EPEAT Standards Development Roadmap (EPEAT SDR)

Background Document

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Zero Waste Alliance

Prepared by Zero Waste Alliance
with support from
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and the
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Purpose

The purpose of this report is to summarize the available data used to help develop the EPEAT Standards Development Roadmap (SDR) recommendations. Data was collected for products of highest interest to stakeholders on existing environmental performance standards, market characteristics as well as environmental and energy impacts of the products under consideration.

The material presented in this document was developed by Zero Waste Alliance and the Center for Clean Products and Materials Policy at the University of Tennessee. It is intended for use as advisory background material. It is preliminary, based on material that is readily publicly available, and likely is not a complete representation of all the information available on these products. This report has been modified based on comments received on the draft document. We have included the most up-to-date data where available. While we believe this information to be useful, it has not been verified nor is it endorsed by this project. It is presented as reported findings for stakeholder awareness.

The data collected below is simply a snapshot. It is not intended to serve as a recommendation regarding how specific environmental issues should be resolved in future product environmental performance standards. While we believe it will be a useful resource for that work, we recognize that any future environmental performance standards development process will have to gather the most complete and timely data before setting detailed specifications.

1.0 Project Overview

1.1 Purpose of SDR Project

The purpose of the EPEAT Standard Development Roadmap (SDR) project is to develop recommendations for development of environmental leadership standards for electronic products that recognize higher environment performance. This is being conducted by gathering input from interested stakeholders on:

1) Which electronics products are the highest priority for the development of new environmental performance standards
2) Groupings of products for environmental performance standards development
3) Sequence and method of environmental performance standard development
4) Issues that need to be considered both in the prioritization and the actual standards development.

This project is being organized and facilitated by a Project Team consisting of representatives of EPA, Green Electronics Council and Zero Waste Alliance. This Team is soliciting and receiving the stakeholder input, and obtaining other sources of data and research to help make the project decisions.

Stakeholder input has been synthesized into a “Standards Development Roadmap” document with recommendations for the process and sequence for developing environmental performance standards for electronic products over the next few years. The recommendations of this Roadmap are expected to significantly inform the future activities for the development of electronic standards for EPEAT. This Roadmap, however, does not imply a commitment by any of the stakeholders or potential funders

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The Standards Development Roadmap recommendations will be implemented through product standard development processes by other groups, through involvement of stakeholders. These groups that will organize the development of the product standards have not been identified, though they will likely include representation from the Green Electronics Council, EPA, state and local governments, manufacturers, retailers, not-for-profit organizations and others.

The EPEAT SDR Project is being managed by Zero Waste Alliance (www.zerowaste.org) with support from U.S. EPA. More information on the project can be found at www.zerowaste.org/epeat/roadmap.htm.

1.2 Products of Highest Interest

Stakeholder input confirmed that the following products are of highest interest for development of environmental performance standards:

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- Mobiles devices – mobile phones, PDAs and SmartPhones
- Imaging devices – printers, copiers and multi-function devices
- Servers
- Televisions and television monitors

Background information on these products is presented in this document.

1.3 Preliminary Observations Regarding Energy and Environmental Considerations

Many of the products considered through this process share similar characteristics and components. All contain a combination of circuit boards, plastics parts and housings, and cabling. Several, including copiers, printers, and MFDs, contain glass components, and use some form of toner or ink. As a result, there are commonalities found across nearly all products, such as:

- Use of toxics metals such as cadmium, lead, mercury, and hexavalent chromium. Products that are manufactured for the European market likely contain significantly less of some materials than those that are not, due to the EU's RoHS directive. However, RoHS exempts certain products from these restrictions, such as the use of lead solders in servers and mercury in LCD displays.
- The lifecycle impacts of plastics production vary widely depending on resin type, and where and how it is produced. The components of some of the most prevalent plastics in electronic products, such as ABS, Polycarbonate, and PVC may pose a risk to workers in the manufacturing process. These impacts will be common among all the products. Product specific concerns are noted where data are available.
- Nearly all products use some flame retardants that have been identified as constituents of concern – including TBBPA (reacted into circuit boards), decabromodiphenyl ether (Deca-BDE – used primarily in housings are large plastic parts), and hexabromocyclododecane (HBCD – also used in housings and plastic parts). All these materials are currently allowed in products in the U.S., but there is significant ongoing research regarding their environmental fate and potential impact on human health and

the environment, and evaluating non-chlorinated alternatives[1]. This indicates a certain level of concern by both the public and private sectors about the lifecycle impacts of these materials. As an example, the State of Washington has banned the use of DecaBDE in certain electronics and home furnishings pending development of safer alternatives, and numerous manufacturers have eliminated or reduced their use of these materials. Though this concern is noted where appropriate, it does not represent a recommendation to "ban" these chemicals.

- Occupational and human health affects are presented for various aspects of electronics manufacturing in the following publications, but would likely apply to all electronics based devices:
    1) Printed Wiring Board Surface Finishes CTSA (Geibig and Swanson, 2001)
    2) Printed Wiring Board CTSA: Making Holes Conductive (Kincaid et al, 1998)
    3) Several include Liquid Crystal Displays (LCDs), which typically is a polycyclic aromatic hydrocarbon (PAH) between 2 thin layers of glass. Liquid crystal compounds are not acutely toxic, mutagenic, or otherwise known to be harmful to humans or the environment. Potential for chronic affects remains unknown. (King County, 2007)

There is not data which allows us to compare the relative quantity of these materials consistently across all the product categories. As a result, per unit mass and total market has been used as an indicator of total environmental impact, rather than a more detailed analysis of the quantity of individual constituents in the particular products.

As stated above, this is not meant to be a comprehensive compilation of data needed for setting environmental standards.

2.0 Mobile Devices (Mobile Phones, Smartphones and PDAs)

2.1 Existing Standards and Proposed Product Definition

Two existing standards were identified for mobile phones; TCO and Blue Angel. Blue Angel's definition was more complete in terms of the various protocols and functions currently in use in mobile phones. However, it did not include all of the existing and emerging protocols (including CDMA, IP-phones, etc.) None of the ecolabels reviewed included PDAs. The definition presented below is a modification of the Blue Angel Mobile Phone definition. The definition

[1] E.g. AEA. 2004. WEEE & Hazardous Waste. A report produced for DEFRA, UK Government. AEA Technology Report AEAT/ENV/R/1688.

J.A. Dye, M. Venier, C.R. Ward, L.Y. Zhu, R.A. Hites, L.S. Birnbaum: Pet Cats in the U.S. Have High Polybrominated Diphenyl Ether (PBDE) Serum Levels. Society of Toxicology 2007 meeting Abstract number 853.

Morose, Gregory: An Overview of Alternatives to Tetrabromobisphenol A (TBBPA) and Hexabromocyclododecane (HBCD), Lowell Center For Sustainable Production, University of Massachusetts Lowell, March 2006.

Fisher, Douglas, The 'toxic effect' of flame retardants, Oakland Tribune, June 3, 2007, www.insidebayarea.com/oaklandtribune/localnews/ci_6051904 focuses on the multi-functionality, to distinguish PDAs from single-purpose devices such as MP3 player or calculators.

Based on comments from the draft, we have modified the proposed definition for mobile phones to be very broad.

Proposed mobile phone definition mobile phone is a portable handheld device that transmits voice at a minimum and its principal function is two way vocal communication. The products shall be primarily designed for the transmission of telephone calls and messages. They may, however, offer additional functions, such as, for example, organizers, as well as wireless internet access and data transmission via infrared interfaces or Bluetooth.

Proposed SmartPhone definition: Smartphones are generally considered any handheld device that integrates personal information management and mobile phone capabilities in the same device. Often, this includes adding phone functions to already capable PDAs or putting "smart" capabilities, such as PDA functions, into a mobile phone. Examples include the Palm Treo, the Blackberry, and the Motorola Q. Smartphones functions can include games, mobile video, e-mail, music mp3 files, news and information, or video and picture taking.

