UNIVERSITY OF CALIFORNIA
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End-of-Life Management of Cell Phones in the United States

A Group Project submitted in partial satisfaction of the requirements
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April 2006

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a four quarter activity in which small groups students conduct focused research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has reviewed and approved by:

Roland Geyer — Ernst von Weizsäcker

April 2006

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Definitions

- **BER**: Beyond Economic Repair
- **B2B**: Business to Business
- **Buy-back**: Refers to the reverse logistic process where EoL products are returned from the consumers to interested or responsible parties with monetary compensation
- **Collection**: Collection is the process in which EoL phones are collected from end-users. The process refers to the collection, storage, and transportation of the phones from the end-users to the processing facility.
- **Curbside collection**: Consists of the collection of e-waste either on a periodic basis such as a general municipal waste collection or by request (e11th-hour, Web site).
- **End-of-Life (EoL) cell phones**: Cell phones that reach the end of the use phase by their current owner/user. Phones can be in a working or a non-working condition.
- **End-users**: End-users refer to the entity that actually uses the phone; those entities can include private, business, commercial, and governmental organizations.
- **Extended Producer Responsibility**: Legislation mechanism that places all financial and sometimes physical responsibility on the manufacturer for the collection, transportation, and disposal/recycling of the EoL products.
- **Extended Product Responsibility**: Legislation mechanism that places shared responsibility for the product among the entire supply chain.
- **Intermediate/ Secondary electronic recycler**: A business engaged in purchasing or acquiring EoL products for the purpose of material recycling. Its operation includes dismantling, shredding and assaying. Pre-treated materials are typically sold to primary recyclers.
- **International Mobile Equipment Identity (IMEI)**: A 15-digit number that uniquely identifies an individual wireless phone or communicator (Audit My PC, Website).
- **Network Service Provider / Carrier/ NSP**: An NSP provides customers with access to ASPs, the Internet and other services over a dedicated private network (ML-IP, Website). In this paper it is used to describe wireless network provider for cellular communication.
- **OEM/ Manufacturer**: Original Equipment Manufacturer
- **Precious metals**: Gold, silver, and the platinum group metals (PGMs) are known as the precious metals; also called the noble metals (Country Silver, Website).
- **Primary recycler**: In this paper primary recycler is defined as a metal recycler that is capable of recovering the metals from various feedstock such

as e-waste. Its operation includes metal smelting and refining. In general a primary operator processes recycle metals as part of its business.

- **Processing facility**: Any physical entity that accepts EoL cell phones and performs any activity such as sorting, scanning, refurbishing, recycling, etc.
- **Retailer**: The seller of goods or commodities directly to the consumers at a retail price (Wbenc, Website).
- **Reuse of product "as is"**: Reuse of a cell phone in a second life time as a second hand device with no major repair or upgrade. This can be done by resale or by donation.
- **Reuse of product "Refurbished"**: Reuse of a cell phone in a second life time as a second hand device after a major repair or upgrade. These phones will usually have some kind of limited warranty.
- **Reuse of parts**: Reuse of functional parts that were disassembled from the EoL phone. The parts can be used in another used phone, in a new phone, or in a completely different device such as a toy.
- **Recycling**: Recycling refers to the process of material and energy recovery. The recycling process can be performed either with or without prior disassembly. Materials such as plastic, glass, and metals are recovered and can be reused as raw materials in another product manufacturing process. The materials can stay in a closed loop of cell phone manufacturing or can move to an open loop. This open loop can be other product production processes such as toys, plastic furniture, jewelry etc. The process can include disassembly, shredding, separation, smelting, and refining.
- **Take-back**: Refers to the reverse logistic process where EoL products are returned from the consumers to interested or responsible parties without monetary compensation.

Common Acronyms

ARF	Advanced Recycling Fee
CDMA	Code Multiple Division Access
CRT	Cathode Ray Tube
BER	Beyond Economic Repair
DfE	Design for the Environment
EPA	Environmental Protection Agency
EoL	End-of-Life
EPR	Extended Producer Responsibility
EU	European Union
GSM	Global System for Mobile communication
LCD	Liquid Crystal Display
NEPSI	National Electronics Product Stewardship Initiative
NGO	Non-Governmental Agency
NSP	Network Service Provider
MJ	Unit of Energy
PGM	Platinum Group Metals
PBB	Polybrominated Biphenyls
PBDE	Polybrominated Diphenyl Ethers
PWB	Printed Wiring Board
OEM	Original Electronic Manufacturer
PCS	Personal Communication Services
PDA	Personal Digital Assistant
PRO	Producer Responsibility Organization
3PSP	Third Party Service Provider
TDMA	Time Division Multiple Access
RoHS	Restriction of the Use of Certain Hazardous Substances
WEEE	Waste Electrical and Electronic Equipment

1. Abstract

The management of electronic waste is emerging as a global environmental problem due to the hazardous materials contained in electronic products and increasing consumption of these products. Cell phones are a unique niche in the e-waste stream not only because of their high rate of displacement by consumers, but also because they have viable reuse and recycling markets. The main objective of this project is to recommend an optimal end-of-life (EoL) management option for cell phones within the United States. This project focused on the end-of-life options market for cell phones, and considered U.S. legislation as well as global design trends that affect the economic and environmental outcomes of various management schemes. The authors of the project considered three end-of-life management options: the reuse of phones, reuse of components, and recycling of materials. Data was collected and analyzed in order to quantify the environmental and economic outcomes of the current market situation. Based on a sensitivity analysis, the key variables were determined and used to construct six scenarios which examine the market outcomes under different conditions. Results highlight the importance of having a minimum reuse rate in order to ensure positive economic outcome. This report makes practical recommendations to ensure the sustainability of the EoL cell phones market in the near future. The authors agree that any policy should be re-evaluated regarding both its economic and environmental benefits as the market develops.

2. Executive Summary

Introduction

Electronic waste is now the fastest growing waste stream in the industrialized world. Thus, the management of e-waste is emerging as a global environmental problem, mainly due to the hazardous materials contained in electronic products and increasing consumption of these products.

Some countries have begun to address the e-waste problem by initiating legislation. The European Union (EU) has emerged as a leader in e-waste management with the adoption of the Waste Electrical and Electronic Equipment Directive (WEEE) and the Restriction on Hazardous Substances (RoHS) Directive.

The EU first introduced the policy concept of Extended Producer Responsibility (EPR), which makes manufacturers responsible for the EoL management of their products. This legislation could in turn incentivize the concept of Design for the Environment (DfE), which is intended to encourage the design of products which are easier to recycle, disassemble, and/or reuse.

Cell phones are a unique niche in the e-waste waste stream, not only because of their large volume and short lifespan of 18 months on average, but also because of the reuse and recycling opportunities they carry with them. Therefore, the policy makers can take either mandatory or voluntary approaches. The voluntary approach could be viable for cell phones since EoL phones still retain residual value and a secondary market already exist. Nonetheless, due to cell phones' small size, the current collection rate is estimated to be less than 5%. In 2005, 130 million cell phones were retired in the U.S., according to the Environmental Protection Agency. If the collection rate stays as low as now, the number of EoL phones that end up in landfills or incinerators will be enormous and policy will be needed to address this issue.

Since the United States has not yet implemented federal-level initiatives for either e-waste in general or for cell phones in specific, it still has an option to explore different approaches that will best fit EoL cell phone management. Several states are in the process of developing/ implementing different take-back policies that address e-waste (including cell phones) or specifically cell phones. If states however do not coordinate their implementation efforts, they may create difficulties for stakeholders to uniformly comply with legislation.

Another important aspect that influences EoL management is product design. Design for Environment can help to facilitate recycling, disassembly, and reuse. This can change the EoL stage process significantly and can alter the cost-effectiveness. Advanced OEMs have already begun to change the design of cell phones in order to potentially create profitable operations from the EoL management of the products, however there still are issues that need to be addressed.

Goals and Approach

The research and analysis presented in this paper aim to recommend an optimal EoL management option for cell phones in the United States. It is also discussed in relation to policy and product design since those two aspects influence EoL market and options significantly.

The authors of this report have divided EoL product management into three main stages:

- Collection
- Fate Determination
- Processing

In the processing stage, the following options have been considered:

- Reuse of phones
- Reuse of components
- Recycling of materials

The authors of this report aim to evaluate how the interaction of these three aspects (policy, design, and EoL) may potentially affect the market and the interaction among one another. The outcome is measured from both an economic and environmental perspective. The results are then incorporated into different market scenarios to identify the one that maximizes economic benefit while minimizing negative environmental impact. Recommendations are made based on the analysis and presented from policy, design and EoL market standpoints.

Economic and Environmental Analysis

Economic and environmental performance was measured for each EoL stage: collection and transportation, pre-processing, reuse options, and recycling options. Economic performance was measured in terms of revenue and costs, and environmental performance was measured in terms of environmental burdens such as energy consumption or benefits as waste savings. In addition, the issue of displacement of ore mining and new production was discussed as the main factor that contributes to increase upstream environmental benefits. The observations and analysis made in this section are incorporated into baseline and scenario analysis.

Sensitivity and Scenario Analysis

First, the baseline was established based on the data that best describes the current market situation. We found out that 80% of the cost is invested in collection and fate determinations of the phones. In the current market conditions, 95% of the revenue is coming from reuse activities and recyclers can not bear the collection cost.

Then, a sensitivity analysis was conducted to identify the important factors/variables that significantly change the market outcome in terms of economic and environmental performance. Based on the sensitivity analysis results, six scenarios were structured to demonstrate different market conditions. The factors that were changed include reuse rate, collection rate, second-hand sale price, and new production displacement percentage. Several important observations were made, and it became obvious that sometimes a factor or a combination of them work in opposite directions regarding the economic and environmental performance.

Economic Outcome

Results demonstrate that a high collection rate is not enough to achieve a positive economic outcome. In order to ensure a positive economic outcome, a minimum reuse rate is required regardless of the collection rate. This indicates that the profit from reuse is the largest contributor for a positive economic outcome and recycling cannot achieve that level by itself. At the current collection rate, if second-hand price decreases and reuse rate decreases due to objection of certain stakeholders to reuse practices, then the market outcome can become negative.

Results also highlight the potential of the growth of the EoL market if collection rate increases, the reuse rate is kept high, and more high-end phones are captured increasing average sale price. Thus, economy of scale in collection will affect dramatically the positive economic outcome.

Environmental outcome

Results demonstrate that as long as no new production displacement is assumed, high reuse rate results in higher environmental burden (more energy consumption and less waste avoided). In this case there is an ongoing contradiction between the environmental and economic performance. There is also an ongoing contradiction between waste and energy indicators. As long as collection rates increase, more energy is consumed but more waste is avoided at the same time.

Results also demonstrate the potential environmental upstream benefits when displacement is taking place. The shift from net energy consumption to net energy saving is substantial. In addition, the waste avoided increases as well due both from ore mining and the production process. Only if displacement is accounted for will the economic and environmental performances align in the same direction.

Without product-level displacement, second-hand phones must be considered as they are expanding the market. Market expansion is associated with incremental environmental burden because there are no savings from expansion. However, a 25% displacement assumption returns significant improvement in environmental performance. It is important to be able to assess how displacement is taking place in the real market.

Recommendations

From the quantitative and qualitative analyses, the authors devised a set of recommendations to hopefully guide market stakeholders and policy makers. The authors divided these recommendations into the following areas of EoL operations, policy, and design:

- Reuse is Critical for Profitability
  - Policy: Set minimum reuse rate
  - Process:
    - Consider reuse activities to support recycling
    - Address "second end-of-life" in developing countries
  - Design: Create incentives for R&D of "Design for Disassembly"

- Displacement is Critical for Environmental Benefits
  - Policy: Displacement can't be regulated
  - Process: Displacement can happen if OEM will include reuse in their business models

- Collection Efficiency is Important
  - Policy:
    - Set collection target
    - Share collection responsibility (OEM, NSP, End-users)
    - Mandate labeling program
  - Process:
    - Share reverse logistics efforts
    - Explore new methods to capture high-end phones
    - Address data security as a barrier for collection

- Additional Policy Actions
  - Ban cell phones from landfill
  - Ban the use of hazardous substances (RoHS)
  - Re-evaluate policy periodically

The authors strongly believe that these recommendations are feasible and achievable in the short and long term.

3. Introduction

Electronic waste (e-waste), represents the broad and growing range of electronic devices produced primarily during the last two decades as a by-product of the Information or High-Tech Revolution. From cell phones, video games, televisions and computers, e-waste is now the fastest growing waste stream in the industrialized world.

Due to a lack of awareness, consumers scarcely question the best method of discarding their electronic products. If current conditions persist, this electronic waste stream will continue to flow in the direction of landfills or incinerators.

Cell phones are small and have an average weight of less than quarter of a pound. Thus, they generate only a negligible quantity of downstream waste per unit. Worldwide, there are over 1 billion cell phones in current use. The high rates of cell phone production, combined with an average lifespan of only 18 months, makes cell phones an increasing source of hazardous e-waste.

Each year millions of cell phones are retired out for various reasons. In 2005, approximately 130 million cell phones, over 25 times the amount in 1990, were retired in the US according to the Environmental Protection Agency. While industry and states have recycling programs for used phones, such efforts recover only a small percentage of discarded wireless handsets. Many of these small phones are initially stored away in closets and drawers, but they will eventually be discarded and wind up in landfills, incinerators, or overseas. With no federally mandated programs in place today, the potential exists for these hazardous toxins to be released into the air and groundwater.

Cell phones contain a number of hazardous chemicals which belong to a class of chemicals know as persistent bio-accumulative toxins. These chemicals are of concern because they:

- Have a long life-span
- Will accumulate in the tissues of animals and increase in levels as they move up the food chain
- Are associated with cancer, reproductive, neurological, and developmental disorders

As discussed in more detail throughout the report, cell phones contain a range of hazardous materials including arsenic, antimony, beryllium, cadmium, copper, lead, mercury, nickel, and zinc. These toxins are listed as hazardous material by the Resource Conservation and Recovery Act's (RCRA) "Waste Minimization List of Persistent, Bio-accumulative, and Toxic Chemicals" standards, and enforced by the U.S. Environmental Protection Agency. If released into the air and groundwater, these toxins can have detrimental effects on human health. For example, brominated flame retardants currently contained in cell phones can cause cancer, liver damage, and thyroid dysfunctions.

With the adoption of the Waste Electronic and Electrical Equipment Directive (WEEE) and Restriction on Hazardous Substances (RoHS), the European Union has emerged as a world leader in e-waste regulation. The WEEE directive has put forth the concept of Extended Producer Responsibility (EPR), which aims to hold manufacturers responsible for their products' end-of-life (EoL) management; their responsibilities include the proper collection, treatment, and recovery of product waste. The RoHS directive restricts the use of certain toxic chemicals. The intent of the directive is to encourage producers to design such products that are easier to disassemble, recycle, and/or reuse.

The United States has also begun through its own legislation to combat the problems associated with e-waste. On a state-by-state basis, the U.S. is in the process of developing initiatives that address EoL management of electronic waste. A recent study funded by the EPA found that due to the amount of lead released by cells phones, these electronics could be classified under federal law as hazardous waste. This finding could force the federal government to develop national policies that govern cell phone disposal.

In response to the European Directives, many international companies have begun to create a variety of control measures to cost-effectively comply with EoL management regulations. They have also begun to change the design of cell phones in order to potentially create profitable operations from the EoL management of the products. Unlike most other forms of electronic waste, cell phones may be profitably refurbished, reused, or recycled because they contain precious metals.

This report will provide a comprehensive analysis of the various recovery initiatives currently possible for EoL management of cell phones. Upon thorough examination, the authors of the report will recommend a financially optimal and environmentally effective measure for cell phone recovery in the United States.

4. Project Scope and Objectives

The focus of this report is the End-of-Life management processes of cell phones. Although EoL is the last stage in the entire product life cycle, it is strongly affected by the design of the product which occurs long before its placement in the waste stream. Legislation too has a significant effect on the product's life cycle by either directly influencing the design (via banning the use of certain toxic substances, as implemented by the RoHS Directive) or by dictating the management process of the product (via placing EoL responsibilities on certain stakeholders, as implemented by the WEEE Directive).

The authors of this report have divided End-of-Life product management into three main stages: (A) collection, (B) Fate determination, and (C) processing. In the processing stage, the following options have been considered: (1) reuse of phones, (2) reuse of components, and (3) recycling of the product, also referred to as material recovery.

As illustrated in figure 1, three interactive aspects (EoL, design, and policy) affect the outcome of the EoL market. For example, design for disassembly can encourage higher rates of repair and reuse, while higher collection rates mandated by legislation can change the dynamics of collection process. These interactions will alter the market outcome from both an economic and environmental standpoint.

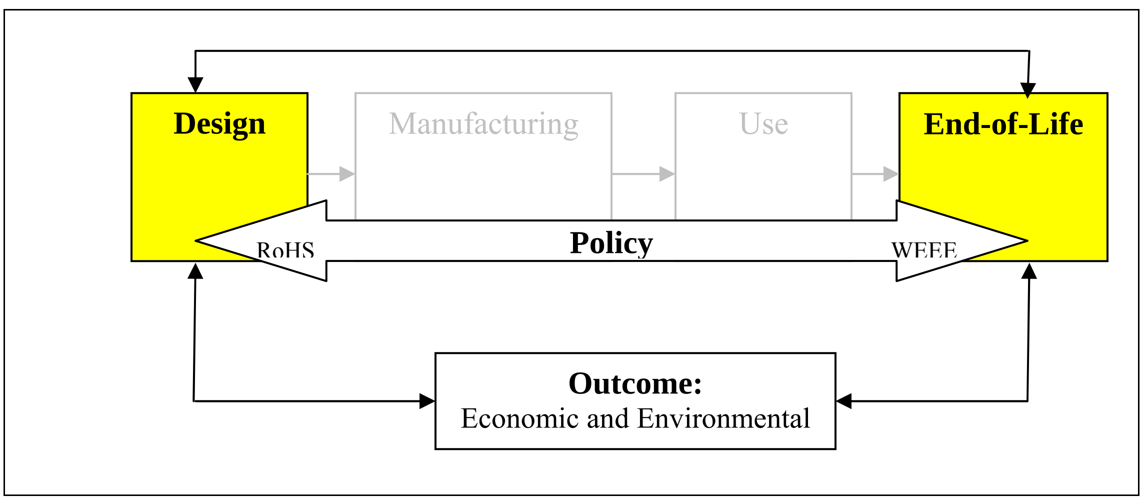

Figure 1: Project Scope

Aiming to maximize economic benefit, while minimizing negative environmental impact, the main goal of this research is to recommend optimal cell phone EoL management in the U.S.

The report covers the following:

- Overview of DfE cell phone trends
- Overview of current and future policy instruments for cell phone EoL management
- Economic and environmental performance analysis of the different EoL options
- Multi-factor scenario analysis for critical factors/variables and their effect on economic and environmental performance
- Recommendations based on the analysis

Since the project incorporates the information and perspectives from different stakeholders in the market, the results aim to serve as an analytical tool for a variety of industry stakeholders and policy makers.

5. Methodology

To achieve the previously stated objectives, the project was divided into two main sections:

Data collection, synthesis and reconciliation

The first part includes gathering of data regarding the cell phone technology and composition, design and legislation trends, and the EoL processes. Resources for data collection include the following:

- Literature review
- Interviews with various industry stakeholders
- EoL cell phone collection campaign conducted by the team
- Recycling process conducted by a third party recycler
- Web Search

The data is quantitative and qualitative and includes product attributes, costs and revenues, environmental performance indicators, and understanding of the market stakeholders and forces among them. When data was not available, the authors used conservative estimates.

The team collaborated with several partners and received insight into the industry's various sectors. Representatives from the following organizations contributed to this research by providing information, donating cell phones, and/or allowing the use of their recycling facilities:

- ECS Refining
- United DataTech
- RMS Communications Group, Inc.
- Nokia Inc.
- Alltel
- Motorola, Inc.
- American Analytics Inc.
- ReCellular Inc.
- CollectiveGood International
- Staples, Inc.
- Hobi International
- Pacebutler Corporation
- Santa Barbara/Ventura County
- Noranda Recycling
- Cingular Wireless

<u>Economic & environmental performance baseline</u>
The data gathered were analyzed and a current market performance baseline was established for both economic and environmental outcomes.

<u>Sensitivity analysis</u>
A sensitivity analysis was conducted by changing the values of the different recognized factors to understand which ones affect most the mentioned outcomes.

<u>Scenario Analysis</u>
Based on the sensitivity analysis, six scenarios were identified to demonstrate the market outcomes under different market conditions. After identifying a scenario that returned the highest economic and environmental performance, a qualitative analysis was conducted, addressing aspects of data security, ethics, and technology innovations.

<u>Recommendations</u>
Recommendations are made based on the analysis results in order to improve efficiency in EoL management from both an economic and environmental perspective.

6. Product Design

Mobile phones, also referred to as cellular phones or cell phones, are “small sophisticated personal two-way radios” that receive radio signals and carry voice and data in personal communication throughout the world (Basel Convention, UNEP). These phones operate by communicating through a network of base stations known as cell sites located throughout a region.

6.1. History and Evolution of Cell Phones

The first wireless phone services appeared in the mid-40s in the United States. Since the technology was extremely pricey and the market was not yet developed, the services used only one tower in each metropolitan area. Demand slowly grew and as technology improved, the phones became more available as they developed into what is now today’s cell phone service (Virtual Museum, Website).

Initially, the wireless phone service utilized a single centrally-located antenna similar to that of an AM/FM broadcast radio. With such limited commodity as the radio frequency (RF) spectrum, it was difficult to meet the needs of many difference cell phone services. Because of the high demand and low level of supply, the wireless industry adopted the “cellular approach”, which allowed multiple cell phone towers to be located in a large geographic area (Virtual Museum, Website).

This new cellular tower system, also referred to as base stations, allowed coverage within a roughly circular region, called a cell. Large geographic areas could then be split into a number of small coverage regions called cells which allowed the different base stations to use the same frequency, or channel, to link communication. This system called “frequency re-use” allowed thousands of cell phone users in a metropolitan area to share far fewer channels for communication. For example, when one cell phone subscriber made a phone call, this new system would assign him/her to a unique cell, but to a channel already in use by dozens of other users (Virtual Museum, Website).

Since many base stations were now in use, each covered a specific small area which enabled cell phones to use less transmit power to reach the stations. This new cellular architecture which now required less transmit power provided a major advantage by increasingly allowing a reduction in battery size and cell phone weight (Virtual Museum, Website). Thus, a world of cell phone miniaturization was born.

As shown in the diagram below, cell phones have evolved in both aesthetics as well as technology over the past twenty years. In the early 80s, cell phones were not only very expensive, but also large and heavy, weighing as much as 10kg. However, with the first Nokia handheld phone released in 1987 at only 5 kg, the next generation of phones slimmed down to approximately 800 grams (Mobira Cityman, Website). Since then, cell phones have increasingly become smaller and lighter, a result of a continuing change in technological advancement. Today's average cell phone, excluding battery, weighs approximately 100 grams.

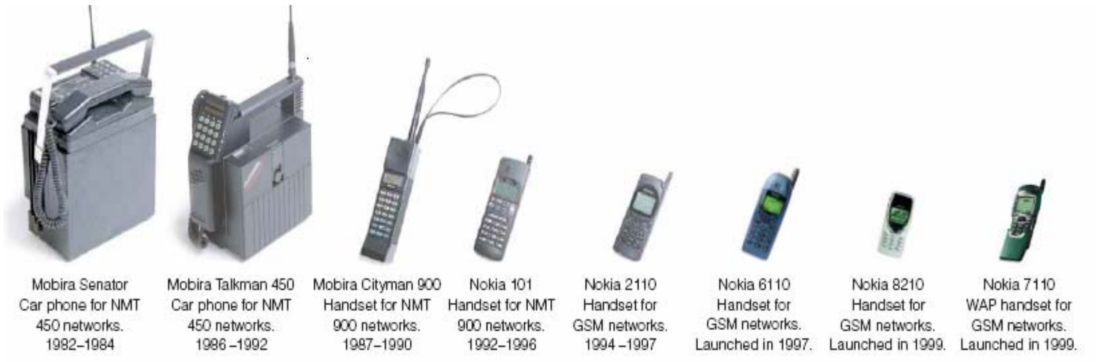

Figure 2: Cell phones over time
(Source: Towards telecommunication, Nokia Website)

As previously stated, the evolution of cell phones is contributing not only to the aesthetics of phones, but also to their material composition. For example, early contained large amounts of iron and steel which contributed to the heavy weight of each product. Recent models have replaced iron with plastics and/or ceramics. The alternative material has not only made a significant difference for consumer end-users, but has also impacted the paths for recycling and material recovery.

Increased functions and the need for higher performance have also changed the material requirements of cell phones. The product's display has shifted from a mere black/gray LED to RGB LED, LCD, or OLED. The new forms allow the ability to deliver white light and reproduce a spectrum of various colors.

Camera functions too require a lens to be installed in the handset. Demand for larger storage for pictures or music files, etc. are boosting the demand for new types of memory such as flash cards.

Additionally, internet, video, music, or other applications require higher processing performance which results in the increasing demand for some rare metals such as Platinum group metals, Indium and so on. Environmental concerns have resulted in yet another trigger for material change; upon introduction of the RoHS Directive which bans the use of lead, as described further in the Legislation Chapter, the tin-lead solder in cell phones is now being replaced by alternatives such as tin-silver-bismuth, tin-copper, and/or tin-copper-silver alloys.

6.2. Transmission Standards

Mobile communication (transmission) systems are complex and continually evolving. The system has required extensive investment in the underlying infrastructure which started from first generation (1G), shifted to 2G, is currently transitioning to 3G, and is expected to move to 4G in the foreseeable future.

The first generation, 1G wireless communication systems, which was introduced in the early 1980s and completed in the early 1990s, was an analog system which supported the analog cell phones with speeds of up to 2.4kbps. With this initial system, only voice transmission was possible. The second generation, 2G system, which began in the late 1980s and finished in the late 1990s, voice transmission with digital signals and speeds up to 64kbps, were made possible (Daniweb.com). The third generation, 3G wireless system, was developed in the 1990s and has continued into the 21st century. With this new system, transmission speeds of 125kbps to 2Mbps were made possible along with many other services including global roaming, superior voice quality and data always add-on (Daniweb, Website). The fourth generation, 4G, is a new framework and a means to address future needs such as high speed wireless networking that can transmit multimedia and date with wire-line backbone networks. Additionally, the new speeds with the 4G can increase potentially to 1Gbps (Daniweb, Website).

Each generation of wireless communication systems has had its own specific standards and protocols which have not always been inter-operational. Standardization of cell phones and their technologies have been an ongoing issue within the mobile communication industry. Quite often the industry as a whole will pursue multiple protocols in the same generation. For example, in the case of the 2G infrastructure, GSM was dominant in Europe and a large region of Asia, while TDMA was dominating the North American market and PDA was being pursued in Japan. Those systems were not inter-operational and therefore the handsets manufactured for PDA did not work for GSM and vice versa. This distinct separation of the systems creates an unfavorable mechanism for the re-use of cell phones.

With the initiation of the 3G infrastructure, the world integrated into two major standards: CDMA2000 and WCDMA, expanding the potential for network providers in various regions. CDMA (code division multiple access) is a mobile digital radio technology that transmits streams and which divides its channels into codes. With this system, a large number of cell phones can be served by a relatively small number of cell sites, which gives CMDA-based standards a significant economic advantage over TDMA (time division multiple access)-based standards. The 3G telecommunication standards are called CDMA2000 which is merely another form of CDMA. It is a registered trademark of the Telecommunications Industry Association in the U.S (Wikipedia, Website). WCDMA (wideband code division multiple access) is another type of 3G cellular network that uses code division multiple access. Although the world integrated into 2 main standards, there seems to be little difference between the two systems; WCDMA uses a broader spectrum and is an evolution of GSM, while CDMA2000 is an evolution of CDMA which has a somewhat related signaling to that of TDMA (GeekZone, Website).

6.3. Basic Components of Cell Phones

The Printed Wiring Board (PWB) of a cell phone is the brains of the phone; it controls all of its functions and composes the electronic components such as the integrated circuits and capacitors connected with mostly copper circuitry that are soldered to the board and secured with protective adhesives and coatings (GeekZone, Website). PWB, by weight, consists of one-third ceramics and glass, one-third plastics, and one-third metals.

As manufacturers increasingly incorporate a variety of functions into their products, cell phones have been able to incorporate an increasing variety of functions in a relatively small space. This change is triggering rapid miniaturization of cell phones which once again calls for the rapid evolving of cell phone composition.

Cell phone handsets are composed of the following units:

- Housing
- Printed wiring board (PWB)
- Antenna
- Display
- Keypad
- Microphone
- Speaker
- Battery

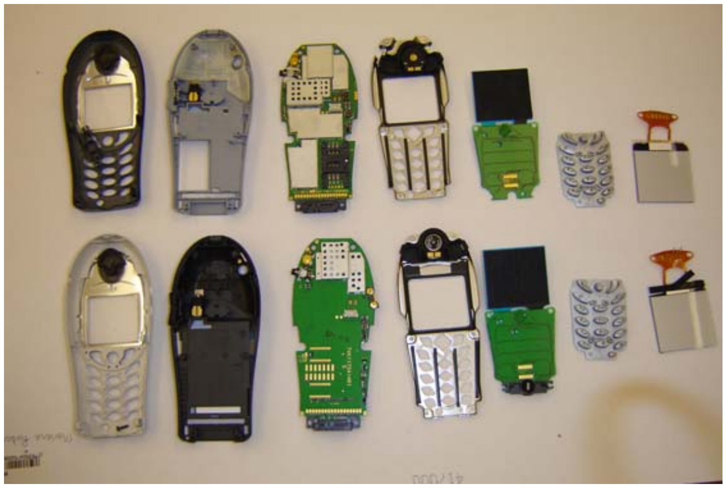

Figure 3: Disassembled cell phones

The PWB is the signal processing which controls incoming and outgoing signals. Additionally, a majority of the cell phone's electrical operations for voice and data communications is conducted from the PWB via the small mounted chips.

The microprocessor handles all of the housekeeping chores including command-and-control signaling with the base station and coordination with the remainder of the board and display.

The ROM and Flash memory chips provide storage for the phone's operating system and customizable features, such as the phone directory. The radio frequency (RF) and power section handles power management and recharging, in addition to hundreds of FM channels. Finally, the RF amplifiers handle traveling signals to and from the antenna. Some phones can also store certain information, such as the SID and MIN codes, in internal Flash memory, while others use external cards similar to SmartMedia cards.

To produce sound and quality, cell phones contain tiny speakers and microphones. The speaker is typically about the size of a dime and the microphone is normally no larger than a watch battery. Watch batteries too are comprised in cell phones and used by its internal clock chip.

With the evolution of technology, all the new functions presented today in cell phones would have filled up an entire floor of an office building just 30 years ago. Today, they fit into a very small package no more than a few inches in height and 100 grams in weight.

6.4. Material Composition of Cell phones

Cell phones are similar to other electronic products in that they comprise of plastics, metals, ceramics, and glass. These heterogeneous products also consist of hundreds of components which are constantly evolving in mass and form. The following chart illustrates the material composition of current cell phones (Huisman, 2004):

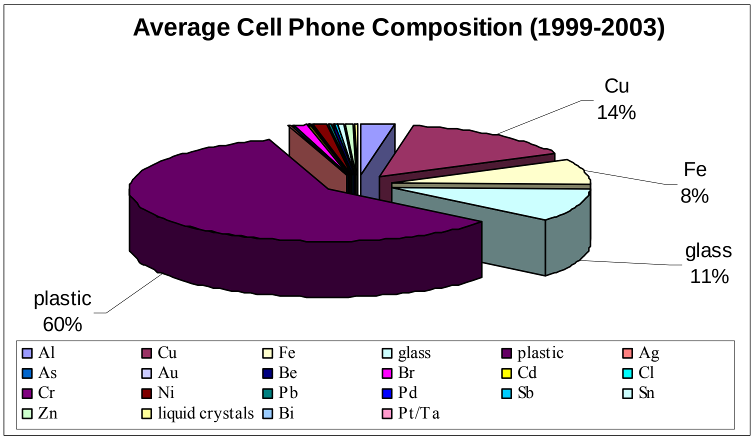

Figure 4: Average cell phone composition (1999-2003)

As shown specifically, plastic is the most prominent material in cell phones:

Material	% of total
Al	2.914
Cu	14.235
Fe	8.039
Glass	10.594
Plastic	59.600
Ag	0.244
As	0.001
Au	0.038
Be	0.003
Br	0.941
Cd	0.000
Cl	0.006
Cr	0.345
Ni	1.124
Pb	0.301
Pd	0.015
Sb	0.084
Sn	0.689
Zn	0.641
Liquid crystals	0.150
Bi	0.031
Pt/Ta	0.004

The data highlighting the evolution of material changes in cell phones is not readily available. This is due to the fact that cell phone composition overall is continually evolving in a fierce competitive industry which therefore does not allow easy access to product matrices for a given year or model. Additionally, because different methods can be employed to analyze material composition, the results are less-than-explicit with regard to exact trends in material composition (Basel Convention, UNEP).

Nonetheless, there are figures available from specific years that show general trends in the use of material within cell phones. The following table shows the difference in material composition from 1999 to 2003 (Huisman, 2004):

Table 1: Difference in Material Composition (from 1999-2003)
(Source: TUDelft, 2004)

Material	**2003/1999** (in %)
Glass	100.0
Plastic	113.8
Liquid crystals	133.3
Ag	40.9
Al	48.2
As	100.0
Au	74.3
Be	66.4
Bi	15.9
Br	100.0
Cd	200.0
Cl	200.2
Cr	181.7
Cu	69.0
Fe	106.2
Ni	77.9
Pb	116.0
Pd	78.0
Pt/Ta	149.7
Sb	91.5
Sn	77.3

Based on the information above, general observations regarding material composition of cell phones can be made. These observations are listed below, and are further discussed later in this chapter as well as in the EoL analysis chapter:

- Increase in non-metal substances (ie plastic and liquid crystals)
- Decrease in precious metals (ie gold, silver, and palladium)
- Variation in the different hazardous substances

6.4.1. Plastic

The plastic cover of cell phones is primarily made from neoprene, polycarbonate, and leather, while the cell phone case is made with rugged plastics usually acrylonitrile butadiene styrene-polycarbonate (ABS-PC) (APA, Website). Plastic normally comprises well over 50% of the cell phone, but because of various factors such as the added flame retardants/coating, and/or the presence of fasteners that make them difficult to disassemble, they are normally not collected and recycled, as are many other plastics.

Currently, the plastic used in cell phones is not completely compatible with the plastic used for other consumer products such as personal digital assistants, MP3 players, televisions, etc. This is yet another hurdle for recyclers when examining the possibility of recycling this material.

6.4.2. Hazardous Substances

The PWB and LCD of cell phones comprise a number of hazardous substances which can pollute the air and water if burned in incinerators or leached into soil and groundwater. Many of the toxins contained in cell phones belong to a group of chemicals which are known as persistent toxins. These substances are remain in the environment for long periods of time without breaking down, and can even accumulate in the food chain. Persistent bio-accumulative toxins (PBTs) have been associated with cancer and reproductive, neurological, and development disorders (Inform, 2003).

Many of the hazardous materials in cell phones decreased, while some such as lead increased for a while and have been decreasing as of late. The hazardous substances contained in cell phones, are listed along with their percentage difference from 1999 to 2003:

Table 2: Difference in Hazardous Materials (from 1999 to 2003)
(Source: TUDelft 2004)

Hazardous Substances	2003/1999 (in %)
Antimony	91.5
Arsenic	100.0
Beryllium	66.4
Brominated flame retardants	Figures N/A
Cadmium	200.0
Copper	69.0
Lead	116.0
Nickel	77.9
Zinc (in large doses)	53.4

The hazardous substance of most concern contained within cell phones is lead. This heavy metal is a suspected carcinogen which has negative effects on the central nervous system, the immune system, and the kidneys, and has been associated with development abnormalities (Inform, 2003). The application of lead in cell phones and other electronic products is in the solder used to attach components to each other and to the PWB.

Other substances of great concern contained in cell phones are brominated flame retardants which are also known to be persistent, bio-accumulative and toxic. Flame retardants in the form of either polybrominated biphenyls (PBBs) or polybrominated diphenyl ethers (PBDEs) are added to the plastics of PWB, cables, and plastic housings as a way of reducing the risk of fire (Inform, 2003). These retardants are associated with cancer and abnormalities in the immune and endocrine system.

As discussed in more detail in Chapter 7, the use of these two substances has been banned under the RoHS Directive which begins in July 2006. As a result, U.S. manufacturers and retailers had to look for alternatives to these substances.

Manufacturers such as Nortel and Motorola have developed phones with lead-free solder; specifically, Motorola has developed a phone with 95% less lead than its conventional phones (Fishbein, 2002). Companies such as Sony and Nokia are also not only developing products that contain lead-free solder, but are also developing programs that promote the slogan “we make it, we take it”; these programs include take-back/recycling of their products and are thought to become profitable parts of the business. More information regarding the substitutes for hazardous material is discussed later in this chapter.

The LCD of a cell phone displays information to the user; it contains liquid crystals embedded between layers of glass, back lighting for illumination, and transistors to provide an electrical charge (Fishbein, 2002). According to a study by Germany's Federal Environmental Agency, cell phones contain a very small quantity, about 5 milligrams, of liquid crystals. Since the EU's forthcoming electronic directive requires the removal and special treatment of LCD's which are larger than 100 square centimeters, cell phones are not subject to the removal requirements; thus no new design and process development has been initiated.

Antimony

Antimony is a chemical element with the symbol Sb. It is used primarily in flame-proofing, paints, ceramics, alloys, electronics, and rubber (wikipedia.org). Antimony is increasingly used as an alloy that greatly increases lead's hardness and strength; its most important use is as a hardener in lead for storage batteries.

Antimony and its compounds are known to be toxic; in small doses, it can cause headaches, dizziness and depression, while larger doses can cause violent and frequent vomiting (wikipedia.org).

Arsenic

Found in the PWB of cell phones, arsenic can cause damage to the nerves, skin, and digestive system of humans and can even cause death if ingested in high levels. Due to their ability to reduce static, gallium-arsenic semiconductors are used in cell phones. (Fishbein, 2002). In use, the chips are harmless. However when incinerated, the chips create a toxic compound.

Beryllium

Beryllium is a hard, lightweight metal which is a good conductor of electricity and heat, and is non-magnetic (OSHA, Website). It is used as a beryllium-copper alloy in cell phones, in order to help expand and contract the springs and contacts. Beryllium can be a health hazard in recycling and manufacturing facilities. Small particles of this metal can easily break off when products are shredded or heated and they can spread through the air. The fumes and dust can then be very toxic if inhaled; workers who are overly exposed to beryllium can suffer irreversible and sometimes fatal scarring of the lungs (US Dept of Energy, Website).

Because of this serious health hazard, beryllium contained in cell phones can create a major obstacle for the products' recycling. Many recycling and metal recovery facilities, such as Noranda located in California, have set a beryllium limit on used electronic products entering their facilities (Fishbein, 2002).

Brominated Flame Retardants

Due to the highly flammable nature of plastics, flame retardants are normally added to plastic in order to reduce the risk of fire. Plastic is used in the printed wiring board, cables, housing, and connectors of a cell phone (EPA.gov). According to the trade association, Bromine Science and Environmental Forum, 39% of all flame retardants are brominated; the rest are based on chlorine, phosphorus, nitrogen, or inorganic materials. Brominated Flame Retardants compose either Polybrominated Diphenylethers (PDBE) or Polybrominated Biphenyls (PBB). Electronic products are known to be the largest application, at 56% of total use, of all brominated flame retardants (Fishbein, 2002).

The dangers associated with brominated flame retardants are that can act as endocrine disrupters and increase the risk of cancer to the digestive and lymph systems. Additionally, once they are released via leaching or incineration into the environment, brominated flame retardants can become concentrated in the food chain (EPA, Website).

Because of the many different types of plastics used in electronic equipment, plastics are the most challenging to recycle. Plastics also often contain hazardous material including metal screws and inserts, coatings, paints, foams, and labels. Additionally, plastics that are treated with flame retardants are even more difficult to recycle, and can be dangerous to the health of those exposed to them (EPA, Website). Information regarding the various flame retardants and their respective applicability is available under the Toxicity Subsection of this chapter.

Cadmium

Cadmium, a heavy metal found naturally in soils and rocks, is soft in texture and silver in color (Trentu.ca.). Cadmium is primarily and increasingly used in Ni-Cd batteries, and followed by consumption in the traditional markets of pigments, stabilizers, coatings, alloys and electronic compounds such as cadmium telluride (Cadmium.org). Its use in Ni-Cd batteries is in the form of cadmium hydroxide which is utilized as one of the 2 main electrode materials with extensive application in the railroad and aircraft industry, and consumer industry in cordless power tools, cell phones, and portable computers. These batteries are cost-effective and have high life-spans (Cadmium, Website).

Classified by the EPA as a Group B1, probable human carcinogen, the acute human effects of cadmium are primarily on the lungs. Chronic inhalation of this metal leads up to a build of the substance in the kidneys and can cause kidney disease and lung cancer (EPA, Website).

