ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CHEMICAL AND BIO ENGINEERING DEPARTMENT

ENVIRONMENTAL ENGINEERING STREAM

APPLICATION OF HYDRO-METALLURGY (WET ETCHING) TO RECOVERY A PRECISE METAL (GOLD) FROM A WASTED PRINTED CIRCUIT BROAD (WPCB): CASE STUDY OF MINISTRY OF INFORMATION COMMUNICATION AND TECHNOLOGY (MICT)

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ABSTRACT

This thesis research is undertaken with the main objective of assessing the existing e-waste management in Ethiopia by taking ministry of information and communication technology as a case study and to propose e-waste recycling approach (hydrometallurgy) to recover gold. To meet the research objectives a blend of qualitative and quantitative methods were used where unstructured key informant interviews, Observation of the e-waste disposal site from the selected govermental organization and computer recycling and refurbishment center (CRTC) at Kality were combined with Case study at laboratory scale hydro-metallurgy to recover gold from waste printed circuit boards (PCB).It is found that E-waste is expected to be a huge problem in the future, given the rise in consumption trend of the target institutions and the general importation trend of the country. There is high accumulation of old ICT equipment in the target institutions of the study. Parallel to that, The current trend of lifecycle management of this electronic waste at CRTC and at Addis Ababa University is out date and the precious metals like that of gold are not properly recycled.in addition by applying hydrometallurgical approach (wet etching), from a sample of 500 gm printed circuit board 1.66 gm of gold was recovered with mineral composition of 99.71% Au, 0.12% Ni,0.16% Cu. this research under takes an experimental procedure where, At the start of the experiment 20 gram of fingers was used for on batch. And added to on an empty beaker. The next step will be dilution of the hydrochloric acid, hydrochloric acid with the concentration of 35% will be diluted by adding 57 ml of water on the biker. Finally we can get hydrochloric acid with the concentration of 15% with a volume of 43 ml. next the addition of hydrogen per oxide which has a concentration of 15% with a volume of 50 ml and the reaction proceeds for 6hr after that The combination of hydrochloric acid and hydrogen per oxide will detached the gold fingers from the silicon chips and a film of gold fingers will float, finally Using kitchen strainer and a large coffee filter the gold foils will be filtered out of the acid peroxide solution. The results were obtained by taking Hydrochloric acid to hydrogen per oxide proportion(1:0.5,1:0.4,1:0.9),retention time(6hr,12hr,21hr) and hydrochloric acid concentration of (5%,10%,15%) as factors and on the basses of the study the optimum conditions to get a maximum amount of gold (0.2455 gm) was HCl: H_2O_2 proportion of (1:0.5), HCl concentration (10%) and retention tine (12hr) .In conclusion, to draft a solution and act accordingly, the government through its instruments should put a system in place.

Key words: printed circuit board, hydrometallurgy, gold

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LIST OF ACRONYMS

AAEPA	Addis Ababa Environmental Protection Authority
ABD	acute beryllium diseases
ARF	Advanced Recycling Fee
BAN	Basal Action Network
BFR	brominated flame retardants
CRT	Cathode Ray Tube
CP	Chlorinated paraffin's
DBDPE	decabromo diphenylethane
DSF	Digital Solidarity Fund
EEE	Electrical Electronic Equipment
ELNI	Environmental Law Network International
EMPA	Swiss Federal Laboratories for Material Testing and Research
EOL	End of Life
EPA	Environmental Protection Authority
EPR	Extended Producer Responsibility
ERCA	Ethiopian Revenue and Customs Authority
EWASA	e-Waste Association of South Africa
HBCD	hexabromocyclododecane
HEXABBZ	hexabromobenzene
HCB	hexachlorobenzene
HP	Hawlet Packard
HW	hazardous waste
IBM	International Business Machine
ICTDA	Information Communication Technology Development Agency
LCD	Liquid Cristal Display

LED	Light emitting diodes
MICT	ministry of information communication and technology
MMIC	microwave frequency integrated circuits
NIOSH	National Institute of Occupational Safety and Health
OECD	Organization for Economic Co-operation and Development
PAH	Polycyclic aromatic hydrocarbons
PBDE	poly brominated di phenyl ethers
PCB	Printed Circuit Board
PCN	Polychlorinated naphthalenes
POP	Persistent Organic Pollutant
PTFE	polytetrafluoroethylene
PVC	Polyvinyl chloride
ROHS	Restriction of Hazardous Substances
SDC	Skill Development Center
SWICO	Swiss Association for Information, Communication and Organization Technology
TBBPA	tetra bromo biphenol-A
UNDP	United Nation Development Program
UNEP	United Nation Environmental Program
USEPA	United States Environmental Protection Authority
VDU	Visual Display Unit
WEEE	Waste Electrical and Electronic Equipment

1. INTRODUCTION

1.1.Background

According to World Bank Pollution Prevention and Abatement Handbook .[151], hazardous waste (HW) can be defined in a number of ways such as: Hazardous characteristics (toxicity, flammability, corrosiveness),Toxic components(arsenic, mercury or PCBs),Types of material (explosives, solvents) Waste from specific process (refining, plating, and clinical) Specific waste streams (sludge from chemical treatment plant) However; there are many other definitions of hazardous wastes in different countries. In Ethiopia, the Environmental Pollution Control Proclamation (Pro. 300/2002) defines "Hazardous Waste" as any unwanted material that is believed to be deleterious to human safety or the environment and "Hazardous material" as any substance in solid, liquid or gaseous states, or any plant, animal or micro-organisms that is injurious to human health or the environment.

Electrical and Electronic waste(WEEE), or e-waste as it is popularly called, is a collective terminology for the entire stream of end-of-life electronic equipment such as used TVs, refrigerators, computers, mobile phones, etc. Nevertheless, e-waste contains significant quantities of hazardous components. Electronic products – usually those with cathode ray tubes (CRTs), printed circuit boards (PCBs), batteries and mercury switches – contain hazardous or toxic materials such as lead, mercury, cadmium, chromium and flame-retardants. Improper recycling and disposal operations of such wastes often results dumping of pollutants into the land, air and water [67].

Due to the hazards involved, disposing and recycling e-waste has serious health and environmental implications. When this waste is land filled or incinerated, it poses significant contamination problems. Landfills leach toxins into groundwater and incinerators emit toxic air pollutants including dioxins. The application of computers, and thereby the development and awareness of mechanization in Ethiopia, is closely related to the introduction of computers into by foreign suppliers. Computer usage started in Ethiopia around 1960s in relation to the major suppliers, namely IBM and Burroughs. And recently, E-waste is emerging as one of the prevailing environmental and health concern to Addis Ababa with the issue of disposal of waste or used products. From electronic wastes, computer waste is the most significant due to the gigantic amounts as well as the rate at which it is generated. As per the information obtained from ERCA indicates, about 315,957 PCs and PC accessories were imported into the country for the year 2006. The importation of PCs (and electronic equipment's, in general) also is growing at a very fast rate (ERCA). This growth has significant economic and social impacts. The increase of electronic consumption rates and higher obsolescence rate leads to higher generation of electronic waste in the future. The increasing obsolescence rates of electronic products added to the huge import of junk electronics from abroad will create complex scenario for solid waste management in Addis Ababa. Like in the many of the developing countries, in Ethiopia, the affordability of computers was limited to only a socio-economically advantaged section of the population till the recent years. However, the importation of reused computers is getting (and continues to be) high as does affordability of used computers. This entails a major problem in the disposal of waste computers and consumables.

No reliable figures are available as yet to quantify the computers generating as waste. The 2003 Solid Waste Assessment Report of Addis Ababa does not indicate e-waste as a noticeable waste in the physicals composition of the waste generated from the city. However, as computers are increasingly becoming more affordable, and there is greater access to technology, the disposal of such waste machines could definitely be higher. To this end, as far as the knowledge of the researcher is concerned no adequate study has been done across the country on the issue.

This study mainly focuses on the assessment of the on-going e-waste management in Ethiopia as a case study on ministry of information communication and technology (MICT) and recommending a recent e-waste recycling approach (hydro-metallurgy) to recover precious metal (gold) from the wasted printed circuit board.

1.2.Statement of the Problem

Today, computers and other electronic equipment's use at almost all our day to day activities is becoming an important aspect for maintaining an efficient work flow and resource saving; however, their environmental impacts are often not realized or considered. These impacts are expressed throughout the manufacturing, use and disposal of the equipment's, and thus require monitoring and an understanding of each stage of equipment's' lifecycle. The computers and other equipment's located in the various sectors of governmental offices, private sector offices and households consume various quantities of energy, but in most cases they are not operating at optimal efficiency as a whole. In addition, the disposal of all obsolete equipment's does not occur in the most environmentally sound manner possible, thus resulting in various government and private offices either diverting unwanted units to landfills or storing them for extended periods of time. Both inefficient use of energy and the manufacturing and disposal of equipment systems lead to the generation and release of toxic compounds into the environment. This phenomenon becomes severe especially in most developing and economic transition countries like that of Ethioia, where the fight against digital divide is promoting massive imports of used and new computers with lenient environmental regulations, lower safety standards, absence of any defined management system and loads of informal actors on the area. Today, millions of used computers and accessories from the developed countries are being shipped to developing countries, especially to East Asian countries and some parts of Africa, under the umbrella of charity [1]

Together with loads of different development interventions the general ICT penetration, use of computing devices and Electrical and Electronic equipment's is highly increasing in Ethiopia. According to ERCA, in the last five years the number of computers and computer related accessories imported in to the country shows an increasing trend.
This thesis research aims to assess the existing condition and prospects of electronic waste in Ministry of information communication and technology (MICT). In doing so the paper seeks answers for the following research questions:

- What is the existing electronic waste condition?
- What specific legal frame-works are formulated to mitigate the problem?
- What is the general awareness of different concerned parties about the problem and what remedy measures are being taken?
- What technology is available to recover valuable materials from e-waste?