Proposed PDA definition: Handheld devices that offer multiple functions including (but not limited to) personal contact storage and retrieval, calendar functions, music player, web browsing, as well as wireless internet access and data transmission via infrared interfaces, Bluetooth, or Wi-Fi. They should have a user interface that allows entering text via touch screen or keyboard.

2.2 Environmental Profile

<u>Product Profile</u>

Mobile phone specifications:

- Average mass per mobile phone without battery was estimated to be 91 grams- based on 2002- 2004 models (Socolof et al., 2007).
- Nokia mobile phone 3595 – 113 grams (Nokia, 2005).
- Average mass of mobile phone and battery – 136 grams (Socolof et al, 2007).
- Average mass of small sampling of batteries - 28 grams (Geibig, 2007).

(Many other sources available for typical mobile phone mass)

Mobile phones typically consist of the following components (IPMI, 2003):

- Electronic circuitry – primarily containing metal circuitry (see below for details), a fiberglass or epoxy resin circuit board, solder containing tin, lead, silver or other metals, and components of various types and compositions.
- Antenna- metal coil antenna (internal) or an external solid or telescopic antenna.
- LCD screen- contains a liquid crystal compound typically a polycyclic aromatic hydrocarbon (PAH) between 2 thin layers of glass. Typically less than 5 mg liquid crystal (http://www.umweltbundesamt.de/uba-info-daten-e/daten-e/lcd.htm).
- Battery – Nickel cadmium (rare), nickel metal hydride, or lithium ion.
- Plastic case or shell- typically made from poly carbonate (PC), acrylonitrile butadiene styrene (ABS), or a mixture thereof.
- Charging base or connector – transformer, wires, and sometimes a plastic base typically made from PC, all used to recharge the battery.
- Accessories- ear phone, blue tooth, etc.

Mobile phones are comprised of the following, exclusive of battery and charger (USGS Fact Sheet, 2006):

- 58% Plastics
- 25% Metals- incl. copper, iron, nickel, silver, zinc, with small amts of aluminum, gold, lead, manganese, tin, platinum, and palladium
- 16% Ceramics
- 1% Flame retardants
- Less than 5 mg liquid crystal (http://www.umweltbundesamt.de/uba-info-daten-e/daten-e/lcd.htm)

Note: Additional detailed breakdown information is also presented in the following references: (Basel, 2006) (http://www.nokia.com/link?cid=EDITORIAL_65032)

Content Specific Environmental or Human Health Concerns

Materials of concern likely found in mobile phones sold today include (Socolof, 2007):

- Metals - lead and hexavalent chromium
- BFRs - tetrabromobisphenol-A (TBBPA) and decabrominated biphenyl ether (DBBE)
- Mercury has been effectively phased out of use in modern mobile phones (Basel, 2006)
- Liquid crystal compounds are not acutely toxic, mutagenic, or otherwise known to be harmful to humans or the environment. Potential for chronic affects remains unknown. (King County, 2007).

Table: Potentially hazardous metal content in mobile phones (IPMI, 2003)

Lead	< 0.5 g	Solder content in older phones. Lead has been banned by ROHS for future phone mfg. – Lead is a PBT
Cadmium	7 g (est.)	Contained in some batteries, typically less than 25% of the battery mass. Mass reported was estimated using 28 g average mass of small selection of batteries (Geibig, 2007)
Beryllium	0.1 grams	Used at electronic circuitry connection points. Beryllium is an inhalation threat to workers.
Silver	1-3 g +	Contained in pad contact as well as in lead free solders (Geibig and Socolof, 2005). Silver is an extreme aquatic toxin.
Copper	common	Most commonly used metal used mostly in electronic circuitry of phone- Copper is an aquatic toxin

Note: More information on other metal content in IPMI report (IPMI, 2003)

Environmental data on mobile phone batteries include:

- Nickel-cadmium batteries have been phased out in mobile phones today, though older phones in storage may still contain them (Basel, 2006)
- Modern phone batteries are based on lithium ion or Nickel metal hydride technology
- Potassium hydroxide and/or lithium cobalite compounds used in battery technologies are corrosive to skin and can cause potentially serious chemical burns upon contact (IPMI, 2003)

Plastics used in most mobile phones include PC, ABS, or some combination of PC/ABS. The plastics themselves do not pose a threat to human health during the use stage. However, the plastics do have life-cycle issues associated with all the plastics used in electronics mentioned above in Section 1.3.

Manufacturing and Use Impacts

Mobile phones do not appear to pose a threat to human health during their normal use, but could result in the release of potentially harmful compounds if not handled and disposed of properly at end-of-life (Mueller, et al, 2003). No information was obtained regarding occupational and environmental health affects during the manufacturing process that are specific to mobile phones.

End of Life

The following information regarding end-of-life disposition and recycling of mobile phones was reported:

- 130 million mobile phones were retired annually in the United States in 2005 (U.S. EPA, 2005), equivalent to:
    - 14,000 metric tons
    - 2,100 metric tons of copper
    - 46 metric tons of silver
    - 3.9 metric tons of gold
    - 2 metric tons of palladium
- 500 million obsolete mobile phones by 2005 would be stored by consumers awaiting disposal (INFORM, 2003).
- Less than 1 % of mobile phones retired annually are recycled. (INFORM, 2003). It is unclear, however, the percentage of retired phones that are held by consumers waiting for disposal. The actual rate of obsolete phones discarded in municipal solid waste is unknown.
- Typically, mobile phones are used for only 1½ years before being replaced (IPMI, 2003).
- Mobile phones at end of life can be effectively refurbished and reused without harm to human health or the environment (IPMI, 2003).
- Many mobile phones are refurbished and sold to developing countries.
- All three battery types can be readily recycled using currently recycled technologies.
- NiCd batteries are considered hazardous waste in many countries at end of life.
- Liquid crystal compounds cannot currently be reclaimed at end of life economically (King County, 2007).

Leachability results from mobile phones indicate that the following metals all leached in amounts that exceeded the Total Threshold Limit Concentrations (TTLC): Copper, Lead, Chromium, Nickel, and Antimony (California DTSC, 2004).

2.3 Energy Profile

Energy Consumption- Use Phase

- Mobile phones are typically powered by batteries, so energy usage is dependent on battery technology, capacity, phone use, and phone feature set.
- Energy use profiles were identified for individual specific phones:
    - Casio W51CA with digital TV tuner – 250 minute duration of mobile phone communication requires 140 minutes of charging time (http://www.mobilewhack.com/casio-w51ca-digital-tv-phone)
- Energy consumption and use profiles for mobile phone chargers were measured to be (Rosen and Meier, 2001):
    - 1 W while machine is in standby, 75% of the time
    - 5 W while in charging, 5% of the time

Life-Cycle Energy/Embodied Energy

- Life cycle embodied energy estimated to be 463 kWh/kg of phone– excludes batteries, LCD, and camera (Socolof et al, 2007)
- No life-cycle manufacturing data specific to mobile phone batteries was readily identified

2.4 Market Characteristics

Overall, mobile phone sales and SmartPhone sales show strong increases, while PDA sales have fallen over the past year. PDAs are being replaced by SmartPhones with multiple services and features.