Copper

Copper is a metal that is found naturally throughout the environment, in rocks, soil, water, and air. It is an essential element for all plants and animals; it is also used to make a variety of products such as wires, pipes and sheet metals (Agency for Toxic Substances and Disease Registry). The EPA requires less than 1.3mg of copper per one liter of drinking water (Agency for Toxic Substances and Disease Registry). On its original list of persistent, bioaccumulative toxins, copper was ranked as number 41 (Fishbein, 2002). Copper is used extensively in cell phones and can cause the formation of dioxins and furans when the products are incinerated.

Lead

Lead is present in almost all electronic products including cell phones. Lead is found in the glass panels of computer monitors and in the lead soldering of printed circuit boards/wiring boards. Approximately 100,000 to 125,000 tons of lead solder have been estimated to be produced globally each year for the electronics industry (Deubzer, et al, 2001).

The quantity of lead found in cell phones is small, compared to large electronic products such as TVs and computer monitors. The PWB of a cell phone contains about 50 grams per square meter, or about .01 ounces of lead (Fishbein, 2002). Compared to the amount of lead, 4 to 8 pounds, contained in a single TV picture tube, the amount found in cell phones can be negligible. However, the short life span of cell phones dictates a larger number of discarded products each year, and therefore there is considerable potential for the lead to end up in an incinerator and/or a landfill. More specific information regarding the lead alloys contained in cell phones can be found in the Toxicity subsection of this chapter.

Lead is regarded as a dangerous metal that has significant health hazards. According to the Environmental Protection Agency's Office of Solid Waste, lead is a bioaccumulative element which is known to cause significant damage to the human central and peripheral nervous system, blood system, kidneys and especially on children's brain development. The primary route of lead found in the environment is via landfill leaching and water contamination. This is especially disconcerting since consumer electronic products are known to be responsible for nearly 40% of the lead found in landfills (EPA, Website).

Because lead and brominated flame retardants are of most concern with regard to hazardous components, a closer examination of alternatives to their use will follow.

Nickel

Nickel is a silvery-white colored metal, which occurs combined with sulfur and/or arsenic. It belongs to the iron group and is hard in composition, malleable and ductile (Wikipedia, Website). This metal is primarily used for nickel alloys, batteries, electroplating, machinery, etc. Classified by the EPA as a Group B2, probable human carcinogen, nickel has long-term respiratory effects and can cause lung and nasal cancers.

Zinc

The fourth most common metal in use after iron, aluminum, and copper, Zinc is blue-whitish in color and used primarily as coatings, rust prevention, cell batteries and as an alloy in brass and bronze (Agency for Toxic Substances and Diseases Registry, Website). Although an essential requirement for the body, an excess amount of exposure to Zinc can be harmful by causing stomach cramps, anemia and changes in the body's cholesterol level. Most of the zinc found in the environment attaches to soil and particles in the air. It is bio-accumulative in fish and other organisms, but not in plants (Agency for Toxic Substances and Diseases Registry, Website).

6.5. Design for Environment

Design for Environment (DfE), also referred to as Eco-Design, is product development that takes into consideration the reduction of the product's negative environmental impact. This includes reduction in resource consumption, both in material and energy terms, and pollution prevention (Dantes, Website).

Although cell phones have evolved into more environmentally favorable products, consideration of environmental impact has not been the driving force behind the change; consumer demand for smaller, lighter products has been the primary catalyst.

Extended Producer Responsibility (EPR) is the legislative concept that makes producers responsible for the end-of-life management of their products. One of the main theoretical objectives of this type of legislation is to create incentives for producers to design products which are easier to dismantle and/or that have components easier to recycle and/or reuse (Castell, Clift, France, 2004). More specifically, EPR aims to incentivize producers to promote "specialized expertise" such as product design and technology development (Lindhqvist, 1997).

Three main areas of emphasis have shown a clear trend over the last few years. These main areas are explained below.

6.5.1. Material change

As mentioned, cell phone design has changed considerably over the last three decades as manufacturers responded to consumer demand while technology rapidly advanced. The most visible change in cell phones was in their size and portability. As previously mentioned the original cell phones were approximately 5kg and have shrunk to their current weight of about 100grams. The first generation of the phones also contained lead acid batteries and came with a carrying bag with shoulder straps (Basel Convention, UNEP).

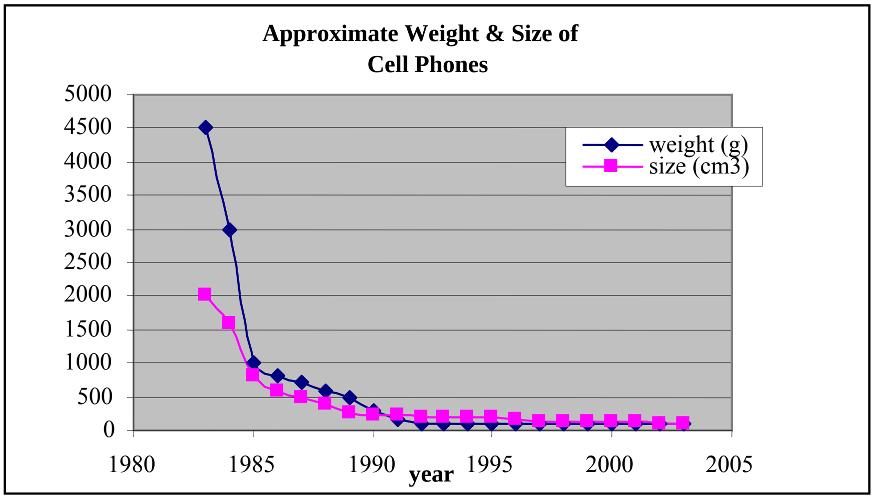

Figure 5: Weight and Size of Cell phones Over Time
(Source: Basel Convention; UNEP)

Consumers not only demanded smaller, more easily portable products, they also needed longer operating time on charged batteries. Producers responded to this demand with significant improvements over the last 20 years; standby operating time of cell phones on a single battery charge increase from 4 hours to more than 10 days, even though the size of the battery decreased greatly. Manufacturers were able to provide such a service as a result of two primary approaches (Basel Convention, UNEP):

First, new types of batteries were introduced. The cell phone industry replaced the original lead-acid batteries, and then replaced the subsequent nickel-cadmium batteries with nickel-metal hydride, and then more recently lithium-ion batteries (Basel Convention, UNEP). As of the year 2000, the most commonly used batteries in cell phones were lithium ion, at 45% of the total number of products, followed by nickel-metal hydride, at 40%, and nickel-cadmium, at 15%. Nickel cadmium batteries are soon expected to be completely phased out.

This continuous change in battery types has resulted in not only increasing performance level and energy density, but also in continually reducing the use of toxic metals, lead and cadmium. Nickel-metal-hydride batteries use an alloy based either on lanthanum nickel or on vanadium-titanium-zirconium nickel. These lithium ion batteries contain lithium and manganese, cobalt, or nickel and while they too have environmental considerations, they are less hazardous than lead and cadmium (Basel Convention, UNEP).

The second approach in meeting consumer demand for longer cell phone operating time was through reducing the energy consumption of cell phones while they are in use. Manufacturers have achieved this by improving the efficiency of components and sub-assemblies, reducing the operating voltage, and reducing overall energy requirements of the circuitry (Basel Convention, UNEP). Simultaneously, manufacturers have been able to reduce energy consumption of mobile phones when the batteries are being charged, and while they are fully charged but sill connected to the charger. These energy reduction approaches have been extremely beneficial to the environment as they decrease the need for carbon-based power sources and the potential subsequent emissions of greenhouse gases.

Precious metals, specifically gold (Au), silver (Ag), and palladium (Pd) contained in cell phones have been the major economic driver for recycling industry despite the small mass contained per unit. However, since cell phones contain a mere 150grams of gold, 2,000grams of silver, and 100 grams of palladium per ton, any added-value in the material recovery of these elements can only be possible by the collection of a large number of cell phones. (Takahashi, 2004) Moreover, because of their high value in terms of price and scarcity, manufacturers continually strive to find substitutes for these precious metals.

It is also important to note that the mass of cell phones has decreased in part due to the increase in plastic use. Plastic is used for housing and other parts of a cell phone. To achieve mobility, the cell phone must be light, but it must also be strong, temperature resistant and shock absorbing. PC, alloys of PC and ABS are the most widely used type of plastic for mobile phones. PPE, PPS or LCP are also being used and each has a different strength in its lightness, shock-resistance and miniaturization adaptation.

Additionally important to note is that there are typically between eight and twelve different resins in the EoL consumer electronics. Moreover, three resins, HIPS, ABS, and polyphenylen ether/high impact polystyrene blend (PPE) accounted for about 87% of the plastics in EoL electronics (Headly 2004).

6.5.2. Toxicity

As discussed in the legislation chapter, the RoHS Directive calls for the elimination of certain hazardous wastes from electronic products. Specifically, these hazardous wastes include lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyls, and polybrominated diphenyl ethers (Basel Convention, UNEP). With regard to cell phones, lead, brominated flame retardants, and in some cases cadmium are of most serious environmental concern because the remaining substances have no essential function in mobile phones and are not normally used. Therefore, the replacement of lead, flame retardants and cadmium have been the focus of cell phone manufacturers over the past few years and there is a clear trend toward the decrease use of these toxins.

As previously mentioned, lead is by far the most common component in electronic products as it is used in large quantities to shield against harmful radiation in cathode ray tubes (CRTs) of computer and television monitors (Basel Convention, UNEP). Specifically in cell phones, which do not contain CRTs, lead is used as a tin-lead solder to bond components together and onto a PWB.

Cadmium is primarily used in the nickel-cadmium batteries of electronics which as described earlier are increasingly replaced with NiMH and Li-ion batteries. Cadmium is also used in very small quantities as a surface finish on PWBs, and in electrical contact alloys for relays and switches (Basel Convention, UNEP).

Polybrominated biphenyls (PBBs) were formerly used as flame retardants in plastics of electronic products. These toxins however are not used in cell phones. Polybrominated biphenyl ethers (PBBEs or PBDEs) have been used as safer substitutes for the former substance. However, cell phone manufacturers have long been searching for halogen-free flame retardants.

Mercury used small quantities as a light vapor to illuminated LCD computer screens, is not known to be used in cell phones. Hexavalent chromium used to plate metal, typically steel, is a corrosion protector which is not required by cell phones.

With regard to cell phone toxicity, there is a clear trend toward a decrease in the use of toxic substances. Even before the RoHS Directive was brought to the forefront of legislation, manufacturers had begun producing phones which used neither lead nor brominated fire retardants. For example, in 2001 Motorola manufactured a cell phone completely free of lead solder and bromine PWB. Additionally, the cell phone's case was made from recycled plastic, accompanied by an energy efficient charger that met the EC Code of Conduct on the Efficiency of External Power Supplies (Basel Convention, UNEP). In 2002, Sony also began its production of lead- and bromine-free cell phones, and Panasonic followed suit with its reduced use of lead and halogens.

<u>LEAD</u>

Currently, the primary mounting component in cell phones is the tin-lead solder which is a 60/40 alloy consisting of 60 percent tin and 40 percent lead (Trumble, 1998). The tin-lead solder coats the copper surfaces and the component leads in order to prevent oxidation of the copper and to improve the solderability of components. Tin-lead solder has a broad application in electronic products; it has a strong mechanical, electrical, and physical performance and is low in material cost. Its low melting temperature of 183˚C coupled with its strong thermal fatigue resistance and thermal conductivity make it a universal choice of electronic circuitry. It is also easy to repair and resists corrosion (Trumble, 1998).

In response to the RoHS and WEEE initiatives, various groups such as NEMI (National Electronics Manufacturing Initiative, Inc.) have been formed to investigate various processes and materials in consideration of lead-free electronic assemblies

(Lead-free Project). Many OEMs are also considering various alternatives to the lead-tin solders in current use. Any new lead-free assembly will affect several aspects of the engineering and design of electronic products.

However, specific considerations including mechanical reliability, thermal fatigue resistance, wetting, low melting temperatures, and compatibility with lead-bearing and lead-free surface coatings for solder should be carefully examined (Lead-free Project). Especially important is the thermal fatigue resistance. Circuits undergo constant switching from on to off and vice versa, therefore they undergo heating and cooling cycles that continually expand and contract circuit board materials and solder joints and can ultimately stress the solder joints (Trumble, 1998). Another solder characteristic that is of importance is wettability, also referred to as the solderability, which is the efficiency and speed with which the solder spreads over a metal surface (Trumble, 1998).

Additionally, cost, availability and patent issues are factors that must also be examined. There are a number of alloy combinations being considered for the replacement substitute of the lead-tin solders. Some of these alloys include tin-bismuth, tin copper, tin-silver-copper, tin-silver-bismuth, etc. The most frequently considered/used substitute is the tin-silver-copper alloy (Geiser, 2001). However, since two metals are easier to blend and more likely to remain stable over the lifetime of the solder joint, binary alloys (alloys consisting of only two metals) are preferred. Thus tin-copper alloys and tin-silver alloys alone have been ranked high on their performance and may become the substitute of choice (Trumble, 1998). Considering the high price of silver, if the tin-silver alloys were to replace the current tin-lead product, the recycling and recovery of the various components of electronic products may become a more attractive business endeavor for OEMs.

Ultimately, all lead-free substitutes will most likely continue to rely on tin as the base metal; this is because tin is considered to be one of the least toxic metals, and it is relatively inexpensive and available, and it possesses desirable physical properties (Trumble, 1998).

Below are some of the physical properties and manufacturability characteristics of tin alloys:

Table 3: Characteristics of Tin Alloys
(Source: Get the Lead Out; IEEE 1998)

Alloy	**Melting point** (C°)	**Process Temp** (peak reflow)	**Tensile Strength** (N/mm2)	**Elonga-tion** (%)	**Surface Tension - Air** (mN/m)	**Surface Tension - N_2** (mN/m)	**Electrical-conductivity** (%IACS)	**Thermal conductivity** (W/cm/C)
Tin-lead	183	220	51	27	468	495	11.5	0.50
Tin-copper	227	245	35	20	491	461	13.4	0.68

Alloy	Melting point (Cº)	Process Temp (peak reflow)	Tensile Strength (N/mm2)	Elonga-tion (%)	Surface Tension - Air (mN/m)	Surface Tension - N_2 (mN/m)	Electrical-conductivity (%IACS)	Thermal conductivity (W/cm/C)
Tin-silver	221	243	31	23	431	493	23	0.73

Because they all have significantly higher melting points than the currently used lead-tin solder, OEMs must consider the higher peak reflow temperatures when attaching a device or a component to a PWB (Ho, et al). Reflow profiles are chosen in such a way that they can reliably melt the solder at all positions on the PWB, to allow for certain variations such as oven characteristics, board size, and the number of interconnect layers. Typically, the peak reflow temperatures are higher than the melting points of the solders (Ho, et al).

This may mean that the PWB of cell phones may have to be redesigned to withstand higher temperatures. For example, the tin-lead solder has a melting point of 183˚C and its reflow temperature is set at 220˚C in order to compensate for the variations and get good solder joints (Ho, et al). As the most agreed-upon alternative, the tin-silver-copper alloy, has a melting point of 217˚C and a peak reflow of 260˚C (Fishbein, 2002). But there are implications such as compatibility with some types of finishes used on external leads. For example, the tin-silver-copper is incompatible with standard silver/palladium finishes; additionally, the cost of the alloy is currently more than double the tin-lead solder (Ho et al).

Many alternatives that have been tested have also proven difficult to rework or disassemble and/or contain elements that are incompatible with recycling processes (Murphy, 2001). The following chart outlines the various alloys that have been tested for various applications, and their melting temperatures:

Table 4: Alloy Alternatives
(Source: Environmentally Benign Materials for Electronics; IEEE 2005)

Alloy	**Melting Point** (Cº)	**Application**
Sn-37Pb	183	All
Sn-58Bi	138	CE
Sn-9.0Zn	198	Toshiba, NEC
Sn-0.7Cu	227	Nortel
Sn-3.5Ag	221	Automotive
Sn-3.8Ag-0.7Cu	217	Nortel
Sn-2.5Ag-0.8Cu0.5Sb	213-218	Motorola
Sn-3.5Ag-4.8Bi	205-210	Sandia
Sn-2.0Ag-7.5Bi0.5Cu	217-218	IBM
Sn-2.0Ag-4.0Bi-0.5Cu-0.1Ge	210-217	Sony
Sn-3.5Ag-1.5ln	218	Indium Corp.
Sn-2.8Ag-20ln	175-187	Indium Corp.

It is important to note that different manufacturers are employing various substitutes. For example, Nokia recently reported they are substituting their lead solder with Sn-Cu.

As stated earlier, an alloy that seems the most attractive to manufacturers seems to be the tin-silver-copper solder. This substitute has a relatively low melting point at 217˚C and seems to have a consistent reliability to the conventional tin-lead solder. Because the melting point is still much higher than the melting point of tin-lead solder, the processing temperatures will still need to be higher and/or the process window is much narrower. This in combination with its poorer wetting qualities means that the PWB may have to go through a pre-baking process and a nitrogen ambient during the soldering process may be need to improve the performance and reliability of the solder. But all of this would also translate to an increase in economic costs as well as environmental impact (Murphy, 2001).

One concern that has arisen involves recycle-ability. Currently PWBs are sent to lead smelters for recovery; however it is not known whether the new lead-free products will be recyclable in the same way as current practices. This is due to the fact that the new products may be more difficult to recover, and it is also because of the concerns that various new metals may be hazardous to other (eg Bismuth) (Murphy, 2001).

Brominated Flame Retardants (BRRs)

As mentioned earlier, many polymers are highly flammable and thus have called for the use of some type of flame retardant. Traditional forms of retardants have been halogenated flame retardant organic compounds that contain either bromine or chlorine. Current cell phones contain approximately 2grams of flame retardant (Basel Convention, UNEP). The following chart outlines the various flame retardants, their current applications, and the legislation regarding each:

Table 5: Flame Retardant Substitutes
(Source: Environmentally Benign Materials for Electronics; IEEE 2005)

Flame Retardant	Applications	Toxicity and Hazards	Legislation
Decabromodiphenyl Oxide (Deca-BDE)	HIPS electronic equipment and polyethylenes (wiring)	Neurotoxic, carcinogenic, bioaccumulative	Banned in EU, 2006
Octabromodiphenyl Oxide (Octa-BDE)	Plastics in monitors; cell phones; copiers and TVs	N/I	Banned in EU, 2006. Banned in CA, USA 2008
Pentabromodiphenyl Oxide (Penta-BDE)	Foams, mattresses, seat cushions, and	N/I	Banned in EU, 2006. Banned in CA, USA

Flame Retardant	Applications	Toxicity and Hazards	Legislation
	carpet		2008
Hexabromocyclo-dodecane (HBCD)	Polystyrene (insulation) and upholsteries	N/I	EU investigating
Tetrabromo-bisphenol-A (TBBA or TBBPA)	Epoxy resins for laminating and coatings in electronics	Bioaccumulation probable, mutagenic, high-risk carcinogen and neurotoxicant	EU investigating
Tris (chloropropyl) Phosphate (TCPP)	Polyurethane foams and building materials	High-risk carcinogen, traces detected in groundwater and seawater, bioaccumulative	N/I
Sodium Borate Decahydrate (borax)	FR for celulosic materials, also used in many household products	Teratogenic effects, high current concentration in foods because of other applications	N/I
Antimony Trioxide	Works synergistically with halogenated FR agents	Many strong human health hazards	Banned by EU, 2006. Antimony Pentoxide is still used.

Brominated flame retardants pose the threat of forming dioxins and furans during incineration or recycling and are also persistent bioaccumulatives (Murphy, 2001). In order to address these hazardous dangers, the RoHS directive has called for the phase-out of the 2 specific flame retardants, polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs) by January 1, 2008 (Murphy, 2001). However, these 2 compounds are currently rarely used in manufacturing. The 2 families of BFRs currently in most wide use are polybrominated diphenyl oxides (PBDPOs and the phenolics which includes TBBPA (tetrabromobisphenol A). As mentioned TBBP-A is used primarily for PWBs; it continues however to be an issue of debate with regard to its environmental toxicity. Currently, it is not a banned substance under the RoHS Directive.
Currently, such companies as Sony are in the process of testing whether phosphate esters and nitrite flame deterrents can be used as substitutes to the current BFRs. Other task forces have investigated the possibility of using large organic aromatic molecules or nitrogen containing compounds that do not burn easily (Murphy, 2001).

Another option is to completely redesign PWBs in such a way that they don't require the use of flame retardants; this would include the use of materials with low rates of combustion and high glass transition temperatures, or material that conduct heat well (Murphy, 2001). Manufacturers such as Nokia have not used flame retardants on their cell phones for the last few years.

The same concerns of recycle-ability arise with the substitution of brominated flame retardants. So far little research has been done to understand how the substitutes will behave during incineration and what the subsequent effects will be on recycling and recovery of the metals.

Cadmium

As discussed in the previous section regarding the cell phones' material change, nickel-cadmium batteries in cell phones have increasingly been replaced by the lithium-ion batteries that contain lithium and manganese, cobalt, or nickel. Additionally, manufacturers such as Nokia have reported that their use of cadmium had previously been in a very limited number of plastics and over the last few months, they have substituted the original plastics with those which do not require the use of such heavy metal stabilizers. Specifically, Nokia reported they currently use material based on calcium-zinc and barium-zinc compounds.

6.5.3. Disassembly and recycle-ability

As described in more detail in Chapter 7, the WEEE Directive mandates that electronic waste must be collected at a rate of at least 4kg per person, and once collected, at least 65% (by weight) of the cell phones must then be recycled. Since this recycling mandate does not include the use of plastics as fuel, and since the typical cell phone comprises more than 40% plastic, some of the product's plastics must be recycled in order to meet the 65% recycling requirement (Basel Convention, UNEP). Manufacturers of cell phones must thus develop such products that will promote easier, more efficient disassembly and recycle-ability of at least some of their plastics, such as that in the handset case.

To meet the recycling requirements set forth by the WEEE in Europe, it is important to design products, specifically the PWB of cell phones, in such a way that the parts are more easily removed and the recycling process is made more tangible.

Disassembly

Design for easier disassembly of products has been gaining increasingly popularity in the past few years. This is based on the idea that "efficient disassembly is a key to carrying out the ideal end-of-life strategies for every product category" (Ishii, et al) Some ways in which disassembly can be made easier through product design include the development of separation technologies to ease separation of components for recycling high quality material. Disassembly of products vary due to the variety of products; for instance, the position and number of screws embedded in each product effect the various means of disassembly and they also effect in turn the recycling potential for each product.

Additionally important are remanufacturing and lengthening of the product's life (Ishii, et al). For example, by enhancing the re-usability of common parts, products may not only divert waste and energy, but also create additional economic value. By developing efficient cleaning and inspection technologies to reduce manufacturing costs and allow easier removal of key components (Ishii, et al), the cell phones' end-life can be increased and the remanufacturing costs decreased.

Various trends have emerged in the composition and build of cell phones. For example, the number of screws and the layers of plastic boards built into the products have varied significantly based on the model, year and type of cell phone. All of these changes have had various impacts. Specifically, the number of inner layers within cell phones has shown reductions of environmental impacts as they went from six to three inner board layers (Muller, et al). This reduced number of layers although beneficial for disassembly of the phones, could have a detrimental affect to the recycling industry because the metal contents are then reduced. Additionally, the change in cell phone designs from a double-sided to a single-sided board would very likely improve the recyclability of the phone if the recycling process took into consideration the separation of the various components from the actual board substrate. Since cell phone recycling does in fact include this process, the variability in the board would then be affected.

Recyclablity of cell phone materials

There are several factors that determine the difficulty in recovering specific material. Even though the emphasis might vary depending on the material used, these factors are all important in the recovery of different material:

- Homogeneous vs. Heterogeneous

  Homogeneous material is much easier to recycle than heterogeneous material. The process is simple and at times more efficient, requiring less input and energy; this is beneficial from both an economic and an environmental standpoint. Secondary material can yield a higher grade and a higher value compared to heterogeneous material.

- Pure vs. Contaminated

  Coating, paint, labels, adhesives, and/or flame retardants on the surface of material can create impurities and degrade the quality of secondary materials. Removing the impurities is an additional process that has extra costs, and is feasible only if an increased quality in secondary material can justify all additional costs.

- Chemical vs. Metallurgical Constraints
  There is always an issue of degradation for molecule-level recycling, especially for organic materials. Metal also has constraints. Depending on the combination, some metals cannot be separated from others and this can inhibit the recovery of both elements.

- Value in Secondary Market
  Even if recycling is technically feasible, materials with lower profit-returns than processing costs are not likely to be recovered.

When these factors work unfavorably for material recovery, recycling can be process/energy intensive only to produce low quality secondary material. In this case, recycling might not be plausible both from an economic and environmental perspective. It is very important to weigh the benefits and burdens to decide which materials to recover.

Cell phones consist of hundreds of small components made of plastic, glass, ceramic and metals, therefore they are inherently heterogeneous as feedstock. Additionally as previously mentioned, the many different models compose varying material composition/mass which has been continually changing over time. As a result, aggregated feedstock can be impure and contaminated. Nevertheless, because of the small presence of precious metals, recycling process can be profitable. Therefore, cell phone recovery industry is characterized as having low recycling rates (recycled weight divided by total weight), but being economically feasible.

The material recovery hierarchy of cell phones comprises precious metals at the top of the chain, followed by copper there-after. Together, they constitute approximately 10% of the cell phone's total mass. In most cases other materials are not recovered and are forgone to facilitate copper-precious metal recovery.

As seen with the replacement of tin-lead solder, the value of recycling may increase if the substitute consists of a silver-containing alloy. However, based on various research results, this change will most likely not be significant because the high cost of silver may keep manufacturers from its use.

Metal

Metals comprise about 30% of total mass of cell phones and are concentrated in printed wiring board (PWB). Copper constitutes about 10% of the total mass. Iron, aluminum and nickel typically constitute more than a couple of percents and other dozens of species are present only with less than 1% concentration. Therefore, from a recycling standpoint, cell phones or more specifically the PWB of cell phones is regarded as copper-rich metal scrap that contains other trace metals. Copper functions as a "carrier" metal. There is already an established process for precious metals recovery from copper-rich feedstock. Many copper-rich ore in the natural environment contain low concentrations of precious metals for which mining/extraction industry has developed the technology and operation to recover precious metals. Therefore, from a technical and economic standpoint, processing copper-rich feedstock can be done to 1) recover and refine copper and then 2) recover and refine precious metals, using existing infrastructure and expertise. Despite the low concentration per unit, these metals can be recovered up to 90 ~ 95% and can be refined to 99.9~99.99% purity, and can therefore retain the same value as primary products.

As previously mentioned, copper is used in electronic products because of its high electrical conductivity. Among all elements, only silver excels in this property, but due to silver's scarcity and high cost, it is reasonable to assume cell phones and PWB will remain copper-rich feedstock for the foreseeable future.

Plastic

Comprising 40% to 65% of total mass, plastic is the primary material in cell phones. However, plastic from cell phones is not suitable for recycling due to several reasons. First constraint is its mechanical design. Plastic recycling requires different technology/facility than metal recycling and therefore plastic parts must be separated in the pre-treatment phase so they can be sent to various plastic recyclers. Cell phones are small and the amount of plastic per unit is also small; relative to the high labor cost for dismantling of these parts, the economic yield is negligible. The second constraint is in material quality. Different models use different plastics with various quality, color, coating and/or adhesives. Thus, the aggregated feedstock can be contaminated and impure, and can only produce lower grade, lower value secondary material.

Furthermore, as mentioned earlier, flame retardants are another obstacle for recycling because it requires special treatment during the process. Therefore currently, plastic recovery from cell phones is not exercised in profit-based operations. When plastic is recovered, it is more for environmental reasons: recovered materials are typically used for asphalt, benches in the park and others that do not require much quality.

In the foreseeable future, an increase in oil price could make plastic recycling more economically feasible, but the situation remains uncertain as long as EOL cell phones are concerned.

Glass

The current situation regarding display or glass recycling from cell phones is almost the same as plastic. Expected profit from glass recycling is too small relative to the labor costs associated with separation of the material for recycling. Also, the material could be heterogeneous and contaminated which results in lower grade secondary material with lower value. Therefore, it is most likely that the glass is incinerated and used as flux during copper smelting.

The overall recycling performance, or decision regarding whether recovery should be implemented for a given material, is driven by a combination of different factors. Whereas plastic and glass have almost no factors that lead to high recycling performances, metals (copper and precious metals) have some. Therefore, copper and precious metals are recovered as a priority.

7. Legislation

7.1. Key Components of Cell Phone Legislation

Several states legislatures have passed measures to focus on the EoL management of cell phones. But the state efforts are not consistent, and if no federal solution is reached, there could eventually be 50 different approaches to collecting, and re-using/recycling cell phones.

The current voluntary take back system in the United States, thus far, has proven to be fairly ineffective. With less than 5% of all cell phones being collected, momentum is building for legislation to be implemented.

The goals of comprehensive cell phone end-of-life management is to promote high collection, re-use and recycling rates for cell phones while encouraging design for the environment.

The issue of “who pays” and who will be the ultimate responsible party in charge of fees and collection is an important aspect of legislation. Some options for financing the costs include:

- Producers are responsible
- Retailers/service providers are responsible for all costs
- Consumers pay through Advanced Recovery Fees (ARFs).
- City and county governments are responsible. This approach may ultimately mean taxpayers pay through local public collection programs.
- Tax credits making tax payers responsible
- An Extended Product Responsibility approach is used where costs are shared among the supply chain agents

In order for any policy to effectively promote and increase the amount of recycling, there must be in place a measure of collection goals and incentives. This may help increase cell-phone take-back numbers. Requiring performance goals to be reported to a government agency for enforcement, such as the EPA, on a periodic basis may be a beneficial mechanism in enforcing collection targets. Performance measures could be reported in a variety of ways, including:

- Collection and recycling of a certain percentage of the company/brands products
- Collection and recycling based on the amount per person

- Collection and recycling based on a level of convenience. This could mean a certain number of drop-off or collection locations per unit of the population.

The scope of electronic waste legislation must be closely defined. Scope is simply defined as which waste gets collected, re-used or recycled. Because electronic waste is a large category, covering products ranging from TVs, CRTs, monitors, laptops, to cell phones. Cell phones are unique in the electronic waste stream due their small size, short life spans, and contain valuable metals.

Some more progressive legislation encourages producers to Design for the Environment (DfE). In DfE producers take into account reducing the electronic products impact on the environment. DfE includes a reduction in the use of resources and energy use. A goal of comprehensive cell phone end-of- life legislation is to encourage reduction in the volume and toxicity of materials used in the making of cell phones.

Another key component of cell-phone take-back legislation are the concepts of “historical” and “orphan waste.” Historical wastes are the cell phones sold on the market before implementation of end-of-life management mandatory take back schemes. Orphan waste includes products made by companies’ no longer in operation or products whose producers are unknown.

Mechanisms to reduce toxic materials in cell phones are another crucial policy component. Banning the sale of products containing certain hazardous substances such as lead, mercury, and bromated flame retardants encourages responsible practices such as design for the environment, and would address the public and environmental health problems on hand.

Finally, social issues and responsible recycling standards must also be addressed in a take-back policy. Currently, e-waste “dumping” is an issue in overseas countries such as China. Thus, policy should include a provision banning all exports of cell-phone waste by companies, which would then eliminate the possibility of the NIMBY (Not in My Backyard) approach. (Computer take-back Website)

7.2. E-Waste/Cell Phone legislation in Europe

7.2.1. WEEE Directive 2002/96/EC

Europe has set the precedent in electronic waste legislation. In February 2003, European Union Policy makers implemented the Waste Electrical and Electronic Equipment Directive requiring producers of electric and electronic products to take responsibility for their products at End-of-Life. Specifically, the WEEE Directive requires producers to finance and orchestrate take-back, recycling, and treatment schemes and achieve mass based recycling and recovery targets. The directive, scheduled to go into effect August 13, 2006 includes electronic products manufactured abroad and sold in the EU. The Waste Electrical and Electronic Equipment (WEEE) Directive 2002/96/EC, as amended by 2003/108/EC.

The Directive is designed to combat the problem of electronic waste based on the principle of extended producer responsibility, which makes the producers financially responsible for managing waste generated by their products. The rational behind the EPR approach is that producers are required to 1) take back products at the end of life free of charge 2) achieve high rates of re-use and recycling and 3) design products that generate less waste.

By requiring manufacturers to be financially and/or physically liable for managing their goods after consumers discard them, policy makers are hoping to create a powerful driver for producers to generate designs that facilitate cell phone reuse and recycling. Because toxic contaminants hinder recycling, EPR could give manufacturers a stronger incentive to design their cell phones with fewer toxic components.

Article 5 of the WEEE Directive sets a compulsory collection target of 4 kg per person per year of electronic and electrical waste will be met without some types of products being collected at all. For example, the recycling target of 65 percent for cell phones will be meaningless if a significant quantity of other products (refrigerators, etc.), which weigh relatively little, fail to be collected. The reuse/recycling and recovery targets are to be revised in December 2008, after which they may be based on the amount of specific products on the market rather than the amount of electrical and electronic waste separately collected.

Article 9 of Directive requires producers to be responsible for historic waste and orphan waste. In the future, producers shall only be responsible for EoL management of products they place on the market. The goal of the WEEE Directive is to encourage producers of electronic and electrical products to be involved at the products end-of-life span.

The producer is responsible for:

- The physical management of the market share of their used products
- All or part of the costs for managing wastes at the end of a product's life
- Liabilities from environmental damage caused by the production, use, or disposal of a product.
- Providing information on the product and its effects during various stages of its life cycle.
- Properly educating consumers

Producers may form a collective system to fulfill their product end-of-life commitments. Producers are not allowed to design features that prevent products from being reused unless such features provide overriding safety or environmental benefits.

Producer responsibility is at the heart of the WEEE Directive. Therefore, a precise definition of who is a producer needs to be established. A producer is defined as any person who i) manufactures and sells electrical and electronic equipment under his own brand, ii) resells under his own brand equipment produced by other suppliers, or iii) imports or exports electrical and electronic equipment on a professional basis into a Member State". [8] Not only is the manufacturer therefore a producer within the meaning of the WEEE Directive, but so too are the importer and the person distributing the equipment under its own brand. (WEEE Directive, Website)

7.2.2. Individual vs. Collective Take Back Responsibility

The differences between individual and collective EoL take back responsibility are not well defined under the Directive. The success concerning individual responsibility for taking back and managing EoL products in accordance with the Directive depends largely on whether the EoL management system rewards companies that design products that are more reusable/recyclable.

A producer pays to manage their own products in an individual responsibility scheme, and therefore benefits from implementing design changes that use of recyclable materials or make easier the disassembly process.

With collective responsibility, companies share the costs of managing the EoL of products based on market share, and therefore do not benefit from design changes. EoL management based on individual responsibility entails the costly process of sorting or tracking of electronic waste products by brand.

The directive permits individual responsibility to be implemented through either individual or collective systems. Under an individual system, a company establishes a take back program for its own products. The exact measure of individual responsibility implementation under a collective system is not clear. The problem lies in arriving at the appropriate fee structure that accurately reflects the cost of end-of-life management for a specific product.

Currently, most producers prefer to work together in a collective take back scheme. However, some companies such as Hewlett Packard and Sony see EPR as an opportunity to be more competitive and economically efficient with the resources they use in products and lobbied for individual responsibility.

7.2.3. WEEE Implementation Status

The WEEE Directive has been transposed into law in 23 of the 25 EU member states. Negotiations concerning the transposition of the WEEE Directive into national law are continuing in the remaining member states of the United Kingdom and Malta, the only member states yet to transpose the directive into law (Perchard, Website).

Table 6: Countries with WEEE Directive Transposed as of November, 2005

Austria	Finland	Italy	Portugal
Belgium	France	Latvia	Slovakia
Cyprus	Germany	Lithuania	Slovenia
Czech Republic	Greece	Luxembourg	Spain
Denmark	Hungary	Netherlands	Sweden
Estonia	Ireland	Poland	

Table 7: Countries with WEEE Directive Not Transposed as of November, 2005

Malta	United Kingdom

The EU does not impose the requirements of its directives directly on companies or consumers, but rather on its member states. It is the task of the 25 EU member states to implement policies in order to comply with the directive. The EU can impose penalties on member states that fail to comply. The legal basis of the WEEE directive is environmental protection. This means the EU sets a minimum standard and member states can choose to implement more restrictive policies.

Article 175 of the directive allows member states to go beyond the categories specified in the directive. Companies may face the risk of barriers to the trade of electronic products in EU member states single market, as they may have to observe different national rules. Also, some companies are left to determine themselves whether or not their goods are covered by these directives and have been advised by the EC to assume the widest scope possible.

Article 5 requires each EU member state to set up a WEEE administrative body. Producers are required to register and provide data on past sales in weight terms. The proper administrators will then calculate the weight of recovered WEEE that each producer is obliged to collect from collection sites and recycle. Producers can offset their obligations by their own collection schemes.

7.2.4. Unresolved Issues

Collection Cost

At a minimum, the directive compels producers to pick up electronic and electrical waste from collection points, instead of from individual businesses or homes. Member state government agencies may pay for the transport of waste to collection points, with the expense determined by the number of collection points and by the amount of sorting. The directive does address these issues. In all likelihood, there will be different interpretations by different member states. The proportion of collection costs to government and to industry will differ from one member state to another. It is possible that a member state hold producers entirely responsible for the cost of collecting their products from individual businesses and households.

Transfer Title

If an electrical or electronic product has transferred into an EU country to be distributed it is considered placed on the market. For example, if a company has product sitting in one EU member state prior to August 13, 2006 and the product is sold into another member state after August 13, 2006 should it be marked? Because the laws weren't enacted until August 13, and the material was already in the market with to be distributed, which means the title transfer had already taken place.

However, the confusion comes into play when some companies say it's the act of selling to the end customer that constitutes when it needs to be labeled. This means some companies are labeling current inventories already in Europe, prior to August 13, which is a very conservative approach. So does placed on the market mean it's the first time title transfers to a legal entity in a European country or is it point of sale?

Registration

Another challenge that has arisen centers on WEEE registration. Some countries are requiring an in-country address for an entity to register. If your company doesn't have such an address then it isn't allowed to registrar with the EoL management likely shifting to your distributor.

But this isn't the case in all EU member states. Some countries will allow a company to registrar even if it doesn't have a legal entity in their country because the producer is the responsible company for recycling.

Labeling

The WEEE directive clearly defines what electronic and electrical equipment is. What is more nebulous is which equipment needs to be labeled. Different companies are approaching labeling in different ways. Some companies label only at the finished goods level, where they place a label on the product, while other companies label not only the box or enclosure, but also subassemblies within the box as well as the cabling.

In different countries there are different requirements. Until the matter is settled, many companies are taking a more conservative approach in labeling their products. Since labeling is part of the manufacturing process it's quite inexpensive so companies are avoiding the risk the penalties and fines by labeling.

The various difficulties of developing WEEE could be accredited to the process that produced more of a “camel” than a “horse.” That is to say, there were too many “committees” involved in the development of the Directive leaving it lumpy and inefficient like camel instead of being an efficient, streamlined thoroughbred during the Directive’s formation at the EU and member state levels (Castell et. al).

Many problems can be avoided if the European Commission issues proper and clear guidance on the scope of the directive. The WEEE Directive sets clear responsibilities for those placing electrical and electronic equipment on the market. However, companies are unsure as to the clear definition of “the producer”. The Directive states that a producer is basically a party who manufacturers, resells, exports or imports EEE into a member state. In the process of transposing the Directive, some member states have adopted this concept in their national laws. However, the European Commission has expressed its view that a product is placed on the European market, and afterward must circulate freely between member states.

The authors of this report believe this can lead to confusion as result of the following: a) one product may end up with several “producers”, depending on the number of member states it has been through before it reaches the final consumer; b) all “producers” of a specific product may be required to make financial provisions for the product without being able to write them off when they ceased to be considered responsible for the product; and c) products may have to be labeled as they move from one member state to another.

Given this discrepancy in interpretation, companies are unclear about when they would become a “producer.”

The possibility exists that as non-EU countries start implementing EoL electronic management laws, there will be multiple sets of regulations, which could create confusion and complexities among electronics producers.

7.2.5. RoHS Directive 2002/95/EC and Basel Convention

The WEEE Directive's companion piece of legislation, the Restriction of the Use of Certain Hazardous Substances requires producers to eliminate certain toxic substances from their products. The RoHS Directive calls for the substitution of toxic substances with less toxic substitutes. The directive includes all electronic equipment sold in the EU, including cell phones. Reference RoHS Directive 2002/95/EC.

As of July 1, 2006, no new electrical and electronic equipment may be sold in the EU containing lead, mercury, cadmium, or hexavalent chromium. Polybrominated biphenyls and polybrominated diphenyl ethers, two types of flame retardant, are also prohibited.

China, Japan, and Korea as well as other nations not part of the EU, have announced that they will also adopt the European RoHS directive in 2006.

In 1992 the United Nation's Basel Convention entered into force seeking to control transboundary movement of hazardous wastes for disposal in undeveloped nations. The main goal of the convention is to protect human health and the environment against the adverse effects which may result from the generation of hazardous waste and its improper disposal in developing nations.

