ELECTRONIC WASTE TREATMENT IN MEXICO
Viability and Obstacles

By

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Submitted in partial fulfillment of the requirements for

M.S. degree in Earth Resources Engineering

Department of Earth and Environmental Engineering

Columbia University

August 2016

Research sponsored by:

COLUMBIA UNIVERSITY

EARTH ENGINEERING CENTER

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EXECUTIVE SUMMARY

Mexico is at the beginning of the clean and renewable energy race. The Energy Reforms were instituted only in 2014 when the new regulatory governmental entities began their work. Nonetheless, they are already working in benefit of new energy companies. There is indeed a very strong basis for a new order and reform, but there are still some areas that have only just begun to get attention.

Current waste management practices are a clear example. There are very few places in Mexico where waste is separated correctly; most places barely reach an Organic/Inorganic distinction of waste. This happens mainly because there has not been a national effort to provide the infrastructure and logistics for proper waste separation. Also, bureaucracy and corruption from waste pickers' and informal recyclers' syndicates make any effort become stagnant. In recent years, the problem has aggravated because of the constant increase in population; particularly in the case of Electronic Waste (E – Waste). Its amounts have increased faster than other wastes' because of advancements in technology, mass production and consumerism (Only last year, more than one million tons of E – Waste were generated). Because of this, it can pose an even bigger threat than hazardous wastes do.

This study found that there are no national regulations for E – Waste treatment; only two general environment and waste laws mention it in some form. Additionally, it was found that the middle/upper class is aware of the situation and has started some private initiatives. However, their progress has been little and E – Waste is not yet seen as a commodity in other industrial sectors.

It was discovered that Mexico's copper smelting capacity is higher than 500,000 tons/yr, focused mainly on a few companies. Also, it was estimated that around 70,000 tons/yr of copper could be recovered if E – Waste was sent to these smelters; their capacity is enough to incorporate them as part of their feedstock. This in fact would make a positive impact on the Mexican copper market since the potential amount of recovered copper constitutes almost 14% of Mexico's smelting capacity.

This study examined the feasibility of creating the basic first steps for the sustainable management of E – Waste. This is a problem that, although not directly related to the renewable energy efforts in Mexico, needs to be addressed in parallel to these efforts. This study summarizes the actual status of Mexican regulation and public perception regarding E-Waste, compares Mexican development with other countries (e.g. Japan has electronic device specific legislations), and suggests the creation of links between the copper smelting industry of Mexico and electronic recyclers, for the recovery of copper, precious and other metals that are present in E-Waste and are soluble in molten copper.

ACKNOWLEDGMENTS

I would like to start by thanking my advisors: Dr. Nickolas J. Themelis and Dr. Athanasios Bourtsalas for all their continuous support and guidance through all my M.S. studies. Their knowledge and expertise form the structure for this project. Thanks also to Liliana Themelis for her warmth and helping hand.

I would like to thank all the companies and people that were kind enough to provide me with the necessary information for this research; more than the facts given, it's their enthusiasm for a better Mexico that is best appreciated. Thank you to my sponsors CONACYT, FUNED and FIDERH for helping me with the funds for my studies.

Finally, I would like to thank God, with whom everything is possible; my family and friends for their unwavering encouragement.

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1. Introduction

Man’s quest for knowledge has led him to discover an innumerable amount of materials and processes that have helped shape today’s world. Sadly, with the ever growing human population and the uncontrolled use of the planet’s resources, creations that echo man’s amassed intellect now strike back with toxic and hazardous implications. This is why there is a concept that aims to reduce these detrimental consequences and even take advantage of them to continue the path of progress. This concept is called Sustainability, and it encompasses the ability of a generation to sustain itself, without implications that would not allow following generations to do the same. Within Sustainability there is an idea called Circular Economy (MacArthur, 2015); one of its goals establishes that there should be no more waste left by advancement. Every artifact that reaches the end of its main purpose has another one still; to provide the raw materials for new products and services.

This goal is particularly essential in the case of Electronic Waste. E – Waste presents the biggest challenges for proper treatment and disposal among non-hazardous wastes (technology for treatment has to keep up with technology for development). Its amounts increase faster than other wastes’ because of advancements in technology, mass production and consumerism. Also by its amounts in some places, it poses a bigger threat than hazardous wastes. E – Waste is a problem that needs to be addressed now and continuously all around the world; based on the principles of true Sustainability and aiming to reach the goals of Circular Economy (For example; reutilizing all metal residues from the once valuable, but now menacing electronic equipment).

1.1. Aim and Objectives

This thesis aims to identify solutions for the “electronic menace” in Mexico through the analysis of methods used by different countries and its comparison with the situation that Mexico faces. Also, through suggestions to areas of opportunity that may bring the Mexican Republic a step closer to achieving Circular Economy.

In order to pinpoint these solutions, the objectives of this investigation are:

- Provide insight into Mexico´s rapidly growing Electronic Waste (E – Waste) problem in the last decade.
- Provide an overview of the public perception of the problem and the current practices of E – Waste disposal.
- Provide a relation of the regulations and legislations that concern E – Waste, as well as governmental and private initiatives taking place.
- Analyze the possibility of creating a stronger nexus between recovered materials from E – Waste and other trades like the Mining and Metallurgic industries, and in particular Mexican copper smelters.
- Analyze the environmental repercussions of this increasing dilemma in terms of Greenhouse Gas (GHG) Emissions, pollution and resources/energy depletion.

- Offer possible solutions to direct Mexican practices towards a closed loop in the disposal of E – Waste.

1.2.The Electronic Menace

As a general definition, Electronic Waste is any electronic device that has completed its useful lifespan. The Oxford definition for E – Waste is *"discarded electronic appliances such as mobile phones, computers, and televisions"* (Oxford University, 2015). Because of difference in regulations in different countries, the appliances that receive this name may vary.

In Australia, as well as in the Directive 2012/19/EU of the European Union, E-waste is defined as *"Waste Electrical and Electronic Equipment that is dependent on electric currents or electromagnetic fields in order to function properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1,000 volts for alternating current and 1,500 volts for direct current (including all components, subassemblies and consumables which are part of the original equipment at the time of discarding)"* (Australian Bureau of Statistics, 2013) (European Parliament and Council of the European Union, 2012). This type of discarded materials is classified into (Australian Bureau of Statistics, 2013):

1. Consumer/entertainment electronics
2. Office, information and communications technology
3. Household appliances
4. Lighting devices
5. Power tools except stationary industrial devices.
6. Devices used for sport and leisure including toys

Whereas in Mexico, the Environment and Natural Resources Secretariat (Secretaría de Medio Ambiente y Recursos Naturales, SEMARNAT) and the Ecology and Climate Change National Institute (Instituto Nacional de Ecología y Cambio Climático, INECC) define Electronic Waste as diverse electrical and electronic equipment that has lost its value, and that if not discarded correctly, may pose health and environmental risks (Rojas Bracho, Gavilán García, Alcántara Concepción, & Cano Robles, 2011, pp. 8 - 11). More precisely, the Ley General para la Prevención y Gestión Integral de los Residuos (LGPGIR) Article 9, Section VIII, defines Electronic Residue as *"technological waste from the Informatics Industry, from makers of electronic products and from others that after their life is spent, because of their characteristics, require a specific management"* (SEMARNAT, 2015).

Some other minor classifications from the mentioned agencies include:

- **E – Waste of Small Appliances**: from small electrical and electronic equipment such as razors, mixers, toasters, coffee machines, cell phones and radios.
- **E – Waste from private households:** from commercial, industrial, institutional and other private sources, which by their nature and amount are similar to private households (Rojas Bracho, Gavilán García, Alcántara Concepción, & Cano Robles, 2011, p. 130).

Since these definitions are similar to the Waste Electrical and Electronic Equipment (WEEE) definition, this study considers the European Directive definition as the one applied in Mexico.

1.3. Global generation of E – Waste

Based on information of the 2014 Monitor for E – Waste from the UNU (Baldé, Wang, Kuehr, & Huisman, 2014), a summary of the world E – Waste treatment policies and current actions for E Waste management is given below:

- **Africa**
  - Total E – Waste generation was of 1.9 million tons
  - Highest generation per inhabitant was 10.9kg in Seychelles
  - Cameroon and Nigeria have E – Waste related legislations already being enforced
  - Ghana, Ethiopia and Kenya had regulations pending approval
  - In general, the lack of E – Waste management laws through the whole continent has made it very difficult to equip each nation with the adequate infrastructure
  - Most E – Waste gets handled by informal recyclers, so the residues end up stored or in landfills (not sanitary in most cases)
  - With some contradiction, the main import of illegal E – Waste to Africa comes through Ghana and Nigeria
  - Although there is no proper regulation, governments are involved and promote collection campaigns that prevent the waste from ending up uncontrollably dumped

- **America**
  - Total E – Waste generation was of 11.7 million tons
  - Highest generation per inhabitant was 22.1kg in the U.S.A.
  - Costa Rica, Peru, Bolivia and Ecuador have proper recycling legislation
  - Brazil and Chile had regulations pending approval
  - Neither Canada nor the U.S.A. had nationwide legislation, but state and provinces mandates for E – Waste recycling are enforced in more than half the country
  - There are two third party certification systems in the U.S.A.: R2 and E-Stewards
  - Mexico, Costa Rica, Colombia, Peru, Argentina, and Ecuador also have E – Waste management regulations, but as there is no national control, these are only half enforced regionally
  - Brazil and Mexico count with R2 certified facilities
  - Most of the area of opportunity lies in the creation of legal framework, awareness of waste control and certifications

- **Asia**
  - Total E – Waste generation was of 16 million tons
  - Highest generation per inhabitant was 21.5kg in Hong Kong
  - China, India, Japan, Hong Kong, South Korea, Vietnam, Bhutan, Cyprus and Turkey have national e-waste related laws

    - The Philippines and Jordan had regulation pending approval
    - China has the spotlight since most of the world's exported E – Waste is treated there
    - China has had important growth in waste treatment capacity in the last few years thanks to proper regulation and attentiveness, but the informal sector still plays a fundamental role
    - Japan is one of the global leaders in E – Waste management since it has appropriate device-specific legislations with proposed recycling targets, evolved collection systems and high quality infrastructure

- **Europe**
    - Total E – Waste generation was of 11.6 million tons
    - Highest generation per inhabitant was 28.3kg in Norway
    - The WEEE Directive is in charge of the uniform legislation for collection and treatment throughout the whole European Union (EU)
    - The WEEE Directive has set an 85% collection target for 2019
    - Although recycling and reuse is practiced in the developed world, there is still some fraction that is exported to the Balkans for salvage or disposal
    - Montenegro, Macedonia, Serbia, Bosnia and Herzegovina enforce E – Waste management regulations
    - In general, there is good infrastructure along the EU except in the Balkan Region where there is still work to be done
    - Russia and Belarus, Kazakhstan, Armenia and Kirgizstan had no legislation whatsoever, but governments are already starting to place E – Waste management in their agendas

- **Oceania**
    - Total E – Waste generation was of 0.6 million tons
    - Highest generation per inhabitant was 20.0kg in Australia
    - Only Australia has national regulation and the government is responsible for collection and recycling
    - Through "The Product Stewardship Act 2011", Australia has set a target of 80% of recycling in 2020
    - New Zealand has no E – Waste management legislation for the foreseeable future; most leftovers are deposited in landfills

Last year the world saw a new record for E – Waste; around 41.8 million tons were discarded. Amounting to a 2 million ton difference from the figures of 2013 (39.8 million tons). According to the United Nations University's (UNU) "Solving the E – Waste Problem" (STEP) Initiative report, the amount of waste is equivalent to 1.15 million trucks. If these were formed in a straight line, they would go from New York to Tokyo and back (Solving the E – Waste Problem, 2015).

A more detailed outline of E – Waste generation in several regions of the world (extracted from the STEP E – Waste World Map site) is displayed in **Table 1.1** (Solving the E – Waste Problem, 2015):

Table 1.1: E – Waste Generation per Habitant and Total

Region	(kg per habitant)	(total, million tons)
United States	22.1	7.1
Australia	20.1	0.5
European Union	18.7	9.5
Japan	17.3	2.2
Russia	8.7	1.2
Mexico	8.2	1.9
Brazil	7.0	1.4
South Africa	6.6	0.4
China	4.4	6.0
Indonesia	3.0	0.8
India	1.3	1.6
All other		**9.2**
WORLD	**5.9**	**41.8**

As can be seen in **Table 1.1** (Forbes/Business, 2015), the E.U., U.S., and China generated 54% of the total E-Waste in 2014. It is important to bear in mind that the amount of E – Waste per habitant is directly proportional to the Purchasing Power in each country (Purchasing Power may be considered as the goods and/or services that one unit of money can buy).

Here are some other facts regarding the future of E – Waste (Causes International, 2015):

- *"The United Nations Environment Programme (UNEP) reported in May 2015 that yearly, 90% of all E – Waste is traded unlawfully…*
- *By 2017, the volume of discarded e-products worldwide is expected to be 33 per cent higher than in 2012 and weigh the equivalent of eight of the Great Pyramids of Egypt…*
- *The Environmental Protection Agency estimates that only 15-20% of e-waste is recycled, the rest of these electronics go directly into landfills and incinerators…*
- *Approximately 80% of e-Waste in the U.S. is exported to Asia."*

An ironic fact is that the world's most famous countries for recycling policies and environmental awareness, are also the ones with the most per-capita E – Waste originators. **Figure 1.1** shows some of the countries numbers (Forbes/Business, 2015).

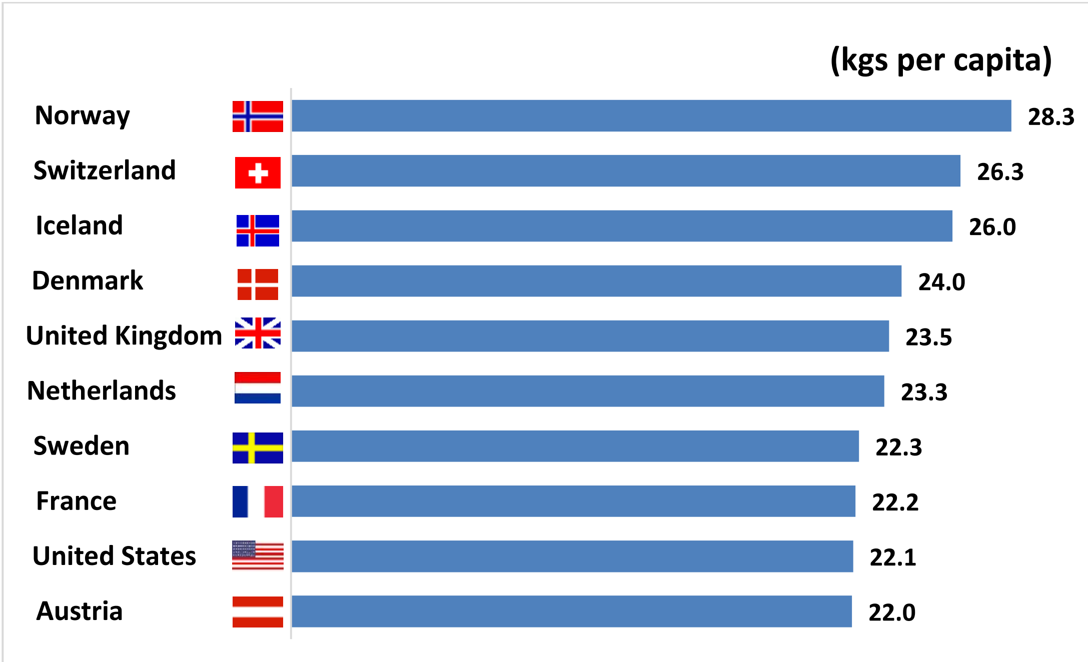


Figure 1.1: The World's Worst Electronic Waste Offenders

To have a full appreciation of the global status on waste management and give some perspective as where E-Waste stands on each country, **Figure 1.2** (Bourtsalas, 2015) depicts the percentage of recycled/treated from the total generation of waste in a nation.

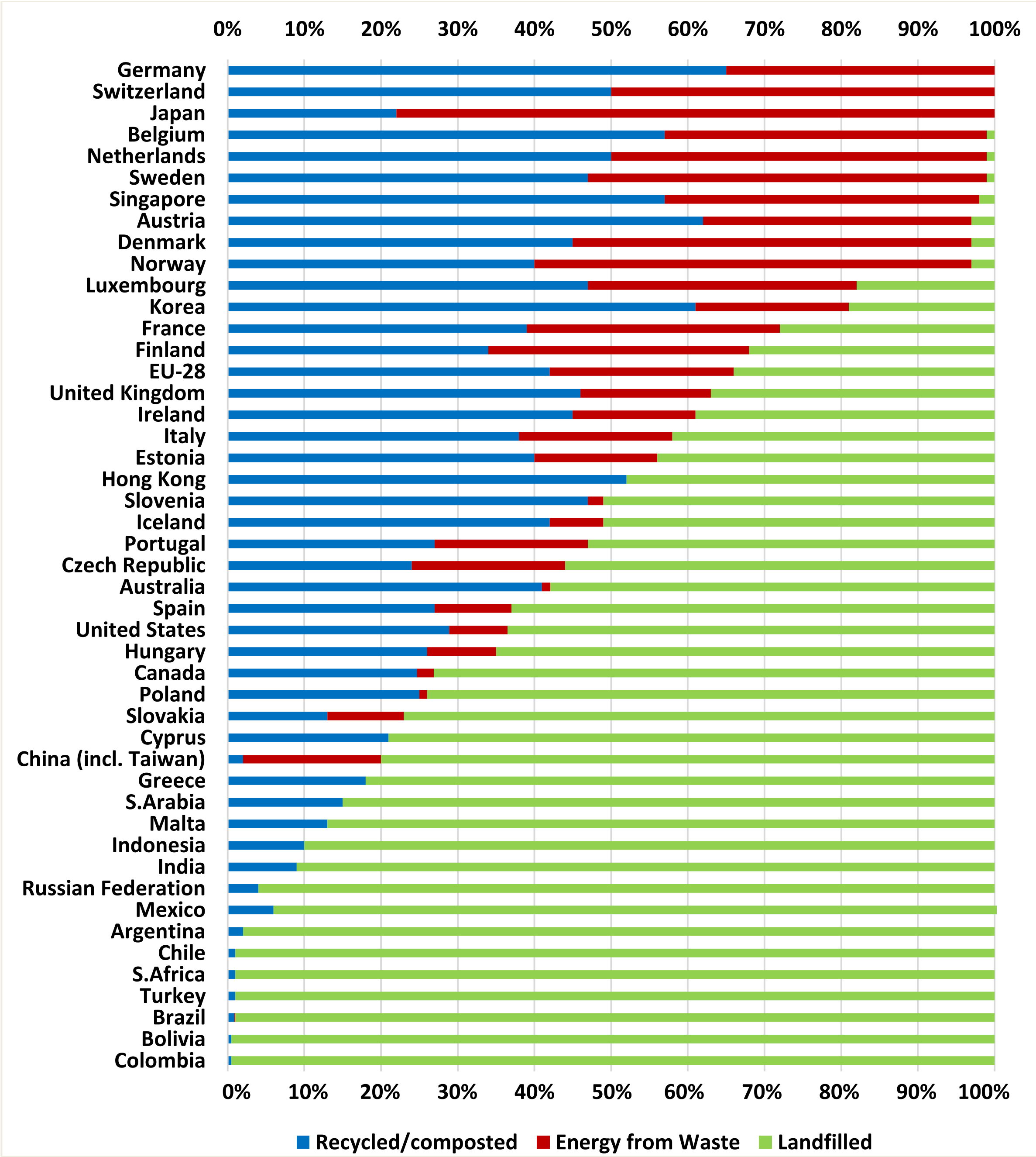


Figure 1.2: Disposition of Municipal Solid Waste in various countries

Clear examples that confirm the discussion above are the U.S., China and Russia, where recycling does not reach even 50%. The case of Russia is an alarming one, because not even 10% of its Municipal Solid Waste (MSW) is recycled. These inconsistencies may be attributed to the fact that the cost that surrounds development of equipment for treating E – Waste is too much (in some cases, as it will be seen later), or that there is a lack of incentives and laws to do proper and complete recycling of wastes. On another note, it can be seen that Mexico barely has a 6% recycling rate; an understatement would be to say that it is urgent for it to start improving this situation.

As discussed earlier, E – Waste is a big problem in today's world; and if trends and predictions are accurate, it is a problem that will keep growing if its proper management does not keep up. But as with every manufacturing practice, proper "operation and process" of E – Waste cannot be achieved without understanding the raw materials it is composed of and their particular handling.

1.4. Classification and Composition of E – Waste

Through the previous chapter, it could be inferred that in different regions around the world E – Waste is treated, even defined differently. These variances are caused by the technological development, the economic situation and/or the current regulations of the locality. Nonetheless, globalization has provided the means to distribute electronic technology all over the world, and therefore a general depiction of E – Waste's components can be used.

Among the various types of electronic and electrical devices, the most common groups that can be found are:

1. **IT and Communications Technology**: which include printers, copiers, and circuit boards
2. **Household Appliances**: being the most common refrigerators, washing and drying machines, television sets and microwaves
3. **Consumer Electronics**: starting by the rising number of mobile phones, music players, tablets, batteries, and other gadgets

All electronic appliances consist of several parts made of different materials such as metals (which as may be seen in the following figures make up the majority of the components), plastics, glass, and many other elements. Many of these components are recyclable or may be put to further use as they are not so difficult (or costly) to separate from the initial apparatus they were installed in. Also, some components like mercury, cadmium or lead are considered hazardous and as such, they should be removed and handled accordingly so they do not pose a threat to the environment.

