An Introduction to Slate and Tablet Computers:
Technology, Markets and Environmental Considerations

A Synthesis of Information Presented and Discussed -
December 2013 Workshop of the
Green Electronics Council and U.S. Department of Energy

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GREEN ELECTRONICS COUNCIL

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1.0 Purpose and Scope

This report is a collation of information presented and discussed at a workshop on the environmental issues and opportunities of slate and tablet computers co-convened by the Green Electronics Council (GEC) and the U.S. Department of Energy (DOE) in December 2013 (GEC/DOE Workshop). The workshop brought together 39 stakeholders with diverse perspectives and a range of expertise, including original equipment and design manufacturers, mobile service carriers, repair and recycling organizations, research institutions, academics, federal purchasers (U.S. and Canadian) and non-governmental organizations to begin a dialogue on this emerging product class, its supply chain, markets, and environmental performance.

The purpose of this report is to summarize and augment the information shared at the workshop. This document is intended to provide a foundation for future environmental standards development work by building a body of knowledge and better understanding of the slate and tablet computer product segment and environmental performance. This report is not intended to be a definitive reference on this product class, and does not include research beyond that presented or referenced at the GEC/DOE Workshop, or additional analyses or recommendations For a summary of the GEC/DOE Workshop discussions and presentations see the meeting summary and presentations.

The topics covered in this report include:

- Markets and trends
- Overview of the supply chain
- Component and material composition
- Lifecycle analysis & carbon footprint
- Environmentally sensitive substances/materials
- Energy efficiency
- Repair, Refurbishment and End of Life

2.0 Introduction to Tablet Computers

2.1 Product Definitions

The terms "slates" and "tablets" are used interchangeably in the marketplace, although "tablets" appears to be the more commonly used term. For the purposes of this report, "tablet" or "tablet computer" will be used.

Oxford Dictionary defines a tablet as "a computer that accepts input directly onto an LCD screen rather than via a keyboard or mouse." [1] Input occurs via a touch screen or stylus pen. Tablets offer Web browsers and run a variety of applications from video, music and photography to computing. These devices are larger than smart phones yet smaller than notebook computers.

At the time of publication of this report, U.S. Environmental Protection Agency (EPA) ENERGY STAR was updating its Computer Specification. The draft of Version 6.1 of the Computer Specification dated March 12,

[1] Oxford University Press, *Oxford Dictionary*, 2014. www.oxforddictionaries.com

2014 includes the following definitions[2]:

Slate/Tablet: *A computing device designed for portability that meets all of the following criteria:*

a) *Includes an integrated display with a diagonal size greater than 6.5 inches;*
b) *Lacking an integrated, physical attached keyboard in its as - shipped configuration;*
c) *Includes and primarily relies on touchscreen input; (with optional keyboard);*
d) *Includes and primarily relies on a wireless network connection (e.g., Wi-Fi, 3G, etc.); and*
e) *Includes and is primarily powered by an internal battery (with connection to the mains for battery charging, not primary powering of the device).*

E-Reader: *A device designed for display and consumption of static images. The display is characterized by a low refresh rate and a display made of bistable materials where no energy is needed to maintain a visible image, only to alter the image.*

Two-In-One Notebook: *A computer which resembles a traditional Notebook Computer with a clam shell form factor, but has a detachable display which can act as an independent Slate/Tablet when disconnected. The keyboard and display portions of the product must be shipped as an integrated unit.*

2.2 Markets and Trends

Tablet shipments are accelerating and overtaking the sale of desktop and notebook computers. IDC forecasts tablet shipments will surpass total personal computer (PC) shipments (desktop + notebook computers) on an annual basis by the end of 2015.[3] According to NPD Display Search, in 2014 tablet computer shipments are expected to account for 65% of the mobile computing market.[4] Figure 1 shows the forecast for mobile PC shipments (i.e., tablets, notebooks, and ultra-slim PCs) from 2013 – 2017.

[2] ENERGY STAR "Version 6.1 Computer Specification Draft", March 12, 2014. https://www.energystar.gov/products/specs/sites/products/files/Version%206%201%20Draft%20Computers%20Specification.pdf

[3] IDC, "Tablet Shipments Forecast to Top Total PC Shipments in the Fourth Quarter of 2013 and Annually by 2015", September 11, 2013. http://www.idc.com/getdoc.jsp?containerId=prUS24314413

[4] NPD DisplaySearch, "Quarterly Mobile PC Shipment and Forecast Report", February 6, 2014. http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/140206_global_tablet_pc_shipments_to_reach_455_million_by_2017.asp

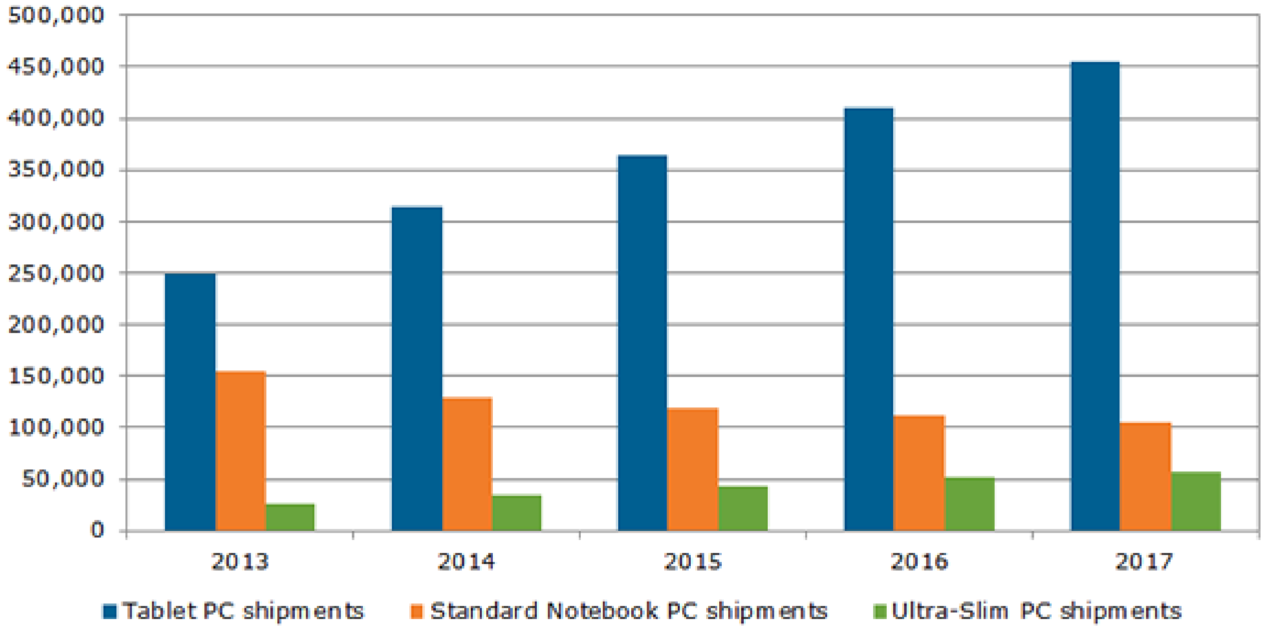

Figure 1: Worldwide Mobile PC Shipment Forecasts[5]