Under the convention, the state exporting the hazardous waste must notify the state of the intended disposal and any state in which the shipment is to pass. The shipment of the hazardous waste can only occur with the written consent of the government of the state receiving the hazardous waste.

The Basel Convention is important to the EoL management of cell phones, because it prevents producers in the EU from dumping their waste cheaply in developing nations. The United States has yet to ratify the Basel Convention.

7.3. E-Waste/Cell Phone Legislation in the U.S.

7.3.1. Federal

Several state legislatures have passed measures to address the growing amount of hazardous waste generated from used electronic products, including computers and televisions, and at least 24 states are considering bills. But the state efforts are not consistent, and if no federal solution is reached, there could eventually be 50 different approaches to reduce and recycle e-waste. If federal legislation regarding electronic waste is not passed "we may very well get a mish-mash of 50 different laws around the country," according to Ben Wu, Assistant Secretary for Technology Policy at the Department of Commerce (Air & Waste Management Association, Website).

Four members of Congress in May 2005 announced the formation of the Congressional E-Waste Working Group, which was created to push for hearings and legislation to recycle and reduce electronic waste. The “Gang of Four” members include Representatives Mike Thompson (D-Calif.), Randy "Duke" Cunningham (R-Calif.), Mary Bono (R-Calif.), and Louise Slaughter (D-N.Y.). These four members of Congress along with the federal government, electronics manufacturers and retailers, and recyclers agree that a consistent approach across state lines is necessary in any legislative effort to reduce and recycle electronic waste.

Rep. Cunningham introduced H.R. 320, which amends the Internal Revenue Code to encourage electronic manufacturers to recycle. H.R. 320 allows manufactures of certain computer, cell phone and television equipment a business tax credit for the disposal and recycling of such equipment. Cunningham’s approach allows for a $1 tax credit for each cell phone taken back by cell phone producers. This is the only bill at the federal level that addresses the end-of-life management of cell phones.

Rep. Slaughter endorses an Advanced Recycling Fee to be added to the price of electronic devices to pay for their proper disposal. This advance-recycling-fee idea is similar to a SB 20 in California applying to computers, but not cell phones, requiring consumers to pay money up front to aid in the disposal of electronics.

The Environmental Protection Agency sponsored a voluntary electronic recycling approach NEPSI (National Electronics Product Stewardship Initiative). NEPSI consisted of representatives from the waste and electronic take-back industry, states and local governments. NEPSI stakeholders considered a funding arrangement with a fee at the time of sale of new electronic goods that would provide flexibility in how the funds collected are managed. Some manufacturers would be able to use collected fees to run their own take-back programs while others could contribute to a pooled program.

The financing issue dividing producers into two groups: those who wanted to impose an advance recovery fee, equivalent to a sales tax, and those who want to incorporate waste management fees in the retail price tag. The latter method encourages producer responsibility because each maker has an incentive to lower its environmental costs. This assumes that each producer pays its share to recycle its own products and not those of everyone else in the pool. Industry is not likely to settle on a pure product stewardship system. Instead, it will focus on some mix of the two approaches as the most equitable way for its businesses to pay into the kitty.

NEPSI encouraged by the U.S. EPA, failed to develop a consensus for a national recycling plan for e-waste when the initiatives funding was cut.

7.3.2. Regional

The Northeast Recycling Council (NERC), consisting of 10 northeastern states, announced plans in early 2005 to convene a stakeholders meeting to develop an approach to funding and implementing EoL electronics management, including cell phones. The 10 Northeastern state governments are seeking to develop a combined approach to electronic waste management for the region. The EoL e-waste management legislation may result in new state laws in the Northeast and possibly elsewhere. A joined Northeastern approach may result in bringing end up bringing a *de facto* national mandate. Concepts from the NEPSI initiative are being raised in the NERC context (NERC, Website).

7.3.3. States

Currently, the United States has no formal directive like the WEEE, but at the state level electronic waste legislation has started to appear. While different states are in different stages of legislation, two main patterns are apparent: some states like California and Illinois are imposing retailer take-back of cell phones while other states like Wisconsin and Vermont are prohibiting the transfer of any fees to the customers and requiring that producers be responsible for the cost and the logistics of the process.

California has led the way in the United States in terms of cell phone take-back. California's Governor Arnold Schwarzenegger signed the nation's first cell phone recycling bill that requires all mobile phone retailers to have a recycling program in place by July 1, 2006. The California Cell Phone Recycling Act of 2004, AB 2901, makes it unlawful to sell, on and after July 1, 2006, a cell phone in California to a consumer unless the retailer of that cell phone complies with the act.

The bill requires a retailer selling a cell phone in this state to have in place a system approved by the California Integrated Waste Management Board for the acceptance, collection, reuse, and recycling or proper disposal of used cell phones. This may simply mean that retailers put bins in their stores to collect the cell phones and then have them shipped to a private recycler.

Other states are looking to California as a template to base their legislation. Illinois passed SB -773 the "Cell Phone Recycling Act," which is similar to California's legislation. The bill requires retailers to have a take back system in place for cell phone collection.

The state of Wisconsin is taking the WEEE extended producer responsibility approach in dealing with the EoL management of electronic waste. Wisconsin's Assembly Bill 877 requires producers to finance collection and recycling of their own products as well as a share of historic and orphan products. Producers may act individually or collectively. The bill prohibits sale of electronic products in state by producers who do not implement and finance the electronic waste program.

Electronic producers are required to submit a take back plan and proof of financial responsibility before selling their products in Wisconsin. Firms may not export the collected electronic waste to any non-OECD country. The bill also prohibits the disposal of e-waste in landfills. Seven years after bill goes into effect electronic products that contain heavy metals, brominated flame retardants and PVC will be banned.

A breakdown of states with specific cell phone recycling legislation either implemented, or in the works is as follows:

Table 8: State legislation status
(Source: National Recycling Coalition, Website)

State	Status
Retailer Responsibility	
California	Cell Phone Recycling Act passed (AB2901). To be implemented in July 1, 2006. Internet and brick-and-mortar retailers treated equally.
Illinois	Cell Phone Recycling Act passed (SB773) Bill very similar to CA's Cell Phone Recycling Act. Retailer must take back phone at no cost to consumer. Internet and brick-and-mortar retailers treated equally. To be implemented in July 1, 2006.
Iowa	Bill introduced 3/10/05 (SF377). Retailer responsible for the enforcement of recycling plan of cell phones. A $100 per day fine will be placed on stores without a recycling plan. Still in active stage of being passed.
Mississippi	Bill died in Environmental Protection Conservation, and Water Resources Committee, but attempted a retail responsibility approach.
Virginia	Bill still in active phase (SB1317). Will require retailers to have a recycling system in place by July 1, 2007. Fines up to $1000 will be placed on those without a program.
New York	Bill still in active phase (HB3390).

State	Status
	Retailers will be required to accept cell phones for recycling.
Producer Responsibility	
Wisconsin	Bill passed (AB877). Requires producers to finance collection and recovery of cell phones (bill also covers TVs, monitors, CPUs, printers, and scanners). Bill very similar to WEEE directive.
Vermont	Bill still in active phase (HB212). Will require producers to finance recycling program. Will also require producers to institute less harmful alternatives for specific cell phone components.

7.4. Stakeholder Positions

Representatives of manufacturers, consumers, environmental organizations, and recyclers are advising the Congressional Electronic Waste Working Group on legislation that would create a national standard for disposal of e-waste. Differing stakeholder positions are listed below.

7.4.1. Original Equipment Manufacturers

The Original Equipment Manufacturers prefer a voluntary approach to the end-of-life management of electronic wastes. But in the face of the patchwork legislation efforts across the United States, they support regional and national solutions to the problem. OEMs, in general, are opposed to extended producer responsibility legislation that seeks to promote design changes, and banning of hazardous substances when no viable alternative exist (Electronics Industry Association, Website).

7.4.2. Retailers

The Consumer Electronics Retailers Coalition favors a voluntary system but views producer responsibility as the most efficient and comprehensive approach should legislation be enacted. The coalition is opposed to advance recycling fees (CERC, Website).

7.4.3. Environmental Organizations

Environmental Non-profits organizations such as INFORM tend to support the extended producer responsibility approach. Inform supports the concepts that: manufacturers are responsible for their market share, states set recovery goals, and flexibility in individual manufacturer programs and 3rd party e-waste handlers (INFORM).

7.4.4. Municipal Waste Managers

Municipal waste managers across the United States are increasingly concerned that discarded electronic waste products will overwhelm landfills resulting in the leaching of toxic chemicals into groundwater supplies. The National Solid Waste Management Association, an organization representing the solid waste and disposal industry, supports legislation that provides financial support for recycling of electronic products (NSWMA, Website).

7.4.5. Resellers

Resellers are businesses which are involved in the reselling and refurbishing cell phones. ReCellular, a leader in this industry, favors legislation placing the responsibility on the service provider because they interact directly with the customer (Recycling Today, Website).

7.5. Policy Approaches

Approaches to combating the e-waste problem basically fall within two main scopes: voluntary initiatives or mandatory regulations through policy implementation. For the basis of our scenario analysis, these approaches are laid out as follows:

Table 9: Policy Approaches

Voluntary Approaches	Mandatory Approaches
Baseline (no policy)	Extended Producer Responsibility
	Retailer Responsibility
Tax credits to OEMs	Advanced Recycling Fees Deposit-Refunds
	Extended Product Responsibility (shared)

7.5.1. Voluntary Approaches

Baseline

In the United Stated no federal legislation regarding the end-of-life management of cell phones exists. Voluntary take back programs put in place by manufacturers have failed to capture large amounts of cell phones. The voluntary approach lets market forces determine cell phone take-back. Currently, the United States utilizes this voluntary approach at the national level.

Tax Credits

This approach is used as an incentive for producers. It gives producers a $1 tax credit of for each cell phone taken back. Tax credits are a provision of law that results in a dollar-for-dollar reduction in tax liabilities. Tax credits may result in a reduction of tax collections or an increase in the value of tax refunds.

7.5.2. Mandatory Approaches

Should the U.S. decide to implement a national legislation, there are a range of mandatory approaches which could be taken. Basically all of these approaches would be a modification on extended product responsibility.

Extended Product Responsibility is an emerging concept which creates a shared responsibility for the product across the entire supply chain to create a locus of responsibility for the product. This concept extends responsibility to life-cycle stages where responsibility did not exist or was not defined before (WasteWise).

Under the concept of Extended Product Responsibility, there are various modifications in assigning responsibility. Responsibility could truly be shared among all of the agents, or 100% responsibility could be assigned via the following approaches: Extended Producer Responsibility (EPR), retailer responsibility, deposit refunds, and advanced recycling fees (ARFs). A brief description of these policy approaches are as follows:

Extended Producer Responsibility

Extended Producer Responsibility places 100% responsibility of take-back on the producer. It is a concept designed to promote the integration of environmental costs associated with products throughout their lifecycles. This means that firms which manufacture, import and or sell products are financially or physically responsible for management of the products at the end-of-life. They must either take back the used products and manage them through re-use, recycling, or delegate responsibility to a third party, a producer responsibility organization (PRO), which is paid by the manufacturer for end of life management. EPR shifts responsibility for waste from government to private industry to internalize the waste management costs in the pricing of their products (Hanish, 2000). One goal of this approach is to promote design for the environment.

Retailer Responsibility

This approach places 100% responsibility on the retailer. It requires retailers to have in place a system to collect used cell phones for proper disposal, recycling or reuse. All financial and physical responsibility is placed on the retailer/service provider for the collection, transportation, and recycling of the product. Retailers must take back any cell phone sold upon replacement and any used cell phone of a customer purchasing a new phone, at no cost to the consumer.

Retailer is defined as an entity who sells a cell phone to a consumer, including a manufacturer of a cell phone who sells that cell phone directly to a consumer. A sale includes, but is not limited to, transactions conducted through sales outlets, catalogs, or the Internet, or any other similar electronic means, but does not include a sale that is a wholesale transaction with a distributor or retailer.

Advanced Recycling Fees (ARFs)
This approach utilizes a visible fee charged to the consumer at the point of sale, placing 100% of the financial responsibility on the consumer. This fee is usually deposited into a centralized fund overlooked by a third party (usually the government) to be used to develop the collection and recycling infrastructure.

Deposit-refund systems
A deposit refund system places a surcharge on the price of a potentially polluting product. Pollution is avoided by returning the products or their residuals; a refund of the surcharge is given.

There is little support for deposit-refund systems. Many stakeholders feel that a deposit-refund system for cell phones would be very difficult to run and too complex to administer and that it would be difficult to ensure that the deposits with such a system would actually cover the costs of collection and transportation. This system would require substantial participation of retailers to administer deposits and refunds, as well as to store used products; while fees could be set to provide funding to offset.

It also might be quite difficult to apply a deposit-refund approach to internet sales. There is also a potential issue of fraud/free riders from across state borders if the deposit amount is not set nationally.

Extended Product Responsibility (Shared)
Under this approach, responsibility is designated across the entire supply chain, with all agents contributing to take-back. For the purpose of our analysis, retailers and producers would be in charge of promotional initiatives and costs to encourage and raise awareness to the consumer of the take-back program. Refurbishers and recyclers would pay for transportation/shipping costs and take-back tools such as bins. In order to promote design changes, producers could receive a tax credit to incentivize the take-back of their own product.

8. End-of-Life (EoL) Management Options

8.1. General

There are two basic EoL management alternatives to landfill and/or incineration: (1) reuse or (2) recycle. Reuse of EoL phones can occur as (a) refurbishment at product level, (b) reuse “as is” at product level or (c) reuse at component level. EoL phones are recycled primarily by recovering precious metals from the components.

From a larger picture, there are two major decisive factors determining the fate of the phone. The first is the residual value. Unlike most “white goods” such as refrigerators or washing machines, the timing of EoL is often not linked to the timing of “worn out” for small electronic devices such as cell phones. “White goods” will retain almost no value when they enter EoL stage whereas cell phones will. A person will have use for a cell phone that still functions properly; therefore, a cell phone’s opportunity for reuse in the secondary market will increase, as opposed to “white goods.”

There is no single condition for EoL cell phones; it is usually a collective sample of different models in different conditions. The deviation among different conditions of the phones determines the residual value and ultimately the fate of the phones.

1. EoL cell phones from consumers
   - Collected at the time of replacement (around 18 months)
   - Collected from “drawers” after hibernation period (18 months up to 10 years or more)
2. EoL cell phones from OEMs/NSPs
   - Excess inventory
     - Still marketable (new)
     - No longer marketable (new but technologically obsolete)
   - Take-back from consumers (condition varies)
   - Other return method

Basically, residual value is determined by the age, model and condition of a given phone. In general it can be assumed that 1) newer products, 2) popular models with current technology, and 3) phones that are functioning and cosmetically acceptable retain higher value.

<u>Market Factors</u>

Decisions that are made in the primary market can affect the EoL market. Transmission technology is one of the most important factors. Transmission technology is usually determined through the collaboration of handset OEMs, network technology providers and network service providers (NSP). The way technology and infrastructure develop depends significantly on how these stakeholders interact with each other. This relationship changes from region to region and also changes from time to time, which often determines which technology is used in which region for which generation.

This has an important implication as to where a given handset can be used in the secondary market because communication technology determines the usability of a given handset (e.g.,American TDMA phones cannot be used in the Japanese PDA system).

Decisions that the specific stakeholders make regarding EoL management also affect the market. Currently some OEMs endorse reuse of phones while others do not. For some, reuse is an extended business opportunity, but for others, the potential negative effects of reuse are higher than the benefits. Therefore, depending on their standpoint, some players focus on reuse as is, whereas others try to expand the recycling or secondary component market. Under such circumstances, EoL phones will go to a specific stream regardless of their residual value. The phones may end up recycled even if they can be resold in a secondary market if an OEM does not want their products to be released in the secondary market. By the same token, if the end-user opts to mechanically crash the phone to cleanse the data stored in the hardware, the only available option is recycling because mechanically-crashed phones no longer work. Either way, it is notable that the decision-making process affects the fate of EoL phones, and the decision-making depends on the situation and is influenced by various factors. Therefore, it is important to consider the fate of EoL products as a function of residual value and market factors.

Figure 7 summarizes the decision making process that determines the fate of an EoL phone.

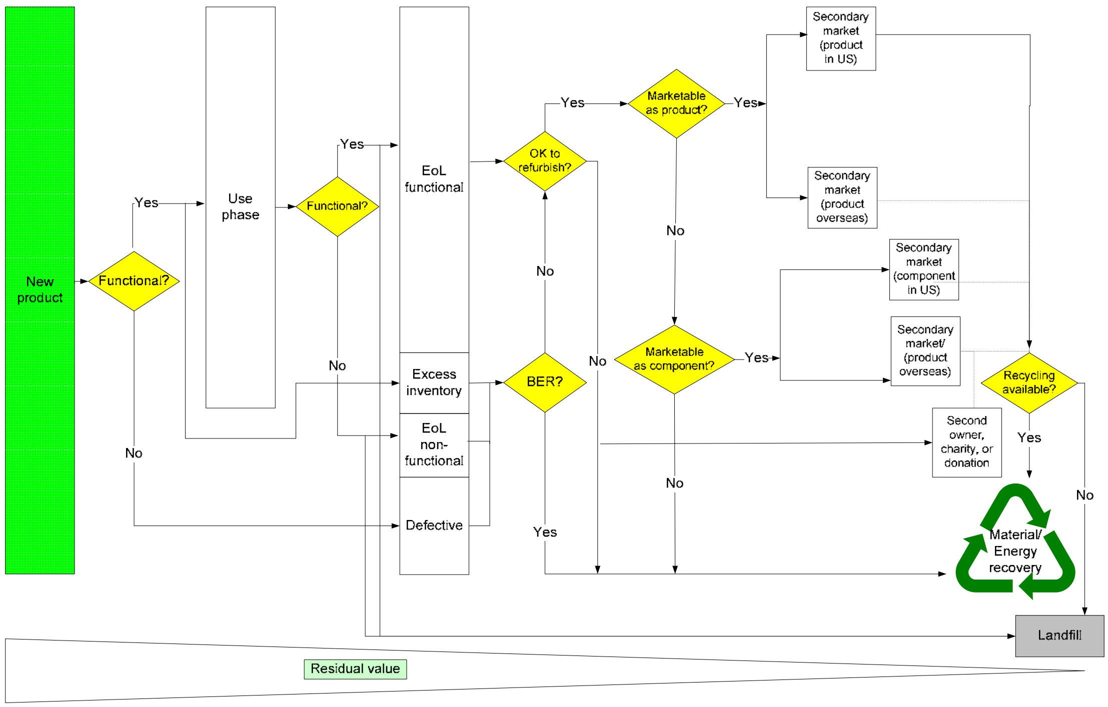

Figure 6: EoL cell phone fate by economic decision

Possible Paths

Given the situation, there are several possible paths for EoL phones in end-users' hands to reach certain EoL options. For each path, there are different stages: 1) Collection, 2) Fate decision, and 3) Processing. Each stage has its own players and options which will be discussed in detail in the following sections. It is notable that there are many different players involved in the collection stage. OEMs, NSPs and other third party companies offer different programs that accept EoL phones from end-users. Mail-in, drop-off and one-day events are the most widely used collection method. Once the phones are collected, they are transported to the accepting facility which is either a refurbisher or recycler. These agents determine the fate of the phones based on the residual value and market demand. Once the fate is determined, the phones are routed to product level reuse, component level reuse or recycling (material/energy recovery).

As illustrated in figure 8, an EoL phone that leaves the end-users' ownership can take different paths to reach the ultimate fate. The highlighted boxes illustrate examples of two paths but as can be seen, there are many paths available; the path chosen mainly depends on the market forces and the collecting agent.

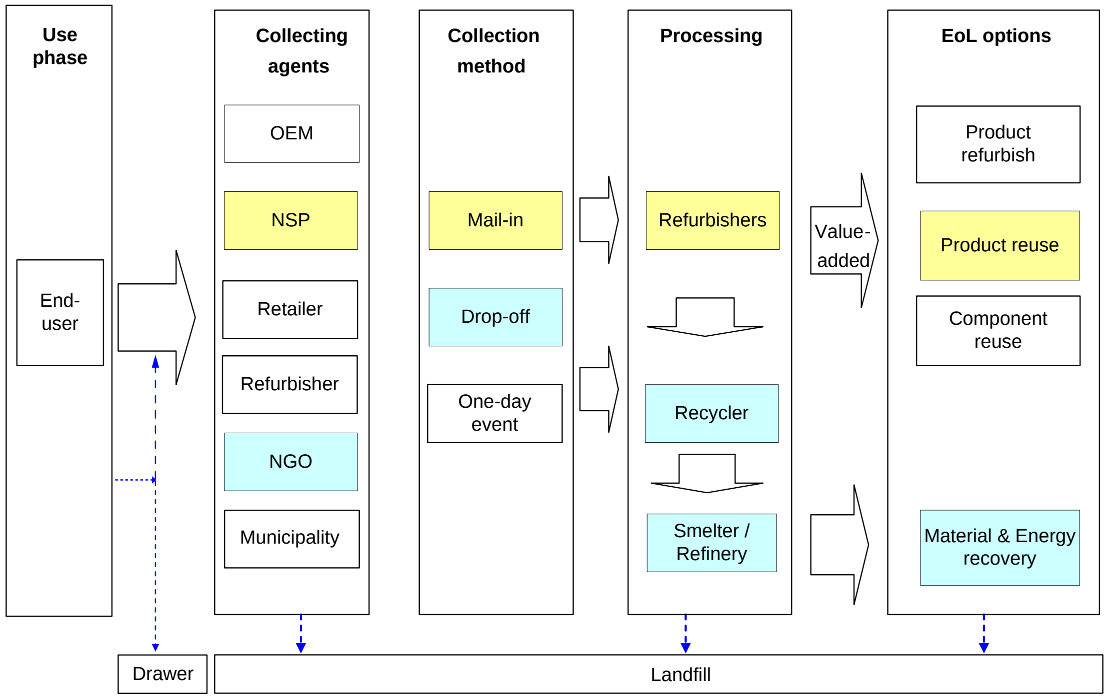

Figure 7: Optional EoL paths

8.2. EoL Market Overview

Currently three different markets are available for EoL cell phones: (1) product reuse, (2) component reuse, and (3) material recovery (recycling).

Globally, the market for second-hand phones has been increasing due to the increasing demand from emerging markets such as Latin America, Eastern Europe or South East Asia. The market for secondary parts and components is still not mature and is in the early stage of development. The recycling industry treats a wide range of products and materials, but for electronic products, including cell phones, metal recovery is the most widely chosen path. Metal recovery has been exercised for a long time for an array of products. Cell phones are only a small fraction of the entire feedstock.

Since cell phones retain residual value when they enter the EoL stage, in most countries the EoL market has been developed by the players who saw economic opportunities. This is in notable contrast to the products whose EoL management is largely driven by legislation.

8.2.1. Market for Second-Hand Phones

Phone Value
Once the EoL phones arrive at refurbishers, they are sorted and classified into different grades based on their condition and required process costs. Phones determined to be "marketable" are released in domestic or overseas secondary markets. A certain portion of the phones are categorized as "Beyond Economic Repair" (BER)—meaning repair cost will exceed estimated revenue because of low residual value. These phones are either diverted overseas where labor is cheap enough to make repair economically feasible or forwarded to the recycling stream after recoverable components are removed. An example of a grading system is presented in Appendix 1.

The condition of the phone and the existing market opportunities together determine the sale value. As the guarantee of the phone quality decreases, the sale value decreases. The economic value of the different conditions is discussed in more detail in the economic performance section later in this chapter.

Phone Branding
The phones that enter the second-hand market could have a different "look" than the new product. Some OEMs or NSPs only allow releasing their products in the second-hand market if they are de-branded and no label of the original OEM or NSP is present. De-branding operations require extra work and usually affect the sale price of the product (ReCellular, Website).

Quantity Available and Market Segments
It is estimated that a minimum quantity of 50 phones is required from the same model to be marketable in the second-hand market. Companies that are able to capture a large quantity of the same model gain a competitive advantage. While for new phones purchasing of higher quantity drives a "volume discount," it is not the case with second-hand phones. The demand for second-hand phones is still higher than the available supply (confidential interviews), meaning that the market is still devalued and opportunities exist both domestically and internationally. For cell phones, an estimated 50% remain in the US and 50% is exported to Latin America, Africa, Russia, China, Pakistan and India (Bhuie et al, IEEE 2004). This estimation was confirmed through interviews conducted with refurbishers who believe 40-85% of the phones stay in the US market and 15-60% is exported to Latin America and Asia, including India and China. The deviation comes from the attributes of the EoL phones such as technology, model, value, fashion and seasonal factors.

In the domestic market, some NSPs offer refurbished phones to replace defective products. This allows the NSP to provide a higher level of service to their clients at a lower cost.

Technology
Technology plays a major role in the market. Compared to the US, the EU market offers more consistency in cell phone standards with a more predictable flow of second-hand phones as a result. (Seliger et al, IEEE 2003). Changes in technology affect the international market substantially. For example, if a developing country chooses to install a GSM technology network, this automatically eliminates a stream of potential second-hand CDMA phones from accessing this market. Changes in technology also affect the US market. For example, when the TDMA technology became obsolete in the US, a large quantity of phones entered the EoL stream. This situation created an enormous amount of obsolete phones (sometimes less than a year old) that had no value and the only fate they had was recycling for materials recovery. According to all of the refurbishers we interviewed, this led to an increase of 5-10% in the recycling rate.

Effect on new phone market
There is an ongoing debate about whether second-hand phones "cannibalize" the new phone market. Companies that might be affected from the second-hand market are mainly OEMs that sell phones to NSPs that in turn sell the cell phones to users as part of the service agreement. While some OEMs believe that the second-hand market hurts their business, refurbishers believe that the new phone market will actually benefit and be extended in the long-term. The rationale for that claim is mainly based on the assumption that people who cannot afford new phones might choose a second-hand phone today, but will replace it with a new phone in the future. According to a study in Romania, 70% of second-hand phone holders said they would buy a new phone once they replace their current one (Forum for the Future report, 2004). It is estimated that the second-hand market cannibalizes less than 1% of the annual OEM new phone market (Seliger, IPL 2003). Although there is not enough research done to accurately capture the user profile of second-hand cell phones, it is highly possible that they are different from the users for new products, either in the US or overseas.

8.2.2. Market for Second-Hand Components

While the market for second-hand phones keeps developing, the market for second-hand components is still limited; however, almost all of the refurbishers that we interviewed mentioned that they are in different stages of getting into the business of component recovery as well.

We identified two main markets for second-hand components:
(1) "Closed loop" - recovered parts are used to repair or refurbish the same or similar model.
(2) "Open loop" - recovered parts are used for products other than cell phones, such as memory devices in toys.

The main parts and components that have value within the loop include:

– LCDs
– Camera lenses
– Antennas
– Batteries

Memory chips are mainly used out of the loop.

Value

The prices of second-hand parts are still not developed in the market and are mainly affected by the phone model. The price for high-end phones such as Motorola RAZR can have a high value of $30-$40 while most of the low-end models will cost only a few dollars.

Quantity Available and Market Segments

In general, it is estimated that 30% of recovered components goes to the domestic market and 70% goes overseas (confidential interview). Refurbishing companies that work closely with OEMs can generate a high volume of parts, 70% of which can be sold in the domestic repair market. One of the major challenges for component recovery is labor cost: disassembly still heavily depends on labor and therefore a large volume is needed to achieve economy of scale. Since the unit price is very low, sometimes quantities of 100, 1000, or more are needed in order to justify the operation. As mentioned before, it is hard to collect a large quantity of the same model of phone. This is one of the current barriers to accessing the domestic repair market. Another limitation is the strong influence of OEMs on the repair companies. OEMs sometimes bind repair companies, making them use only original parts if they want to be OEM certified.

8.2.3. Market for Recovered Materials

For economic reasons, basically only precious metals (gold, silver and palladium) and copper are recovered from EoL cell phones. Companies have utilized metal recycling for a long time and, as mentioned earlier, cell phones are only a small percentage of the entire feedstock.

Metal recovery processes such as smelting and refining are capital- and volume-intensive operations. Only primary producers (the companies that do mining, extraction, smelting and refining) have such capacity and expertise. For cell phones, due to their metal composition, EoL products are ultimately sent to copper smelters and precious metal refineries. In North America, there are only 1 or 2 such smelters/refineries. Even worldwide, there are only dozens of them. Recycling of e-waste became popular in the recent years but there is no company that exclusively processes e-waste or cell phones.

Once the metals are refined, they are traded in the world metal market. As long as they are refined to 99.9% purity there is no distinction between primary and secondary material. They can meet the same demands from different applications.

Since primary operators deal with large volumes, they do not engage in business with individuals or companies that need to dispose EoL products. Intermediate or secondary recyclers mediate between these two agents. They accept EoL products, sort, pre-treat and assay them so the feedstock is ready for primary operators to process.

There are about 450 electronics secondary recyclers nationwide with annual revenue at $700 million. About 75% of them operate on a relatively small scale with less than 50 employees. In terms of process volume, cell phone contribution is estimated at less than 0.1% (IAER, 2004).

8.3. Stakeholders in EoL cell phone market

There are different stakeholders involved in the EoL cell phone market. As described in table 10, we have identified OEMs, NSPs, retailers, collectors, refurbishers and recyclers as the main players. Each player has a different standpoint, perspective, role and market power in relation to EoL management. The players interact or compete with each other depending on corporate policy and the market/regulatory environment. But as the importance of across-the-board EoL management receives more emphasis, increased collaboration seems to complement each business's characteristics.
The important difference between the players is their interaction with the end-users who are the sources for EoL phones. While the end-users vary in their motivations and interests, different players interact with them to collect cell phones. Table 10 provides an overview of the players, including examples of companies falling under this category, and general information related to EoL phones.

Table 10: Main Players Overview

<table>
<tr><th>Player</th><th colspan="6">Description</th></tr>
<tr><td rowspan="8">OEMs[1]

Main role:
Collection, determining EoL fate</td><td colspan="6">As “producer”, they share significant responsibility for EoL management both from treatment and design perspectives. They also have influence on policy formation. However, the programs currently offered are relatively poor compared to NSPs.</td></tr>
<tr><th rowspan="2">Company</th><th rowspan="2">Main business</th><th rowspan="2">EoL policy</th><th colspan="3">EoL program offered in the US</th></tr>
<tr><th>Program type</th><th>Fundraise/ Charity</th><th>eBay rethink[2]</th></tr>
<tr><td>Motorola</td><td>Cell phone handset</td><td>Reuse, refurbish, recycle</td><td>Free take back</td><td>Race to recycle</td><td>Yes</td></tr>
<tr><td>Samsung</td><td>Electronics</td><td>Recycle</td><td>Pilot with EPA- Not cell phone specific</td><td>N/A</td><td>No</td></tr>
<tr><td>Nokia</td><td>Cell phone handset</td><td>Recycle and component reuse</td><td>Free take back</td><td>WWF</td><td>Yes</td></tr>
<tr><td>Kyocera (Qualcomm)</td><td>Wireless technology</td><td>Leave to NSP</td><td>Free take back</td><td>N/A</td><td>No</td></tr>
<tr><td>Sony Ericsson</td><td>Cell phone handset</td><td>N/A</td><td>N/A</td><td>N/A</td><td>No</td></tr>
<tr><th>Player</th><th colspan="6">Description</th></tr>
<tr><td rowspan="8">Network Service Providers (carrier)[3]

Main role:
Collection, determining EoL fate</td><td colspan="6">In the US they have significant control as the point of contact to customers, therefore offering richer EoL management programs compared to OEMs.</td></tr>
<tr><th rowspan="2">Company</th><th rowspan="2">Number of subscribers</th><th rowspan="2">EoL policy</th><th colspan="3">EoL program offered in the US</th></tr>
<tr><th>Program type</th><th>Fundraise/ Charity</th><th>eBay rethink</th></tr>
<tr><td>Verizon</td><td>37,522,000</td><td>Recycle</td><td>Take-back in the store</td><td>Hopeline</td><td>Yes</td></tr>
<tr><td>Cingular</td><td>26,225,000</td><td>Recycle and component reuse</td><td>Take-back in the store</td><td>N/A</td><td>No</td></tr>
<tr><td>Sprint PCS</td><td>28,782,000</td><td>Internal reuse and recycle</td><td>Buy-back</td><td>Project Connect</td><td>No</td></tr>
<tr><td>T-Mobile</td><td>13,128,000</td><td>Reuse, recycle</td><td>Take-back in the store</td><td>Get more, Give more</td><td>No</td></tr>
<tr><td>Alltel</td><td>8,023,000</td><td>Reuse, refurbish, recycle</td><td>Take-back in the store</td><td>Eco-smart</td><td>No</td></tr>
</table>

[1] See Appendix 2 for details
[2] Information as of January 2006. The Rethink Initiative at eBay brings together industry, government and environmental organizations to offer a fresh perspective and new answers to the challenge of e-waste. (http://rethink.ebay.com/)
[3] See Appendix 2 for details

Player	Description					
Retailers **Main role:** Collection	Retailers handle a wide variety of electronic products of which cell phones are a small fraction. They have potential to become large-scale e-waste collectors. There are an increasing number of programs jointly established with other parties/stakeholders.					
	Company	**Number of stores**	**EoL policy**	**EoL program offered in the US**		
				Program type	**Fundraise/ Charity**	**eBay rethink**
	Staples	1,188	Reuse, refurbish, recycle	Take-back in the stores – collaborate w. Collectivegood	Sierra Club	No
	Best Buy	668	Reuse, refurbish, recycle	Take-back in the store: ReCelluar	Boys and Girls Clubs of America	Yes
	CompUSA	244	Reuse, refurbish, recycle	One-day events	N/A	No
	Wal-Mart	2,949	Reuse, refurbish, recycle	Take-back in the store: ReCelluar	N/A	No

Player	Description					
Collectors **Main role:** Collection, pre-processing (mainly take off batteries), determining EoL fate	We define “collectors” as those who collect EoL products but do not change mechanical and/or chemical properties of the main hardware. Also, collectors whose main business is elsewhere are excluded such as OEMs, NSPs, retailers and so forth. Collectors therefore collect phones and send them to the next processor as is. An increasing number of parties are involved in collecting activities for either profit or non-profit purposes. Due to the economic characteristics of the EoL cell phone market, it was created spontaneously.					
	Collector[4]	**Main business**	**EoL policy**	**EoL program offered in the US**		
				Program type	**Fundraise/ Charity**	**eBay rethink**
	Web-based collectors	Collection	Collect & resell	Buy-Back/Take-back	Indirectly by helping those who collect	No
	NGO and charities	Vary	Collect & resell	Take-back	Myriad of programs	No
	Municipalities	Local government services	e-waste recycling	One-day events	Indirectly thorough county programs	No

[4] See Appendix 3 for details

<table>
<tr><th>Player</th><th colspan="6">Description</th></tr>
<tr><td rowspan="7">Refurbishers

Main role: Collection, determining EoL fate, pre-processing, processing, selling in second-hand markets</td><td colspan="6">The market is expanding as EoL management draws increased attention. Refurbishers collect phones by themselves or receive them from arrays of collectors. Refurbishers play an important role to determine the fate of phones as to whether they are reused or recycled on the product or component level. Scale of economy counts for business growth.</td></tr>
<tr><th rowspan="2">Company</th><th rowspan="2">Market share (%)</th><th rowspan="2">EoL policy</th><th colspan="3">EoL program offered in the US</th></tr>
<tr><th>Program type</th><th>Fundraise/ Charity</th><th>eBay rethink</th></tr>
<tr><td>ReCellular Inc.</td><td>~50</td><td>Reuse, refurbish, recycle</td><td>Take-back in the stores + direct mail in</td><td>Via Wireless Recycling</td><td>Yes</td></tr>
<tr><td>RMS Communication</td><td>~15</td><td>Reuse, recycle</td><td>Mainly direct mail-in</td><td>Via Wireless Fundraiser</td><td>No</td></tr>
<tr><td>Pacebutler</td><td>~5</td><td>Reuse, recycle</td><td>Take-back with partners + direct mail-in</td><td>Fundraiser program</td><td>No</td></tr>
<tr><td>Collectivegood</td><td>~3</td><td>Reuse, refurbish, recycle</td><td>Take-back in the stores + direct mail-in</td><td>Collectivegood foundation</td><td>Yes</td></tr>
</table>

<table>
<tr><th>Player</th><th colspan="6">Description</th></tr>
<tr><td rowspan="4">Recyclers

Main role: Processing, material recovery.</td><th rowspan="2">Example company</th><th rowspan="2">Category</th><th rowspan="2">EoL policy</th><th colspan="3">EoL program offered in the US</th></tr>
<tr><th>Program type</th><th>Fundraise/ Charity</th><th>eBay rethink</th></tr>
<tr><td>ECS Refining</td><td>Intermediate recycler</td><td>Reuse, recycle</td><td>Buy from collectors/ refurbishers/ commercial and industrial clients</td><td>N/A</td><td>No</td></tr>
<tr><td>Noranda Inc.</td><td>Primary copper smelter</td><td>Recycle</td><td>Buy from intermediate recyclers</td><td>N/A</td><td>No</td></tr>
</table>

Clearly the companies in the same category can have different policies or activities among them. Different companies will adapt different strategies based on what they think will affect their business and the EoL market. For example, some OEMs promote components reuse and recycling and see take-back programs as a cost center while others approach it as a new market opportunity. OEMs still have a very small number of dedicated employees to work on EoL programs (2-3) relative to the total workforce that ranges from 1,000 to 10,000.

NSPs mainly consider EoL programs as a service to their customers. Most of them established programs in response to the customers' demands.

Retailers are involved in broader e-waste collection programs including collection of ink toners, computers, monitors, TVs, cell phones and so forth. Some of the retailers collaborate directly with refurbishers by allowing them to place bins in their stores. Collected phones are directly shipped to refurbishers. Some only organize one-day events in stores instead of permanent programs, and some others offer such programs because of the legislative requirement.

The refurbishing industry in the US is dominated by one major company and several middle-sized players. While some chose to partner mainly with NSPs and retailers, some chose to work with individuals, charities and NGOs.

The interaction of the players affects the market outcome. As the number of players change, economic and environmental performance might change. The next section explains the different programs offered in the market.

8.4. Existing programs

In the current marketplace there are many programs that target different sectors and consequently have different outcomes. These programs can be divided as follows:

Table 11: Main programs description and their incentives

Program	**Description**	**Incentives to end-users**	
		Economic	Social/Environmental
Buy-back	Collecting agents offer to buy back EoL cell phones from end-users	▪ Monetary reimbursement ▪ Electronic fund-credit (tradable points)	▪ Safe alternative to discard old cell phones
Take-back	Collecting agents accept the return from end-users free of charge. Almost no costs are incurred to end-users whereas potential economic benefits are expected for collecting agents	▪ Free-of-charge disposal	▪ Safe alternative to discard old cell phones while making someone better off
Fundraising	Collecting agents (3PSPs, NGOs, schools and so forth) gather EoL cell phones from end-users with charity purposes. Then collecting	▪ Fund collection (wide variety of purposes)	▪ Help institutions raise money for scholastic and extra-curricular activities

Program	Description	Incentives to end-users	
		Economic	Social/Environmental
	agents trade EoL phones with collecting sponsor to raise funds. Collecting sponsor agents will buy-back those cell phones to finally cash them in with the best bidder		▪ Seek a good cause: donations to NGOs, charities, etc.

It is important to point out that incentives do not always represent a monetary transaction between the end-user and the respective collection party. In fact, end-users may want to avoid a regulatory disposal cost or even transfer any monetary reimbursement to a third party via donation. Obviously in these cases we assume end-users make socially responsible decisions.

Despite the existence of these programs and incentives (Appendix 4), the current collection rate is still low. This may be due to a lack of public awareness and a certain level of inefficiency in the allocation of resources to foster collection rates. While the quantity of phones collected is important, the quality is crucial in the reuse market. Different sources provide different qualities of EoL products and consequently its fate and ultimate impact in the market are affected by that. Table 12 illustrates how these categories can be divided.

Table 12: Scale, Quality and potential fate of cell phones provided by different end users categories

Phone Sources	Scale of Collection	Quality of Collected Phones	Fate: Reuse vs. Recycle
Network Service Providers	Large	Mix	Unit Reuse > Recycle
Businesses	Medium - Large	Same brand and model is most likely in good shape	Component and parts reuse might increase.
Straight from Individuals	Small	New ~ Old	Unit Reuse > Recycle most likely
Nonprofit Organizations[5]	Small	Mix	Recycle > Unit Reuse
Municipalities	Very Small	Old > New	Recycle

As seen in Table 12, collectors should target the proper end-user category and allocate resources according to their economic and/or environmental interests.

[5] Not considering programs such as Hope Line by Verizon Wireless

Our forthcoming analysis will reflect on the ratio of different EoL fates, which ultimately depends on their condition. The Tables above briefly describes how condition (quality) varies and is tied to their sources, the collection program and collection methods.

8.5. Process Overview

There are three main stages in the EoL management: (1) collecting, (2) fate determination, and (3) processing. Transportation is used in between the stages. Each stage shown in figure 9 is described in detail later in this section. As demonstrated, the set of individual processes is sequential rather than independent. They relate to each other and influence the total economic outcome.