Some examples of these components, privided by the European Environment Agency in 2009 and the UNEP in 2013 , are given in **Figure 1.3** (Joint Implementation Network (JIN), 2009) and **Figure 1.4** (UNEP's International Environmental Technology Center Branch, 2013)**:**

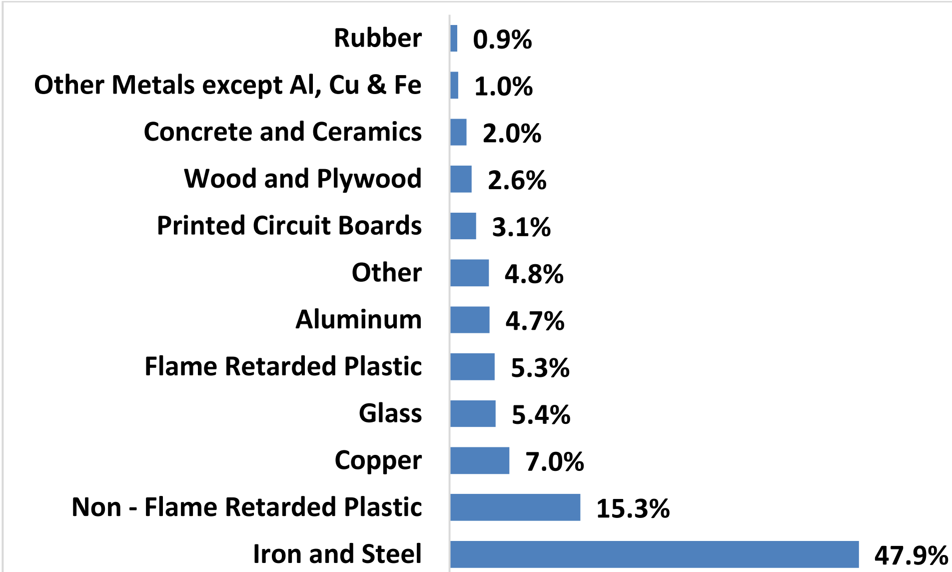


Figure 1.3: Average WEEE Composition by Weight

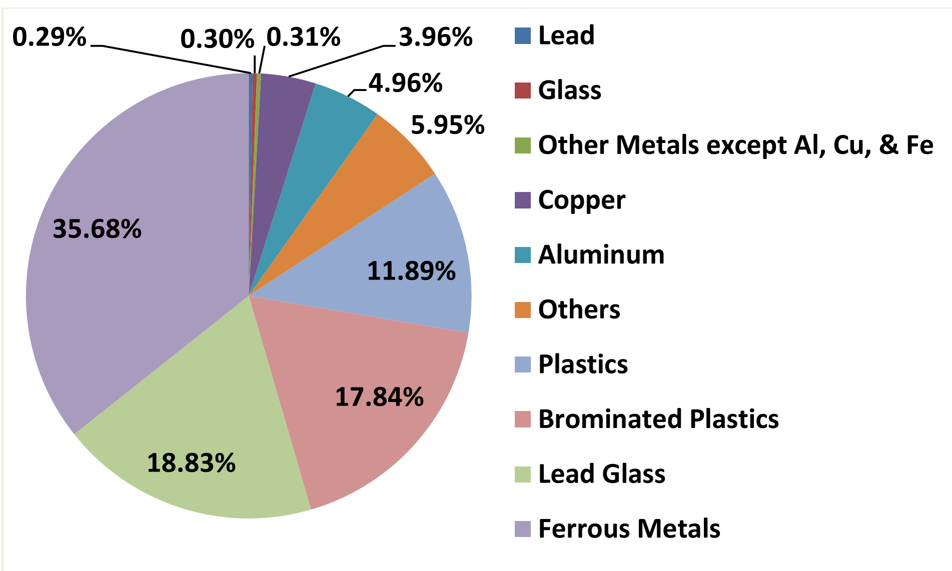


Figure 1.4: Average IT and consumer electronics waste composition

1.4.1. Examples of Metal content of E – Waste

Specific research was made for the metal content in the three major groups of E – Waste mentioned earlier as it will become pertinent in some of the following chapters in this thesis. The content is exemplified in the tables and figures below:

For **IT and Communications Technology**, with the example of a desktop computer; the material composition is shown in **Table 1.2** (US EPA, 2015). The table was extracted from a Waste Reduction Model Report from the US EPA in March 2015.

Table 1.2: Material Composition of a Desktop PC (CPU and CRT Monitor)

Product/Material	Application(s)	% of Total Weight	Weight (kg) Assuming a 31.8kg Computer
Plastics	Monitor Case and other molded parts		
ABS[a]		8.0%	2.5
PPO/HIPS[b]		5.3%	1.7
TBBPA[c] **(Flame Retardant)**		5.7%	1.8
Glass	CRT Glass/Substrate for PWB's[d]	22.0%	7.0
Lead	CRT Glass/Electronic connections	8.0%	2.5
Steel	CPU case/CRT shield	28.6%	9.1
Copper	PWB conductor/wiring	6.6%	2.1
Zinc	Galvanization of CPU case	3.0%	1.0
Aluminum	Structural components/PWB conductor	9.5%	3.0
Other	Metals and plastics for disk drives, fasteners and power supplies	3.3%	1.0
Total		**100.0%**	**31.8**

As can be seen from the **Table 1.2**, metals make up a minimum of 55.7% of the whole weight of the computer. This is a significant amount to be considered for recycling or other useful purposes.

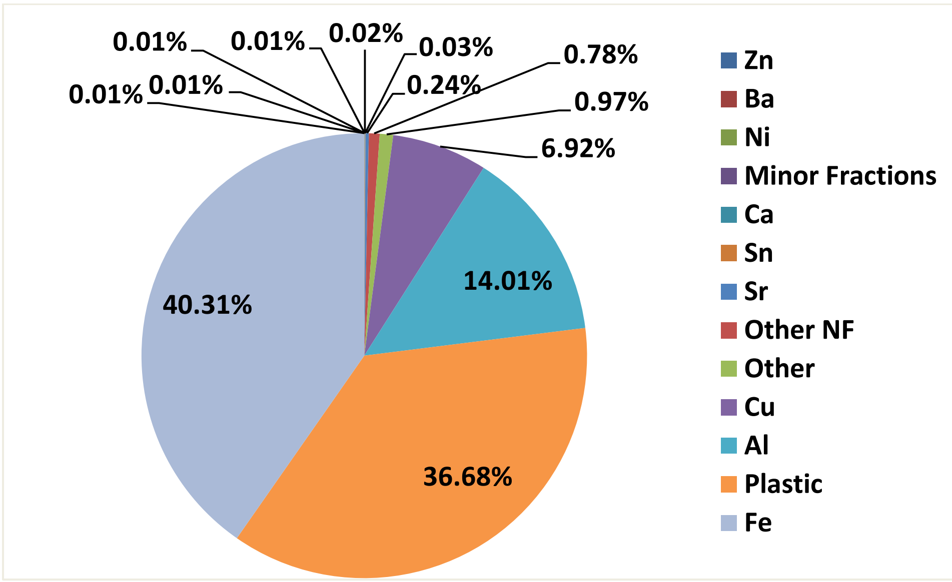
In the case of **Household Appliances**, a division between small and large appliances was used as the example. Extracted from reports of the Office of Resource Conservation and Recovery of the US EPA, and the Waste and Resource Action Programme (WRAP) in the United Kingdom (UK), **Table 1.3** (US EPA, 2014) and **Figure 1.5** (WRAP, 2012) show the material composition of E – Waste.

Table 1.3: Composition Percentage of Appliances

Equipment	Material Type							
	Steel	Copper/Brass	Aluminum	Metals Total	Plastic	Glass	Other	Total
Refrigerator	50%	4%	3%	57%	38%	0%	5%	100%
Dryer	98%	0%	< 1	98%	< 1	0%	< 1	100%

[a] Acrylonitrile butadiene styrene
[b] Polyphenylene oxide/High-impact polystyrene
[c] Tetrabromobisphenol A
[d] Printed wiring boards

Washing machine	53%	4%	3%	60%	22%	0%	18%	100%
Dishwasher	50%	0%	5%	55%	30%	0%	15%	100%
Range Stove	87%	1%	3%	91%	1%	6%	2%	100%
Air Conditioner	55%	17%	7%	79%	11%	0%	10%	100%



*NF = negligible fraction

Figure 1.5: Average composition by mass of major fractions (>0.01%) in small house appliances

As in the previous example, metals make up most of the composition in Household Appliances. In fact a commercial dryer is 98.00% metal.

Finally, for **Consumer Electronics**, the same WRAP overview was used. The average equipment (including VCR's, DVD players, loudspeakers, and digital cameras, among others) has metal in more than half of its composition as it may be observed in **Figure 1.6** (WRAP, 2012).

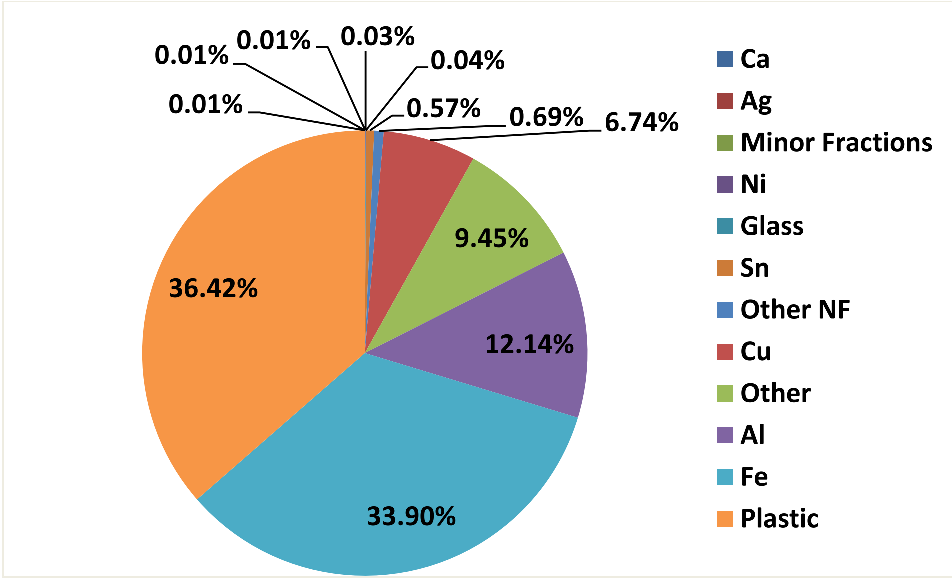


Figure 1.6: Average composition by mass of major fractions (>0.01%) in Consumer Equipment

The problem with containing so much metal in its parts is that electronic equipment is frequently exposed to processes of oxidation and corrosion that lead to hazardous leachates that constitute the most dangerous characteristic of E –Waste.

1.5.Hazardous materials in E – Waste

The company Waste Management Incorporated (WM) rounded up some of the principal toxic substances in E – Waste, the equipment that contain them, and the possible health consequences; they are displayed in **Table 1.4** (Waste Management Inc., 2013):

Table 1.4: Toxics substances found in E – Waste and their impacts on human health

Toxic Substance	Human Health Impact
Berylium (Used in springs, relay connections, computer motherboards)	Increased risk of developing lung cancer
Brominated flame retardants (Used in circuit boards and plastic castings)	Can impact brain function, cause thyroid problems
Cadmium (Used in laptop batteries, wire insulation, coating for CRT's, semiconductors, as a plastic stabilizer)	Can lead to kidney damage, development of lung cancer and/or respiratory illness

Lead (Used in electrical solder on circuit boards, cathode ray tube (CRT's), stabilizers in PVC[e] formulations)	Can impact brain development in children, cause kidney damage, respiratory illnesses
Mercury (Used in lights to illuminate flat screen displays, computer batteries)	Can impact brain development in children, harm, central nervous system, cause kidney damage
PVC (Used to insulate wires and cables)	Incineration can cause lung disorders

These substances have very grave repercussions on human and ecosystem life. It is imperative that they are removed from any process through which they may end up as destroyers; somehow rendering useless the usefulness in their lifetime.

Through these numbers, the dangers E – Waste pose when left unattended and untreated are left clear. It is now prudent to explore the options currently used for proper disposal and the means available for the further utilization of the materials; especially in Mexico where there is not much being done about this issue yet.

[e] Polyvinyl Chloride

2. E – Waste Management Current Practices

2.1. The Importance of Treating E – Waste

By a quick analysis from the previous chapter, obvious reasons to support E – Waste management can be inferred (like prevention of hazardous components in ecosystems), but some other reasons need a deeper assessment to become tangible. One of such reasons is that waste is a potential commodity; in the case of E – Waste, this conceptualization is explained via its different life stages.

2.1.1. Extraction of Resources

Many of the materials needed to produce some of the consumer electronics we see today on a daily basis are precious and rare metals that are naturally occurring but are not so easy to extract and/or are being depleted faster than they should. These metals are part of the called "Critical Raw Materials" as specified by the European Commission (European Commission, 2016) For example, in the foreseeable future the production of Beryllium (Be) and Chromium (Cr) may turn problematic due to lack of sources for these metals in the world (Backman, 2008). Besides of their depletion, the energy and work needed for their acquirement could be avoided through methods of utilization of E – Waste and Waste to Energy (WTE) processes.

2.1.2. Material Processing and Product Manufacturing

Materials that make up electrical and electronic equipment (EEE) are produced in a series of processes that may leave beneficial byproducts (Lead production by-products are silver, gold, arsenic, antimony, and bismuth (Fthenakis, 2003) for example), but their environmental impact is significant in terms of gaseous emissions and residues of hazardous materials.

2.1.3. Distribution and Use

Impacts from these two aspects of the Life Cycle of EEE have the least pertinence for the End-of-Life management of the finished products. Even so, they are not to be ignored. It is appropriate to mention that through better design and use of recovered materials the lifetime of the products may be increased, thus delaying their disposal. Also through better and more sustainable designs, pollutant and greenhouse gas emissions from some of the EEE (e.g. refrigerators, washing/drying machines) may be reduced. Design even affects the ability to carry more products in a single load; reducing the contamination created by transport.

Caution and care in the use of electronics by the end user extend the life of the equipment; awareness of best disposal practices provides a better End of Life management. It is very important that producers, retailers and even governments get involved in public education toward the use of EEE.

2.1.4. End of Life

The recycling and managing advantages at the End of Life of any EEE are manifold as has been mentioned. Some examples of these advantages not detailed before are:

Public health risks are not only mitigated by the use of recovered and recycled materials as seen throughout this analysis, but also by removing E – Waste from landfills. Since 70% of the hazardous waste in a landfill comes from the heavy metals in EEE, its removal would avoid serious health issues to waste operators; especially in developing countries (China or India) where there are no proper environmental regulations, nor any adequate infrastructure/equipment for handling toxic materials (Namias, 2013).

There are also economic and sensitive information factors that are worth mentioning. Many of the metals contained in E – Waste are of high value since they are precious like gold and silver, or rare like nickel, cobalt and titanium (Namias, 2013). A profitable industry can be developed from the recovery of these metals since they make up between 40 – 70% of the value of the appliance (Cui & Zhang, 2008). Also, sensitive information of individuals and institutions may be still obtained from their E – Waste, so the proper disposal and management is crucial for the destruction of such information.

2.2. Treatment Options

As it was mentioned in the previous section, the most important part of E – Waste is the metal content (precious and critical metals in particular). For this reason, the best management process is that from which the optimum amount of metals can be recovered and reused. This can mean the reuse of the still operational equipment, the repair of the electronics in an acceptable condition, or the strip-down of the components and recovery of the composing metals and materials. That said, there are many ways to recover constituents of E – Waste, but as it will become clear during this section, not all current techniques are efficient or safe.

2.2.1. Crude Recycling

It is a depressing fact, but many developed countries export their E – Waste illegally to developing countries because it is cheaper to process the materials in Asian or African countries than it is in the exporting nation. In these developing countries is where "backyard activities" take place. These include many unsanitary, unsafe and environmentally polluting activities like open incineration, simple smelting, and cyanide leaching. Also, there is an immense waste of resources during these processes and the recovery yield is too low (Hicks, Dietmar, & Eugster, 2005).

Sadly, there are many reasons that make Crude Recycling an appealing option in developing countries:

- *"In developing and industrializing countries waste is viewed as a resource and income-generating opportunity.*
- *There is a general reluctance to pay for waste recycling and disposal services, particularly when consumers can make some money by selling their old and broken appliances.*
- *Waste collection and disposal services in developing countries cost a higher proportion of the average income than in developed countries.*

There is lack of awareness among consumers, collectors and recyclers of the potential hazards of WEEE, crude 'backyard' recycling and other disposal practices." (Hicks, Dietmar, & Eugster, 2005), (Kang & Shoenung, 2005)

2.2.2. E – Waste Management and Recycling

To achieve efficient recycling of E-waste, specific and complex technology has to be developed and used in the recovery process. **Figure 2.1** below, provided by ThemeScape® and the World Intellectual Property Organization, shows the patents for currently developed technologies for the recovery of specific components found in E – Waste (White & Singh Gole, 2013).

Figure 2.1: Thematic Concept Map of E – Waste Patent Landscape

For the complete extraction of these components via recycling, there are several steps to follow as it will be described in this section. The equipment design needs to consider the previous and subsequent stages of the process during dismantling and separation.

Collection

Collection of E – Waste is relatively easy and does not necessarily involve a lot of technology. It is usually done by the end user of the equipment at a household or company. The right way to provide an optimum collection is by separating all electronics from other types of waste and placing them in a sturdy container to avoid pieces to fall off. If the waste is not picked up by the municipality, collection of E – Waste can be done by various organizations; some private which may be non-profit or profit from waste companies that have their own recycling programs. Companies that invest in collection of E – Waste range from small manufacturers of electronics to large waste management companies. Neighborhoods where recycling is not customary yet, usually conduct events to collect E – Waste from time to time.

The next step is the identification of reusable equipment or parts of equipment. In some cases, the discarded electronic is just outdated but still functional; it can be donated to charities or sold on secondary markets. It is important to note that if the equipment contains sensitive information (for example from a banking or medical institution), this needs to be deleted permanently before the appliance is used again. Most E – Waste recycling companies perform this operation the moment they receive the apparatuses, even though the end user should be responsible for this operation before disposal.

Disassembly

E – Waste is taken apart into its larger components for easier handling and further processing. This way, hazardous materials are identified, as well as valuable and reusable materials. **Figure 2.2** (Cui & Forssberg, Mechanical recycling of waste electric and electronic equipment: a review, 2003) shows a simple diagram of disassembly) (Ragn-Sells Elektronikåtervinning AB, 2000).

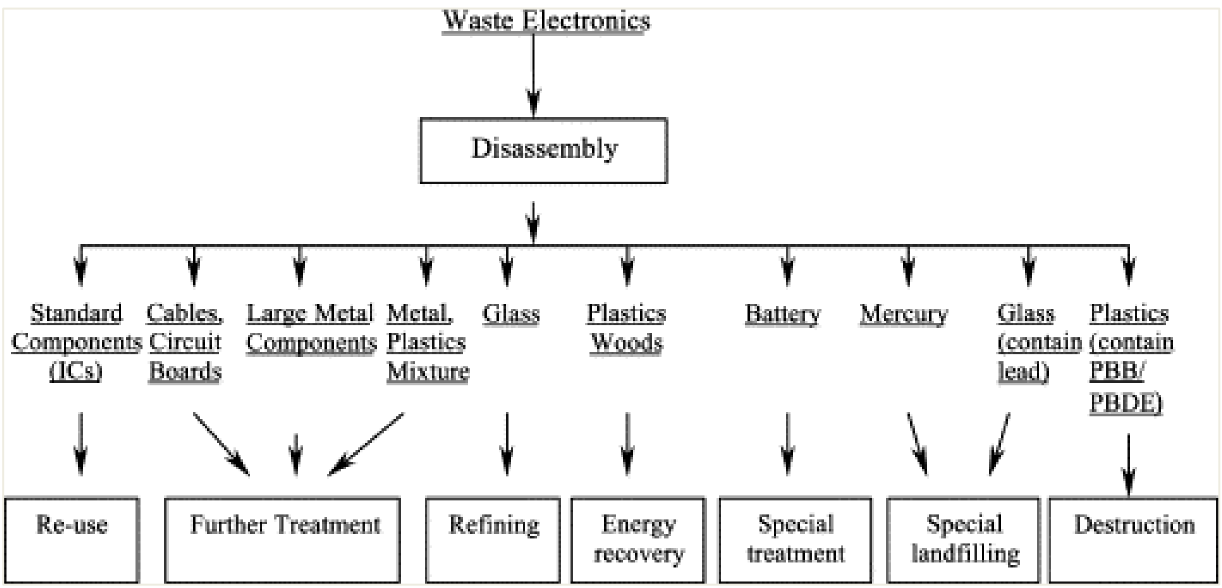


Figure 2.2: Recycling process developed by Ragn-Sells Elektronikåtervinning AB

Physical Separation

After the recovery of the reusable pieces, the separation of the composing materials is next. Some materials like batteries, plaques, or wires may be extracted by hand. This is the first step where technology starts to really get involved comes up; reduction. Reduction in particle size is essential for an ideal sequence of salvaging. It is achieved by shredders, and these must be of particularly high quality in order to rip though the metal components of the electronic equipment. Finally, advanced sorting techniques are applied to set materials apart into glass, plastics, base metals and precious metals waste streams.

A detailed separation by physical characteristics of the components is carried out. The separation processes may include very simple shape separation or magnetic separation for split-up of ferrous metals, non-ferrous metals and non-magnetic wastes; also, electric conductivity or density separation may be induced (Osibanjo & Nnorom, 2007).

1. Optical Separation

By the use of different sensors and cameras, specific materials are identified in the waste stream and separated by the use of compressed air (usually). Optical separators are predominantly used for separating various types of plastics, but they can also be used to separate metals. Some examples manufactured by the CP Group's Division MSS Optical Sorters are the following:

- CIRRUS™: Used to separate specific types of plastics like ABS, HIPS, PC, PC-ABS, etc.
- L-VIS™: Advanced to sort through particles even less than 1mm in size. It is also used mostly for plastics, but it can be used to separate certain kinds of metallic parts too.
- MetalSort™: An all metal detector hat removes any traces of metal left after other conventional techniques (CP Group, 2012).

