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COLLEGE OF ENGINEERING

DEPARTMENT OF CHEMICAL ENGINEERING

CENG 291 ENGINEERING IN SOCIETY

THE E–WASTE CONUNDRUM IN TEMA

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ABSTRACT

The spectacular development in modern times have undoubtedly enhanced the quality of our lives. At the same time, these have led to manifold problems of massive amount of hazardous wastes and waste from EEE. The environmental, social and economic problem posed by inappropriate and uncontrolled dumping of EEE in Africa and in Ghana in particular has drawn the attentions of many policy making bodies both in developed and developing countries. Africas, and for that matter Ghanaians, have developed a strong taste for these affordable secondhand EEE as a result of high level of poverty. Sadly, most of these equipment that find their way to Africa have outlived their usefulness and have led to alarming waste generation. These waste comprises of a whole range of equipment which include refrigerators, washing machines, televisions, printers, computers, DVD players, mobile phones, etc.

In Tema, a suburb of Accra, e–waste has become an immediate concern as its unregulated accumulation and recycling has led to major environmental problems endangering the health of many. This reports, therefore, traces the route of e-waste from the improper disposal of it, by the inhabitants of this region to the crude recycling of it. Also, how the old system of disposing e-waste causes environment havoc and as such immediately being done away with in other parts of the world. Later chapters focus on the new and advance method of retrieving precious metals through extractive metallurgy from the e-waste. This method is used in various industries across the globe. Light is also thrown on how individuals in their own shear tenacity have capitalize on it to create a business.

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LIST OF ACRONYMS AND ABBREVIATIONS

WEEE	Waste Electrical and Electronic Equipment
EEE	Electrical and Electronic Equipment
CRT	Cathode Ray Tube
LCD	Liquid Crystal Display
TV	Television
PM	Precious Metals
PC	Personal Computer
ppm	Parts per million

CHAPTER ONE

INTRODUCTION

1.1. BACKGROUND TO COURSE

Engineering in society (CENG 291) is a practical course for all first year engineering students in the College of Engineering of the Kwame Nkrumah University of Science and Technology. Students undertake projects which seeks to identify development challenges in their various study communities, specifically where students live and generate solutions to these challenges identified.

1.2. OBJECTIVES OF ASSIGNMENT

The overall aim of the course is to inculcate in students an appreciation of the fact that the purpose of engineering is to solve societal problems. This course is aimed at encouraging students early in their programs of study to draw a link between their chosen field of engineering and the application of this field to the issues that confront the day to day lives of people. At the end of the course students would develop an appreciation of the areas of life that their field of study can be applied to and deepen their interest in and appreciation of their disciplines of engineering. It will also improve their sense of innovation and application of engineering to development.

1.3. ENGINEERING AS A FIELD OF STUDY

Engineering is the application of scientic knowledge to solving problems in the real world. While science (physics, chemistry, biology,) allows us to gain an understanding of the World and the Universe, Engineering enables this understanding to come to life through problem solving, designing and building things. The electronic device you are using to read this article was engineered from raw plastic, metal, silicon and lines of software code before being transformed into a usable device. Pretty cool! Engineers can be distinguished from other professions by their ability to solve complex problems and implement solutions in cost effective and practical ways. This ability to face a problem, work through various thoughts and abstract ideas and then translating them into reality is what is so exciting about engineering.

1.4. CHEMICAL ENGINEERING AS PROGRAM OF STUDY

Chemical engineering is the detailed study of systems involved in the transformation of materials and energy from one form to another. It has developed from its initial base around the reaction and processing of liquids and gases to that of biological materials and solid or solid-like materials of all

kinds. Chemical Engineers provide and improve chemical processes and devices, which are environmentally sound.

It is a branch of engineering that applies physical sciences (e.g. chemistry and physics) and life sciences (e.g. biology, microbiology and biochemistry) together with mathematics and economics to produce, transform, transport, and properly use chemicals, materials and energy. It essentially deals with the engineering of chemicals, energy and the processes that create and convert them.

Modern Chemical Engineers are concerned with processes that convert raw materials or chemicals into more useful or valuable forms. They are also concerned with pioneering valuable materials and related techniques which are often essential to related fields such as nanotechnology, fuelcells and bioengineering.

1.5. SCOPE OF CHEMICAL ENGINEERING

Chemical engineering is a discipline influencing numerous areas. It covers a wide scope which includes the following:

Mineral based industries	Petrochemical plants
Synthetic fiber units	Petroleum refining plants
Synthetic fiber units	Chemical industries
Refineries	Pharmaceuticals
Paint and dyes	Fertilizers
Textiles	Plastics
Nuclear energy	Water and its treatment
Recycling metals	Food processing
Paper	Oil and Gas
Fuel Combustion Technology	Pharmaceuticals
Healthcare	Design and construction
Pulp and paper	Specialty chemicals
Microelectronics	Electronic and advanced materials
Polymers	Business services
Biotechnology	Environmental health and safety industries.

Within these industries, chemical engineers rely on their knowledge of mathematics and science particularly chemistry to overcome technical problems safely and economically. And, of course, they

draw upon and apply their engineering knowledge to solve any technical challenges they encounter. Their expertise is also applied in the areas of law, education, publishing, finance and medicine specifically. Chemical engineers improve food processing techniques, and methods of producing fertilizers, to increase the quantity and quality of available food.They also construct the synthetic fibers that make our clothes more comfortable and water resistant; they develop methods to mass-produce drugs, making them more affordable; and they create safer, more efficient methods of refining petroleum products, making energy and chemical sources more productive and cost effective

CHAPTER TWO

LITERATURE REVIEW

2.1. EXECUTIVE SUMMARY ON PREVIOUS REPORTS

Matsuoto T. Jung CH , Tanaka N (2004), examined domestic efforts to recycle used appliances in Japan , focusing on recent legislation (The Home Appliance Recycling Law) that requires appliance producers to take the responsibility for collecting and recycling of end-of-life products. The author surveyed recycling plants to investigate operational data such as the material content in each type of designated product, the material balance, recovery rate of heavy metals and the configuration of recycling of the recycling process. He concluded that waste generation and emission reduced drastically by the implementation of these laws. This report provides a unique perception as to how to structurely deal with the e–waste menace in Ghana.

Also , Basel Action Network and Silicon Valley Toxics report on hazardous substance emission associated with recycling process and the international movements of hazardous waste were consulted. A conclusion was drawn based on the report that hazardous chemicals which are released into the atmosphere was due to inappropriate recycling methods. This reports provides information on hazardous waste in WEEE, care and treatment procedures to follow when dealing with these poisonous chemicals domestically or whether they are exported.

Another report on how to properly dispose of WEEE, its costs and benefits, written by Macauley M and Palmer K. , provided valuable insights on WEEE. For example, the glass in CRTs contains a large amount of lead, which can adversely affect human health, soil and water quality. They examined the costs and benefits associated with several policy scenarios for the disposal of the CRTs used with computers.

Articles and Journals published by the Basel Action Network on the trans–boundary shipment of waste material. These articles confirmed the illegal importation of WEEE into developing nations such as Ghana.

Workshops organized by Greenpeace, held discussions that covered aspects such as environmental impacts, health concerns, legal frameworks, international co–operation and economic development and also reflected on the complicated dimensions of E-waste. This report shared light on the adverse effects of inappropriate disposal of WEEE in Africa which were vital to this report.

2.2. STATISTICAL DATA

E.F Amankwa conducted an analysis on the E–waste workers. His findings reveal that the majority of workers 73% are young , ranging from 15 to 30 years of age. In terms of education , 83.6% of them either completed Junior High School or have no formal education at all. The findings also show that e-waste enterprise is nearly exclusively male dominated (89.3%), yet women are on the site as market vendors, cooks, and traders in collectors and dismantling tools such as hammer, spiner and screw drivers. Futhermore, 60.7% are either single or cohabiting, suggesting that the workers are still youthful and would want to secure a stable financial status before marriage. A vast majority (70%) of the people have migrated from the poorest part of the nation (Upper East, Upper West and Northern Region).