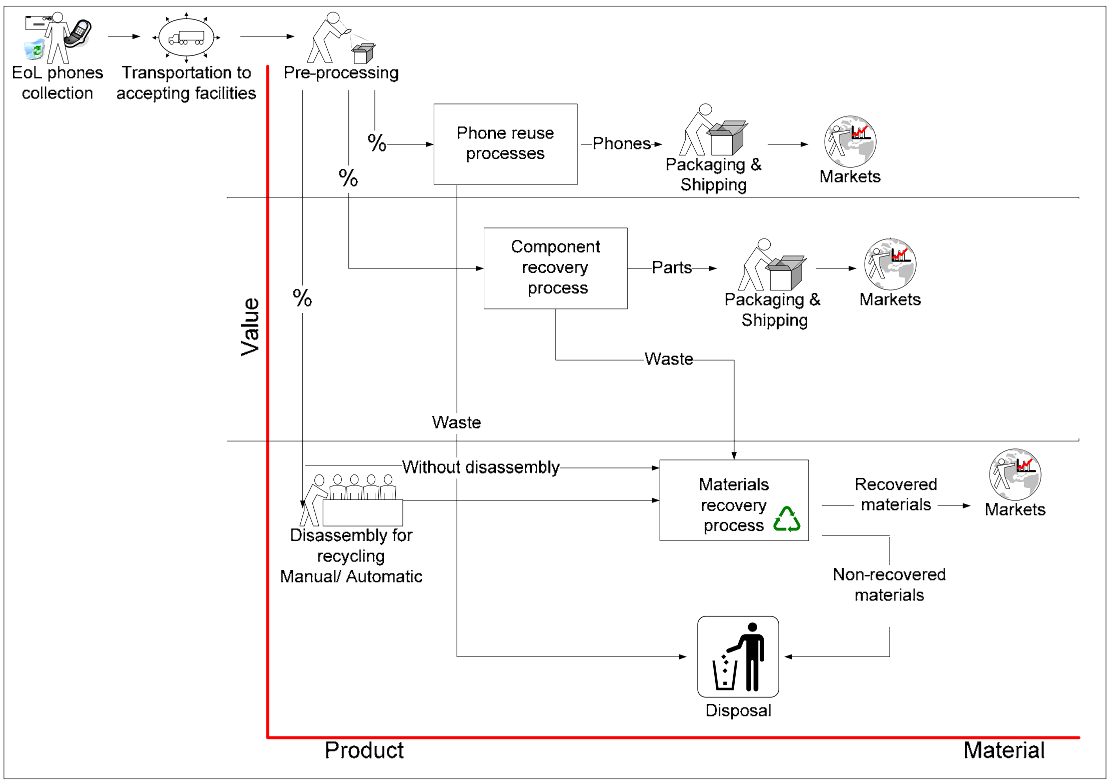

Figure 8: Process Overview

8.5.1. Collection and Transportation

Collection is the first step in the EoL process. As a matter of fact, the collection process is one of the key factors (Hai-Yong Kang and Julie M. Schoenung, 2005) among others that will be mentioned later on in the processing of cell phones.

Moreover, when interviewed, most parties agreed that this process is what makes the whole EoL business succeed or fail.

The collection process refers to the activities performed to transport cell phones to accepting facilities. In order for this to happen, a combination of programs, channels, and transportation means need to be laid down. Figure 10 describes the collection flow process with its main stages.

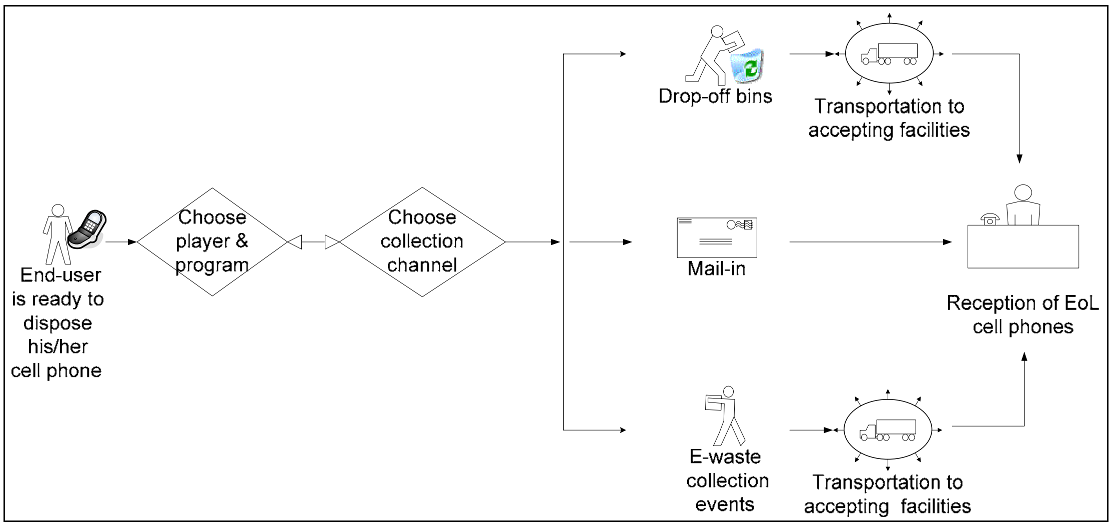

Figure 9: Collection and Transportation flow process

Cell phones enter the EoL stream either after a long hibernation period in end-users' drawers or once end-users decide they are ready to dispose them in the proper way.

Different collection programs are put in place by several interested parties. These collection programs are ultimately combined with collection channels (Appendix 5). As Figure 10 demonstrates, the most popular channels involve dropping the cell phone in a bin, mailing it in a prepaid envelope, and patronizing one-day e-waste collection events. The decision depends upon the suitable program/player and convenience to the end-user. Still, cell phones share some collection methods with general electronic waste, especially at special one day events (Appendix 7) where they are classified as non-CRTs. Each collection channel has different logistics aspects and corresponding advantages and disadvantages (Appendix 8).

In most of the collection channels, consumers provide transportation by bringing their cell phones to the collection site. After this point, commercial transportation will connect collection sites with accepting facilities. As we will see later, transportation occurs in between each stage to process EoL of cell phones.

8.5.2. Pre-Processing

Once the collected phones reach the accepting facilities, they go through a pre-processing stage. Currently, this stage is done mainly by the refurbishers in their facility. However, this stage can also happen in other players' facilities such as collector facilities.

As illustrated in figure 11, the phones are first separated from any accessories. Then the batteries are removed and separated from the main phone case[6]. The batteries are either sent to battery recyclers or refurbished and sold as refurbished products. The phones are then screened to determine the model, condition and value. Sorting is conducted based on the results from screening.

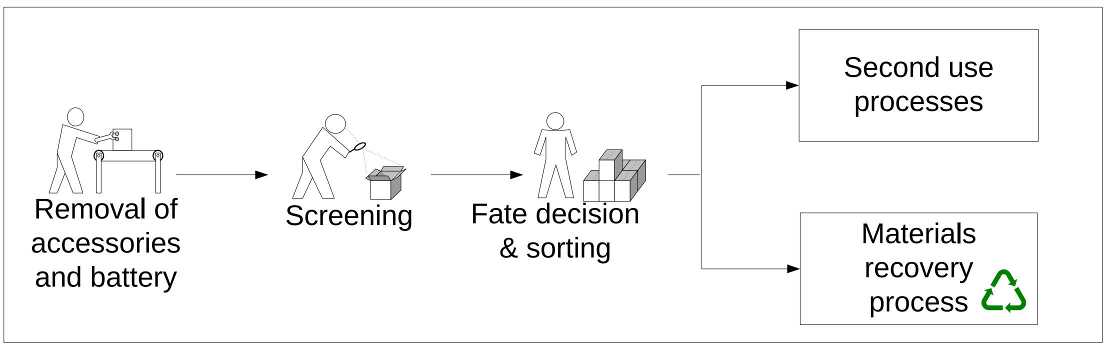

Figure 10: Pre-processing stages

Smaller facilities may still be using manual labor for the screening and sorting. This process requires the employee to be highly familiar with the different models and technology in the cell phone market. High-capacity facilities have already developed dedicated software tools for screening and fate determination. The software automates some of the decisions during the process and makes the process faster and more accurate. One of the screening methods scans the International Mobile Equipment Identity (IMEI). When scanning the IMEI number, the software is programmed to recommend what to do with each phone based on certain criteria. Then the software instructs the employee to either divert the phone to the second-market-use option or to material recovery only (recycling). The scanning process reduces the screening and sorting time substantially and provides a large-scale processing capacity opportunity. It is estimated that 50% of phones are sorted using the semi-automated process while the other 50% are still sorted manually. Clearly, pre-processing is a critical stage because this is when the fate of the phone is determined.

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[6] In our forthcoming economic and environmental analysis all data is per phone with no battery included.

8.5.3. Reuse of Phones

As mentioned earlier, there are two opportunities for phone reuse: reuse "as is" and "refurbish." Some of the EoL phones go through data clearance and basic functional and cosmetic tests. If a phone passes the test, it will be reused "as is tested." If it does not pass the test and requires repair, it will be refurbished as long as it is economical. Obviously, refurbishment is viable only if the expected resale value is higher than the cost of refurbishment process, which is much longer than the reuse process. Some phones are not tested at all and are just sold as "untested." Figure 12 illustrates the decision making process.

If the phone is in working condition and passes the call test, minor cosmetic adjustments might be needed, but no disassembly or parts replacement is required. It goes through software update, cleaning and repackaging, then it is stocked in inventory and eventually sold in the market "as is." If the phone is in working condition but does not pass the call test, it requires certain repairs to restore its function. If the repair is economical, the phone is forwarded for disassembly (manual or semi-automatic), cleaning, parts replacement and reassembly. Then it is repackaged, stocked in inventory and eventually sold in the market as a refurbished phone.

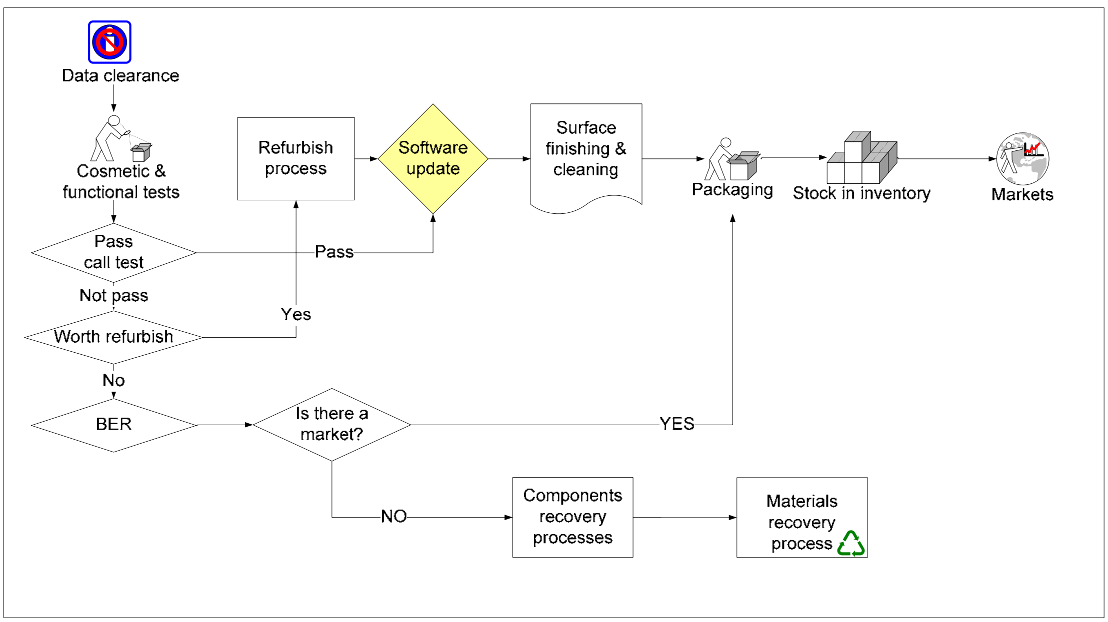


Figure 11: The reuse decision process

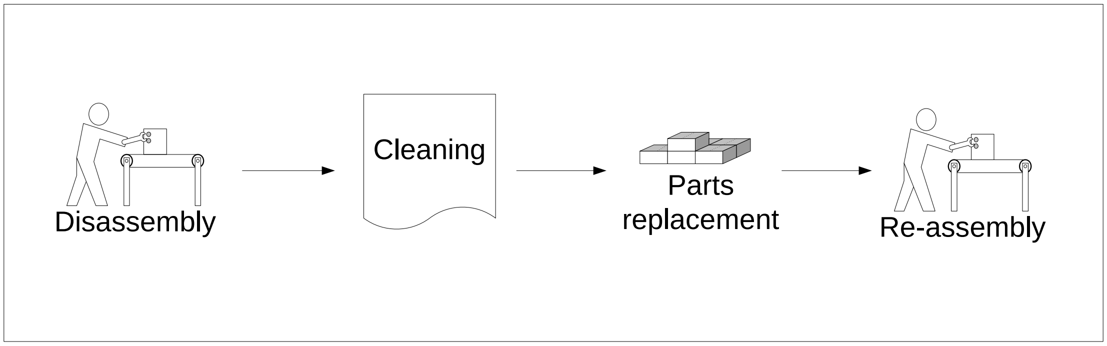


Figure 12: Refurbishing process stages

Prior research (Seliger et al, IEEE 2003) and our interview with major refurbishing companies indicate that only less than 10% of the phones that enter the product second-hand market are fully refurbished. In other words, more than 90% of the phones are being sold "as is" in different conditions.

8.5.4. Reuse of Components

The first few steps of components recovery for reuse are similar to the product-level refurbishing process. Phones are first disassembled, and the components with economic value in the second market are depopulated and recovered.

Disassembly can be automated or manual. However, most companies rely on manual labor since the capacity of that operation is still relatively small. Quality assurance plays a major role in the process where each component is tested for functionality (Stobbe et al, IEEE 2002).

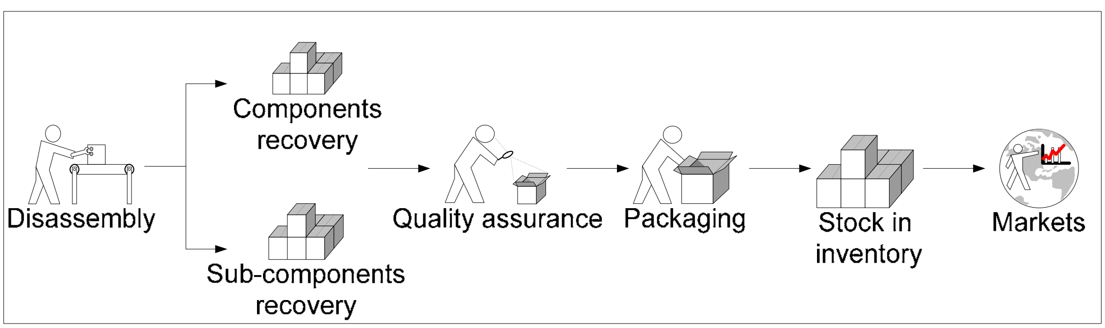


Figure 13: Component recovery process

8.5.5. Recycling of Materials

Recycling is defined as the processes for material recovery. Technically, all materials that are present in a given feedstock can potentially be recovered, but it does not usually happen in reality. Usually only the materials that bring economic profit are recovered. In the case of cell phones, the profitable materials are precious metals and some base metals including copper. Therefore, unless otherwise stated, "recycling" or “material recovery” in this paper means precious metals and copper recovery. Generally, intermediate or secondary e-waste recyclers collect and pre-treat EoL cell phones, then send them to large-scale primary metal smelters and refineries for metal recovery.

From a metallurgical standpoint, there is no substantial distinction between primary and secondary metal recovery. When metals are mined as ore, the concentration of targeted metal is low. Through extraction, concentration, smelting and refining, these different techniques gradually increase the concentration. The metal is purified until it is of marketable quality. In the same manner, secondary material increases its concentration through different processes until it reaches marketable purity. Intermediate recyclers pre-treat e-waste including cell phones and send them to those operators where they process aggregated feedstock from primary and secondary sources. Secondary feedstock is only a small fraction of total operations. Figure 15 demonstrates the copper and precious metals recycling process.

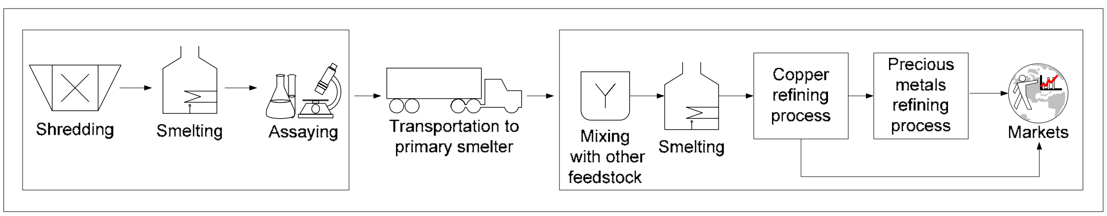


Figure 14: Recycling process

Stage I (Pre-treatment) occurs through intermediate recyclers who send pre-treated materials over to primary smelters who carry on the operation from Stage II (Copper recovery). The project team conducted Stage I at ECS Refining, Santa Clara, CA; the experience and collected data is described in Appendix 9.

I. Pre-treatment

1. Weighing
   Weight is used to reconcile operation fees and profit from metal recovery.
2. Dismantling (optional)
   Parts can be dismantled to realize separate recycling for different materials. This stage is exercised only if economically feasible. Cell phones do not go through this process.

3. Shredding
   The sample is shredded and granulated into particles to enhance material liberation.
4. Material Separation (optional)
   Ferrous or non-ferrous metals can be separated by magnetic or eddy current separation if the concentration is high. Typically iron and aluminum are separated from this process but cell phones do not go through this.

5. Smelting (for assaying)
   Shredded sample is put in a high temperature furnace. Copper-rich metal (called copper shot), slag and dust are recovered from this process.
6. Assaying
   Metals of economic interest are assayed for financial reconciliation among involved parties.

II. Copper recovery

7. Reactor
   Copper-rich feedstock is fed into the liquid metal bath of the reactor until the concentration reaches 70%.
8. Converter
   Concentrated matter is further oxidized to remove most of the remaining sulfur ion and other impurities to reach 98% pure blister copper.
9. Anode furnace
   Through an anode furnace, the copper achieves 99.1% purity.
10. Electrolytic copper refining
    Copper anodes are refined to 99.99% pure copper cathode that is sold to the market. Precious metal residues that sink in the bottom of the cells are removed for further processing.

III. Precious metals recovery

11. Electrolytic silver refining
    Silver is further purified and gold with Platinum Group Metals (PGMs) concentration are removed. Then silver is cast into bars which are sold in the market.
12. Gold process
    Gold is further purified and PGMs are removed. Then gold is cast to the bars which are sold to the market.
13. PGMs refining
    Palladium and platinum are separated and purified, then sold to the market.

IV. Recovery rate

In general, the recovery rate is estimated to be 99% for copper, 98% for gold, and 90% for silver, palladium and platinum.

Among available EoL options, metal recovery requires the heaviest capital investment, the longest process and the highest energy/input requirement.

8.6. Economic and Environmental Performance

One of the main objectives of this project is to evaluate the economic and environmental performance of different EoL management options.

Regardless of the size of the market, the economic performance is the main driver for the EoL market in the absence of regulatory framework. It is critical for the economic outcome to be positive in order to develop a self-sustainable market. For EoL cell phones where a secondary market already exists, it can be assumed that there is a positive economic performance. As the market expands and grows, the performance might further improve. However, there is much more uncertainty with regard to environmental performance of the EoL cell phone market. As the market develops, the performance of EoL stages such as collection and processing is expected to improve and become more efficient. But since economic transactions are usually associated with environmental burden, it is important to find how to strike the balance between positive economic performance and minimum environmental burden. The environmental performance is especially important for the EoL market because it can be the basis for environmental policy formation.

Both economic and environmental performances are measured for each EoL process that was discussed in the previous section:

1. Collection and transportation
2. Pre-processing
3. Reuse options (including reuse of cell phones and components)
4. Recycling option (recycling of materials)

8.6.1. Economic performance

8.6.1.1. Data sources

The data was gathered from existing literature and from information provided by the project partners. The recycling data is based on the actual process that was conducted by ECS refining, using 910 pounds of EoL cell phones collected by the project team. When data varied, a range of values was used. Underlying calculations and/or assumptions (marked *) are described in Appendix 10. All economic values are measured in US dollar value.

8.6.1.2. Findings and Analysis

Collection and Transportation Stage

The collection and transportation stage is often the most costly stage towards the reuse and recycling of electronic devices (Lonn and Stuart, 2002; IAER, 2003). In fact, prior research estimated that collection and transportation costs represent more than 80% of the total cost (Hainault and Smith, 2000). While different collection methods have been widely studied in connection with many pilot e-waste recycling projects (Lonn and Stuart, 2002; Eglise and Pierre, 2000; Hainault and Smith, 2000), there is no one identifiable method that works best for cell phones. Table 13 describes the different methods and the costs associated with them.

Table 13: Collection costs[7]

Process	**Stage**	**Method**	**Cost** ($/phone)
Collection and Transportation to accepting facility	Collection from end-user	Mail-in envelope (take-back)* average	1.4-1.9
		Mail-in (buy-back) average*	8-10
		Drop-off bins*	0.1-2.7
		One-day event*	0.16-0.20/pound
	Shipping from collection points to accepting facility	Ground*	0.22

The major factors that affect the collection cost are the number of phones mailed per transaction (i.e., one for mail-in versus 100-1000 for drop-off bins), and the incentive attached to the program (i.e., buy-back). Buy-back using mail-in is by far the most costly method, but it is intended to effectively capture high-end and newer phones in good condition.

The mail-in envelope method generates high shipping volume because one shipment can only handle the package from one customer. On the other hand, drop-off bins might seem less expensive as a collection method, but it has a disadvantage when the shipment to the accepting facility has to wait until the bin is full. In fact, it might take a few months during which the EoL phones can lose their residual values significantly. Therefore, some collectors who seek resale opportunities already shifted from high volume bins (~1,000 phones) to small or medium bins (~30 phones) where the filling turn-around time is much quicker. Although the cost becomes higher, it makes economic sense if collected phones are much newer and retain higher residual value. In the same manner, the collectors who wish to capture the phones with highest residual values prefer mail-in methods.

Although one-day events could be seen as the most cost-effective method, we found in our local experience that the number of cell phones collected in those events is very small (~one phone per 100 pounds) compared to CRT products (Ventura County, Feb 2006). In addition, the quality of the phones collected at these events is usually poor; they are most likely old and only good for recycling purposes. In this case, the collection cost falls on the municipalities/organizers of the events. A more

[7] Part of the data presented in that table is based on the project team effort to collect phones within a period of three months. For the description of the collection effort, please refer to Appendix 11.

quantitative analysis of the mentioned economic efficiency on these events is described in Appendix 7.

As we described above, the collection cost accounts for a large potion of the total process cost. Traditionally the cost has been absorbed by the collectors and refurbishers that have been trying different methods to reduce this cost. However, as the reuse market grows and matures, the focus is now shifting to find effective ways to capture high-value EoL phones much faster. Although not the most environmentally efficient, nowadays the market is shifting to mail-in envelope as the preferable collection method to capture high valued cell phones. Thus, not only the absolute cost, but the cost relative to the expected revenue is now strategically considered. However, this should not mean that the market must focus only on high-value phones. Collecting low-end or old, non-working products has significance in reducing the volume of EoL phones from landfill or incineration.

Pre-Processing

The pre-processing stage usually occurs at collectors or refurbishers. However, the operation is more efficient when refurbishers who process the phones also complete the pre-processing. Table 14 outlines the main costs associated with pre-processing.

Table 14: Pre-processing costs

Process / Option	**Stage**	**Cost** ($/phone)
Pre-processing	Semi-automated sorting*	0.83
	Manual sorting*	4.17
	Shipping to processing facility*	0.17- 0.39

Manual sorting of phones is the largest cost throughout the pre-processing operation. But since sorting determines the opportunity for economic profit from the EoL phones, it is one of the most important processes in the business. As the scale of reuse business grows, it is becoming increasingly important to reduce the cost within this process while increasing the accuracy and efficiency. As a result, some refurbishers have introduced semi-automatic sorting processes that have reduced pre-processing cost and time by as much as 5 times (confidential interview).

The shipping involved at this stage is different in nature from the shipping at the collection stage. Cell phones are re-packaged and palletized after the next destination is decided (reuse or recycle); therefore they can be shipped in bulk, which brings the cost per phone down. Ground shipping is the most widely used method between accepting facilities and processing facilities (i.e., from refurbishers to recyclers) because it further decreases the shipping cost.

Reuse Options

<u>Revenue</u>

As was observed in the previous section, cost is not an independent factor that always has to be minimized in the EoL cell phone market. Rather, the balance of the residual value minus cost (expected profit) has to be maximized. In order to do so, expected profit has to be captured as accurately as possible.

Expected profit from a phone is largely determined by 1) model, 2) age and 3) condition. Among these three conditions, model is the most important because it is tied to the initial value. For the purpose of this project, the model is classified into three categories: 1) high-end, 2) middle-range and 3) low-end. Different OEMs use slightly different segmentation for their product offerings, but for the purpose of simplicity they are classified into one of those three categories.

In the new product market, middle range is dominant in terms of revenue and low-end is dominant in terms of volume. A small volume of high-end phones contributes to the revenue significantly. Table 15 shows the categories, their share, and the average price for new products.

Table 15: Category and share of new products in US market[8]

Category	**Description**	**US market share**		**Price range** ($)	**Average price** ($)
		Revenue (%)	**Volume** (%)		
High-end	Smartphone, premium, advanced, business	20	6.9	226-500	356.25
Middle range	Business, basic, fashion, entertainment	45	33.8	131-225	166.25
Low-end	Entry, everyday, young, entertainment	35	59.6	1-130	72.5
Total		100	100		

From the interviews and information available on-line, we assume that the market share of these three categories roughly applies to the EoL market as well.

As previously mentioned, the economic success of the EoL cell phone market largely depends upon the collection of high-value phones. The value is determined by the model, age and condition of the phone. Consequently, new, high-end, mechanically-functioning and cosmetically-appealing phones should retain the highest value. However, there are other factors that contribute to value. For example, more phones are available for the middle-low range. This helps increase the demand by satisfying minimum lot size requirements (i.e., 50 units) with ease. Also, popular models retain higher values than others in the same category.

[8] Data are based on confidential information sources and web research

Figure 16 provides an example of the average sale price for different categories and conditions. EoL phones can be resold as fully refurbished, "as is," as repair stock or as BER. Obviously refurbished phones will sell at the highest price and repair stock/BER at the lowest, but there are significant differences in prices among categories. While the average sale price of second-hand phones is estimated at $16, there are different grades of phones with varying average sale prices For example, refurbished high-end phones can be sold for as much as $160, whereas low-end phones will only be labeled as $1 (ReCellular, Website). When averaged, reuse sales price will be between $10 and $50.

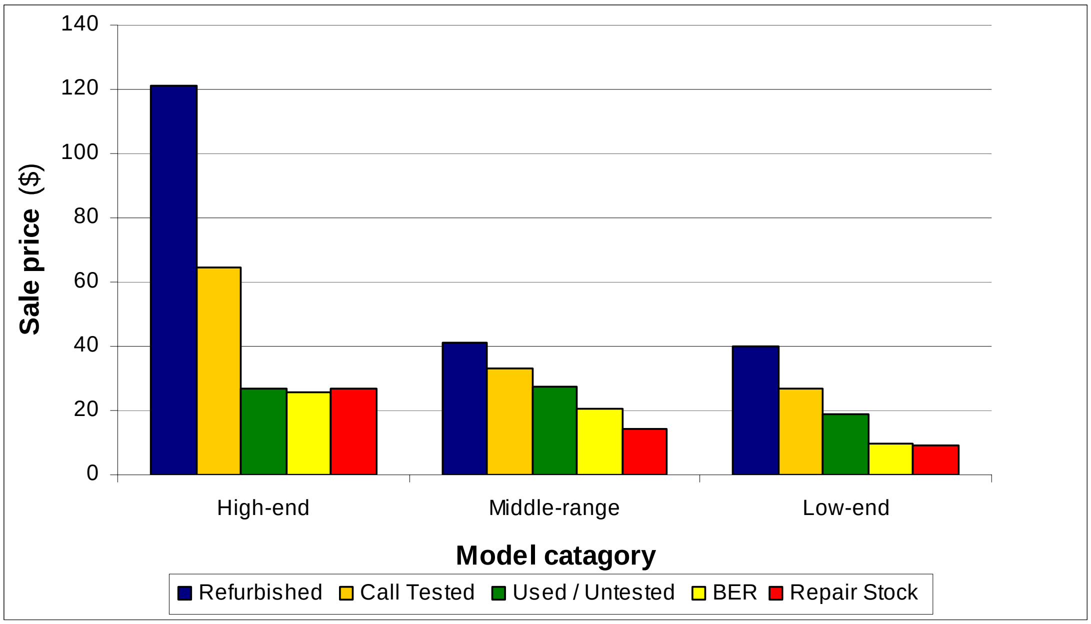


Figure 15: Sale price per category

Although refurbished phones retain high value, currently a very small percentage of the collected phones are worth full refurbishment. Refurbishing requires a longer process time and cost. The phones have to retain good quality in terms of model, age and condition in order to justify the total process cost. Currently it is estimated that less than 10% of total EoL phones at refurbishers call for full refurbishment or remanufacturing (Seliger et al, IEEE2003 and interviews) mainly due to the fact that the ultimate net profit remains almost the same compared to "as is." This is the reason why the industry offers solutions such as buy-back programs as strategic investments to collect a certain amount of high-value phones.

If a phone is BER stock, it is difficult to find a domestic market. In fact, most BER phones are sold overseas where the labor cost is low enough for economically-feasible operation.

While the condition of the phone affects its fate and value, age is another factor as it clearly affects the price of different models. Figure 16 illustrates how the models released in 2000 have the lowest prices whereas the models released in 2003 have the highest. But it is also clear that age is not the only factor in pricing because different models from the same release period behave differently. For instance, some models fluctuate in price and others regularly lose substantial value every few months, while still others lose only small amounts every few months, and those phones with very low value might retain it for a longer time before they are no longer re-marketable.

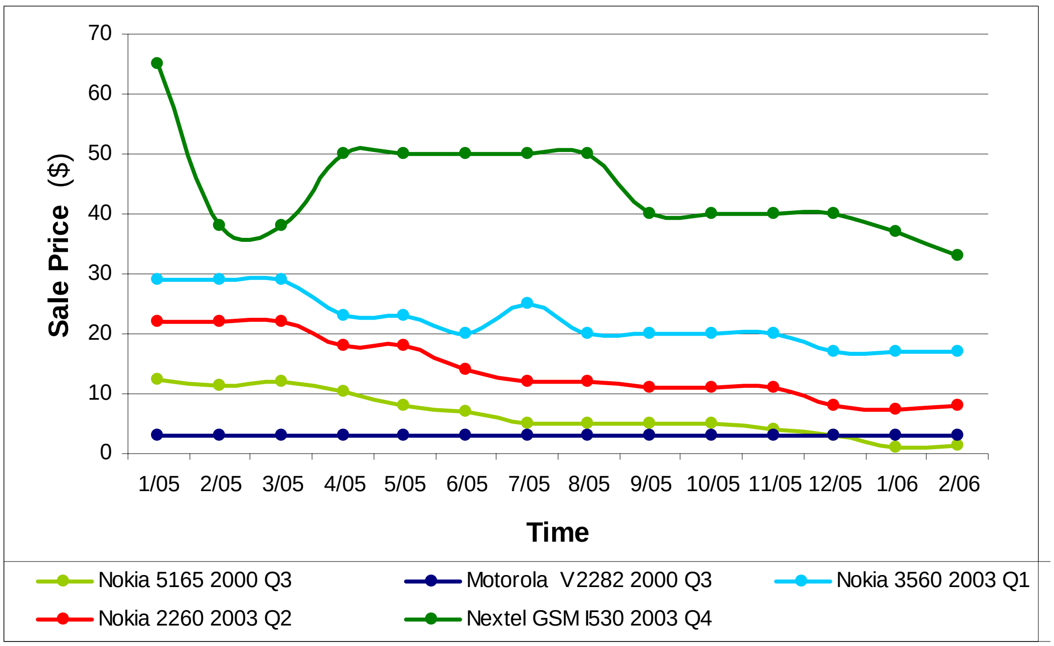


Figure 16: Average sale price

Sale prices of second-hand phones continuously change depending on the model, age, condition and other attributes of the product. Therefore, as is the case with a new-product market, the EoL phones have to be captured and sold at the right time to maximize their economic value. This requires assessing the investment in relation to the revenue received from the phones.

Cost

Buy-back is an important part of the cost for collectors engaged in reuse operations. In most cases, the value for the end-user will decrease as the sale price of a phone goes down. Figure 18 demonstrates the buy-back price of certain models within the first quarter of 2006 (Pacebutler, Website).

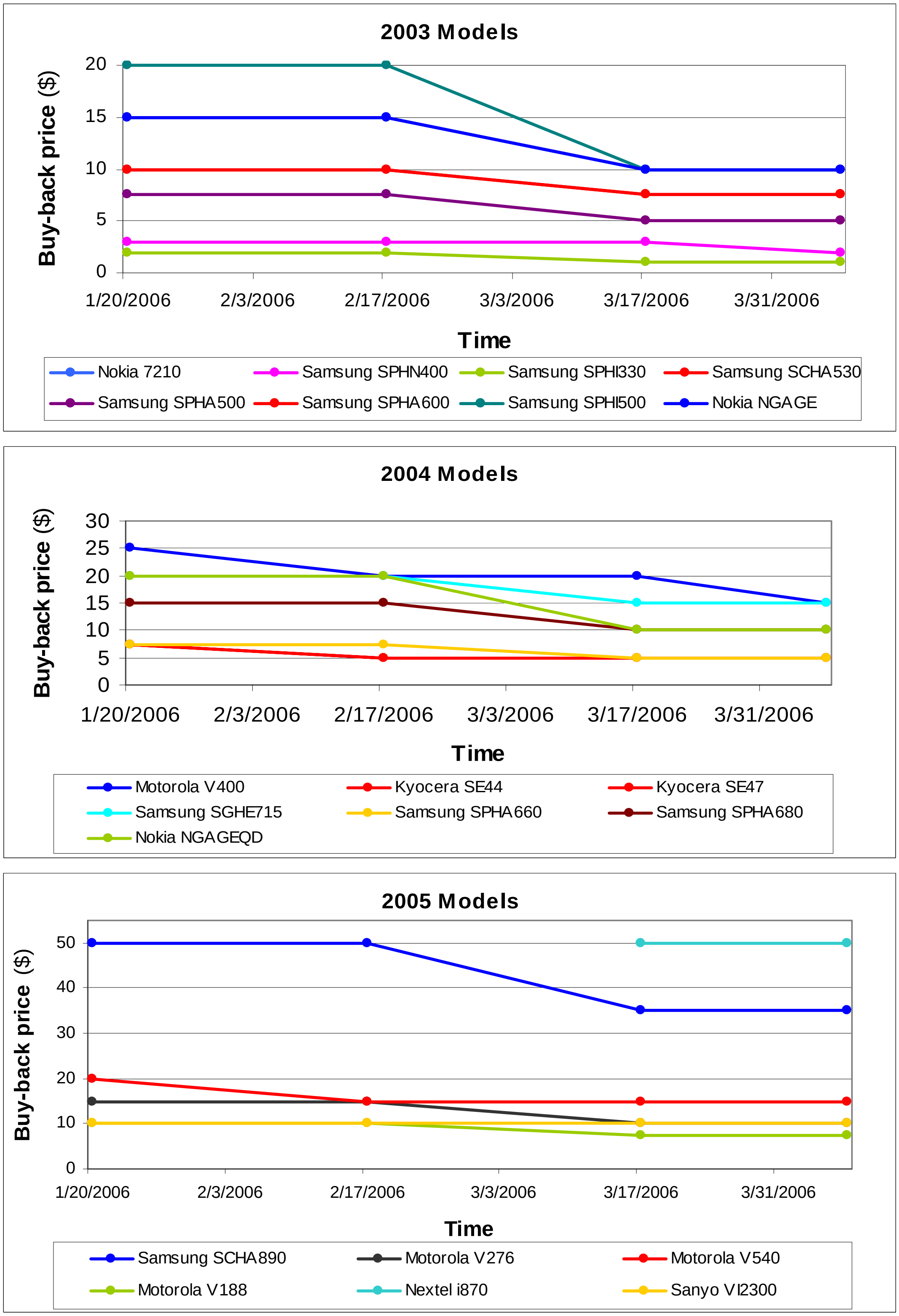


Figure 17: Buy-back price for different models

Middle range to high-end models from 2003, 2004 and 2005 were compared in the figure 18. As with the sale price, model and age are two major factors in deciding the buy-back price. The models that are about 1 year old could retain a maximum $50 value whereas after 2-3 years they will only retain $20 to $30 at the highest. But this is not always the case: Popular models can keep the high value for a long time. For example, "PalmOne Treo 600" was released in 2003 Q4 but still retains a $25-$35 value.

In the processing stage, since most of the operation is still completed manually, labor costs contribute to the largest portion of the total operation costs. This is the primary reason why a substantial number of the phones must be sold outside of the US where labor cost is much lower. However, if a phone simply needs testing or cosmetic repairs, processing time falls dramatically and the operating cost decreases accordingly. The operation costs for this process are about $2-3. After subtracting all the costs, the refurbishers are left with an average profit of approximately $3-4 per phone.

Since the market of second-hand components is not yet mature, it was hard to estimate the cost and value associated with this option. However, LCDs seem to retain the highest value. As technology evolves and cell phones become more widely used to retrieve e-mails, browse the web and play games, the size of the LCD increases and its value will probably increase as well. We estimated the sale value of a set of working components within one phone to be similar to the repair stock average sale value. However, for high-end phones, only the LCD can have a value of $30. We also found out that some models can amount to a total of $40 and $50 parts value. The main cost associated with the process is the labor involved with disassembly that usually requires more technically skilled employees. As mentioned earlier, minimum quantity for the similar model is required so the process is economically viable. Table 16 summarizes the average cost and revenue for the different reuse options.

Table 16: Reuse option - cost and revenue per phone

Option	Stage	Cost ($/phone)	Revenue ($/phone)
Reuse of Phone	Operation average cost for reuse	2-3	16
Reuse of Component	Sale value all components – low end phones		<10
	Sale value all components – high end phones		10-50
	Disassembly labor cost	0.5 - 2	

Recycling option

<u>*Revenue*</u>

Revenue for cell phone recycling comes from precious metals (gold, silver and palladium) and copper. Precious metals are the largest portion of the profit. They are present in very tiny amount per unit, but since the prices are high enough they can make the recycling process profitable. However, the metal market—especially the precious metal market—is volatile due to the issues that are pertinent to those metals. Consequently, the supply and demand balance and prices fluctuate for those metals, which in turn can affect the economic performance of recycling. In general, the price of gold and silver is increasing continuously. Palladium is fluctuating around $200/oz after it hit a record high in the year 2000-2001. Table 17 shows the price change for gold, silver and palladium from 2003 to 2005 (USGS Mineral Book, 2006).

Table 17: Price history for precious metals

Metal	Application	Unit	2003	2004	2005
Gold	Bonding wire Connector	oz	365	411	440
		lbs	5322.9	5993.8	6416.7
Silver	Conductive adhesives Substitute for Pd in MLCC Substitute for Pb-based solder	oz	4.91	6.69	7.15
		lbs	71.6	97.6	104.3
Palladium	Multi layered ceramic capacitor (MLCC)	oz	203	232.93	190
		lbs	2960.4	3396.9	2770.9

If the probability for recycling is the only concern, a price increase might be good news because it increases the profit. But one must keep in mind that high prices increase production costs. Therefore as the price increases, the industry starts to look for substitutes. Along with the miniaturization trend, it is triggering the decrease in mass present in a unit of phone. One research estimates that the decrease in production from 1999 to 2003 has been 60% for silver, 25% for gold and 35% for palladium (Huisman, 2004).

We conducted our own recycling process, and Figure 19 indicates the concentration of derived precious metals from this analysis.