2. Magnetic Separation

These are used specifically to separate ferrous from non-ferrous metals and other non-magnetic wastes. Advances in technology in recent years have allowed making high intensity magnetic separators that extract certain alloys and that can be manipulated to separate metals in different magnetic field gradients.

3. Electric Conductivity

The three most common types of separators based on the resistivity of materials are the Eddy Current Separator or ECS, the Corona Electrostatic Separation and the Triboelectric Separation. **Table 2.1** (Cui & Forssberg, Mechanical recycling of waste electric and electronic equipment: a review, 2003) illustrates in detail each of these techniques.

Table 2.1: Mechanical separation processes based on electric characteristics of materials

Processes	Separation criteria	Principles of separation	Sorting task	Workable particle size ranges
Eddy Current Separation	Electric conductivity and density	Repulsive forces exerted in the electrically conductive particles due to the interaction between the alternative magnetic field and the Eddy currents induced by the magnetic field (Lorentz force)	Non-ferrous metal/ non-metal separation	> 5mm
Corona Electrostatic Separation	Electric conductivity	Corona charge and differentiated discharge lead to different charges of particles and this to action of different forces (particularly image forces)	Metal/non-metal separation	0.1 – 5mm (10mm for laminar particles)

Triboelectric Separation	Dielectric constant	Tribo-charge with different charges (+ or −) of the components cause different force directions	Separation of plastics (non-conductors)	< 5mm

Although the most generally known E – Waste separators are the Eddy Current Separators. (ECS's), they still have efficiency problems with splitting certain components. A newer, more effective machine is the Titech X-Tract Separator and Finder, the problem is its cost of $700,000 USD (Krikke, 2008).

4. Density Based Separation

Because some materials are heavier than others, especially metals and non-metals, separation is achieved by taking advantage of this property. Some examples are:

- Sink-float separation
- Gravity separator
- Hydrocyclone (takes advantage of resistance to motion by a fluid)
- Sorting by jigging
- Sorting in chutes and on tables
- Up-stream separation

Once each type of material is separated, recovery also makes use of particular technology.

Refining

There are many methods and procedures to return the separated materials to a usable form. Highly developed technology needs to be implemented in this stage. Some of the methods and current technologies applied for refining are explored in the next section. It is worth mentioning that even though there is a considerable amount of glass and plastic in E – Waste, and that technology is also advancing for their optimum recovery; the aim of this thesis focuses on the reuse of metals, which have the most economic value.

By means of the equipment mentioned above, the ferrous metals can be separated from the non-ferrous because of their magnetic properties. Then, nonferrous metals are extracted from non-metallic particles through the Eddy Current separators, because of their electrical conductivity. Some of the metals found in E – Waste, as well as their "separating" properties are shown in **Table 2.2** (Kang & Shoenung, 2005):

Table 2.2: Materials that can be separated by an Eddy Current Separator, and their properties

Materials	σ (10^{-8}/Ω m)[f]	ρ(10^3 kg/m^3)[g]	σ/ρ (10^3 m^2/Ω kg)[h]
Al	0.35	2.7	13.1
Zn	0.17	7.1	2.4
Ag	0.63	10.5	6
Cu	0.59	8.9	6.6
Brass	0.14	8.5	1.7
Pb	0.05	11.3	0.4

As for specific element separation, a brief description of the processes for the main metals in E – Waste is provided next (Kang & Shoenung, 2005):

Copper (Cu): Copper extracted from E – Waste is a very lucrative source, since its concentration is higher than that of Cu ores (10-50 times higher (Liu, 2014)). Due to the importance of Cu recovery, there are 2 main methods described in this thesis:

- **Pyrometallurgy:** Simply put, it is the melting of crushed scrap at high temperatures (~ 1,250°C) in order to recover non-ferrous and precious metals. Through this technique, metal oxides and plastics are differentiated, and later on, the pure metals are extracted through chemical reactions. There are variations to the process depending on the technology used, but as an example, **Figure 2.3** (Veldhuizen & Sippel, 1994) depicts the **Noranda Process** as explained by Veldhuizen and Sippel. It is important to note that the reactor works with an excess of oxygen in the introduced air to improve combustion (39%). Separation takes place after the molten slag is removed from the reactor and into the converter and then the electrorefining anodes. The purity of the recovered copper from the anodes is of around 99.1%. The other 0.9% contains precious metals (gold, silver, platinum and palladium along with selenium, tellurium, and nickel) (Cui & Zhang, Metallurgical recovery of metals from electronic waste: A review, 2008). Benefits from this one step/continuous process are that it is already established worldwide in industry and compared to other smelting processes; its gas emissions are low. Noticeable downsides of this process are the intense energy use for the combustion process (amount of excess O_2 supplied) and the quantity limitation by the reactor's size.

[f] Electrical Conductivity
[g] Denisty
[h] Ratio of electrical conductivity to density

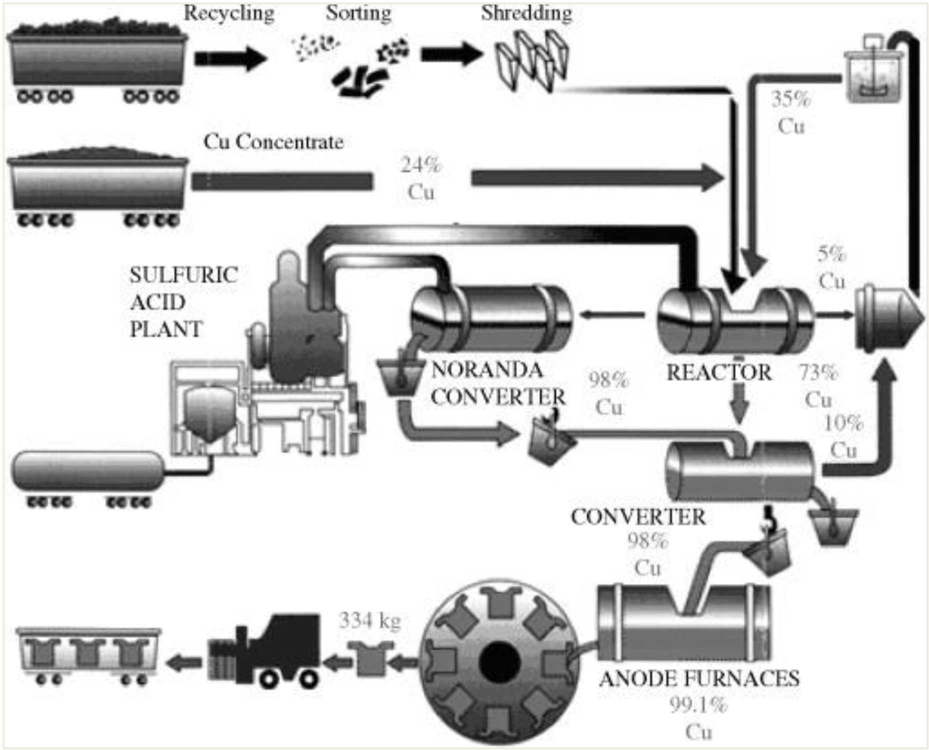


Figure 2.3: Schematic diagram for the Noranda Smelting Processing

- **Hydrometallurgy:** Even though pyrometallurgy has been practiced for over 30 years, hydrometallurgy offers a more efficient method of recovery of metals. The main and first step is the oxidizing leaching of metals by an established agent (e.g. cyanide, halide, thiourea or thiosulfate) depending on the metals to be extracted. The process is followed by the purification of the leaching solution (usually achieved via filtration and precipitation) and finally, by the recovery of the metals (Cui & Forssberg, Mechanical recycling of waste electric and electronic equipment: a review, 2003)**. Figure 2.4** (Quinet, Proost, & Van Lierde, 2005), provides an example of the process illustrated by Quinet, et. al.

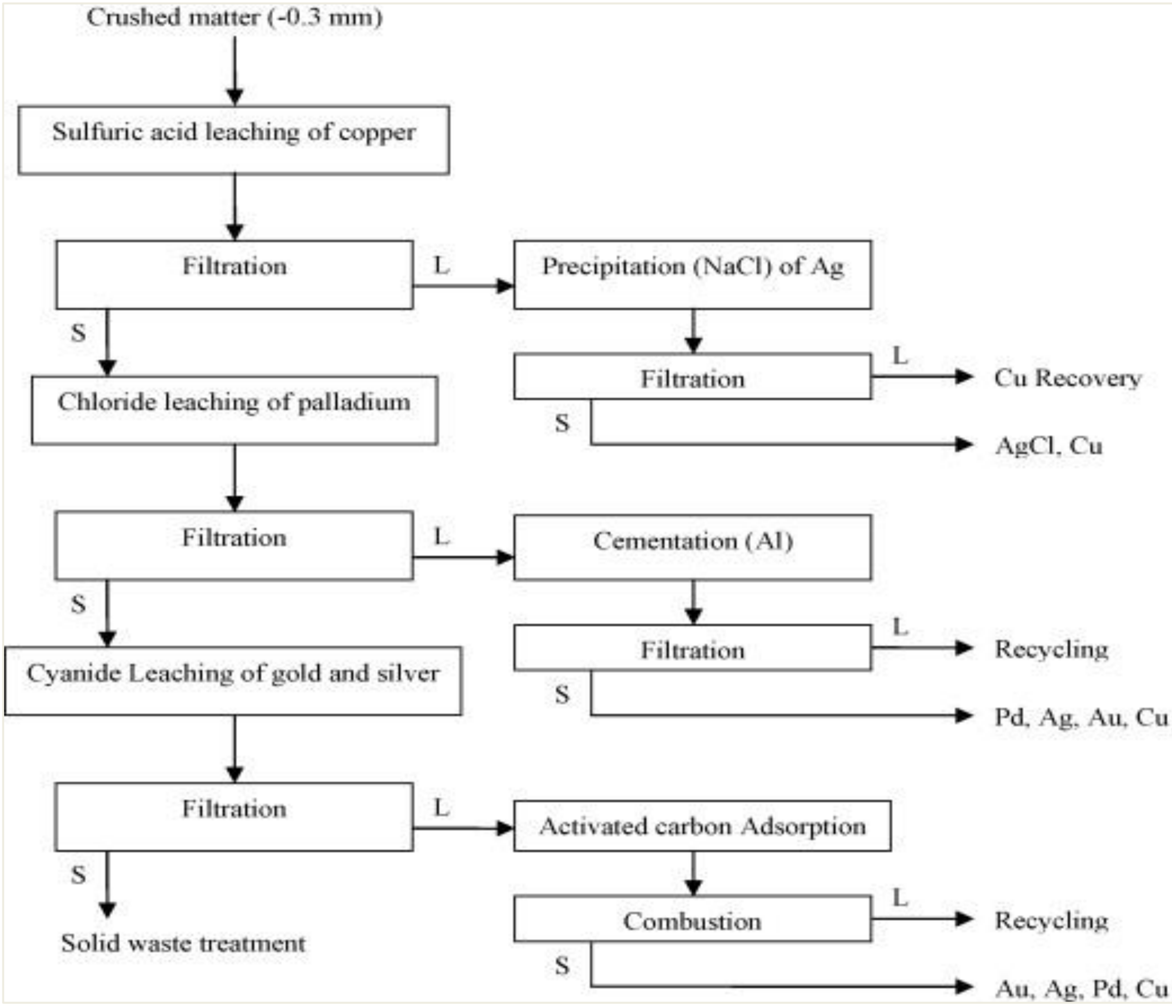


Figure 2.4: Proposed flowsheet for the recovery of precious metals from electronic scrap

In some instances the percentage of recovery is of 100% depending on the type of electronic equipment. The disadvantages of hydrometallurgy are the extensive care of hazardous substances it requires and that many of the hydrometallurgical processes have not reached an industrial scale.

Precious Metals: Without a doubt, recovery of precious metals is the most profitable process in recycling E – Waste since among these precious metals gold, silver, palladium, and platinum can be found. Their recovery is actually a byproduct of copper's; they are usually found together in E – Waste because both make part of Printed Circuit Boards; which in turn are abundant in electronics. The recovery process takes place just after the electrolytic refinery as seen in the diagram above. The anode slime that comes out of this procedure is leached by pressure. The leach then gets dried and burned in a precious metals furnace among fluxing agents. The recovered material is primarily silver, that is cast into a silver anode (a byproduct is selenium). Then, through another high-intensity electrolytic refining process, a silver cathode and gold anode slime are recovered in high purity. Finally, the gold anode slime is leached to recover high-purity gold, palladium and platinum (Quinet, Proost, & Van Lierde, 2005).

Mercury (Hg): Mercury is mentioned in this section because of its in hazardous properties in E – Waste more than for its economic value. Mercury must be extracted from cold cathode fluorescent lamps (CCFL) tubes in the backlights of LCD monitors, LCD television and laptops. Thankfully, this is achievable via manually separating these components (Liu, 2014).

Cadmium (Cd): For similar reasons as mercury, Cadmium must be extracted. It is usually found in semiconductors (PV modules) and PCB's. Its separation is relatively easy as it is found in dust and may be removed as cadmium oxide through heating processes (Liu, 2014).

Nickel (Ni): As is it found on a relatively high amount among E – Waste (mostly in capacitors), Nickel may be extracted through leaching with HNO_3 at 90 °C (Cui & Forssberg, Mechanical recycling of waste electric and electronic equipment: a review, 2003).

The quantity and quality of the End of Life treatment given to E – Waste depends enormously on the economy and regulations of the country involved. Due to the increasing amount of electronic waste in the last few years and its expected growth, E – Waste treatment has already attracted a lot of attention. New technologies and methods are currently being developed to enable society to deal with this problem in an efficient, economic, and environmentally friendly way. These issues will be explored in the next chapters for the case of Mexico.

2.3.Global Technologic Status

As has been stated, some developed countries have very high recycling percentages of their waste streams; this is done mainly through the use of the advanced equipment mentioned earlier. Even so, as it may be graphically related in the following figure and **Figure 1.2**, there are some inconsistencies with the relationship between the implementation of recycling in a country and technological progress for recycling in that same country. The most noticeable inconsistencies are the U.S., China and Russia; **Figure 2.5** (White & Singh Gole, 2013) measures the amount of innovation carried out in the world for E – Waste treatment, and confirms that technological development and the actual recycling rates in a given country may be unrelated.

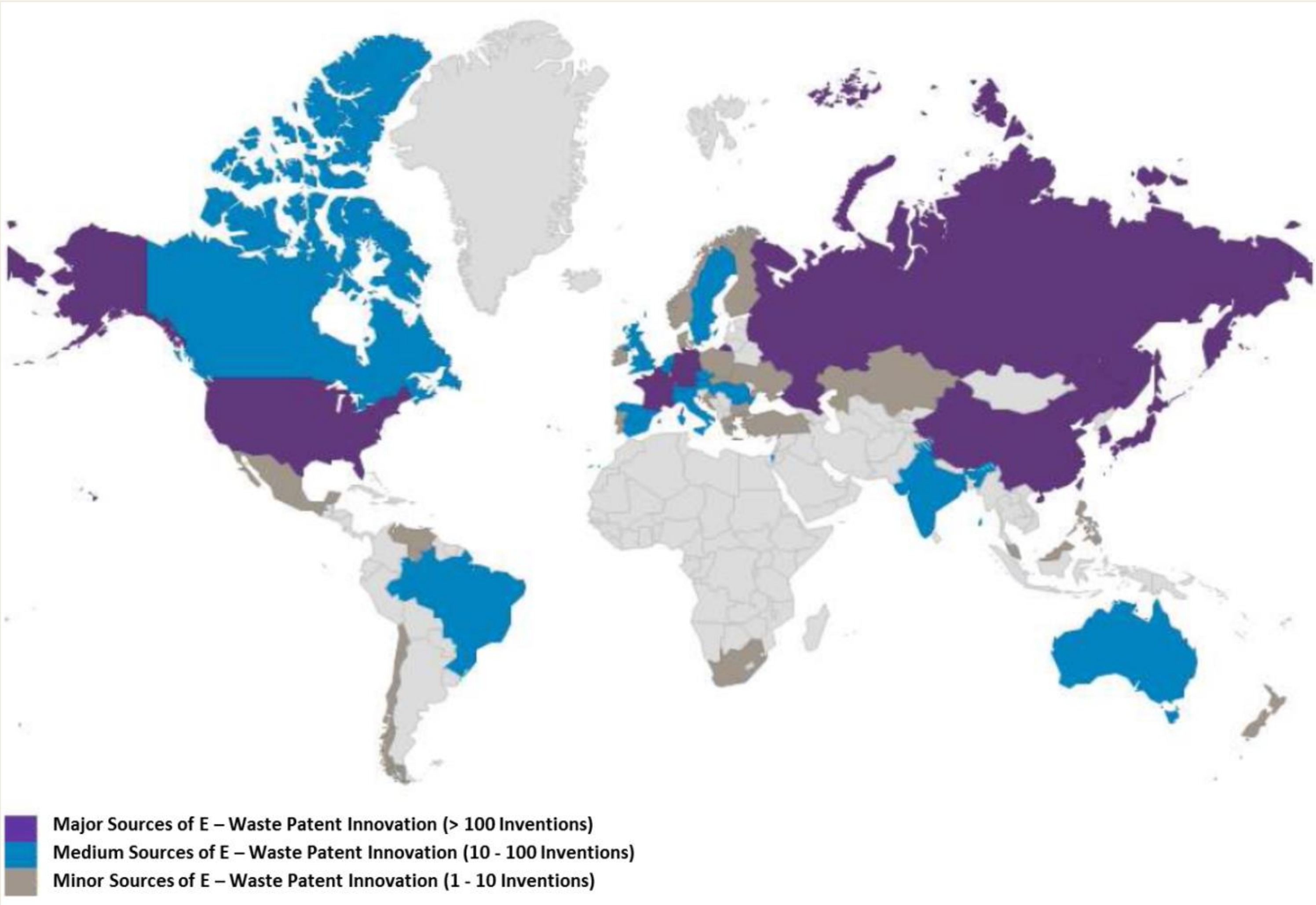


Figure 2.5: Geographic Map of Sources of E – Waste Patented Innovation

2.4. The economics of managing E – Waste

A very important issue with proper E – Waste management is the economic factor. The parties involved may be the government, private companies that wish to use recycled materials for their products, manufacturers of the electronics being processed, or even the consumer. As it will be explored in this section, the cost may fall directly on only one of these players or it may be collaboration between all to reduce the expenses.

Likewise, the expenditures for treatment are divided throughout the whole procedure. Starting with the collection of E – Waste by separating it from other MSW. For the finances of E – Waste management, the most important cost (but probably not the highest) is the collection cost because removing a discarded electronic product from the environment comes before the later use it may be given.

Depending on the legislations and economy of a country, the salvage disbursement may fall on:

2.4.1. The Consumer

An increase in the sale price of the electronic product due to the proper End of Life handling may be paid by the buyer to share in responsibility with the manufacturer. This expense may lead to discourage consumers when buying electronics; therefore, it is essential to inform shoppers about the long term benefits of reducing E – Waste even if they pay something extra at the beginning.

2.4.2. The Manufacturer

Usually referred to as Extended Producer Responsibility (EPR), it is *"an environmental policy approach in which a producer's responsibility, physical and/or financial, for a product is extended to the postconsumer stage of a product's life cycle"* (OECD, 2001).

Naturally, this impacts the profits of the producer, but by creating awareness in the consumers and good resource planning, the losses may by reduced to a minimum, or it may even serve as a beneficial publicity campaign.

Complementing the commentary above, the cost may be alleviated by increasing the sale price by selling the collected material to the next user, or by reusing the recovered material and thus saving in raw materials acquisition. Some firms are already on this path, they accompany their EPR with public awareness and most of all, reduction in the use of hazardous materials in their products.

2.4.3. Private Institutions

As part of a "green" program, a corporation may be willing to pay for the gathering of E – Waste in order to use recycled material in its manufacturing process. These also include recycling companies that sell their refined products as raw materials to other industries and the Waste to Energy (WTE) companies that will be later addressed in this thesis. For example, Best Buy has an E – Waste drop off program for costumers, from which it makes revenue by selling the collected material to other businesses that need to cover a recycling quota. (Anston, 2012)

2.4.4. Government

As part of the governmental agenda, some of the ecological and sustainability budget may be destined for recycling of E – Waste (If the country's GDP and resourcefulness allows). If well adopted, this may even be profitable for the national, regional or local government. For example, hiring "informal" recyclers for the collection and collaborating with companies for the renewed use of the recovered materials.[i]

For the physical separation of the components and their salvaging, refurbishing, and/or refining processes, a suitable handler must intervene (e.g. Waste to Energy Company). For these handlers, the cost of the aforementioned operations may begin during the acquirement of the waste. In this case, the revenue comes after selling the processed material/energy and byproducts. The cost may only be operational, since the recycler is only an intermediary step for a company that wishes to reuse recovered materials. For example COVANTA ENERGY CORPORATION, a world leader in Waste to Energy,

[i] One of the principal challenges in Mexico for financing collection of E – Waste appropriately is that most of the valuable materials and metals are recovered by informal recyclers and these sell them on secondary markets.

offers sustainability consulting services to companies as well as WTE technology that transforms tons of waste into electricity for homes and industries (COVANTA ENERGY CORPORATION, 2015). The costs they may assume are surpassed by the different products and services they offer and that make them such a successful company.

It is important to note that all the interactions between companies, government and recyclers may be at different stages of the treatment of E – Waste because there may be interest in the recovery of the unshredded waste or after the composing materials have been extracted and refined for further use.

There are many means to distribute the cost of handling E – Waste and they mainly rely on each country's economy and legislations, because ultimately companies and individuals are bound by law and the market. Nonetheless, the optimum solution is where every party involved has a shared responsibility and "pays" for a part of the electronics life.