He also added that e-waste employs about 4,500 to 6,000 people directly and 20,300 to 33,600 people indirectly. Recyclers also earn about GH25.00 depending on the number of their 'burning rounds'. These data escpecially regarding the analysis on workers in this industry, lays much emphasis on the future impact this growing menace will have on Ghana's human resource if attention is not drawn to it.

2.3. IMPORTS OF WEEE

2.3.1. POLICIES AND LEGISLATIONS REGARDING EEE

Currently, there is no infrastructure for the environmentally sound disposal of hazardous fractions of WEEE. A policy and legislation analysis illustrates that in Ghana there currently exists a specific policy or legislation governing WEEE management. The Parlaiment of Ghana passed an Act which seeks to streamline the activities in waste collection and management industry. This will ensure sound waste management and recycling systems which will save the country's forests and future generation. The new act prohibits the importation, sale , transport , purchase and the deposit of hazardous waste and other e-waste on any land in the country.

2.3.2. ILLEGAL IMPORTS OF WEEE

Regarding imports of WEEE, Ghana has ratified the Basel Convention on the control of Trans boundary Movements of Hazardous Waste and their disposal. This prohibits import and exports of e–waste but its provisions have yet to be incorporated into the national legislations.

2.3.3. NO ENFORCEMENT

As regards imports of secondhand equipment, energy efficiency regulations which prohibit the import, sale and distribution of secondhand refrigerators, freezers and air conditioners came into force in 2010 but a full and total enforcement has not taken place yet. Imports of other secondhand equipment such us computers and televisions are not regulated. There are a number of laws and regulations such as the EPA Act, that have some relevance to the control and management of of hazardous waste but they do not address the dangers posed to humans and the environment from such waste. Specific regulations covering environmentally sound disposal of e–waste and disposal of hazardous fractions are not available.

CHAPTER THREE

MATERIALS AND METHODS

3.1. METHODOLOGY

The e-waste assessment was conducted based on the following line of method seen below

3.2. SURVEYS AND QUESTIONAIRE SAMPLING

Surveys were done using different categories of questionnaire in the following areas : Community 1 , 2 , 4 , 5 , 8 , some parts of Tema New Town and areas around Tema Overhead. Also various stakeholders such as consumers of EEE, dealers in secondhand EEE, dealers in WEEE popularly called scrap dealers, repairers of faulty EEE and various sites in Tema Community One and New Town, where these WEEE are dumped were surveyed. Investigations were carried out using an audio recorder.

3.3. FIELD WORK

Visits were made to individual homes in the communities listed above. Here information was gathered on the of EEE used in households, how long the EEE last and what is done with most of these when they are damaged or faulty. Also enquiries were made on the adverse effects of the Energy Crises faced by the nation on these EEE in the household in general. From there, visits were made to repairers of EEE along with the dealers as well. Another visit was made to dealers in WEEE. To conclude the entire field trip, a final visit was made to sites where these WEEE were dismantled, various parts were retieved and how residues from these activities are treated.

3.3.1. Problems observed during field trip

- Lack of appropriate site designated for activities of scrap dealers.
- Traditional methods such as operation with hammers, knives and shredders were undertaken by these scrap dealers without safety precauitions.
- The scrap dealers had no record of the number of EEE they dealt in.
- Various households had no record of WEEE disposed.

3.4. LIMITATIONS OF THE METHODOLOGY USED

The main limitations include

- inaccurate statistics provided by individuals and stakeholders. This was especially true of scrap dealers.
- the unharmonized manner of data dealing , a lot of assumptions were made and this could create a margin of error
- the region of survey. The survey was conducted in six communities out of the about 30 communities in Tema , hence it doesn't represent a metropolitan dimension.

CHAPTER FOUR

DISCUSSION OF RESULTS

4.1.1. DISCRIPTION OF COMMUNITY

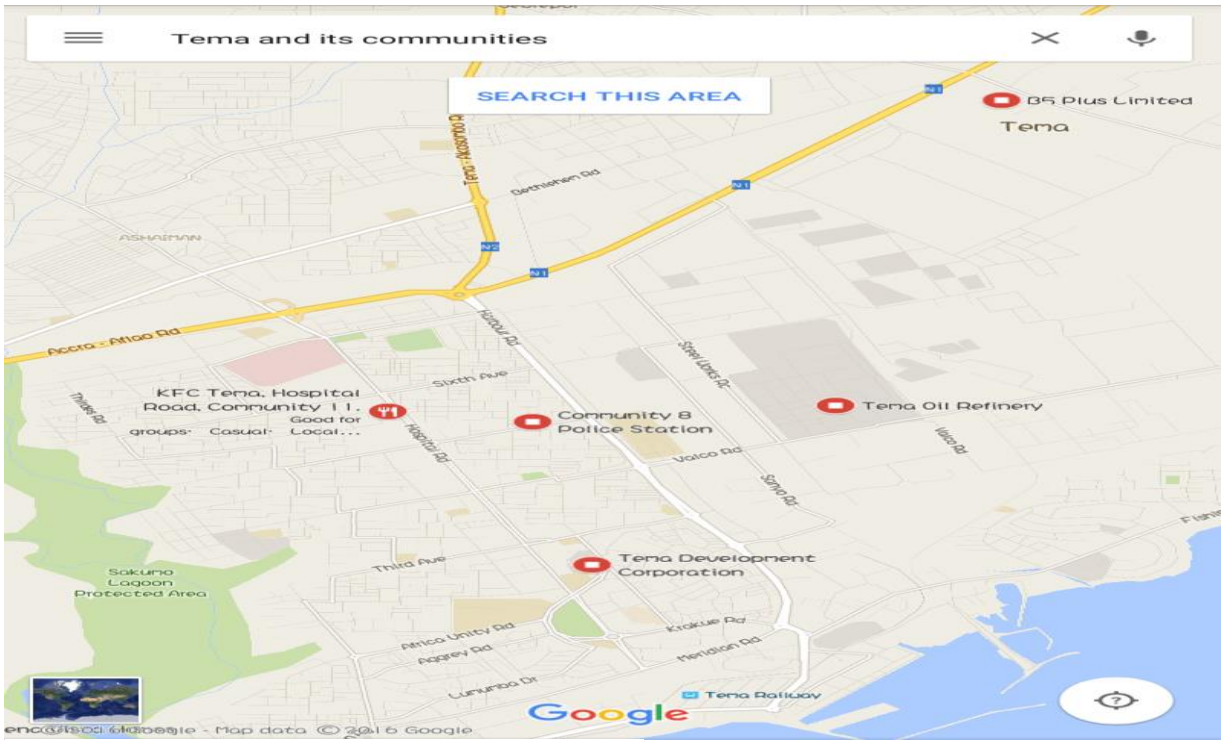


Figure 1*: a map of Tema and its communities*

4.1.2. Location

Tema is a city on the coast of Ghana. It shares boundaries on the North East with the Dagme West , South West by Ledzekuku Krowor Municipal , North West by Adenta Municipal and South by the Gulf of Guinea. The metropolis covers the coastal savannah zone. The Greenwich Meridian passes directly through the city. The southern tip lies within latitude 5^0 N .The metropolis covers an area of 396km^2.

4.1.3. Population

It is one of the most populous metropolis in Ghana with an estimated population of 402, 637 people. Of which 193,334 are males and 209,303 are females. Out of the total population 97.2% live in households.

4.1.4. Geography.

It lies within the coastal savanna zone. The topography is generally flat. Due to this nature, it has made some parts of the metropolis flood prone. The region enjoys dry equatorial climate with mean rainfall ranges between 730mm too 790mm. The rainy season is usually from April to July. The annual average temperature ranges between 25^0C to 30^0C.

4.1.5. Government.

Tema is divided into three continuencies, i.e. Tema Central, Tema West and Tema East, which are represented by Honourable Kofi Brako , Honourable Irene Naa Torshie Addo ,and Honourable Daniel Nii Kwartei Titus–Glover as members of Parliament respectively. The current Mayor of Tema is Honourable Isaac Ashai Odamtten.