The following **usage data** for the U.S. and worldwide were reported:

- 1 billion mobile phones in use worldwide in 2002 (USGS Fact Sheet, 2006)
- 180 million in use the U.S. in 2004 (USGS Fact Sheet, 2006)
- An estimated 2.6 billion mobile phones are projected to be in use world wide by the end of 2009 (Gartner, 2005)

Market **sales data** reported include:

- Worldwide, mobile phone sales of 779 million units per year were reported for 2005 (USGS Fact Sheet, 2006)
- Cell phone sales are projected to exceed 1 billion units per year world wide in 2009 (Gartner, 2005)
- U.S. consumer sales of cell phones and PDAs doubled every 5 years from 2002 to present and will be 130 million units in 2007 (CEA, 2007)
- PDA handheld sales worldwide dropped 28.5% in 2006, primarily due to converged mobile devices and SmartPhones (IDC, 2007b)
- PDA sales worldwide for 2006 totaled 5.5 million units (IDC,2007b)
- Converged mobile device market grew 42% in 2006 totaling over 80 million units sold world wide (IDC, 2007a)
- SmartPhone sales grew by 63% in 2006 to 64.1 million units worldwide (Palm Infocenter, 2007)
- Projected sales to exceed 200 million SmartPhone sales in 2008 (Gartner, 2005)
- SmartPhone penetration of U.S. market is 2.0% ranging up to 6.6% in other countries (M:Metrics, 2006)

3.0 Printers

3.1 Existing Standards and Proposed Product Definition

Six existing standards were identified for printers; ENERGY STAR, TCO, Nordic Swan, Japanese Eco-Mark, Environmental Choice EcoLogo and Blue Angel. Printers capture a broad range of devices and technologies that put images on paper. A definition was sought that encompassed both the various technologies (e.g. laser vs. ink jet), and modes of use (e.g. stand alone, networked, etc.) typical of office printers. The ENERGY STAR and Nordic Swan definitions, which are the same, appear to be the most easily understandable and complete.

Proposed product definition from ENERGY STAR: A commercially-available imaging product that serves as a hard copy output device, and is capable of receiving information from single-user or networked computers, or other input devices (e.g., digital cameras). The unit must be capable of being powered from a wall outlet or from a data or network connection. This definition is intended to cover products that are marketed as printers, including printers that can be upgraded into multi-function devices in the field.

3.2 Environmental Profile

Product Profile

No information was located.

Content Specific Environmental or Human Health Concerns

Based on comments from the draft document, we suggest that the following information associated with toner be verified and updated. Several commenters indicated that the data cited below is out of date, and that the carbon black in modern toners do not pose the suggested risks. However, these are the most recent publicly available articles on the topic that were found during this research.

- Toner powder consists of 70-95 % synthetic resin, 15-20 iron oxide, and 0-5 % carbon black (Ahmadi et al, 2003).
- Carbon black can contain traces of nitropyrenes and polyaromatic hydrocarbons discovered to be a potential cause of mutagenic effects (Nicholson, 1989).
- Entrained dust from toner cartridges can pose a respiratory threat for the worker changing or refilling the toner cartridge (Ambruster et al., 1996).

Printers may also include brominated flame retardants that have been identified as constituents of concern above (TBBPA in circuit boards and DecaBDE) A number of manufacturers have voluntarily removed DecaBDE from their products (see www.hp.com/hpinfo/globalcitizenship/environment/productdesign/materialuse.html), either through substituting other flame retarding chemicals (to primarily phosphorous-based products) or changing plastic types. Time did not permit a careful analysis of the environmental or human health impacts of those alternative approaches.

Manufacturing and Use Impacts

Based on comments from the draft document, we suggest that the following information regarding the use impacts be verified and updated. Several commenters indicated that the data cited below is out of date, and that the indoor air concerns for modern printers do not pose the suggested risks. However, these are the most recent publicly available articles on the topic that were found during this research.

Operation of printers contributes to poor indoor air quality through the generation and release of ozone, TVOCs, and particulate matter:

- When in use, electrophotographic (laser) printers create a strong corona effect responsible for generating ozone through the reaction of charged ions and electrons with atmospheric gases (Lee et al, 2001).
- Tests indicate generation of ozone to be 10 ppm and did not exceed the World Health Organization guideline for ozone of 150 micrograms/m^3 (Lee at al., 2001).
- Charcoal filters capable of reducing ozone levels from 430 micrograms/min to 100 micrograms/min are available on some models (Aerias, 2007).
- Ozone can cause asthma, throat irritation, and other respiratory ailments.
- At least one study reported maximum particulate levels from laser printers in excess of the national ambient air quality standard of 75 micrograms/m^3 (Lee et al., 2001).
- Entrainment of toner into the indoor air has been reported at least in one case to lead to acute or chronic distress (Ambruster, et al., 1996).

- The four greatest measured VOC emissions were toluene, ethylbenzene, m-p-xylene, and styrene, all used as solvent in toner (Lee, et al., 2001).
- Styrene, benzene, toluene, and xylene are all suspected or known human carcinogens.
- TVOCs released by laser printers were 6 times that of Ink Jet printers due to the higher fusing temperatures volatilizing VOCs in the toner (Lee et al., 2001).

End of Life

- Ink jet printers average lifetime is approximately 4 years, triggered by repair or obsolescence (EUP, 2007).
- Second hand markets for Ink Jet printers are virtually non-existent (EUP, 2007).
- Electrophotographic printers average lifetime is approximately 6 years, triggered by repair or obsolescence (EUP, 2007).
- 22,000 metric tones per year of office equipment waste were generated in the EU for 2006 (EUP, 2007).
- Canon claims remanufacturing allows for 89% of product parts and materials to be recycled into other imaging products of equal or greater value (Canon, 2006).
- 97% of the content of toner cartridges can be reused or recycled (NAGPI, 2007)
- At least one study indicated that printers leached copper, lead, and antimony at levels that exceeded regulations (Cal DTSC, 2004).

3.3 Energy Profile

Energy consumption- Use Phase

Measurement of the energy consumption of office equipment is made difficult by the many operational modes and varying usage patterns of the individual devices. Energy estimates and usage patterns for **printers** identified in the research include the following:

- Energy consumption measured for printers during operational mode include (Rosen and Meier, 2000):
    - Standby mode- 3.6W (49% time)
    - Idle mode- 12.1W (50% time)
    - Active mode- 361W (1% time)
- Total estimated average annual energy consumption for printers – 100 kWh/yr (Rosen and Meier, 2000).

3.4 Market Characteristics

There is convergence with other imaging devices in the consumer printer market, and likely a decline in single function consumer printers (with the exception of the consumer single function photo printer).

The following sales information was collected – note that the definitions of "printers" may vary accounting for the differences in quantities.

- According to IDC's Worldwide MFP Forecast and Analysis 2006-2010 (IDC, 2006) the U.S. sales for printers are projected to be:
    - 2007 -12.7M units
    - 2010 – 11.2M units
    - Projected decrease of 15% from 2007 to 2010
    - Institutional vs. consumer split market:
        - 2007 - 52% institutional and 48% consumer
        - 2010 –57% institutional and 43% consumer

- CEA estimates that U.S. **consumer** sales of printers (product as defined by CEA) are relatively flat at 20 million units/year (CEA, 2007).
- In 2005, a total of 106.8 million printers were estimated to be in use in the European Union- 90.2 million Ink Jet and 16.6 million EP printers (EuP, 2007a).
- Toner sales in the EU are reported as 220,000 tonnes/yr, and are expanding 3-5% per year (Wacker, 2006).

4.0 Copiers

4.1 Existing Standards and Proposed Product Definition

All five of the eco-labels reviewed, as well as Environmental Choice EcoLogo, include copiers in their standards. Copiers include a broad range of technologies that create multiple copies from hard copy or electronic originals. Most definitions in existing eco-labels focus on the "sole function" of making copies from paper originals, to distinguish them from standard desktop printers. However, most include equipment that can be upgraded to operate on a computer network. Several of the labels distinguish copiers from "digital duplicators", which use a stencil input with digital reproduction. The definition used by ENERGY STAR and Nordic Swan was selected; however there were not great differences between these and the others.

Proposed product definition from ENERGY STAR: A commercially-available imaging product whose sole function is the production of hard copy duplicates from graphic hard copy originals. The unit must be capable of being powered from a wall outlet or from a data or network connection. This definition is intended to cover products that are marketed as copiers or upgradeable digital copiers (UDCs).