Similarly, U.S. consumer data from the Consumer Electronics Association (CEA) indicates significant growth in the shipment of tablets, while shipments of desktops have decreased and notebook sales increased only slightly from 2011-2014. Household penetration (i.e., ownership) of tablets and e-readers combined is expected to reach almost 70% in 2013, which is significant given that these devices have not been on the market long. The majority of users of tablets and e-readers report that they started using these devices no more than 2 years ago.[6]

2.3 Overview of the Supply Chain

According to IDC based on 3rd Quarter shipments in 2013, the top five tablet vendors are Apple (40.2 %), Samsung (12.4 %), ASUS (6.6%, making Google Nexus), Lenovo (1.1 %) and Acer (0.9%). The remaining 38.8% of market share represents a combination of vendors (such as Amazon, Microsoft, HP, and Dell) and lesser-known "white box" vendors that typically sell lower cost Android devices.[7]

Many of the tablet brands on today's market are assembled by five Original Design Manufacturers (ODMs) in Asia, with few brand owners assembling tablets in-house, as shown in Figure 2.

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[5] NPD DisplaySearch, "Quarterly Mobile PC Shipment and Forecast Report", February 6, 2014. http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/140206_global_tablet_pc_shipments_to_reach_455_million_by_2017.asp

[6] Alcorn, Consumer Electronics Association "Slate/Tablet Market Statistics, Trends and Consumer Behavior", *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

[7] IDC, "Android Growth Drives Another Strong Quarter for the Worldwide Tablet Market", October 30, 2013. http://www.idc.com/getdoc.jsp?containerId=prUS24420613

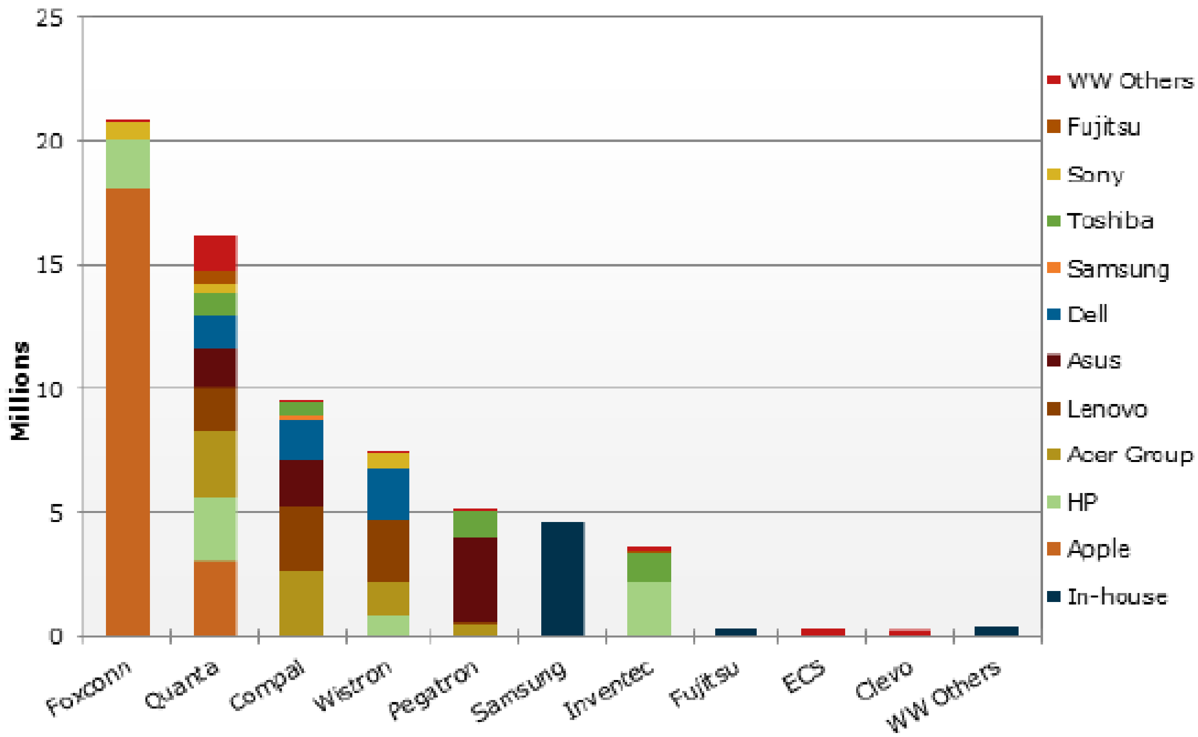

Figure 2: OEM Shipments to Mobile PC Brands[8]

3.0 Composition of Tablet Computers

3.1 Components and Materials

The exploded diagram below (Figure 3) illustrates the component parts of an Apple iPad Air. Three parts – the battery, display and aluminum enclosure – contribute over 80 percent of the weight of this tablet computer.[9]

[8] NPD DisplaySearch, "Fiercely Competitive Tablet Segment Alters 2013 Supply Chain Strategies, According to NPD DisplaySearch", December 12, 2012. http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/121212_fiercely_competitive_tablet_segment_alters_2013_supply_chain_strategies.asp

[9] Based on Apple's product environmental reports: http://www.apple.com/environment/reports/

Figure 3: **Exploded Diagram of Apple iPad Air**[10]

Some tablets, like the Apple iPad, use aluminum enclosures, while others use plastic materials for the enclosures. Figure 4 provides a material breakdown of tablets, comparing side-by-side, tablets with plastic enclosures and aluminum enclosures. The composition of these devices is similar, with the exception of the enclosure materials. For example, the display with glass dominates the materials for both device types at 39 - 46% by weight, followed by the battery at 22 - 26 % by weight. Printed circuit boards contribute 8 - 9 % of the product weight.[11] Batteries in tablets are typically lithium-ion.