4.1.6. Agriculture and Industrial

Due to its industrial nature and geographical location along the coast, crops are hardly grown but farming activities such rearing of animals are done in the remote areas within the metropolis. The agricultural activities takes about 20% of the total land area. Types of food crops grown include maize, cabbage and lettuce. Fishing is also one of the major agricultural activities on the shores of this city.

Approximately 7.5% of the total land is used for industrial purposes. With heavy duty vehicles, trucks and articulators plying the roads. The town's chief industrial products include aluminium, steel, processed fish, and textiles. Some major companies operating in Tema include Volta Aluminium Company, Tema Oil Refinery and Nestlé Ghana Limited. The city is nicknamed the Habour City because of its status as Ghana's largest seaport.

THE MAJOR PROBLEM
GENERAL PROBLEM INTRODUCTION

4.2.1. Definition of E-Waste.

E-waste is a term used to cover all items of electrical and electronic equipment (EEE) and its parts that have been discarded by its owner as waste without the intent of re-use. It is also referred to as WEEE , electronic waste or e–scrap in different regions. E-waste includes a wide range of products, which are used in almost any household, work place and other region where humans could be located.

4.2.2. NATURE AND CHARACTERISTICS OF PROBLEM

E-waste describes old, end-of-life EEE or waste generated from any equipment running on electricity or a battery including computers, laptops, TVs, DVD players, mobile phones, MP3 players, etc., which have been disposed off by their original users.

EEE's have become a vital part of human life. It is hard to imagin life without the electronic equipment. We have come to rely heavily on information technology and computers for everything from production, to rendering of services and entertainment. Daily activities such as cooking, cleaning, weeding, communicating, entertaining and preserving of food employ the use of EEE. With respect to low income and the widespread of poverty in many homes, access to low cost secondhand equipment have become very vital. It is through this secondhand goods that an increase in e–waste has abounded. The reason being that most of these goods have outlived their usefulness. These EEE are sold at lower prices and most consumers tend to patronize them as compared to brand new. In an interview with Mr. Ayasorgbor Agbeko, a secondhand equipment dealer and repairer, he explained that most consumers preferred home used appliance (secondhand goods) to brand new ones because they are affordable even though they may have a short life span. He added that it's mostly a gamble patronizing such equipment because one could get one that last longer or otherwise. Mostly after these EEE become damaged they are left lying waste within the confines of his shop creating an unpleasant scene. Fortunately for him, if an e-scrap dealer comes around, he is most likely to strike a deal with such individuals and get rid of the WEEE.

Another consumer, Kwame Joe , shed a little light on the fact that most of the appliances at their end–of–life ly waste in his area. The equipment have become breeding grounds for mosquitoes. With most consumers , there is a primitive lack of knowledge concering how these WEEE are disposed off. These WEEE are left lying in various landfills in the community and with time an e–scrap dealer gets a hold of it. The whole problem stems up from the fact that there are no appropriate waste management system in the country and in the township as a whole , these equipment end creating sanitation problems in the community, yet many continue to patronize them.

Also in an interview with a repairer Mr. Nimo , he explained that the menace had compounded due to the actions of most owners of equipment. Most of them bring it for repairs and never return to check on them. He cited an instance where he repaired and sold an appliance that had been in his shop for over two years. The owner returned to make claims of his equipment. He was later held captive in police cells until he was able to repay it. He added that the business he is into is one he inherited

from from his father , hence he had no right to dispose of any appliance that is at it's end-of-life, though the owners have not come to make claims of their EEE. In a nutshell, the owners of these appliances contribute greatly to this environmental challenge.

Figure 2: *is an area around community four roundabout where old fridges have been discarded disrupting the beauty of the community.*

Figure 3*: An area around Tema Community four where faulty and old washing machines*

Figure 4*: The front porch of a house where an old, faulty washing machine has been kept.*

Figure 5: *A house in Tema community two, where waste TVs have been dumped*

Table 1: *Types and quantities of EEE found in 30 selected household in Tema(2016)*

Household appliances	Average per household	I.T Equipment	Average per household
Air conditioners		Fax machine	
Dish washers		Mobile phones	
Stove		laptops	
Washing Machine		PC's	
Fridges		Moderms	
Electric heaters		Alarm Clocks	
microwave		cameras	
Fans		DVD Players	
Mowers		radios	
Kettle		TV	

4.2.3. E-WASTE GENERATION

One of the greatest cause of e–waste is technology upgrades. Manufacturers and consumers alike are eager to make life more comfortable through EEE. This yields a desire to get a more advance form of existing EEE. As people patronize these newer versions, the old EEE are done away with. In Ghana, there is no existing infrastructure that is responsible for collecting these older versions, hence an increase in e-waste generation. Below are some of the common ways by which e–waste is generated.

- Cell phone upgrades
- Digital Television Conversions, that is the CRT TV's have been replaced with LCD ones.
- Computer software upgrades.
- Printers and Photocopy machines.(Here most ink jet printers are being replaced with laser printers due to their efficiency)

4.2.4. COMPOSITION EEE

EEE are made up of several materails. The figure below shows main materials found in in EEE and their percentage:

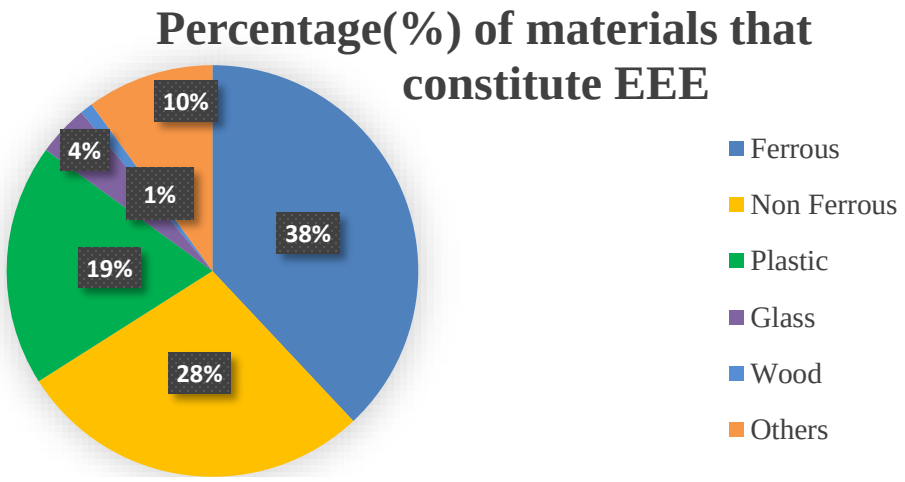


***Figure 6**: Shows the composition EEE. Some examples of ferrous metals found in EEE are iron and steel , while copper and silver constitute some of the most popular ferrous metals used.*

4.2.5. END-OF-LIFE OPTIONS FOR EEE

EEE consist of precious metals as stated in ***Figure 6***. The ferrous metals found in EEE consist of steel and iron while the non ferrous metals include copper, aluminium and lead. Due to the presence of these metals, individuals have resorted to crude ways retrieving these metals.

4.3.0. CRUDE METHODS OF RECYCLING E-WASTE

In this informal sector, this business seems to be booming for all involved in it. The activities in this sector exhibits a highly stratified system which is crude but quite appreciable in some perspective. It comprises of collection, disassembling, retrieval of precious metals and the eventual disposal of the residuals. The EEE are stripped of their most valuable and easily extracted components which are processed to directly reusable components or secondary raw materials in a variety of refining and conditioning processes. The remaining parts are dumped or burnt in an open ground.

The diagram below shows the route through which an EEE goes through at its end-of-life.