4.2 Environmental Profile

Product Profile

No information was located.

Content Specific Environmental or Human Health Concerns

See printers, above. The content specific concerns for copiers are similar to those cited for printers.

Manufacturing and Use Impacts

Based on comments from the draft document, we suggest that the following information regarding the use impacts be verified and updated. Several commenters indicated that the data cited below is out of date, and that the indoor air concerns for modern printers do not pose the suggested risks. However, these are the most recent publicly available articles on the topic that were found during this research.

Operation of copiers contributes to poor indoor air quality through the generation and release of ozone, VOCs, and particulate matter:

- When in use, copiers create a strong corona effect responsible for generating ozone through the reaction of charged ions and electrons with atmospheric gases (Lee et al, 2001).
- Tests for 5 copiers found ozone ranging from 16-131 micrograms/copy prior to routine maintenance, which reduced ozone emissions to 1-4 micrograms/copy afterwards (EPA, 1995).

- U.S. manufacturer for six different copiers gave time weighted average concentrations for ozone ranging from 0.010 ppm (10 ppb) to 0.066 ppm (66 ppb) (Nicholson, 1989).
- Charcoal filters are available on some models that are effective at decomposing 94% of the ozone into oxygen (Nicholson, 1989).
- Ozone can cause asthma, throat irritation, and other respiratory ailments.
- The four greatest measured VOC emissions were toluene, ethylbenzene, m-p-xylene, and styrene, all used as solvent in toner (Lee, et al., 2001).
- Styrene, benzene, toluene, and xylene are all suspected or known human carcinogens.
- Entrainment of toner into the indoor air has been reported at least in one case to lead to acute or chronic distress (Ambruster, et al., 1996).

End of Life

- EP copiers average lifetime is approximately 6 years, triggered by repair or obsolescence (EUP, 2007b).
- Frequent leasing of copiers likely to lead to more frequent upgrading to improve product energy performance (EUP, 2007c).
- 97% of the content of toner cartridges can be reused or recycled (NAGPI, 2007).

4.3 Energy Profile

Energy Consumption- Use Phase

Measurement of the energy consumption of office equipment is made difficult by the many operational modes and varying usage patterns of the individual devices. Energy estimates varied drastically in identified sources likely resulting from differences in personal and professional machines. Energy estimates and usage patterns for **copiers** identified in the research include the following:

- Energy consumption measured for copiers during operational mode include (Rosen and Meier, 2000) (Ahmadi et al., 2003):
    - Standby mode- 4 -360 W (0% time)
    - Idle mode- 30 W- 1920 W (99% time)
    - Active mode 100 W- 7440 W (1% time)
- Total estimated average annual energy consumption for copiers – 270 kWh/yr (Rosen and Meier, 2000)

4.5 Market Characteristics

According to IDC's Worldwide MFP Forecast and Analysis 2006-2010 (IDC, 2006), the U.S. sales for copiers is projected to be:

- 2007 -1.33M units
- 2010 – 1.26M units
- Projected decrease of 5% from 2007 to 2010
- Institutional vs. consumer split market:
    - 2007 - 100% institutional and 0% consumer
    - 2010 –87% institutional and 13% consumer

There are a reported 6.3 million electrophotgraphic copiers in use in the European Union in 2005 (EuP, 2007a).

5.0 Multi-Function Devices (MFDs)

5.1 Existing Standards and Proposed Product Definition

Multifunction devices typically combine the functions of a copier, scanner, printer, and sometimes a fax machine. ENERGY STAR, Nordic Swan and Eco-mark specifically define MFDs, though the latter two cover them in their copier standards. TCO and Blue Angel simply include MFDs in their definition of a "printer" and include MFDs in their printer standards. The selected definition was common to those that specifically addressed the product. Environmental Choice EcoLogo also includes MFDs in their standards.

Proposed product definition from ENERGY STAR: A commercially-available imaging product, which is a physically-integrated device or a combination of functionally-integrated components, that performs two or more of the core functions of copying, printing, scanning, or faxing. The copy functionality as addressed in this definition is considered to be distinct from single sheet convenience copying offered by fax machines. The unit must be capable of being powered from a wall outlet or from a data or network connection. This definition is intended to cover products that are marketed as MFDs or multifunction products (MFPs).

5.2 Environmental Profile

Specific data on MFDs was not located, with the exception of the life span information below. The environmental profile of MFDs is likely similar to the combined profiles of printers and copiers.

End of Life

- Ink jet MFDs average lifetime is approximately 4+ years, triggered by repair or obsolescence (EUP, 2007b).

5.3 Energy Profile

Specific energy estimates and usage patterns for MFDs was not identified in this research. However, the environmental profile of MFDs is likely similar to the combined profiles of printers and copiers.

5.4 Market Characteristics

According to IDC's Worldwide MFP Forecast and Analysis 2006-2010 (IDC, 2006), the U.S. sales for MDFs is projected to be:

- 2007 -19.8M units
- 2010 – 21M units
- Projected increase of 6% from 2007 to 2010
- Institutional vs. consumer split market:
    - 2007 - 87% institutional and 13% consumer
    - 2010 - 87% institutional and 13% consumer

6.0 Servers

6.1 Existing Standards and Proposed Product Definition

Servers are a broad category of equipment that range from desktop-sized units to large, modular rack mounted systems requiring significant infrastructure. Any future environmental performance standard will likely have to address the similarities (and differences) between all servers; desktop derived, mid-range, and larger servers. These products differ in their design cycles, their expected serviceability and reliability, utilization rates, configurations, and other attributes. This needs to be considered in developing final requirements for a purchasing specification. In addition, high end systems have stringent serviceability and reliability requirements which require the use of some materials which may not be present in smaller, desktop derived servers.

One existing environmental standard was identified for servers: ENERGY STAR. ENERGY STAR divides servers into two categories – desktop derived servers, which fall under their new computer standard, and mid-range and larger servers, for which standards are currently in development. A number of commenters suggested we follow or adopt the definitions that are developed within the ENERGY STAR effort to establish specifications for servers and datacenters. Those definitions have not yet been published. As a reference, we include the ENERGY STAR definition for desktop derived servers below, recognizing that it is not complete for this product category.

Current definition from ENERGY STAR:
Desktop-Derived Servers (in ENERGY STAR's computer standard):
A desktop-derived server is a computer that typically uses desktop components in a tower form factor, but is designed explicitly to be a host for other computers or applications. For the purposes of this specification, a computer must be marketed as a server and have the following characteristics to be considered a desktop-derived server:

- Designed and placed on the market as a Class B product per EuroNorm EN55022:1998 under the EMC Directive 89/336/EEC and has no more than single processor capability (1 socket on board);
- Designed in a pedestal, tower, or other form factor similar to those of desktop computers such that all data processing, storage, and network interfacing is contained within one box/product;
- Designed to operate in a high-reliability, high-availability application environment where the computer must be operational 24 hours/day and 7 days/week, and unscheduled downtime is extremely low (on the order of hours/year);
- Capable of operating in a simultaneous multi-user environment serving several users through networked client units; and
- Shipped with an industry accepted operating system for standard server applications (e.g., Windows NT, Windows 2003 Server, Mac OS X Server, OS/400, OS/390, Linux, UNIX and Solaris).