1.3.Objectives

1.3.1. General Objective

The general objective of this thesis paper is to assess the existing e-waste management in Ethiopia by taking ministry of information communication and technology (MICT) as a case study and to propose e-waste recycling approach hydro-metallurgy (wet etching) for recovering a precise metal (gold) from a wasted printed computer board by taking a laboratory taste.

1.3.2. Specific Objective

- To assess the existing e-waste management in MICT and se and to investigate(assess) the degree of awareness by e-waste generates
- To apply Hydro-metallurgy to recover a precious metal(gold) from the wasted printed circuit board

1.4.Significance of the Study

In recent years Penetration of ICT and many other development interventions in the country are in a very high speed and large magnitude than ever. Using computer and other electronic technologies, unquestionably, is imperative for all sectors of development in maintaining a fast and reliable communication, work flows of day to day activities and in the large for the process of catching up the age of information of the world. As the magnitude of the equipment's; however, increases from time to time tied with the high obsolesce rate the question of proper and environmentally sound handling of the technologies will be a must case to arrest the potential problem both the country and its capital likely to face in the future. Therefore, conducting a study to identify the problems pertaining to electronic waste is crucial, timely and hence different parties could benefit from the outcome of this thesis research. In particular, it could have the following contributions:

- Revealing the existing state and prospects of the problem, the study may bring to the attention of policy makers, the EPA and other concerned stakeholders for appropriate action.
- Introduce the economic and social advantages of e-waste in its cradle-to grave environmental approach.
- Suggest areas of mitigation for the present and potential problem under investigation and provide an introductory approach of sustainable electronic waste management.

1.5.Scope of the Study

The scope of the assessment is listed as follows

- assess waste management system of MICT being operationalized at Kalite station;
- assess the operational activities of waste generators assumed relevant to this particular study i.e. governmental offices (Addis Abeba university)
- conduct a depth study on the sampled waste printed circuit board; and
- Propose as to how to recover a precious metal (Gold) from the wasted printed circuit board.

2. LITERATURE REVIEW

2.1.What is e-waste?

E-Waste for short - or Waste Electrical and Electronic Equipment (WEEE) - is the term used to describe old, end-of-life or discarded appliances using electricity. It includes computers, consumer electronics, fridges etc. which have been disposed of by their original users.

2.2.E-waste Production

2.2.1. Current Situation

The global e-waste production is assessed at 20-50 Mt/year [1], equal to 1-3% of the estimated global urban waste production (1636 Mt) [2]. PCs, cell phones and TVs will contribute 5.5 Mt in 2010 and will amount to 9.8 Mt in 2015. In wealthier countries, e-waste will stand for 8% of the urban waste volume [4]. Each electronic item's participation in the annual e-waste production, E (kg/year), depends on each electronic item's mass, M (kg), its quantity (number) in the market and consumption, N, and its average life cycle, L (year).

$$E = MN/L \text{--} \quad (1)$$

Electronic computers with an average 3-year life cycle [5] contribute to a greater extent to the total e-waste flow compared to refrigerators and electrical cook-stoves, having an average life cycle of 10-12 years. Certain e-waste types along with their mass and estimated life cycle are summarized in Table 1

Particularly for the European Union, the e-waste quantities increase by 3-5% per year [6], a rate three times faster than the urban solid waste. During the 1990-1999 periods the quantities produced in EU-15 were approximately 3.3-3.6 kg/resident, while estimated quantities for the 2000-2010 periods vary between 3.9-4.3 kg/ resident [4]. Using the equation (1), Swiss is estimated to produce 9 kg/person/year [7], the European population 14 kg/person/year [8], with the total EU-15 production amounting to 5.5 Mt/year and, in case of EU-27, 8.3-9.1 Mt/year [9]. USA produced approximately 2.6 Mt [3], while China produced 2.5 Mt in 2005 [10]. There are no available data for poorer countries, but it was assessed that India and Thailand produced 0.3 and 0.1 Mt of e-waste in 2007 [3].

According to another calculation based on the equation (1), Tab.1 and available data for the total number of PCs (0.78 billion units), cell phones (3.4 billion units), stationary phones (1.2 billion units), TVs (1.4 billion units), and radios (2.5 billion units), the total production amounts to 11.7 Mt/year [11]. Moreover, considering the constantly increasing production of e-waste and the fact that the relatively large-mass electrical appliances (refrigerators, air-conditioners etc.) are not included in the aforementioned calculation, it is estimated that the total e-waste quantities will be rather larger. If the global increase of GDP by approximately 20% in the last 6 years is also considered, then the aforementioned estimate of 20-50 Mt/year [1] is justified.

Table 2:1 E-waste types and their estimated life cycle.

Item	**Mass of item (kg)**	**Estimated life (year)**
Personal computer	25	3
Fax machine	3	5
High-fidelity system	10	10
Cell phone	0.1	2
Electronic games	3	5
photocopier	60	8
Radio	2	10
television	30	5
Video recorder/DVD player	5	5
Air-conditioner	55	12
Dish washer	50	10
Electric cooker	60	10
Food mixer	1	5
Freezer	35	10
Hair-dryer	1	10
Iron	1	10
Kettle	1	3
microwave	15	7
refrigerator	35	10
Telephone	1	5
Toaster	1	5
Tumble dryer	35	10
Vacuum cleaner	10	10
Washing machine	65	8

2.3.Hazardous Components of E-waste

Added to the burden of the management of hazardous municipal waste, the management of huge and growing quantities of electronic waste is emerging as one of the most important environmental problems of developing countries, e-waste has become more of a problem than all other wastes because of the very significant health and environment hazards associated with it. E-waste is getting generated at a 10 per cent annual growth rate which is one of the highest in the world.

The problems associated with electronic waste are now being recognized. E-waste is highly complex to handle due to its composition. It is made up of multiple components some of which contain toxic substances that have an adverse impact on human health and environment. These components are listed as follows.

2.3.1. Printed Circuit Boards

A printed circuit board, or a PC-board, is the piece of hardware that acts as a base in electronic equipment, and provides electrical connections to the mounted components. PC-boards are present in almost all types of e-waste, including cell phones, computers, TVs and printers. PC-boards are made of woven glass fiber sheets hardened with a flame retarded epoxy resin. Most commonly, brominated flame retardants (BFR), such as tetra bromo biphenol-A (TBBPA) and poly brominated di phenyl ethers (PBDE), are incorporated into the resin, but chlorinated and inorganic compounds also occur. The glass in the glass fiber sheets mainly contains oxides of common base elements, such as silicon oxide, calcium oxide and aluminum oxide. The PC-board is layered with copper traces facilitating the conductivity [12], and it is generally the most valuable parts of e-waste that are most beneficial to recycle due to their substantial contents of copper and precious metals [13]

Components such as switches, resistors and capacitors are mounted on the boards and connected to the copper circuitry by solder, which usually consists of a mixture of tin and lead (in the ratio 60/40 tin-lead) [14], but sometimes also antimony or an alloy of copper and beryllium (typically containing 2% beryllium). The typical solder content in scrap PC-boards ranges between 4-6% by weight, or approximately 50g/m2 of PC-board [12]. The components soldered to the PC-boards vary a lot and may contain many different substances. Relay and switches often contain mercury. Switches may also contain small amounts of cadmium, which also is the case for plated contacts. Light emitting diodes (LEDs) contain gallium arsenide (GaAs), and resistors, capacitors and microchips may contain various metals, although copper and aluminum is most common [15].

2.3.2. Batteries

Batteries are present in all portable electronic devices, such as laptops, cell phones and portable power tools. They are produced in many shapes, sizes and types. From an environmental perspective, mercury containing batteries and rechargeable batteries containing cadmium, nickel and lead are of most concern. Mercury-containing batteries are banned in many countries due to concerns over their hazardous properties. Rechargeable batteries include nickel-cadmium (Ni-Cd), nickel metal hydride (NiMeH), lithium ion and lead acid batteries. About 80% of the rechargeable batteries worldwide is Ni-Cd batteries [15]

2.3.3. Cathode Ray Tubes

Cathode ray tubes (CRTs) contain the greatest amount of all substances of concern in older desk top computers and TV sets [13]. The hazardous compound that is present in largest amounts is lead, as it is used in the glass to shield people from the x-rays produced as a by-product during the electron acceleration [16]. An older polychrome CRT can contain 2-3 kg of lead, while a new one typically contains about 1 kg of lead [13]. The cone glass (or funnel glass) thus contains about 20-24% lead oxide (Pb_o), the neck glass about 28-30% Pb_o, and the glass frit about 80% Pb_o, whereas the screen glass (or panel glass) normally contains no lead. The lead is encapsulated in glass and, thus, immobilized unless and until the glass is broken. However, the glass most be broken in relatively small pieces before significant levels of lead would be available for release into the environment. The inside of the CRT panel is coated with a fluorescent phosphor layer, containing various metals, which presents an inhalation hazard if managed in dry state. Some older CRT screens may be coated with cadmium sulphide [16]. In addition, the screen and/or cone glass may contain antimony. The electron gun of the CRT contains a small getter plate, weighing approximately 1-2 g including its frame that contains barium and barium compounds [13].

