</td>
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<td>- Metrics and analytical tools for assessing the impact of processes, systems and enterprises</td>
<td>- Social impacts and sustainability through the supply chain</td>
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<td>- Modeling sustainable manufacturing processes, systems, and supply chains</td>
<td>- Sustainable packaging</td>
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The Sustainability Consortium

TSC informs decision makers on **product sustainability** throughout the entire product life cycle **across all sectors.**

- **Category Sustainability Profile (CSP)**
- **Key Performance Indicator (KPI)**

Sustainability for **100+ product categories across 9 industry sectors.**

**Website:** [http://www.sustainabilityconsortium.org/](http://www.sustainabilityconsortium.org/)
The Electronics Sector Working Group leads the investigation of sustainability issues and improvement opportunities for a variety of electronic consumer product categories.

The life cycle evaluation of electronics and materials relevant to electronics production involves engagement from material producers, manufacturers, retailers, waste managers, and other experts and stakeholders spanning the entire supply chain.

Product Categories

- Computers
- Display Monitors
- Mobile Devices
- Printer Ink
- Printers
- Televisions

Website: http://www.sustainabilityconsortium.org/electronics/

Email: carole.mars@asu.edu
The EOL Innovation Working Group

Underway – Project Complete in 2014

Successful Takeback Program

Collection + Treatment

Consumers

Convenience (Scoping)

What constitutes convenience (definition), and how is this measured and communicated?

Volume/Takeback

Product Demand in Secondary Markets

What volumes of products are moving through different collection routes, and how does this impact mandatory collection targets?

Product Capture

How does an organization successfully engage with product users to capture product at EOL?

“WEEE Arising”

Product Recyclability

How does an organization calculate and report a consistent recyclability number that accurately reflects actual material capture and recycle rates?

Downstream Treatment

Recycling Efficiency

EOL Pathways Project

How do products travel through the reuse and recycling refurbishment stage and what is the efficiency of disassembly and treatment for standard consumer electronic products?

Supply Chain Transparency

Executive Summaries

June 2014
“Better processing of e-waste would not only reduce the amount of potentially toxic waste sent to landfill or illegally exported overseas, but lead to greater recovery of valuable raw materials” – European Parliament

Before we can improve e-waste processing we need to have a better understanding of the e-waste system
**E-waste** is a generic term encompassing various forms of electric and electronic equipment that have ceased to be of any value to their owners (*Widmer 2005*)

![Graph](image_url)
Resource use and metals mining

- Materials composition of electronics
  - Material intensive products
  - Number of elements in chips (11 to 60)

- Metals Mining
  - 80% of technology metal mining occurred over last 30 years
  - Ore degradation

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<tr>
<th>Product</th>
<th>Elements used</th>
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<td>Automobiles</td>
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<td>Gas turbine blades</td>
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<td>Medical equipment</td>
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(Hageluken 2012) (UNEP 2011)
Material Composition

“In particular, recycling materials from mixed-material products discarded in mixed waste streams, is most difficult – but with the increased complexity of many high-value products, this stream is potentially the largest and most valuable “- Allwood 2011

(Brown-West 2010)
End-of-Life Project Objectives

- Pathways Project
  - Develop a representative set of pathways that consumer electronics follow in the end-of-life phase
  - Focus on formal collection and processing of e-waste in the U.S.

- Recyclability Calculator
  - Develop model to assess product recyclability
  - Value, Mass, and Design based criteria
  - Inherent flexibility to be used on a variety of product categories
  - Align with current industry efforts and standards

Alignment and input from key stakeholders in the industry as well as current industry standards and efforts was an integral part of this work.
END OF LIFE PATHWAYS PROJECT
Scope of Material Flow Analysis

**Products**
- Televisions
  - LCD, Plasma, CRT
- Computers
  - Laptops
  - Desktops
  - Tablet PCs
- Monitors
  - LCD, CRT
- Mobile Phones
- DVD/VCR

**Collection**
- Consumer
  - Retail Return
  - Collection Program
  - Direct
  - OEM takeback
- Business
  - OEM
  - Enterprise
  - Government
  - Schools/Univ.