2.5.Waste to Energy

A complete treatment of E – Waste is portrayed in the methods described earlier, but what if there were further or alternative processes? Thanks to developing technology since the 1970's, energy may be obtained from what can't be reused, recycled or refined. Nowadays, most of the processes for recovery of energy with waste have very little emissions of toxins and/or Green House Gases (GHG). Additionally, WTE is an important source of revenue for the waste treatment industry.

Now, depending on the composition (organic content, moisture and calorific value mainly) and amount (size of the components and density) of the waste, a particular path can be taken, since there are several ways in which to take advantage of the energy stored in matter. The main processes are: Thermal Treatment, in which an energy source may be recovered from the heat and the gases that come out of the waste by combustion, gasification or pyrolysis; and Physic-chemical Treatment, in which Solid waste is treated so that high-energy fuel pellets are drawn from the calorific filled portion of the waste.

Completing the treatment of E – Waste by converting its disposed fraction into energy includes a number of benefits that are not widely known due to the general and biased knowledge given by open incineration methods. These advantages should be made known to the public and especially to governments so further attention is given to this renewable source of energy. Some of these benefits include:

- Reduction of use of fossil fuels as energy sources.
- Reduction of transportation impacts and landfill space due to large waste residues.
- Reduction in GHG emissions by eliminating methane outputs.
- Recovery of previously unrecycled metals.

2.5.1. E – Waste to Energy?

When subjecting electronic waste to this type of treatment it is important to ensure that previous management has been done. Reuse or refurbish of the functional parts and recycling and/or refining of the metals that can be recovered by separation is essential and preferable, but further handling can be applied to the left-over material.

Now that all the principal processes for E – Waste have been covered; the most important factors that affect these methods, such as legislative pressures, public opinion and current initiatives must be delved into, in order to provide the whole scope for this study. These factors will be addressed in two instances to provide a comparison: the global situation as one and the particular case of Mexico as the other.

3. Adjacent Factors

There are different cultures all around the world, but there are some perspectives that even the most traditionally diverse nations share; an example: a product constitutes a responsibility from all that come in contact with it. From its creation to the end of its life, every man-made artifact needs monitoring and proper handling.

Of course this isn't always the case, nor does it apply to every country in the world (yet). Through time and development of economies, people have realized firsthand the Conservation of Mass Principle: Everything you have laid hands on does not disintegrate when you are finished with it, it ends up somewhere. How did they come to understand this? When the objects discarded came back indirectly in a threatening form to them or the place they live.

The following section provides some insight on how waste is dealt with in many parts of the world; general points of view from different countries, measures taken and the technology used to implement those measures.

3.1. Legislative Pressures

Many factors have led the world to be conscious about its waste through time, and a lot more in the last decades. This has created many global policies and legislations like:

Extended Producer Responsibility (EPR)**:** "*Aimed for 'prioritization of preventive measures over end-of-pipe approaches' "*(Nnorom & Osibanjo, 2008). This means that as the manufacturer has the responsibility for the End of Life treatment of its product, optimization of material use and manufacture is desired to avoid further complications. It was developed to comply with the ***"Polluter pays Principle"*** (Kibert, 2004), and it is exercised through product fees and taxes such as advance recycling fees (ARF's), product take-back mandates, virgin material taxes, and combinations. Other policies include pay-as-you-throw, waste collection charges, and landfill bans (Nnorom & Osibanjo, 2008).

EPR proposes to:

- Reduce and prevent waste
- Reutilize products
- Augment the use of recycled materials
- Consume less natural resources
- Integrate environmental costs into the price of the product
- Recover energy from non-recyclable materials (Langrova, 2002)

Take Back Laws: Could be called EPR as well, because they involve responsibility for a product after its use, but in this specific instance it means not only to oversee the destiny of the artifact, but to handle it directly again.

These and others measures have been adopted by several companies and countries around the world as may be inferred from the previous summary. Many of these policies have even helped create new sectors of industry.

Also as seen previously, there are some countries further along the way like Japan, Taiwan or the EU. Through very disciplined and rigorous efforts they aim to become Circular Economies that take advantage of all the materials that make up waste. These efforts are not only done because of "command and control" from the corresponding governments, but also from the volunteer communities that constitute those countries. Developing nations are in need to follow these examples not only to achieve sustainable living, but to boost their economies as well.

Thankfully, the path has been already laid down for the developing world in many instances. To provide a standard for sustainability (the proper management of waste included) several certifications have been put in place.

3.2. Certifications

The same way every professional process or activity has its own; there are standards that set the quality of E – Waste management of a certain organization or company. These standards, based on the general objectives E – Waste management should accomplish, follow a set of rules and demand previously established requirements at various levels to determine the efficiency of the examined party. Some of these accreditations are valued internationally and others depend on the individual legislation of every country, or even of very municipality.

3.2.1. ISO 14001

The most famous and internationally known organization that has developed thousands of sets of standards is the International Standardization Organization (ISO). It is important to introduce them in this section because their 14000 series addresses all issues for Environmental Management, and the 14001; the one that includes E – Waste management, just had a revision this 2015 (International Organization for Standardization, 2015).

Looking out for sustainability from the environment's perspective, the ISO 14001 Standards establish the requirements for organizations that want to achieve optimum environmental recognition through their due responsibilities. These standards are made to fit any type of institution since they provide a Life Cycle Analysis perspective for any product or service the evaluated organization provides. Though there are thousands of certifications that apply the ISO 14001 standards, here are some (with their respective criteria) recognized as the highest (globally) that are employed directly to E – Waste management.

3.2.2. Recycling Industry Operating Standard® (RIOS)

Although institutionalized for the scrap industry and for the United States, the RIOS is recognized internationally and it is suitable for electronics recycling. It comprises a mixture of the ISO 9001, ISO

14001 and OHSAS[j] 18001 Standards, which means it aims to verify the environmental, health, safety and overall quality of a company. It was established by the Institute of Scrap Recycling Industries (ISRI), and it forms part of a double program called the Certified Electronics Recyclers® (National Sanitation Foundation, 2015). It aims to give the inspected organization a higher prestige in order to broaden its horizons and to be able to cooperate with other companies since it reflects integrity and responsibility. It also looks for the well-being of all employees of the company, as well as more job opportunities by increasing the processes a product is put through, even after its use.

The process, which may take from three to eighteen months, is divided into several steps. These include a RIOS Membership application, in order to be handed a Guide Book and/or *"Train the Trainer"* Workshops. These previous steps are needed for the implementation of the Management System that is later audited in two stages by an American National Standards Institute-American Society of Quality (ANSI-ASQ) National Accreditation Board (ANAB) representative team in two audit stages (ISRI Services Corporation, 2013).

3.2.3. Responsible Recycling (R2)

This certification serves as a complement to the Certified Electronics Recyclers® of RIOS. It is focused for electronics recyclers and it is based on internationally approved recycling practices that address the separation and reuse processes for disposed-of electronics. This accreditation is also EPA approved it allows the evaluated institution to interact with international counterparts.

One particularity regarding these combined certifications; they mainly focus on the proficiency and improvement of a company in terms of productivity and positioning, leaving out many aspects important to the environment. For example it has ample allowance for the disposal of toxic substances, for the export of waste (viewed as a legal business operation with the importer) and for the working conditions of the waste handlers, where other certifications have stricter standards (Electronics TakeBack Coalition, 2010).

3.2.4. e-Stewards® Certification

Probably the most complete certification recognized internationally; it was developed by The Basel Action Network (BAN) in 2003 with a global range in order to abide by the very high standards of the ISO 14001. The e-Stewards aims to complete the circle of an electronics life, and in case there is no reuse option, it sees that the waste is disposed of in an environmentally and healthy safe manner (National Sanitation Foundation, 2015). Its adherence to such rigorous requirements is what makes it so prestigious. For example, it does not allow export of non-working hazardous equipment to developing countries, it does not allow the incineration of toxics from E – Waste on landfills, and it does not allow the use of prison work for the handle of toxic substances (Electronics TakeBack Coalition, 2010).

This standard has set the bar for outstanding recycling because it has not only proven to require the best out of the certifying candidates; it helps them achieve progress via a safe and responsible marketplace for used electronics and electronic waste. Some important enterprises that hold the e-Stewards certification are Raytheon, Samsung and Iron Mountain (E-Stewards, 2015).

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[j] Occupational Health and Safety Assessment Series

3.2.5. WEEELABEX

The European equivalent of the certifications described above. It was created in 2009 by a collaboration of Process Industry stakeholders and it is run by the WEEE Forum. Financed by the European Union's environmental program LIFE (LIFE07 ENV/B/000041), it aims to watch over the complete End of Life treatment of E – Waste. It follows a strict procedure, and by auditing the certification candidates, it determines if the recycling and disposal of the waste is done properly and under all applicable legislations. Some properties of the certification include:

1. All standards are normative requirements that evaluate all stages in End of Life treatment; from collection of the waste to the preparation for re-use
2. All standards include the 10 WEEE categories
3. WEEELABEX systems must be applied in all the stages
4. All standards are part of legislative requirements of the Directive 2002/96/EC (WEEELABEX, 2015)

Certifications are an integral part of a sustainable company and a fundamental part in a recycling organization. Internationally or locally accepted, these endorsements reflect the quality of a corporation; they set the bar for newer industries and establish the basics for areas of opportunity. Examples of leaders that hold these certifications and more are presented next.

3.3.Successful E – Waste Treatment Initiatives

Treatment of old electronic devices and parts worldwide is done by two types of companies. Electronic product manufacturers that get involved with the End Of Life management of their products in order to act sustainably and profit from it, and organizations that specialize in the treatment of E – Waste. A couple of exemplary firms from both categories are mentioned in the following paragraphs; more examples can be found in **Appendix 2**.

3.3.1. Stena Metall Group AB

This family owned company was founded in Sweden in 1939 by Sten Allan Olsson and is dedicated to the recovery and recycling of any type of waste (from metals to chemicals and hazardous waste). It started by trading metal scrap and raw rubber; it still does today by being involved in the steel and aluminum business through processing, distribution, and international trade of these and other metals, as well as oil. Through dedication and innovation, Stena has been expanding since its foundation and is now working in more than 10 countries and has more than 3,200 employees. It began dealing with electronic scrap since 1995.

The group is made up by three parent companies (Stena AB, Stena Sessan AB, and Stena Metall AB) that form the "Stena Sphere". These in turn are divided into seven business areas, one of which is the Recycling, Environmental Services and Training. This area has several subsidiaries that address specific recycling streams and operations:

1. **Recycling:** Offers customized solutions for any type of client regardless of waste type. It offers products and various services through its 165 facilities all over Europe. Examples are waste collection, authorization applications, statistics, logistics and training.
2. **Recycling Electronics:** Offers high quality solutions for electronics recycling by innovating processes and keeping up with the newer and more complex electronic devices.
3. **Trading and Sales:** Trades ferrous, non-ferrous, stainless scrap, raw steel and various steel products all over the world through more than 30 representative offices. It foresees the whole process from the collection of the scrap to its distribution as a finished product.
4. **Aluminum:** Stena Aluminum is a subsidiary of the Group that specializes in recycled aluminum products for industrial processes.
5. **Steel:** Stena Stål is another subsidiary specializing in recycled steel products.
6. **Oil:** Not the strongest area of the Group, but still an important one, Stena Oil is the *"leading physical supplier of Marine fuels in the Scandinavian and North Sea waters"* (Stena Metall Group, 2015).
7. **Finance:** As such a large company, it has its own internal bank in charge of accounting for its subsidiaries. Some of the divisions even have stocks and bonds in European Markets that are managed by this internal bank.

With a focus on having the most sustainable processes in all of its areas, the Stena Group has its own Innovations and Research Department that focuses mainly on achieving all the available environmental benefits and safety for its clients and itself as well (Stena Metall Group, 2015).

3.3.2. Umicore NV

Umicore is the integration of some very old Belgian mining companies like Société Anonyme des Mines et Fonderies de Zinc de la Vieille-Montagne (1837) and Union Minière du Haut Katanga (1906). Now a colossal company, it employs more than 10,000 individuals over 38 countries and has a turnover of about €8.8billion. Its mission is *"Materials for a better life"*; this means it seeks to develop and produce recyclable materials from recyclable parts and materials as well. Umicore's R&D and technology has the goal to create sustainable value.

Through innovation applied by its more than 900 colleagues in 20 different research centers, and its €140 million per year investments, Umicore strives to achieve sustainability in the following areas:

- **Resource scarcity:** It recovers more than 20 elements including precious and other metals through recycling.
- **Clean air:** To help abide by stricter emissions standards, it provides newer technologies in automotive catalysts.
- **Vehicle electrification:** Produces lithium ion batteries for a new generation of electric vehicles.
- **Clean energy:** Develops highly efficient photovoltaic technologies.

Umicore provides products and services in many industries, which are summarized in **Table 3.1**:

Table 3.1: UMICORE N.V. Industries

Automotive	Recycling	Energy	Chemicals	Electronics	Construction	Optics and Displays	Precious Metals
Emission control catalysts for cleaner air	Recycling of end-of-life rechargeable batteries	Rechargeable battery materials for electrified mobility and portable electronics	Recycling industrial catalysts	Rechargeable battery materials for portable electronics	Zinc powders for anti-corrosive and UV resistant coatings and paints	Optical lenses for clearer night vision & thermal imaging	Recycling and recovering precious & specialty metals
Recycling of end-of-life rechargeable batteries	Recovery of precious & specialty metals	Germanium substrates for space & terrestrial photovoltaics	Zinc compounds for industrial & pharmaceutical solutions	Recycling and recovering precious & specialty metals	Sustainable zinc construction materials	Anti-reflective coatings for better optical lenses	Physical delivery and price-hedging of precious metals
Rechargeable battery materials for electrified mobility	Recycling germanium from electro-optic materials	Thin film materials for high-performance touch screens	Nickel chemicals used in surface treatment applications	Thin film coatings for semiconductors	Cobalt and pre-alloyed powders for stone and concrete cutting tools	Catalysts for TFT & organic LED displays	Precious metals for jewellery and industrial applications
Recycling of catalysts to recover precious metals	Recycling jewellery for re-use of precious metals	Zinc powder for cylindrical alkaline batteries	Platinum equipment for production of high-purity & special glasses	Electroplating solutions for technical and decorative applications	Cobalt and nickel compounds for the production of colors used in ceramics		
Cobalt compounds for better tires	Recycling zinc from the galvanizing industry	Cobalt and nickel compounds as precursors for Rechargeable Battery Materials	Platinum ammonia oxidation gauzes		Cobalt as chemical to ensure fast drying of paints		
Cobalt & nickel compounds to remove impurities from petroleum	Recycling of cobalt out of spent catalyst and Tungsten Carbide recycling side flows	Contact materials to enable power distribution	Precious metals chemicals & catalysts		Brazing alloys for heating, ventilating & cooling installations		
Cobalt powders for hard metal machining and drilling tools			High potency active pharmaceutical ingredients		Contact materials for power distribution		

It also has public shares and stocks in European markets and an amazing website where all its history, technologies, materials, products, services and finances are explained in a very interactive manner (Umicore N.V., 2016).

Most of these companies have had many years to have the global capacity they now present, but many started out as a little local organization based on a garage. As they have grown they have crossed frontiers and have introduced themselves in regions with different legislations and regulations, but this has not prevented their expansion. For the next chapters of this thesis, the walls to break and the enterprises that are already doing so in Mexico will be explored.

4. Mexican Reality

Now that global aspects on E – Waste have been reviewed, it is pertinent to address the particularities that regard this thesis; the situation Mexico faces with its ever-growing electronic waste problem. As it will be mentioned and explored in the following sections, Mexico is starting to steer in the right directions, and with the appropriate push, it may give the third world an example to address the E – Waste problem.

4.1. Government Institutions and Regulations

As it happens in every country, Mexico's regulations set the stage for the enrichment or downfall of its own progress. Due to several factors within its regulatory system, Mexico has been stuck in some areas and has not yet developed the potential to reach a first world status. But things are changing; slowly but surely improvement is coming along, and two of the most promising fields are Energy and Environmental Care thanks to new laws and decrees established by the current administration.

The Environment and Natural Resources Secretariat (Secretaría de Medio Ambiente y Recursos Naturales, SEMARNAT) is the main authority on environmental law in Mexico. It establishes all the regulations concerning the use of Mexican natural resources and the safekeeping of all flora and fauna on national soil. Along with other agencies such as the Ecology and Climate Change National Institute (Instituto Nacional de Ecología y Cambio Climático , INECC) or the National Institute of Geography and Statistics (Instituto Nacional de Estadística y Geografía, INEGI) it carries out studies to help maintain the balance between Mexicans and their resources.

As more resources are consumed and more waste is generated, Mexican society must adapt to continue to prosper. This adjustment is best achieved by the establishment of laws and regulations proposed by the government and its institutions. That said, there are two main regulations controlled by SEMARNAT that include E – Waste management in Mexico. These are designed to protect the environment and those that establish the procedures to manage and dispose all types of waste in different locations (e.g. industrial, municipal, etc.).

The General Law for Ecological Balance and Protection of the Environment (Ley General Del Equilibrio Ecológico y la Protección al Ambiente, LGEEPA) proceeds from the Constitution of the Mexican United States. It states through its various articles (especially Article 137), that it is responsibility of the Secretariat, State and Federal governments to use all means necessary to eliminate any wastes that may be harmful to the environment. Chapter 5 is dedicated exclusively to Hazardous Materials and Wastes (Diario Oficial de la Federación, 2012).

A subsequent directive of this General Law is **NOM-083-SEMARNAT-2003** (SEMARNAT, 2012)**.** It establishes environmental protective measures for the siting, design, construction, operation, maintenance and closure of landfill for MSW. These include:

- Biogases capture
- Leachates recollection

- Proper rain water drainage
- Animal control
- Lightweight material aspersion control

On the other hand, there is the General Law for Prevention and Integral Management of Wastes (Ley General para la Prevención y Gestión Integral de los Residuos, LGPGIR) that classifies E – Waste as waste that needs special handle. Specifically, Article 19 of this law describes E – Waste as technological waste from manufacturers and other electronic products at the end of their lifespan. It also states that state governments are responsible for the specially handled waste. To date, 19 states (Aguascalientes, Baja California, Chiapas, Chihuahua, Durango, Guanajuato, Guerrero, Hidalgo, Jalisco, México City, Michoacán, Nuevo León, Puebla, Querétaro, Quintana Roo, Sonora, Tabasco, Tamaulipas, and Veracruz) have legal framework for special waste management plans. Chapter 2 and Title II of this General Law elaborate on all legal and technical specifications for Special Treatment Waste management plans (SEMARNAT, 2015), (Rojas Bracho, Gavilán García, Alcántara Concepción, & Cano Robles, 2011).

Some electronic equipment contains hazardous materials (e.g. Lead, Mercury, Cadmium, Tellurium, etc.). These are defined in the LGEEPA Chapter V, Article 146 as materials that match one of the characteristics of the acronym CRETIB: Corrodible, Reactive, Explosive, Toxic, (In)flammable, Biological-Infectious. Article 31 establishes the components which contain this type of waste. But also, **NOM-052-SEMARNAT-2005** (SEMARNAT, 2006) establishes the characteristics and procedures to identify, classify, and separate hazardous wastes. Regarding hazardous components in E – Waste, List 5 of the norm classifies the following:

- *"Welding waste from producing electronic circuits containing lead or other metals defined as a toxic hazard.*
- *Waste from solvents used in cleaning the plates in the production of electronic circuits.*
- *Waste generated in the preparation of magnetic pigments and the preparation of mixture for coverage in magnetic tape production.*
- *Waste from the electronic tubes coating during their production"* (SEMARNAT, 2006).

For the proper management of these wastes, the standard **NOM-161-SEMARNAT-2011** (SEMARNAT, 2013) establishes the criteria and procedures to follow in order to establish management plans. Furthermore, the amount of MSW generated in Mexico is calculated by the Social Development Secretariat (Secretaría de Desarrollo Social, SEDESOL) in accordance to what is established in the norm **NMX-AA-61-1985** (SECRETARIA DE COMERCIO Y FOMENTO INDUSTRIAL, 1985).

Other Mexican regulations that in some instances apply to E – Waste are (SEMARNAT, 2012):

- **NOM-147-SEMARNAT/SSA1-2004**: Criteria for remediation of arsenic, beryllium, cadmium, hexavalent chromium, mercury, nickel, lead, selenium, thallium and/or vanadium polluted soil (published on DOF, 11-11-2005).
- **MX-AA-139-SCFI-2008**; Toxic compounds extraction test (PECT) (published on DOF, 06-18-2008).
- **NOM-055-SEMARNAT-2003**; Requirements for hazardous waste confinement site location (published on DOF, 11-03-2004).

- **NOM-056-ECOL-1993**; Requirements for hazardous waste additional infrastructure (published on DOF, 10-22-1993).
- **NOM-057-ECOL-1993, NOM-058-SEMARNAT-1993**; Requirements for hazardous waste confinement site construction and operation (published on DOF, 10-22-1993; DOF, 12-10-2001 respectively).
- **NOM-053-SEMARNAT-1993, NOM-054-SEMARNAT-1993**; Procedure for the extraction and determination of incompatibility between two or more hazardous wastes. Published on DOF, 10-22-1993; DOF, 04-23-1993 respectively).
- **NOM-098-SEMARNAT-2002**; Environmental protection – waste incineration, operation and limitation of pollutant emissions (published on DOF, 10-01-2004)

A representation of the main Mexican regulations and their area of focus in waste treatment are depicted below as a summary.