[10] IHS Technology (www.technology.ihs.com) as cited by Long, Wistron "Overview of the Supply Chain", *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

[11] Marwede, Fraunhofer IZM, "Disassembly of Tablets; Examples of Designs for Easy Access to Components", *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

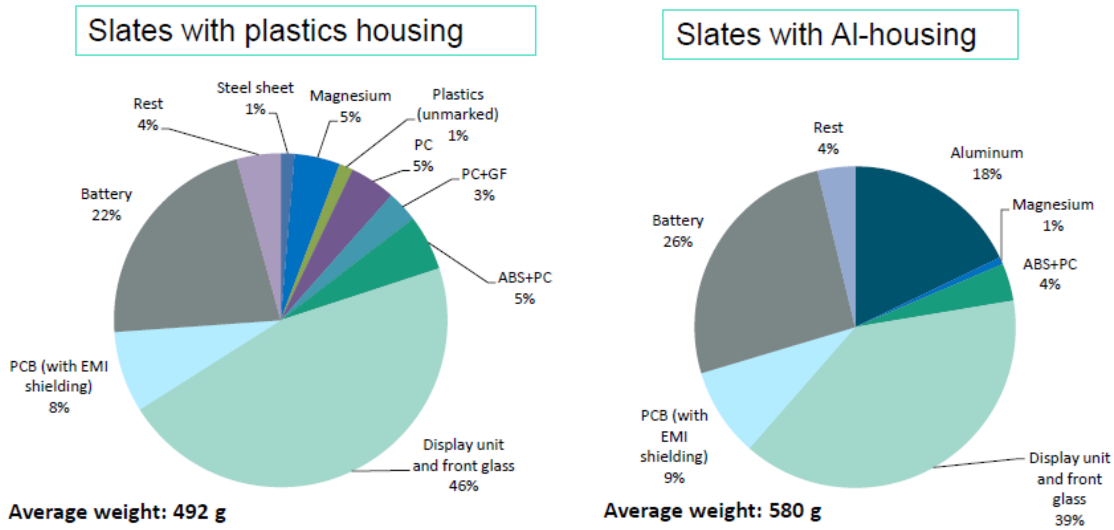

Figure 4: Material Composition of Tablet Computers[12]

The monetary value or acquisition cost of the various component parts going into the final assembly of a tablet are provided in Figure 5. The components of greatest value in the device (in descending value) include the display, touch screen, mechanical, wireless and memory, as shown in the figure below. Components are manufactured by a wide range of companies.

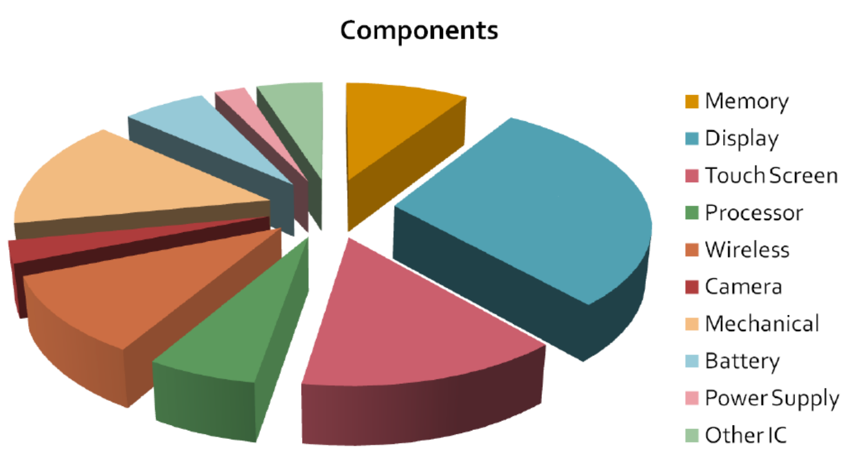

Figure 5: Component Values[13]

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[12] Marwede, Fraunhofer IZM, "Disassembly of Tablets; Examples of Designs for Easy Access to Components", *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

[13] iSupply as cited by Long, Wistron, "Overview of the Supply Chain", *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

3.2 Comparison to Other Products

At the GEC/DOE Workshop, there was a general consensus that tablet computers are on a spectrum between smart phones and notebook computers, with some devices resembling a smart phone more than a notebook computer and vice versa. However, in general, the smart phone is a better benchmark for most tablets than a notebook, which is inherently more complex. Smart phones and tablets tend to have similar complexity and components with variation based on make and model.

Table 1 below provides a summary and comparison of the materials by weight derived through a teardown of 4 devices: a cell phone, notebook, e-reader, and tablet. The data presented is based on the teardown of one device in each category. These values were compared to other products and deemed representative, by the recycler, of products in the class.

Material	Smartphone (with plastic casing)	Notebook (15 inch screen & plastic casing)	E-Reader (7 inch screen & plastic casing)	Tablet (10 inch screen & plastic casing)
Battery	14%	17%	11%	26%
Metals	54%	56%	35%	21%
Glass/Ceramic	19%	20%	33%	38%
Plastic	13%	7%	21%	15%

Table 1: Comparison of Material Composition of Four Product Types (Based on an End-of-Life Tear Down)[14]

4.0 Lifecycle Analysis & Carbon Footprint

A compilation of environmental reporting data published by Apple provides a comparison of the carbon footprint for the Apple family of computing products. For battery operated mobile devices, such as laptops, tablets, and smartphones, production by far accounted for the largest contribution of greenhouse gas emissions, with the environmental impact from production increasing in proportion to product size, as shown in the Figure 6 below.[15]

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[14] Boswell, HOBI International, "Composition of a Slate/Tablet: Material Breakdown & Component Inventory", *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

[15] Teehan, "LCA Studies of Tablets; Embodied CO2 of Tablets; Comparison with Similar Products", *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

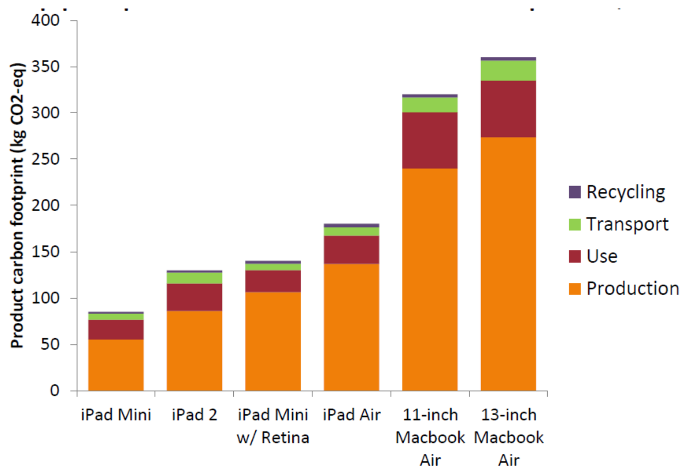

Figure 6: Summary of Apple Product Environmental Reports, 2013[16]