2.3.4. Liquid Crystal Displays

Liquid crystal displays (LCDs) are found in all kind of electronic equipment containing a flat display, e.g. cellular phones and notebook PCs. As the name reveals LCDs contain liquid crystals that are embedded between display glass and electrical control elements. The liquid crystals are suspected to be hazardous even though studies on their toxicity are scarce [12]. It should also be pointed out that LCDs are often back lighted with cold-cathode fluorescent lamps that contain mercury [17].

2.3.5. Plastics and Polymers

Plastics, constituting more than 20% of e-waste [18], can be of concern in them or contain substances of concern as additives. Polyvinyl chloride (PVC) is one of the most widely used polymers, which also is common in EEE and thereby in e-waste. Among others, it is commonly used as coatings on wires and cables [13]. The reasons for concern are both the fact that the PVC-polymer contain chlorine (up to 56% by weight) and that most PVCs are loaded with additives. Although the polymer in itself is not hazardous, as the chlorine is bound to the polymer, it may function as a source for chlorinated dioxins, and also irritating hydrochloric acid as the plastic is incinerated. The additives may be of great variety, but most concerns have been raised regarding the use of metals, particularly cadmium, lead and organotin, as stabilizers, phthalates as plasticizers and brominated compounds (e.g. PBDE and TBBPA) as flame retardants [15]. These additives may be present in other types of plastics as well, which therefore also are of concern. Another polymer that needs special attention is poly tetra fluoro ethylene (PTFE) or Teflon (DuPont’s brand name). Although, Teflon generally is present in much lower amounts than other polymers in EEE, it is of concern because it can give rise to a wide range of toxic and persistent compounds during thermal degradation processes [19].

2.3.6. PCB Containing Capacitor

A capacitor is a passive electronic component that is widely used in electronic circuits for purposes such as blocking the flow of direct current while allowing alternating current to pass, to filter our interferences, and to smooth the output of power supplies. It consists of a pair of conductors separated by an isolating “dielectric”, which in some older capacitors consisted of PCB-oil (polychlorinated biphenyls). Because PCBs have adverse effects on humans and the environment these capacitors are of environmental concern, and they have also been banned in a large part of the world since the 70s. However, PCB-containing capacitors are still present to some extent, although rarely, and they are difficult to distinguish from other capacitors, even for qualified personnel [20]

2.3.7. Equipment Containing Freons

Refrigerating circuits in refrigerators, freezers and air-conditioners may contain freons, i.e. chlorofluorocarbons, hydro chlorofluorocarbons and fluorocarbons, which after emissions to the atmosphere have deleterious effects on the ozone layer [21].

2.3.8. Toner Cartages

Toner cartridges are found in all laser printers, photocopying machines, faxes etc. Toner cartridges contain toner, which is an extremely fine powder, consisting mainly of carbon particles and polymers. Toners may also contain up to 7% carbon black, which is a material produced by the incomplete combustion of heavy petroleum products [22]

2.4.Hazardous Compounds of E-waste

The majority of the hazardous compounds that are associated with EEE and e-waste are found in the components listed above. However, there are other e-waste components that may contain hazardous compounds, and there may also be other hazardous compounds present than those found in the components listed above. Below follows an extensive list of hazardous compounds that, in one way or another, can be associated with EEE and e-waste. Included are compounds that may be present in EEE as well as those that may be formed as e-waste is handled, deposited or recycled.

2.4.1. Metals and Inorganic Compounds

2.4.1.1.Antimony (sb)

Antimony and its compounds have a number of uses in EEE. For example, antimony compounds are used in semiconductor manufacture (antimony tri hydride), and in flame retardant formulations in plastics (antimony trioxide). In the latter case it is normally combined with brominated flame retardants, especially PBDE [23], though there are also reports of use in combination with phosphorus based flame retardants. Antimony is also used in the manufacture of lead acid starter batteries [24] and can occur as a component of electrical solders as well as in CRT glass.

Antimony shows many chemical similarities to arsenic [25]. Like arsenic, it can undergo methylation as a result of microbiological activity (i.e. to form its tri methylated derivative, often called tri methyl stibine), albeit at slower rates than for arsenic [26]. It also shows some similarities in its toxic effects, especially to skin cells [27]. However, unlike arsenic, there are relatively few studies concerning the toxicity and eco toxicity of antimony and its compounds. Those studies which are available indicate that the toxicity of antimony depends greatly on its particular form (i.e. its oxidation state). Trivalent antimony, such as is present in antimony tri hydride and antimony trioxide, is the most toxic state whereas its pentavalent form is far less toxic [28]. Some organic antimony compounds (including tri methylstibine) are very toxic [29]. Antimony compounds have been associated with dermatitis (skin problems) and irritation of respiratory tract, as well as interfering with normal function of the immune system. Antimony trioxide and antimony tri sulphide have been listed by the International Agency for Research on Cancer as "possibly carcinogenic to humans", with inhalation of dusts and vapors being the critical route of exposure [30].

2.4.1.2. Arsenic (As)

Arsenic is a naturally occurring element that is widely distributed in the earth's crust. It is frequently referred to as a metal but it is chemically classified as a metalloid or a semi-metal Arsenic has predominantly been used in wood preservatives and pesticides, but also for some other applications. In EEE and e-waste, arsenic is mainly found in the form of gallium arsenide, which is an important semiconductor used to make devices such as microwave frequency integrated circuits (MMICs), infrared light emitting diodes (LEDs), laser diodes and solar cells [31].

Arsenic may occur in many different forms, e.g. elemental arsenic, arsenide (As_3) arsenate ($HAsO_4$), and arsenate ($H\ _3AsO_3$). Several of these are classified as toxic and dangerous for the environment and are also confirmed carcinogens [32, 33]. Acute exposure to arsenic will cause disturbance of the metabolism and energy productions in cells, which may lead to death via multi-system organ failure. Chronic exposure to arsenic can lead to various diseases of the skin and decrease nerve conduction velocity. It may also cause tumor formation in the lungs, urinary bladder, kidneys and on the skin, which often is fatal [32, 33]. The toxicity of Gas specifically is however unknown [31, 34].

2.4.1.3.Asbestos

Asbestos is a group of natural occurring silicate minerals that consist of long, thin fibrous crystals. Asbestos have previously been widely used in our society due to its strength, flexibility and heat resistant properties. In electronic equipment it was formerly used in products such as coffee pots, toasters, irons, heaters and other items that benefit from the heat resistance of the material [35]. Today, however, the use of asbestos is very limited, as it has been banned in a large part of the world, due to its negative health effects. The asbestos fibers may thus get stuck in the lungs and cause serious illness, including malignant lung cancer (mesothelioma).

2.4.1.4.Barium(Ba)

Barium is a metallic element that occurs in the environment mainly as barium sulphate and barium carbonate. Barium and its compounds have a variety of uses. In the electronic industry it is mainly used in sparkplugs, fluorescent lamps and “getter plates” in vacuum tubes. Being highly unstable in its pure form, barium is oxidized when in contact with air. In the natural waters, most barium is then precipitated as sulphate or carbonate compounds. Barium sulphate is not very toxic as it is poorly available for uptake in the body. However, barium carbonate can dissolve in the stomach fluids and there by become available for uptake, which consequently may lead to harmful effects. All water-soluble forms of barium, e.g. barium acetate, barium chloride, barium hydroxide, barium nitrate and barium sulphide, may also be toxic [36]

Short-term exposure to large amounts barium can cause disturbed heart rhythm, paralysis or even death in humans. Short-term exposure to smaller amounts can cause vomiting, abdominal cramps, diarrhea, difficulties in breathing, increased or decreased blood pressure, numbness around the face and muscle weakness. Long-term effects in humans are less known, but animal studies reveal heart and kidney damages, increased blood pressure as well as decrease in body weight and survival [36]

2.4.1.5.Beryllium(Be)

Beryllium is used in EEE as copper-beryllium alloys, typically containing 2% beryllium, which increases it strength to six times that of pure copper. The alloy is used in springs, relays and solders, and historically also in computer motherboards [37]. Beryllium may also be found in power supply boxes and x-ray lenses.

Beryllium is both acutely and chronically toxic to humans, mainly affecting the lungs. The primary health concern is inhalation of dust, fumes or mists of beryllium or beryllium oxide [38]. Breathing high concentrations of beryllium dusts or fumes can result in acute beryllium diseases (ABD), with a range of effects including shortness of breath, coughing, chest pain, rapid heart rate and death in extreme cases. Beryllium has also been classified as a human carcinogen, based upon the increased rates of lung cancer in beryllium production workers [39]. Long term exposure to beryllium, even at very low levels, can lead to beryllium sensitization, which may lead to development of what is known as Chronic Beryllium Disease (CBD or berylliosis) [40 & 41]. This debilitating and currently incurable disease gives symptoms including emphysema and fibrosis of the lungs that can sometimes be fatal [39]. Furthermore, exposure to beryllium can cause a form of skin disease that is characterized by poor wound healing and wart-like bumps. Studies have shown that people can still develop beryllium diseases even many years following the last exposure [41]

2.4.1.6.Cadmium (Cd)

Cadmium and its compounds are used in a number of applications within electrical and electronic products [42]. Cadmium metal is used in some contacts, switches and solders joints. Many devices contain rechargeable nickel-cadmium (Ni-Cd) batteries, which contain cadmium oxide. Cadmium compounds have also been used as stabilizers within PVC formulations, including those used as wire insulation [43]. In addition, cadmium sulphide has been used in cathode ray tubes (CRTs) as a “phosphor” on the interior surface of the screen to produce light [42].