6.2 Environmental Profile

Product Profile

Servers can be grouped into at least three categories:

- Blade servers- Blade enclosure contains all non-computing functions such as power supply, cooling, and network connections; while multiple blade computers containing memory, HDs, and processors perform the computing functions of the server
  - Components in blade enclosure serve all blades limiting the need for multiple devices such as power supplies, fans, and i/o devices.
  - Multiple motherboards, processors, hard drive units, and memory modules to match the number of blades in the system.
- Rack Servers- A rack system with individual stand alone server units networked together often with redundant feature sets to meet a higher operational load.
  - Rack frame of aluminum or steel to provide structure, connections, and security

    - Server units (essentially stand alone) containing most components central to computing including circuitry, power supplies, i/o connections, cooling, processors, memory, etc.
- Off the shelf servers- Servers resembling personal computers commonly available on the consumer market are networked together to perform server functions.
    - Composition resembles a multiple of a personal computer case without display devices, floppy drives and multimedia components.
    - Will likely be handled well by existing EPEAT standard for computers

Server specifications: due to the wide variation in data server size, type and configuration, it is difficult to provide basic average across the product category. Data provided below relates to specific models. Mass of individual servers range from 14.1- 22.7 kg:

- Apple XServe RAID, 31.7 pounds (14.4 kg) for base configuration (www.apple.com/xserve/specs.html)
- HP 24xx series rp2430/rp2470, 22.7 kg
- Dell PowerEdge SC1435, maximum weight of 31 pounds (14.1 kg)

Typical server components include:

- Printed wiring board – primarily containing metal circuitry (see below for details), a fiberglass or epoxy resin circuit board, solder containing tin, lead, silver or other metals, and components of various types and compositions
- Power Supply- transformer, metal cage, wiring, metal heatsink, fans, and circuitry with components
- Hard drives
- Microprocessors
- Cooling fans
- Network or input/output connections
- Plastic case or shell- typically made from poly carbonate (PC), acrylonitrile butadiene styrene (ABS), or a mixture thereof. Also likely to contain brominated flame retardants that may be hazardous to human health

Content Specific Environmental or Human Health Concerns

Servers components are similar in composition to other computer products, so they likely have similar constituents of concern. Servers are exempt from the RoHS restrictions on lead in solder, so they likely contain significantly more lead solder than electronic products that are covered by RoHS.

Larger rack systems and data centers also may have significant infrastructure equipment (e.g. cooling, power reliability systems, cabling) that contain additional constituents of concern. We have not researched these in depth.

Servers are much more processor and memory modules intensive than other electronic devices, such that dram memory module require 3.5 pounds of fossil fuels, 0.16 pounds of chemicals, 70.5 pounds of water and 1.5 pounds of elemental gases-mainly nitrogen to manufacture (http://www.eurekalert.org/pub_releases/2002-11/acs-ttp110502.php).

End of Life

Very little information specific to the end-of-life disposition and recycling of servers was found. Many anecdotal sources were found, which suggest that servers are somewhat unique in being used as long as serviceable, as well as often being stored on site for long periods of time. "The biggest issue in server disposal is getting around to it. In the rush to handle new technologies, many companies send aging boxes somewhere to be handled "later." Yet, there they sit, sometimes for as long as half a decade." ("Hardware Today: Strategic Server Disposal," www.serverwatch.com , 9/18/2006).

Electronic circuitry, processors, and other typically computer-based server components can be reclaimed, reused, or recycled at EOL using traditional electronic recycling processes.

6.3 Energy Profile

Energy Consumption- Use Phase

- A recent study by Koomey on Estimating Total Power Consumption by Servers in the U.S. and the World (Koomey, 2007) estimated:
    - Average annual energy usage per server unit in the U.S. as 250 kWh/yr
    - Total U.S. server energy usage in 2005 as 3B kWh (direct energy consumption) and 45B kWh (including HVAC and auxillary equipment)
    - Projected a possible 40% increase in total server energy usage from 2005 to 2010 if there was no significant increase in efficiency
- Energy consumption is the prominent environmental concern currently being documented in the literature. Data centers in the U.S. now consume an estimated 20 to 30 billion kilowatt hours of electricity annually (ACEEE calculations, based on a value of roughly 300 W per each of 10 million servers suggest U.S. data center electricity consumption being around 30TWh/year, depending on the assumed operating hours/year-ACEEE, 2007).
- Data centers typically consume 15 times more energy per square foot than a typical office building, and may be 100 times more energy intensive (ACEEE, 2007; LBNL, 2005).
- Daily uptime for servers is commonly assumed to be 24 hours/day (IDC, 2006; ACEEE, 2007).
- Energy use profiles were identified for individual specific servers:
    - Apple XServe RAID: 300 W
    - HP 24xx series rp2430/rp2470*: maximum theoretical, 600 W, maximum actual, 275 W*
- Cooling of the server farm can account for between 50-100 % of power consumption (IDC, 2006).
- Energy efficiency has improved dramatically in the last few product generations, with manufacturer-reported improvements of 35% to 150% per watt. Major areas of processor efficiency improvements include multi-core processors, low voltage processors, and smaller chips made with advanced materials (ACEEE, 2007).
- Server energy use was estimated at 560 kWh/yr (Servers), 5,840 (Minicomputer), and 58,400 (mainframe) in the U.S. (Kawamoto et al, 2002)

Energy Consumption Protocols:

- Small, desktop-type servers fit within the ENERGY STAR defined-parameters for computer devices.
- The Standard Performance Evaluation Corporation (SPEC) expects to complete its first energy performance protocol for small- and medium-sized servers in early 2007 (ACEEE, 2007).

6.4 Market Characteristics

The following usage and sales data for servers in the U.S. were reported:

- Research firm IDC estimated that there were 1.8 million new servers installed in 2002, and estimates that by 2009, that number will increase to 4.9 million per year (www.publiccio.com, 12/19/2006).
- In a February 2007 EPA technical workshop on energy efficient servers and datacenters, workshop participants identified the identification of growth trends in IT data and data centers (both historical and projected) as a key data need (EPA, 2007).
- By year, IDC estimated the following **U.S. sales** (derived from IDC presentation, V. Turner, Spring 2006):
  - 2.8M units in 2005
  - 3.3M units in 2006
  - 3.9M units in 2007
  - 4.4M units in 2008
  - 4.9M units in 2009
  - Total unit sales 2005-2009 = 19.3M
- As reported by Gartner, **worldwide** server shipments totaled 8.2 million units in 2006, representing an 8.9 % increase from 2005 (www.internetnews.com, 2/22/07)
- Manufacturer market share for 2006 shipments, again reported by Gartner, included
  - Hewlett Packard: 27.5 %
  - Dell: 21.7 %
  - IBM: 15.7 %
  - Sun Microsystems: 4.5 % (www.internetnews.com, 2/22/07)
  - 90% of sales are smaller servers (sales price < $6,000) (from IDC presentation, above)
- Percentage of market in U.S. by server type includes: 61% servers, 37% minicomputers, and 2% mainframes (Kawamoto et al., 2001).

7.0 Televisions and Television Monitors

7.1 Existing Standards and Proposed Product Definition

Three existing standards were identified for televisions; ENERGY STAR, TCO and Nordic Swan. All the definitions were closely related. The standards differentiate TVs from computers monitors mainly on their primary function as viewing devices as opposed to being an output device for computing. ENERGY STAR's definition was the most complete and clear in terms of the distinction between a TV and computer monitor.

Proposed product definitions from ENERGY STAR:

Television (TV): A commercially available electronic product consisting of a tuner/receiver and a monitor encased in a single housing. The monitor usually relies upon a cathode-ray tube (CRT), liquid crystal display (LCD), plasma display, or other display device. The TV is designed to receive and display a television signal broadcast by antenna, satellite, or cable. To qualify, the TV must be capable of being powered from either a wall outlet or a battery unit that is sold with an AC adapter. This definition includes analog and digital televisions in addition to televisions that require additional power to receive and process signals that contain information and/or data for electronic programming guides. Television products with a tuner/receiver and computer capability (e.g., computer input port) may qualify as long as they are marketed and sold to consumers as televisions (i.e., focusing on television as the primary function). However, products with a tuner/receiver and computer capability that are marketed and sold as 1) computer monitors or 2) dual function televisions and computer monitors are not included in this specification.