A Dell study of the carbon footprint of its 5-inch Streak tablet (Figure 7) indicated only slightly higher carbon emissions for production compared to the use phase, assuming a two-year lifespan. Two subassemblies, the mainboard and the display, accounted for 85 percent of the total greenhouse gas emissions from manufacturing due to the energy-intensive processes. The emissions from display manufacturing correlated strongly with display size. In the use phase, the Dell study assumed 10 hours of charging every night, including 2 hours of active charging and 8 hours of maintenance, where the battery discharges slightly then re-charges. This "maintenance no load" cycle dominated the use-phase emissions due to the high energy use and number of hours charging.[17]

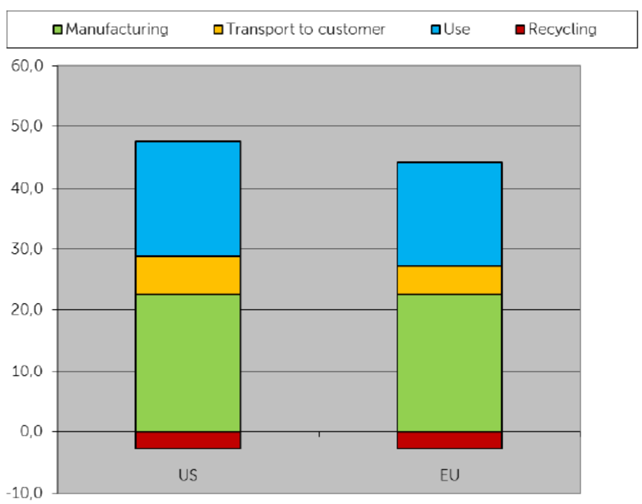

Figure 7: Carbon Footprint Analysis (kg CO_2eq) in US and Europe for Dell Tablet[18]

[16] Teehan, "LCA Studies of Tablets; Embodied CO2 of Tablets; Comparison with Similar Products", *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

[17] Carbon Footprint of the Dell Streak Tablet, April 2011. http://www.epeat.net/documents/tabletworkshop/CarbonFootprintDellStreakTablet.pdf

[18] ibid.

A life cycle assessment (LCA) of an e-reader (with e-ink) showed similar results. The most significant impacts across multiple impact categories accrued from device production, with negligible use impacts.[19]

Research by Paul Teehan at the University of British Columbia compared the embodied CO_2 emissions of 11 computing devices, from tablets to notebooks, desktop computers and monitors, illustrating that the smaller the device, the lower the embodied CO_2.[20] The environmental impact was roughly linear with the mass of the product. For tablet devices, and specifically the Apple iPad, the display module and integrated circuits contributed most to the total embodied CO_2 of the device, at 39% and 34%, respectively. Figure 8 plots the various components in the iPad tablet device by mass and embodied CO_2/unit mass, demonstrating the impact of highly complex integrated circuits. Other electronic components such as circuit boards and displays were in the middle in terms of impact/unit mass, while materials such as plastics and metals had a lower impact/unit mass.[21]

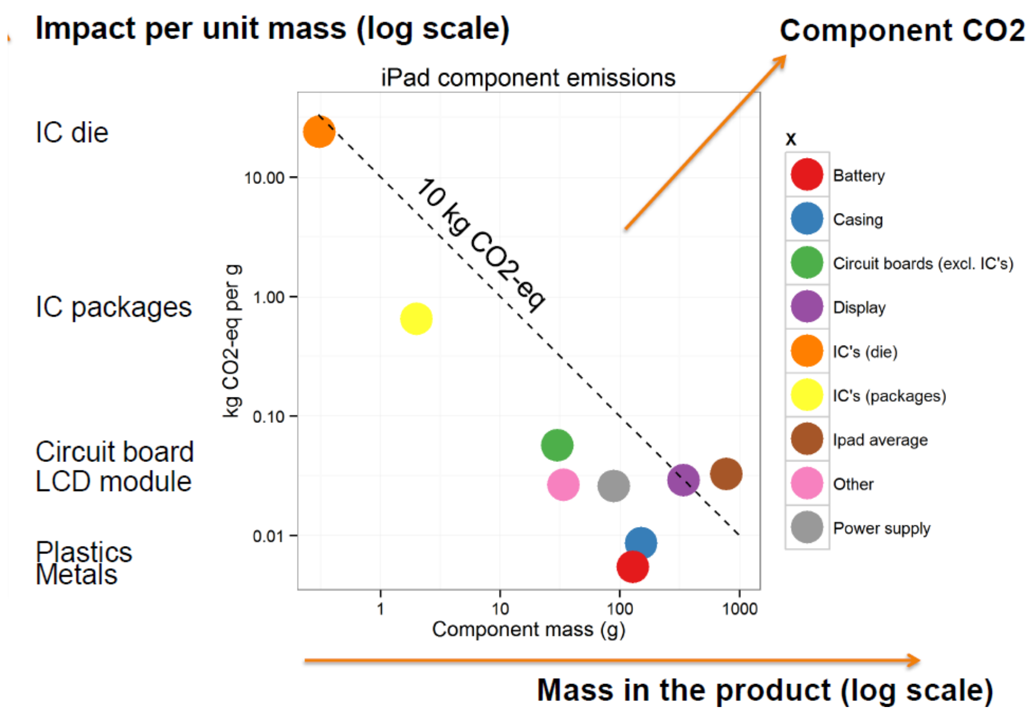

Figure 8: Component CO2 Impact by Mass[22]

[19] Moberg, Asa et al., "Printed and Tablet E-paper Newspaper from and Environmental Perspective – A Screening Life Cycle Assessment," *Environmental Impact Assessment Review* 30, No. 3, April 2010.

[20] Embodied CO_2 included emissions from materials extraction through component production and final product assembly, including transportation within the supply chain, but did not include final transport to the end user, the use phase, or end of life. It was noted that the data available was limited.

[21] Teehan, "LCA Studies of Tablets; Embodied CO2 of Tablets; Comparison with Similar Products", *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

[22] ibid.