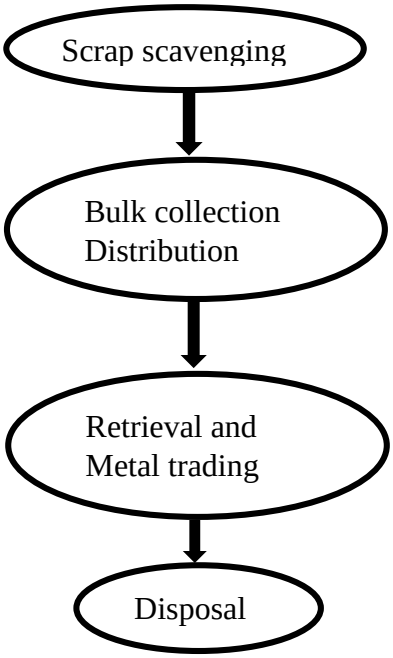


Diagram 1*: It demonstrates the stages through which WEEE go through before retrieved metals are sent to companies such as Wahome Steel Company Ltd, who will then process them into iron* rods.

4.3.1. WEEE collection and disassembling(Scrap scanvenging/ Bulk collection)

The collection of WEEE is the most difficult part of the entire process. Here individuals popularly called scrap scavengers collect WEEE from private homes, institutions, dump sites and along streets. The scrap scavengers knock on doors of most private homes in their quest to purchase WEEE. As a matter of fact, some households do give them out for free since they are even looking for ways and means to dispose these WEEE. They embark on this activity mostly by foot, pulling/ pushing their track and in some rare occasions, on motor bikes.

Though it is a tedious activity, these scrap scanvengers are proud to make a living as opposed to the prospects unemployment. After collecting the e-waste, they are sent to individuals involved in the bulk collections of them. Here depending on how negotiable your deal is, one could get a price higher than the average price.

The table below presents the average prices scavengers buy WEEE (scavangers' price) and how much they sell to the bulk collectors (bulk collectors' price) in the Tema Metropolis. (***Table 2***)

Electronic Equipment	Scavangers' price	Bulk collectors' price
Cell Phones	0.50	1.00
CRT Monitors	10.00	15.00
Desktop Computers	5.00	8.00
Laptop	4.00	7.00
TV	10.00	13.00
Air conditioners	10.00	13.00
Microwaves	5.00	7.00
Electric Iron	1.00	2.00
Refrigerators	20.00	25.00

Figure 7: *An image of a site where there is bulk collection of e-waste, which have been stripped off their plastic components.*

Figure 8: *An image of two trucks loaded with e-waste. Aside these trucks, some of them also use motor bikes.*

At this stage, the WEEE are disassembled using rudimentary tools such as hammers, pliers and wire cutters. In an interview with Mr. Nahiru Osabutey, EEE's are processed informally in small workshops using rudimentary methods such as manual disassembling and open–burning. He added that the burning had minimized due to the intervention by Officers of the Environmental Protection

Agency and the Ghana Police Service. The dissembling is quite risky especially when dealing with appliance with glass component. Abu Bakr, another dealer in WEEE, stated that he had no workshop, hence he operated along road side. Despite all the hazardous conditions they are exposed to, Abu Bakr said he is still in the business because it is quite lucrative if one is able to retrieve an appreciable quantity of metal parts of WEEE. Below is an image of where this gentleman does his disassembling of EEE.(figure 7) and an ongoing open–burning disassembling.

Figure 9: *An area around Tema Commmunity One roundabout (close to the market) where Abu Bakr dismantles WEEE*

Figure 10: *An image of a site where WEEE are burnt in order to retrieve metal parts*

4.3.2. Retrieval and trading of metals

Precious metals such as copper, iron and silver are retrieved through open-burning and other disassembling practices such the use of hammer(hammering). But the open-burnining as stated earlier on has been minimized due to the actions of by Officers of the Environmental Protection Agency and the Ghana Police Service because of the harmful environmental effect. From then, the metals are sent to companies such as Western Steel and Forging Limited , Wahome Steel Limited, Ferro Fabric and Tema Steel for processing.

***Figure 11**: A track loading with e-scrap , to be transported to Wahome Steel Company Ltd*

***Figure 12**: A bulk collection of metals parts retrieved from WEEE excluding copper.*

4.3.3. Disposal

After the retrieval of desired parts from WEEE , unwanted parts are disposed of . Abu Bakr, one the leaders in the scrap industry, explained that sometimes they pay about Gh10.00 to the refuse collectors , who will then dispose these waste to various dump sites in Tema.

4.3.4. DISADVANTAGES OF THE CRUDE METHOD OF RECYCLING WEEE

- The disposal of e-waste on landfills has multiple disadvantages including the contamination of underground water and soil. Poisonous metals such as lead and mercury, which were not retrieved during the retrieval process are carried by rain water into our various water bodies. This makes such water bodies harmful for human use.

- Protective clothing are not worn when dismantling e-waste such as CRT, hence poisonous chemicals could be inhaled which can cause respiratory damage.

- Large amounts of precious metals that could have been retrieved and recycled through appropriate means are wasted.

- Though Officers of the Environmental Protection Agency and the Ghana Police Service have made efforts to prevent open-burning, some recalcitrant individuals continue to burn e-waste after disassembling, which pollutes the immediate environment.

Figure 13: *A gentleman dismantling the motor of a mill machine in order to obtain copper. He does this with his bare hands , without any protective clothing at all.*

4.4. CAUSES OF THIS PROBLEM

- **Lack of Processing Infrastructure and High Capital Costs**

  The first and most important barrier to WEEE conundrum is the lack of facilities and the cost involved when appropriate channels of operation are followed. Currently, there is no facility for collection of e-waste, neither a place to dismantle and let alone retrieve precious metals. There are no infrastructure that facilitates the preprocessing procedure.

- **Lack of enforcements of Environmental regulations**

  Though Officers of the Environmental Protection Agency and the Ghana Police Service have made efforts to prevent open–burning , they lack the requisite equipment to curb the menace.

- **The need for people to make earns meat.**

  Lack of employement coupled with harsh economic conditions has forced individuals to engaged in any money generating activity without regard to the effects of their actions on them and the environment as a whole.

- **Lack of adequate knowledge on the part of individuals involve in this sector.**

  Per my interaction and investigation, none of the people involved have had any form of formal t training pertaining to recycling of WEEE.

- **Lack of enforcement of laws on the import of EEE**.

- **Lack of technical barriers**

  One of the barriers affecting the potential of e-waste recycling is the underpinning knowledge of smelting and refining process. It is decisive to have the knowledge of feed material composition, its possible reactions and final product . The recovery of PMs from e-waste using technology similar to their natural ores is challenging. When processing natural ores, the relationship between PMs and other accessory metals is well understood and investigated. However, for e-waste recycling using conventional metallurgical routes, the knowledge on the behavior of complex input materials is not well understood. To extract small quantities of PMs from e-waste, thermodynamic knowledge of more than one metal including copper, lead, nickel and zinc is required.

4.5. WHY CATHODE RAY TUBES ARE ESSENTIAL IN THE CRUDE RECYCLING OF WEEE?

To most individuals who have found employment through WEEE, CRTs are very vital to their operation. CRTs are used in old televisions and computer monitors. Most locals patronize CRT televisions because they provide a cheap alternative to modern LCD (Flat Screen) televisions. In an interview with Miss Betty, she confirmed the fact that people have a perception that CRT televisions are stronger than modern flat screen televisions. She also stated that most people believe that the heavier an appliance is, the stronger and longer the device will last. A twelve inch CRT television cost about GH₵200.00 whilst a flat screen of similar size costs GH₵ 900.00.

The most important and valuable component of CRTs to the scrab dealers is copper, which makes up more than 60% of the total intrinsic value. The majority of this copper is used for the focusing and deflection coils and is found within a glass matrix inside the television. The glass matrix contains large amount of lead-oxide, barium oxide and strontium-oxide which are very poisonous. Although under normal conditions the substances are bound in the glass matrix, when it is crushed to retrieve the copper, these poisonous substances are exposed to the environment. It effects on the environment is why attention needs to be drawn to it. These substances pollute underground water and soil.

Aside CRTs , appliances such as motor of fridges , motor of mill machines , microwaves, electric fans, and car automators , all contain large amounts of copper but due to CRTs large concentration of copper, it is sort after more than the others. After the retrieval of the copper metal,

they are then sold to individuals involved in making copper earrings and watches. Companies such as Wahome Steels also export most of these copper metal to Western countries and some parts of Asia. Below is an image of various metals and parts retrieved from CRTTs.