<u>Television Monitor:</u> An electronic product intended to display a video signal from an external tuner or other video source such as a VCR or DVD Player on a CRT, LCD, plasma display, or other display device. To qualify, the television monitor must be capable of being powered from either a wall outlet or a battery unit that is sold with an AC adapter. This definition includes analog and digital television monitors. Television monitors with computer capability (e.g., computer input port) may qualify as long as they are marketed and sold to consumers as television monitors (i.e., focusing on television/video as the primary function). ***However, products with computer capability that are marketed and sold as 1) computer monitors or 2) dual function television and computer monitors are not included in this specification***.

7.2 Environmental Profile

<u>Product Profile</u>

TVs and display devices include traditional cathode ray tube (CRT) technology as well as new and maturing technologies such as plasma displays (PDs), and liquid crystal displays (LCDs).

LCDs are characterized by the following:

- LCDs use small electric current applied to a thin layer of LC dispersed between two plates of glass to transmit light provided from an array of backlights.
- LCDs used in TVs rely on a set of up to 8 backlights which can sometimes contain mercury to illuminate the screen (King County, 2007)
- TVs are primarily active matrix displays, using a thin film of transistors to activate the pixels, making them brighter and sharper than passive matrix displays.
- Recent technology improvements have led to larger possible screen sizes (65 inches +) making them more applicable as display devices.
- Typical LCD contains 20-25 LC compounds (Socolof et al, 2001 & King County, 2007)
- There is approx 0.6g of LC per sq. cm of display area (Socolof et al., 2001)

Plasma displays are characterized by the following:

- Plasma tech uses mixtures of inert noble gasses- primarily neon and xenon- to excite phosphors (same as CRTs) between two pieces of glass.
- Large screen sizes up to 80 inches have been produced using plasma, not suitable for computer displays due to flickering (King County, 2007)
- Mass of 42 inch plasma TV is 65 lbs (http://www.plasmatvbuyingguide.com/plasmatv/nec-42xm2.html)
- Susceptible to screen burn making them less than ideal for display applications.
- Plasma technology does not utilize mercury lamps (King county, 2007)

CRTs are characterized by the following:

- High voltage electron guns accelerate electrons through a shadow mask toward phosphors deposited on a faceplate that convert the kinetic energy to and image
- Average mass of TV is 65 lbs (http://www.epa.gov/epaoswer/non-hw/reduce/wstewise/pubs/g2gfinal.pdf)
- CRTs have 15-90 lbs of glass (depends on size), containing high lead content required to shield users from x-rays and other emissions from the electron gun and electromagnetic fields generated
- Some states have banned the disposal of these devices, requiring instead that they be recycled

Flat panel displays (includes both Plasma displays and LCDs) consist of the following materials (Socolof et al, 2001 & Townsend et al, 2004):

- Ferrous Metal (25-44%) - structural pieces
- Plastic (28-31%) - Mainly PVC, ABS, PC, and HIPS used in the FPD housing and wire jackets.
- Glass (10-23%) - Display unit, does not typically contain lead
- Printed wiring board (6-10%) – comprised of fiberglass resin, components, and TV tuner elements
- Nonferrous metal (3-9%) - includes mercury in CCFLs, lead in PVC and solder, beryllium and cadmium
- Wires (4%) - typically PVC jackets surrounding copper wires, cord connectors and plug
- Other materials (<1%) – Includes cold cathode fluorescent lamps (CCFLs) and LCs

Note: A comprehensive list of materials in LCDs and other flat panels can be found in the following reports by King County (2007) and Socolof et al, (2001).

Content Specific Environmental or Human Health Concerns

Televisions and television monitors are similar in composition to other computer products, so they likely have similar constituents of concern. In addition, they have larger concentrations of the following:

Information collected on the human health and environmental impacts of liquid crystals used in **LCDs** includes the following (http://www.umweltbundesamt.de/uba-info-daten-e/daten-e/lcd.htm):

- Liquid crystals were determined to not be mutagens or pose an acute threat to human health (Socolof et al, 2001).
- A test of five common LCs observed no known toxic affect to aquatic organisms (Socolof et al, 2001).
- Limited information suggests no carcinogenicity, however testing only on a small percentage of LCs (Socolof et al, 2001).
- Biodegradability of liquid crystals ranged between 0-30 % (King County, 2007).
- Primary exposures of potential concern over the LCD life-cycle include occupational exposures during the manufacture of the LCs, and exposure to dust during recycling or reclamation.

Information collected on mercury, present in CCFLs used to backlight **LCD** displays includes the following:

- Mercury in CCFLs ranges from 4-12 mg depending on the length of the backlights (Note: value scaled up from 4 mg Hg reported in Socolof et al for 15 inch light). TVs can have up to 8 lights per set.
- Mercury is a possible human carcinogen, a persistent bioaccumulative toxin, and poses many other acute and chronic human health threats (ATSDR, 1999).
- Exposure to mercury vapor from broken CCFLs during reclamation and recycling is expected to be a primary route of exposure (Socolof et al, 2001).
- Mercury in CCFLs are exempt from RoHS restrictions for mercury

Information collection on lead in **CRT**s includes the following:

- Sources of lead in CRTs include the funnel (22-28% by wt.), front panel (0-4%), CRT neck (26-32%), and the frit (70-80%) (Socolof et al, 2001).
- A 17 inch CRT monitor contains approx. 2.6 lbs of lead, bigger TVs would contain much more (Socolof et al, 2001).

- Lead is rated a probable human carcinogen, is a PBT, and is a neurotoxin to human health among other chronic and acute threats to human health.
- CRTs have demonstrated leaching that exceeded allowable thresholds for at least one or more compounds including lead.
- Lead in CRTs is exempt from RoHS restrictions.

There are likely higher quantities of DecaBDE in TVs than other products. According to Washington State, U.S. television manufacturers constitute 45–80% of all decaBDE use. According to research by Cleaner Production Action, four of the top TV sellers in the U.S. – representing 29% of the market - have either eliminated or plan to eliminate decaBDE by 2010 (ht tp://www.safer-products.org/downloads/Electronics%20BFR%20Fact%20Sheet.pdf).

End of Life

The following end-of-life data was identified regarding reclamation, recycling, or disposal of TVs and display units:

- Disposal of CRTs has been banned in a number of states in the U.S. due to concerns over lead and other toxic materials.
- Several studies have indicated large numbers of TVs are in storage in homes in the U.S.: 2.9 million in CA in 2001, (CIWMB, 2002); 170,000 in Washington (Cascadia, 2002).
- An estimated 500 million lamps (all lamps, not just CCFLs) are disposed rather than recycled (King County, 2007).
- Assuming 40% of lamps disposed result from TVs or displays, and using an average mercury content of 8 mg per lamp from previous page, unreclaimed lamps potentially account for over 3,500 lbs of mercury released into the environment annually.
- TVs in the waste stream are typically an average of 15-17 years old (U.S. Department of Commerce, 2006).
- 70 tons of liquid crystals were manufactured in 2001, while liquid crystals cannot yet be economically reclaimed at end of life (King County, 2007).
- LCDs last as long as the lamps, which is approx 60,000 hours of use. Only one manufacturer to-date offers a TV that allows lamp changeouts. (http://www.lcdtvbuyingguide.com/lcdtv/lcdtv-lifetime.shtml)
- Electronic circuitry, processors, and other typically computer-based TV components can be reclaimed, reused, or recycled at end of life using traditional electronic recycling processes.