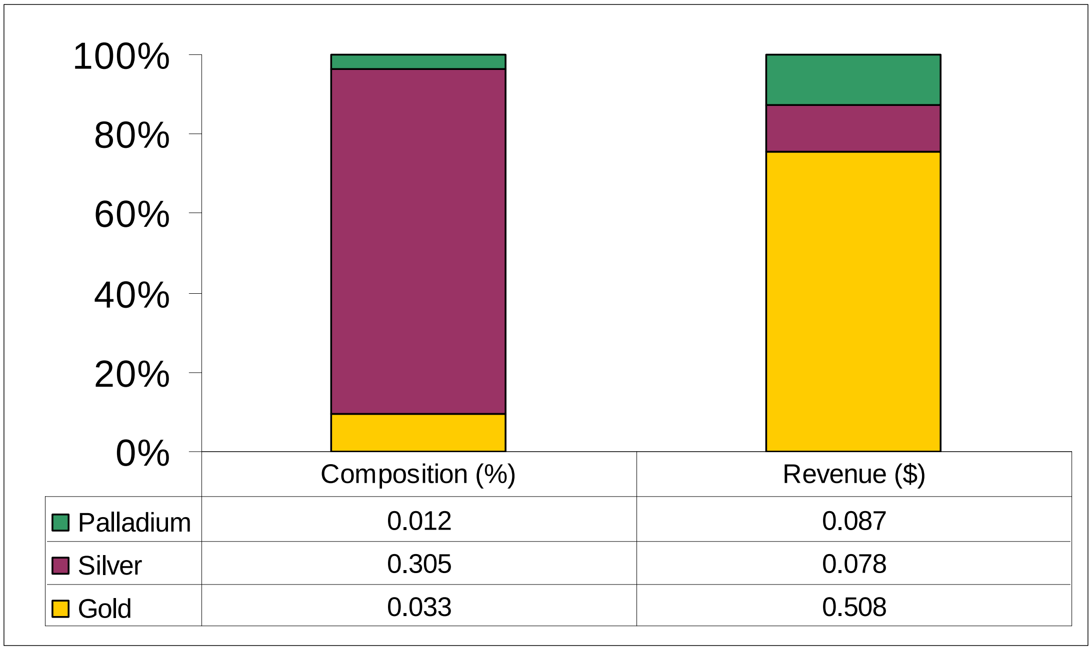


Figure 18: Precious metals recovery per cell phone[9]

Using the average market prices for 2005-2006, the profit from these three metals is approximately $0.67 per phone. Notably, 0.03% of gold concentration comprises almost 80% of the total profit. Compared to existing literature, (stating gold concentration 0.02% ~ 0.04%, silver concentration 0.1% ~ 0.4% and palladium concentration 0.01% relative to the total mass [excluding battery]), the mass of precious metals in our sample was relatively high. Most likely this is due to the age of the phones we collected. The average production year for our sample was 1999 including a substantial number of much older phones (See Appendix 12). Trends in miniaturization accelerate a decrease in mass of metals used per phone; therefore it is highly possible that the concentration for those three metals has decreased for newer models. The economic impact of a decrease in precious metals is discussed further in the sensitivity analysis section. The costs of recycling should be taken into account relative to this profit.

Cost

The data presented below is for a sample of 910 pounds (3,959 phones), that were entirely shredded and then assayed by smelting 58 pounds of the shredded material to calculate the values of the recovered metals (gold, silver, palladium and copper). The data represents the economic performance of an intermediate recycling process as described in section 8.5.5. (Stage I: Pre-treatment).

[9] Concentration is based on third party lab analysis

Table 18: Intermediate recycling process - cost and revenue

Option	Description	Cost ($ /cell phone)	Revenue ($ /cell phone)
Shredding	Labor weighting/shredding	0.02	
	Cost of energy - electricity	0.003	
Smelting	Labor furnace/pouring	0.05	
	Additives (Borax and Soda Ash)	0.01	
	Raw copper	0.09	
	Cost of energy - gas	0.02	
	Cost of water	0.00001	
General	Metals value paid to client	0.8	
	Extra processing charge to client		0.199
	Metals sale value		0.89[10]
	Shipping of slag to processing facility	0.001	
	Shipping to primary copper smelter	0.004	
Sub Total		0.995	1.093

As discussed in section 8.5.5, recycling is generally a two-layered operation: pre-treatment occurs at intermediate recyclers and actual material recovery occurs at primary smelters/refineries. The project did not have the opportunity to witness the operation at primary smelters for the processed sample; therefore the information at the primary smelter is missing. However, the operation at the primary smelters is much larger in scale than the one at intermediate recyclers, as well as the input (process volume, energy and other materials). Although the operation at the primary smelter is more efficient, the cost is not insignificant.

What makes the recycling process different from other processes is that the profit margin per phone is very small. Revenue minus cost per unit is less than $0.10 because both the weight per phone and the mass of recovered metals are small. However, recycling operations are often "processed per batch." Regardless of the weight or mass, the same operation has to be run for every given sample and each run generates a cost. Therefore, it becomes critical to process a large volume at one time to increase operation efficiency and bring the cost down. Economy of scale affects recycling as it requires for more phones to break even compared to the reuse business. Since our sample of 910 pounds returned less than $0.10 profit per phone, this operation will require a much larger volume in order to make a profit. Indeed, based on our recycling experience we estimate that a minimum of 1,500 pounds is needed to secure a net profit per batch.

Since cell phone recycling profitability depends on a very small amount of precious metals and the operation requires a very high volume, clearly the entire process remains vulnerable to metal market fluctuation, EoL phone collection efficiency, and

[10] The revenue is based on the actual market price in the time of recycling for precious metals and copper; in later analysis we used a lower number that reflects average metals market prices for 05-06.

product design trends. In the current situation, in order to remain profitable, recyclers cannot bear the cost of collection.

Additional Economic Data

Through interviews, we were able to collect some additional qualitative information regarding economic benefits and costs associated with the different process options:

- Job Creation

The growth of the EoL market will, in turn, create more jobs. We identified two main sectors that will be affected as the market continues to grow. As individual mail-in envelopes gain popularity as a collection channel, in all likelihood more post office clerk positions will be needed in major mail processing locations. If the volume of the envelopes increases by a few thousand a day, an additional full-time clerk will be needed, unless the distribution centers develop a separate system to divert the envelopes from the main mail stream before they reach the local post office. In general, as collection rates increase, third party shipping companies (FedEx, UPS, etc) will expand their sales volume according to that market.

The second sector that will generate more jobs the refurbishers and collectors. Companies keep recruiting and growing as the market grows. If the collection rate increases dramatically, more jobs will be created within existing companies or new companies that will enter that business. Furthermore, other supply chain agents such as logistic service providers, bin manufacturers, etc. will benefit and expand their market opportunities.

- Advertising methods and cost by different sectors

Currently, the agents involved in collection do not spend much of their budget in specific advertisement strategies. In fact, most have stated their intentions to keep their advertisement costs to “a minimum.” However, we discovered several noteworthy marketing behaviors and advertisement strategies among the different agents.

The table below gives rough estimates of the budget proportion allocated to advertisement and marketing of cell phones and general e-waste (government) collection. It also briefly describes the main strategies these players set to promote collection from stakeholders.

Table 19: Estimated costs and strategies of cell phone collection

Player	Estimated expense range per month ($)	Strategy	Comments
Resellers/ Refurbishers (collectors)	~10,000 or less	Target existing clients and strategic marketing partnerships.	Mail In > Drop off bins. No marketing positioning
Collectors	A few thousand	Direct mail methods (i.e., postcards, flyers, etc.)	Raise public awareness
OEMs	A few thousand	Agencies and partners with previous advertisement experience	Most likely indirect involvement
Government[11]	Varies depending on main strategy: range from few to several thousand (~15,000).	Radio & Newspaper ads (both sensitive to targeted community size), brochure (flyers) and direct mail. Free-cost partnerships (i.e., municipal trash hauling companies)	One-day events. General e-waste oriented (not cell phone targeted). Strategies vary among counties, area served, and human resources capacity.
Recyclers	N/A	B2B	No end-user contact

All agents mentioned in the table above have web-based advertisements to promote their programs, services and business. Therefore, the internet is as an effective tool for advertisement in the EoL cell phone market. For example, one interviewed OEM stated that he experienced six times the increase in his EoL phone collection rate (from hundreds to thousands) after advertising in its monthly newsletter.

- Environmental Compliance Cost

While we discuss in great detail the environmental performance of the different processes and options in the following section, it is worth observing the environmental compliance cost of the main two processors, refurbishers and recyclers

Table 20: Environmental compliance cost

Option	Annual cost ($)
Refurbishers	~100,000
Intermediate Recyclers	~250,000

Since recyclers operate furnaces, they are required to adhere to strict environmental regulations, especially when considered as the point source of emission. Furthermore, some of the materials they handle are considered hazardous and require appropriate treatment. Recyclers usually process a wide variety of products and materials

[11] Information provided by Santa Barbara and Ventura County for One-Day Special Recycling Events

including cell phones so the cost reflects their total process compliance, and not necessarily just cell phones. Refurbishers only process cell phones and accessories so the cost reflects specifically the cell phone operation.

In general, these companies use environmental aspects as part of their marketing tools. We found out that some companies choose to offset some of their energy consumption by purchasing wind energy RECs. Also, some companies are ISO 140001 certified. The larger companies have at least one dedicated full-time employee that is in charge of environmental compliance issues.

8.6.1.3. Conclusions

Under the free market mechanism, companies seek to maximize their economic performance, which is equal to revenue minus cost. In order to achieve the highest economic benefit from EoL cell phones, agents must collect as many high-quality phones as possible, which is a process that often requires additional costs. Therefore, each agent has to make strategic decisions as to their investment vs. ROI. The summary of the main observations in this section is below:

1. **Quality of EoL phones**
   The quality of collected phones—mainly as a function of model, age and condition—determines the residual value (expected profit) and the fate of the phone. Among the different EoL options, reuse of phones has the highest positive economic performance and the higher quality of these cell phones helps retain the greater net profit. Components reuse has a potential to be profitable, however the market is still developing and it is unclear as to how far it will grow, if at all.

2. **Economy of scale**
   Regardless the stage and the option considered, economy of scale is critical for market development and sustainability in the long run. In the reuse market, at product level, a minimum of 50 units per model is required. At the component level, a minimum of 100-1000 units per model is required. Recycling also requires a large volume to operate well (i.e., ~6600 units based on our experience).

3. **Collection rate and method**
   Collection takes place before determining the fate of the EoL phone. However, it is closely linked to that fate. Mail-in captures higher quality phones, especially when tied with buy-back incentives. On the other hand, one day collection events and charity donations are associated with older phones with almost no residual values. In order for the collection methods to help reach a high collection rate, they have to be aligned with the strategic decision of what quantity and quality of phones are sought. Currently mail-in is preferred by the market to capture high-value phones.

However, drop-off bins have the possibility to reduce costs by achieving economy of scale, whereas mail-in costs do not decrease as the collection rate increases. Consequently, agents should focus on creating better collection methods to increase the volume of high-quality phones while decreasing the collection cost. The more phones that reach the EoL stream, the more volume will end up at the different EoL options and the more profit the market will make. Thus, raising the collection rate has become very important in order to draw more cell phones into the EoL market.

8.6.2. Environmental performance

8.6.2.1. Data sources

The data were gathered from existing literature, information provided by the project partners and through direct measurement when applicable. When figures vary, they are recorded as a range rather than fixed values that ultimately used the sensitivity analysis in section 8.6.4. Sub-calculations and/or assumptions (marked **) are described in Appendix 13. The environmental performance is measured in units of energy (MJ), emissions (lb CO_2), water (gallon) and materials used (pound) for the entire set of processes where applicable.

8.6.2.2. Findings and Analysis

Economic performance is measured in terms of revenue and cost, which is straight forward. For environmental performance it becomes more complicated especially when measuring environmental benefits from appropriate EoL management. The environmental benefits mainly come from upstream[12] displacement, which is difficult to measure. Therefore, we presented the environmental burdens and benefits that we measured and we qualitatively discussed the benefits associated with displacement.

Collection and Transportation Stage

The main environmental burden associated with the collection stage comes from transportation that requires energy and produces emissions. It is estimated that the average energy consumption per phone is about 5 MJ for a mix of different collection methods (Geyer and Kirkman, 2004).

We assume that most of the collection efforts rely on ground transportation by the United States Postal Service or third party shipping companies like UPS and FedEx. Therefore other products and services that also use these shipping methods share the environmental burden. An example of the energy and emissions from different shipping methods is shown in Table 21.

[12] Upstream in this case refers to ore mining and new production.

Table 21: Energy and emission per phone[13]

Shipping method	**Energy per phone** (MJ/ mile)	**Emission per phone** (lb CO_2/ mile)
Ground	0.00041	0.00011
Air	0.0016	0.00043
Sea[14]	0.000015	0.000003

As mentioned in the economic performance section, the mail-in method is the most commonly used to collect EoL phones that creates a large volume of shipping transactions. If the ratio of mail-in stays high, it will result in a high amount of energy spent and emissions produced per phone. If the total mail-in volume increases, the cumulative energy consumption and emissions will increase accordingly.

Pre-Processing

As well as in the collection stage, the major environmental burdens come from energy consumption and emissions at the pre-processing stage. Those facilities that have invested in semi-automatic scanning systems contribute with higher energy consumption (scanner + computer) than those where the process is still done manually. However, this contribution is negligible compared to the energy consumption from transportation. In this stage, transportation occurs in bulk, which reduces the environmental burden per phone compared to the collection from individual end-users. Most of the shipping is from collectors to refurbishers and from refurbishers to recyclers. Table 22 demonstrates the average distance between the main players in the market.

Table 22: Average distances between main players in the US (Mapquest, Website)

Description	**Ground distance** (miles)
Michigan – Texas	1,360
Florida – Texas	1,040
California – Texas	1,735
Michigan – California	2,385
Florida – California	2,775

Those collectors that collect and sort phones but do not process them increase the environmental burden by having an extra shipping transaction of the phones to refurbishers and recyclers (depending on their respective fate). On the other hand, refurbishers that collect, sort, and also process the cell phones at one location have a lower environmental burden because they only ship to recyclers those phones that are not suited for reuse. This situation suggests that eliminating the middle-man would reduce the amount of transactions and their resulting drain in energy.

[13] A detailed disclosure of these numbers is in Appendix 13

[14] Dividing MJ/phone in the distance 5728km divided by 1.6 to get for miles (Wright, 1999)

Most of the companies in the EoL market are already involved in collection and pre-processing. In the short term, if the number of interested parties in the market grows faster than the amount of available EoL cell phones, most likely the environmental efficiency of each transaction will decrease until the market will reach equilibrium.

Reuse Options

Currently, no facilities exclusively perform reuse of components. In fact, refurbishers and recyclers that deal with product reuse also recover components as part of their business. As a result, the environmental burden for the reuse options both at product and component level is presented together. While there is some energy and water consumption associated with the operations, the consumption level is fairly low and it is mostly from regular office activities. We estimated that the energy consumption of the facility operation is similar for both reuse of phones and of components since the components recovery is done at parts level (e.g., LCD, antenna, etc.) and not at the sub- component level (such as chips).

Table 23: Environmental burden of the reuse options[15]

Process	**Stage / Fate**	**Energy** (MJ/ phone)	**Emissions** (lb CO_2/ phone)	**Water** (Gallon / phone)	**Additives** (lb/phone)
Reuse of Phone	Facility Operation**	1-1.5	0	0.113	Appendix 9
	Saving new production of phones**	200	N/A	N/A	N/A
Reuse of Component	Facility Operation**	1-1.5	0	0.113	N/A
	Saving new production of parts**	< 60	N/A	N/A	N/A

The final stage of this process is the shipment to the second-hand market. This means that another shipping transaction generates more energy consumption and emissions. An estimated 50% of reused products stay within the US and another 50% is shipped out of the US. However, energy consumption and emissions depend on the size, distance, frequency and method of each shipment. Most transactions out of the US ship via air, while those within the US ship via ground transportation. Table 24 outlines the distances for major overseas markets.

[15] A detailed disclosure of these numbers is in Appendix 13

Table 24: Distance (miles) between main players' location and second-hand markets overseas[16]

		Market locations				
		Mexico	Sao Paulo	Buenos Aires	Hong Kong	New Delhi
Refurbisher Location	Michigan	1,811	5,120	5,515	7,861	7,384
	Florida	1,262	4,328	4,634	8,748	8,211

Displacement of new production is the largest upstream environmental benefit expected from proper EoL management of cell phones. It can occur at both the material extraction level (metal ore mining) and production level (cell phones and components). As we mentioned in the market overview, it is widely debated if the second-hand market (reuse market) cannibalizes any new cell phone production. Also, it is not clear if second-hand phones displace any new production and if any burden is avoided. Furthermore, one might argue that if second-hand phones just expand the new phone market, replacing those phones may increase the total environmental burden in the long run. Later on in our sensitivity analysis we analyze the effect of the displacement factor on the environmental performance of the reuse options.

Recycling option

Similar to the economic performance, the data presented below is for a sample of 910 pounds of cell phones (3,959 phones) that was entirely shredded and then assayed for metal value by smelting 58 pounds of the shredded sample. Remember that the performance described below is only for the "pre-treatment" process that occurs at intermediate recyclers—material recovery operation takes place at the primary recyclers that receive pre-treated materials from intermediate recyclers.

Table 25: Environmental burden of shredding and assaying process per phone [17]

Process	Stage	Energy (MJ)	Water (Gallons)	Additives (Lb)
Recycling	Shredding* *	0.11	N/A	N/A
	Smelting**	1.39	0.003	0.06
	Shipping to primary copper smelter – rail**	0.06	N/A	N/A
	Saving from displacement of ore mining 50%	9	N/A	N/A

[16] This is based on the most probable overseas markets for refurbish & reuse. The distances were calculated with the aid of a web site calculating the distance based on "as the crow flies" between two cities across the globe: see http://www.indo.com/distance/index.html

[17] A detailed disclosure of these numbers is in Appendix 13

Note: this table does not include emissions data of the recycling facility. The facility is in compliance with their permit and no specific emission data was available.

The furnace is operated at very high temperature (1900-2200 Fahrenheit), therefore the smelting requires very high energy consumption. Since we could not receive a “hands-on” estimate regarding the energy consumption of the primary copper smelter operation, we used an estimation of 0.03MJ per phone based on previous research (Wright, 1999). A summary of the data suggests 1.6MJ energy consumption per phone (not including the saving).

In the recycling option, we conservatively accounted for 50% displacement of ore mining when recycling (i.e. the precious metals recovered in recycling save 50% of the resources required to ore mine the same amount). When accounting for displacement, the total energy consumption is shifting to energy saving of 7.4MJ per phone.

Since the entire phone including plastic is shredded and smelted, the plastic content contributes to energy recovery. It is estimated that the thermal value of plastics add 8.8 million BTU heating value to each ton of e-waste (Shuey and Taylor, 2004). This means savings of 0.37 MJ per phone incinerated. In our case, the data was recorded from direct measurement, meaning the net energy used in the process was already considered.

Material Input /Output

Through pre-treatment at ECS Refining, we obtained copper-shot, slag and dust samples. We assayed these to come up with a detailed material composition list of cell phones that serves as “Input” fed into the copper precious metals recovery system. “Output” is assessed by identifying what goes out of the loop or what is foregone. The input/output analysis helps to demonstrate the potential materials for recovery in the different outputs of the process.

The recycling process is a series of decisions as to which material to recover first since it is impossible to recover everything at the same time. Recovering one material often means foregoing other materials. Values of materials play the most important role for the decision because they determine how much economic profit the process can return. It is often the reason why plastic is not recovered rigorously – the value is not high enough to justify the process cost. For cell phones, precious metals and copper are the first priority due to the high value they retain. The chance to recover other metals is determined by their economic value, but metallurgical factors are also important to determine technical feasibility. Cell phones contain more than 30 different metal species that have different properties. They react and behave differently through the process that determines their destination.

In a copper and precious metal recovery system, the scrap is first introduced to the furnace to be smelted. Through this process the metals melt and other metals dissolve into copper. Metals that are not malleable to copper and have low density separate and float to the surface of the slag. The slag is rich in aluminum, magnesium and barium but also contains lead, cadmium and beryllium.

Other metals with low melting points and high vapor pressure at furnace temperatures volatilize and are emitted into air. Typically heavy metals such as lead, zinc, mercury and cadmium are emitted and found in the furnace dust in high concentration. Therefore the dust has to be captured and treated properly to avoid the emission of these toxic substances.

Our lab test showed that tin, titanium, chromium and arsenic were found in all three mediums—dust, slag and copper shot.

As described, the smelting process results in three main outputs. The main sample of copper shot goes to copper refining and then precious metals recovery. The slag is typically sent to lead recycling. When the furnace is used to process array of e-scrap, the dust can contain various elements from different products whereas copper-shot and slag is a direct output of the smelted sample. The dust is usually forwarded to different facilities for silver or lead recovery depending on the highly concentrated metals.

Smelting that takes place at an intermediate recycler (for assaying) and a primary recycler (for material recovery) is basically the same process, and therefore produces all three outputs. Since all three still include possible valuable metals, the intermediate recycler does not dispose of any. As described above, copper shot is sent to a copper smelter, whereas dust and slag is sent to other metal recovery facilities. Theoretically there is no waste generated through intermediate recycling: all the output is sent for possible material recovery. It is after the process at primary recyclers when the waste is generated. In general the slag created after recovered materials are taken out is directed to an approved engineered impoundment that is monitored and reported to the government authorities on a monthly basis (confidential interview). The slag waste is considered later under the waste sub-section.

Technically, the materials recovered that contain value are including zinc from dust, tin, iron and aluminum from slag and nickel and selenium (in any concentration) from copper shot. But we did not find any facilities that recover these materials from cell phones. This may be because the expected profit from recovery is too small to run additional operations.

Figure 20 shows the primary destination of the metals of our sample after smelting. It includes furnace dust, slag and copper shot. The results shown are only for the species that were tested. It is possible that additional elements exist in the output. Within the project, we have tested the output using two different analytical laboratories. However, the results of the analyses vary and no one conclusion can be made. The lab results are shown in Appendix 14; however, we found inconsistency in the results and chose to discuss the results in a qualitative way only. We believe that different analysis methods might be needed in order to achieve accurate analysis results. This area should be further investigated in order to understand the potential of the process outputs.

Element	Price ($/lbs)	Behavior through smelting: Volatilize – Dust	Behavior through smelting: Float – Slag	Behavior through smelting: Sink – Copper shot	Recycling – Type
Group1: High concentration in dust or slag					
Low melting point					
High vapor pressure at melting temperature					
Pb	0.610	?	?		**Lead**
Zn	0.632	?	?		
Hg	750.000				
Group2: High concentration in slag					
Low density					
Al	0.880		?		**Alminum**
Fe	0.044		?		**Iron**
Mg	1.350				
Ba	16.148				
Mn	0.002				
Be	100.000				
V	17.500				
Tl	861.825				
Group 3: High concentration in copper shot					
High melting point					
Malleable to copper					
Cu	1.690			Recovered	
Ni	6.600			?	**Nickel**
Co	15.800				
Sb	1.450				
Au	6,416.707			Recovered	
Ag	104.271			Recovered	
Pd	2,770.851			Recovered	
Se	52.000			?	**Precious metal**
Mo	32.690				
Group 4: Found in all medium					
Sn	3.690				**Tin**
Ti	0.235				
Cr	0.050				
As	1.070				

Recovered	metals currently recovered through copper-precious metal recovery system
?	metals that can be recovered with copper-precious metal recovery system

Figure 19: Output destination of elements

NOTE: Furnace dust includes the dust from other scrap such as e-waste, and photochemical waste that were previously processed.

From the chart above, several observations can be made:

- Among more than 30 species, the possibility for material recovery is limited to only a few elements.

- Many metal elements in cell phones are present only with trace concentrations (0.01% ~ less than 2%). After smelting, they are further dissipated in the dust, slag and copper shot, which require different processes. Copper shot usually goes to electro-refining whereas slag will end up as waste. Through these processes the targeted metal has to be concentrated until it reaches a marketable level. Considering the cost that is associated with those processes, the metals with less value and smaller concentrations will have very little chance for recovery.

- Toxic substances such as lead or mercury have to be treated properly. These elements can be harmful to the employees working in recycling facilities as well as to the environment. Although most of these substances are banned by the RoHS directive and will be phased out eventually, the EoL cell phone will contain them for the foreseeable future especially because there is about 6 years time lag (Appendix 12) between production year and the year the phones end up in the recycling stream. Treatment of those substances will also affect the recovery process of other material because the dust and slag will have to be contained in impoundment to avoid the leakage to the natural environment.

Depending on the property of the metals, there are several recovery technologies available. The process we witnessed and evaluated is a pyrometallurgic process. It is expected that different methods will be tested to see the opportunities for further recovery.

Waste

Currently no data is available for the number of EoL phones that end up in landfills. We estimate the weight of avoided waste of phones being collected based on the average weight of the cell phone (0.23 pound). Later on we calculate the avoided waste in the entire market depending on the collection rate.

As mentioned in the input/output section, there is a slag waste associated with the recycling process in the primary recyclers. Based on our recycling experience, 0.26 pound of slag is associated with each phone (based on a 58 pound sample that was smelted). This is of course a maximum estimate because as the quantity of phones smelted together increases, less input materials of borax, soda ash and copper per pound are needed and less slag is generated per phone.

In addition, as mentioned in regard to displacement, material recovery avoids the waste associated with the ore mining. Table 26 presents the avoided waste per phone.

Table 26: Waste avoided- materials recovery

	Mass (lb/phone)	**Waste factor for raw material**	**Waste** (lb/phone)
Silver	7.007E-04	7500	5.25
Palladium	2.795E-05	350000	9.80
Gold	7.574E-05	350000	26.50
Copper	4.597E-02	420	19.30
Total			60.85

Generally, the concentration of precious metals in the ore, especially the concentration of gold and PGMs, is very low (4g/ton ~ 7g/ton) (Platinum Today, Website). This reflects the enormous amount of waste avoided for palladium and gold. Without considering waste from product manufacturing, a total of about 60 pounds of waste per phone can be avoided by recovering the materials in the table above. However, metal recycling is not capable of completely displacing raw material extraction due to their characteristics. Depending on the combination, some metals cannot be removed from other metals once mixed. Copper and iron is such an example. Therefore to purify targeted metals to a marketable quality, virgin metal has to be added to dilute impurity. If the scrap includes many different metals, the possibility of needing to add more virgin metals increases.

Landfill leaching

According to a research done by the CA Department of Toxic Substances Control, cell phones exceed the regulatory threshold of total concentration (TTLC) for several elements: Sb, Cu, Pb, Cr and Ni. In the leaching test (TCLP), cell phones failed for Pb, and were 10 times the regulatory leaching threshold (E-waste report, January 2004). Those results were confirmed in a different research done in the University of Florida, suggesting that 10 out of 14 cell phones tested exceeded the TCLP regulatory threshold of 5mg-Pb/L (Platinum Today, Website). Diverting the collected cell phones from landfill will avoid the burden associated with leaching of lead to soil and groundwater. As mentioned before, this issue might be solved in the near future if regulation similar to RoHS is in full compliance in the US as well; however, it will take a few years to clean up the EoL market from existing lead-based products.

8.6.2.3. Conclusions

First of all, if no displacement is considered, all processes come with additional environmental burdens. As mentioned above, displacement can occur at the product (new phones avoided from production) or material level (raw materials avoided from extraction). Since we argue that it is difficult to quantify the displacement effect, it is not discussed in our environmental performance conclusions and is left for the upcoming sensitivity analysis. Without considering displacement effect, below are the main findings:

1. **Transportation and energy requirement / CO_2 emissions**
   Regardless of the method, all shipping transactions are associated with energy consumption and CO_2 emissions. Depending on the process, sometimes one phone can travel a very long distance, so is important to consider ways to reduce the total mileage traveled per phone to minimize these burdens.

2. **Energy requirement**
   Except for recycling, the EoL operations are relatively clean and require minimum energy. But for recycling, energy use is high because it involves processes such as running a high-temperature furnace to reach high melting points. Consequently, primary and secondary recycling facilities cannot avoid high energy use when processing the metals. So, despite the fact that some energy recovery can be achieved by incinerating plastic in the smelting process, high energy consumption still occurs in the metal recovery process.

   In our project the operation performance at the primary recycler was not assessed because of the lack of information. However, it has to be kept in mind that these facilities take on a considerable amount of the environmental burden.

   An aspect of the recycling process that potentially can reduce energy requirements from furnace operations is the assay procedure. Currently both intermediate and primary recyclers run the process to reconcile results and agree on the respective transaction. It is an important process to determine the value of the processed scrap and it is the reason why both parties need to conduct it. However, if they could agree to merge this process into once instead of twice, the environmental burden could be reduced.

3. **Waste**
   Avoided waste is associated with diverting the collection phones from landfill (downstream). However, the major waste saving benefit is when displacement of ore mining and new production is accounted for (upstream).

4. **Other**
   The operations for reuse produce almost no emissions and wastes except for the ones related to the daily operation of the facilities or employee use. It requires some additives, but they are not quantified in terms of toxicity to the environment. For recycling, emissions are a problem and are strictly controlled by law. Water consumption is very low for the recycling process and waste is generally treated at primary operators.

8.6.3. Baseline Analysis

In order to describe the current market status we have developed baseline performance indicators. For this purpose we chose the economic and environmental factors and variables that influence the market condition and quantified them to measure the performance of the EoL market today. This will serve as a quantitative baseline for the forthcoming analysis.

Table 27 describes the factors and variables that were used as the baseline. Values are based on literature, extensive interviews with project partners and professional assumptions.

Table 27: Baseline factor values

Description	Baseline value
Potential number of EoL phones/ year in the market	130,000,000
Current collection rate	5%
Collection Method used: – Mail-in envelopes – Mail-in web (buy-back) – Drop-off bins – One day event	 50% 20% 29% 1%
Collection Cost (per phone): – Mail-in envelopes – Mail-in web (buy-back) – Drop-off bins – One day event	 $1.9 $9 $1.6 $0.01
Operation Cost: – Pre-processing – Reuse of phones – Reuse of components – Recycling of materials	 $2.8 $2.1 $1.7 $0.2
Reuse rate at the product level	65%
Reuse rate at the component level	0%
Recycling rate	35%
New production displacement due to reuse	0%
Ore mining displacement due to recycling	50%
Average sale value of second-hand phone	$16
Components value per phone	$10
Material recovery value per phone[18]	$0.75

[18] Precious metals plus copper, 05-06 average market price

Results:

Table 28: Baseline Outcome

Process/ Option	**Cost for the market** ($)
Collection	(20,866,885)
Pre-processing	(18,021,250)
Reuse process- phone	(8,802,083)
Reuse process - components	0
Recycling process	(409,500)
Sub-Total	(48,099,718)
Process/Option	**Revenue for the market** ($)
Sales of second-hand phones	67,600,000
Sales of second-hand components	0
Sales of materials recovered	1,707,784
Sub-Total	69,307,784
Process/Option	**Negative environmental impacts**
Energy consumption throughout processes (MJ)	41,226,068
Water consumption throughout processes (gallon)	790,238
Max waste generation from recycling slag output (lbs)	582,478
Process/Option	**Positive environmental impacts**
Materials recovered due to recycling (lbs)	51,188
Waste avoided by collection (lbs)	1,462,500
Max waste saving from avoiding ore mining due to recycling	138,447,307
Energy saving from avoiding ore mining due to recycling	20,475,000
Indicators for market outcome (Net value)	
Revenue – Cost ($)	21,208,065
Energy consumption (MJ)	20,751,068
Waste saving (lbs)	(139,327,323)
Water consumption (gallon)	790,238
Materials recovered due to recycling (lbs)	51,188

From the baseline results (Net Value) above we derived the following observations that reflect current market situation:

<u>*Economic outcome*</u>

- Collection and preprocessing account for 80% of the entire cost of EoL processes (38.8/48 million dollars).
- As for revenue, more than 95% of it will come from sales of second-hand phones as long as the reuse rate stays at the current level of 65%. Profit from recycling is a small portion. The economic performance of the current EoL cell phone market is positive, so it justifies the existence of different parties interested in the EoL cell phones.

Environmental outcome
As discussed previously, quantifying displacement effect is a very controversial process because it cannot be directly measured. Moreover, it has been impossible for us to quantify the environmental impact throughout the entire production process. Therefore in the baseline analysis, only extraction (ore mining) displacement is accounted as the ratio of 50% and no production displacement is considered. Based on this assumption, we derived the following observations**:**

- As long as no displacement of new cell phone production is taken into account, there is net positive energy consumption throughout the EoL process. Some energy is saved by avoiding ore mining through recycling, but it is not enough to offset the total energy consumption of the recycling and reuse processes.
- Even with conservative ore mining displacement rate at 50%, there is a net waste saving. This demonstrates the significance of environmental benefit brought by avoiding raw material extraction through recycling.

8.6.4. Sensitivity Analysis

After establishing a market baseline from an economic and environmental perspective, it is important to determine which factors most affect the outcome. In order to achieve this, we perform the sensitivity analysis while modifying the factors previously discussed. Conclusions from the analysis are summarized in the end of this section.

Table 29 outlines the factors considered in the analysis and the range they were varied for. Each factor was changed individually while keeping the other factor values fixed as they were set in the baseline.

Table 29: Sensitivity analysis factor range

Factor	Range
Collection Stage	
Collection rate (%)	1-50
Mix of collection method used: o Mail-in envelopes (%) o Drop-off bin (%)	 35-70 44-9
Buy-back collection cost ($)	4-16
Residual Value	
Average phone sale value- second-hand market ($)	5-40
Average material value per phone ($)	0.2-2.5
EoL Fate	
Reuse rate ($)	30-70
Recycling rate (%)	30-70
Components reuse rate (%)	1-25
New Production Displacement	
Phones reused (%)	0-100

8.6.4.1. Economic Outcome

***Factor**: Collection Rate*

As demonstrated in figure 21 (below), the economic outcome is affected directly by the collection rate. As collection rate increases, the net economic outcome increases. This will remain true as long as the value of the collected phones and recovered materials remain as in the baseline.

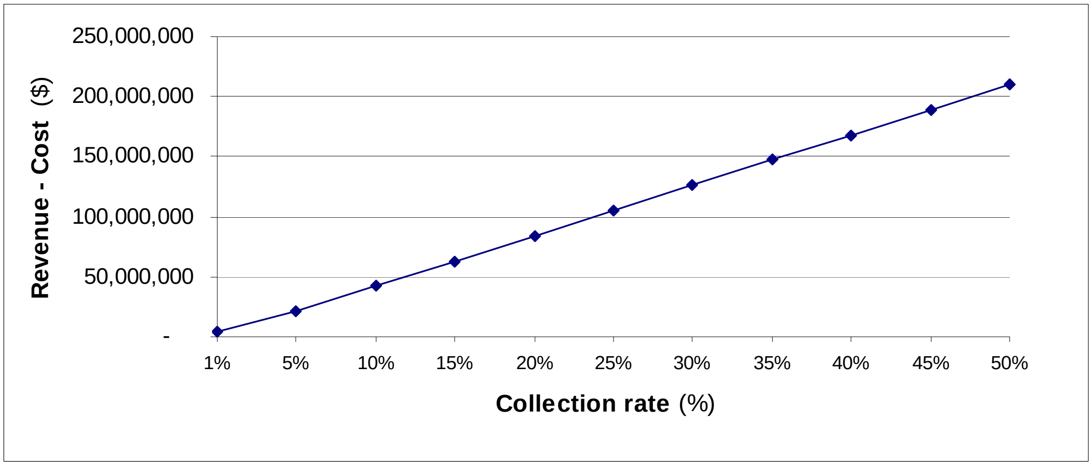


Figure 20: Change in economic outcome as function of collection rate

***Factor**: Mix of Collection Method used*

Since we believe that mail-in envelopes and small-volume drop-off bins will be the common collection methods in large scale operations, we kept the ratio of one day event (1%) and buy-back (20%) the same as the baseline, then changed the ratio of mail-in envelopes and drop-off bins for the remaining 79%.

The mix of the collection methods affects the outcome much less than the collection rate does. However, as mentioned earlier, different collection methods (mail-in envelopes vs. drop-off bins) can be associated with the quality of the collected phones. In this analysis, the quality of phones remains constant regardless of the collection method. If the quality of phones changes (which is very likely), the net outcome can change more significantly.

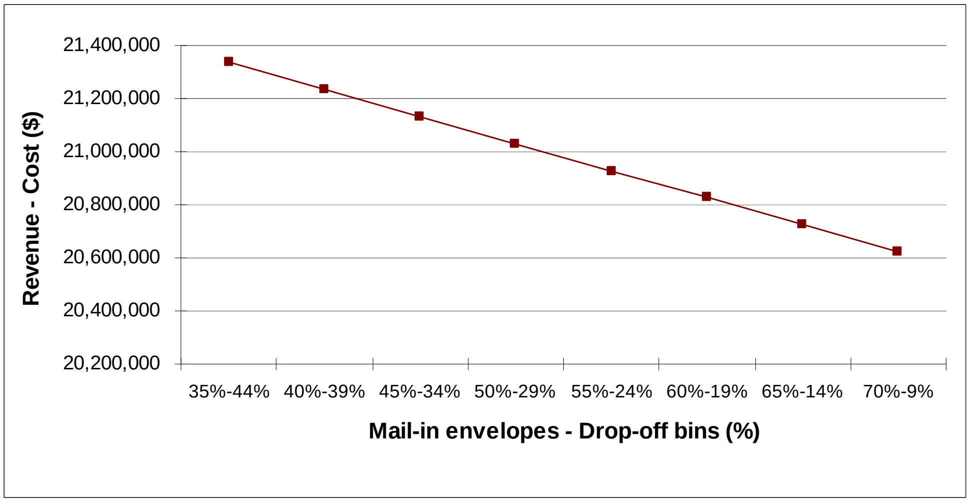


Figure 21: Change in economic outcome as function of collection methods

***Factor**: Buy-back collection cost*

Looking into another aspect of collection, we tested how a change in the collection cost will affect the economic outcome. We observed that take-back costs (mainly shipping costs) will remain relatively fixed or will go down if economy of scale is achieved. But in the case of buy-back, the cost largely depends on the residual value of the phone (model, age and condition), in which case we assumed that a change in the buy-back cost can affect the economic outcome of the market.

From the analysis, it can be seen that an increase in the buy-back cost still does not change the net economic outcome from positive to negative, even when the cost per phone is doubled. This must be because the market share of buy-back is kept constant at 20% as the baseline assumption. As the market grows and more attention is paid to capture high value phones, the ratio of buy-back might increase and the effect of buy-back cost might become significant as well.

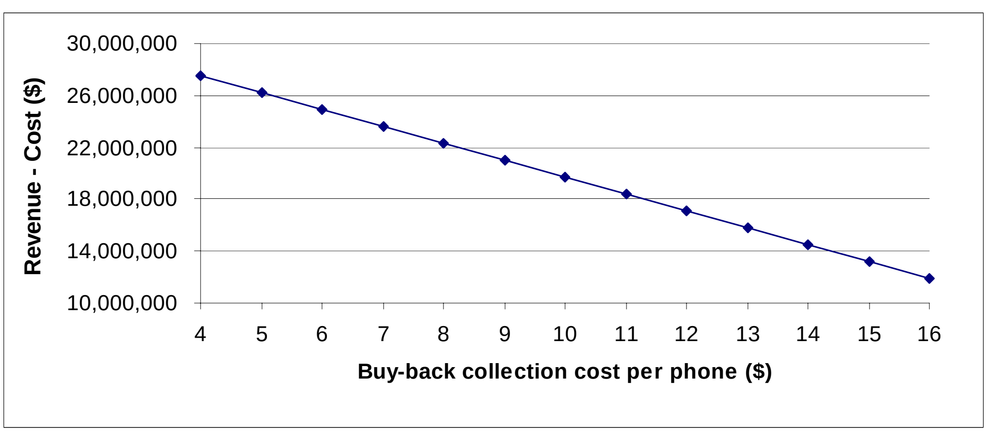


Figure 22: Change in economic outcome as function of buy-back cost

***Factor**: Average sale value- second-hand market*

The revenue is another side of economic performance that needs to be analyzed. The sale value of the phone is the main driver for a positive economic outcome in the current market condition. If the average second-hand phone price (currently $16) drops below $10, the net economic outcome will become negative.

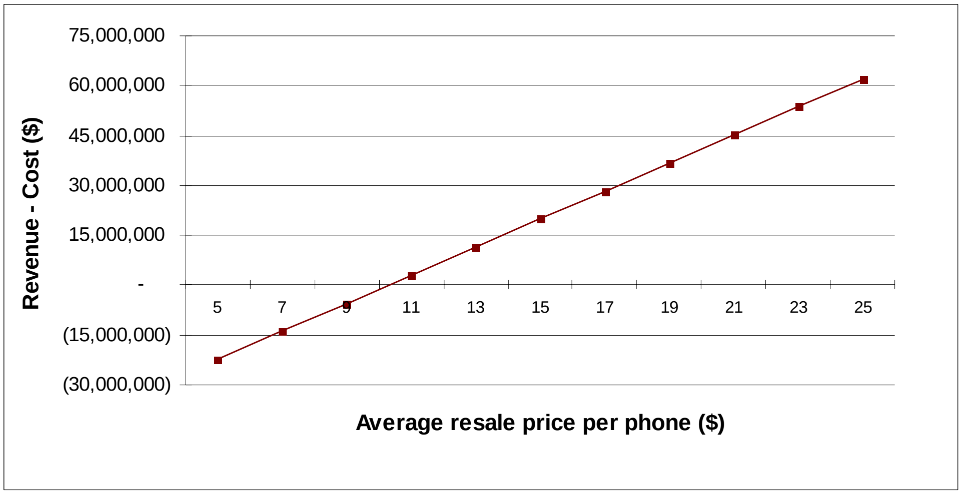


Figure 23: Change in economic outcome as function of second-hand phone sale price

***Factor**: Average Material Value*

<u>Analysis 1</u>

Another source of revenue is from material recovery. However, the value of recovered materials per phone is ~$0.8 and is more than 10 times smaller compared to second-hand phone value. Therefore net outcome is affected less dramatically by material value change with the current recycling rate at 35%. However, in case of increased recycling rate, the outcome might change substantially.