Figure 14*:Focusing and deflecting coils of manually dismantled CRTs. These are mostly made of copper.*

Figure 15*: An old trunk in which copper retrieved from WEEE is kept temporary*

Figure 16: *Motors of mill machines dismantled showing a reddish brown metal(copper), interlocked in it.*

Figure 17 : *The motor of a standing fan, which will be dismantled to retrieve copper.*

4.6. IMPACT OF THIS MENACE ON SOCIETY

- Dwindling in the quality of Ghana's human resource.

  A vast majority of individuals involved in these activities are youthful. They could have been in school, being trained in various professions, yet they have resorted to these activities as a quick means of earning a living. Also, children who are supposed to be in school are sometimes forced to assist their parents in these activities. These children in the future are unable to contribute their quota to the country's economy since they don't have any formal training in any vocation.

- The burning of e-waste to retrieve copper metals possess health concerns not only to individuals involved but communities around the site. Most of these toxic substances can cause kindney problems and damage to the respiratory track especially when dismantling e-scrap and certain toxins are inhaled. With the health risk involved, individuals are prone to certain diseases in the near future, and will not be able to contribute to the economy of the country.

- The activity also lead to poor sanitation. Figure 9, an image of Community One roundabout , an area treaded by many pedestrains yet its mostly occupied by e-scrap dealers who dismantle the equipments along the road.

4.6.1. HOW SOCIETY RESPONDS TO THIS MENACE

Every individual in our country has a daily contact with EEE and especially those which have become part and parcel of our lives. Some even say we can't live without them. In other words, without them life could be a little bit complicated. After these products have been used, they usually end on the streets, along the roads , infront of homes , commercial places and companies where they are discarded as waste.

Figure 18: *An abandoned television on the premises a house.*

Figure 19*:. abandoned photocopy machine at the premises of a house*

On the international scene , many European and Asian countries have placed laws and measures in place to deal with the increasing growth of e-waste. A typical example is Australia, where billions of dollars have been invested in contruction of smelters along with infrastructure to ensure efficient preprocessing stage.

In Ghana, issues of waste are deeply interlinked with the much higher profile issues of sustainability, consumption and employment. Yet, the issue of how we resolve our waste dilemma and its role in sustainability rarely makes headlines. When waste is in the news it is usually around issues of litter and political debate over which political party has been able to deal efficiently with the waste during their tunure of office. A typical example was when it was reported that the government owed one waste collecting company called "Zoomlion" and there was another dilemma over the transfer of waste management to another company. That incident became a public spectacle. While this debate is important it overshadows the serious problems in Ghana from the growing mountain of waste generated by our society which has been filling landfills almost as quickly as they are excavated. The problem is getting worse and is in lock step with our growing patterns of consumption. A visit to one dump showed that a time will come when we may not have any place to dump our waste any more. Dump site in Kpone has been particularly filled. Individuals therefore need to re-evaluate themselves, public educations should be made through televisions and newspapers on the adverse effects of not dealing with this menace.

CHAPTER FIVE

PROBLEM SOLUTION

5.1. BACKGROUND IN CHEMICAL ENGINEERING RELATED TO SOLUTION PROVIDED

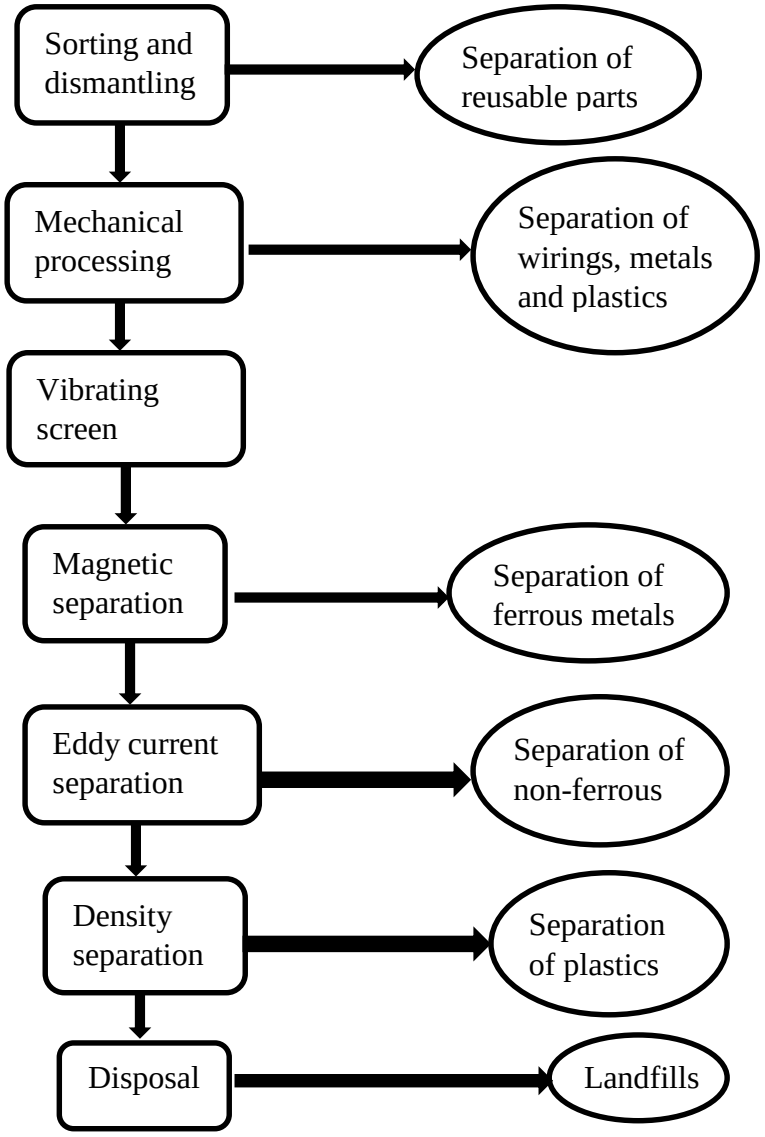
- In chemical thermodynamics, the reactivity of metals, and their stability in compounds, as measured by Gibbs energy of formation varies widely from each metal. With this knowledge, dealing with various PM's in e-waste would come in handy.
- Also metals have wide differing melting and boiling points , the form of which are produced based on temperature at which the required chemical reaction takes place. Such knowledge mostly used in the extraction of metals from their ore would also come in handy when addressing the issue of retrieving PM's from e-waste.
- Also due to the principle of simultaneous chemical equilibrium and electric charge neutrality , various thermodynamic equations could be derived for the extraction of various metals and also based on MatLab programming these equations could be confirmed. This will ensure accuracy in the extraction process which will later be discussed in details.

5.2. APPROPRIATE METHOD RECYCLING OF E-WASTE

WEEE processing and recycling constitute three main steps: collection, preprocessing and end processing, with each procedure vital to the retrieval of metals and the recycling economy. First and foremost, there should be appropriate government policies, of which the government of Ghana has just recently put in place. Then there should be advertisement. This will bring the attention of the public on the menace of the crude method of WEEE recycling and its adverse effect on the environment.

Next, collection facilities could be created in public places for collection of e-waste. It should be noted that certain reusable components could also be returned to the consumer through a series of chain. Preprocessing of WEEE is one of the most important steps in the recycling chain. A basic flow sheet diagram of preprocessing is shown in the next page.

Diagram 2



The daigram explains how WEEE are manually dismantled at collection facilities. Individual components are then tested and isolated from e-waste. At the early stages of the entire process, components such as housing, wires and capacitors are separated. Mechanical processing is an integral part of the process. Here, WEEE scrap is shredded into pieces using hammer mills. Metals and non-metals are separated during this stage using techniques such as screening, magnetic separation, eddy current and density separation. The final stage in the recycling chain of e-waste is the end processing, where the non-metal and metal fractions of e-waste are further processed. It is from here that the precious metals such as gold, silver and copper can be retrieved from WEEE through ***extractive metallurgy***.