7.3 Energy Profile

The following energy usage information is based on a recent paper by CNET on TV power consumption (Nadel and Moskovciak, 2007 http://reviews.cnet.com/4520-6475_7-6400401-1.html?tag=lnav):

Assuming an active mode of 8 hours/day and a standby mode of 16 hours/day:

- Average CRT:
  - Active mode - 146 watts
  - Standby mode – 2 watts
  - **Total avg. = 438 kWh/yr**

- Average plasma:
  - Active mode - 328 watts
  - Standby mode – 4 watts
  - **Total avg. = 981 kWh/yr**

- Average LCD:
  - Active mode - 193 watts
  - Standby mode – 10 watts
  - **Total avg. = 622 kWh/yr**

Other less recent data includes:

- CRT digital TVs use roughly 8.8W in standby, while consuming an average of 177W when active (Rosen and Meier, 2000).
- CRT consumption averaged 114 W for 30-36 inch TVs (Rosen and Meier, 1999).
- CRT average phantom power load when power off is 5.3W (Rosen and Meier, 1999).
- A check of current TV specs on 10 plasma and 10 LCD 40-42 inch TVs resulted in an average power consumption of 240W for **LCDs** versus 375W for **PDs**, a full 43% more energy consumption.

7.4 Market Characteristics

Television technology has changed rapidly over recent years. There has been a dramatic rise in flat panel sales as price points decline. In addition, the upcoming switch from analog to digital TV in February 2009 has had a significant impact on the market and will continue to do so. The January 2007 CEA report on U.S. consumer electronics sales indicated that (CEA, 2007):

- Sales of analog tuner TVs are declining rapidly
- Sales of digital tuner TVs are increasing rapidly
- From 2002 to 2007 digital TVs went from 0% of the market to 93% of the market
- U.S. sales of TVs overall are relatively flat around 31-34 million units/year from 2002 – 2007

Data from : iSuppli's "CRT Still Tops – But Share Falling as Flat-Panels Gain," – Television Systems Market Tracker, Q3 2006, indicates that:

- 2007 Projected total in U.S.: 35,178,000 units
  - CRTs = 10,367,000
  - Plasma = 13,748,000
  - LCDs = 17,567,000

- 2010 Projected total in U.S.: 44,716,000 units
  - CRTs = 2,105,000
  - Plasma = 6,036,000
  - LCD = 32,683,000

- 2007 to 2010 projected increase of 27% (based on numbers above)

Other market sales and trend data reported includes the following:

- By 2008 devices containing FPDs are projected to account for 85% of the U.S. market (King County, 2007)
- FPDs are expected to replace **CRTs** in every application, particularly in TVs (King County, 2007)
- Of FPDs sold in 2003, 85% were **LCDs**, 13% were **plasma** displays (http://www.lcdtvbuyingguide.com/lcdtv/lcdtv-misconceptions.shtml)

- In May 2004, for 30-39 inch sets, **plasma** accounted for 47% and **LCDs** accounted for 53% of FPDs. In the same time period, for 40-49 inch sets, FPDs account for a full 43% of all TV sales**.** (http://www.lcdtvbuyingguide.com/lcdtv/lcdtv-misconceptions.shtml)
- Average U.S. home in 1997 had 2.1 TVs per home, 30% of which had 3 or more TVs. All are expected to be higher today (www.homeenergy.org/archive/hem.dis.anl.gov/eehem/99/990510.html)
- World wide sales of **LCD** TVs were 9 million pieces with and an average display diagonal of 21.3 inches in 2004- average display area of 218 square inches (King County, 2007)
- Projected LCD TV sales to exceed 55 million sets with a display diagonal of 30.4 inches- 480 square inches display areas (King County, 2007)
- Anecdotal information indicates possible split of 10% institutional purchases and 90% consumer purchases

8.0 References

ACEEE, 2007. Greenburg, Steve, et al., “Best Practices for Data Centers: Lessons Learned from Benchmarking 22 Data Centers,” *ACEEE Summer Study on Energy Efficiency in Buildings.*

Aerias.org. (Information about emissions from printers.) http://www.aerias.org/desktopmodules/articledetail.aspx?articleId=87#printer-health (accessed June 2, 2007)

Ahmadi, A., B. H. Williamson, T. L. Theis and S. E. Powers, 2003. “Life-cycle Inventory of Toner Produced for Xerographic Processes,” *Journal of Cleaner Production*, Volume 11, Issue 5, August 2003, Pages 573-582.

Ambruster, C., G. Dekan, and A. Hovorka, 1996. “Granulomatous Pneumonitis and Mediastinal Lymphadenopathy Due to Photocopier Toner Dust,” *Lancet* 348 (1996), p. 690.

Apple.com, (Information about servers.) http://www.apple.com/xserve/specs.htm (Accessed April 7, 2007)

ATSDR. 1999. Toxicological Profile for Mercury. U.S. Department of Health and Human Services. March 1999. http://www.atsdr.cdc.gov/toxprofiles/tp46.html

Basel, 2006. Basel Convention: Mobile Phone Partnership Initiative, Guidance Document, Environmentally Sound Management of Used and End-of-Life Mobile Phones

California DTSC, 2004. “SB20 Report: Determination of Regulated Elements in Discarded Laptop Computers, LCD Monitors, Plasma TVs, and LCD TVs,” California Department of Toxic Substances Control (DTSC), 2004.

California Integrated Waste Management Board (CIWMB). 2002. Electronic Product Management Issues. Publication Number 441-02-002. February 2002.

Canon, 2006 . Canon Sustainability Report, 2006. p.42. http://www.canon.com/environment/eco2006e/p42.html (accessed on June, 2, 2007)

Cascadia Consulting Group, Inc. (Cascadia). 2002. Assessment of Electronic Waste Generation, Collection, and Processing in Eastern Washington. Final Report. Prepared for Washington State Department of Ecology. December 31, 2002.

Consumer Electronics Association (CEA), 2007. U.S. Consumer Electronics Sales & Forecasts 2002-2007. January, 2007.

EUP, 2007a. *Task 1 Interim Report for EuP Preparatory Study Lot 4: Imaging Equipment*. Preparatory Studies for Eco-design of Energy-using Products, Fraunhofer IZM Bio IS Öko-Institute CODDE PE Europe DUH.

EUP, 2007b. *Task 2 Interim Report for EuP Preparatory Study Lot 4: Imaging Equipment*. Preparatory Studies for Eco-design of Energy-using Products, Fraunhofer IZM Bio IS Öko-Institute CODDE PE Europe DUH.

EUP, 2007c. *Task 3 Interim Report for EuP Preparatory Study Lot 4: Imaging Equipment*. Preparatory Studies for Eco-design of Energy-using Products, Fraunhofer IZM Bio IS Öko-Institute CODDE PE Europe DUH

Gartner, 2005. "Mobile Phone Sales to Exceed One Billion in 2009," July 21, 2005, www.palminfocenter.com/news/7978/mobile-phone-sales-to-exceed-one-billion-in-2009/

Gartner, 2007. "Server Growth Up 8.9 Percent in 2006," February 22, 2007, www.internetnews.com/bus-news/article.php/3661546

Geibig, 2007. Mass of cell phone batteries determined through collection and weighing of 10 cell phone batteries using a laboratory scale. April 7, 2007.

Geibig, J. and M. Socolof, 2005. *Solders in Electronics: A Life-Cycle Assessment.* Design for the Environment Printed Wiring Board Project. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington, D.C. (EPA 744-R-05-001).

Geibig, J.R. and M.B. Swanson, 2001. *Printed Wiring Board Surface Finishes: A Cleaner Technologies Substitutes Assessment:* Volumes I and II. Design for the Environment Printed Wiring Board Project. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington, D.C. (EPA 744-R-01-003).

Hardware Today, 2006. "Strategic Server Disposal," http://www.serverwatch.com, September 18, 2006.

IDC, 2006. Worldwide MFP Forecast and Analysis 2006-2010. IDC number 204136 (2006).

IDC, 2007. "Handheld Sales Dropped By 28.5% in 2006." February 8, 2007, www.palminfocenter.com/news/9239/idc-handheld-sales-dropped-by-28.5-in-2006/

INFORM, 2003. Calling All Cell Phones: Collection, Reuse, and Recycling Programs in the US. November 2003.