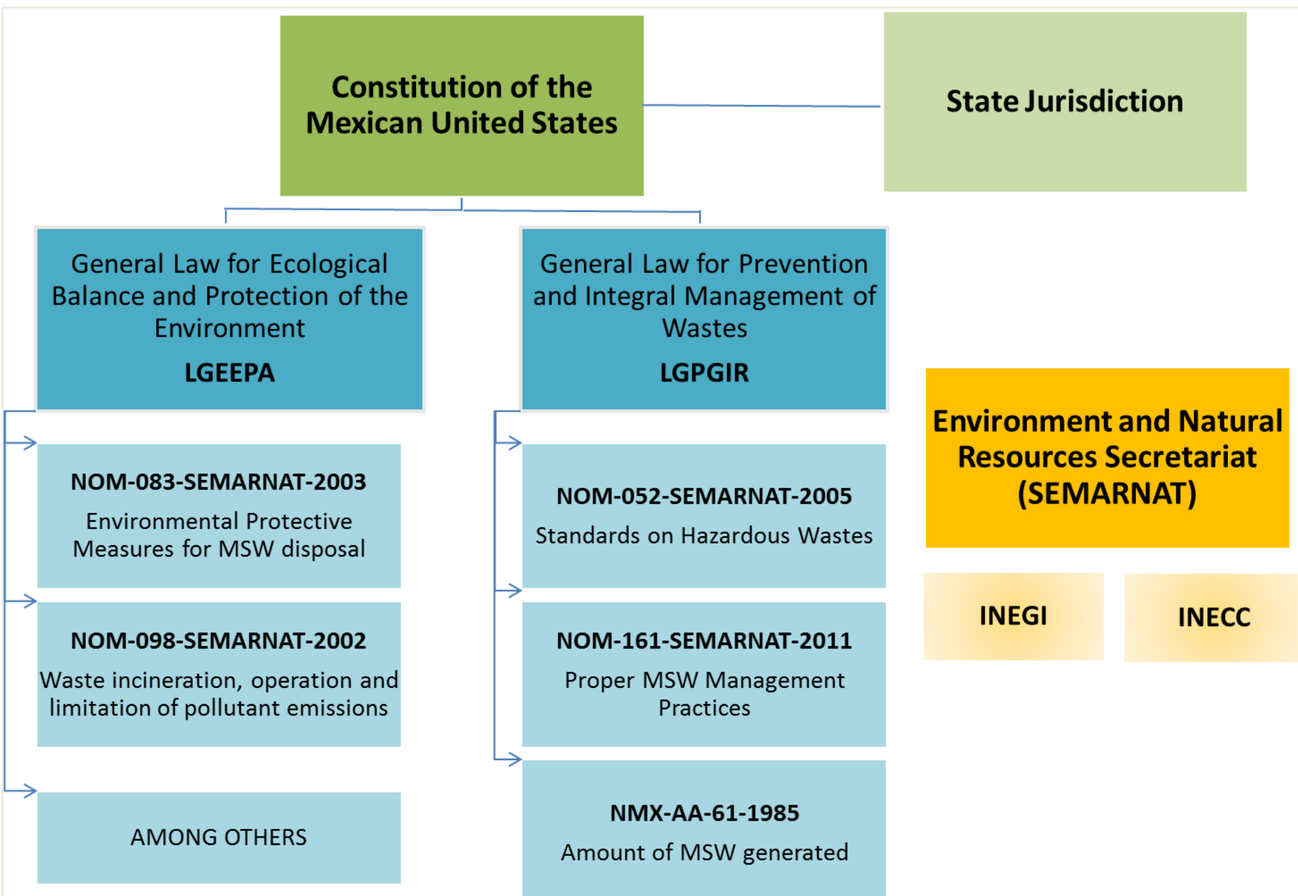

Figure 4.1: Mexican Regulations that involve E – Waste Management

4.2.Private and Governmental Programs

Thanks to the Energy Reform and others, as well as the regulations and agreements mentioned above, the opportunity has opened for many entrepreneurs and foreign companies to enter the world of recycling in Mexico in a profitable way. Here are some examples of these endeavors and their accomplishments so far in the Mexican market. The information below was procured from the website of these businesses, although there was an effort to contact them all for additional information.

4.2.1. Recicladora Electrónica

Company that started in 2012, completely dedicated to the recycling of commercial E –Waste. From the moment the equipment becomes useless, until its reuse or strip down for the refining of parts, Recicladora Electrónica provides the service. One of the reasons it gives for providing the recycling service is to help companies comply with NOM 161 from SEMARNAT (mentioned in previous section). Its set of clients comprises from little to large industries.

It enlists four types of services:

- **Collection of E – Waste:** for eligibility of this service, the only requirements are that the amount of E – Waste is cost-effective for the company and that a list (preferably with pictures) of the disposed equipment is presented before the recollection is made.
- **Data Elimination:** When the waste collected may contain integral information about the client, the physical destruction of any hard disks or any type of recording object is the first step after recollection.
- **E – Waste Reimbursement:** Prices for the waste vary depending on the amount and quality of the disregarded electronics, which are usually bought in batches.
- **Separation and classification of components:** By classification of every part and component and their respective marketability, Recicladora Electrónica makes its revenue.

The organization prides itself on the logistics, prices for the waste, infrastructure it provides, and its aim to make the 3R's be accomplished in great quality (Recicladora Electrónica, 2012).

4.2.2. Recall International

Part of the International Association of Electronics Recyclers, it specializes in the disposal of mobile phones and has several programs for their proper End of Life use. The programs include:

- **EcoPoint's®:** The EcoPoint's® are large receptacles scattered throughout the municipalities (**Figure 4.2** (Recall International, 2012)), where people can securely deposit their old phones. In case the phone is in conditions to be reused, it is required to put a label on the phone before placing it inside the collection bin.
  The agreements between Recall International and the local governments helped this initiative be set forward. There are currently 500 EcoPoint's® only in Mexico City.

Figure 4.2: EcoPoint®

- **Agreements with carrier companies like Telcel:** The recollection program from mobile carriers has the following premises purchase (**Figure 4.3** (Recall International, 2012)):

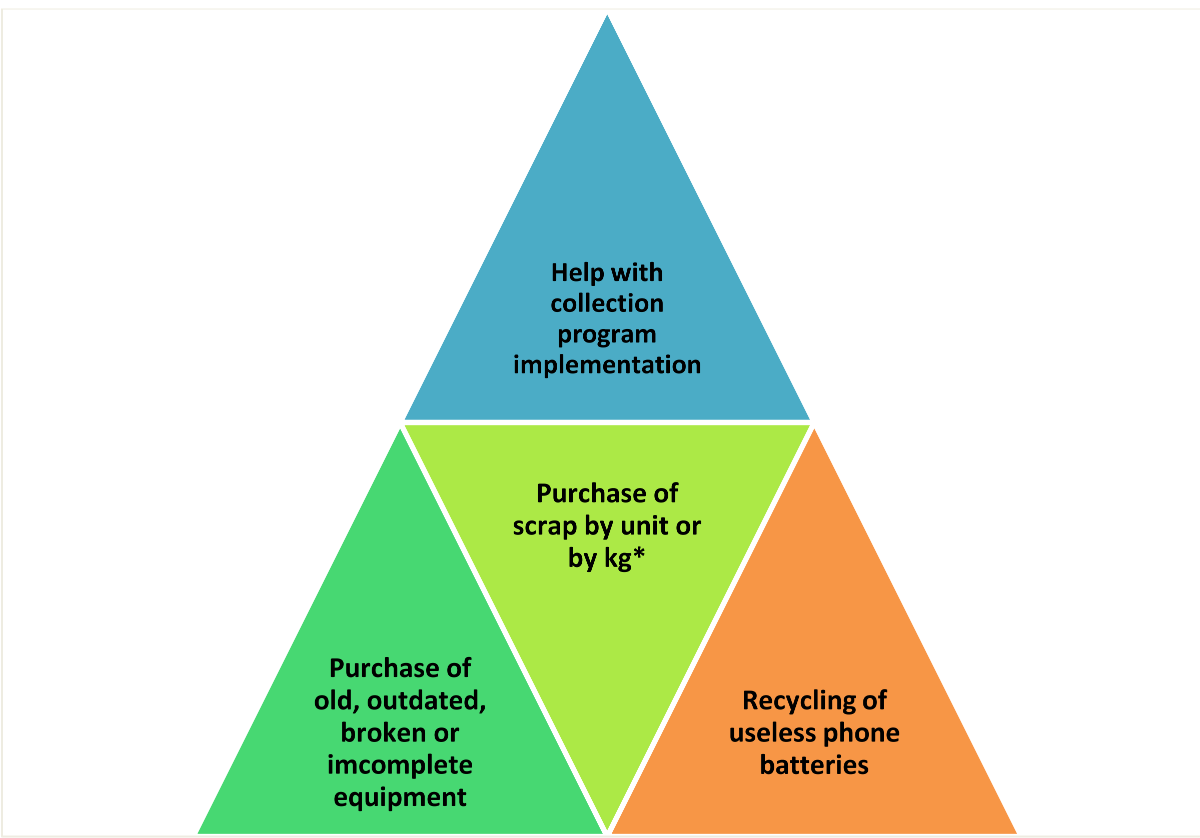

Figure 4.3: Mobile Carrier Program

* Depending on the amount and models, the purchase may be done by kg of merchandise or by a fixed unit price assigned to each model.

They also offer the option of installing an EcoPoint® on site for recollection and later sale to Recall International.

This program also applies for small, medium and large companies that wish to establish business relationships with Recall International.

- **Donations:** These are divided into two categories.
    - Donations of < than 40 phones; they add up to other similar donations and then are taken to a designated charitable institution.
    - Donations > than 40 phones; the donor chooses the institution where the phones are to be reused.

They have a fund raising modality where they enable individuals with the possibility of collecting the neighborhood's old phones (with the help of campaign material sent by Recall International) and then receiving funds by selling them to Recall International (Recall International, 2012).

4.2.3. Secretaría del Medio Ambiente del Distrito Federal (SEDEMA)

Started in 2013 by SEDEMA, Reciclatrón is a monthly organized event proposed by the Government of Mexico City to recycle all type of household E – Waste. All collected scrap is sent to a company called Recupera for its primary separation. The most significant categories recovered, for which people are asked to separate previously, are (SEDEMA, 2016):

Table 4.1: Reciclatrón Categories

Categories			
A	B	C	D
Keyboards, printers, fax machines, DVD/VHS/Beta, MP3, mini consoles, cameras, camcorders, scanners, mini components, radio-recorders, fixed phones, cordless phones, projectors, No-breakers, mouse, radios, car radios, multiplexers, amplifiers/speakers, equalizers, microwaves, vacuum cleaners, blenders, irons, dishwashers, dryers, plates, coffee makers, hair dryers, engines	CPUs, monitors, laptops, mini laptops, hard drives, televisions	Mobile phones and batteries	Chargers, cables, discs and movies

Later on, the recovered material is sent to Cali Resources S. A. de C. V., in Tijuana, Baja California for its proper reuse and recycling.

The results for last year are displayed in **Table 4.2** (SEDEMA, 2016):

Table 4.2: Reciclatrón Results 2015

Edition	Place	Date	Net Weight (tons)	Category A (tons)	Category B (tons)	Category C (tons)	Category D (tons)	People
1	UAM-Xoc	Jan 29 & 30	18.53	7.82	10.59	0.02	0.10	566
2	UAM Azcapotzalco	Feb 27 & 28	16.30	6.82	9.34	0.03	0.12	478
3	Centro Deportivo Xochimilco	March 27 & 28	13.03	5.45	7.47	0.02	0.10	323
4	ESIME Culhuacan	April 24 & 25	8.62	3.33	5.21	0.01	0.07	241
5	Bosque de Tlalpan	May 15 & 16	6.86	2.65	4.15	0.01	0.05	188
6	UAM Rectoría	June 25 & 26	18.26	7.51	10.62	0.03	0.11	365
7	Bosque de San Juan de Aragón	July 24 & 25	15.34	6.48	8.72	0.03	0.12	507
8	Zoológico "Los Coyotes"	Aug 28 & 29	21.57	8.89	12.53	0.03	0.12	554
9	IPN Zacatenco	Sep 24 & 25	33.78	15.22	18.23	0.06	0.27	699
10	UNAM	Oct 29 & 30	31.14	12.28	18.70	0.04	0.13	662
11	Universidad Iberoamericana	Nov 19 & 20	15.31	6.13	9.09	0.02	0.07	228
TOTAL			**198.75**	**82.58**	**114.63**	**0.29**	**1.25**	**4,811**

4.2.4. REMSA

Recicla Electrónicos México (REMSA) is a 100% Mexican company dedicated to the treatment of all kinds of E – Waste from all kinds of sources. It has the necessary infrastructure to identify, collect, separate and recycle monitor glass, plastics, electronic cards and metals (ferrous and non-ferrous). It has branches all over the 31 states of the Mexican Republic and the Federal District.

It serves companies by recollection of their E – Waste and the subsequent treatment needed to reduce, reuse and recycle. For recollection logistics it applies two methods; the direct recollection by vehicle or payment for parcel deliveries. In the case of hard disks, it provides an in-situ destruction procedure; for any other type of recording device, it grants the client a "Destruction Certificate" 30 days after the recollection of the waste.

Its main program is called "Punto Verde®" and it has the following objectives (REMSA, 2016):

- Create conscience in Mexican society through various blogs, events, and conferences.
- Establish donation rallies to help schools with equipment that still works. These computers get refurbishment and a 6 month warranty seal by Punto Verde®, and they must be returned to Punto Verde® at the end of their second life.

- Establish meetings with government officials to demand compliance of new environmental regulations to manufacturers that evade responsibility through corruption and bribes.
- Distribute recycling points (Puntos Verde's®) and recycling events (Reciclón®) all over the country where people are able to bring their E – Waste. These sites are coordinated by volunteers of non-profit organizations or government employees.

It exemplifies its recovery process through the following diagram (REMSA, 2016)[k]:

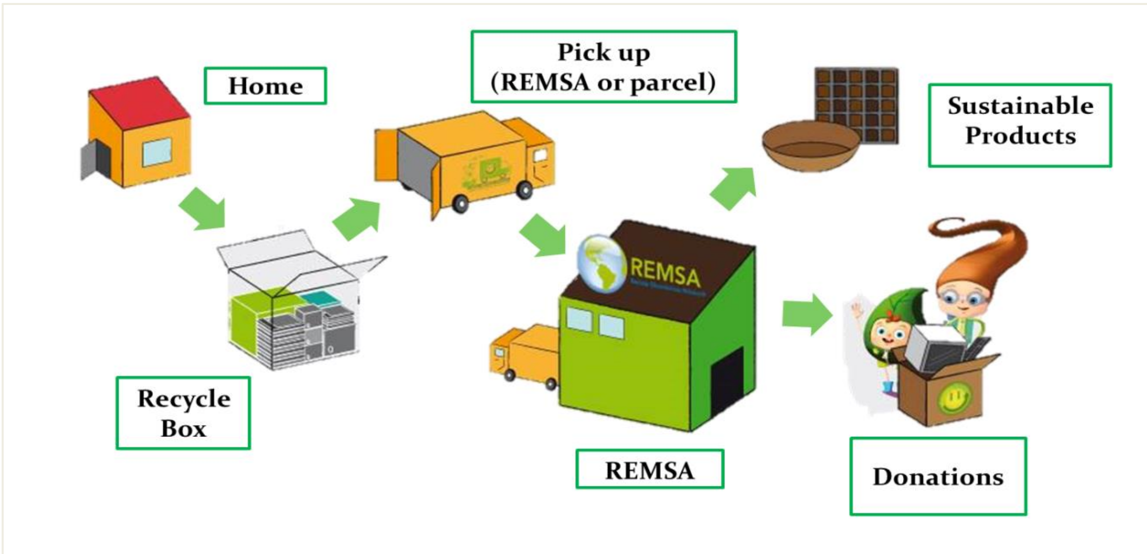

Figure 4.4: REMSA Recovery Process

Other E – Waste management businesses, including collectors, disassemblers, and recyclers are displayed in **Table 4.3** along with their most significant characteristics:

[k] All logos and trademarks are property of their respective company

Table 4.3: E – Waste Management Companies in Mexico

Name	Collection		Disassembly	Destruction of Info		Reuse		Recovery			
	Fixed	Personalized		In Situ	Outside	Donations	Resellers	Plastics	Glass	Metals	Hazardous
Glezco Plásticos S.A. de C.V.	✓	✗	✓	✗	✓	-	✓	✓	-	✓	-
Proambi, S.A. de C.V.	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓
TES-AMM Latin America S. de R.L. de C.V.	✗	✓	✓	✗	✓	-	✓	✓	-	✓	✓
WRS World Recycling Service S. de R.L. de C.V.	✗	✓	✓	✗	-	-	-	-	-	-	✓
BT Company México S de R.L. de C.V.	✓	✗	✓	✗	✓	-	-	✓	✓	✓	-
ECORECIKLA Servicios de Reciclaje Mixtos SA de CV	✓	✗	✓	✗	✗	-	-	✓	✓	✓	✓
Grupo Ecológico MAC S.A. de C.V.	✗	✓	✓	✓	✗	-	✓	-	-	✓	✓
Promotora Ambiental, S.A.B. de C.V	✗	✓	✓	✗	✓	✓	-	✓	✓	✓	✓
AER Worldwide LLC.	✗	✓	✓	✗	✓	-	✓	✓	✓	✓	-
Residuos Industriales Multiquim S.A. de C.V.	✓	✗	✓	✗	✓	-	✓	✓	✓	✓	✓
Ing., Technology Conservation Group Inc.	✓	✓	✓	✗	✓	-	✓	✓	✓	✓	-
In Cycle Electronics Inc.	✗	✓	✓	✗	✓	-	✓	✓	✓	✓	-
Destrucciones y Reciclados Industriales Rubert, S.A. de C.V.	✓	✓	✓	✗	✓	-	✓	✓	-	✓	-
TBS Industries de México, S.A. de C.V.	✓	✗	✓	✓	✓	-	✓	-	-	-	-
Sistemas de Tratamiento Ambiental (SITRA S.A.)	✗	✓	✓	✗	✓	-	-	-	-	-	✓
Environmental Recycling (EER), S.A. de C.V.	✗	✓	-	✗	✓	-	-	-	-	-	-
Recycle Tech, S.A. de C.V.	✓	✗	✗	✗	✓	-	✓	✗	✗	✗	✗
Orkosistem Recicla S.A. de C.V.	✗	✓	✗	✗	✓	-	✓	✗	✗	✗	✗
TECNOREC S.A. de C.V	-	-	✓	✗	✗	-	✓	✓	✓	✓	-

As it may be gathered from the table, most of the companies manage their clients' sensible information and destroy it; although most of them do it at their respective facilities and not in presence of the client. More than half include recollection services, which gives a lot of added value to the service. Also, the majority of the companies disassemble the waste in order to make use of the components. There are very few that make donations, and most make their profits out of the scrap and recovered materials. Finally, it can be observed that many provide recovery of various types of materials, although most are not prepared to handle the hazardous wastes that may be carried by the E – Waste.

4.3. Public Motivation and Actions

The last section explored the extension and reach of the current market of E – Waste management programs and companies in Mexico. In this section, public awareness and attitudes towards this "industry" is summarized to provide the counterpart of this market and allow a richer analysis.

To get a better idea of this awareness, a survey was developed online and sent to people of middle to high level of income in Mexican standards (US$25,000 – $125,000 annual income). The questionnaire was responded to by 202 people and all questions are shown in **Appendix 1** of this report. A summary of the results is described below.

- It is clear that there is a certain degree of conscience among the Mexican wealthier sector, for around **80%** separate garbage.
- Nonetheless, households and offices that do separate wastes do not practice a complete separation; **~60%** only make a distinction between Organics and Inorganics.

  If from the beginning, this exercise is not carried out, the first bottleneck in sustainable E – Waste management is encountered. A first and critically important step must be to create public awareness of proper separation. Thankfully, E – Waste is properly distinguished in the minds of Mexicans as may be seen in the questions of this survey (**Appendix 1**). The problem is mainly of logistics and not so much of ignorance; at least in this economic sector of Mexican economy.
- People in this economic status are aware that E – Waste needs to be treated differently than regular trash. Most of the claimants (**86%**) separate their electronics for disposal; the problem comes when they do not know what to do with them.
- Almost half of them (**45%**) try to pass on the electronics for further or other uses and/or they look to give them to parties responsible for proper recycling.
- Unfortunately, more than half (~**60%**) of the interviewees do not know any recycling programs.

  How can there be public conscience and action toward a sustainable management, when the options for treatment are not even known? These results call for development of campaigns by the private initiatives and government.

- People, who do know recycling programs, know these programs from private companies rather than from the government. This undoubtedly calls for serious local and national governmental efforts that are long overdue.

Now, for deeper insight, the results from a 2010 survey made by the INECC to 1,000 people of middle to low income ($2,000.00 – $10,000.00 USD annual income) in the Valley of Mexico's Metropolitan Area (ZMVM in Spanish) were taken into account and displayed here (Meraz, 2010). They asked the interviewees about the amount of time they tend to use certain electronics and their opinion on the destination of these electronics after they have been discarded. The study was applied at offices, schools and shopping malls.