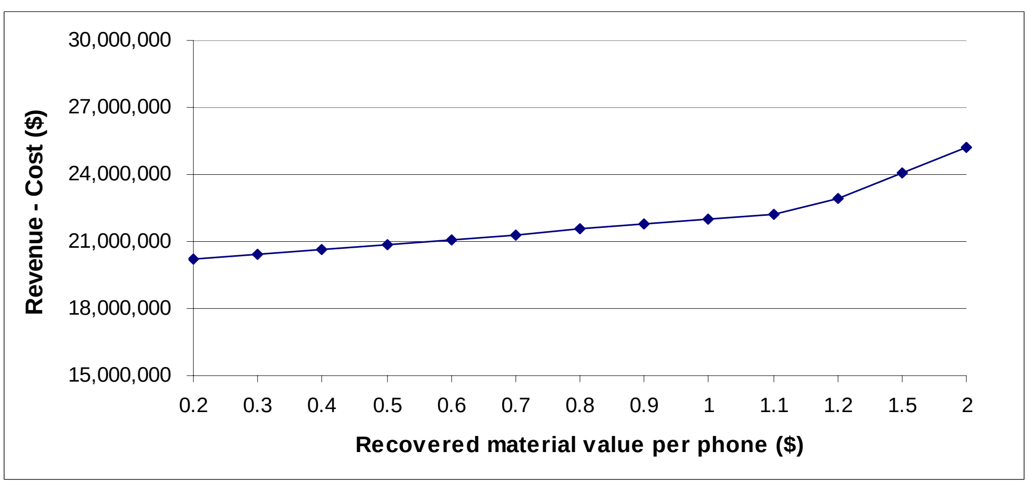


Figure 24: Change in economic outcome as function of material value

Analysis 2

For product or component reuse, the value is associated with product attributes such as model, function or condition. But for recycling, the value is determined only by the kind of elements and their mass that are recovered. For cell phones, a tiny amount of precious metals are producing economic profit but the material composition is changing over time. Moreover, the prices for those metals fluctuate because the market is quite volatile. Together, these factors will affect the performance of recycling. Therefore, even if the recycling rate goes above 35%, net economic outcome can change from positive to negative if not enough elements and mass are present in the cell phones. In this analysis we changed both the metals concentration and metal prices using different data points.

The three data sets we used for concentration were:

- Data 1: derived from our recycling operation. Average production year is 1999 (Appendix 12) and average weight per phone is 0.23 lbs
- Data 2: derived from literature. Production year is unknown; the literature was published in 2004 and the phone weight was 0.1 lbs (Takahashi, 2004).
- Data 3: derived from literature. Average production year was 2003, and average phone weight was 0.176 lbs (Huisman, 2004)

Three metal prices were used: average for 2003, 2004 and 2005 (U.S. Geological Survey web site, 2006) to incorporate price fluctuation.

In addition, the following assumptions were made:

- Assumption 1: use the lowest concentration for each metal among three data points.
- Assumption 2: use the highest concentration for each metal among three data points.
- Assumption 3: assume that gold and palladium concentration decreases whereas silver concentration stays constant[19].

Unit weight per phone was assumed to be 0.176 pounds, which is the same level as Data 3. As observed in table 30, the possible combination of materials value changing the mass and prices are numerous and it is difficult to derive one obvious trend. However, the difference between the highest and lowest value per ton is substantial ($6,300 - $2,900 = $3,400). Also, it has to be kept in mind that a market price increase will work more strongly to encourage industry to look for substitutes or use less material. A price increase is not directly linked to increased profit for recycling. It is quite the opposite as it might accelerate the decrease in mass used per unit.

[19] The assumption is based on the rational that for gold and palladium, there is a projection for decreased mass applied for bonding wire or connector (main application of gold) and multi layered ceramic capacitor (MLCC) (main application of palladium). However, silver can be a substitute for lead in lead-free solder and palladium for MLCC.

Table 21 also shows different possible weights per phone. When decrease in mass is combined with decrease in unit weight, the recycling facility has to collect more phones to produce the same level of profit. Indeed, one of the reasons why cell phones do not appeal to certain type of recyclers is because of this small weight per phone. For those recyclers whose business is “per pound,” cell phones turn out to be too cumbersome to handle because much more units are needed to achieve the targeted weight.

As is discussed earlier, collection cost is one of the largest economic burdens in EoL management. As the technology advances and less valuable materials are found per unit, collection and process efficiency will become more critical to maintain the self-sustainability of recycling. Since the composition and weight continuously changes for electronic products, it is important that the recycling industry understands this fluctuation. Sharing product design information will become the key to make recycling process more efficient.

Table 30: Material recovery analysis

	Data 1 (Project sample)					
	Weight/phone 0.23			Production 1999		
	# of phones per 1 ton 8,966					
	Concentration per phone (0.23lbs)	Recovered mass/unit lbs	Recovered mass lbs/ton	Profit/ton 2003 $/ton	profit/ton 2004 $/ton	profit/ton 2005 $/ton
Au	0.033%	0.000076	0.66	3,507.9	3,950.0	4,228.7
Ag	0.305%	0.000701	6.10	436.6	594.9	635.8
Pd	0.012%	0.000028	0.24	720.0	826.2	673.9
Total	0.350%	0.0008044	7.00	**4,664.6**	**5,371.1**	**5,538.4**

	Assumption 1 (Lowest)					
	Weight/phone 0.176					
	# of phones per 1 ton 12,500					
	Concentration per phone (0.176lbs)	Recovered mass/unit lbs	Recovered mass lbs/ton	Profit/ton 2003 $/ton	profit/ton 2004 $/ton	profit/ton 2005 $/ton
Au	0.025%	0.000044	0.55	2,927.6	3,296.6	3,529.2
Ag	0.140%	0.0002464	3.08	220.5	300.5	321.2
Pd	0.007%	0.000012	0.15	455.9	523.1	426.7
Total	0.172%	0.0003027	3.78	**3,604.1**	**4,120.2**	**4,277.1**

	Data 2 (Takahashi)					
	Weight/phone 0.1			Production NA		
	# of phones per 1 ton 21,739					
	Concentration per phone (0.1lbs)	Recovered mass/unit lbs	Recovered mass lbs/ton	Profit/ton 2003 $/ton	profit/ton 2004 $/ton	profit/ton 2005 $/ton
Au	0.030%	0.000031	0.67	3571.8	4021.9	4305.7
Ag	0.098%	0.000099	2.16	154.4	210.4	224.9
Pd	0.007%	0.000007	0.14	425.7	488.4	398.4
Total	0.135%	0.000137	2.97	**4151.9**	**4720.8**	**4929.0**

	Assumption 2 (Highest)					
	Weight/phone 0.176					
	# of phones per 1 ton 12,500					
	Concentration per phone (0.176lbs)	Recovered mass/unit lbs	Recovered mass lbs/ton	Profit/ton 2003 $/ton	profit/ton 2004 $/ton	profit/ton 2005 $/ton
Au	0.034%	0.000060	0.75	3,981.6	4,483.4	4,799.7
Ag	0.318%	0.000560	7.00	500.9	682.6	729.5
Pd	0.013%	0.000023	0.29	846.7	971.5	792.5
Total	0.365%	0.0006424	8.03	**5,329.2**	**6,137.4**	**6,321.6**

	Data 3 (Huisman)					
	Weight/phone 0.176			Production 2003		
	# of phones per 1 ton 12,500					
	Concentration per phone (0.176lbs)	Recovered mass lbs	Recovered mass lbs/ton	Profit/ton 2003 $/ton	profit/ton 2004 $/ton	profit/ton 2005 $/ton
Au	0.033%	0.000058	0.73	3864.5	4351.5	4658.5
Ag	0.142%	0.000250	3.12	223.7	304.8	325.7
Pd	0.012%	0.000021	0.26	781.6	896.8	731.5
Total	0.187%	0.000329	4.11	**4869.7**	**5553.1**	**5715.8**

	Assumption 3 (Gold and Palladium decrease, Siliver stablize)					
	Weight/phone 0.176					
	# of phones per 1 ton 12,500					
	Concentration per phone (0.176lbs)	Recovered mass/unit lbs	Recovered mass lbs/ton	Profit/ton 2003 $/ton	profit/ton 2004 $/ton	profit/ton 2005 $/ton
Au	0.020%	0.000035	0.44	2,342.1	2,637.3	2,823.4
Ag	0.200%	0.000352	4.40	315.1	429.3	458.8
Pd	0.005%	0.000009	0.11	325.6	373.7	304.8
Total	0.225%	0.0003960	4.95	**2,982.8**	**3,440.2**	**3,586.9**

Factor*: Reuse Rate*
The EoL fate decision and consequent processing options affect both the economic and environmental outcome. Due to the difference in the value of phones and materials, the ratio between reuse and recycling is an important factor that determines the economic performance. As can be seen in figure 26 (below), EoL phones must maintain a minimum 45% reuse rate in order to achieve a positive net economic outcome.

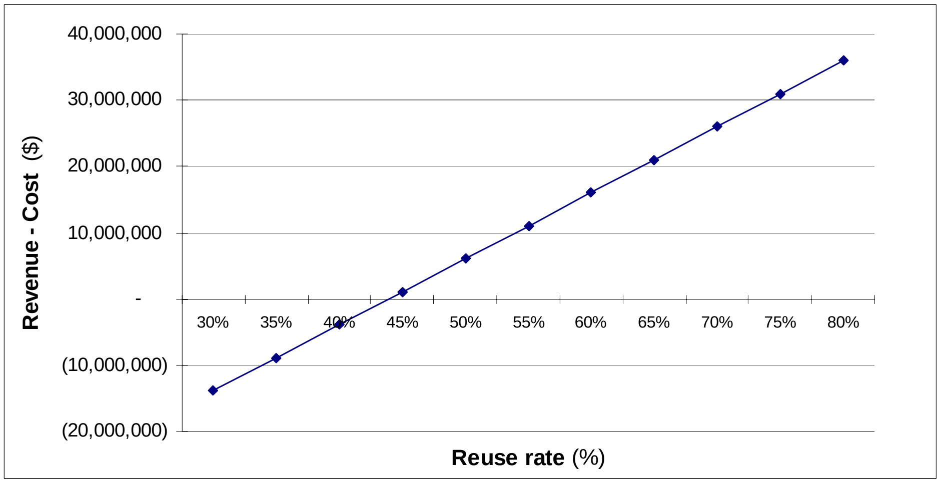


Figure 25: Change in economic outcome as function of phone reuse rate

Factor: *Components Reuse Rate*
While we assumed that the components market is not yet mature, we also tested the economic outcome to evaluate how the growth of the components market will change it. The ratio of reuse (both product and components) was held at the same level as the baseline at 65%. In this situation, reuse of components affects the net outcome much less because increased component reuse means decreased product reuse. Figure 27 (below) shows that a components reuse ratio affects the economic outcome negatively due to the fact the components value is less than the phone's value.

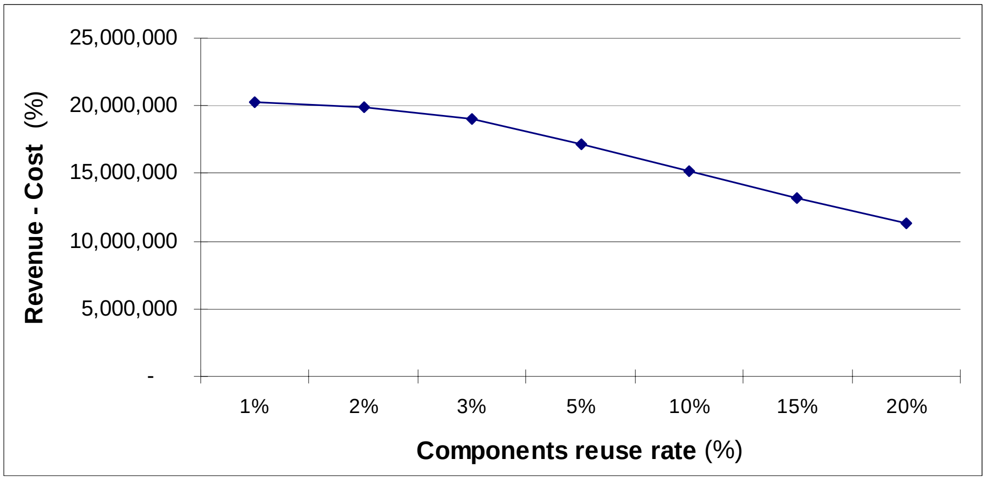


Figure 26: Change in economic outcome as function of components reuse rate

8.6.4.2. Environmental Outcome

Looking at the environmental outcome, we concentrated on waste, energy, and materials recovery indicators. We excluded the water consumption since it is similar in all processes and linear with the operation. We also excluded emissions since the data was not complete. As shown in the graphs below, under certain circumstances these indicators can return positive environmental performance (i.e., saving in resources rather than burden of consumption).

Factor: *Collection Rate*

Higher collection rate works favorably as far as the waste is concerned. More waste is avoided as collection rate increases because it diverts EoL phones from landfill and it avoids ore mining through recycling. While there is some waste generated during the recycling process (slag), the savings are greater than the generation and there is a total net saving of waste. As explained earlier, ore mining is a waste intensive process and by avoiding ore mining, waste associated with the process is avoided as well. Consequently, as the recycling rate decreases the net waste avoided decreases.

However, the situation is different with energy: Assuming no displacement of new phone production, all processes are energy consuming. The larger the market operation becomes, the more energy is consumed.

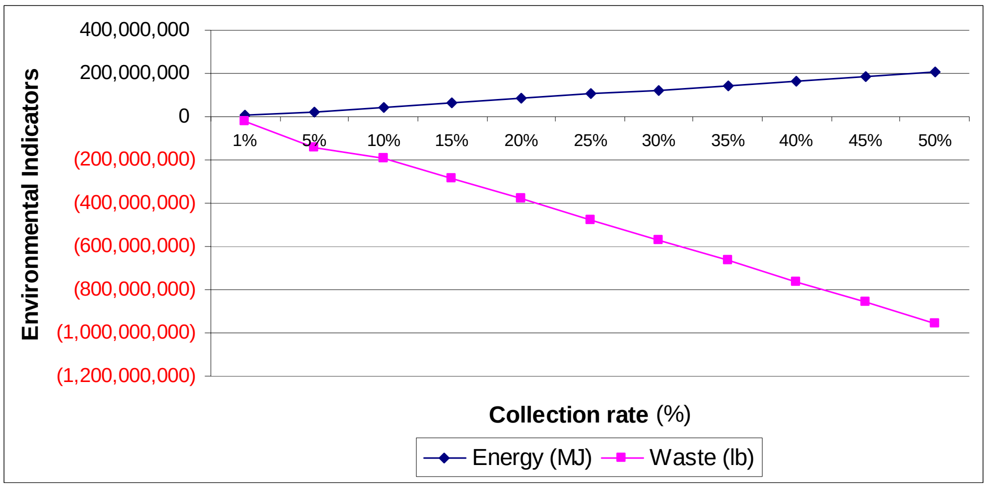


Figure 27: Change in energy consumption and waste saving as function of collection rate

Materials recovery is relatively straightforward. As collection rates increase, more phones are recycled and a higher amount of materials are recovered. However, since the amount of material recovered per phone is small, the aggregated amount is still small compared to the magnitude of waste generated. It demonstrates how the electronics industry (which includes cell phones) can generate a large amount of waste during its production. Just because a finished product is small, it does not necessarily reflect a small input of production materials. In fact, the opposite is usually the case.

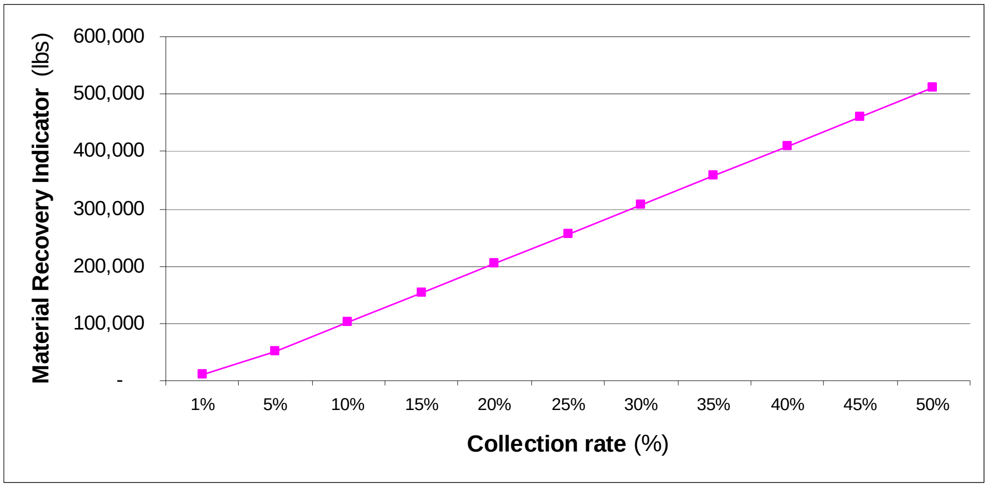


Figure 28: Change in materials recovery as function of collection rate

***Factor**: Reuse Rate*

In the case of the reuse rate, the energy and waste indicators seem to move in opposite directions. With the assumption of 50% displacement of ore mining due to recycling and no displacement of new production, only recycled phones save on energy and waste. Thus, the total net outcome for energy is still positive (i.e. consumption) while the net waste outcome is negative (i.e. saving). Figure 30 demonstrates that as reuse rates go up, total energy consumption increases and less waste is avoided. This is because the decreased recycling rate is associated with decreased ore mining displacement and the savings associated with that.

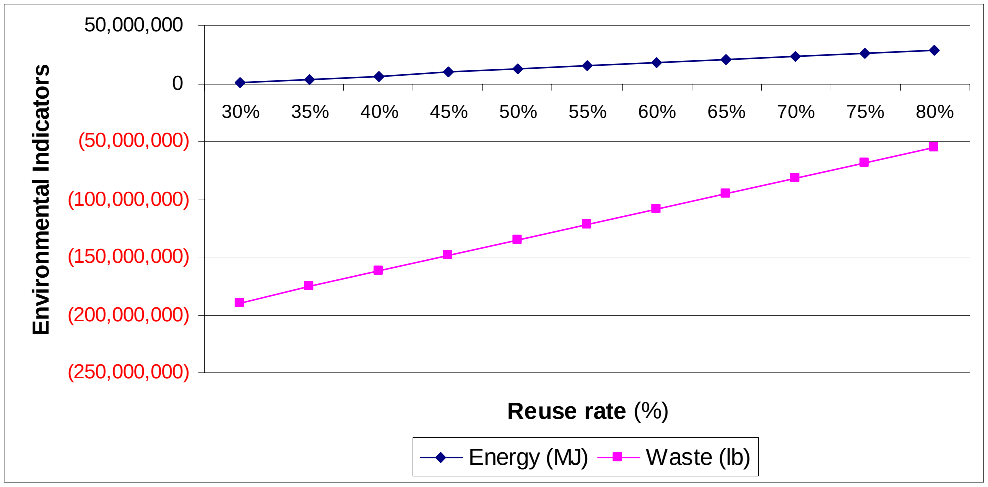


Figure 29: Change in energy consumption and waste saving as function of reuse rare

The same rule applies to material recovery. As recycling rate decreases, total materials recovery decrease accordingly.

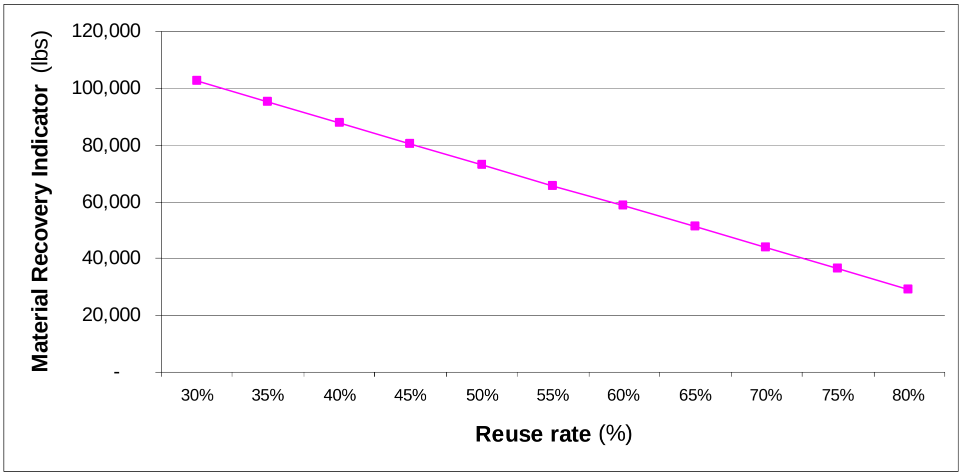


Figure 30: Change in materials recovery as function of reuse rate

Factor: *New production displacement*

As mentioned earlier, unless some new phones production displacement is taken into account, the energy indicator will increase (i.e. higher energy consumption) as the EoL market grows. In order to assess how displacement assumption affects the energy indicator, we have tested for 0-100% displacement (i.e. the % of phones reused that displace new production).

Figure 32 suggests that if only 4% of the reused phones displace new phone production, net energy is being saved; and as the percentage of displacement increases, the total energy saving increases.

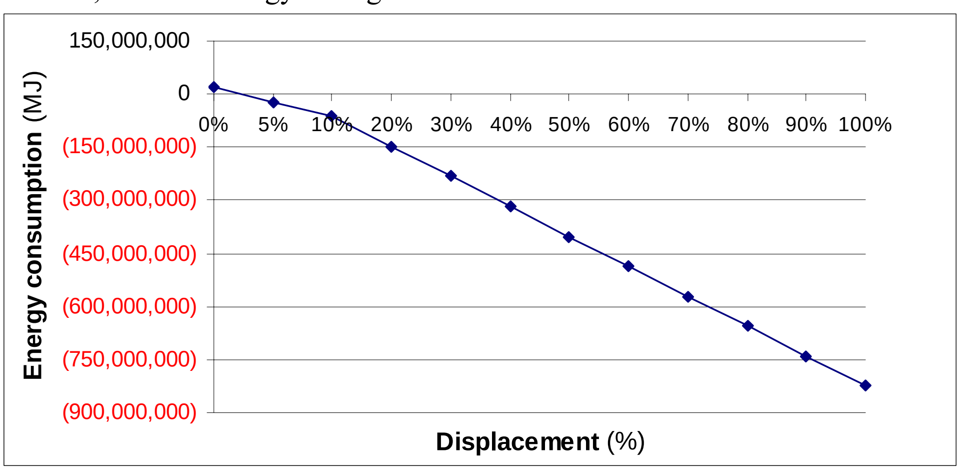


Figure 31: Change in energy consumption as function of displacement

As to waste, the baseline assumes 50% ore mining displacement. Therefore, there is already a net saving. As additional displacement occurs, more waste generated from ore mining and production processes is avoided, which further increases net saving.

8.6.4.3. Conclusions

The sensitivity analysis performed above suggests that the economic and environmental performances of the EoL market are sensitive to different factors and can contradict each other in some cases. As shown in this analysis, there were some factors that significantly change the net outcome:

1. EoL fate

Minimum reuse rate is critical in order to ensure net positive economic outcome. The reuse rate affects the economic and environmental outcome in opposite directions. While higher reuse rate results in better economic outcome, the energy consumption increases and less waste is avoided. Thus, with no displacement of new production accounted for, there is a tension between economic and environmental performance. However, if only 4% of the reused phones under the current conditions is actually displacing new production, it creates the opposite situation where reuse is environmentally preferred, aligning the economic and environmental performance in the same preferred direction.

2. Collection Rate

Collection rate has a significant effect on the economic outcome. Basically the collection rate helps improve the economic performance. It also brings benefit to the environmental outcome: as more phones are collected, more waste is avoided and more materials are recovered. However, it has a downside: energy consumption increases as the entire EoL process consumes energy. Although it is important to increase the collection rate, it has to be accompanied by improved efficiency to minimize energy requirements. Especially efficiency of transportation needs to be considered because EoL phones can travel long distances from the time of collection until they arrive at their final destination.

3. Residual Value

Average sale value of second-hand phones is important to maintain the EoL cell phone market as self-sustainable; the positive economic outcome is mostly brought by the revenue of the sales of second-hand phones. If recycling and components reuse were the only available options, the market may shift toward a negative economic outcome depending on the ratio of those options.

Materials value might have less significant impact than product sale value but still can alter the performance. For example, miniaturization and decreasing in mass is an ongoing trend that has been accelerated after 2000. It will have an impact on the recycling business because it could mean decreasing profit per EoL phone. However, since there are about 6 years of time lag between the production year and the time they end up in the EoL stream, the impact will be more accurately evaluated in coming years.

9. Scenario Analysis

9.1. Scenario Description

Based on the results of the previous chapter, six market scenarios were constructed. In order to demonstrate different market conditions, the values for the factors that affect the outcome the most were changed. Table 31 outlines the value of the factors that were changed in each scenario. The rest of the values were kept the same as in the baseline.

Table 31: Scenarios outline

	Factors				
Scenario number	**Collection rate** (%)	**Reuse rate** (%)	**Second-hand avg. phone value** ($)	**New production displacement** (%)
1	High (30)	35	16	0
2	High (30)	65	16	0
3	Low (5)	35	7	0
4	Low (5)	65	22	0
5	High (30)	65	22	0
6	High (30)	65	22	25

<u>Collection rate: 5% / 30%</u>
The baseline number is 5% and 30% is the possible attainable rate. According to the WEEE directive, the initial targets were based on a collection of 25% of the waste. In addition, according to research done in Japan (Japan Telecommunications Carriers Association, 2004), the service providers were able to collect almost 20%[20] of the phones according to their calculation. If this collection level is applied to the US market, it will be equivalent to an increase of at least 4 times the current collection rate.

<u>Reuse rate: 35% / 65%</u>
The maximum reuse rate (65%) is the baseline number. We consider this rate to be high since the current market is based on a free market mechanism where refurbishers will remarket and reuse the highest possible amount of phones they collect. However, if legislation is put in place with responsibility on OEMs or retailers, the reuse rate might decrease since some of them are not interested in expanding the second-hand market and will opt for recycling.

<u>Second-hand phone value: $7 / $16 / $22</u>
The second-hand phone value is closely tied with the phone quality (model, age and condition); consequently it continuously changes as it reflects the market trend. We have considered possible extreme prices both for high ($22) and low ($7) relative to the baseline ($16). The highest extreme is supposed to reflect the

[20] In 2001, Japanese NSPs collected a total of 13,100,000 phones. The number of subscribers by the end of that year was 67,100,000.

maximum attainable profit capturing more high-end phones and the lowest extreme is supposed to reflect the market where second-hand handsets severely compete with so-called "ultra-low-cost" models. (Appendix 15 shows the possible combinations of high, middle and low-range products for each price assumption) As the cell phone market matured in industrialized countries, OEMs started to look at emerging/developing markets as potential for high growth. Ultra-low-cost models are intended to boost those markets that are the primary destination of exported second-hand handsets. It is likely that the ultra-low-cost models will compete with second-hand models in these markets. In that case, the second-hand handset business might be affected significantly.

<u>Displacement: 0% / 25%</u>

The 6th scenario assumes 25% displacement of new production in order to demonstrate the positive effect of a change in this factor. Through interviews and information collected, we assume that second-hand phones that are exported to emerging or developing countries do not really cannibalize the new phone market share because they are mostly purchased by users that cannot afford the new products. Therefore, second-hand phones are instead developing new market segments that current new products do not capture. However, within the US market it might be possible for high-end second-hand phones to displace new production. This could be enhanced if more high-quality EoL phones are captured and resold in the US market or if legislation mandates a minimum reuse rate.

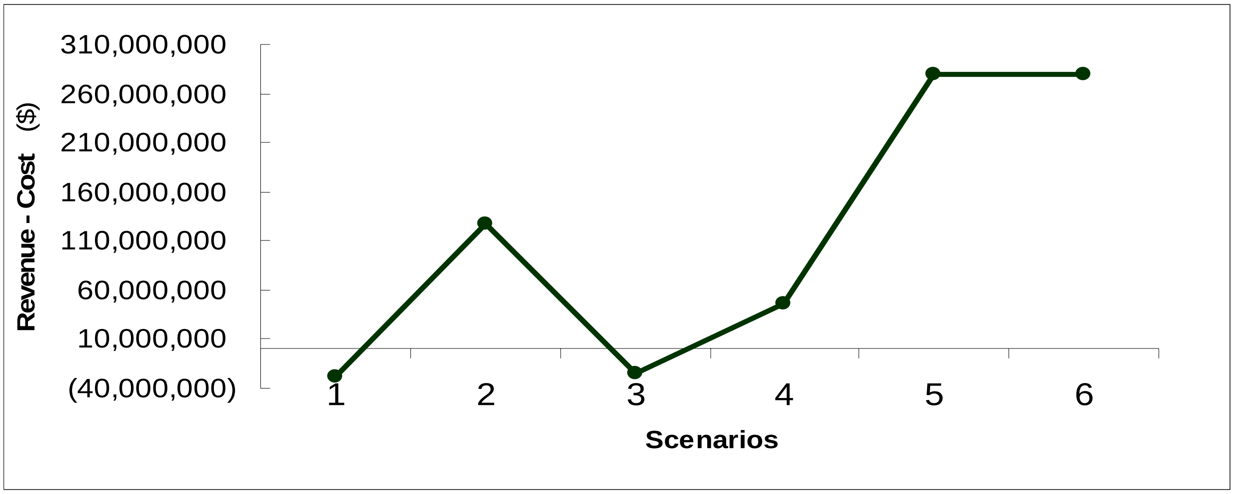
9.2. Results and Discussion

Table 32: Summary of scenario results

Indicator	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Cost to the market ($)						
Collection	(125,201,310)	(125,201,310)	(20,866,885)	(20,866,885)	(125,201,310)	(125,201,310)
Pre-processing	(108,127,500)	(108,127,500)	(18,021,250)	(18,021,250)	(108,127,500)	(108,127,500)
Reuse- phone	(28,437,500)	(52,812,500)	(4,739,583)	(8,802,083)	(52,812,500)	(52,812,500)
Reuse - components	0	0	0	0	0	0
Recycling	(4,563,000)	(2,457,000)	(760,500)	(409,500)	(2,457,000)	(2,457,000)
Total market	(266,329,310)	(125,201,310)	(20,866,885)	(48,099,718)	(288,598,310)	(288,598,310)
Revenue to the market ($)						
Reuse sales- phones	218,400,000	405,600,000	15,925,000	92,950,000	557,700,000	557,700,000
Reuse sales- components	-	-	-	-	-	-
Materials recovery	19,029,588	10,246,701	3,171,598	1,707,784	10,246,701	10,246,701
Total market	235,448,459	414,779,939	18,766,410	92,950,000	557,700,000	557,700,000

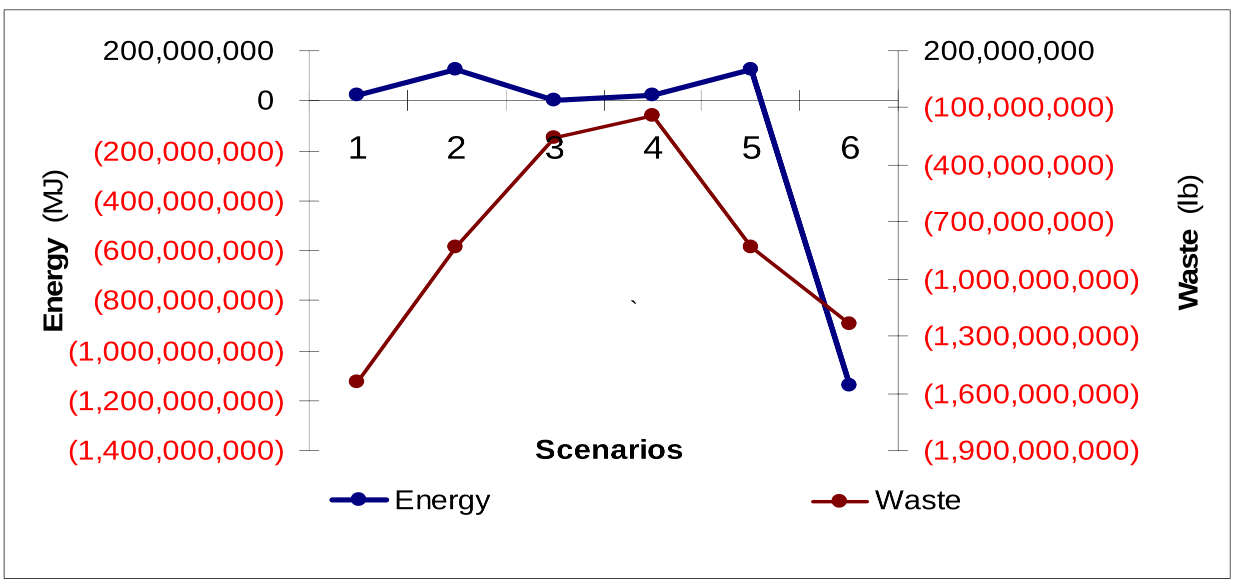
Indicator	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Negative environmental impacts						
Energy consumption (MJ)	250,654,618	247,356,405	41,775,770	41,226,068	247,356,405	247,356,405
Water consumption (gallon)	5,028,075	4,741,425	838,013	790,238	4,741,425	4,741,425
Max waste from slag (lb)	6,490,474	3,494,871	1,081,746	582,478	3,494,871	3,494,871
Positive environmental impacts						
Materials recovery (lb) **- recycling**	570,375	307,125	95,063	51,188	307,125	307,125
Waste avoided by collection	(8,775,000)	(8,775,000)	(1,462,500)	(1,462,500)	(8,775,000)	(8,775,000)
Max waste saving from avoided ore mining	(1,544,983,024)	(835,963,936)	(257,497,171)	(139,327,323)	(835,963,936)	(830,683,807)
Max waste saving from avoided production	0	0	0	0	0	(403,419,624)
Energy saving recycling 50% displacement	(228,150,000)	(122,850,000)	(38,025,000)	(20,475,000)	(122,850,000)	(122,850,000)
Energy saving new production displacement	0	0	0	0	0	(1,267,500,000)
Outcome indicators (Net value)						
Revenue – cost ($)	(30,880,851)	126,181,629	(25,621,809)	46,380,272	278,281,629	278,281,629
Energy consumption/saving (MJ)	22,504,618	124,506,405	3,750,770	20,751,068	124,506,405	(1,142,993,595)
Waste avoided (lbs)	(1,544,983,024)	(835,963,936)	(257,497,171)	(139,327,323)	(835,963,936)	(1,239,383,561)
Water consumption (gallon)	5,028,075	4,741,425	838,013	790,238	4,741,425	4,741,425
Materials recovery (lb)	570,375	307,125	95,063	51,188	307,125	307,125

In this analysis, we only concentrate on the economic outcome (revenue – cost) and environmental indicators (energy and waste). The objective of this analysis is to demonstrate the different market outcomes and based on that, to conclude how the market should evolve to sustain its operation in a balanced manner. Figures 33 and 34 draw a graphic representation of the scenario results.



Reuse %	35	65	35	65	65	65
Collection %	30	30	5	5	30	30
Phone Price	16	16	7	22	22	22

Figure 32: Economic outcome per scenario



Reuse %	35	65	35	65	65	65
Collection %	30	30	5	5	30	30
Displacement %	0	0	0	0	0	25

Figure 33: Environmental outcome per scenario

From the results above, the following observations can be made:

9.2.1. Economic Outcome

The results of scenario 1 and 2 demonstrate that a high collection rate is not enough to achieve a positive economic outcome; it has to be accompanied by a minimum reuse rate. This indicates that the profit from reuse is the largest contributor to a positive economic outcome and recycling cannot achieve that level by itself.

The results of scenario 3 and 4 demonstrate that even with a low collection rate, the market can still retain a positive economic outcome if minimum reuse rate is achieved. A high collection rate helps increase the economic performance — especially with a high second-hand phone sale price. Therefore, profit can be secured at the current collection rate. However, if the second-hand phone price and the reuse rate decrease, the market outcome will become negative.

The results of scenario 5 highlight the potential of EoL cell phone market growth with high collection rate, high reuse rate and high second-hand phone value. Economy of scale in collection will dramatically affect the positive economic outcome.

Scenario 6 does not affect the economic outcome since displacement of new production does not affect the EoL market directly.

9.2.2. Environmental outcome

The results of scenario 1 and 2 demonstrate that as long as no new production displacement is taken into account, a high reuse rate results in higher environmental burden (more energy consumption and less waste avoided). In this case there is a tension between environmental and economic performance.

The results of scenario 3 and 4 demonstrate that there is also a tension between the waste and energy indicators. As the collection rate increases, more energy is consumed, but more waste is avoided at the same time.

Scenario 6 demonstrates the potential environmental benefits when displacement occurs. The shift from net energy consumption to net energy savings is substantial. In addition, compared to scenario 2 and 5, the waste avoided increases as well due to the waste avoided both from ore mining and the production process.

Without product-level displacement, second-hand phones have to be considered as simply expanding the market. Market expansion is associated with incremental environmental burden: there are no savings from expansion. However, a conservative 25% displacement assumption returns significant improvement in environmental performance. It is important to be able to assess how displacement is taking place in the real market.

9.3. Conclusions

The reuse rate factor creates a tension between the economic and environmental outcomes. As long as no new product displacement is accounted for, higher reuse rate draws a better economic outcome while a higher recycling rate creates a better environmental performance with regards to waste and material recovery indicators. In addition, within the environmental performance, there is tension between the energy indicator and waste and material indicators. When energy saving is accounted from recycling only (scenarios 1-5), the net total energy remains positive, meaning there is energy consumption associated with the market operation. However, waste is avoided and materials are recovered regardless of the mix of reuse and recycling. A higher collection rate will increase the tension between the environmental indicators, as energy consumption will increase while waste and materials saving will increase. Looking at scenario 6, accounting for new production displacement is the only way to offset the energy consumption with substantial energy saving. By accounting for 25% displacement, both tensions disappear and the economic and environmental outcomes improve and align with each other.

9.4. Additional Qualitative Discussion

In this section the authors examined factors that can affect the market outcome and should be addressed regardless of the quantified outcome.

9.4.1. Data security issues as a barrier for collection

As consumer awareness toward e-waste increases and consumers become more willing to practice appropriate EoL management of electronic products, the collection rate for EoL cell phones should increase in coming years. However, due to the fact that cell phones are increasingly multi-functional and carry important personal information, people tend to be less willing to give up old handsets.

It is still not apparent in the US where cell phones usage is still limited, but in Japan’s case, where a substantial number of people already use cell phones for making payments, exchanging emails, downloading internet contents, gaming and so forth, the reluctance is much more obvious.

Telecommunications Carriers Association (TCA) conducted a consumer survey in 2004 regarding EoL cell phone management. According to the results, only 24% of the consumers who replaced their handsets at the NSP agreed to give up their old phones. Another 76% chose to bring them back home, and 21.6% of them did so because they were concerned about the data security. Also, as cell phones store emotionally attached information such as photos, emails or downloaded files, people are less willing to give up the handset. Another reason for reluctance stems from people wanting to utilize the many available functions, such as the games, the digital camera, address book and so forth.

At least in Japan, it seems that the more functions a cell phone loads, the more people feel attached to it and become reluctant to give it up. Unfortunately, when it comes to the decision to finally dispose of a phone, 36% of the people surveyed answered that they simply throw it away, despite the fact that the industry already has a take-back campaign to promote proper management.

One of the major NSPs (mentioned as NSP X) in Japan that has an established take-back program tracks the number of collected phones (Table 33).

Table 33: Number of collected phones in Japan

Year	**Member NSPs of TCA**	**Relative to 2001** (%)	**NSP X**	**Relative to 2001** (%)
2001	13,100,000	100.0	10,570,000	100.0
2002	11,370,000	86.8	9,070,000	69.2
2003	11,710,000	89.4	8,884,000	67.8
2004	8,520,000	65.0	5,580,000	42.6

Considering the fact that NSPs have promoted a take-back campaign on a permanent basis, these results show a stark decline. One of the triggers for this decline is the series of information thefts from EoL cell phones reported in 2004. Consumers became concerned about disposing of their handsets, so NSP X began mechanically crashing each handset in front of the consumers who came to the store to replace their old phones because protecting data security and maintaining user privacy is a priority. As a result, the concern toward information security not only decreased the collection rate drastically, but also decreased the opportunity for reuse significantly by mechanically destroying the hardware.

It is important to note that as cell phones advance and start to develop many more functions that involve personal information, it will become an obstacle to promote an efficient collection effort.

However, this could be resolved by changing the information storage system. For 3G handsets, the NSP provides a detachable chip that looks like a SIM card which contains the information related to contract/subscription. When this card is removed, the handset is considered to be “not covered by subscription.” And since other information can be saved and transferred to a mini SD card, the consumers do not have to rely on the handset for data storage. Product design is expected to take into account the issue of information security so the OEMs can offer solutions to make it easier to remove information from an EoL product.