A study of notebook computers published by the Federal Agency of Environment in Germany concluded that the environmental impacts of production are "so high" that they cannot be compensated for by energy efficiency gains in the use phase. In this 2011 study, production accounted for 56% of total GHG emissions for a notebook with a 5 year use phase. With a 10% increase in energy efficiency, replacement of the notebook was justified after 33 to 89 years from the perspective of environmental impact, emphasizing the importance of extending the useful lifetime of the product.[23] At the GEC/DOE Workshop, the study's authors presented similar results for a tablet computer (see Figure 9), estimating that it would take 28 years to recoup the global warming potential (GWP) impact resulting from the production of a 20% more energy efficient tablet.[24]

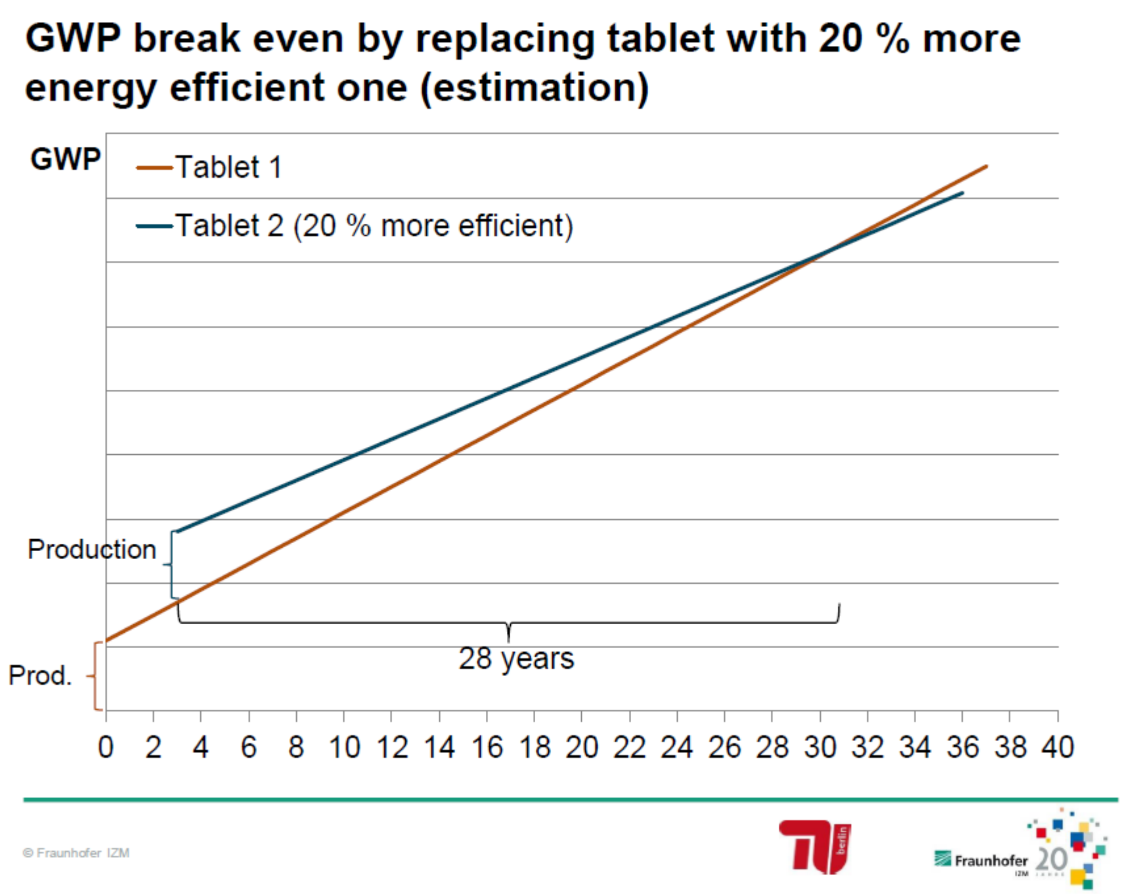

Figure 9: Global Warming Potential (GWP) of Two Tablets[25]

[23] Siddharth Prakash, Ran Liu, Karsten Schischke, and Dr. Lutz Stobbe, *Timely replacement of a notebook under consideration of environmental aspects,* Umwelt Bundesmat (Federal Agency of Environment in Germany), September 2012. http://www.umweltbundesamt.de/publikationen/timely-replacement-of-a-notebook-under

[24] Marwede, Fraunhofer IZM, "Disassembly of Tablets; Examples of Designs for Easy Access to Components", *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

[25] ibid.

The various LCA studies discussed above reveal several opportunities to reduce the environmental impact of computing products, including, where feasible, replacing heavier computing devices (e.g., desktop and monitor) with lighter weight, integrated products such as notebooks and tablets. Extending the life of the product and reusing components will also reduce the impacts from production of new components.

5.0 Environmentally Sensitive Substances/Materials

As tablets are fairly consistent in terms of materials with similar product categories, they are not unique in their use of environmentally sensitive substances/materials. A report, *Information on Chemicals in Electronic Products*[26], provides information on chemicals present in electronic products, specifically focused on computers and mobile phones. The report states that the main hazardous substances found in computer and mobile phones include lead, mercury, cadmium, zinc, yttrium, chromium, beryllium, nickel, brominated flame retardants, antimony trioxide, halogenated flame retardants, polyvinyl chloride (PVC), and phthalates. Tablets contain LED technology and therefore do not contain mercury.

Discussion of tablet-specific environmentally sensitive substances at the GEC/DOE Workshop was limited. However, meeting participants identified some potential areas and substances of concern during production of tablet computers, including semiconductor manufacturing, fluorinated greenhouse gases used in flat panel display manufacturing, and indium tin oxide used to coat displays.

It is also important to note that materials use in tablets is becoming increasingly complex as more components are added to shrinking form factors, as manufacturers increase use of more complex mixtures of materials – both plastic mixtures and metal alloys - and as designs increasingly rely on critical minerals[27] without demonstrated ability to recover them.[28]

Tablet devices are similar to other products such as mobile phones and notebooks in the amount of special handling required at end-of-life due to environmentally sensitive substances/materials. However, the reduction in potential worker and environmental exposure due to lack of mercury lamps in tablets considerably reduces the need for special handling over that required in older laptops. Tablets also do not typically contain lithium button cells, which can be a fire hazard. A recycler at the GEC/DOE Workshop whose operation does not include shredding these devices indicated that for worker safety, mechanical hazards such as broken glass or getting a screw in the eye are of more significant concern.