The results of this investigation provided the following information:

- **57%** of the people interviewed do not believe E – Waste poses a risk to human health.
- **34%** claim to know what happens to their electronics after they get rid of them.
- Out of this 34%, they think that E – Waste goes to:

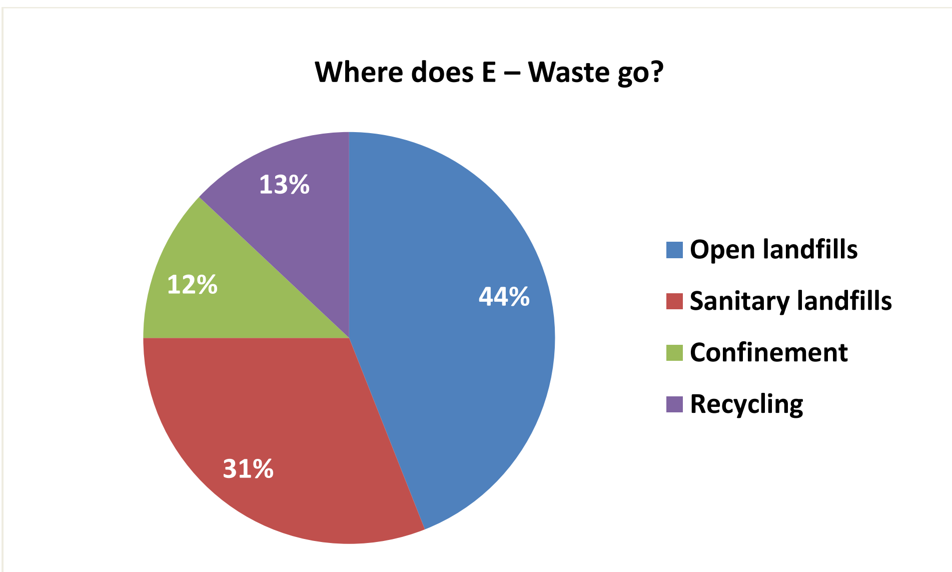

Figure 4.5: E – Waste Destination

- When asked about what method of disposal they use, the answers were:

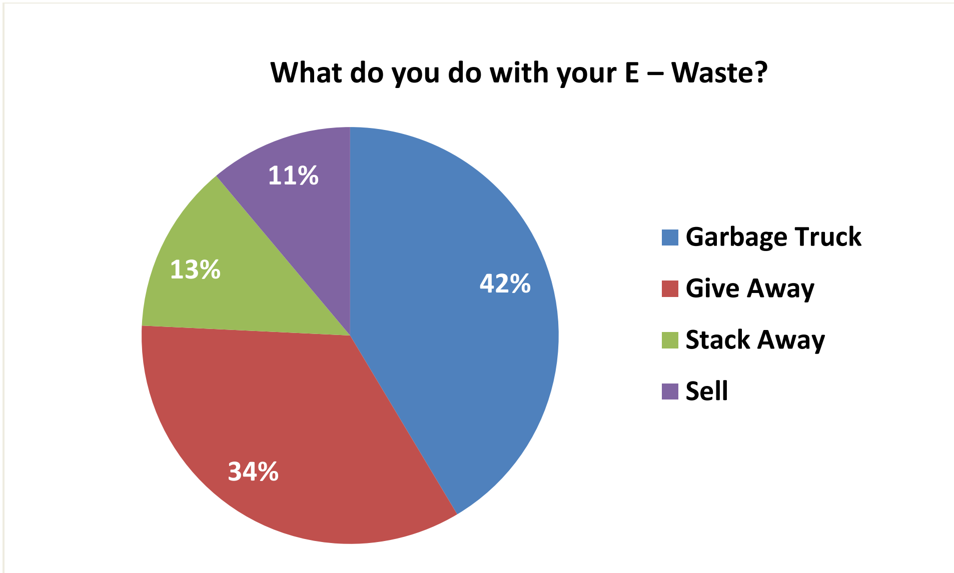

Figure 4.6: Disposal Method

- **86%** of the examined claim not to know any recycling programs or companies.
- Out of the **14%** that do identify recycling initiatives, they know them through the government, private initiatives or educational institutions.

From the previous section it was concluded that the tracks have been laid and that governance towards E – Waste, as well as initiative to alleviate the problem has begun. However, public awareness towards the situation is still poor; especially in the lower economic strata. Hopefully, the results gathered from this and the Mid-Income surveys will provide a handful of useful ideas for orienting the future of E – Waste management in Mexico.

Clarity to some belated points needed to be addressed, and a summary of the others that have already been laid out and just need follow up and growth will be given in the Recommendations of this research. But before giving any suggestions to these points, the last link between the end of life of electronics' components and their "rebirth" must be held under review. Metals extracted from E – Waste may provide valuable assets to one of Mexico's most important industries: Mining and Metallurgy.

4.4. Recovery of Metals from E – Waste

4.4.1. Mining and Metallurgy

These two activities refer to the extraction, melting, and refining of metals and non-metals for the production of different items and components. Due to the mineral and mine availability in Mexico, these industries provide around 5% of the national GDP (Góngora Pérez, 2013).

Mines in Mexico are distributed all over the country, but the ones that provide the most important metals are concentrated on the NW as it can be seen in **Figure 4.7** (Belasko, 2014).

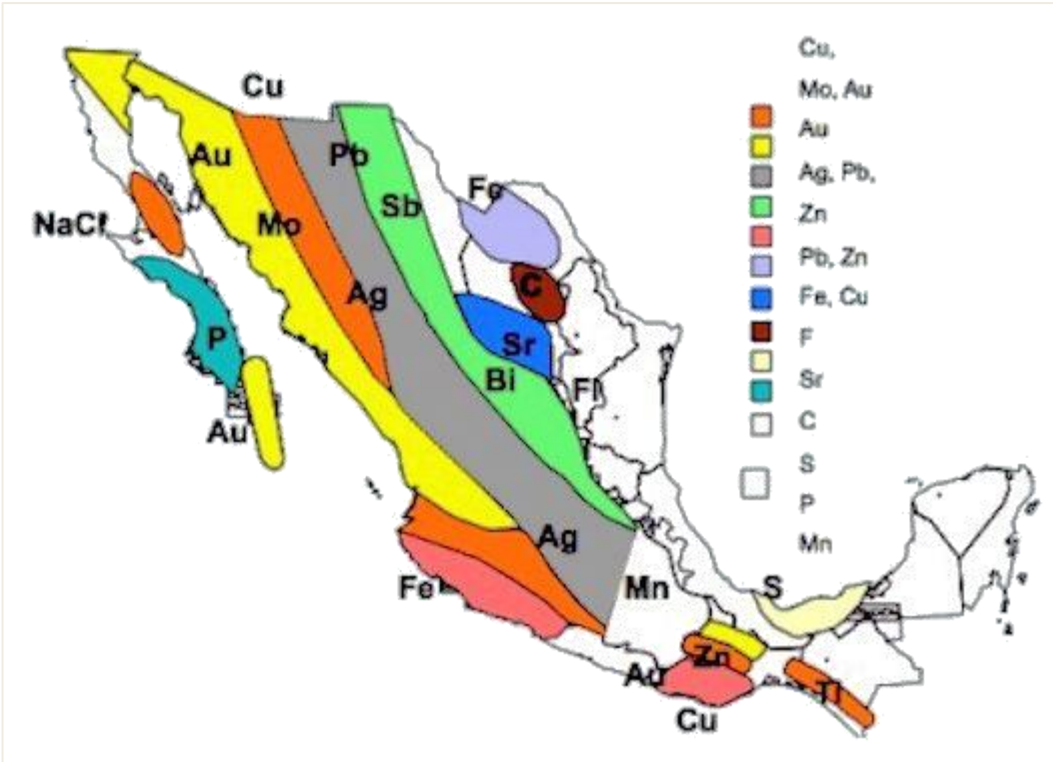

Figure 7.7: Metalogenetic Map

As seen on the map, the principal metals procured from the various mines in the Mexican Republic are Iron, Silver, Copper, Zinc, Lead, and Gold. Taken from the Bank of Economic Information of INEGI in Mexico, the production of these metals in 2014 and 2015* (up until November), along with its variation is given in **Table 4.4** (INEGI, 2016).

Table 4.4: Principal Metals Production in Mexico 2014-2015*

Material/Period		2014	2015*	Variation
Gold		98	112.211	14.31%
Silver		4,730	4,913.904	3.90%
Lead		196,746	202,773	3.06%
Copper	**Tons**	452,419	458,763	1.40%
Zinc		449,146	460,625	2.56%
Iron Pellets		7,855,096	7,732,114	-1.57%

Besides these main examples, there was an overall growth in the industry of about 2.6% between November 2014 and November 2015 (INEGI, 2016). In fact, this growth may be attributed in part to the Mining Development Program 2013-2018; "Programa del Desarrollo Minero 2013-2018 (SE, 2014)" from the SE, which is currently in action.

4.4.2. Metallurgic Companies in México

There are many mining-metallurgic companies listed in the Economy Secretariat in Mexico. For the aim and objectives of this thesis, some of the ones that have the biggest Copper smelting capacity are described below. For further information on other important mining and metallurgic companies in Mexico, refer to **Appendix 3**:

México Compañía Constructora S.A. De C.V. (Grupo México)

There are several mining and metallurgic industries in Mexico; Grupo México is one of the biggest ones, if not the biggest. It was founded more than 70 years ago. It is the fourth main copper producer in the world and it has been in the Mexican Stock Market since its IPO (Initial Public Offering) in 1966. It has three main divisions: Mining, Transport and Infrastructure. These generated revenues for $1,705 million USD in 2014.

The Mining Division is represented by subsidiaries in Mexico, Peru and the U.S. (Southern Copper Corporation and American Smelting and Refining Co.) that own 14 mines (largest reserve in the world) through a main subsidiary called Americas Mining Corporation (AMC). To give an example of its output, its production of copper in Mexico in 2014 was of 118,600 tons.

It works all year long to promote and increase sustainability by investing in infrastructure that enables it to shred and transport mining material in a more efficient way (200, 285m^3 of reused ballast scrap for train tracks). It also utilizes energy for its mining operations from the Solar PV plant "Proyecto Solar Avalon" (35MW), as well as the wind farm "El Retiro" (239GWh annually). It also reported in 2014 to have recycled 63% of the 12,294 tons of hazardous waste it generated. Nonetheless, it has no projects regarding E – Waste as a source of copper for its industry (Grupo Mexico, 2015).

Peñoles S.A.B. de C.V.

This Mexican mining company has been in existence since the 19th century and is one of the biggest mining and chemical companies in Mexico. As a matter of fact, it holds the leadership in several markets (zinc and silver mostly). It owns 14 mines that extract base and precious metals all over the Mexican Republic. Its production in 2014 was of 17,956.6 metric tons of gold, 1,542.21 metric tons. of silver, 79.8 million metric tons of lead, 265.7 million metric tons of zinc and 37.4 million metric tons of copper. Its total revenues were $1,200 million pesos (~ $640 million USD) (Peñoles, 2016).

Even though it is a very big company, its recycling numbers are rather low. In its 2014 report, it acknowledges only a 6.79% recycling percentage of all its wastes; this means 585,871 metric tons of residues out of its 8,630,515 metric tons of total waste (Peñoles, 2015).

Minera Frisco S.A.B. de C.V. (Grupo Carso)

Minera Frisco is a Mexican mining company owner of the mines El Coronel, Asientos, Provenir, Tayahua, San Felipe, María, San Francisco del Oro, Ocampo y Concheño. It extracts gold, silver, copper, lead and zinc from these mines and has been operating since 1962 under its current name. In 1985 it was bought by Grupo Carso. According to its annual report, its gold and silver production was of 12 tons, and 251 tons respectively, which represented considerable increase compared to 2013. Zinc production decreased by 7% (58,913 tons), and the production of lead and copper fell 3% to 18,275 and 26,296 tons respectively. This translated to revenues of only $495 million pesos (~40 million USD); in 2013, the revenues had been of $2,301 million pesos (~ 176 million USD) (Minera Frisco, 2016).

Through the use of third parties, it has established proper waste management. It operates under all legislation and strives to ensure minimization of confinement or landfilling of its wastes. Its recycled materials in 2014 consisted of wood, PET and cardboard from two of its operating facilities (Minera Frisco, 2015).

Although there may be some very substantial initiatives to be sustainable, as it may be seen through the information provided, there is not yet a noticeable link between the E – Waste recyclers and the producers of virgin metals. Given the amounts of both recovered material and raw material usage for these industries, it would be highly beneficial for both sides to cooperate and engage in business. To evaluate the potential Mexico has to integrate E – Waste recycling into the mining industry business model, a BCG Matrix[l] including some competitors, was developed for the companies described above[m].

[l] A BCG Matrix (Stern & Stalk Jr., 1998) consists in a relation between the growth rate of a company and its relative position in the market. It is divided into four quadrants classified as STARS: high growth and high share; CASH COWS: low growth, high share; ?: high growth, low share; DOGS: low growth, low share. It is used to evaluate the investment potential for a product in a company or a company itself.

[m] All logos and trademarks are property of their respective company

Figure 4.8: BCG Matrix for E – Waste Recycling Potential

The matrix was developed on the basis of the information provided above, as well as studies conducted by PricewaterhouseCoopers,LLP (PwC) (PWC, 2011) and Cámara Minera de México (CAMIMEX) (CAMIMEX, 2014) on the major participants in the Mexican market in 2014.

From the graph, it is noticeable that the majority of the companies are at their highest growth point, or at least still generating good revenues. This is no surprise since these are the best mining companies in Mexico. Only two are left on the right side; one still in growth and the other waning because of difficult market conditions. However, among these few chosen there is something that stands out; the first places in the diagram are companies that produce copper. Copper recovery from E – Waste is essential, for it not only has significant value in itself, but the impure copper produced in smelters contains the precious and rare metals that have the most value within the E-waste. So, it can be concluded that the copper smelters of Mexico hold a key for closing the lifecycle of electronics.

4.4.3. Copper Smelters

Special interest was taken on copper smelters in Mexico, since production of copper supports a measurable amount of Mexican Economy. For example, the copper smelting capacity of Mexico is around 500,000 tons, concentrated within a few companies (García de Quevedo, 2016). Furthermore, it is important to pay attention to the extraction of copper, since precious and rare metals are extracted alongside the copper slag in metallurgical processes as mentioned before. The study applied here delves into the current relationship between the E – Waste recyclers mentioned in previous sections and the principal copper smelters in the country. These smelters were identified from a business study conducted by the National Institute of Social Economy of Mexico (INAES) in 2012 (INAES, 2012). Information was required from these companies regarding the metallurgical processes applied in their plants, and whether or not they used E – Waste as part of their metal sources. The results (from the companies that were able to provide information) were as follows:

Table 4.5: Copper Smelters of Mexico Using E – Waste

Company Name	E – Waste Use	Metallurgical Process
Ames Sistemas de Riego, S.A. de C.V.	NO	BLAST FURNACE/OTHER
Fundición Inyectada del Centro, S.A. de C.V.	NO	BLAST FURNACE/OTHER
Aluminio y Bronce de Saltillo, S.A.	NO	BLAST FURNACE/OTHER
Fusión y Aluminio, Bronce y Hierro, S.A. de C.V.	NO	INDUCTION FURNACE
Etal, S.A. de C.V.	NO	INDUCTION FURNACE
Cobre de México, S.A. de C.V.	NO	CONTIROD
Fundición Artística, S.A.	NO	GAS FURNACE
Fundición de Campanas, S.A. de C.V.	NO	GAS FURNACE/MELTING POT
Fundición de Precisión Eutectic, S.A. de C.V.	NO	INDUCTION FURNACE
Bronces Comerciales, S.A.	PLANNED	BLAST FURNACE/OTHER
Fundiciones de Metales Centrifugados, S.A. De C.V.	YES	INDUCTION FURNACE/ELECTROLYSIS
Fundición y Maquinados García, S.A. de C.V.	NO	NOT DISCLOSED
Industrial P&AC S.A. de C.V.	NO	BLAST FURNACE/OTHER
Bronces y Aleaciones de Monterrey, S.A. de C.V.	NO	BLAST FURNACE/OTHER
Okendo S.A. de C.V.	NO	BLAST FURNACE/OTHER
Industrial Metalúrgica Imesa, S.A. de C.V	NO	BLAST FURNACE/OTHER
Bronces Potosí, S.A. de C.V.	YES	BLAST FURNACE/OTHER
MECOMSA S.A. de C.V.	NO	METAL PROVIDER/NO SMELTING
Stannum de México S.A.	NO	BLAST FURNACE/OTHER
FITSA, S.A. de C.V.	NO	CUPOLA FURNACE
Industrias Rodas, S.A. de C.V.	YES	CUPOLA FURNACE
Plata Panamericana S.A. de C.V.	NO	NOT DISCLOSED
Grupo Mexico S.A. de C.V.	PARTIALLY	LIUTENANT CONVERTER
Industrias Peñoles S.A.B. de C.V.	NO	BATCH LEACHING AND ELECTROLYSIS
Grupo Carso S.A.B. de C.V. (Minera Frisco)	NO	NOT DISCLOSED

Table 4.5 shows that only three copper smelters in Mexico, out of 25, include recycled metals in their feedstock. A fourth smelter has plans to start working with electronic cards (Bronces Comerciales). As for the metallurgical processes they employ for smelting, it can be observed that these are predominantly simple furnaces and kilns with an exception of a couple that use more advanced processes like Leaching and Electrolysis (Peñoles and Fundiciones de Metales

Centrifugados). It is also worth mentioning that out of these 25, three of the largest ones are Grupo Mexico, Peñoles and Grupo Carso; from which only Grupo Mexico has a partial use for E – Waste.

A great area of opportunity can be seen here since the smelting capacities of these "big three" are more than capable enough to incorporate the potential recovery of copper from electronic waste (García de Quevedo, 2016) (Peñoles, 2016). As it may be seen in **Table 4.6**, the amount of copper that could be extracted from E – Waste if all E – Waste generated was collected and smelted is equivalent to 14% of the total smelting capacity in Mexico. The added value given by this recoverable metal to the Mining Sector is definitely worth boosting.

Table 4.6: Mexico's Smelting Capacity by Company and E- Waste Copper Potential

Smelter	Copper Feedstock to Smelter [tons/yr]	Smelting Capacity [tons/yr]
Grupo Mexico	1,000,000	250,000
Grupo Carso	900,000	225,000
Peñoles[n]	180,000	36,600
TOTAL[o]	**2,800,000**	**511,600**
E - Waste Generated and Recovered	1,000,000	
Copper Content in E - Waste	**7%**	**70,000**
Percentage of E - Waste Copper in Smelting Capacity		**13.68%**

[n] Value includes other metals besides copper

[o] There is another "big" copper smelter other than Peñoles (Elementia, S.A.B. de C.V. with a capacity of 70,000tons/yr (Elementia, 2015)), but no information regarding E – Waste use could be gathered.

5. Environmental Analysis

As one final section of this research, the environmental aspects regarding sustainable E – Waste management in Mexico are discussed. This segment provides further insight into the threats that ecosystems and human health in the Mexican Republic are being exposed to by the unsanitary disposal of electronics. The threats, as well as the potential benefits of addressing these problems are explained in subsections.

The benefits include, but are not limited to:

- Conservation of natural resources, especially rare and precious metals
- Reduction of pollutants and hazardous materials emissions to the environment
- Reduction in energy use by reducing extraction and manufacture processes
- Reduction of GHG emissions by reducing extraction of metals and manufacture processes
- Improvement of human health by reducing exposure to hazardous wastes leached from disposed electronics

5.1. Conservation of natural resources

The technique through which avoidance of depletion of mineral resources is achieved is by the optimum recovery of the raw materials that constitute E –Waste. As it has been examined, the majority of these components are metals and plastics, with some small percentage of glass, wood, or other materials. From these components, the most valuable are the metals; especially the rare earth and precious metals.

Similar to the example for the copper used in E – Waste via smelters, and given the brief description of the technologies and methodologies given so far for the recovery of materials, it is possible to perform a simple analysis of their potential benefits provided the following assumptions:

- Preprocessing of E – Waste is done mostly by hand, although shredding and grinding is done mechanically.
- Collection of materials by formal recyclers is of around 90% (Grupo Reforma, 2011).
- Recovery of materials by informal recyclers is not included in the analysis. There is little accurate quantification of the amount of E – Waste collected, and even less of the amount recycled.
- Only 10% of all generated E – Waste is recycled (La Razón de México, 2015).
- A general composition of E – Waste by weight is used.
- Plastics are mostly recovered by physical separation. The fraction that burns in the recovery process of the metals is negligible and regarded as combustion fuel.
- Glass is not considered in the analysis
- A hydrometallurgical process is done for the recovery of the metals. It is also assumed that pyrometallurgy and smelting have similar efficiencies.

If there were 1,000,000 metric tons approx. of E – Waste generated in Mexico in 2014;

Table 5.1: Potential Metal Recovery through Hydrometallurgy

E – Waste Generated (tons)	E – Waste Recollected (tons)	Pre-processed (tons)	Material	Fraction in E –Waste (%)	Fraction in E –Waste (tons)	Efficiency	Amount Recovered (tons)
1,000,000	100,000	90,000	**Cu**	7.00%	6,300	**99.10%**	6,243.30
			Au	0.01%	9	**97.00%**	8.73
			Ag	0.01%	9	**98.00%**	8.82
			Pd	0.01%	9	**93.00%**	8.37
			Al	4.70%	4,230	**93.00%**	3,933.90
			Fe	40.00%	36,000	**98.00%**	35,280.00

The benefit of this recovery can be seen through the following example. In 2014, 98 tons of gold were produced in Mexico; if gold from E – Waste had been recovered that year, 8.89% (8.71 tons) could have been saved from extraction. Recovery from other metals represent between 0.1% and 5.0% of their respective 2014 production. This number does not seem much, but this implies only a 10% recycling of all E – Waste generated; if recycling was increased, so would the recovered amounts. Moreover, out of the proposed million tons generated, 10,203.12 tons of non-ferrous metal could be recovered. This number confirms that the capacity of smelters in Mexico reported in the previous section.

The recovery efficiencies of the hydrometallurgical process were gathered from a review of metallurgical processes applied to E – Waste by Khaliq, et. al. (Abdul & et. al., 2014) and the EPA Waste Reduction Model (WARM) Standards (EPA, 2015). As mentioned in **Section 2.2**, hydrometallurgy is a process that needs perfection to reach industrial scale; this makes it expensive. But if pyrometallurgical approaches were applied (Noranda Process), these would reach very similar efficiencies for all metal fractions and could be implemented at reasonable costs for the Mexican market. Pyrometallurgy still has a lot to offer for the recovery of metals; newer and cheaper technologies are being developed, and their marketability looks promising.

It is important to consider that even though mineral reserves in Mexico are still abundant, it is perfectly known that resources of many metals included in electronics are being exhausted at a very fast rate. Therefore, it is essential to provide industries with the means to achieve a Circular Economy for the sake of future generations.