Cadmium is highly toxic to plants, animals and humans, having no known biochemical or nutritional function [44]. Like lead, cadmium can accumulate in the body over time, with long-term exposure causing damage to the kidneys and bone structure. For the general population and for animals, cadmium exposure through diet primarily affects the kidneys [45, 46, 47]. Recent studies have demonstrated kidney damage in humans at lower levels of exposure than previously anticipated [48]. Other health effects from cadmium exposure include disruption to calcium mechanisms causing bone effects, as well as the development of hypertension (high blood pressure) and heart disease. In the short term, inhalation of cadmium oxide fumes or dusts can also affect the respiratory system [44, 45, 46]. Furthermore, cadmium and its compounds are known to be human carcinogens, primarily for lung cancer following inhalation of contaminated fumes and dusts [49]. When cadmium is released to aquatic environment it is more mobile than most other metals [44].

2.4.1.7.Chromium (hexavalent in particular, Cr[VI])

Chromium is widely used in steel alloys because of its hardness, anti-corrosive properties and high conductivity. In EEE and e-waste it is commonly found in metal housings among others. While some forms of chromium are non-toxic, and may actually be trace nutrients for animals and humans, hexavalent chromium (Cr[VI]) is highly toxic even at low concentrations [50]. It is easily absorbed in the human body and can produce various toxic effects within cells. Most Cr[VI] compounds are irritating to eyes, skin and mucous membranes, and chronic exposure to Cr[VI] can actually cause permanent eye injury, unless properly treated. Cr[VI] may also cause damage to kidney and liver, and is considered a human carcinogen that causes lung cancer among others [50, 51]. Hexavalent chromium is far more reactive and soluble in water than other forms of chromium, making it more mobile in the environment [52]

2.4.1.8.Copper (Cu)

The copper content in e-waste may exceed 10%. This is because copper is one of the base elements in electronic products, and is used in a wide variety of applications and components. It is mainly used because of its excellent conductivity of heat and electricity. Among others, copper is used in wires and cables, PC-boards, relays, switches, electromagnetic motors and leadfree solders [53].

Copper is essential in all plants an animal, and because of its role in facilitating iron uptake, copper deficiency can often produce anemia like symptoms in humans. However, at high concentration copper may become toxic and produce a number of adverse health effects, including gastrointestinal distress (nausea, vomiting, abdominal pain), respiratory tract irritation, liver and kidney damage, anemia, immunotoxicity, and developmental toxicity. Many of these effects are consistent with oxidative damage of membranes and macromolecules [54]

Furthermore, it is believed that copper and zinc compete for adsorption in the digestive tract so that the diet that is excessive in one of these metals may result in deficiency in the other. In the environment, the solubility of copper increases with decreasing pH, leading to higher mobility and bioavailability. Under these conditions, copper is considerably toxic to a wide range of aquatic animals and plants [54, 55, 56]. Copper associated with e-waste may be of concern just because its abundance.

2.4.1.9.Lead (Pb)

Lead is widely used in electronic goods as a major components of solders on PC boards (in alloy with tin), as lead oxide in the glass of cathode ray tubes (TVs and monitors), as well in lead-acid batteries [53]. Lead compounds have also been used as stabilizers in some PVC cables and other products [57].

Lead is highly toxic to humans, as well as to animals and plants, and it has non known biochemical or nutritional function [58, 59]. Short-term exposure to high levels of lead can cause vomiting, diarrhea, convulsions, coma or even death. Repeated low-level exposure, leads to accumulation of lead in the body, which potentially can result in irreversible effects on the brain and the nervous system. Particularly the developing nervous system in children is of concern, as the effects may lead to intellectual impairment [60]. However, lead can also damage the blood system, have negative impact on the kidneys and on reproduction. It is currently thought that there may be no level of blood-lead that does not produce a toxic effect, particularly in the developing central nervous system [58, 60]. Similar toxic effects are seen in animals, and lead is also toxic to all aquatic life [61, 62]. The effects of exposure to lead are the same whether through ingestion or inhalation, and some appear to be irreversible [58, 63, 59]. Following release to the environment, lead has low mobility compared to most metals.

2.4.1.10. Mercury (Hg)

Mercury is one of the most toxic yet widely used metals in the production of EEE. It is still used in some batteries and lighting devices for flat screen electronic displays, and was formerly also used in switches and relays among other things [42].

Mercury and its compounds are highly toxic, and have no biochemical or nutritional value [64]. Inhalation of high levels of mercury vapor may cause a range of effects including impact to the brain and the central nervous system (CNS) [65, 59]. Long-term exposure to lower levels of mercury vapor can also cause damage to the brain and the CNS, particularly during early development. In addition, it can have negative impact on the liver and the kidneys [66, 59]. Once in the environment, mercury can be converted, by bacteria, to its organic methylated forms, which is the mercury form the general population primarily is exposed to [67]. Methyl-mercury can accumulate in the body and cause damage to the nervous system. Furthermore, methyl-mercury can readily pass through the placental barrier and the blood-brain barrier, potentially causing adverse effects on the developing brain and CNS in fetuses and children, even at very low levels [68].

2.4.1.11. Nickel (Ni)

In electrical equipment and e-waste nickel is mainly found in nickel-cadmium and nickel metal hydride batteries, and also to some extent in the electron guns of CRTs.

When ingested in high doses, nickel can cause stomach aches as well as adverse effects in blood (increase blood cells) and kidneys (increased protein in urine). However, the most serious harmful effects from nickel exposure have occurred in people who have breathed dust containing nickel compounds while working in nickel refineries or nickel processing plants. These effects include chronic bronchitis, reduced lung function as well as lung and nasal sinus cancer [69]. Nickel sulphide fumes and dust is thus believed to be carcinogenic, which also may be the case for various other nickel compounds [70, 71]. Furthermore, sensitized individuals may show an allergy to nickel affecting their skin, also known as dermatitis, and nickel is therefore an important cause of contact allergy [69].

2.4.1.12. Selenium (Se)

The largest use of selenium worldwide is to colorize glass and ceramics during manufacturing. However, selenium is also used in the electronic industry, which is mainly due to its photovoltaic and photoconductive properties. Selenium is thus used in photocopying machines, photocells, light meters and solar cells as well as in some rectifiers and x-ray cameras.

Although selenium is an essential micronutrient for most organisms including mammals, it is toxic in large doses [72]. Exposure to high concentration of selenium compounds cause selenosis [73]. The major signs of selenosis are hair loss, nail brittleness, and neurological abnormalities (such as numbness and other odd sensations in the extremities). Extreme cases of selenosis can result in cirrhosis of the liver, pulmonary oedema and death [73]. The toxicity is dependent on form of selenium. Elemental selenium and most metal selenides (Se_2) are relatively non-toxic, while most selenates (SeO_4) and selenites (SeO_3) are very toxic. Hydrogen selenide (H_2Se) is extremely toxic as well as corrosive [74]. Several organo-selenium compounds are also toxic.

2.4.1.13. Tin (Sn) and Organo-Tin

Metallic tin is widely used in electronic products, in the form of lead-tin alloys, in solders. However, this is of little concern as metallic tin is relatively non-toxic. When bound to an organic moiety, on the other hand, the toxicity of tin increases dramatically. The best know example of this is tributyltin (TBT), which, as a result of its widespread use in antifouling paints on ships and boats, has led to widespread changes in sexual development in marine snails. In consumer products, including electronic equipment, organotin compounds are mainly found in PVC plastics, in which they are added as stabilizers, and in certain glass coating applications. Mono- and dibutyltin (MBT and DBT) are most common for these applications. In PVC, the orgaotin compounds may comprise 2% by weight of the finished product [75].

Organotins are known to be toxic at relatively low levels of exposure, not only in marine invertebrates but also for mammals. For marine invertebrates the effects are acute and lethal. In mammals, immunotoxic and teratogenic (developmental) effects have been demonstrated [76]. DBT is neurotoxic and causes increased incidence of cell death (apoptosis) in certain brain tissues of rats exposed during development [77]. Furthermore, exposure to trimethyltin (TMT) during development have been observed to affect the memory and cause impaired learning [77], as well as having toxic effects on testes development in mice [78].

2.4.1.14. Yttrium (Y)

Yttrium is a metal that most importantly is used to make phosphors in CRTs and LEDs, to generate the red color. Other uses include the production of electrodes, electrolytes, electronic filters, lasers and superconductors; various medical applications; and as properties enhancing traces in several materials [79]. In EEE it is mainly found in CRTs

Yttrium has no known biological role, but exposure to some of its compounds may cause lung disease. Workers exposed to airborne yttrium europium vanadate dust experienced mild eye, skin, and upper respiratory tract irritation. Though this may have been caused by the vanadium content rather than the yttrium [80]. Acute exposure to yttrium compounds can cause shortness of breath, coughing, chest pain, and cyanosis [80]. National Institute of Occupational Safety and Health (NIOSH) recommends a time-weighted average limit of 1 mg/m3 and an IDLH (Immediately dangerous to life or health concentration) of 500 mg/m3 [81]. Yttrium dust is also flammable [80].

2.4.1.15. Zinc

Zinc is a metal that is widely used as an anti-corrosive agent. The most common use is for galvanization of iron and steel. However, zinc is also found in electronic products, and then mainly as zinc sulphide, which is used in luminescent pigments on the interior of CRT screens.

Although zinc is an essential requirement for good health of both animals and plants, excess zinc can be harmful. Excessive absorption of zinc suppresses copper and iron absorption [82]. If ingested, zinc may also cause damage to the stomach lining due to the high solubility of the zinc ion in the acid stomach fluids, resulting in corrosive zinc chloride. [83].The free zinc ion in solution is highly toxic to plants, invertebrates, and even vertebrate fish [84]. Levels of zinc in excess of 500 ppm in soil interfere with the ability of plants to absorb other essential metals, such as iron and manganese [85].