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[26] Nimpuno, N & C Scruggs, *Information on Chemicals in Electronic Products*, 2011. http://www.chemsec.org/images/stories/publications/ChemSec_publications/110629_Information_on_Chemicals_in_Electronic_Products.pdf

[27] U.S. Geological Survey, "Going Critical: Being Strategic with Our Mineral Resources", December 13, 2013. http://www.usgs.gov/blogs/features/usgs_top_story/going-critical-being-strategic-with-our-mineral-resources/

[28] Kyle, "What Does the Growth in Semiconductor Components in Tablets and Smart Phones Mean for Resource Optimization?", *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

6.0 Energy Efficiency

In January of 2012, the California Energy Commission (CEC) adopted energy efficiency regulations for battery chargers, including those found in tablets.[29] EPA analyzed the CEC data for small battery chargers for CEC-certified tablets as shown in the graph below (Figure 10). This graph shows how close the individual active charging performance of certified tablets are to the CEC active requirement, which is based on a combination of measured charge and maintenance energy over a 24 hour period.

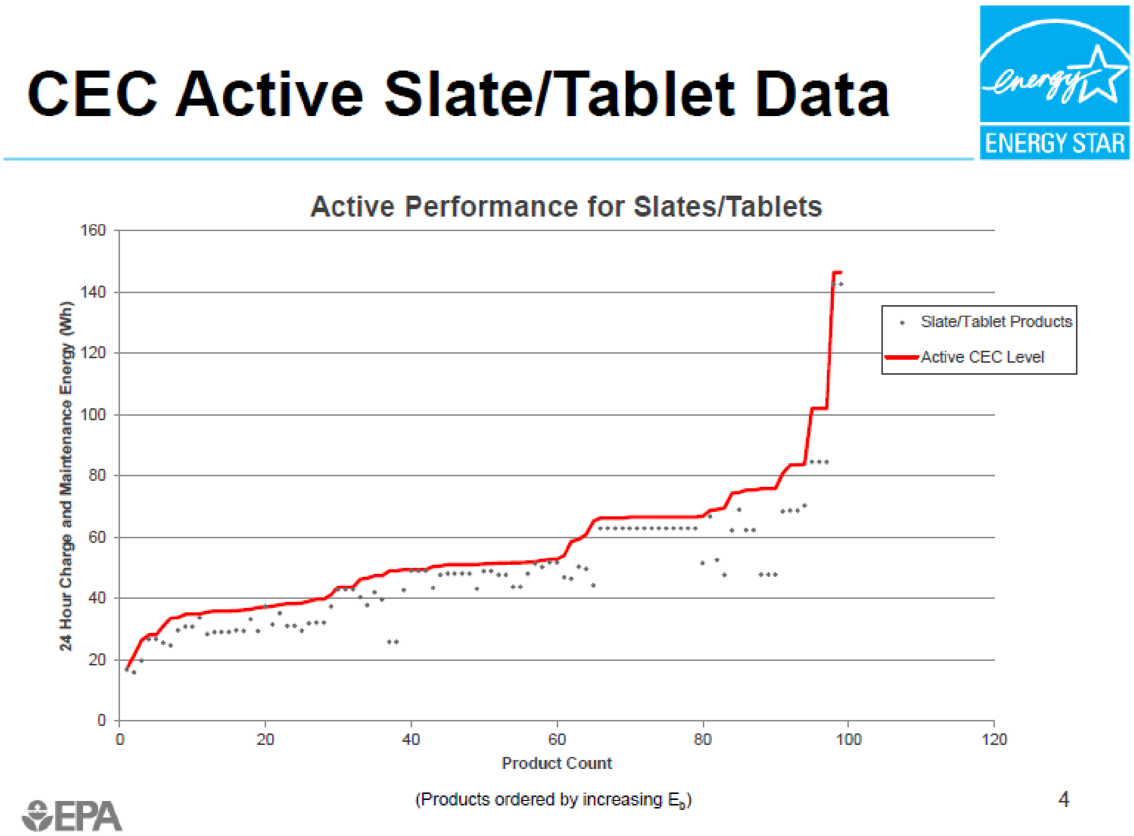

Figure 10: EPA Analysis of CEC Data on Tablet Energy Consumption[30]

After analyzing this data from the CEC, EPA concluded that there is little, if any, opportunity for differentiation in tablets' active charging efficiency beyond the current CEC requirements. Therefore, EPA has proposed to sunset the ENERGY STAR specification for Battery Charging System products and instead addresses the energy performance of tablets through an upcoming Version 6.1 Computers Specification revision.[31]

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[29] California Energy Commission (CEC), "Battery Charger Systems and Self-Contained Lighting Controls Rulemaking", 2013. http://www.energy.ca.gov/appliances/battery_chargers/

[30] Clinger, ICF International, "What is Happening with ENERGY STAR Specifications?", *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

[31] ibid.

According to Clinger, it is possible that many tablets will be able to meet the ENERGY STAR Computer Specification performance requirements. However, incorporating tablets into this ENERGY STAR specification will generate additional data for these devices that could be used to further differentiate tablet products in future specifications. It might also allow them to be recognized as more energy-efficient alternatives compared to traditional notebook computers, depending on the end-user's needs.[32]

The proposed energy performance requirements for tablets in the ENERGY STAR Computer Specification Version 6.1 will be the notebook requirements in Table 6 of the specification, based on installed hardware (see Figure 11). Since Version 6.1 Computers Specification is still under development as of the publication of this report, the performance requirements are subject to change based on feedback from stakeholders.

Category Name	Graphics Capability[iv]	Desktop or Integrated Desktop		Notebook	
		Performance Score, P[v]	Base Allowance	Performance Score, P[v]	Base Allowance
0	Any Graphics dGfx ≤ G7	$P \le 3$	69.0	$P \le 2$	14.0
I1	Integrated or Switchable Graphics	$3 < P \le 6$	112.0	$2 < P \le 5.2$	22.0
I2		$6 < P \le 7$	120.0	$5.2 < P \le 8$	24.0
I3		$P > 7$	135.0	$P > 8$	28.0
D1	Discrete Graphics dGfx ≤ G7	$3 < P \le 9$	115.0	$2 < P \le 9$	16.0
D2		$P > 9$	135.0	$P > 9$	18.0

iv Discrete Graphics capability is categorized based on frame buffer bandwidth, as shown in Table 7 of the ENERGY STAR Version 6.0 Computers Eligbility Critera

v P = [# of CPU cores] × [CPU clock speed (GHz)] , where # of cores represents the number of physical CPU cores and CPU clock speed represents the Max TDP core frequency, not the turbo boost frequency.