**Facility**
- Type of Facility
  - Recycle
  - Refurbish
  - Reuse
- Region
  - United States
- Temporal
  - 2012
- 14 Facilities

**Pathway**
- Recycle
- Reuse
  - Whole System Component
- Refurbish
  - Whole System Component

% Mass Laptops → Retail Returns → Facility X → Whole System Refurbish
Data Collection & Survey Development

- Primary Data Collection
  - Surveys and Interviews

- Surveys sent to 35 facilities with a 40% response rate

- Distribute to variety of material processing facilities
  - Follow up and support to ensure data quality

Section 1 – Facility information: Facility size, location, amount of e-waste processed, operating model, and certifications

Section 2 – Material Flows: What products are being collected and processed, and the pathways they follow through the facility

Section 3 - Process flow: Details of processes and process flows at each facility

Section 4 – Resource use: Energy and resource use facility level data
Participating Material Recovery Facilities

- 14 Participating Facilities
- Concentration in Midwest, New England, and the West

Total e-waste processed

(Mangold 2013)
Collection Methods

- Business Sector – 64%
  - B to B Contracts
- Consumer Sector – 36%
  - OEM Takeback Programs
  - Collection Program
- Barriers to collection

Opportunity to increase collection from consumer sector

(Mangold 2013)

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<th>Consumer</th>
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Example Material Flow Results

- Over 95% of products directed to Recycling
- Reuse & Refurbishment
  - Primarily Computers & Mobile Phones
- What about Design for Reuse?

(Mangold 2013)
RECYCLABILITY CALCULATOR
Product Recyclability Model

- Develop standard methodology and tool that can be used to determine product recyclability in consumer electronics industry

Project Goals
- Align with current industry standards
- Move beyond mass based criteria
- Easy to use

Scope
- Consumer electronic products
A mass based approach is misleading
- Materials present in low amounts
- High economic value and environmental impacts

**Model Approach**

- **Mass Based** – *What materials are recycled and how efficiently?*
- **Value Based** – *What value is recovered from the product?*
- **Design Based** – *How easy is it to separate materials to be recovered?*
Materials and Components

- Recycling Efficiency
  - Single Materials
  - Component Compositions

- Components included
  - Printed Circuit Boards
    - Motherboard, Display, etc.
  - Desktop & Integrated Display
  - Optical Drive
  - Hard Drive
  - Power Supply Unit
  - Battery
Model Architecture

User inputs basic product data

Model Outputs

Recycling Efficiency of Materials
- Al
- Au
- Ag
- ....

Component Composition Models
- Hard Disc Drive

Scrap Value of Materials
- Al
- Au
- Ag
- ....

Model and Database
- Product Recyclability Model
- Recycling Efficiency
- Scrap Value

Model Outputs
- Recyclable Mass of Product (g)
- Product Recyclability (%)
- Recycled Material Value (US $)
Recyclability Model User Interface

**User Inputs**
- Material Type
- Material Mass
- Components
- Component Mass
- PCB by application
- Battery Type

**Model Outputs**
- Recyclable Product Mass
- Product Recyclability (%)
- Recyclable Value (USD)

![Electronics Recyclability Calculator](Mangold 2013)
Example Case Study

- **Case Study**
  - 15” LCD Laptop Computer

- **Components**
  - Hard Disc Drive (Al)
  - DVD Drive
  - Lithium-ion Battery
  - PC/ABS Housing

- **Model Results**
  - 36.8% Recyclable by Mass
  - Recyclable Value - $4.90

**Next Steps**
- Test more products
- Economic evaluation with MFA results
Considerations for Product Design Criteria

- **Separation Potential – Component and part connections**
  - Types of Connections
  - Quantity of Connections

- **Contamination – Coatings, paints, material mixing**
  - Number of different materials used
  - Material mixing (e.g., metal inserts in plastic components)

- **Material Compatibility – Metals and plastics**
Design Criteria

- **Material Compatibility – Metals**

![Diagram of material compatibility](image)

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*Must separate* | *Should separate* | *Don't separate*

(Adapted from Castro 2005)
## Design Criteria

- **Material Compatibility – Plastics**

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*Good compatibility over a wide range of mixtures*

*Limited compatibility for small excess component amounts*

*Incompatible*

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*ECMA-341 2008*
Directions for future work

- Key Performance Indicators
  - Development of improved performance measures
  - Implementation within the industry

- Information Exchange
  - Communication between designers, manufacturers, and EoL practitioners
  - Continuous feedback and systematic assessments

- Consumer Engagement
  - Beyond education
Thanks!

- Additional Contact Information
  - Jennifer Mangold - jam@me.berkeley.edu

- LMAS
  - http://lmas.berkeley.edu
  - http://green-manufacturing.blogspot.com
  - https://www.facebook.com/GreenManufacturingBerkeley

- The Sustainability Consortium
  - http://www.sustainabilityconsortium.org/electronics/
  - Carole Mars – carole.mars@asu.edu