2.4.2. Organic Compounds

2.4.2.1.Brominated Flame Retardants (BFR, e.g. PBDE, TBBPA, and HBCD

Brominated flame retardants (BFRs) are a diverse group of brominated organic compounds that are used to prevent materials and products from catching fire [86]. In electronic equipment, BFRs are mainly found in plastics and foams, in which the content may exceed 20% [87]. Although more than 75 different brominated compounds or groups of compounds have been used as BFRs, three chemicals dominate the current usage, viz. polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD), and tetrabromobisphenol-A (TBBPA) [88]. Of these, TBBPA and HBCD are single compounds, while the PBDEs consist of a group of 209 individual compounds that all contain the diphenyl ether molecule but differ in their degree of bromination. The chemical structures for the PBDEs, TBBPA and HBCD. TBBPA is generally used as a reactive component, being chemically bound to the polymer, whereas PBDEs and HBCD are used as additives, simply blended with material and therefore more likely to leach out of the products [86]. In electronic goods TBBPA is used primarily in PC-boards, while PBDEs and HBCD are found to a larger extent in other plastic details, such as casings etc. [86, 89].

As mentioned above, there are many other brominated compounds that are used as flame retardants besides PBDEs, TBBPA and HBCD, e.g. hexabromobenzene (hexaBBz), decabromo diphenylethane (DBDPE) and 1,2-bis-2,4,6tribromophenoxyethane (BTBPE). Some of these compounds are in fact gaining importance as they are more and more frequently used as substitute for the traditional BFRs in many applications. This is because many of the traditional BFRs have been shown to cause serious negative effects on both human health and the environment (as discussed below), which have led to restrictions of the use of these compounds. However, some of the new, emerging BFRs may actually be as bad as the traditional ones, but they have been much less studied [90, 91].

While the acute toxicity of BFRs is considered to be low, the long-term effects seem to be more serious. Chronic exposure to certain PBDEs (especially in the womb) has been shown to interfere with brain and skeletal development in animals [92], which may lead to permanent neurological effects such as impaired learning and memory functions, as well as behavioral effects [93]. There are concerns that similar effects may also be of relevance in humans, especially after neonatal exposure to PBDEs via mother’s milk. There is also some evidence that PBDEs, HBCD and TBBPA are neurotoxic and that they may exhibit endocrine (hormone) disrupting properties. At least PBDEs and TBBPA, may thus interact with both the estrogen and thyroid hormone systems either as the parent compound or as metabolites which may result in delayed onset of puberty, altered circulating levels of estradiol and reduced reproductively for women. Effects of BFRs on the immune system have also been reported, as well as adverse effects on the liver and on foetal development [94].

In addition to these direct effects of BFRs, there is also a risk that these compounds may be transformed into even more toxic dioxins during handling and recycling of the material in which they are present, e.g. e-waste [95]. This may happen during thermal processes, such as combustion, pyrolysis and gasification, during which the bromine in all BFRs may give rise to brominated dioxins. However, the dioxin formation is particularly prevalent if PBDEs are present, which easily may be transformed into dioxins in such way [96].

2.4.2.2.Dioxins, Chlorinated (PCDD/F), Brominated (PBDD/F) and Mixed (PBCDD/F)

Dioxin is a generic term commonly used for chlorinated dibenzo-p-dioxins (PCDDs) and chlorinated dibenzofurans (PCDFs), but may also include the brominated analogs of these compounds (PBDD/Fs). The dioxins and furans all contain the dibenzo-p-dioxin and the dibenzofuran molecules, respectively, as a backbone structure, but with different numbers and patterns of chlorine and bromine atoms. In total, there are 210 so called congeners each of PCDD/Fs and PBDD/Fs. In addition, there are dioxins and furans containing both chlorine and bromine (PBCDD/F), which theoretically amounts to 4600 additional congeners [86].

Brominated dioxins (or actually mainly furans) may be present in flame retarded plastics as a BFR impurity [96]. However, the main concern about dioxins during e-waste handling is because these compounds may be formed during combustion and other high temperature processing of chlorinated and brominated materials, including PVC coated wires and flame retarded plastics [97,]. PVC may thus act as a precursor for chlorinated dioxins and BFRs (PBDEs in particular) as very potent precursors for brominated dioxins. The processes are catalyzed by copper and antimony, respectively [98], which makes e-waste a very good starting material for dioxins.

Dioxins are highly persistent in the environment and are able bioaccumulation, so that the concentrations in organisms may become higher than in the surrounding media. Dioxins have also shown a wide spectrum of toxic effects. Human exposure to high levels of dioxins results in the acute skin disease chloracne, while long-term effects include teratogenicity, carcinogenicity, reproductive disturbance and lymphoid disorders [99,]. Other mammals and organisms are also affected, although the effects are strongly species dependent. The effects of dioxins are also highly dependent on the number and position of the chlorine and bromine atoms on the molecules. PCDD/Fs with chlorine atoms at the 2,3,7 and 8 positions have the most pronounced toxic properties, and the vast majority of toxicity data reported for PCDD/Fs relates to the effects of the 17 congeners with chlorines at these positions, using toxic equivalence factors (TEFs) and toxic equivalents (TEQs) 2,3,7,8-tetrachloro dibenzo-p-dioxin (TCDD) is the most toxic congener. The toxicity of the brominated dioxins is much less studied than that of the chlorinated analogs. However, studies that have been performed indicate that their toxicity patterns are similar [100].

2.4.2.3.Various Brominated Compounds Such as Brominated Phenols and Benzenes

The abundance of BFRs and bromine in e-waste will, besides the PBDD/Fs, also lead to the formation of various other brominated compounds during combustion and high temperature processes. For example, it has been observed that brominated benzenes and phenols may be formed in substantial amounts [101]. Although, the toxicity of these compounds have been poorly studied there are some evidences that they have negative effects on humans and the environment. In addition, these compounds may act as precursors for further dioxin formation [102].

2.4.2.4.Polychlorinated Biphenyls (PCB)

Polychlorinated biphenyls (PCBs) are a group of organic chemicals that contain 209 individual compounds (known as congeners), all containing the biphenyl molecule in the backbone structure, but with different numbers and positioning of chlorine atoms. PCBs have been used in a wide variety of applications, including transformer oils (as insulating fluid), capacitor dielectrics, hydraulic fluids, plasticizers and printing inks [103]. The use in transformer oils, frequently with tri- and tetrachlorobenzenes as solvents and capacitors accounted for the greatest tonnages. Production of PCBs was banned in 1977 when their ability to accumulate in the environment and to cause harmful effects became apparent [103]. At least one third of the PCBs that have been produced are now estimated to have entered the environment [104], while the rest either remain in old electrical equipment and other materials, or have been destroyed through incineration or other processes. The PCBs that remains in equipment and materials will unfortunately continue to leach into the environment, including when obsolete electrical equipment is dismantled, recycled and/or disposed of. Furthermore, PCBs can be formed during the combustion of chlorinated organic materials such as PVC, similarly as dioxins [105].

PCBs are highly persistent, and may bioaccumulate in organisms, leading to higher levels in the organism than in the surroundings. For aquatic organisms and fish, levels can reach many thousands of times higher than the concentration in the surrounding water [103]. PCBs can both be absorbed through the skin as well as through ingestion and inhalation. For the general population today, food is undoubtedly the primary route of exposure to PCBs [106], although dermal exposure may be dominant amongst those directly handling PCBs or PCB-contaminated material.

PCBs exhibit a wide range of toxic effects in animals, including immunosuppression, liver damage, tumor promotion, neurotoxicity, reproductive toxicity, endocrine disruption and behavioral changes. The PCBs show dioxin like toxicity and are therefore contributing to TEQs calculated for dioxins. Although it is difficult to assess the impact on animal populations in the wild, not least because they are exposed to complex mixtures of chemical contaminants, some immunological and reproductive disorders in marine mammals have nevertheless been linked to elevated levels of persistent organochlorines, in particular the PCBs [104]. Studies on the general populations of the Netherlands and the Arctic and families of Swedish fishermen suggested that even relatively low levels of exposure to PCBs can result in impacts on the immune system, growth retardation and neurological effects [107].

2.4.2.5.Polychlorinated Naphthalenes (PCN)

The PCNs which also comprises a group of compounds, were the predecessors to the PCBs, once used extensively in capacitors and as insulating compounds in wiring, among many other uses [108]. PCNs may still be present in some old electronic equipment from which they may leak during recycling and disposal. In addition, they may, like the PCBs, be formed during combustion of chlorine containing materials, such as PVC [108]. The PCNs share many properties with the PCBs and the PCDD/Fs, including environmental persistence, bio accumulative properties and toxicity, which include effects on the skin, liver, digestive tract, nervous system and reproduction [109] Like PCBs, PCNs also have dioxin-like toxicity.

2.4.2.6.Chlorinated Paraffin's (CP)

Polychlorinated paraffin's (CPs) or polychlorinated n-alkanes are chlorinated derivatives of paraffinic hydrocarbons, i.e. alkanes, with 10-30 carbon atoms and a chlorine content of 30-70% by weight. The CPs may be subdivided into three categories: short chain (SCCP), medium chain (MCCP) and long chain (LCCP) compounds, containing 10-13, 14-17, and 18-

30 carbons, respectively [110]. CPs have been produced in large amounts around the world for usages such as lubricants in metal working fluids, and as flame retardants and plasticizers in plastics, rubbers, paints, adhesives and sealants. In EEE and e-waste CPs (particularly MCCP) are mainly found in PVC and other plastic material, from which they may leak during handling and disposal of the EEE. The leakage and emission of CPs may be particularly high during thermal destruction and modification of the materials. In these processes, the CPs may also be transformed into PCDD/Fs, similarly to other chlorinated compounds.