9.4.2. "Second end-of-life" in developing countries

Regardless of displacement of new production, expanding the use stage of cell phones by selling them in the second-hand market increases the utilization of the materials and energy invested in the production phase. However, it is not clear what will happen to second-hand phones once the second life span is over, especially in developing countries. Since it is not likely that there will be an opportunity for a third use phase, the phones will either end up dumped in open landfills or recycled for materials recovery, depending on infrastructure available in each country.

There is almost no recycling infrastructure in the developing world, and the main operation is disassembly of the products and burning them in the open air so metals are melted and can be recovered. This is a very primitive technique that contaminates the air, soil and water resources. In addition, the people that work to smelt those devices put their health at high risk when exposed to such operations due to lack of environmental regulations in their countries or lack of infrastructure and education.

Since some policy specifically promotes re-use practices, policy makers should make sure they provide a broader solution and do not just shift the problem out of the US. Our analysis did not account for the economic and environmental outcomes in those countries once the second-use period of the phone is over. If there is no mechanism to handle adequately the EOL cell phones in developing countries, the landfill problems will shift and expand beyond the under-developed countries to affect the global population. Developing take-back programs in those countries will be a necessary stage in order to really avoid the environmental burden of EoL for those phones that are exported to second-hand markets outside of the US.

9.4.3. Technological advancement

Transmission technology plays a major role in the cell phone market. As technology improves, models are changed and the products are upgraded, which substantially affects the EoL market. New technology can lead not only to a high replacement rate of phones, but it is expected that stakeholders will collaborate to assess the consequences of technological change to the EoL market.

10. Recommendations

The following recommendations are based on the previous quantitative and qualitative analysis. These recommendations hope to guide the EoL market stakeholders and policy makers towards a sustainable market that maximizes the economic outcome while minimizing environmental impacts. The recommendations are divided into five main sections covering the different aspects of the EoL cell phone market.

Each EoL stage has different implications in terms of economic and environmental performance. The recommendations are constructed into the main processes and suggest future actions.

10.1. Collection

The collection stage is one of the most important stages to determine the growth of the EoL cell phone market. We found that increasing the collection rate is important to expand the market and to allow for different opportunities for EoL options. A steadily increasing supply of EoL phones will help market growth with reasonable economic profit. However, from an environmental perspective, increase in collection rate can be associated with an increase in environmental burden because it requires a wider-scale operation.

- Use existing infrastructure of retailers and network service providers to interact with end-users in order to minimize capital investment and shipping transactions.
- Set targets to ensure minimum collection rates. These targets should be monitored and reviewed on a regular basis in order to be both stringent and feasible.
- Share reverse logistics efforts between supply chain agents in order to improve efficiency and streamline the collection methods.
- Explore more efficient methods to capture high value phones with larger collection methods such as drop-off bins.
- Require that all new cell phones sold on the market be labeled for collection.
- Require that all retailers, network service providers and producers take back used cell phones when customers return them.
- Require that OEMs, retailers and network service providers include mail-in envelopes at the time of purchase.
- OEMs, NSPs, and retailers must inform customers of the different options they have in returning their used phones.

10.2. EoL Fate

The reuse rate has a significant impact both on economic and environmental performance. A high reuse rate is essential in keeping the market self-sustainable because it brings a positive economic outcome. It is this revenue from reuse that may help finance other future activities such as recycling or charities.

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- Set a minimum reuse rate for processing facilities.
- Encourage OEMs to participate in reuse through tax credits.
- Introduce federal legislation that bans electronic equipment containing hazardous materials from landfills and incinerators.
- Ban the export to non-OECD countries of non working cell phone waste for dumping.
- Tax credits should be offered to OEMs to promote design for disassembly and recyclability and R&D efforts. Create flexible mechanisms to allow OEMs take-back their own products to incentivize DfE

10.3. Processing

Pre-processing determines the fate of EoL phones and processing involves most of the EoL operations. Since most of the operations are still completed manually, there is not much environmental input throughout these stages. However, they contribute to the large portion of the cost.

- Economy of scale: Once enough of a supply of EoL products is secured, it is important to achieve economy of scale at the processing stages. It will shift from manual to semi-automatic operations, which will bring down costs and improve efficiency. It will also facilitate satisfying the minimum lot required to be sold in the secondary market. A minimum of 1,000 units of the same model could be needed, especially for component reuse. Increased scale will help expand the business opportunities. Recycling is also volume intensive: since material mass decrease is expected, it is critical to ensure that large batches can be collected and processed to maintain efficient and profitable operations.
- Certifiable performance standards need to be set by the appropriate government agency to ensure that materials are managed in an environmentally superior manner.

10.4. Business Strategy

There are several business strategies that can help achieve the recommendations suggested above.

- Marketing:
  Currently, marketing and advertising are not significant portions of the associated cost. However, our analysis shows positive economic performance when collection rate increases and reuse rate is kept high. However, it is worthwhile for collecting agents to look for effective advertising methods to increase customer awareness and capture more phones.
- Incentives:
  Another way to increase the amount of high quality phones in the EoL stream is to create incentives to make OEMs and NSPs become part of the EoL take-back process. Incentives can come in various forms such as tax credits or deposit mechanisms for collected phones.
- Consumer awareness:
  Create incentives for end-users to encourage them to return high-end phones faster, thus eliminating the hibernation period.
- Promote “smart” displacement:
  By focusing on capturing high-end cell phones, re-branding them and reselling them in the second-hand market with quality assurance and a competitive price, OEMs could cannibalize competitors’ ultra low-end cell phone market share.
- Close the loop in the secondary market:
  Promote establishment of recycling infrastructure in emerging/developing markets in order to ensure appropriate recycling operations at the end of the second end-of-life stage.
- Technology phase out:
  OEMs and NSPs should work together to avoid flooding the market with potential obsolete new phones (case of TDMA).

10.5. Additional Actions

Effective end-of-life cell phone management must be a multi-pronged legislative approach in order to achieve positive environmental and economic outcomes. Along with the legislation approaches listed above, the following legislative actions should be considered:

- The legislation should use a broad scope in defining “hand held electronic equipment” in order to include cell phone waste as well as anticipate new hand held electronic devices that will enter the market.
- The legislation should require specific reporting periods in which retailers, network service providers and producers must detail their

take-back programs to the appropriate government agency to ensure compliance and enforcement.

- Cell phone manufacturing should phase out specific hazardous materials, which include but are not limited to lead, mercury, polyvinyl chloride and brominated flame retardants. Adoption should be similar to RoHS legislation that makes it easy to comply since most OEMs already comply in EU.
- Legislation must address the fate of “orphan” and “historic” waste.
- Legislation should keep an eye on every mandatory target and the consequent impact on the market in the short and long term in order to be able to reevaluate their policies.

11. Bibliography

Advanced Packaging "Lead-Free Project Focuses on Electronic Assemblies" http://ap.pennnet.com/Articles/Article_Display.cfm?Section=Archives&Subsection=Display&ARTICLE_ID=75809&KEYWORD=Lead-free

Agency for Toxic Substances and Disease Registry; "Tox. FAQs for Copper"

Alltel; "Phone Interview", December 2005; http://www.alltel.com; Viewed December 2005

American Psychological Association; http://www.apa.org

American Red Cross; http://www.redcross.org/ ; Viewed January 2006

Audiovox; http://www.audiovox.com; Viewed December 2005

Audit My PC; http://www.auditmypc.com/acronym/IMEI.asp

Bhuie, A. K., O.A. Ogunseitan1, J-D. M. Saphores, and A. A. Shapiro. "Environmental and Economic Trade-Offs in Consumer Electronic Products Recycling: A Case Study of Cell Phones and Computers" In *2004 ISEE International Symposium on Electronics and the Environment*. Phoenix, AZ, 2004

Bowman, H.; "The Electronics Recyling Debate: New Consumer Tax Vs. Cost Internalization", 2004

Cadmium Organization; http://www.cadmium.org

California Department of Toxic Substances Control (Hazardous Material Laboratory); *Determination of Regulated Elements in Seven Types Consumer Electronic Products*, 2004

CARE; http://www.careusa.org/ ; Viewed January 2006

Cash my phone; http://www.cashmyphone.com ; Viewed January 2006

Cash old phone; http://www.casholdphone.com; Viewed January 2006

Castelle, A., R. Cliff, and C. France; "Extended Producer Responsibility in the European Union" *Journal of Industrial Ecology* 8, no. 1-2, 2004: 4

Center for Domestic Violence Prevention; http://www.corasupport.org/; Viewed October 2005

Charitable Recycling; http://www.charitablerecycling.com/CR/home.asp;
Viewed January 2006

Cingular Wireless, "Phone Interview", March 2006

CollectiveGood, "Phone Interview", January 2006

Commodity Statistics Information; U.S. Geological Survey 2006
http://minerals.usgs.gov/minerals/pubs/commodity; Viewed February 2006

Congressional Budget Office; "Energy and Emission Calculation"
http://www.cbo.gov/ftpdocs/53xx/doc5330/doc02b-Part2.pdf;
Downloaded February 2006

Consumer Electronics Retailers Coalition Position on a National Electronic Management System; http://www.csgeast.org/pdfs/CERC_Position_on_eWaste.pdf

Country Silver; http://countrysilver.com/JewelryTerms.html

DaniWeb; http://www.daniweb.com/techtalkforums/post176782-1.html

Dantes; http://dantes.info/Projectinformation/Glossary/Glossary.html

Deubzer, O., et al. *Lead-Free Soldering – Toxicity, Energy and Resource Consumption; Proceedings of the 2001 IEEE Symposium on Electronics and the Environment,* . New York: Institute of Electrical and Electronics Engineers, 2001

Don Sheppard; County of Ventura Water & Sanitation Department; Environmental & Energy Resources Division; "E-Mails", January-March 2006

Earth Works; http://www.earthworksaction.org/

eBay Rethink; http://rethink.ebay.com/; Viewed January 2006

Encyclopedia Wikipedia; http://en.wikipedia.org

ePipe; http://www.ml-ip.com/html/support/glossary.html#N

Fishbein, B. K.; "*Waste in the Wireless World: The Challenge of Cell Phones";*
Inform, 2002

Fisher, APC, and D. Kingsbury; "Sustainable Electrical and Electronic Plastics Recycling" *IEEE* , 2004

Franke, C., B. Basdere, M. Ciupek, and S. Seliger; "Remanufacturing of Mobile Phones—Capacity, Program and Facility Adaptation Planning" *Omega*, 2004

Geekzone; http://www.geekzone.co.nz Viewed January 2006

Geiser, T. *Materials Profile of the Computer and Semiconductor Industries; Lowell Center for Sustainable Production*. University of Massachusetts, 2001

Geyer, R., and G. A. Kirkman; "Environmental and Economic Evaluation of Mobile Phone Take-Back and Reprocessing" case study for the *Journal of Industrial Ecology*, version 4.0, 2004

Goodman, J.; *Return to Vendor: How Second-Hand Mobile Phones Improve Access to Telephone Services*, Forum for the Future, 2004

GRC Wireless Recycling; http://www.grcrecycling.com; Viewed March 2006

Ho, V., et al. *Get Ready to Get the Lead out;* Fabless Forum; Semiconductor Insights

Hoovers web site; http://www.hoovers.com, Viewed March, 2006

Hope Line by Verizon Wireless;
http://www.verizonwireless.com/b2c/aboutUs/communityservice/hopeLineRecycling.jsp
Viewed January 2006

Huisman, J. *Qwert; "Eco-Efficiency Analysis on Cellular Phone Treatment in Sweden";* TU Delft OCP-Design for Sustainability Program, 2004

IEEE Virtual Museum;
http://www.ieee-virtual-museum.org/collection/tech.php?id=2345893&lid=1

Ishii, Rose, Masui, and Mizuhara; "*Development of Products Embedded Disassembly Process Based on End-of-Life Strategies"*. MIT; Stanford, 1999

Johnson Matthey "Platinum Today" Website;
http://www.platinum.matthey.com/production/africa.html; Viewed February 2006

Kang, H., and J. M. Schoenung. "Electronic Waste Recycling: A Review of U.S. Infrastructure and Technology Options" *Resources, Conservation and Recycling* 45 368–400, 2005, downloaded fron http://www.sciencedirect.com

Kyocera-Wireless; http://www.kyocera-wireless.com/, Viewed February 2006

Lambert, E. "Use It up, Wear It Out" Forbes, 2005

Legislation & Policy; "Elements of Model E-Waste Legislation" ,2006
http://www.computertakeback.com/legislation_and_policy/essentials.cfm

LG; http://www.lge.com/about/environment/Environment.jsp, Viewed February 2006

Lindhqvist, T. "Extended Producer Responsibility; What's in a Name: Producer or Product Responsibility?" *International Institute for Industrial Environmental Economics* ,1997

Lindhqvist, T. and R. Lifset; "Can We Take the Concept of Individual Producer Responsibility from Theory to Practice?" *Journal of Industrial Ecology*, 7, 2003

Mapquest; http://www.mapquest.com ,Viewed February 2006

Marborg Industries; phone conversation; http://www.marborg.com/, Viewed February 2006

March of Dimes; http://www.marchofdimes.com/howtohelp/646_7983.asp, Viewed January 2006

McCurdy, D. "President and CEO Electronic Industries Alliance before the Subcommittee on Environment and Hazardous Materials; United States House of Representatives", 2005
http://72.14.203.104/search?q=cache:i43L0Gn7TukJ:www.eia.org/resources/dmccurdy_eia_house_testimony.doc

Most, E. *Calling All Cell Phones: Collection, Reuse, and Recycling Programs in the US*, 2003

Motorola, Inc., "Phone Interview and Meeting", http://www.motorola.com; January-February 2006

Murphy, C. F. "Survey of Alternatives to Tin-Lead Solder and Brominated Flame Retardants" *IEEE*, 2001

National Electronics Product Stewardship Initiative, 2004;
http://eerc.ra.utk.edu/clean/nepsi/

National Recycling Coalition; "State Electronics Recycling Programs and Policies", 2005; http://www.nrc-recycle.org/resources/electronics/policy.htm

National Solid Wastes Management Association, 2003

Nokia Inc; "E-Mails, Interviews, and Meetings", April 2005- March 2006

NRC Calls for Increase in Electronics Recycling, 2005; http://www.recyclingtoday.com/news/news.asp?ID=8574

Occupational Safety & Health Administration; http://www.osha.gov/

PaceButler; "Phone Interview, Website Search, and E-Mails"; http://www.pacebutler.com/home.cfm, February – March 2006

Phone is Cash; "Phone Is Cash, Website" http://www.phoneiscash.com; Viewed January 2006

Phones 4 Charity; "Phones 4 Charity, Website" http://www.phones4charity.org/ Viewed January 2006

Rebitzer, and Muller, Desai, Zollo, and Jolliet. *Environmental Performance of Printed Wiring Board Assemblies- Optimizing Life Cycle Impacts and Recyclability*. Groups for Life Cycle System, 2002

ReCellular; "Interviews and E-Mails", http://www.recellular.com December 2005- April 2006

RMS Communications Inc; "Phone Interview", November 2005

Robinson, L. "E-Mails" January - March 2006; http://www.santabarbaraca.gov/SolidWaste/all_electronics.htm#easy: http://www.electronicsrecycling.com/cdr/Index.aspx

Rose, C. M., and A. Stevels; "Metrics for End-of-Life Strategies (Elseim)" *IEEE*, 100-105, *2001*

Santa Barbara County; "Waste Reduction Program, Website" http://www.lessismore.org/Programs/electronics.html, Viewed January 2006

Seligerl, G., B. Başdere, M. Ciupek, and C. Franke; "Contribution to Efficient Cellular Phone Remanufacturing" In *CIRP Seminar on Life Cycle Engineering*. Copenhagen, Denmark, 2003

Seligerl, G., S. J. Skerlos, B. Basdere, and M. Zettl; "Design of a Modular Housing Platform to Accommodate the Remanufacturing of Multiple Cellular Telephone Models" In *EcoDesign 2003*. Tokyo, Japan, 2003

Sell old cell phone; http://selloldcellphone.com; Viewed January 2006

Sell your old cell phone; http://selloldcellphone.com; Viewed January 2006

Shuey, S. A., P. Taylor (Colorado School of Mines); "A Review of Pyrometallurgical Treatment of Electronic Scrap" In *SMEnnual Meeting*. Denver, Colorado: SME, 2004

Simply sellular; http://www.simplysellular.com;Viewed January 2006

Skerlos, S. J., G. Seligerl, B. Basdere, A. Prasitnarit, W. R. Morrow, K. Chan, F. Zhao, and A. Hula; "Economic and Environmental Characteristics of Global Cellular Telephone Remanufacturing" In *IEEE 2003*, 99-103, 2003

Smith, S.; "Analytical Framework for Evaluation the Costs and Benefits of Extended Producer Responsibility Programs", 2005

SonyEriccson; http://www.sonyericcson.com; Viewed January 2006

Special Olympics; http://www.onlinedonationcenter.com/specialolympics/

Stobbe, I., et al "Quality Assured Automated Disassembly of Electronic Components for Reuse" In *IEEE 2002*, 299-305.

T-Mobile; "Website". http://www.t-mobile.com; Viewed January 2006

Takahashi, K. (Yokohama Metal Co., Ltd); "Precious Metal Recycling from the Most Advanced Electronic Devices (E.G. Cellular Phones) and Its Ecological Aspects" 2004

The Environmental Protection Agency; http://www.epa.gov/epaoswer/hazwaste/recycle/ecycling/faq.htm

The e11th Hour; http://www.e11th-hour.org/resources/backgrounders/environmental.glossary.c.html

The European Commission; "Waste Electrical and Electronic Equipment Directive”, 2003

The National Energy Foundation; "Energy Calculator, Website" http://www.nef.org.uk/energyadvice/co2calculator.htm; Viewed February 2006

The Nunavut Wildlife Health Assessment Project; http://www.trentu.ca/nwhp/glossary.shtml

Townsend, T., et al.; "*RCRA Toxicity Characterization of Computer Cpus and Other Discarded Electronic Devices"*. Department of Environmental Engineering Sciences, University of Florida, 2005

Treanton, K.; "Net Calorific Values"

Trumble, B.; "Lead-Free Electronics Come of Age; Get the Lead Out!" *IEEE,* 1998

UNEP; "The Basel Convention of the Control of Transboundary Movements of Hazardous Wastes and Their Disposal; Mobile Phone Partnership Initiative"

US Department of Energy; http://www.energy.gov/

Utstarcom; http://www.utstarcom.com; Viewed December 2005

Ventura County Recycler; http://www.ew-recycling.com/ ; Viewed February 2006

WBENC; "Women's Business Enterprise National Council, Website" http://www.wbenc.org/certification/standards/standard7.html

Wireless Recycling; http://www.wirelessrecycling.com; Viewed February 2006

Wireless Week; http://www.wirelessweek.com/article/CA236977.html?spacedesc=Special+Section

Wright, L. "Engineering Doctorate: Volume II, Part D, Section B.", 86-151, 1999

12. Appendixes

Appendix 1: Second-hand phone grading system
(Source: ReCellular, Website)

Grade	Condition Description	Warranty	Potential Use/ Buyers
New	Less than 30 minutes activation time. Come with individually box or as bulk with or without accessories	Based on manufacturer's warranty.	Individual customers, carriers,
Refurbished	Cosmetically renewed and functionally capable as new cell phones	Up to 90 days depending on value	Carriers, distributors, retailers
Certified	Call-tested. Charging mechanism, display, keypad and all features must be functioning. No water damage. Handset memory cleared. Cosmetics are not guaranteed	30-day	Carriers, distributors, pre-paid
Call Tested	Power-up, have a good LCD, and make a call no guarantee on cosmetics	15-day exchange	Pre-paid
Pre-Screened	Power up, have clear functioning display, working keypad, and signal strength. All cell phones have antennas, lens, complete housing and keypad	15-day exchange	Refurbishers, repair facilities and companies capable of cosmetically renewing cell phones for activation
Used – As Is	Unprocessed, untested, and may require repair	N/A	Refurbishers, insurance providers, repair facilities and other trading companies
Repair Stock	May have cosmetic and functional defects.	N/A	Repair and OEM parts supply
BER	No guarantee on any functionality, cosmetics or presence of parts	N/A	Repair and refurbish centers

Appendix 2: OEMs and NSPs

Today's cell phone industry mainly comprises of handset providers, also referred to as OEMs and NSPs or carriers.

In general, OEMs and NSPs closely collaborate to develop and evolve cell phone telecommunications. However, the market balance and/or relationship alliance vary temporally as well as spatially. For example, the European market is said be more dominated by OEMs whereas other regions are more saturated and controlled by NSPs.

The cell phone market is fiercely competitive with regard to technology development and service offerings. Despite or perhaps as a result of its rapid growth, the handset market has experienced an in/out-flow of companies while the network carriers have gone through a series of mergers and acquisitions, often on a global level.

Original Equipment Manufacturers (OEMs)

Despite the fierce competition, the OEM industry is controlled by a few limited companies. In the US, there are 5 leading vendors including Motorola, Nokia, LG Electronics, Samsung, and Kyocera. These corporations together held 87% of the total share of market in the 1st quarter of FY 2005. Among them, the only US-based manufacturer is Motorola, while all others are European and Asian-based.

Over the past several years, the industry experienced a number of mergers and acquisitions. Sony and Ericsson formed Sony Ericsson, while Kyocera acquired the consumer handset division of Qualcomm, and UTStarcom acquired the handset division of Audiovox. These activities reinforce the fierce competitive atmosphere in this industry and perhaps shed light on the potentially strong impact of various take-back programs employed by few controlling companies.

Compared to the extensive programs offered by many network carriers, the take-back programs employed by the manufactures are relatively poor. Among the top 5 global vendors, only Motorola and Nokia have explicit policy statements regarding their corporate environmental strategies that include their product EoL management and/or take-back programs. While Motorola and Nokia offer free-of-charge take back programs, Motorola also sponsors school fundraising events in order to collect its electronics. Kyocera Wireless also offers free-of-charge take back, but the company has not employed any type of advertisement to create customer awareness.

Nokia Corporation

Nokia Corporation is the world's #1 maker of cell phones. Ahead of its competitors, Motorola, Siemens, and Samsung, Nokia's revenues exceeded $40.5 billion in

FY2005. The company is headquartered in Finland, Europe, but it employs over 58,000 people worldwide. Nokia's products are divided primarily into four main divisions including mobile phones (all wireless voice and data devices for personal and business use), multimedia (home satellite systems and mobile gaming services), networks (wireless switching and transmission equipment), and enterprise solutions. (wireless systems for businesses) (Hoovers, Website).

Nokia's environmental strategy is to eliminate risks, while strengthen financial performance. Its operations have four key focuses including design for environment, supplier network management, environmental management systems, and end-of-life practices.

With regard to cell phones, Nokia for years has been offering take-back programs to its global consumers. In the U.S. Nokia's customers have the ability to return their EoL phones free of charge. The collected phones are sent to Nokia's approved recyclers for recycling. Currently, Nokia does not retain relationships with refurbishers because it believes there are more sustainable solutions for emerging secondary markets. One solution is to utilize the significant technological progress during the past decade and offer emerging markets more optimized products. The first of these products includes Nokia 2100 which is a cost-optimized phone based on the latest mobile technologies. (Environmental Report of Nokia 2004)

Motorola, Inc.

Headquartered in Schaumburg, Illinois, Motorola, Inc. is the #2 manufacturer of wireless handsets. The company is a leading supplier of wireless infrastructure equipment including cellular transmission base stations, amplifiers, and servers. With 69,000 employees world-wide and approximately $37 billion sales in FY 2005, Motorola is a leading global supplier. The company recently experienced re-organization, as it spun-off its semiconductor units. Its remaining operations have been focused in four main business segments that include consumer broadband service systems, networks and software, government and enterprise, and mobile devices. (Hoovers, Website)

With regard to the environment, Motorola has made an official commitment to conducting business in a manner consistent with its "Corporate Citizenship Business Principles" and "Code of Business Conduct". (Motorola Website) Rated by the Citizen Index as a top 10 corporate citizen for its efforts to improve the environment, Motorola has in place various programs including its Green Energy, Benign Emissions, Zero Waste, and Closed Loop.

Specifically, with regard to cell phones, the Company has developed a program called "Race to Recycle" which is the first plan of its kind that calls for the involvement of children and schools. Through a fund-raising drive, Motorola invites schools to earn extra cash ($3.00 per phone) by collecting old cell phones and returning them to the company. Additionally, Motorola provides printable pre-paid postage shipping labels on its website, which allows anyone to participate in the program. Moreover, the majority of Motorola's new cell phone packages include a pre-paid postage packet which enables customers to drop their old products in the mail for delivery to a recycling center. (Motorola, Website)

Depending on the residual value of the EoL product, each collected phone is then refurbished, reused as-is, or recycled. Currently, there are no programs in place to reuse the small components contained in cell phones.

Kyocera Corporation

Headquartered in Kyota, Japan, Kyocera Corporation manufactures a range of components and fine ceramic products. Its product line includes fiber-optic connectors, semiconductors, and capacitors which are targeted primarily at customers in the electronics industry. Kyocera also manufactures various finished electronic products including cell phones and digital cameras. Kyocera Wireless is the 100% owned subsidy of Kyocera Corporation, and is headquartered in San Diego, CA. With 58,559 employees worldwide, and 2005 sales of $11,034.2 million, Kyocera Corporation is a key competitor of the industry leaders, Nokia and Motorola. (Hoovers, Website)

Environmentally, Kyocera has been involved in developing and implementing programs related to environmental preservation, resource saving, energy saving, and the development of global environment preserving products, as part of its Environmental Charter. These products are based on the corporate motto "Respect the Divine and Love People." Further, the company is ISO 14001 Certified.

With regard to cell phones, Kyocera has a "Consumer Mobile Phone Recycling Program" in which it supplies shipping cost at no charge to the consumer for proper return. However the customer must provide the envelope. This program is outsourced an operated under Metech. Mailing instructions can be found on the company website. (Kyocera-wireless, Website).

LG Electronics

Headquartered in Seoul, Korea, LG Electronics (LG) specializes in manufacturing display and media products, home appliances, and wireless telecommunication devices. Their product range includes TVs, VCRs, microwaves, and cell phones. LG is the fastest growing international cell phone manufacturer. With 66,414 employees worldwide, LG ended FY 2004 with sales of $23,542.3 million.

LG Electronics vows to observe the basic philosophy and principles of environmental management to ensure sustainable development and improve quality of life for its customers. The company strives to develop eco-friendly products, as well as reduce its energy use, waste, and emissions of pollutants. (LGE, Website)

LG has dedicated an environmental section on its website, but no information about their take-back policy is readily available.

Samsung Electronics Corporation

Headquartered in South Korea, Samsung Electronics Corporation (Samsung) manufactures a range of electronics including DVDs, microchips, computers, and digital cameras. Additionally, the company manufactures wireless telecommunication products such as cell phones. With 123,000 employees worldwide, Samsung ended FY 2004 with sales of $78,250.1 million.

Environmentally, Samsung is dedicated to producing and implementing a "Green Management Report." Goals of this report include the greening of management, processes, workplaces, and communities. Samsung also has a program for recycling end-of-life products.

Samsung's recycling program is not cell phone specific, but does include the collection of cell phones. The company has created a nationwide system for collecting its old products at some 1,560 sales outlets and 24 regional logistics centers. It also has global recycling programs in Europe, Japan, and China (Hoovers, Website).

Sony Ericsson

Sony Ericsson Mobile Communications was formed in 2001 by the conglomeration of Swedish telecommunications company Ericsson and Japanese consumer electronics giant Sony Corporation. The company is owned equally by Ericsson and Sony and announced its first joint products in March of 2002.

Sony Ericsson's global management team is located in London, and R&D is performed in Sweden, Japan, China, the United States and United Kingdom. Sony Ericsson Mobile Communications net sales were approximately $8.72 billion in FY2005.

Sony Ericsson employs approximately 5,000 employees worldwide. The company is actively involved in product research, design and development, marketing, sales, distribution and customer services.

Environmental concerns at Sony Ericsson focus on a life cycle approaches concerning design, manufacturing, product use, and EoL treatment. Sony Ericsson's Banned & Restricted Substances Lists assures the company is working with more environmentally compatible materials.

With regard to cell phones, Sony Ericsson was the first manufacturer to phase out nickel cadmium batteries in all its phones. The company is currently working to phase lead, halogenated flame retardants and hexavalent chromium, Cr (VI) (Sony Ericsson, Website)

Audiovox (UTStarcom)
Audiovox Corporation was founded in 1965 in Hauppauge, New York. The company was founded in 1965 in the car radio business and went public in 1987. On November 1, 2004, the Audiovox sold the assets of its cellular subsidiary Audiovox Communications Corp to UTStarcom. The transition period for this sale lasts until October 31, 2005 (Audiovox, Website)

UTStarcom was founded in 1991 and is based in Alameda, California. The company's net sales for 2005 were 2.7 billion dollars. The company has research and design operations in the United States, China, Korea and India (UTStar, Website)

Network Service Providers/ Carriers

While handset providers manufacture cell phones, network service providers offer communication services to end-users. They also maintain solid contact points with them. In the U.S., the leading NSPs are currently Verizon Wireless, Cingular, Sprint, T-Mobile, and Alltel. Together, they capture over 60% of total market share and are poised to continue growth as demand continues to increase.

Table 34: Carrier Market-share

Carrier	# of Customers	Market Share (%)
1. Verizon Wireless Inc. (Verizon Communications Inc.)	37,522,000	23.30
2. Cingular Wireless LLC / AT&T	24,027,000 +21,98,000	14.90 + 13.6
3. Sprint PCS (Sprint Corp.) / NEXTEL	15,900,000 + 12,882,000	9.90 + 8
4. T-Mobile USA (Deutsche Telekom AG)	13,128,000	8.10
5. Alltel Corp.	8,023,000	4.90

Source: 2004 FCC Annual Report and Analysis of Competitive Market Conditions With Respect to Commercial Mobile Services (http://www.publicintegrity.org/telecom/industry.aspx?act=phones)

Verizon Communications, Inc.
Formed as a result of the merger between GTE and Bell Altantic, Verizon Communications, Inc. is one of today's leading providers of wireline and wireless communications services. The company is headquartered in New York, NY and has over 145 million access lines in 29 U.S. states and Washington D.C. Verizon employs 210,000 people worldwide and has revenues of over $75billion. Its subsidiary, Cellco Partnerships which operates as Verizon Wireless, Inc. began its operations in 2000

when Bell Atlantic and Vodafone combined their U.S. wireless assets. It is currently the #2 U.S. cell phone operator and serves over 51 million customers.

Parent Company, Verizon Communications, serves over 45 million customers in the U.S. and 33 million customers outside of the U.S. The company also has nearly 18 million U.S. long-distance lines and has expanded its enterprise services with the recent acquisition of MCI (Hoovers, Website).

With regard to the environment, Verizon's protection objectives are to reduce carbon dioxide emissions and increase recycling rates. The company is working toward the realization of its objectives by implementing various programs including the creation of its Team Energy which continually seeks to improve energy efficiency of its buildings and investigating alternative source of commercial power. Additionally, Verizon has developed a recycling and waste reduction program which focuses on recycling marketable materials, minimizing waste, and using quality products made from recycled material. The company's efforts have earned Verizon the Energy Star certifications from the EPA and the Dept of Energy (DOE) for eight of its office buildings. Verizon is the first company in the telecommunications industry to earn so many Energy Star certifications.

Specifically regarding cell phones, Verizon has an exclusive HopeLine program which works to assist victims of domestic violence. The long-running HopeLine program collects EoL wireless equipment from any service provider and after refurbishment or recycling of the products, Verizon sells the used products and donates wireless phones and airtime to victims. Additionally, Verizon provides funding and other contributions to non-profit domestic violence shelters and prevention programs across the nation.

Verizon also collects for recycling all spent rechargeable batteries. Through its recycling efforts, Verizon has been able to keep over 200 tons of electronic waste and batteries from landfills. Specifically, the company reported that 275,000 phones were recycled in an environmentally safe way through its HopeLine program, and nearly 150,000 pounds of batteries were recycled in 2005.

Cingular Wireless
Cingular Wireless, based in Atlanta, Georgia is the largest wireless company in the United States, with more than 54 million subscribers and 19 billion dollars in sales in 2005.

Cingular is a joint venture between the US wireless divisions of AT&T and BellSouth. AT&T owns 60 percent of the company and BellSouth owns 40 percent, based on the value of the assets both contributed to the venture.

Concerning the environment, Cingular has policies in place to handle returned phones. Returned phones are sent to a facility where they are tested and evaluated. Phones considered repairable are restored and placed into service in secondary markets, or used for warranty exchanges. Phones that cannot be repaired are sent for the recycling of plastics and precious metals.

Sprint PCS

Headquartered in the United States, Sprint PCS provides personal and business voice and data services, including networking, internet and IP, conferencing, and wireless cell phones. With regard to cell phones, Sprint offers calling plans, as well as phones and accessories. Sprint is one of the nation's leading long-distance providers with FY 2005 net revenues approximately $34.7 million.

Sprint PCS does not currently provide website information related to its stance on the environment or environmental programs. However, the company has its own program with the Wireless Foundation called "Project Connect". This program collects donated phones and then resells them with all proceeds going to Easter Seals and the National Organization on Disability (Wireless Week Network).

T-Mobile USA

Headquartered in the United States, T-Mobile is a national provider of wireless voice, messaging, and data services. T-Mobile USA is a subsidiary of T-Mobile International AG & Co., which is one of the largest telecommunications carriers around the world. With more than 29,000 employees across the country, the Company ended FY 2005 with revenues of approximately $14.8 million.

Environmentally, with regard to cell phones, T-Mobile has a recycling program called "Get More, Give More". This program promotes the recycling and reuse of old cell phones. Phones will be repaired, refurbished, or recycled depending on the highest value which can be yielded from the phones. Phones can be dropped off at any T-Mobile retailer store, and all proceeds go to charity. Since beginning the program, T-Mobile has collected 42,000 phones (T-Mobile, Website).

Alltel

Allied Telephone, referred to as Alltel, is a network service provider headquartered in Little Rock, Arkansas and serving primarily the Midwest and Southeast. With over 21,000 employees and sales of approximately $9.8 billion in FY2005, Alltel is a major net service provider in the United States. It also provides wireless, local telephone, and internet services to over 13 million customers. Alltel is a diversified company which earned revenues of $9.8 billion in FY2005 (Alltel, Website).

The firm provides local wire line services to 3 million to primarily rural customers, in 15 states. It operates as a competitive local-exchange carrier in nine states and offers long-distance services to nearly 2 million customers, as well as Internet access and paging services. Alltel's wireless operations serve 10 million customers following expansion through acquisitions (Alltel, Website).

With regard to environmental issues, Alltel Corporation in an agreement with the U.S. EPA in 2003 carried out cross-cutting environmental compliance audits at its facilities nationwide. The agreement settled claims that Alltel violated the Clean Air Act, Clean Water Act, and the Community Right-to-Know Act at 205 of its facilities in 18 states.

Appendix 3: Collectors

	Web-based	**NGOs and Charities**	**Municipalities**
Description	These companies offer cellular telephone "recycling" services. Most of them are web based. The online collector system has found the competitive advantage of giving some customers the possibility of tracking the residual value of their cell phone models and selling them if they find any residual value according to that collector. This incipient business promises to be economically sound at least for those customers acquainted with the potential salvage value of their cell phones.	NGO and charities have found a unique fundraising opportunity through the recycling of retired cell phones.	As part of the community services many counties have incorporated an electronic recycling program into their recycling programs portfolio.These programs vary depending on the county. However, they all share some characteristics: ▪ One day collection events ▪ Agreement with a private environmental contractor to manage the waste collected ▪ Do not track cell phones collected ▪ Costs positively affected by SB20/50 ($ reimbursement /lb by the recycler) ▪ Collect CRT and non-CRT waste
Main Players	▪ Sell your old cell phone (http://www.sellyouroldcellphone.com) ▪ Cash my phone (http://www.cashmyphone.com) ▪ Simply sellular (http://www.simplysellular.com) ▪ Phone is cash (http://www.phoneiscash.com) ▪ Cash old phone (http://www.casholdphone.com) ▪ Sell old cell phone (http://selloldcellphone.com) ▪ Sell your cell (http://www.sellyourcell.com/) ▪ PaceButler (http://www.pacebutler.com/home.cfm)	▪ American Red Cross (Red Cross web page): Response to Hurricane Katrina ▪ Earth Works (Earth Works web page): Earthworks is dedicated to protecting communities and the environment from the destructive impacts of mineral development, in the U.S. and worldwide. ▪ Center for Domestic Violence Prevention (CORA web page): aka CORA, Community Overcoming Relationship Abuse, is committed to ending the inter-generational cycle of violence for adults and teens. ▪ CARE (CARE web page): CARE provided relief in Asia following deadly tsunamis earlier this year. Their mission is to relieve human suffering and build sustained capacity for self-help in the world's poorest communities. ▪ Shelter Alliance: A program of GRC Wireless Recycling (www.grcrecycling.com), a Miramar, Florida private sector company dedicated exclusively to socially responsible cell phone recycling. With over 2000 active participants in 50 states, Canada, and Puerto Rico, Shelter	We focused on our local area: ▪ Santa Barbara County: The County collects all types of electronic waste at its recycling and transfer stations and at special one-day events. The mentioned events, which are run once a year in each area, have gain popularity in the last years. Thanks to its waste reduction programs Santa Barbara county has achieved a waste diversion rate of 63% (Statewide is 48%). ▪ Ventura County: The County owns a Permanent Household Hazardous Waste Collection Facility (PHHWCF) which is operated by the County's Environmental & Energy Resources Division. The facility is called the Pollution Prevention Center (PPC) and is fully

	Web-based	NGOs and Charities	Municipalities
		Alliance is now the largest cell phone recycling program in the United States. Participants have earned over $3,000,000 since 2001. ▪ March of Dimes (March of the Dimes web page): With the cell phone donation program, you can make the call to help find out why babies are born early and help fight pre-maturity. ▪ Charitable Recycling (Charitable Recycling web page) ▪ Wireless Recycling (Wireless Recycling web page) ▪ Phones 4 Charity (Phones for Charity web page) ▪ Hope Line by Verizon Wireless (Hope Line Verizon wireless web page) ▪ Special Olympics (Special Olympics web page)	permitted to receive most all types of Household Hazardous Wastes and Universal Wastes, which includes electronic waste. Each calendar year there are 9 monthly collection events held at this facility in which all types of Universal Electronic Wastes are collection from residents and qualifying businesses on an appointment basis. Additionally, the County sponsors temporary Community Beautification Events are in targeted, unincorporated area communities in which electronic wastes are collected along with recyclable materials, such as metal, paper, plastic, and yard waste.
Main Role	Collect and sell cell phones to best bidder	They offer community organizations, religious organizations, private and public organizations, shelters, social service providers, schools, and individuals a viable and profit fundraising option.	▪ Waste reduction and diversion from landfills.
Main characteristics	▪ Web based ▪ Free shipping (free return postage); shipping reimbursement with ultimate check. ▪ No cost to participate ▪ Price by manufacturer and model ▪ Nationwide and statewide	▪ They pursue a noble cause ▪ Well known which gives them credibility ▪ Social benefits: o Account for community service hours	Regarding electronic waste: ▪ Permanent electronic collection at transfer stations ▪ Electronics collection and recycling one day event
Programs in place	▪ BBB Reliability Report Schools, churches and other organizations who wish to raise funds by collecting used cell phones	▪ Recyclers ▪ Refurbishers ▪ Resellers	▪ SB: http://www.lessismore.org/ ▪ Ventura: http://www.ew-recycling.com/

Appendix 4: Incentives Description

Program	Incentive	Description
Buy-back	Direct transaction	End-users can get their cell phones quoted on-line based on model and age and working condition. After receiving the unit and checking its conditions a check will be issued to the end-user. The whole process might take around 3 weeks.
	Electronic fund-credit	Interested party offers a web based trade of "old" cell phones per points. After testing and checking the quality of working cell phones, the company will issue points proportional to the cell phone appreciation value based on a previously established rate (i.e., 1 point = $1). Customers (mostly teenagers) can trade these points to upgrade their new cell phones with current entertainment partners. A good example of this system is CollectiveGood with its RIP Mobil program @ http://www.ripmobile.com/
Take-back	Voluntary approach	End-users return their cell phones when they switch to a new plan, damage their phone, disconnect the service, or just offer to give it for donation at the retailer location. No incentive is offered in this case.
	Negligible salvage value	End-users are able to ship for free their cell phones even when it doesn't have a salvage value. Interested parties will take care of it and most likely send it to recyclers. In this case the incentive lies in the willingness to get rid of a non-working or priceless cell phone.
	Local recycling events	This system is based on the incentive that it is free to dispose CRT and non-CRTs at the local transfer station. Otherwise, customers have to pay the current fees to the local transfer station to fix for this type of waste (i.e., Table 1, Appendix). At the local level, this incentive has proved to be enough to raise the local response three times from last year (2005).
Fundraising	School programs	This incentive represents a direct remuneration for K-12 schools with fundraising interest. Registered schools receive boxes and shipping labels to ship phones back. Each school is responsible of collecting, handling and shipping back the boxes using the provided postage. As an example, Motorola has created the program "race to recycle" which can be found at http://www.racetorecycle.com/index.html
	Donation	Several organizations have found cell phone collection to be one more source to collect funds; i.e., ➢ To environmental NGOs: CollectiveGood donates ~ $1, 3 to Sierra Club per cell phone collected via Staples. ➢ To non profit organizations: Best Buy donates ~$1.0 to Boys and Girls of America Clubs of America per cell phone collected. The current target of the retailer store is to reach $500,000/year. ➢ NGOs & Charities play a main role in donation as well

Appendix 5: Collection Channels Description

Collection Channel	Description
Mail-in	Through this channel the interested party provides the end-user with a prepaid[21] label or envelope to dispose its "old" cell phone. This "pre-paid envelope program" has proved to be cost effective and is paid for by itself for 3PSPs companies (mainly refurbishers) and OEMs as well. Some OEMs have already started and others are seriously considering including a prepaid envelope with every new cell phone they put in the market. By implementing this strategy, they expect to recover the "old" cell phone in the same transaction at the retail store and this way maximizing the salvage value of the "old" unit. Another increasing use of this collecting channel comes from web-based collectors who have substantially increased in number in the recent years boosting the use of the "mail in" alternative.
Drop-off at retailer stores	The interested party (i.e., 3PSPs, OEMs, etc) signs a contract with big retailer stores offering to handle EoL cell phones at these specific sites. This program, less expensive[22] than the "mail in" from a capital budgeting perspective offers no economical incentive to customers, and has proved to be less efficient when analyzing collected quantity vs. quality in terms of residual value. However, collection outcome might change depending on the amount of retail stores nationwide the party might reach and the frequency of shipment to and from the retailer store. At the same time, this collection process seems to be one of the most achievable and currently feasible for those interested parties who cannot access customers (like OEMs) via prepaid envelopes at the NSP store. As an example, we can mention ReCellular, one of the biggest refurbisher in the US market. Among its partners, ReCellular has placed between 20,000 and 30,000 collection boxes so far. This effort together with mail-in has yielded around 3,000,000 cell phones in 2005. (Lambert, Emily, and Forbes; 2005). This collecting avenue is also currently explored by other big refurbishers like Collectivegoods (Collectivegood; 1-28-2006) who have placed their bins at big retailers like Staples and FedEx Kinko's.
Drop-off Random locations	Depending on the party's incentives, and business strategy, collection bins can be strategically located in many random Locations like public buildings, universities, shopping malls, libraries, grocery shops, mall kiosks, etc. This channel is commonly used by local communities, advocate groups and academic interested groups at the local level. However, small and medium refurbishing companies have opted for this option as well. (Lambert, Emily, and Forbes; 2005)

21 The term prepaid involves the average cost of an envelope which is between 2 and 5 cents assuming thousands of envelopes purchased; the return postage, which ranges between $1, 4 and $1, 8, considering a flat rate for the US; and distribution process which could be neglected since it is handled together with the new cell phone.