Figure 20: *An image of a separation and dismantling facility in Brasil*

5.3. EXTRACTIVE METALLURGY

Copper is the most widely used metal in electronics due to its high electrical conductivity. Metals are often added to copper in order to change the strength, hardness, and resistance to corrosion. When mixed with certain metals, alloys such as bronze which is made of either tin, aluminium or silicon are formed. Brass is also another alloy produced from the combination copper and zinc. There are other metals such as silver, gold and palladium that are alloyed with copper. Because most metals can be alloyed with copper, one can conclude that they can dissolve in it at high temperatures. Gold, silver, platinum, palladium, selenium and tellurium are metals that exhibit such quality. Hence the process of recovering metals from EEE focuses on smelting them to recover impure copper and then electrorefining the impure copper into pure copper and all other metals. There are two main processes involved in this procedure, **pyrometallurgy** and **hydrometallurgy**.

5.3.1. PYROMETALLURGYICAL PROCESSING

It is by far one of the most common processes used for metal recovery from WEEE. Pyrometallurgy serves as the primary method of the entire smelting and refining . In this process the e-waste is exposed to very high temperature furnace causing them to melt. This liquefied form contains the copper and all other metals. As said earlier on, certain metals dissolve in copper on melting. These

include silver, gold, platinum, and palladium. Iron and aluminium are not recovered in the copper smelting process, and instead are oxidized to slag.

This process can be done in small furnaces. However, the most common industrial process is to co-process them with Copper Sulphide concentrates in large copper smelting furnaces, such as copper converters, anode copper furnaces, copper smelting and converting furnaces such as the Noranda process. There are four global leaders in the recovery of metal values from e-waste by means of smelting and refining:

- Boliden, (Skelleftehamn, Sweden)
- Xstrata Copper (formerly Noranda), (Quebec, Canada)
- Aurubis (Hamburg, Germany)
- Umicore. (Hoboken, Belgium)

Aside these four major smelting and refining industries, there are moderately e-scrap smelters located in Japan and South Korea. The need for e-waste recycling and processing capacity is widely recognized by the global leaders in smelting. Recent developments have proved that the plastic residue after disassembling could be used to produce energy. This school of thought would be further explained later in this chapter.

In January 2008, Xstrata Copper announced plans to double electronic scrap recycling capacity at its horne smelter, providing the smelter with the capacity to receive and process 100,000 metric tons per year. In April of 2010, Boliden announced that it would be investing ($202 million U.S. dollars) in order to triple its electronic scrap recycling capacity in its Ronnskar smelter from 45,000 to 120,000 metric tons per year. This expansion will allow for 2.7 million metric tons of e-waste to be recycled, and increase e-scrap's share of Ronnskar's raw material feeds from 6% to 14% (Boliden, 2010). The capacity of the major global smelters can be seen in ***Table 3*** below.

Company/Smelter	2008 Electronic Scrap Recycling Capacity (metric tons)	2012 Electronic Scrap Recycling Capacity (metric tons)	2012 Original Volume of Electronics to be recycled based on capacity of smelter (metric tons)
Boliden's Ronnskar Smelter	45,000	120,000	2,700,000
Xstrata Copper's Horne Smelter	50,000	100,000	2,250,000
Aurubis's Elektro Recycling NORD GmbH Smelter	N/A	60,000	1,350,000
Umicore	27,000	40,000	900,000
Total	142,000	290,000	6,525,000

Table 3: *Major smelting facilities across the globe and the metric tons e-waste processed as at 2012*

5.3.2. DISADVANTAGES OF THE PYROMETALLURGICAL PROCESSING

- The entire process cannot recover certain components such as chips
- Iron and Aluminum cannot also be recovered
- The entire process cannot fully separate all metals

5.3.3. HYDROMETALLURGYICAL PROCESS

Hydrometallurgy is a low temperature method. Here aqueous chemistry is applied in the recovery of metals. This method of treating e-waste is more preferred compered to the former. This is because it is more exact, predictable and more easily controlled. The entire process can be broken down into three general areas;

- leaching,
- solution concentration , separation and purification
- metal recovery.

5.3.3.1. Leaching.

E-waste goes through a series of acid or caustic leaches, which is a process whereby a soluble component is extracted from a solid by means of a solvent. The most efficient leaching agents are acids, due to their ability to leach both base and precious metals. Cyanide, halide, thiourea and thiosulfate are the most popular leaching agents. The following agents are used to leach specific metals: Leaching Agents used in Hydrometallurgical Processing

Metal	Leaching agent
Base metal	Nitric Acid
Copper	Suphuric Acid and Aqua Regia
Gold and Silver	Cynide
Palladium	Hydrochloric and Sodium Chlorate

Table 4:*: Shows the various leaching agents for various metals in WEEE*

5.3.3.2. Separation and Purification. The leachate solutions then go through separation and purification processes in order to concentrate the valuable metals and separate impurities.

5.3.3.3. Precious Metals Recovery. Recovering precious metals from leachate can be done via electrorefining processes, chemical reduction or crystallization.

5.3.4. DISADVANTAGES OF THE HYDROMETALLURGYICAL PROCESS

- The hydrometallurgical routes are slow and time consuming.
- Mechanical processing of e-waste takes longer to reduce size for efficient dissolution. It is reported that 20% of precious metal is lost by mechanical force during the process and that significantly contributes loss in revenue. (***Boliden Smelters with the use Kaldo Technology***)
- Cyanide, is a hazardous leachant and therefore should be used with high safety standards. Any mishap can cause contamination of rivers and seawater.
- Halide leaching is difficult to implement due to strong corrosive acids and oxidizing conditions.
- The use of thiourea leachant is expensive.

5.4. GENERAL PROCESS

Before the entire extraction procedure begins one needs to understands the procedure.The general process followed at the global smelters is as follows

5.4.1. Sorting and Dismantling

Here hazardous components, such as batteries, cathode ray tubes and mercury bulbs, are removed at designated sorting stations. At **Xstrata's Horne smelter**, cathode ray tubes are completely recycled; the plastic tube is sent to a smelter, the glass is re-used at the facility as a fluxing agent, and the lead is recovered. The image below shows how these parts are dissembled and vital parts are removed at designated stations.This image is taken from an industry in Brazil involved in recycling of e-waste.

Figure 21*: A facility in Japan where there is dismantling of e-waste before extractive metallurgy is applied*

5.4.2. Particle Size Reduction.

Once the electronics have been removed of their hazardous components, they are shredded into scrap metals and fines. The shredded material is then further separated using vibratory conveyors, shaker tables, cross-belt magnets, eddy current and sand flow units, among other density and magnetic separation methods. In figure 12 , more light is thrown on the entire process, this is in regards to the various methods of separating after dismantling.

Dusts are generated during pre-treatment processes and are collected in filter and bag house systems. These dusts can have high precious metals content but also contain significant amounts of pollutants and high burn-loss components like plastics, paper and wood. The dusts can be sent to the smelting process for recovery of precious metals.

It is common for high-grade e-waste not to go through mechanical shredding processes. In the process certain metals and materials are lost. These include aluminum, iron and plastic. Nevertheless the economic value gained outwits the losses encountered.

5.4.3. Sample Assay.

E-scrap is sampled in order to assess copper and precious metals content. Separated materials are then sent to the smelter.

5.4.4. End-Processing

This is the most important stage of the entire recycling process. Shredded e-scrap is sent to an integrated smelter. A solution of copper and iron sulfide is produced ("matte") while iron and other oxides form a silicate solution called "slag". The precious metals are contained within the matte, which goes to the converting stage. The slag is treated separately through the use of a lead blast furnace, lead refinery and special metals plant.

5.4.5. Converting Stage.

Here the matte is converted to impure copper, called "blister" copper. The liquid blister copper is then refined in the anode furnaces where they are are electrorefined to pure copper. Leaving metals such as silver, gold, selenium and tellurium as precipitates at the bottom of the electrorefining cell. These are called the metal residue. The metal residue is then melted, casted and refined to produce precious metal bullion. Plastics are highly flammable hence energy usage is reduced due to the combustible nature.