Although, the acute toxicity of CPs seems to be low [111], they share many properties with other organochlorines compounds (e.g. PCDD/Fs, PCBs, PCNs, etc.) meaning that they are highly lipophilic and persistent and thereby have potential for bioaccumulation. This may possibly lead to long term effects instead, even if this area has been poorly investigated for the CPs. However, there are studies showing that SCCPs have severe negative effects on aquatic biota after chronic exposures [112], and that SCCPs may cause tumors and cancers in rodents [113]. The SCCPs have also been categorized in group 2B by IARC [111], i.e. compounds that are possibly carcinogenic to humans.

2.4.2.7.Chlorinated Benzenes, e.g. Hexachlorobenzene (HCB)

Chlorinated benzenes, or chlorobenzenes, are chlorinated derivatives of benzene, possessing between one and six chlorine atoms (i.e. mono- to hexachlorobenzene). Chlorobenzenes, especially mono-, di-, tri- and hexachlorinated forms, have had a variety of uses, including as solvents (e.g. in commercial PCB formulations) and intermediates in the manufacture of other chemicals such as antioxidants, dyes and pigments, pharmaceuticals and agricultural chemicals [114]. Today only mono- and dichlorobenzenes continue to be manufactured in substantial quantities. Although, chlorinated benzenes are not present in electronic equipment, they may be emitted during the combustion of PVC plastics and other chlorine containing materials [115].

Chlorobenzenes are relatively persistent in the environment and can bioaccumulate in both terrestrial and aquatic systems. Both acute and chronic effects have been reported in a wide range of aquatic organisms and mammals. The effects vary depending on the chlorobenzenes in question, though common impacts include those on the liver, thyroid and CNS, as well as on developing fetus. In general terms, toxicity tends to increase with increasing degree of chlorination [116,]. Hexachlorobenzene (HCB), the most toxic of the chlorobenzenes, is both toxic to plants, animals and humans [110]. It is listed, by the IARC, as a possible carcinogen to humans and it appears to have tumor promoting properties. Furthermore, HCB has been shown to be an endocrine disruptor in laboratory animal studies and to have dioxin-like toxicity that contribute substantially to the overall dioxin-type toxic effects in humans and wildlife [117].

2.4.2.8.Polycyclic Aromatic Hydrocarbons (PAH)

Polycyclic aromatic hydrocarbons (PAHs) is a large group of non-halogenated organic compounds that consist of fused benzene rings in linear, angular or clustered arrangements (F PAHs are, as dioxins, not present in EEE or other consumer products, but are formed as the products are subjected to combustion processes [118]. Poor combustion conditions, including low temperature and oxygen supply, result in larger amounts of PAHs as well as other products of incomplete combustion. Although the physicochemical properties of PAHs differ substantially from the smallest to the largest compound, they are generally considered as lipophilic compounds with low water solubility and high affinity for organic matter [118]. This means that they are strongly sorbed to particles in the environment, which make them unavailable for degradation processes. As a consequence, PAHs show high persistency in the environment, and may also accumulate in some invertebrates. However, most animals, including humans, have the capability to metabolize PAHs leading to low bioaccumulation in general [119].

PAHs show a wide range of toxic effects, including acute toxicity, reproductive and developmental toxicity, endocrine disruption, and immunotoxicity [119]. However, the main cause of concern has been due to their genotoxic and carcinogenic properties. Several PAHs have thus been shown to cause genotoxic effect in laboratory cell systems as well as tumor formation and carcinogenicity in laboratory animals. These PAHs are also most likely carcinogenic to humans [119]. The genotoxicity and carcinogenicity varies among the PAH, and the individual potencies are often related to that of benzo[a]pyrene, which is one of the most carcinogenic PAHs known. This compound has also been most extensively studied of all PAHs [120]. The genotoxic effects of PAHs arise when the compounds are metabolized in the body of higher organisms, leading to highly reactive epoxide-intermediate. These epoxides may react with DNA to form adducts that subsequently may result in mutations and cancer [121]

2.4.2.9.Freons

Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs), commonly known as freons, are compounds composed of carbon, fluorine, chlorine and sometimes also hydrogen and bromine. Freons have mainly been used as refrigerating agent in cooling units and during the production of insulation foam. However, today the freons have been more or less phased out due to their deleterious effects on the ozone layer and their contribution to the global warming, when released into the atmosphere [21]. The depletion of the ozone layer has resulted in increased incidence of skin cancer in humans and in genetic damage in many organisms [122]. The freons are very stable compounds that may survive in the environment for more than hundred years.

2.4.2.10. Nonylphenol and Nonylphenol Ethoxylates

Nonylphenol (NP) is a chemical most widely known as a breakdown product of nonylphenol ethoxylates (NPEs) surfactants that have been used as detergents, emulsifiers, and wetting agents in a variety of industrial and consumer applications [123]. However, NPEs has reportedly also been used as an antioxidant in some plastics .The main hazard associated with NPEs result from their partial degradation to shorter chain ethoxylates and to NP, both of which are toxic to aquatic organisms and to higher organisms through secondary poisoning (i.e. resulting from the accumulation through the food chain).The most widely recognized effects are undoubtedly oestrogenic activity, i.e. the ability of nonylphenol to mimic natural oestrogen hormones, leading to altered sexual development in some organisms, most notably the feminization of fish [124]. Hazards to human health remain unclear, although recent studies have highlighted concerns directly relevant to humans.

2.4.2.11. Organophosphorus Flame Retardants, e.g. Triphenyl Phosphate

Triphenyl phosphate, one of a number of so-called triaryl phosphates, has long been used as a flame retardant in polymers and resins of electronic equipment [125]. Other applications include use as a plasticizer in photographic films and as a component of hydraulic fluids and oils. Loss of TPP to the environment as a result of leaching from polymers in which it is incorporated has long been recognized.

All triaryl phosphates in common use are acutely toxic to aquatic life, but TPP shows the highest toxicity [125]. TPP has been reported as a contaminant in human blood and is a strong inhibitor of a key enzyme (monocyte carboxyl esterase) in human blood cells [123]. Recent research has also indicated that TPP is a probable endocrine disruptor that may inhibit human androgen hormone reception [121]. Furthermore, contact dermatitis following exposure to TPP has been reported by several authors, with some cases dating back to the 1960s [125].

2.4.2.12. Fluorinated Compounds Originating from Teflon

Teflon is a brand name of the polytetrafluoroethylene (PTFE) polymer which today is used in numerous applications, due its low friction and inertness. The most well-known use is as a non-stick coating for pans and other cookware, but it has also found widespread use in bearings, gears, slide plates and other applications where low friction is needed. In addition, PTFE has excellent dielectric properties which make it useful as insulator in some high performance cables and connector assemblies and as a material for PC-boards used at microwave frequencies. Other fields of applications for PTFE in EEE are as measuring heads in radiometers and as low friction feet for computer mice.

PTFE is not a cause of concern in itself, but during thermal degradation of the polymer a wide range of hazardous compounds may be formed [126]. This includes several fluorinated alkenes, such as tetrafluoroethylene (TFE) and hexafluoropropene (HPF); fluorinated alkanes, such as octafluorocyclobutane (OFCB), perfluorobutane (PFB), perfluoroisobutane (PFIB) and carbon tetrafluoride (CF_4); fluorinated acetic acids, such as mono-, di- and trifluoroacetic acid (MFA, DFA and TFA); long chain fluorinated acids, such as perfluorooctanoic acid (PFOA); as well as hydrofluoric acid (HF), carbonyl fluoride (COF_2) and various fluorinated fine particulates. At least four of these compound is extremely toxic to animals and humans; PFIB, which have been used as chemical warfare agent; COF_2, which is the fluorinated analog to the warfare gas phosgene; MFA, which can kill people at low doses and HF, which is a highly corrosive gas [127]. Birds seem to be particularly sensitive to these compounds, but other animals and humans are affected as well, humans initially by developing a flu-like symptom called polymer fume fever. Other decomposition products of PTFE, that may be less acutely toxic, are instead extremely persistent in the environment and can withstand most (or virtually all) natural degradation processes [128]. These compounds, which include PFOA, TFA, CF4, PFB as well as some of the particulates produced, may accumulate in the environment and thereby potentially cause serious effects on a long term basis. Some of these, e.g. CF4 and PFB, are also very potent greenhouse gases [127].

2.4.2.13. Liquid Crystals

Liquid crystals are found in LCD-screens between the display glass and electric control elements. Commercially available liquid crystals are mixtures of 10-20 substances, which belong to groups of substituted phenylcyclohexanes, alylbenzenes and cyclohexylbenzenes. About 250 substances are used for formulating more than a thousand marketed liquid crystals. Studies conducted so far have not found any carcinogenic potential or acute oral toxicity, although a few substances showed corrosive, irritant or sensitizing properties to the skin [129]. A cell phone can contain about 0.5 mg of liquid crystals, and a notebook PC displays about 0.5 g.