Figure 11: ENERGY STAR Version 6.0 Computers Base TEC Allowances[33]

Recent research (not yet published) conducted by Paul Teehan at the University of British Columbia explored the total energy use of tablets beyond what is required to charge the device's batteries. The research focused on the energy consumed by the delivery of services and media-rich content to these devices (e.g., streaming movies, connectivity to mobile networks) and asked the question "Are we transferring some of the energy use from the device to the cloud?" Teehan's analysis indicate that energy consumed in networks and datacenters servicing tablet end-uses appears to significantly exceed the direct energy use of

[32] ibid.

[33] ENERGY STAR "Version 6.0 Computers Eligibility Criteria", U.S. EPA, October, 2013. http://www.energystar.gov/ia/partners/product_specs/program_reqs/Final_Version_6_Computers_Program_Requirements.pdf

tablet devices themselves, and that tablets connected to the mobile infrastructure incur a significant energy premium due to the higher energy cost per unit of running mobile networks.[34]

7.0 Repair, Refurbishment and End of Life

7.1 Challenges and Opportunities for Enabling Repair and Refurbishment

While there is limited information available about tablets' life expectancy and after-market value due to the relatively recent introduction of these products, significant work is being undertaken with regard to repair of these devices. One organization involved in the repairability of these devices is iFixit, an organization that provides guidance and tools for the repair of electronic products and a repairability scorecard.

iFixit promotes the following design principles to facilitate repair:[35]

- Make cases easy to open
- Make consumables (batteries) user-removable
- Use screws, not glue
- If it snaps shut, it should snap open
- Special/proprietary tools should be used only for very good reasons
- Avoid solder, particularly on batteries
- Use modular components
- Service manuals, circuit schematics and printouts are incredibly helpful for service technicians

The iFixit Tablet Repairability Scorecard rates devices based in the ease of disassembly (opening of the devices, types of fasteners, etc.), the complexity of replacing major components, upgradability, use of non-proprietary tools, component modularity and availability of a service manual.[36]

The experience of a recycler/refurbisher at the GEC/DOE Workshop indicates that the vast majority (on the order of 90%) of tablet failures are due to broken screens, which they can generally repair. For a refurbisher, spare parts availability, volume of devices, and the device market value impact the decision to repair versus recycle. If spare parts are not generally available (except to authorized-repair facilities), other repair facilities must rely on harvesting parts from other products, which, depending on availability, can limit the repair of some tablet makes and models.

There can be a tradeoff between repairability, reliability and durability (resulting in a longer life). For example, while screws and fasteners facilitate repair, use of adhesives may make the device more durable. A key challenge and question is - can these devices be designed for both durability and repairability?

[34] Teehan, "LCA Studies of Tablets; Embodied CO2 of Tablets; Comparison with Similar Products", *Slates/Tablets Workshop – Meeting Summary,* December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

[35] Schaffer, iFixit, "iFixit Slate/Tablet Tear Downs; Challenges and Opportunities for Enabling Repair", *Slates/Tablets Workshop – Meeting Summary,* December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

[36] iFixit, "Tablet Repairability", http://www.ifixit.com/Tablet_Repairability

Another recycler at the GEC/DOE Workshop indicated that tablets are becoming more difficult to repair due to:

- Low cost per unit
- Rapidly evolving features/functionality
- Cover difficult to open
- Difficult to justify labor for repair vs. cost of replacement
- Massive install base with limited number of properly trained repair techs

A refurbisher at the GEC/DOE Workshop indicated that there is a strong resale market for tablets. This company resells 100% of its refurbished tablet inventory (approximately 12,000 to 15,000 tablets/month) through eBay and another online reseller. Workshop participants noted that it is easier to sell used tablets in the U.S. than mobile phones, because the tablets market is not subsidized by carriers, like the mobile phone market, which artificially reduces the price of new mobile phones.

A joint report by McKinsey & Company and the Ellen MacArthur Foundation found that increasing reuse and refurbishment of mobile phones in the European market could reduce greenhouse gas emissions by 3 million tons of CO2 equivalents (or 65% or primary production emissions) and generate $2.2 billion USD in net material and energy savings. [37] Similar opportunities are likely for tablets.

7.2 Design for Disassembly for Repair and Recycling

In 2013, Fraunhofer IZM conducted a study, "Disassembly of Slates: An Evaluation of Repair and Recycling," to investigate the current status of tablet designs with respect to repair and recycling[38]. The study compared 21 devices for ease of opening the device and removing the battery, and dismantling the motherboard, display and subassemblies.

The study concluded that disassembly of the main components is complex and time-intensive. In every case, removal of the battery required multiple steps – ranging from a low of 3 steps to a high of 14 steps. Removal of the battery at end of life is required by the European Union WEEE Directive. Similarly, access to the motherboard and its precious metals content typically required numerous steps. Predictably, the study found that availability of disassembly instructions/procedures (manual or video) significantly improved the disassembly quality and time effectiveness.

The study included the following recommendations for design elements:

- Provide information regarding the opening mechanism
- Opening mechanism uses a slide rail, and no tools are needed, and the opening/closing is reversible
- Slide-lock cover for batteries and no tools are needed for removing/replacing batteries
- Ease of removal of the main board – few screws and connectors

[37] McKinsey & Company and the Ellen MacArthur Foundation, *Towards the Circular Economy, Volume 1*, page 41-42, 2012. http://www.ellenmacarthurfoundation.org/business/reports

[38] Fraunhofer IZM, *Disassembly Analysis of Slates: Design for Repair and Recycling Evaluation, Final Report*, August 9, 2013. http://www.izm.fraunhofer.de/content/dam/izm/de/documents/News-Events/News/2013/urn_nbn_de_0011-n-255111-18-1.pdf

- Damage-free separation of display unit from the device, and damage-free separation of the touch screen and LCD panel

7.3 Current Approaches to End of Life Management of Tablets

Material Recycling

As noted earlier in this report, tablets are a relatively recent introduction into the marketplace. Consequently, end of life managers have not been handling these products in large quantities nor for a substantial length of time. Therefore, there is limited data and information available about their recyclability.