5.5. IMPORTANCE OF PROPER RECYCLING

When proper recycling procedures are followed the benefits are enomous. Below are some benefits

5.5.1. Economic Relevance

- Processing e-waste reduces the burden on mining ores for primary metals. Therefore the scares resources especially gold and silver could be conserved.

  Below is a table showing the composition of major metals that consumed by electronic equipment.

***Table 5:**: Concentration of Metals in Electronics as at (2007)*

EEE	Copper(%by weight)	Silver(ppm)	Gold(ppm)	Palladium(ppm)
Television Board	10%	280	20	10
PC Board	20%	1000	250	110
Mobile Phone	13%	3500	340	130
DVD Player scrap	5%	115	15	5
Portable Audio Scrap	21%	150	10	4

- EEE are made of different elements such as gold, silver, platinum , gallium , palladium , tantalum, germanium and selenium. When recovered monies that could be used in extracting them from their ore could be used for other projects in society**.**

- Another benefit is in terms of energy conservation.

  An article published by the U.S Environmental Protection Agency has identified enormous benefits of using recycled iron, copper and steel over their virgin materials. One of the major benefits is energy saving. In a nut shell, using recycled metals mentioned above saves a lot of energy. The graph below shows the amount of energy saved according the research done by the U.S Environmental Protection Agency

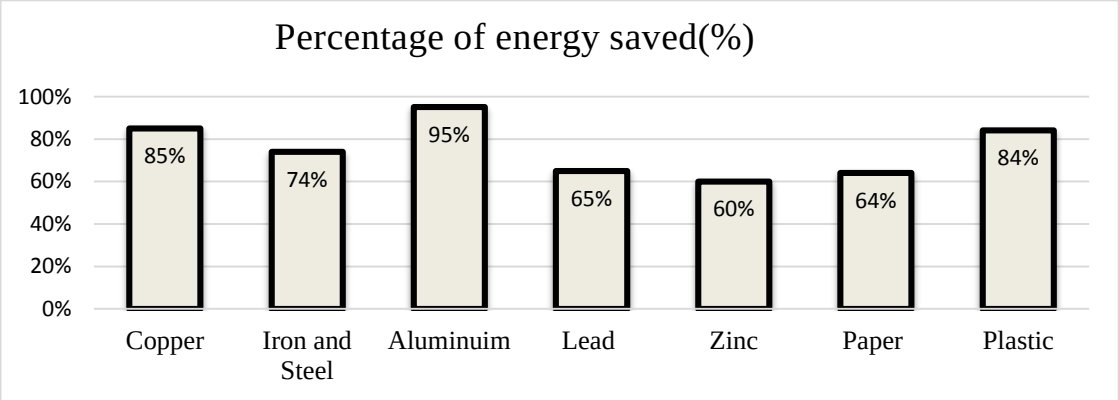


***Figure 22**: Demonstrates the percentage of energy conserved when recycled metals are reused in EEE. This research was done by the U.S Environmental Protection Agency*

5.5.2. Environmental benefits

- Extraction of precious minerals such as gold from the land is having a devastating effect. With an alternative method of recovering these methods that effect would be minimized drastically.
- Initially most of these EEE were buried on landfills. With an option to recycle these equipment efficiently these lands could be used for other purposes.

5.5.3. Public health

Also the crude methods of recovering precious metals from these EEE such as the open burning of EEE to harvest copper in places released a large amount of toxic into the atmosphere. with safer and more environmentally friendly methods all these would be avoided. A typical area is Agbogbloshie

***Table 6**: Potentially hazardous materials in E-waste*

Hazardous Component	Electronic component and Device
Lead	Cathode ray tubes and Solder
Mercury	Switches and housing
Selenium	Circuit boards
Cadmium	Circuit board and semi-conductors
Cobalt	Structural strength and magnetivity in steel
Chromium	Corrosion protection for steel
Antimony trioxide	Flame retardant

Aside retrieving PM's from e-waste, e-scraps could also be used to generate energy.

CHAPTER SIX

6.1. CONCLUSION

The striking effects of the currently practiced crude method of e-waste recycling in Tema and Ghana as a whole on human health and the environment are significant. Hence, there is a need for urgent actions to address the menace. These activities do not only lead to severe land/water pollution and negative health impacts on the people engaged in it, but there is a release of poisonous metals into the atmosphere (air pollution). These go a long way to increase global warming and the ozone layer depletion. Ghana, as a developing nation should be ready to embrace an increase in e–waste , due to an unwavering and unquenching thirst of its inhabitants for technology.

National agenda should therefore be geared towards facility building in the e–waste recycling sector. These should include the state providing assistance to industries such as Wahome Steels Company Ltd and Western Castle to expand their operations. Not only should they be converting e-waste to iron rods but hydrometallurgical processing methods should be adopted. Global experts on e-waste recycling could be brought to train individuals in the country to ensure that the hazardous components of e-waste are dealt with properly. This will in turn reduce its environmental impact.

When the appropriate recycling procedures are followed , millions of revenue will be generated. In other words , this industry could bring an industrial revolution into Ghana's economy because a lot of employment opportunities will be created.

6.2. RECOMMENDATIONS

With reference to the problems stated in Chapter three, the following recommendations were made

- **Construction of Processing Infrastructure**

  With increasing number of WEEE, the government should seize the opportunity and set-up infrastructure especially those for preprocessing of WEEE. When these facilities are built, separating ferrous and non-ferrous metals would be easier. Plastics could also be easily separated. This will make the extraction and refining process much easier

- **Enforcement of Environmental regulations**

  The law enforcement bodies such as the Ghana Police Service and Officers of the Environmental Protection Agency (EPA) should ensure that indiscriminate burning of WEEE is curtailed. This is similar in the case of Tema community one, where burning of E-waste has reduced drastically due to the intervention of the EPA and the Police Service.

- **Public Education**

  The public and individuals involved in this sector should be educated on the adverse effects of improper disposal of e–waste .

- **Training of experts in the field of extractive metallurgy.**

  Individuals should be trained to understand the thermodynamic knowledge of extracting precious minerals and other metals such as iron and aluminum which are lost during the extractive process. Due to the mining industry, some Ghanaians have been trained as engineers in the extraction of precious minerals from their ore, but such cannot be said of e-waste. With trained expertise in this field, loss of metals will be reduced especially during the smelting stage. Individuals could also be trained in efficient ways of the preprocessing stage, hence making it much more effective and efficient.

CHAPTER SEVEN

7.1. APPENDICES

7.1.1. QUESTIONAIRES FOR E–SCRAP SCAVENGERS

Name: …… Date:……

1. How long have you been in this business?
   ……
   .....
2. What kind of WEEE do you deal in?
   ……
   ……
   ……
3. Which communities do you visit most often?
   ……
   ……
   ……
4. At what prices do you mostly purchase WEEE from your various sources?
   ……
   ……
   ……..
5. After purchasing these WEEE , what do you do with them?
   ……
   ……
   ……
6. Is the business lucrative, if Yes , How?
   ……
   ……
   ……

7.1.2. QUESTIONAIRE FOR BULK COLLECTORS OF E–WASTE .

Name……Date……..

1. How long have you been in this business?
   ……
2. Do you deal with Scap Scavanger?

   ……..…….

3. Aside the scrap dealers, are there other groups of people you deal with in order to obtain e-waste?
   ……
   ……
   ……
4. What do you do with these WEEE you purchase ?
   ……
   ……
   ……..
5. After retrieving metal parts from WEEE, what do you do with the plastic waste?
   ……
   ……
   ……

6. What do you you think are some of the environmental effects of the inappropriate disposal of the platic components of WEEE?

   ……..

7.1.3. QUESTIONAIRE FOR COMMUNITY MEMBERS

Name…… Age…….