2.4.2.14. Toner Dust

Photocopiers and laser printers use toner as part of the printing process. The toner is an extremely fine powder, which in itself is not classified as a hazardous substance, but as any dust in substantial concentration it may cause respiratory tract irritation resulting in coughing and sneezing [130]. Toners may also contain up to 7% carbon black. Carbon black became a cause for concern when a group of Swedish scientists noticed that certain toners caused genetic changes in bacterial test systems, and it was later regarded as a possible carcinogen for humans [131]. After this was noticed, the manufacturers of carbon black changed their process, leading to a much less genotoxic product. Since then, numerous studies have been carried out to determine the effects of exposure to carbon black. In all instances, there was no evidence of cancer production and no unusual death rates. The small content of carbon black is therefore probably not a cause for concern today.

2.4.2.15. Nanoparticles

Nanoparticles are small particles in the nanometer range (one billionth of a meter) that have attracted a lot of attention the last few years. The nanotechnology is growing steadily and nanomaterial are constantly finding new areas of usage [132]. In electronics, a number of different nanomaterials are already being used commercially or are being used for research and development purposes. Most common are carbon nanotubes in semiconductor chips, quantum dots in lasers and silver nanoparticles as surface coatings [133].

The concerns about nanoparticles and their impacts on human health and the environment are mainly based on the particle's tiny size, the shape of some particles and their properties (e.g. reactivity) [133]. It is already known that ultrafine particle in polluted air may cause respiratory illness and adverse cardiovascular effects in human. It is plausible that synthetically produced nanoparticles can give the same effects. Another concern has arisen specifically about possible impacts of carbon nanotubes on human health [134]. This is because carbon nanotubes are structurally similar to asbestos fibers, which are known to cause serious impacts on health. Indeed, exposure of rodents to carbon nanotubes has shown such effects [135]. Furthermore, due to the nanoparticle's large surface area, they have often increased potential for interaction with other substances and organisms compared to large scale materials. For example, silver nanoparticles have anti-microbial effects, which is of concern because they are likely to kill microbes that are beneficial to living beings and ecological processes besides killing harmful microbes [133].

2.5.Recycling and End-Of-Life Treatment of E-waste

After an electrical or electronic product has been abandoned by its owner and thereby become e-waste, it may encounter various fates. It may be treated as any municipal solid waste and thus be incinerated or just put on landfills or it may be recycled with the objectives to recover its content of valuable materials and energy and/or to remove hazardous components and thereby reduce the impacts on human health and the environment. End-of life treatments thus include landfilling and incineration as well as reuse and recycling. It should be noted that incineration sometimes also is considered as recycling, as it may be used for heat and energy recovery as well as a first step in the metal recovery process. However, many times incineration is only used to reduce waste volumes prior to landfilling.

The processes and methods used for recycling differ a lot depending on where and under what circumstances they are carried out. In the developed world, the economy has allowed the development of more comprehensive solutions to the e-waste problem, and therefore a significant fraction of the e-waste generated (even if this fraction could be much larger) is collected and sent to authorized recycling facilities, in which both valuable materials and hazardous compounds are separated and treated appropriately. In the developing world this system has not yet had a chance to thrive, due to the competition from the informal recycling industry, through which many poor people earn their only income. Here, the primary goal is to recover the valuable materials in the e-waste, and consequently little or no regard is paid to the impacts on the environment and human health. Sadly, the processes used by the informal recycling industry are also much less efficient than the processes used by the formal recycling industry in terms of recovering valuable materials.In the following sections, the processes used for recycling of e-waste are described. This includes processes carried out in controlled recycling facilities as well as the more rudimentary methods used in many developing countries.

2.5.1. Recycling of E-waste Under Controlled Conditions

The recycling of e-waste under controlled conditions generally engages two types of facilities according to the nature of the methods involved. In the first one the e-waste is dismantled and mechanically processed so that materials can be separated and further recovered. In the second type of facilities, metallurgical processes are used to recover metals, and various other processes to recover plastics and other materials.

2.5.1.1.Manual Dismantling and Sorting

The first step in the recycling process is manual dismantling, which allows the recovery of whole homogenous parts that may be reusable, valuable or recyclable, e.g. whole components, metal, plastic or glass parts, and hazardous components that require further special treatment, e.g. mercury containing components, batteries, CRT-glass and LCDs [136, 137]. Following separation, mercury containing components are normally sent to specialized mercury recovery facilities or authorized hazardous waste incinerators with modern flue gas cleaning systems [138]. Batteries are normally sent for processing to recover cadmium, nickel, mercury and lead; the former three through heating of the batteries in a furnace, leading to evaporation of the metals that later can be collected through condensation [139], and lead by smelting the whole batteries or parts of them in a metallurgical process [140]. The leaded CRT glass may be used in the production of new leaded glass, for the recovery of lead or may just be put on landfill. LCDs may be sent for glass recovery or destruction in authorized incineration facilities [138].

2.5.1.2.Mechanical Shredding and Separation

Further liberation and size reduction of the recyclable materials, e.g. PC-boards, is usually achieved by some kind of shredding or crushing process. After the size reduction, the materials are sorted into defined output fractions based on their specific physical characteristics, such as weight, size, shape, density, and electrical and magnetic characteristics. Typical sorting processes used are screening, magnetic separation of ferrous parts, eddy current separation (electric conductivity) of non-ferrous metals (e.g. copper and aluminum), and density or gravity separation (water or airflow tables, heavy media floating, sifting) of plastics. Alternatively, or in addition, manual sorting or new optical sorting techniques are also used. Furthermore, the sorting may sometimes be supported by screening as well as further size reduction steps. Final output streams are usually components taken out as a whole (for reuse or further treatment), a magnetic fraction (going to steel plants), an aluminum fraction (going to aluminum smelters), a copper fraction (going to copper smelters), and in some cases various plastic fractions. Usually a waste fraction is also generated at this stage, which among others consists of a mixture of plastics, glass, wood and rubber. This fraction, which often is called “the shredder light fraction”, is sent for further processing, incineration or landfilling [134, 141].

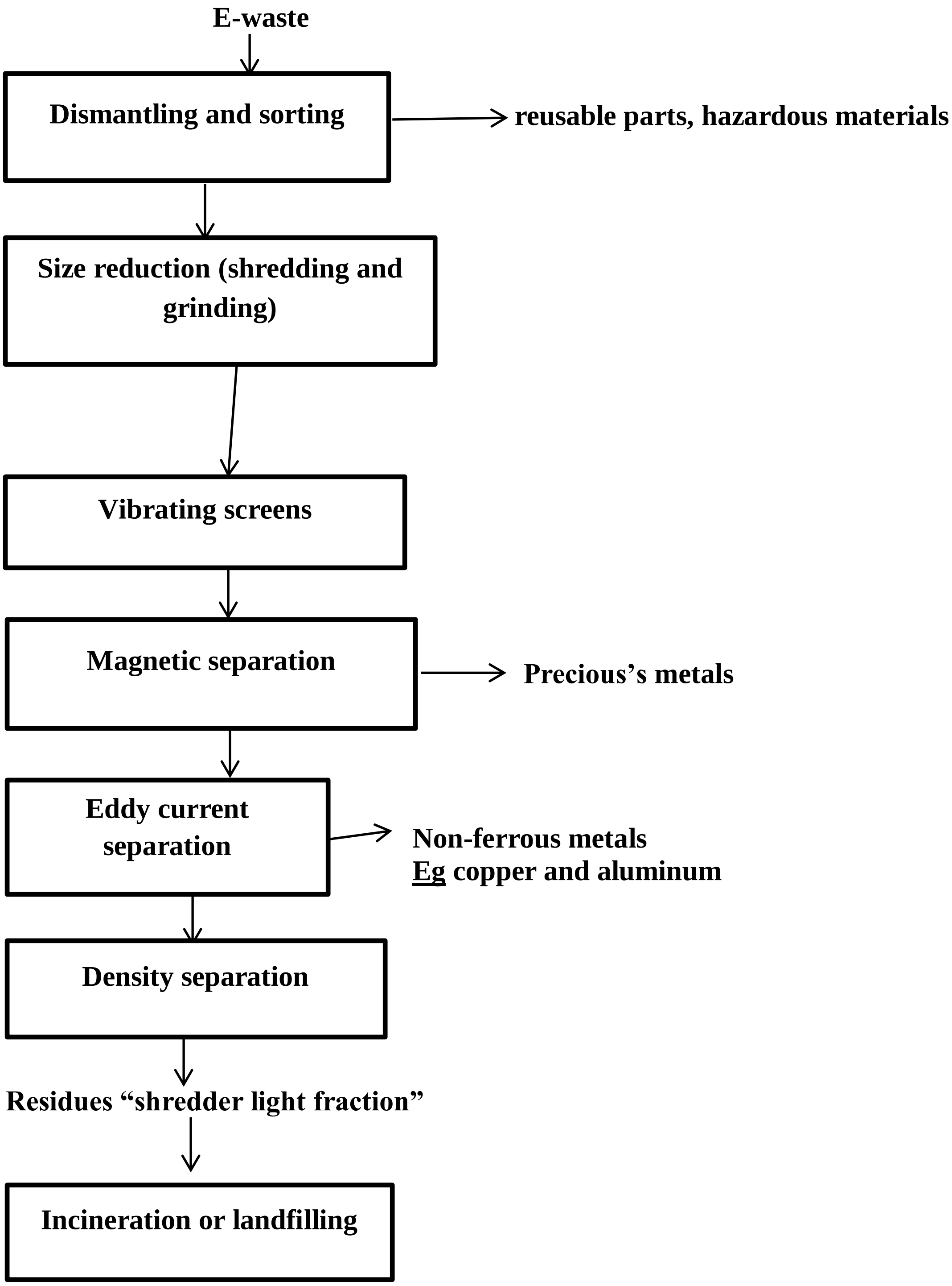

Figure 2: 1 Schematic of the first steps in a typical e-waste recycling process

The facilities that are doing the dismantling and separation vary in throughput, from relatively small to quite large operations, and also in degree of automation (from manual labor based to highly automated operations). Figure 1 shows a schematic of the processes used at typical e-waste recycling plant [142].