International Precious Metals Institute (IPMI), 2003. *Environmentally Sound Management of Used Mobile Telephones*. IPMI Pensacola, Florida.

iSuppli, 2006. "CRT Still Tops – But Share Falling as Flat-Panels Gain," – Television Systems Market Tracker, Q3 2006.

Kawamoto, K, Koomey, J. Nodman, B, Browm, R. , Piette, M., Ting, M. and Meier, K., 2002. "Electricity used by Office Equipment and Network Equipment in the U.S.", *Energy*, 23 (2002) 255-269.

Kincaid, L.E., J.R. Geibig, and M.B. Swanson, 1998. *Printed Wiring Board Cleaner Technologies Substitutes Assessment: Making Holes Conductive*. Volumes I and II. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington, D.C. (EPA 744-R-97-002).

King County, 2007. "Literature Review, End-of-Life Management: Flat Panel Display Devices," King County Solid Waste Division (Seattle, Washington).

Koomey, 2007. Estimating Total Power Consumption by Servers in the U.S. and the World, Lawrence Berkeley National Laboratory.

LCD TV Buying Guide, 2004. "LCD TV Lifespan: How Long Will It Last?" Review by Jack Burden, 2004. http://www.lcdtvbuyingguide.com/lcdtv/lcdtv-lifetime.shtml.

LCD TV Buying Guide, 2004. "LCD TV Misconceptions: Six Common Myths About LCD Displays." Review by Jack Burden, 2004. http://www.lcdtvbuyingguide.com/lcdtv/lcdtv-misconceptions.shtml.

Lee, S.C., S. Lam, and H.K. Fai, 2001. "Characterization of VOCs, Ozone, and PM_{10} Emissions from Office Equipment in an Environmental Chamber, *Building and Environment*, 30 (2001), pp. 837-842.

Meier, A. and Rosen, K., 1999. "Video Networks: A Surprising Energy Drain," *Home Energy Magazine*, May/June 1999.
http://www.homeenergy.org/archive/hem.dis.anl.gov/eehem/99/990510.html
(Accessed April 8, 2007).

Mobile Whack, Casio W51CA Digital Mobile TV Phone, http://www.mobilewhack.com/casio-w51ca-digital-tv-phone/ (Accessed June 2, 2007).

M:Metrics, 2006. "Smartphone Report on Mobile Content Use," July 10, 2006, www.palminfocenter.com/news/8738/smartphone-report-on-mobile-content-use/ (accessed April 14, 2007)

Mueller, J., Griese, H., Hageluken, M., Middendorf, A., and Reichl, H., 2003. "X-free Mobil Electronics--Strategy for Sustainable Development,", IEEE Symposium on Electronics and the Environment, 2003, p. 15.

Nadel, B. and M. Moskovciak, 2007. CNET TV power consumption (Updated April 19, 2007) http://reviews.cnet.com/4520-6475_7-6400401-1.html?tag=lnav.

NAGPI, 2007. Buying Environmentally Preferable Office Electronics: Printers, Copiers, and Fax Machines. North American Green Purchasing Initiative, Commission for Environmental Cooperation. http://www.cec.org.

Nicholson, K, 1998. "Photocopier Hazards and a Conservation Case Study" The Book and Paper Group Annual- Volume 8, The American Institute for Conservation, http://aic.stanford.edu/sg/bpg/annual/v08/bp08-05.html (Accessed April 4, 2007)

Nokia, 2005. Integrated Product Policy Pilot Project, Stage I Final Report: Life Cycle Environmental Issues of Mobile Phones, Nokia Corporation, 2005.
http://ec.europa.eu/environment/ipp/pdf/report_02_08_06.pdf
http://europa.eu.int/comm/environment/ipp/pdf/nokia_mobile_05_04.pdf

Nokia, November 2006. Substance Management, Safe and Environmentally Sound Products. What's in a Phone? http://www.nokia.com/link?cid=EDITORIAL_65032 . (Accessed April 8, 2007).

Palm Infocenter, 2007. "Converged Mobile Device Market Grows 42% in 2006,"March 1, 2007, www.palminfocenter.com/news/9277/converged-mobile-device-market-grows-42-in-2006/

Palm Infocenter, 2007, "Report: 64 Million Smartphones Chipped in 2006," February 13, 2007, www.palminfocenter.com/news/9247/report-64-million-smartphones-shipped-in-2006/.

Plasma TV Buying Guide, NEC Plasma TV Specifications, NEC 42XM2 Plasma Monitor, http://www.plasmatvbuyingguide.com/plasmatv/nec-42xm2.html
(Accessed April 6, 2007).

Rosen, Karen B. and Alan K. Meier, 2000. Energy Use of U.S. Consumer Electronics at the end of the 20th Century LBNL-46212. In the Proceedings of the 2nd International Conference on Energy Efficiency in Household Appliances and Lighting. 27-29 September 2000, Naples, Italy: Association of Italian Energy Economics (Rome). http://eetd.lbl.gov/EA/Reports/46212
(Accessed May 1, 2007)

Rosen, Karen B. and Alan K. Meier, 2001. Energy Consumption of Set-top Boxes and Telephony Products in the U.S.. Report to the U.S. Department of Energy. LBNL-45305. June 2001. http://eetd.lbl.gov/EA/Reports/45305/45305.pdf (accessed June 2, 2007)

Socolof, M., Overly, J., Kincaid, L. and J.R. Geibig, 2001. *Desktop Computer Displays: A Life Cycle Assessment. Volumes I and II* . U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington, D.C. December, 2001. (EPA 744-R-01-004a,b)

Socolof, Maria, et al., 2007, *Expansion of the Electronics Environmental Benefits Calculator: Mobile Phone Reuse and Recycling,* Abt Associates*, s*ubmitted to the Eastern Research Group, under Subcontract Agreement No. 0160.04.002/2, March 9, 2007.

Townsend, T.G., Vann, K., Mutha, S., Pearson, B., Jang, Y.C., Musson, S., and Jordan, A., 2004. RCRA Toxicity Characterization of Computer CPUs and Other Discarded Electronic Devices. Department of Environmental Engineering Services, University of Florida. July 15, 2004.

Turner, Vernon, 2006. "Defining the Landscape: Trends and Forecasts for the Enterprise Sever Market and Data Centers," Presentation to IDC, Spring 2006.

Umweltbundesamt.de, August 2000, Statement of the German Federal Environment Agency Concerning the Ecotoxicology of Liquid Crystals in Liquid Crystal Display, http://www.umweltbundesamt.de/uba-info-daten-e/daten-e/lcd.htm (Accessed April 2, 2007)

U.S. Department of Commerce, 2006. Recycling Technology Products: An Overview of E-waste Policy Issues. U.S. Department of Commerce, Technology Administration, Office of Technology Policy. July 2006.

U.S. EPA, 1995. Hetes, Robert, et al, *Project Summary- Office Equipment: Design, Indoor Air Emission, and Pollution Prevention Opportunities,"* U.S. EPA, EPA/600/SR-95/045, June 1995.

U.S. EPA, 2005, "E-Cycling: Basic Information," www.epa.gov/e-Cycling/basic.htm.

U.S. EPA, 2007. Technical Workshop on Energy Efficient Servers and Datacenters in the United States, *Summary of Identified Data Needs*, February 16, 2007, www.energystar.gov/ia/products/downloads/Workshop_Data_Needs_21Feb2007.pdf

USGS Fact Sheet, 2006. "Recycled Cell Phones – A Treasure Trove of Valuable Metals," http://pubs.usgs.gov/fs/2006/3097/

Wacker Worldwide (WWW), Oct 2006, (2.6), 4 (Available from: Wacker Chemie AG, Hanns-Seidel-Platz 4, 81737 Munchen, Germany, http://www.wacker.com) (Accessed April 8, 2007).

Wall Street Journal, 2006. "Surge in Internet Use, Energy Costs, Has Big Tech Firms Seeking Power," June 13, 2006.