22 Together bin purchasing for shipping purposes, shipping to store, and collection/shipping back to collector accounts approximately $0.37/cell phone. However, the investment in in-store bins may drive the price up depending on bin size. For instance, ~30 cell phones bins cost around $2.67/cell phone while ~1000 cell phones bins cost around $0.06/cell phone. The business strategy lies in the time span each party allocates for marketing the cell phones back to the market vs. the amount they can wait to collect more of them.

Collection Channel	Description
Permanent transfer stations/ "one day event"	Many counties operate permanent hazardous waste transfer stations where they process all types of electronic waste they collect on a regular or semi regular basis. Transfer stations sort materials into CRTs and non-CRTs or "other electronics" categories. Fees may vary among states, counties and even transfer stations. In our experience we found electronic items to vary from $2, 50 to $15, 00 per unit in the order of 0 to 100 pounds. Above 100 pounds fees are assessed per ton. (Appendix 6) (Santa Barbara County, 2006). In our local experience we found many Californian counties that have started to organize one stop free-dispose events once or twice a year where they accept all types of e-waste customers are willing to get rid off. In our area (Santa Barbara) for instance we have seen a three fold increase (from 1000 to 3000) in the amount of participants since last year (2005) (County of Santa Barbara Public Works Department; 2/7/2006). This increased take-back willingness has been empowered after awareness that both CRT and non-CRTs were banned from improper disposal in the state of California. These programs do not keep track of cell phones; however, they estimate the amount of cell phones to be 0.01% of the total non-CRT e-waste amount collected (County of Ventura Water & Sanitation Department; Environmental & Energy Resources Division; 2006). A detailed explanation of how this local electronic collection event works could be found at http://www.lessismore.org/Programs/electronics.html.
Collection lines	Not specifically for cell phones but for e-waste in general most communities have a reference to collection line services already working in the local area (i.e., private or public waste company). However, at these facilities, e-waste should be under the "accepted categories" and then no economic incentive will be given in return. For instance, in our local area (Santa Barbara) MarBorg Industries (MarBorg Industries web page) is a good example of this partnership with the local municipality. These companies work as electronic waste collectors and incur costs that fall between $18 and $20 per ton[23] for transporting this type of waste from collection points to responsible parties (mainly recyclers).

23 Average cost for this process is $80/hour for an estimate of 2.5 hours roundtrip collection trip. Cost per ton of electronic waste may vary significantly depending on truck capacity. For instance, trucks may have around 10 to 12 tons capacity or even 25 tons capacity.

Appendix 6: Fees assessed per electronic waste category and weight at local transfer stations
(Source: http://www.lessismore.org/Programs/electronics.html)

Material	**Weight** (lb/unit)	**Fee**[24] ($)
Cathode Ray Tubes (CRTs) (i.e., computer monitors, televisions, and laptop computers)	No limit	No charge
Other Electronics (non-CRTs) (i.e., printers, fax machines, copy machines, scanners, paper shredders, audio and video cassette recorders, turntables, amplifiers, speakers, compact disc/DVD players, telephones (**including cell phones**), camcorders, cameras, radios, microwave ovens, toasters, hair dryers, vacuums, electric typewriters, and electric shavers.	0 - 10	2.50
	11 - 25	5.00
	26 - 50	10.00
	51 - 100	15.00
	Over 100	640.00

24 Fees effective December 1, 2005 through June 30, 2006

Appendix 7: Santa Barbara County non-CRT collection efficiency at one-day events

County	Population[25]	Year	Program	Recycler	Pounds Collected (non-CRTs)	Collection Cost ($)	Recycling Cost ($)
Santa Barbara	~404,262	2005	One day event (8 hours, two locations)	Electronic Recyclers of America[26]	~85,000	17,000[27]	10,200[28]
	~406,688	2006			~140,000	~22,000[29]	Freight to recycling facility[30]

The County conducts one South Coast collection event per year. In addition, the County collects electronics year-round at three Recycling and Transfer Stations (one in Santa Barbara, one in Santa Ynez, and one in New Cuyama). (Source: County of Santa Barbara Public Works Department Resource Recovery and Waste Management Division; 2006)

25 County statistical estimate based on census as of 2004 (http://quickfacts.census.gov/qfd/states/06/06083.html)

26 http://www.crasd.com/

27 Including labor, equipment, facility expenses, and promotion – $.20/lb (which is NOT reimbursed)

28 Recycling costs were $.12/lb in 2005

29 This figure is an estimate and wasn't been accurately calculated as of this report was delivered. However, it shows an increase in the collection efficiency (lower collection cost/pound collected) in comparison with the previous year. This cost represents labor, advertising, and supplies among other things.

30 The price has decreased to $.05/lb in 2006. However the recycling facility waived all fees for non-CRTs for this one-day special event.

Appendix 8: Summary of collection options and transportation responsibilities
(Source: H.-Y. Kang, J.M. Schoenung; 2005)

Collection Options	Responsible for Transportation		Advantages	Disadvantages
	To collection site	To processing site		
Mail-in envelope	Consumer	USPS	No collection site needed. Economically appealing. Fast take back process.	Shipment cost. Need special packaging. Consumers have to visit shipping location.
Drop-off at retailer store	Consumer	Collector	Low cost. High visibility is promoted by retailer.	Retailer commitment. Need storage space.
Drop-off at random locations	Consumer	Collector	Low cost. High exposure to public many hours a day.	High visibility should be promoted by collector. Host approval. Potential theft. High transportation cost.
Permanent drop-off site (transfer station)	Consumer	Local government or recycler	High sorting rate. Low transportation cost. Most cost-effective	Need regular checking. Not effective for all communities
Special drop-off events	Consumer	Local government or recycler	Increases recycling awareness. Good for rural area	Irregular collection amount. Need storage space.
Collection Lines (Curb side)	-	Local government or recycler (local collector)	Convenient. Resident participation	Potential theft and abandonment. Need extra sorting to separate from electronic waste. High transportation cost.

Appendix 9: Cell phone recycling process

Recycling of cell phones

The project collaborated with ECS Refining (Santa Clara, CA) to shred/smelt the EoL cell phones that we collected through the campaign and donation. ECS Refining is a recycler of a broad spectrum of metal bearing scrap, residues and wastes. It has more than 20 years of experience in handling e-waste and is one of only three recyclers in California that has the capacity for smelting.

Process description – intermediate recycler

Processing took place at ECS Refining facility in Santa Clara, CA on December 22nd, 2005. About 1,000 pounds of cell phones went through the following process. The process is also demonstrated in the figure below.

I. **Initial weighing**

Our sample of 3,959 units of cell phones weighed 910 pounds before starting any process.

II. **Shredding**

After weighing, the sample went through shredding where it was pulverized into particles about 1 inch in size. At this size, the particles do not look homogeneous: they still retain the shape of original parts such as plastic, mounted subcomponents on PWB, Cu-rich board from PWB, antenna, rubber, iron sheet, button battery and so forth. The shredded sample was sent through the climbing conveyer whose last section vibrated to shake the sample to mix it well. Then the sample was dropped into the sacks and bins.

III. **Material separation**

When the concentration of ferrous/non-ferrous metals is high, the operation involves a couple of separation techniques such as magnetic or eddy current separation. Typically iron (Fe) and aluminum (Al) is separated through these processes. For cell phones, the presence of Fe and Al is low (about 3-8% of total mass). Moreover, there is a risk that precious metals are drawn and go out of the process along with Fe and Al. Since Fe and Al are sent to iron/aluminum recyclers that do not have recovery capacity for precious metals, trying to recycle small amount of Fe and Al could lead to potential loss of precious metals which have more value and significance. Hence the trade-off occurs: Fe and Al are forgone to facilitate Cu-precious metals recovery.

IV. **Balance after shredding**

The sample weighed 902 pounds after shredding. 1 pound of dust was produced from the process that was captured through the pipes running throughout the facility. Ultimately the dust is sent to the smelter; therefore the virtual loss is 910-903=7 pounds. Considering the scale tolerance of plus or minus 1 pound, the loss from shredding was 0.7%-0.9%. Actually, two employees were assigned to the shredding process and recovered the remaining particles from the floor and equipment several times. Shredding took 40 minutes requiring two employees.

Then the shredded sample was divided into 87.5% (786 pounds), 6.5% (58 pounds) and another 6.5% (57 pounds). 87.5% is sent straight to the smelter. 6.5% is smelted at ECS Refining to be assayed. Another 6.5% is kept by the customer in case the parties disagree with the results of assaying. Therefore, 93.5% of the total sample is not processed any further at ESC refining; they are directly sent to the smelter as shredded feedstock. Remaining 6.5% is smelted and assayed before sent to the smelter.

V. Tray furnace

6.5% (58 pounds) of the shredded sample is divided into several trays and put into tray furnace where organic compounds, glass etc is incinerated to reduce total weight. Any harmful emission from volatilization through this process is captured by the hood installed on top of the furnace.

Through this process, 10 pounds were lost and the sample output was 48 pounds. Then virgin copper (three times of sample mass = 174 pounds) was added to make the sample homogeneous. Copper functions as a "carrier metal" for other trace elements including precious metals that are recovered at the smelter. Borax (50 pounds) and soda ash (20 pounds) were also added as flux. Total weight before smelting was 292 pounds. The furnace ran at 1900 F degrees for 3.6 hours by one employee.

VI. Smelting for assaying

After the stage at the tray furnace, the sample is smelted in the main furnace. As described above, the intermediate recycler does not recover material from this process whereas the smelter/refinery will do so. The aim of the smelting here is to extract a sample homogeneous enough for assaying. Assaying is an important process because it determines the amount of materials to be recovered materials and their values that will be reconciled among involved parties.

This is an energy intensive process: the furnace runs at 2200 F degrees for 2.2 hours. Due to metals' high melting point, high temperature, and high energy requirement, this smelting is necessary for the metal recovery process. After the smelting process, copper-rich metal chunk sank to the bottom and slag that contain other metals with lower density automatically surfaced on top.

Input to this process was 292 pounds. Output was 186.18 pounds of metal and 66 pounds of slag, totaling 252.18 pounds. The difference of input and output of 39.82 pounds is the loss from the process through emissions and dust.

Once the result from assaying is obtained and the amount/value is agreed upon, the entire sample is sent to copper smelter. In case of ECS Refining, it is sent to Noranda Recycling, RI. Then the sample is processed to recover copper, gold, silver and palladium.

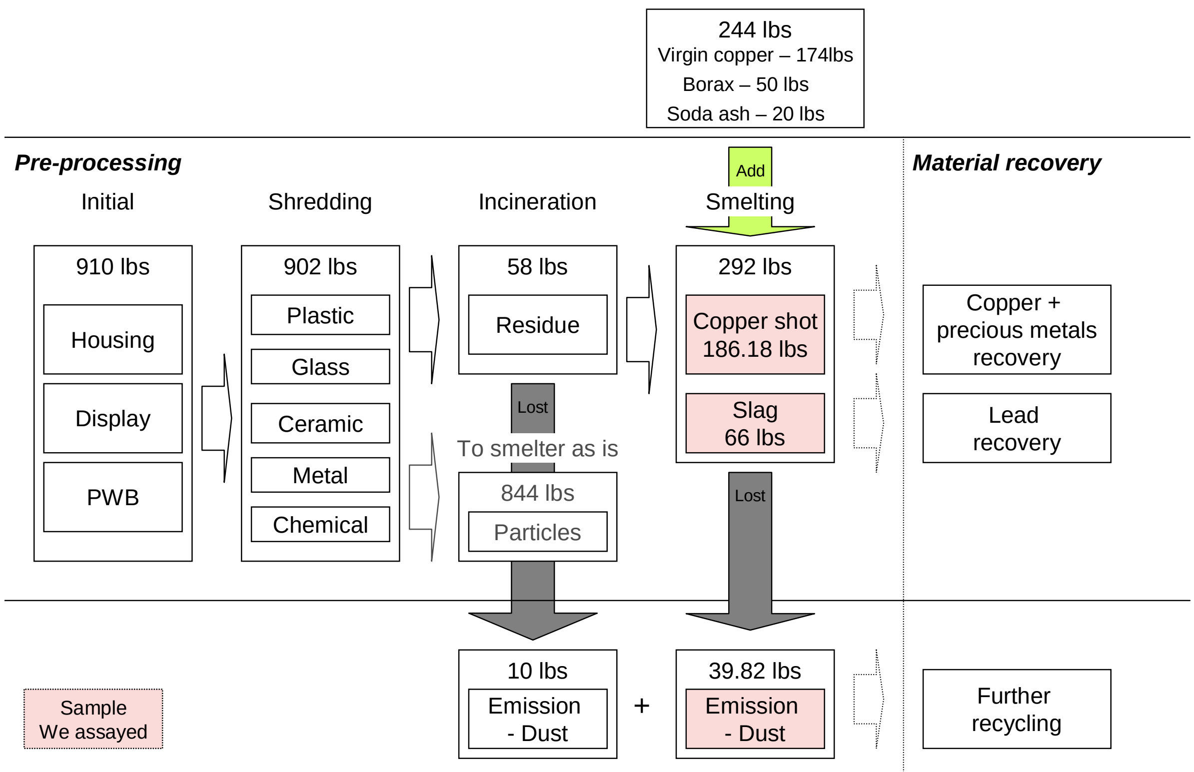

Figure 34: Input – Output chart of recycling prices at ECS Refining

Pictures of the recycling process at ECS Refining:

Shredded Phones

Into the Tray Furnace

Adding Copper, Borax, and Soda Ash

Into the main furnace

Furnace in Action

Pouring

Metals Ready for Separation 	Output from the furnace  

Appendix 10: Economic performance data and calculations

	Data	Sub calculation	Comments/Data source
Table 13: Collection costs	Mail-In (take-back)*	N/A[31]	Data from interviews and literature sources
	Mail-In (buy-back) average*	N/A	Data from interviews and literature sources
	Drop-Off Bins ($/pound)*	Unit cost/weight capacity	Team collection campaign and interview sources
	One Day Event*	Collection: Average of 2005 and 2006 collection events. Transportation: From collection site to treatment facility (assuming $2^{1/2}$ hours round trip and truck size between 10 and 25 tons)	Based on local experience (Santa Barbara County). Transportation data from local collection line company.
	Ground*	FEDEX Web site quote	Weight: 8 lb (25-30 phones) ground shipping from local area (Santa Barbara) to major refurbisher in the northeast (i.e., ReCellular).
Table 14 : Pre-processing costs	Semi-Automated Sorting*	$25 per hour wage; two minutes per phone	Estimated hourly wage (including overhead) in the refurbishing industry
	Manual Sorting*	$25 per hour wage; ten minutes per phone	Estimated hourly wage (including overhead) in the refurbishing industry
	Shipping to processing facility*	Cost to ship one pallet of cell phones/amount of cell phones	Range covers air/ground shipping options from refurbisher to recycler and collector to refurbisher and recycler.
Table 16: Components reuse- cost and revenue per phone	Sale value all components – low end phones*	Based on repair stock average price: LCD, antenna, keypad, case.	Data from interviewed refurbishers
	Sale value all components – high end phones*	LCD, antenna, keypad, case.	Data from interviewed refurbishers
	Disassembly labor cost*	N/A	Data from interviewed refurbishers

[31] N/A: Not Applicable

Appendix 11: Collection campaign

As part of "hands-on" research, the project team decided to collect and process EoL cell phones. The team was able to collect a total of 4,019 phones during less than three months. The purposes of the collection were to:

- Execute the recycling process with a third party smelter and analyze I/O of the process
- Analyze the characteristics of the current EoL phone stream

Collection method

A collection campaign was launched within UCSB. Bins were located in the main residential halls, the University center, main library, and the Bren school. The team participated in a sustainability fair within the campus, aiming to educate students and staff about cell phone recycling and at the same time to advertise the collection effort. The advertisement of the campaign was mainly done via the project web site, e-mail messages, and printed flyers. The team also approached different carrier's stores around Santa Barbara and Goleta in order to receive phone contributions. However, both attempts generated a relative small amount of phones.

After realizing that those efforts would not generate enough phones within the project timeframe, the team decided to take a different approach and contacted major collectors, recyclers, and refurbishers around the US in order to receive a larger amount of phones. As a result of that effort, the team received a contribution of a non-working phone pallet containing over 4,000 phones.

Collection campaign outcome and lessons learned

- Is 18 months really the cell phone life time period? People might upgrade every 18 months but the phones do not reach the EoL stream so quickly
- Very low rate of student participation
- Some stores had programs in place, while some did not– this may be employee education issue
- After the holidays the participation did not increase
- Central places as University Center generated more participation
- People are still not used to recycling cell phones as they would do for batteries, glass, etc.
- Phones collected in UCSB were newer models, most likely because students upgraded phones for fashion purposes

Appendix 12: Sample Analysis

After the collection stage was completed the team documented the phone sample including the details of the manufacturer, model number, shape, and service provider if known. In addition, data as the year released, weight, size, and technology was added through web search and information from the manufacturers. The data was analyzed to determine the profile of the sample and to learn about the age, market share, weight differences, and value of the sample.

From the entire sample, 3,871 phones were received from one of the project partners (RMS) under the definition of non-working phones. This sample (set 1) represents the profile of phones that will end up in the recycling route. The phones were received with no batteries. They were sorted and separated from the working phones that fit the second use market. Those phones represent approximately 35% of the EoL phones market. The rest of the phones that were collected within the campus and surrounding stores (set 2) represent the main stream of the phones. Those phones represent the main stream of phones that usually contain 65% potential phones for a second use market (reference to interviews and literature).

The analysis of the sample profile is divided into two parts. The first part is a general analysis for the entire sample. The second part is a sub analysis for the two different sets of phones, looking for the differences between the two.

Entire Sample

- **Total Quantity by OEM**

Figure 35 represents the distribution of the collected phones, by OEM. The values shown are the number of phones per OEM and the percentage they represent from the entire sample.

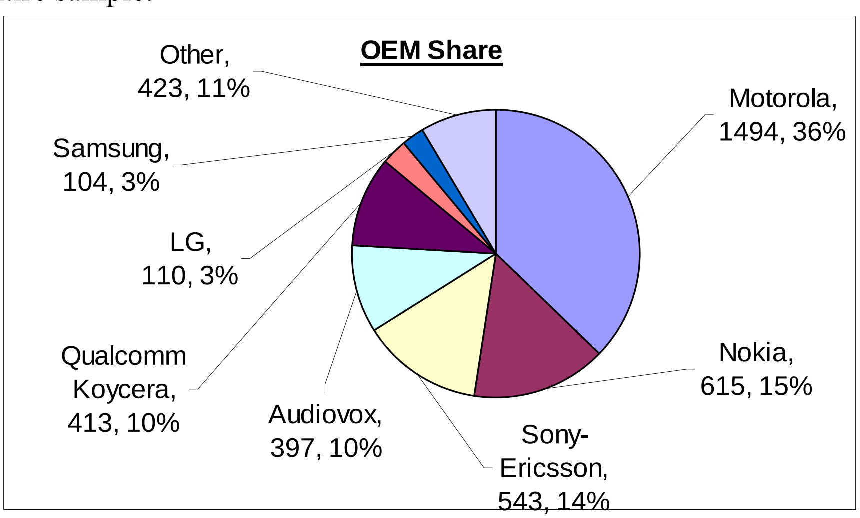

Figure 35: OEM share by quantity and percentage

- **Age and Weight Distribution by OEM**

  Figure 36 shows the distribution of the phone ages and the average weight of the phones in each year. As seen, the weight of the newer phones decreases as age increases.

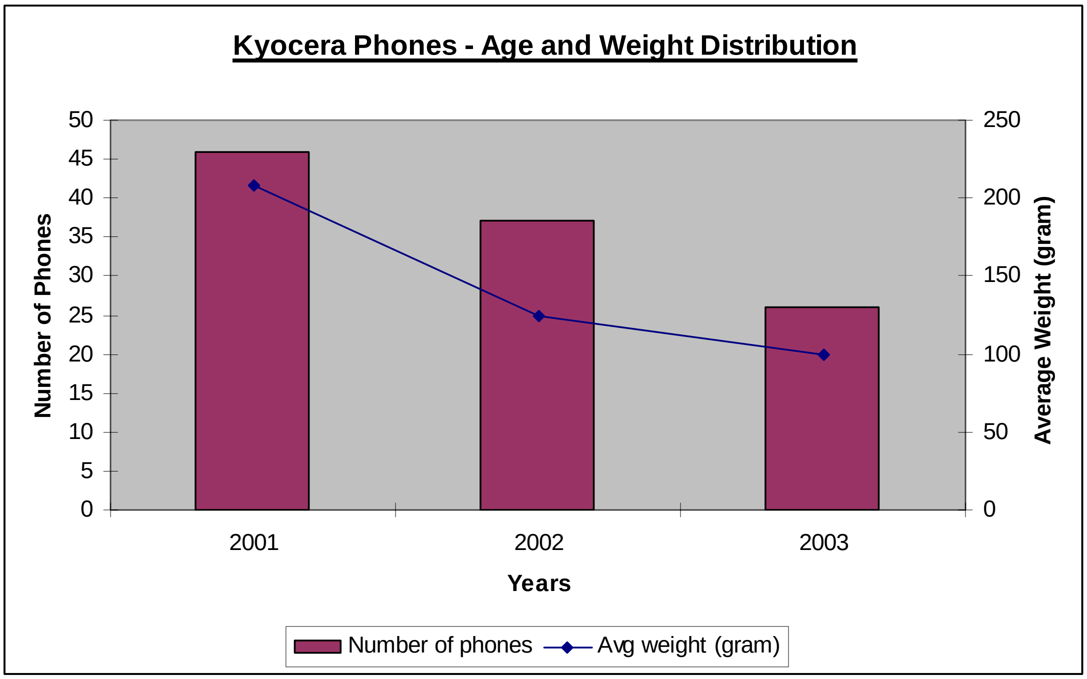

Figure 36: Phones by age and weight

Comparison between the two sets

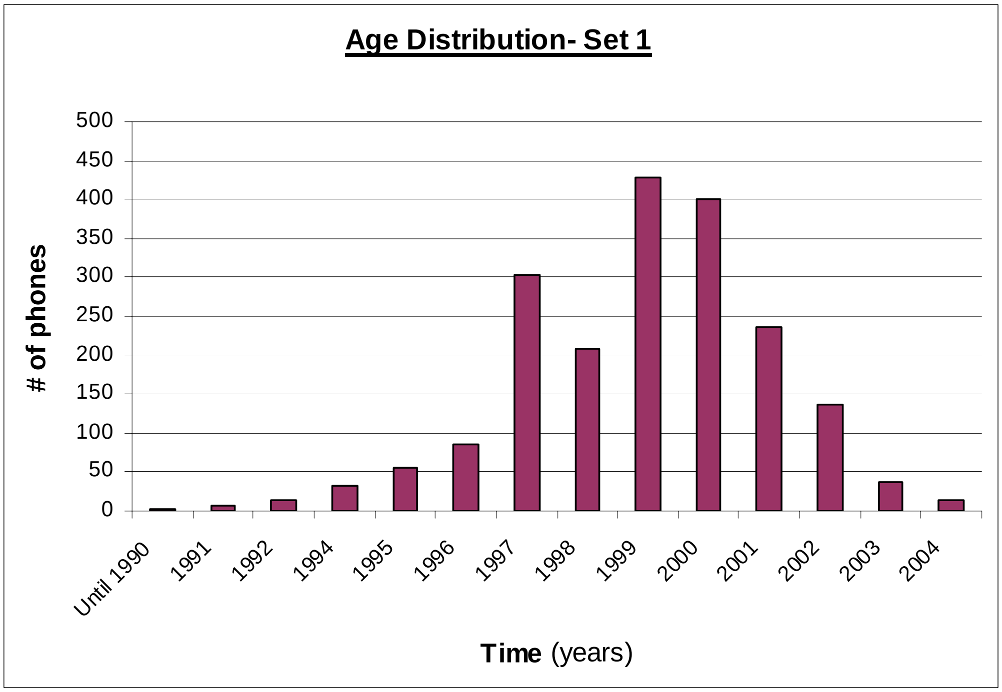

Figure 37: Average age of recycling sample

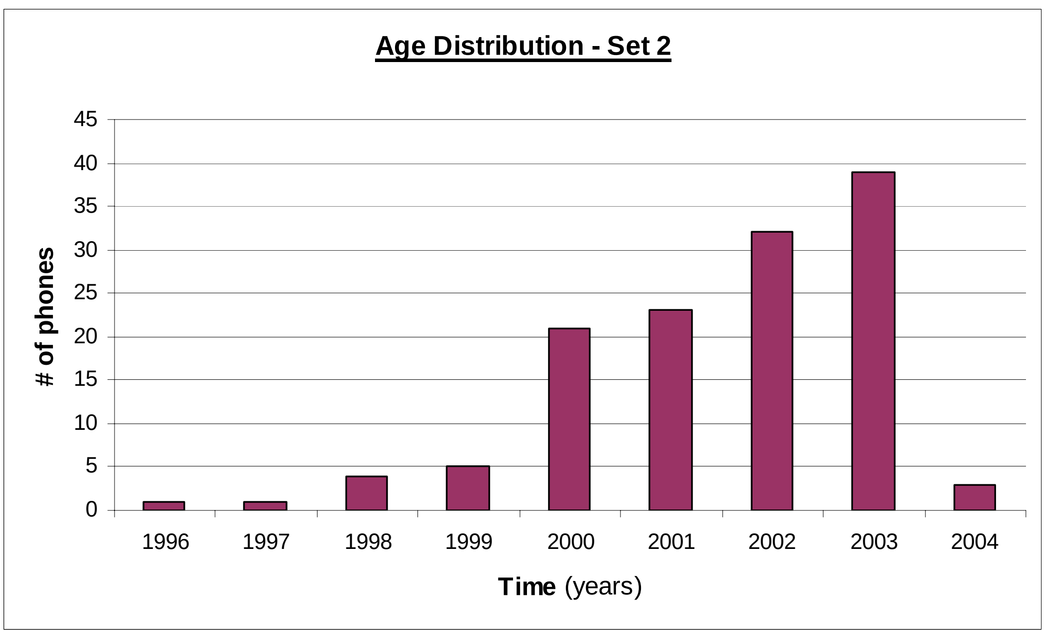

Figure 38: Average age of EoL main stream

As can be seen, phones that end up being recycled have an average age of over 6 years, compared to the main stream that contains newer phones.

Appendix 13: Environmental performance data and calculations

	Data	Sub calculation	Comments/Data source
Table 21: Energy and emission per phone	Ground shipment**	BTU ➔ MJ Net ton ➔ pound ➔ cell phone (0.225 pounds)	➔ 3,420 BTU/net ton*mile (CBO Web Page) ➔ Energy to CO_2 (NEF Web Page)
	Air shipment**	Air freight consumption: 377g/tonne Km (Lucy) Kerosene = 44,590 KJ/Kg (calorific value) Kerosene ρ: 0.81 g/cm3	➔IEA Web Page ➔ Wright, 1999 ➔ Energy to CO_2 (NEF Web Page)
	Sea shipment**	Cell phone (0.225 pounds) Distance: 5728 km	➔Wright, 1999 ➔ Energy to CO_2 (NEF Web Page)
Table 23: Environmental burden of the reuse options	Reuse of phone: Facility Operation**	N/A[32]	Literature + Interview with Refurbishers
	Reuse of phone: Saving new production of phones**	N/A	Average of compatible Literature
	Reuse of component: Facility operation**	N/A	Assumed to be the same as Reuse of Phone: Facility Operation
	Reuse of component: Saving new production of parts**	Literature calculus based on 2 to 3 chips per cell phone.	Based on literature
Table 25: Environmental burden of shredding and assaying process	Shredding* *	Batch size of 910 lb	Direct measurements at ECS facility
	Smelting**	Two furnaces- batch size of 58 lb	Direct measurements at ECS facility
	Shipping to primary copper smelter – rail**	BTU ➔ MJ Net ton ➔ pound ➔ cell phone (0.225 pounds)	➔ 1,720 Energy (BTU)/net ton*mile (CBO Web Page) ➔ Energy to CO_2 (NEF Web Page)

[32] N/A: Not Applicable

Appendix 14: Input/output analysis

As discussed in the materials input / output section, we obtained three samples: dust, slag and copper shot. They were sent to two different laboratories for composition evaluation. Our primary target was to try to quantify as many metal species as possible. However, the effort encountered several issues.

- **Addition of virgin copper**
  Through pre-treatment process, three times as much virgin copper was added to the sample to make it homogeneous. As a result, copper concentration became more than 90% in the copper shot sample. This high concentration of copper required a specifically developed lab testing method in order to avoid the interference. Due to the high concentration, copper was calculated "by difference" (i.e. 100% minus the total concentration of the other metals detected). This probably caused that copper and other elements that are potentially interfered by copper to be inaccurately quantified. Therefore, the only copper concentration used was the one from a third party lab that tested only for copper.

- **Too many metal species**
  Lab test has to be conducted in the appropriate method so that it achieves an accurate result. It requires predicting what kind of species will be in the sample so the best method of analysis can be used. Cell phones include more than 30 different species which made choosing the best method difficult. Since we used standard methods, we only tested what the instruments available were capable of testing.

- **Unknown metals**
  Besides the number of species, electronic products could include some trace/rare metals with very small concentration. However, the material composition changes over time and it is hard to track every metal present at the sub-component level even for OEMs. It will require large budget to identify all the species present in a given product/sample.

Currently, only the metals that are of economic interest (precious metals, copper) or of environmental interest (toxic/hazardous substances) are looked into. Other metals are not analyzed thoroughly because it requires time and is a cost consuming process with little economic benefit to do so. However, electronic products including cell phones can contain rare metals which are under vulnerable supply/demand balance. It is also possible that other metals will emerge as an environmental concern as the research develops.

Our lab tests demonstrated the difficulty in knowing the exact material composition once it is introduced in a product. Now, with the introduction of the RoHS directive, material declaration is becoming increasingly important through the supply chain. It helps all the agents throughout the chain (metal fabricator, sub-components, components and product manufacturer) understand/share the information about what materials are in the products.

It is argued that the cost of introducing a material declaration system is too high, however the benefit could be high as well especially when the information is shared throughout the product life cycle. It is expected that material declaration will help promote stakeholders' knowledge and awareness towards a better way to efficiently use the materials and close the loop at the end of life.

The lab results were obtained but not used in a quantitative way due to the uncertainties are included below. Original copies of the report are available upon request.

Lab name: ECS Refining, TX
Results: Metals Sample

		%
Sample ID	Sn	**0.000**
I-12790	Pb	**0.086**
	Sb	**0.0000**
Date	Cu	94.0500
12/28/05	Ni	0.1799
Time	Zn	0.4605
17:13	Cd	0.0000
	Bi	0.0000
	As	0.0000
	Al	0.4199
	Fe	1.4644
	Ag	0.1092
	Au	0.0124
	Pd	0.0044
I-12790		
	In	0.0000
	B	2.2690
	S	0.0000
	Si	0.0000
	Ca	0.3254
	Mg	0.5007
	Se	0.0000
	Cr	0.1210
	Sum of metallic Elements	100.00
I-12790		

Results: Furnace Dust

		%
Sample ID	Sn	**0.428**
I-12834	Pb	**0.472**
	Sb	**0.0019**
Date	Cu	0.3493
1/31/06	Ni	0.0028
Time	Zn	0.5876
13:38	Cd	0.0080
	Bi	0.0069
	As	0.0046
	Al	0.2524
	Fe	1.5547
	Ag	4.9701
	Au	0.0062
	Pd	0.0000
I-12834		
	In	0.0000
	B	3.3537
	S	6.3558
	Si	0.9458
	Ca	16.9474
	Mg	0.1921
	Se	0.0004
	Cr	0.0088
	Sum of metallic Elements	36.45
I-12834		

Results: Shredder Dust

		%
Sample ID	Sn	**1.457**
I-12833	Pb	**1.827**
	Sb	**0.1724**
Date	Cu	1.1347
1/31/06	Ni	0.2853
Time	Zn	0.5496
13:34	Cd	0.0212
	Bi	0.0240
	As	0.0000
	Al	2.9958
	Fe	3.9274
	Ag	0.1775
	Au	0.0474
	Pd	0.0073
I-12833		
	In	0.0000
	B	0.4723
	S	0.6318
	Si	3.3221
	Ca	2.8021
	Mg	0.3221
	Se	0.0002
	Cr	0.0846
	Sum of metallic Elements	20.26
I-12833		

Lab name: American Analytics, Inc.

Results: Metals Sample

SAMPLE ID	**METALS**
DATE PREPARED	**3/7/2006**
DATE ANALYZED	**3/7/2006**

TOTAL METALS BY EPA 6010/7000

ANALYTE	**CONC. mg/Kg**	**MRL mg/Kg**
Aluminum (Al)	2300	20
Antimony (Sb)	200	10
Arsenic (As)	7.3	0.5
Barium (Ba)	880	10
Beryllium (Be)	12	1
Cadmium (Cd)	ND	1
Calcium (Ca)	1200	3
Cobalt (Co)	130	3
Copper (Cu)	880000 (1)	3
Iron (Fe)	16000	3
Lead (Pb)	1100	3
Magnesium (Mg)	1400	3
Manganese (Mn)	230	3
Molybdenum(Mo)	37	5
Selenium (Se)	ND	0.5
Silver (Ag)	770	1
Thallium (Tl)	ND	5
Vanadium (V)	ND	10
Zinc (Zn)	1300	3
Potassium (K)	49.9	10
Boron (B)	12000	5
Tin (Sn)	2400	5
Titanium (Ti)	1200	5
Silicon (Si)	78000	5
Mercury (Hg)	0.012	0.02
Nickel (Ni)	2800	3
Chromium (Cr)	570	3

(1) The analytical result for copper (Cu) was calculated by difference. The concentrations of the above indicated metals with the exception of copper were added and the sum was subtracted from 1000000 mg/Kg to obtain the copper concentration. This assumes the sample contains only the above indicated elements.

Results: Furnace Dust

SAMPLE ID	**Furnace Dust**	
DATE PREPARED	**03/07/06**	
DATE ANALYZED	**3/7/2006**	
TOTAL METALS BY EPA 6010/7000		
ANALYTE	**CONC. mg/Kg**	**MRL mg/Kg**
Aluminum (Al)	500	20
Antimony (Sb)	36	10
Arsenic (As)	41	0.5
Barium (Ba)	15	10
Beryllium (Be)	ND	1
Cadmium (Cd)	14	1
Calcium (Ca)	94000	3
Cobalt (Co)	ND	3
Copper (Cu)	850	3
Iron (Fe)	1300	3
Lead (Pb)	2300	3
Magnesium (Mg)	1100	3
Manganese (Mn)	20	3
Molybdenum(Mo)	38	5
Selenium (Se)	ND	0.5
Silver (Ag)	170	1
Thallium (Tl)	ND	5
Vanadium (V)	2.2	10
Zinc (Zn)	2300	3
Potassium (K)	7400	10
Boron (B)	13000	5
Tin (Sn)	1100	5
Titanium (Ti)	37	5
Silicon (Si)	21000	5
Mercury (Hg)	18	0.02
Nickel (Ni)	12	3
Chromium (Cr)	7.6	3

Results: Shredder Dust

SAMPLE ID	**SHREDDER DUST**	
DATE PREPARED	**3/7/2006**	
DATE ANALYZED	**3/7/2006**	
TOTAL METALS BY EPA 6010/7000		
ANALYTE	**CONC. mg/Kg**	**MRL mg/Kg**
Aluminum (Al)	2700	20
Antimony (Sb)	990	10
Arsenic (As)	3.6	0.5
Barium (Ba)	220	10
Beryllium (Be)	ND	1
Cadmium (Cd)	250	1
Calcium (Ca)	25000	3
Cobalt (Co)	360	3
Copper (Cu)	12000	3
Iron (Fe)	51000	3
Lead (Pb)	9500	3
Magnesium (Mg)	1400	3
Manganese (Mn)	2100	3
Molybdenum(Mo)	21	5
Selenium (Se)	ND	0.5
Silver (Ag)	320	1
Thallium (Tl)	ND	5
Vanadium (V)	ND	10
Zinc (Zn)	4600	3
Potassium (K)	1300	10
Boron (B)	5100	5
Tin (Sn)	9500	5
Titanium (Ti)	1300	5
Silicon (Si)	22000	5
Mercury (Hg)	0.05	0.02
Nickel (Ni)	2800	3
Chromium (Cr)	330	3

Results: Slag

SAMPLE ID	**Slag**	
DATE PREPARED	**3/7/2006**	
DATE ANALYZED	**3/7/2006**	
TOTAL METALS BY EPA 6010/7000		
ANALYTE	**CONC. mg/Kg**	**MRL mg/Kg**
Aluminum (Al)	11000	20
Antimony (Sb)	35	10
Arsenic (As)	6.6	0.5
Barium (Ba)	4100	10
Beryllium (Be)	58	1
Cadmium (Cd)	ND	1
Calcium (Ca)	6200	3
Cobalt (Co)	13	3
Copper (Cu)	15000	3
Iron (Fe)	2600	3
Lead (Pb)	93	3
Magnesium (Mg)	8400	3
Manganese (Mn)	260	3
Molybdenum(Mo)	8.4	5
Selenium (Se)	ND	0.5
Silver (Ag)	140	1
Thallium (Tl)	6	5
Vanadium (V)	17	10
Zinc (Zn)	17	3
Potassium (K)	350	10
Boron (B)	12000	5
Tin (Sn)	880	5
Titanium (Ti)	730	5
Silicon (Si)	61000	5
Mercury (Hg)	ND	0.02
Nickel (Ni)	180	3
Chromium (Cr)	620	3

From the above results, the concentration per phone was calculated and compared but results were too contradicting. Further analysis should be performed in this area.

Appendix 15: Sale price assumptions

To give a clearer idea about how second-hand phone value can be determined, the authors conducted several simulations by combining prices and shares of each product category. The highest price ($22) comprises with a higher share of High-end phones with high price, and the lowest price ($7) comprise with higher share of Low-end phones with low price.

Table 35: Sales Price Assumptions

Assumption	Category	Average Price	Share
$22	High-end	35	25%
	Middle range	22	50%
	Low-end	10	25%
$16	High-end	30	10%
	Middle range	20	37%
	Low-end	10	53%
$7	High-end	15	5%
	Middle range	10	35%
	Low-end	5	60%