5.2.Hazardous materials reduction

During the account of the composition of E – Waste in **Section 1.4**, it was seen that the main hazardous substances are Beryllium, Brominated Flame Retardants, Lead, Cadmium, Mercury and PVC (to give some examples) depending on the electronic device. Some of these substances like the PVC coatings may be easily removed and handled, but the heavy metals are harder to separate.

Even so, there are many processes through which these metals may be recovered and even put to further use.

This is reflected on **Table 4.4** in **Section 4.2**. Some of the recycling initiatives in Mexico include hazardous material handling in their treatment portfolio. Be that as it may, the number of initiatives doing so is less than half. This is a big area of opportunity for E – Waste management in Mexico. Furthermore, informal recycling is not likely to treat hazardous components of electronic waste, or at least not in a safe manner. This fact emphasizes the need to promote proper management.

To provide a quantitative example; **Table 5.2** (Robinson, 2009) provides the hazardous material content in some electronic devices and an overall estimate of the current control done in Mexico in 2014 to reduce the release of these components to the environment.[p]

Table 5.2: Estimation of environmental contaminants arising from E-waste disposal or recycling

Contaminant	E –Waste Component	E –Waste concentration (mg/kg)	Amount generated In Mexico (tons)	Amount recycled By Initiatives (tons)
Total Amount of E – Waste			**941,700**	**42,377**
Polychlorinated biphenyls (PCB's)	Condensers and transformers	14.00	13	0.59
Americium (Am)[q]	Smoke detectors	0.0015	0.0014	0.0001
Antimony	Flame retardants and plastics	1,700.00	1,600	72
Barium (Ba)[r]	Getters in (CRT's)[s]	0.000000023	0.000000021	0.000000001
Cadmium (Cd)	Batteries, toners and plastics	180.00	170	8
Chromium (Cr)	Data tapes and floppy disks	9,900.00	9,323	420
Copper (Cu)	Wiring	41,000.00	38,610	1,737
Indium (In)[t]	LCD displays	257.60	243	11
Lead (Pb)	Solder, CRTs and batteries	2,900.00	2,731	123
Mercury (Hg)	Fluorescent lamps, batteries and switches	0.68	0.64	0.03
Nickel (Ni)	Batteries	10,300.00	9,700	436
Tin (Sn)	Solder and LCD screens	2,400.00	2,260	102

[p] Concentrations of hazardous substances in electronic waste components reported in the table are estimations gathered from the information sources
[q] Reference value for concentration from (World Nuclear Association, 2014)
[r] Reference value for concentration from (Mear, Yot, Cambon, & Ribes, 2006)
[s] Cathode Ray Tubes
[t] Reference value for concentration from (Takeshi, Igarashi, Ishiwatari, Furukawa, & Yamaguchi, 2013)

Zinc (Zn)	Alloy in general components	5,100.00	4,803	216
Total			**69,453**	**3,125**

From this table it can be detected that the biggest contaminants are Copper, Chromium and Nickel. These fortunately have an added value aside from the benefit of their removal from the environment if recovered. Other components with significant concentrations, but that may not be given further use still need to be better handled than what is estimated here. More initiatives need to include hazardous waste management in their E – Waste recycling practices, but also the government should be further involved as well. As it is clearly seen, control of these substances still has a long way to go, not only for the protection of human health and ecosystems, but for the advantages the recycling of these components represent.

5.3.Energy saving

The main focus for saving energy in E –Waste starts with analyzing whether the recycling process of the waste is less energy intensive than the manufacture of an electronic product out of the raw materials extracted from the earth. Another way to do this is by comparing the energy input for the recycling process against the energy recovery that could be made from the combustion of the materials; of course this would assume the disposal of the E – Waste to an energy recovery facility instead of landfilling. **Table 5.3** below provides examples of energy use for materials in electronics in the four processes mentioned (EPA, 2015).

Table 5.3: Potential net energy use arising from E-waste landfilling, combustion, E – Waste recycling, and manufacture of components [MMBTU/ton]

Material	Production	Recycling	Combustion	Landfilling
Copper Wire	134.83	-91.04[u]	0.63	0.58
Glass	7.57	-2.35	0.58	0.58
PVC	53.43	NA	-8.37	0.58
HDPE	67.48	-55.51	-21.73	0.58
PP	73.45	NA	-21.68	0.58
PS	82.70	NA	-19.53	0.58
Mixed Metals	65.60	-73.46	-11.98	0.58
Personal Computers	1,054.63	-32.23	-6.91	0.58

As is may be appreciated from the examples in this table, combustion from the materials provides a net negative energy use in most cases. This means that compared with traditional production methods, combustion for energy recovery saves energy except for glass and copper wire, which take

[u] Negative values mean energy savings

energy. In the same manner, and naturally more effective, the recycling processes of these materials also save energy except in the case of the plastics, which are regarded as not recyclable in this example. Lastly, all materials here are regarded as positive energy users in landfilling due mainly to the energetic toll of transportation to the landfill.

Naturally, an economic analysis should also be taken into account since energy costs for an electronics producer are always a major issue. Depending on the value of the product, it may or may not be worth the effort of recycling. Also, the level of remanufacture is important. This means, the energy and economic costs of the whole manufacture and recycling processes have to be weighed; for in some cases recycling of the product may only mean replacement of a few parts.

Refurbishment and reuse is a technique already practiced in Mexico. Sadly, it is practiced mainly by informal recyclers to provide goods for second hand markets. If management is correctly implemented, one tangible benefit will be the reduction in energy use for the manufacture of lots of electronic merchandise. Likewise, if energy recovery from waste were to be implemented in Mexico, combustion of high calorific value materials from E – Waste would have added benefits to the recycling and reuse of the products. This would have to be weighed economically as well.

5.4. Greenhouse Gases Emissions Reduction

The GHG contribution of electronics comes from the fuels spent in their production (including some influence from their recycling process) and the fuels employed for their usage. Unless the electronics are combusted, contaminants from after disposal do not include GHG's in their leachates. Therefore, much like the energy savings explained above, GHG emissions can be reduced significantly from recycling of E – Waste since this implies fewer processes in the manufacture of new electronic products. Naturally, refurbishment reduces even more emissions for this reduces fuel consumption even more.

As an example, based on the electronic refuses generated in Mexico in 2010 and the values calculated by (Halim, 2014) in that year (estimated using the EPA's carbon footprint calculator (Environmental Protection Agency, 2016)); an estimation of possible GHG reductions in 2010 is given in **Table 5.4**. To offer a simple illustration, E – Waste is categorized in three classes. Also, 307,224.00 and 30,722.40 tons of E – Waste are considered to have been generated and recycled respectively in Mexico in 2010[*].

[*] Values gathered from (Cano Robles, 2014)

Table 5.4: Comparison of E – Waste GHG Emissions in Mexico in 2010

Electronics	Manufacture	Use	Recycling	Fraction of E - Waste	With Recycling	W/O Recycling
	GHG Emission Factor [kgCO2eq/kg·yr]			%	[tonCO_2eq]	[tonCO_2eq]
Household Appliances	2.90	3.52	0.97	65.4%	1,180,430	1,289,940
Office & Communication	47.92	3.59	2.56	18.1%	2,592,150	2,864,340
Entertainment Electronics	1.53	4.17	2.56	16.5%	273,030	288,940
Total				**100.0%**	**4,045,600**	**4,443,220**

As it can be calculated from the table above, recycling of E – Waste in 2010 provided alleviation of 397,620 tons of CO_2eq in that year. Even if this is a small percentage of the entire emissions (not to mention the emissions from the whole country), the potential for GHG emissions reduction from recycling is considerable and should most definitely be pursued. Furthermore, if reuse was made instead recycling, the reduction would have been of 444,320tonCO_2eq. It is extremely important to prioritize reuse of disposed equipment as part of sustainable E – Waste management practices.

Unfortunately E – Waste management cannot help optimize energy consumption during the use of the products since this is an engineering and design problem that comes even before the product is fabricated. Less energy consuming and more durable products are needed to be designed to promote energy savings and GHG emissions reduction. Likewise, energy use during the lifetime of a product needs to be reduced. A possible remediation technique could be achieved through public conscience campaigns of E – Waste where tips for efficient energy use on electronics are mentioned.

For the final section of this environmental analysis, a summary on human health and societal benefits from better E – Waste management is pointed out below.

5.5. Other Impacts

As it has been hinted at on other parts of this thesis, there are several other important environmental aspects affected positively by proper E – Waste management. Principally, the main two are:

- **Human Health:** By incorporation into a formal recycling system, workers would find safe conditions to work and avoid contact with perilous materials contained in E – Waste. Also, by decreasing landfill disposal of electronics, potential leachates to main water sources can be avoided, therefore heading to healthier living standards among the Mexican population.
- **Job Opportunities:** In part attributed to incorporation of informal recyclers into a formal system, but also by the creation of more opportunities in the recycling business.

Sustainable E – Waste management has several activities needed to be adopted by initiatives that NEED to be created/expanded to address Mexico´s situation correctly. Additionally, creation of a nexus between recyclers and smelters would bring a new branch in both industries that would create several more jobs.

Other benefits include the overall improvement of quality of life by providing more accessible sources of electronic products (reused, refurbished or recycled), reduction use of landfill space, and propagation of sustainable work/recreational activities due to a renewed point of view on consumerism (specifically towards electronic products acquisition).

6. Conclusions

Since 2003, the amount of electronic products used in Mexico has been increasing dramatically; this of course has also increased the amount of electronic waste generated. Just this past year (2015), it was estimated that the E-waste would exceed 1,000,000 metric ton per year (Román, 2014). On the other hand, recycling rates in Mexico barely reach 10% (Bourtsalas, 2015).

There are other factors to consider. Recycling statistics do not include the informal sector, which if properly managed could bring many benefits to Mexican economy. Collection of E – Waste is not made particularly by the local regulated waste pickers and public awareness towards this issue is very low. Regulations that aim specifically on E – Waste management are yet to be developed and implemented on a national scale. A positive factor is that in recent years, the Sustainability sector in Mexican economy has begun an accelerated pace thanks to the Energy Reforms put into action during this presidential administration. Also, since Mining and Metallurgy are primary industries in Mexico, there is a possible link between these fields of economy and recycling that should be explored.

Cooperation with other countries that are already thriving in this battle should be established, as well as a stronger link between academia and the industry.

Technological advancements are necessary to meet all the steps for the full reuse of electronic scrap. Through newly researched metallurgical processes like Hydrometallurgy, there would be special attention for the recovery of metals where the true potential from E – Waste is found. Through these processes, 10,203.12 tons of non-ferrous metals could be extracted out every million tons of E – Waste generated with the current E – Waste treatment practices

Mexican copper smelters are the key to provide recyclers with the indispensable tools for the recovery of metals from electronics. Mexico's copper smelting capacity is higher than 500,000 tons/yr, of which ~ 90 % is held by only 3 or 4 companies. There are 70,000 tons/yr of copper that could be recovered if the generated E - Waste was incorporated as feedstock of these smelters. Their capacity is enough to include them in their process. This in fact would make a positive impact on the Mexican copper market since the potential amount of recovered copper constitutes almost 14% of Mexico's smelting capacity.

In conclusion, there must be an integrated effort between the local/federal governments, private companies and initiatives (local and foreign), and the population in order to achieve the necessary measures to avoid a problem that is already eating at the nation's heels and that will not stop unless it is met on all fronts.

7. Recommendations

Based on the previous research, the current situation in Mexico, and the explored scenarios, it is recommended that:

- **Regulations specific to E – Waste are enforced on a national level.** It has been assessed that the current approach from the existing legal framework does not address the E – Waste problem correctly. The directives for the disposal methods and management of E – Waste are scattered through the existing laws that address other types of waste as well. There is need for a specific E – Waste Directive that encompasses treatment of electronics from the moment they no longer serve their primary purpose, until they have been given a new one. These laws need to be applied on a national level as well as in all successive levels in a way that individuals give full compliance; for example, by setting a required collection and recycling target by state or municipality. If the target is not reached there would be an economic penalty that would be used for better collection and recycling mechanisms in that community.
- **Public awareness campaigns are carried out regularly.** Every certain period of time individuals should be reminded of their responsibility toward their electronic wastes, because this is not practiced in Mexican society as an everyday activity yet. These reminders could be applied via:
    - Propaganda in public places and transport (posters, adds)
    - Word of mouth through public officials and waste collectors
    - Media advertisements (radio and television mainly)

  These campaigns should not only be applied by the government, private companies should have in their best interest to conduct them every once in a while as well; especially recycling companies and producers of electronics.

  It is also of the utmost importance to create awareness through education. Every level of schooling should include an environmental class where the correct treatment of E – Waste is taught and practiced. By giving future generations the tools to act accordingly, the problem could be eliminated faster than just letting the currently responsible to manage what they can.
- **There is an increase in collection efforts.** Part of the governmental plan for enforcing collection and recycling of E – Waste, and creating awareness in peoples' minds should also be through incentives in collection. Regulations do not need to be only enforced by avoidance of penalties, but by incentives such as the EcoPoint's®, which provide electronic consumers an easy way to dispose of their electronics. This type of booth should be implemented by the government all over the Mexican Republic.

  An increase in collection efforts would also mean an increase in jobs and a boost to the Mexican economy. If implemented correctly and without the customary problem of corruption, the formalization of waste pickers would allow better working conditions on many fronts for these people. Regulated secondary markets could even profit from this effort by participating in any of the activities that envelop truthful processing and recycling of E – Waste.

- **Public willingness to "pay" for correct separation is encouraged.** This could be called the other side of the coin. If from one part, the government provides more collection services, incentives and campaigns for a better treatment of E – Waste nationwide; the public should also "pitch in" and contribute for whatever electronics they are responsible of. Individuals could pay a pickup fare when buying electronic equipment. That way they are invested in the proper treatment of their waste since they already paid for it; companies would be engaged in Take Back policies to do their part as well. The fee could also be paid to the municipal collector; this would stimulate collection efforts in every community. Another way to device this fee could be through taxation.

  Additionally, this measure could be kept only while the recycling industry establishes and a market for E – Waste flourishes. After formalization of the sector and institution of the appropriate practices, companies and even the government could begin to offer revenues to consumers for the delivery of their E – Waste. This in turn would also incentivize the further development of the market.
- **A strong nexus between Recyclers and Smelters is created.** Costs of recycling E – Waste are taken mainly by the equipment for the recovery of the primary materials; especially for the metals since these cannot be extracted manually. Recyclers must invest great amounts of money in infrastructure and labor that is often not part of the initial assets of the company, in order to complete the cycle of their products. By making the link between the current Mexican smelters and E – Waste recyclers, capital and operating costs for the recyclers and lack of infrastructure for the treatment of the waste could be avoided. Benefits for the smelters would include a wider range of sources for raw materials.

  This link could be initiated as part of a sustainability program from the smelters; where they agree to buy the copper containing equipment that could be hauled out from the E –Waste collected by the recyclers. Of course, there would have to be agreements for the investments of appropriate infrastructure for the metallurgical processes.
- **Noranda and other Hydrometallurgical processes are integrated.** The switch from furnaces to other types of processes may seem too hard at first, but it is cost effective. If smelters invested in research and development of more advanced metallurgical methods, the payoff would prove worth the venture. Also, many of these techniques can be implemented in small scales, so capital and other costs may not need to be so steep.

  Furthermore, since Hydrometallurgy does not involve combustion of any kind, emissions of contaminants and possible GHG's is greatly avoided; this also means avoidance of remediation and pollution control costs. There may be some efforts needed to treat any hazardous byproducts, but these are proven easier to handle than the fumes from combusting the waste.

  Moreover, as technology advances and electronics become more complex so must treatment approaches keep evolving. The link between academia and industry has to be pursued fully so that the power of response to new "threats" is always parallel to the threats themselves. There is no commercial or industrial progress without the adequate research to back it up, and there is no research without the economic incentives to back it up too; the loop must always be fed with reciprocity.

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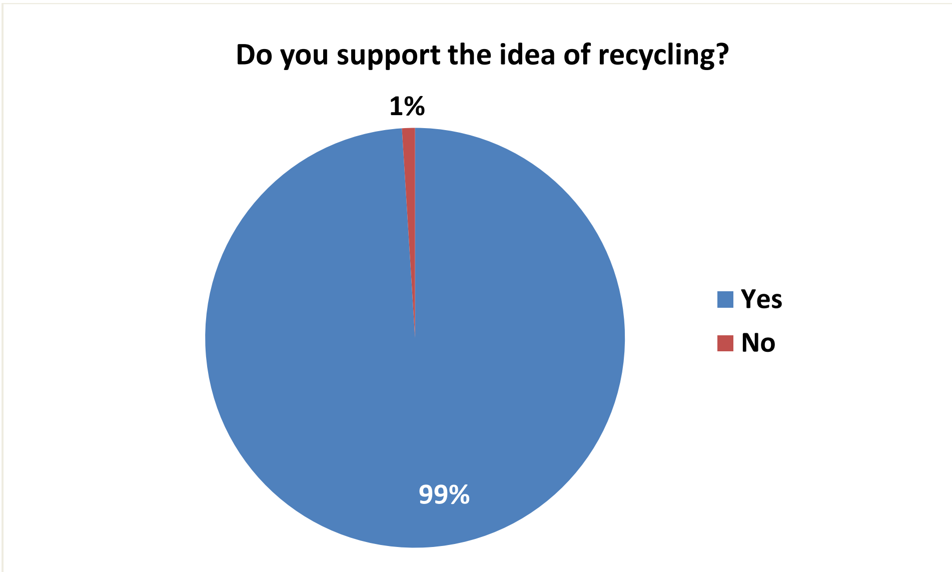
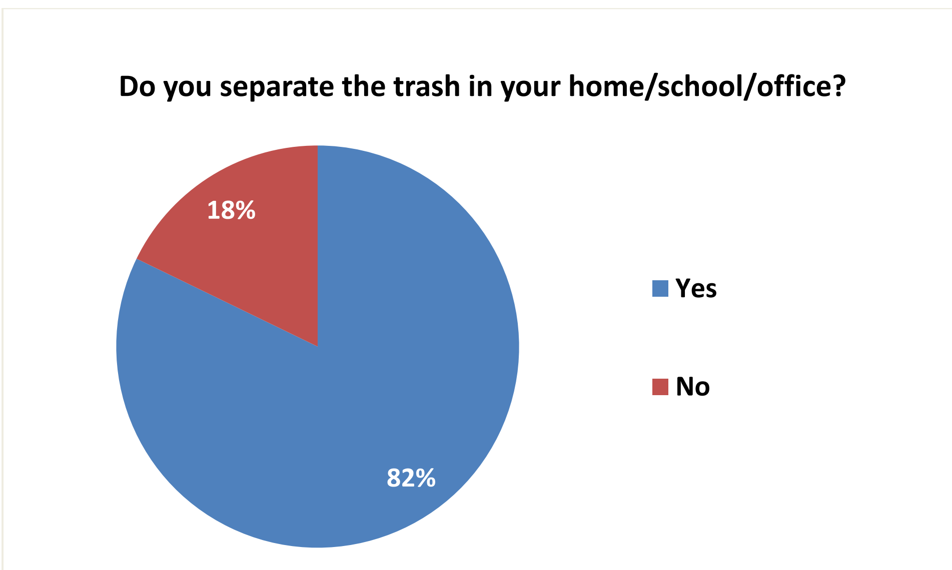
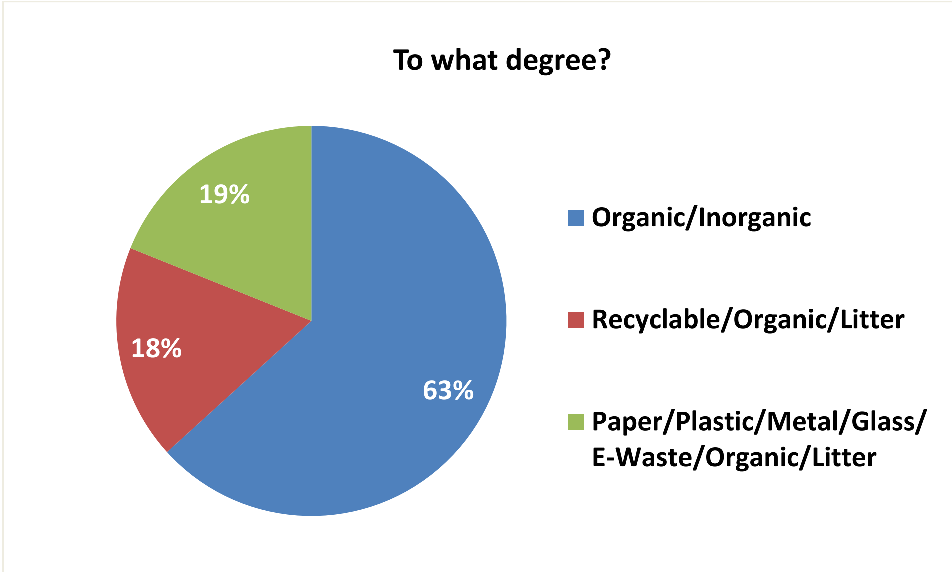
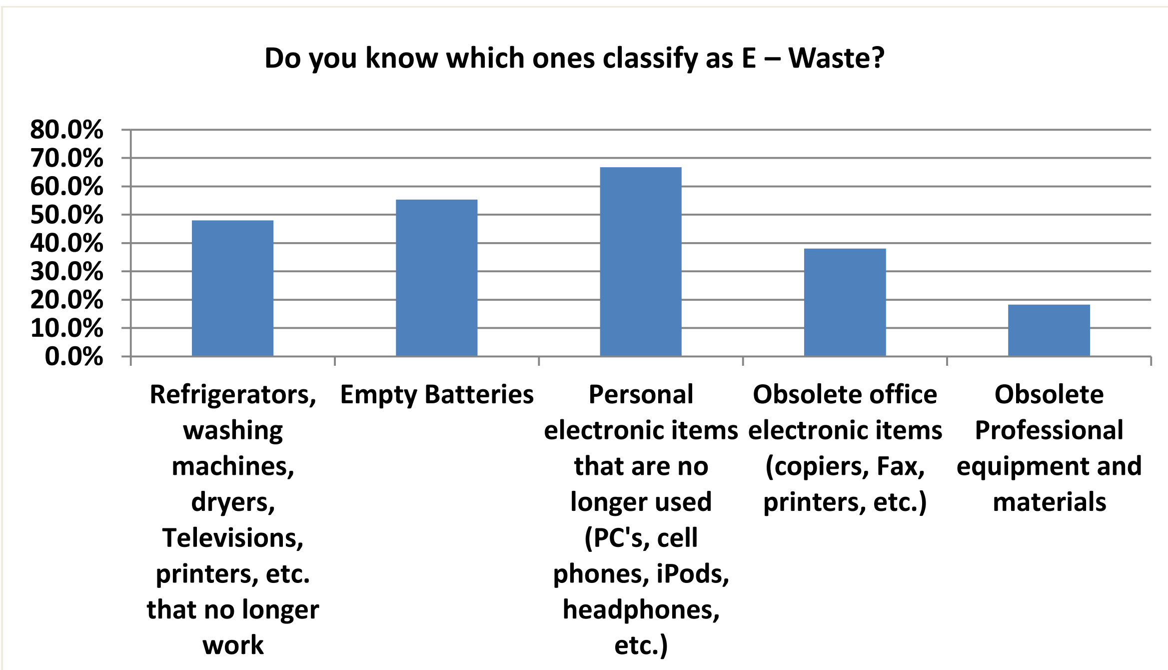
APPENDICES