1. How long have you lived in the community?
   ……
   ……
   ……

2. What kind of electrical equipment do you use?
   ……
   ……
   ……....

3. With respect to secondhand and brandnew equipment, which do you prefer and why?
   ……
   ……
   ……

4. What immediate action do you take when an electrical equipment becomes faulty?
   ……
   ……
   ……..……

5. How do you deal with an equipment that is beyond repairs?

……
……
……

6. Have you ever had a business interaction with a scrap scavenger and if YES, what do you think happens to faulty appliances people sell to them?

……
……
……

7. What are some of the effects of the energy crises on the EEE?

……
……
……

7.1.4. QUESTIONAIRE FOR REPAIRERS OF FAULTY EEE

Name: ……Date: …….

1. How long have you been in this business?

……
……

2. What kind of appliances do you repair?

……
……
……

3. What is your efficiency rate in terms of repair of faulty appliances?

……
……
……

4. How do you dispose off appliances that are beyond repairs?

……
……
……

5. Have you ever had a business interaction with scrap dealers?

……
……
……

6. What do you make of their operations?

……
……
……

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INTRODUCTORY LETTER

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Our Ref: Coe-PO/CENG 291/ Date: May 15, 2015

TO WHOM IT MAY CONCERN

Dear Sir/Madam,

LETTER OF INTRODUCTION

The bearer of this note is a first year engineering student of the College of Engineering conducting a project in a course titled "Engineering in Society".

The overall aim of the course is to inculcate in students an appreciation of the fact that the purpose of engineering is to solve societal problems. This course is aimed at encouraging students early in their programmes of study to draw a link between their chosen field of engineering and the application of this field to the issues that confront the day to day lives of people.

We should therefore be most grateful if you could facilitate his data collection and provide any other assistance that he may need.

Counting on your usual cooperation in such matters.

Yours sincerely,

ING. PROF. S.I.K. AMPADU, *FGHIE*
Provost, CoE

GALERRY

An old and dismantled CRT lying waste in front of a house. Investigation showed that the owner was once a repairer and tried to fix it when it got damaged but failed.

An area in Tema Community Two where old fridges have been abandoned infront of a house along the road.

An old CRT television lying under a tree

Old fridges lying waste behind a house in Tema community one.

An old fridge lying in front of a fridge repairers shop.

Old and faulty appliances kept in shop that is no longer in use my its owner

Abandoned washing machines on a site in community four.

An abandoned repairer's shop where old WEEE ly together with other waste.

Old fridges dumped on a site in Community four together with other waste. The area used to be an a fridge repairers workshop

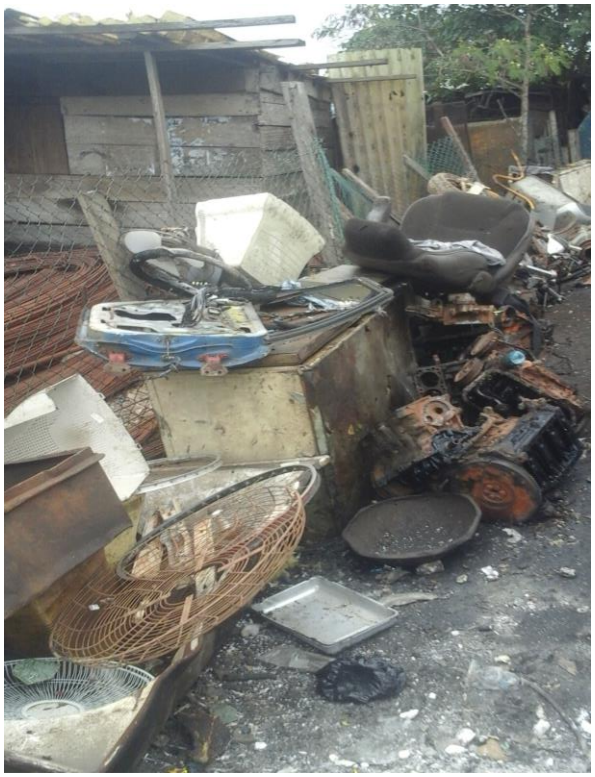
Old CRT televisions abandoned behind a house

Two trucks loaded with e-waste. These are being assembled to be sold to bulk collectors in community one.

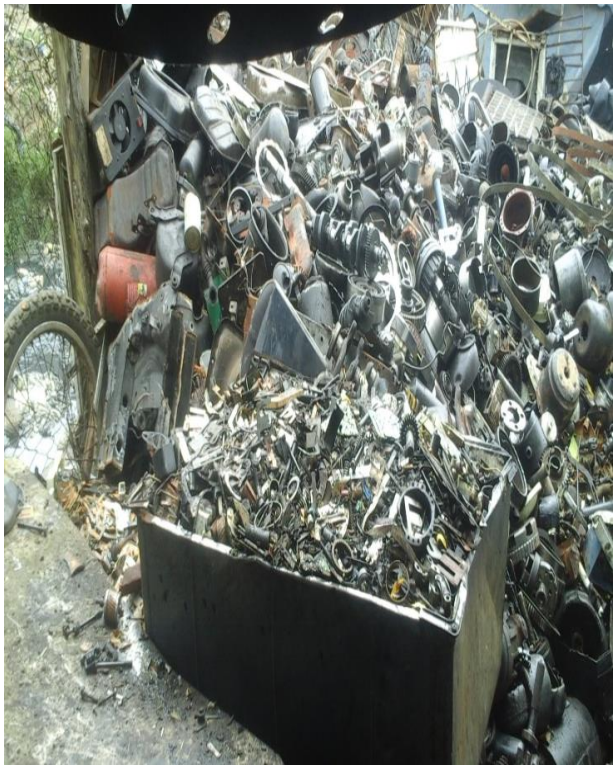
An image of a motor bike at the site of collection of scraps. This bike is used for collection of e-waste from various site.

A collection of WEEE whose metal parts have been retrieved.

Old computer System Units, ready to be dismantled.



An area in one of the workshops visited during the research. Samples of old appliance and car parts to be dismantled.

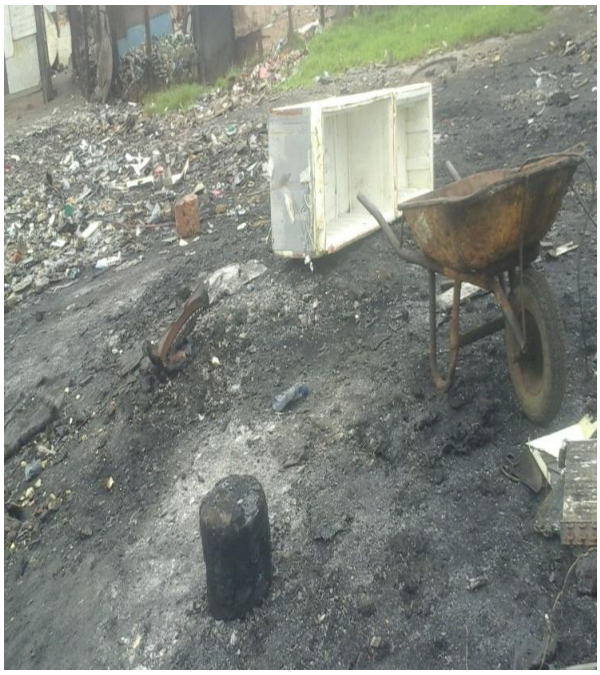


A collection of metal parts retrieved from WEEE excluding copper

A sample array of metals that are still insulated, ready to be sent to the site for burning. This will help separate the metals from their insulators.

The foam found in old fridges are used to burn WEEE in order to retrieve the metals within. They are widely used because they are highly flammable.

A gentleman unloading e-waste to be burnt to retrieve



An image of the site where e-waste are burnt

A vehicle being loaded with metal scraps to be transported to Wahomey Steels Company Ltd.

Remains of glass parts, at the site where WEEE are burnt. Currently, there is no crude way of disposing of these waste glass

The burning of WEEE , releases poisonous chemicals that cause air pollution. This goes a long way to increase global warming and ozone layer depletion.

Individuals exposed directly to these chemicals in WEEE, are prone diseases such as cancer and other respiratory diseases. Most of them are ignorant of such future effects.