ERI International, a large volume U.S. electronics recycler, provided a breakdown of the materials' value and cost to demanufacture a generic tablet. Table 2 shows a net loss of $0.50 per pound for material recycling when the cost of labor is factored in, indicating a less-than-favorable scenario for this end of life management approach. Workshop participants noted that if components were salvaged for spare parts the economics would be more favorable.

	wt.	units	% by wt.		Commodity Value ($/lb.)	Value/Device	
Cast aluminum	0.08	lb.	9.30%		$ 0.64	$ 0.05	
Digital boards	0.04	lb.	4.65%		$ 1.95	$ 0.08	
LCD screen	0.20	lb.	23.26%		$ (0.02)	$ -	
black plastic	0.34	lb.	39.53%		$ 0.28	$ 0.10	
Li ion batteries	0.2	lb.	23.26%		$ 0.10	$ 0.02	
Total weight	**0.86**		**100.00%**			**$ 0.24**	
						0.78	Labor cost
						$ (0.50)	total per pound

Table 2: Material Value Breakdown for Generic Tablet[39]

Another recycler at the GEC/DOE Workshop stated that the commodity value of various devices is driven by the mass of the printed wire board with tablets having a value of approximately $1.75. Notebooks, with a greater board mass, have greater value (~$3.50) and cell phones, with a small board mass, have less value (~$1.00).

Smelting for Precious Metals Recycling

Tablets that are not repaired typically go to a smelter for precious and special metals recovery. After the battery is removed, tablets (like cell phones) can be fed directly into a smelting furnace without shredding, due to their small size. However, the optional method of recovery of precious and special metals for tablets has not yet been determined in terms of whether the circuit boards should be removed prior to smelting. According to a representative from the recycling and metals recovery firm Umicore at the GEC/DOE

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[39] Watson, ERI International, "Key Metrics; Profile of Tablet/Slate Commodity at End of Life; Long-Term Outlook, *Slates/Tablets Workshop – Meeting Summary*, December 11-12, 2013. http://greenelectronicscouncil.org/wp-content/uploads/2013/12/slateswkshp/Slates-TabletsDec2013MeetingSummary.pdf

Workshop, 17 precious and special metals - a number of which are found in tablets - can be recovered in the Umicore smelting process for electronic devices. Precious and special metals typically recovered from the circuit boards and gold plating in contacts include palladium, platinum, rhodium, and ruthenium, plus selenium (displays), iridium (camera chip) and indium (LCD panels).[40] Processing of LCD panels as a single feed stream to recover metals (such as indium) is currently not economical.

Metals such as gallium (found in semiconductors and processors), silicon and rare earth metals (e.g., dysprosium from disc drives) are lost in Umicore's process. Rare earth metals are not currently recovered since the process flow cannot recover them in high enough concentration to make the process economical. Electronics scrap is not treated in isolated loads, but rather is mixed with all incoming materials.

Rechargeable batteries are recycled in a separate Umicore facility that recovers metals such as nickel and cobalt. A material fraction from the battery operation is also sent to a rare earth metal processor in France.

The "Metal Wheel" in Figure 12 from a United Nations Environmental Program (UNEP) report, *Metals Recycling, Opportunities, Limits, Infrastructure* shows the elements that are recovered, probably lost and definitely lost during typical metals recycling.[41] Each slice represents the complete infrastructure for production and refining of the main metals (also known as carrier metals) shown on the innermost circle. During refining of the main or carrier metals, other metals may be recovered depending on their compatibility with the carrier metal.

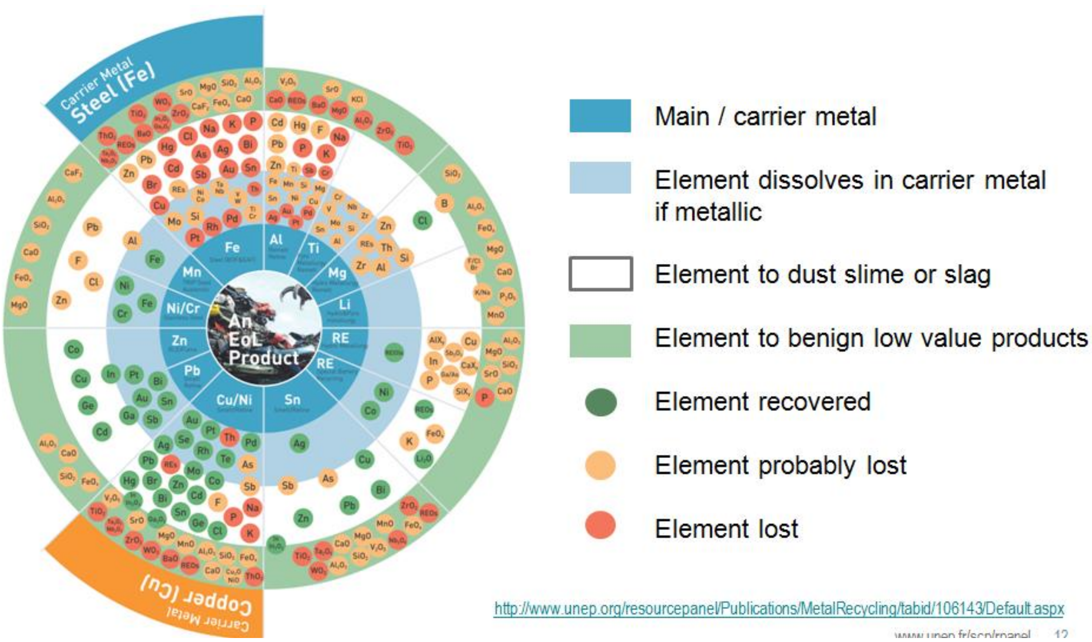

Figure 12: Metals Recovery by Main/Carrier Metal[42]

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[40] http://www.preciousmetals.umicore.com/PMR/AboutUs/

[41] United Nations Environmental Program (UNEP), *Metals Recycling, Opportunities, Limits, Infrastructure*, 2013. http://www.unep.org/resourcepanel/Portals/24102/PDFs/Metal_Recycling_Full_Report.pdf

[42] ibid.

8.0 In Conclusion

This report provides a foundation for future environmental standards development work by analyzing tablet markets and trends, providing an overview of the tablet supply chain, and presenting information on the material composition, environmental and energy performance and repair, refurbishment and end of life for this relatively new and growing product segment. While this report covers many aspects of the tablet life cycle questions remain for further exploration, such as:

- What are the key health and environmental impacts on workers and communities from manufacturing and mining associated with tablets?
- What tablet design choices can minimize environmental impacts and improve product sustainability?
- How to maximize product durability (lifespan) as well as repairability and/or recyclability of tablets? Does there need to be a tradeoff between them or can they all be optimized?
- What are the causes of the end of first life, the pathways for second life and the causes of final end of life?
- What is the feasibility and utility of developing a parts inventory infrastructure that would further enable repair and secondary market opportunities?
- Are there opportunities for charger and connector standardization? What are the tradeoffs?
- Which critical minerals and rare earth metals are contained in tablet devices? And are these recoverable with current or near future technology?
- What is the optimal method(s) for end of life processing to minimize environmental impact and protect worker health?