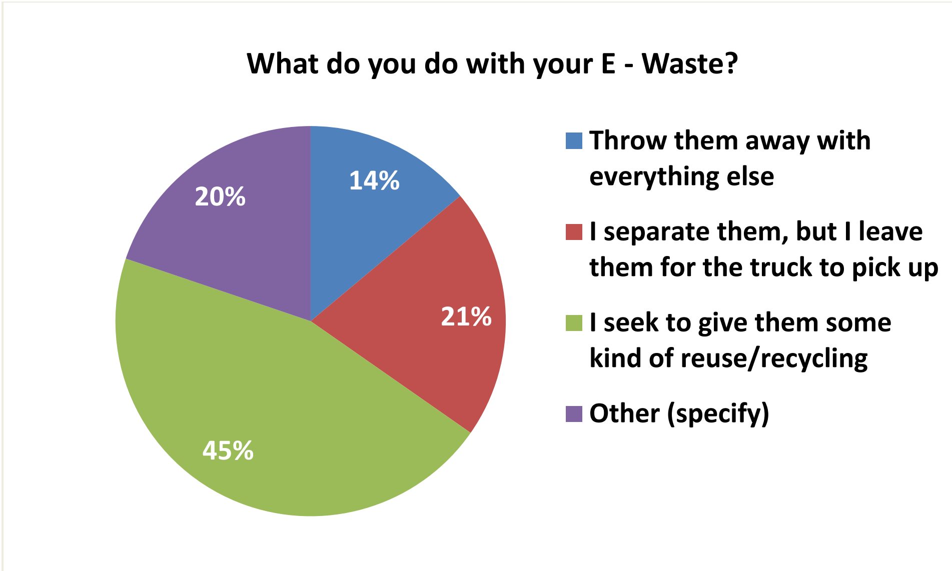
Appendix 1: Mid-Income Status, E – Waste Management Survey Questions

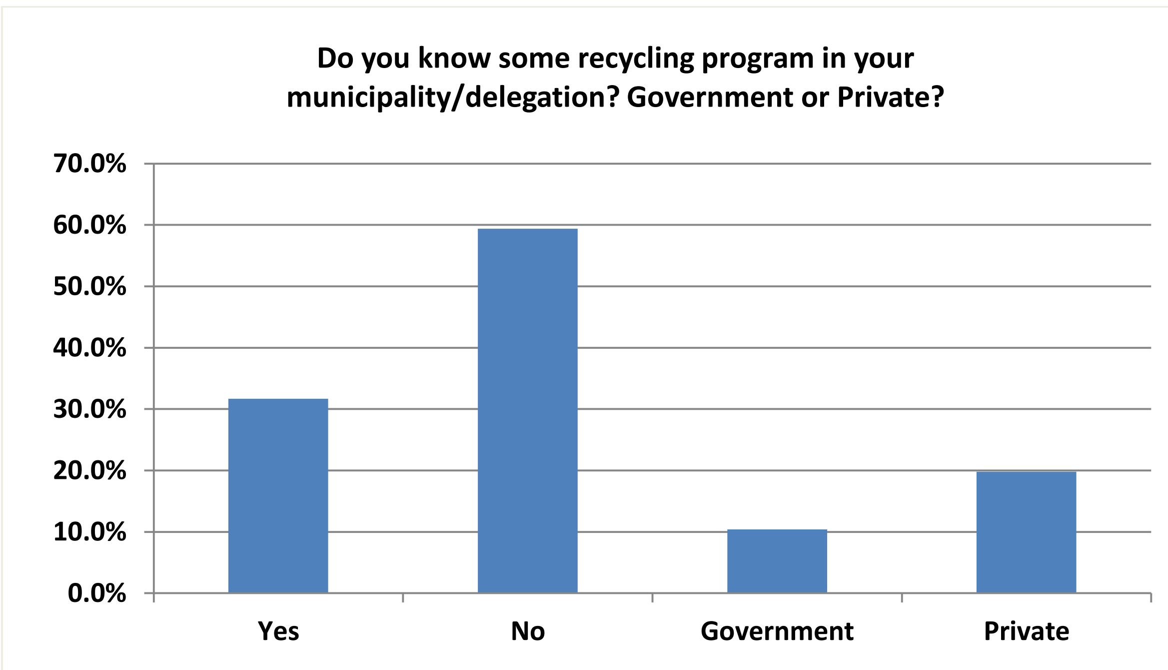


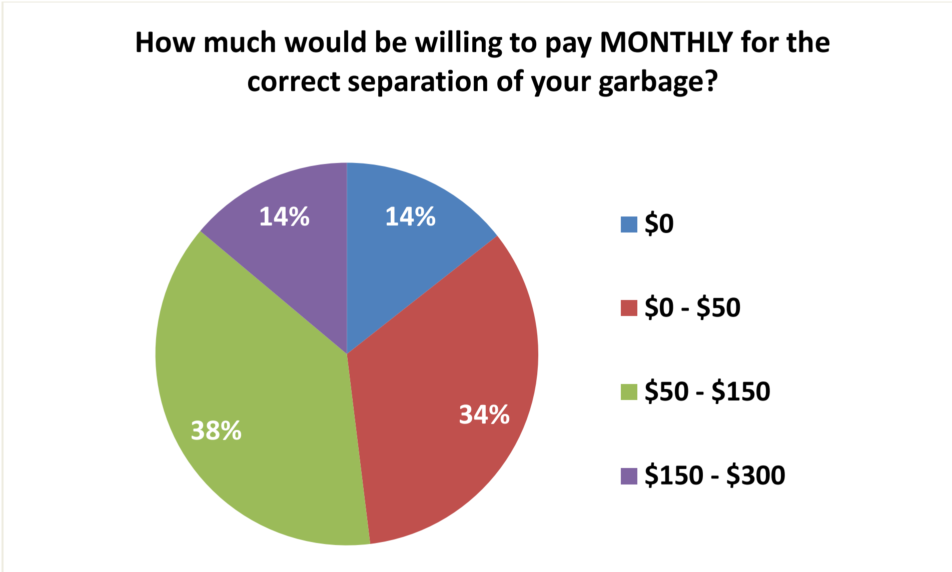


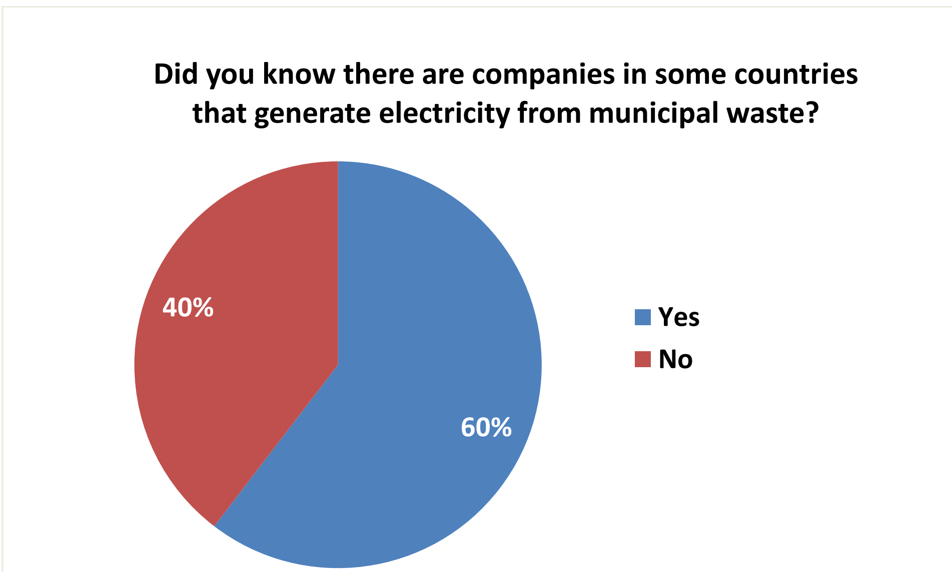

To what degree?
19%
18%
63%
Organic/Inorganic
Recyclable/Organic/Litter
Paper/Plastic/Metal/Glass/
E-Waste/Organic/Litter

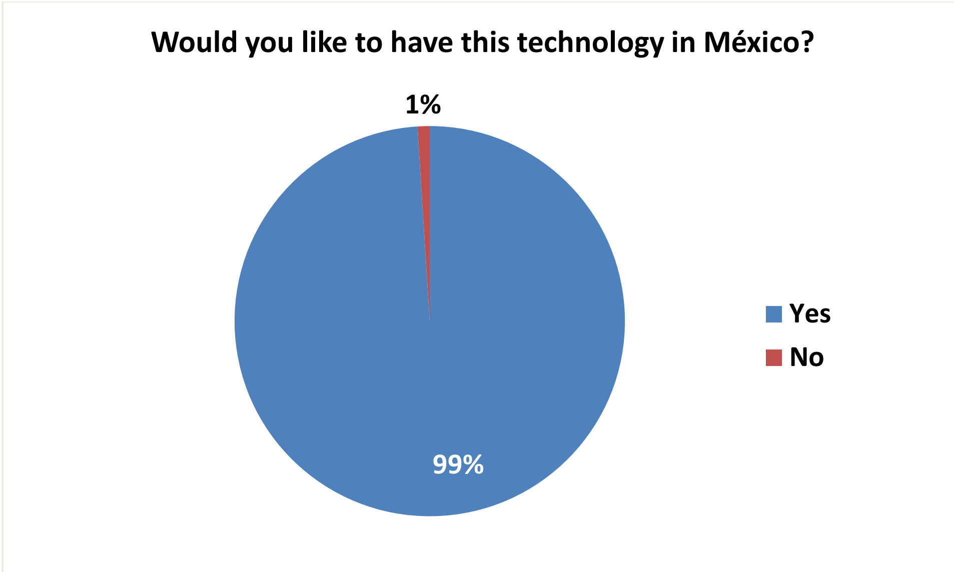

Do you know which ones classify as E – Waste?
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Refrigerators, washing machines, dryers, Televisions, printers, etc. that no longer work
Empty Batteries
Personal electronic items that are no longer used (PC's, cell phones, iPods, headphones, etc.)
Obsolete office electronic items (copiers, Fax, printers, etc.)
Obsolete Professional equipment and materials


What do you do with your E - Waste?
14%
21%
45%
20%
Throw them away with everything else
I separate them, but I leave them for the truck to pick up
I seek to give them some kind of reuse/recycling
Other (specify)


Do you know some recycling program in your municipality/delegation? Government or Private?
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Yes
No
Government
Private


How much would be willing to pay MONTHLY for the correct separation of your garbage?
14%
14%
34%
38%
$0
$0 - $50
$50 - $150
$150 - $300


Did you know there are companies in some countries that generate electricity from municipal waste?
40%
60%
Yes
No


Would you like to have this technology in México?
1%
99%
Yes
No

Appendix 2: Examples of Successful E – Waste Treatment Initiatives

1. SIMS METAL MANAGEMENT Limited

Australian company dedicated to metals and electronics recycling. It has facilities all over the world and in more than 200 locations; it has more than 5,500 employees, and it is even part of the Dow Jones Sustainability Indices. Focused mostly on commercial and industrial clients, it has begun developing a municipal waste recycling practice in some regions.

It works through three main divisions:

- **Sims Metal Management:** Involved in marketing (14 million tons of scrap annually) and processing of recycled ferrous and non-ferrous metals. Depending on the location, operations may vary in the processing facilities. It possesses over 15 shredding services in the United States alone.
- **Sims Recycling Solutions:** The developing division in the firm, since it is still expanding in Africa and Asia. It takes care of all End of Life treatment for electric and electronic devices.
- **Sims Municipal Recycling:** Stationed only in the U.S., it takes care of the recycling services for municipality's recyclables.

Its services include:

1. Wire chopping and recovery from various sources in form of pellets (aluminum and copper)
2. Recollection of obsolete equipment
3. Recollection and shipping of all types of recyclables and scrap through a vast fleet of trucks and an intricate layout of routes
4. Ship repair and service
5. Cargo handling and Logistics
6. Assessment in recycling solutions for companies
7. Brokerage of ferrous and non-ferrous metals (SIMS METAL MANAGEMENT, 2015)

2. MBA Polymers Inc.

American firm that recycles plastics from different types of waste streams, most of all, from E – Waste. Sources for their material are pre-processed and shredded plastics from different sellers and separated plastic waste from landfills. With headquarters in Richmond, California; this 22 year old garage started company has now several recycling plants in America, Europe and Asia (the most important are located in Guangzhou, China and Worksop, Nottinghamshire). The technology and processes it employs are famous for being very environmentally friendly; compared to typical petrochemical processes, its processes tremendously reduce the energy required to make a recycled product. Additionally, they also save the planet from huge Green House Gas emissions.

Its products are high quality recycled polymers. These include ABS, HDPE[v], HIPS, PP, and filled PP in pellet forms for all types of electric and electronic appliances and/or consumer products. These

[v] High-density polyethylene

products may also be fitted for the construction and automotive industries. It also produces EvoSource™ resins from the recycled plastics (MBA Polymers, 2011).

3. *Triple M Metal LP*

A ferrous and non-ferrous recycler with presence in European and American countries (including Mexico) that operates over 16 facilities in Ontario alone. Sources for its processing material include governmental, public and private sellers of scrap and numerous other scrap dealers, demolition and construction sites, foundries, steel mills, etc. It takes care of the collection of the scrap as well as its pre-recycling shredding process.

Triple M Metal is mostly proud of its versatility in accepting all types of metal scrap and waste. Its products come in a wide range thanks to the multiple processing capabilities of its plants. Products include processed brass, copper, aluminum, stainless steel, lead, zinc, catalytic converters, and specialty alloys as well as several types of ferrous products. Also, due to the extent of its know-hows it can perfectly work with E – Waste from any seller.

Its services include metal markets specialized brokerage, highly efficient and cost effective transportation services and logistics for all scraps (one of Canada's largest truck fleet), and handling of material (70,000 tons of shredded material per month).

Its driver is a combination of the strong work ethic of all its employees and their effort to exceed the customer's expectations in quality. The incessant investments on infrastructure and equipment enable Triple M Metal to be avant-garde and provide for their customers on a 24x7x365 basis. Another focus for Triple M Metal is to keep the motto "reduce, reuse, recycle" among its core principles. Its investments are also used to prevent pollution and conserve resources (Triple M Metal LP, 2016).

4. *Sprint Co.*

Sprint is not a recycling company, but it is an electronics distributor, and as such it knows well the responsibility of releasing electronic products. It is aware of the End of Life treatment its products should have, and since a few years ago it started acting up on it.

It has implemented a BuyBack system that offers customers a reward for their device, it doesn't matter if it was signed up to a different carrier or if it has been long since its last use. The advantages for Sprint are that most of the returned phones are still in shape and may be refurbished easily and sold again after some tests. The phones that cannot be reintroduced to the market (about 10%) are sold to recyclers that make use of most of the parts after disassembly and refinement.

Sprint has already been recognized by the EPA for its assumed responsibility, and it sure sets an example for other electronics companies (Fava, 2012).

Appendix 3: Other Leader Mining and Metallurgic Companies in Mexico

1. *ArcelorMittal S.A.*

The global leader in iron and steel production has its headquarters in London and has mining operations in nine countries including México (started in 1992). In 2014, it generated revenues of $79,300 million USD (ArcelorMittal, 2016). Although not a Mexican Company, the global leader in steel mining has three iron mines in Mexico from which in 2013 reported revenues of $1,563 million USD, $72 short of its sales the previous year. In 2014, ArcelorMittal Mexico produced nearly 4 million metric tons of steel from these mines and held a 22% share of the industry's market.

Also in 2014, it reported that out of its managed waste in Mexico, it made use of 9.34% in the form of recycled steel (232,537.39 tons) (ArcelorMittal, 2016).

2. *Coeur Mining Inc.*

The largest silver producer of the U.S. and one of the biggest gold producers as well; it has its headquarters in Chicago and in 2014 had revenues of $635.7 million USD. It owns a silver and gold mine in Palmarejo, Chihuahua since 2009. It is also developing a project in La Preciosa, Durango. The Palmarejo mine reported a production of 187.1 tons of silver and 2.5 tons of gold in 2014 (Coeur Mining, 2016).

Its recycling numbers for the whole company in 2014 were as follows (Coeur Mining, 2016):

- 42% average decrease in non-hazardous and hazardous waste disposal per metric ton of ore processed
- 3,542 metric tons of scrap metal recycled
- 1,181 average annual metric tons of scrap metal recycled

3. *Nacional de Cobre S.A. de C.V. (Nacobre, Elementia's Metals Division)*

Elementia is a Mexican Company leader in construction and industrial products. It has four main divisions: Cement, Plastics, Metals and Construction Systems, which in 2014 reported revenues for $530 million pesos (~ $30 million USD). Its metal division is called Nacobre; it operates three mines in Mexico (Elementia, 2013). Nacobre grew a 30% in 2014 according to Elementia's Financial Report, allowing it to take 48% of the copper market in Mexico. It´s revenues for that year were of $393 million pesos (~ $2.3 million USD) (Elementia, 2014).

As part of its sustainability report, this company reported that it recycled 38.36% of its metals used. It also states that it provided proper management of 851 metric tons of hazardous waste (Elementia, 2014).

4. *Minera Autlán S.A.B. de C.V.*

Founded in 1953, this company is dedicated to the production of manganese and ferrous articles. It now owns three mines and three ferrous alloys plants in Mexican territory. It has also started developing electricity production projects. Its revenues in 2014 were of $52.5 million pesos (~ $2.8 million USD), and its metal production reached 19 million metric tons allowing it to grow 4.1%

compared to 2013. These numbers reflect an increased market share; nonetheless, the actual position is not given in their report.

Although it declared several developments in sustainability in its report like decreased water use or decreased electricity consumption, it did not present numbers for recycling of any kind (Minera Autlán, 2015).

5. Mexichem S.A.B. de C.V.

With a history of more than 50 years, Mexichem is another one of the biggest vertically integrated companies in Mexico. It provides products and services in various sectors, from petrochemicals to agriculture; it generates over $115 million USD every year. Thanks to its wide variety of products it holds leading positions in many local and even international markets (Mexichem, 2016).

Although it only possesses 2 fluorite mines (including the biggest one in Mexico), it is worth including in this study given the importance it has on Mexico's productivity. It manufactures over 68,000 different products divided into 25 product categories. From all production, there is an 11% recycling of used materials which includes water, wood, cardboard, paper and plastics, but no metals nor E – Waste in general. It has recently incorporated hazardous waste management. In 2014, it handled over 530 metric tons of hazardous waste (Mexichem, 2016).

6. Golden Minerals Co.

Mining company founded in Delaware that owns several properties for mining exploration in Mexico. The only project since 2009 that has been extracted for gold, silver, lead, and zinc has been the Velardeña Mine in the state of Durango. The extraction of these metals gave the company $8.5 million USD of revenues in 2014. The difficult market conditions have stopped operations in the mine from time to time, but the company resumes mining once market values rise to profitable standards. In 2014 the mine produced a total of 60 million Ag eq oz of silver and gold with lead and zinc byproducts. It has become engaged with the communities near the mine in some sustainable projects, although recycling is not mentioned in the report (Golden Minerals Company, 2014).

7. Pan American Silver Corp.

Relatively new, this silver and gold (with zinc, lead and copper byproducts) mining company was founded in 1994 with operations at a single mine in Peru. Today, it owns three operating mines in Mexico and has two current projects in development. From these mines (La Colorada in Zacatecas, Alamo Dorado in Sonora, and Dolores in Chihuahua), the production and revenues in 2014 were as follows:

Pan American Silver Corp. 2014 Mexican Mine Production

Production	Units	Mine		
		La Colorada	Dolores	Alamo Dorado
Silver	**kg**	141,748	107,728	98,373
Gold		73	1,894	500
Zinc		7,700,000	-	-
Lead		3,740,000	-	-

Copper		-	-	30
Revenues	**USD**	$ 10,134,000.00	$ -164,271,000.00	$ -19,083,000.00

Due to its other operations, it generated $751 million USD in revenues that year. Furthermore, according to its Chairman and Founder Ross Beaty, the reserves of the company allow it to keep one of the leading places in the silver and minerals market (Pan American Silver Corp., 2014).

As for the sustainable management of its wastes; the Colorada mine reused/recycled 18.84% of its total waste, including hazardous materials. Dolores reported 23.28% and Alamo Dorado 40.97%, which compared to other mines in the industry, are good recycling rates (Pan American Silver Corp., 2014).