2.5.1.3.Metallurgical Processes

Further upgrading and refining of the metal containing fractions are performed by metallurgical processes. Both pyro-metallurgical processes, in which the metals are melted, and hydrometallurgical processes, in which the metals are dissolved, are used, and often in combination. Pyro-metallurgical processing in copper smelters followed by electrolytic refining has thus become the dominant method to recover non-ferrous metals, including precious metals as well as other valuable metals, from e-waste in the last two decades [141]. In the process, the crushed scraps are burned in a furnace or in a molten bath to remove plastics. At the same time metals such as iron, lead and zinc are converted into oxides that will become fixed within a silica based slag. The melt that mainly contains copper (but also silver, gold, palladium, nickel, selenium, tellurium and zinc) is further refined in a converter and an anode furnace where it is cast into anodes with copper content exceeding 99%. The remaining 0.9% contains the other recoverable metals, including the precious metals. The metals in the anodes are then typically refined and recovered by electrolysis in acidic solution.

The metallurgical processes may be carried out by the general metallurgical industry, which usually are designed to extract metals from ores, where electronic scrap only represents a small part of the feedstock. There are however a few large metallurgical industries in the world that are processing larger quantities of e-waste. These so called “integrated” smelters, which recycle many different kinds of copper containing materials, include Boliden in Sweden, Umicore in Belgium, Noranda in Canada, Norddeutsche Affinerie AG in Germany [143] and Dowa Eco-System in Japan [138]. The term “integrated” is used to define the smelters, as they represent a sophisticated combination of several metallurgical and chemical units that are closely interlinked and designed to work together [141, 143]

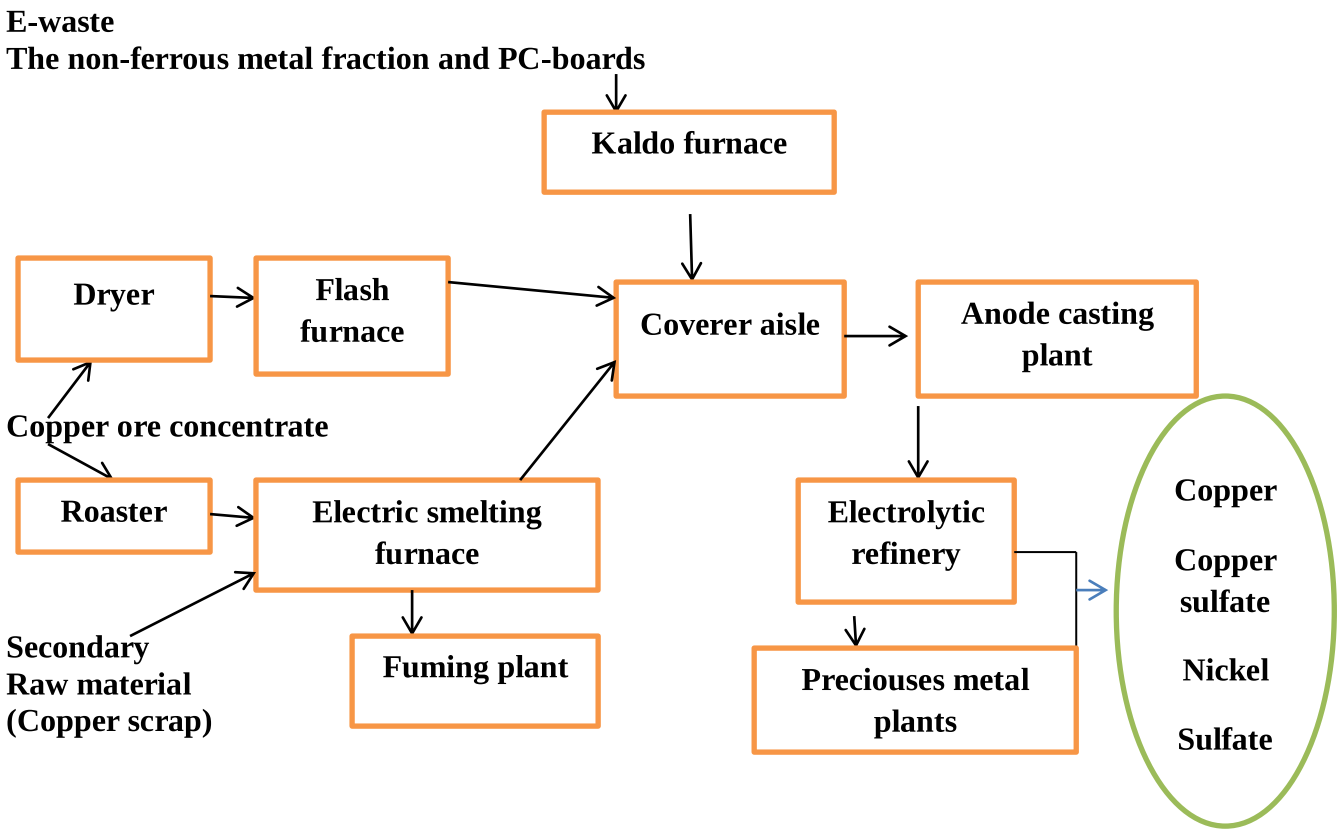

Figure 2:2 Schematic of the process used to recover copper and precious metal from E-waste

Hydrometallurgical processes are normally used for the final refining of the metals, following the pyro-metallurgical processes, but they may also be used as an alternative to the pyro-metallurgical processes. Although not yet widely used, hydrometallurgical processes have many advantages over pyro-metallurgical processes, including being much less energy consuming as well as being more exact, more predictable and more easily controlled. The main steps in the hydrometallurgical processing consist of a series of acid or caustic leaches of solid material, which normally requires a small grain size to increase the metal yield. Leaching solvents are commonly solutions of cyanide, thiourea, thiosulfate, and sodium hydroxide and acids such as aqua regia, sulfuric acid, nitric acid, and hydrochloric acid. From the solutions, the metals of interest are then isolated and concentrated via processes such as solvent extraction, precipitation, cementation, adsorption, ion exchange, filtration and distillation [140, 141].

2.5.1.4.Recycling of Plastics

After metals, the plastics in e-waste have the greatest potential recycling value [142]. Still, only a minor fraction (less than 25%) of all the collected e-waste plastics is actually being recycled. This is because plastics are very complex materials, consisting of numerous polymers and additives that make the recycling process very complicated [144]. Different qualities thus have to be separated and unrecyclable fractions have to be removed before the recyclable plastics can be turned into new products, which today often mean low-grade products such as traffic cones, road material, outdoor furniture etc. The separation is usually performed by techniques such as sieving, density separation (in various aqueous or non-aqueous media), electrostatic separation (e.g. triboelectric separation) and air-separation, in combination with various size reduction steps, such as grinding, milling and granulation [142]. Paint and coatings are removed by further grinding, abrasion, solvent stripping and washing in high-temperature aqueous solutions, while other foreign materials are removed by similar methods as used for fragmented e-waste in general, i.e. magnetic separation, eddy current separation and air-separation. The separated plastics that are deemed recyclable may then be turned into new plastic products through processes such as melting, molding and extrusion. There have also been attempts to develop alternative recycling methods for plastic materials such as pyrolysis and de-polymerization techniques with which the plastics are converted into coke, coke oven gas as well as other chemicals [142]. However, it is uncertain to what extents these alternative recycling techniques have been used in larger scale applications.

However, as mentioned, the majority of the e-waste plastics are not being truly recycled. Much is instead incinerated in municipal waste incinerators with heat and energy recovery systems, while some are just dumped on landfills. In addition, a significant fraction is following the metal fraction to the smelter where it is combusted and thereby decomposed. This latter option may be justified by the argument that the plastic acts both as a fuel and a reducing agent in the smelter process, and thereby replaces some of the coke that normally is used [142]. On the other hand, this activity contravenes with the current waste management practice, as well as the WEEE Directive of the EU, which stipulates that materials in e-waste (as well as in other waste fractions) should as far as possible be separated, recovered and reused in the production of new products [143].

A report commissioned by the Swedish take-back system for electronic products (El-Kretsen) studied whether the 'direct smelter route' for mobile phones was environmentally and economically better or worse than the 'disassembly route' where the casing was manually removed for recycling [144]. The calculations in the report were based around sending the phones to Boliden's Rönnskär smelter for processing, considering transport costs and the costs for recycling. The report concluded that the 'direct smelter route' was the most eco-efficient process. However, it has later been criticized on a number of points by Ökopol, Institute for Environmental Strategies [146]. This critic noted that the environmental effects of emissions from burning BFRs in the plastics were not considered, and that there were uncertainties with regard to the economic calculation because of a lack of transparency. In addition, it was questioned whether the calculations would be transferable to other smelters and whether the transport costs would be transferable to other countries.

2.5.2. Recycling of E-waste Under Uncontrolled Conditions

The informal recycling sector in developing countries has one primary goal; to recover valuable materials in the e-waste, including copper, steel, plastics, aluminum, printer toner and PC-boards. The activities are often carried out in small workshops or just outdoors, using rudimentary methods [147]. In the processes used there is no real control over the materials processed, the performance of the processes or the emission generated. The typical processes used are:

2.5.2.1.Manual Disassembly and Recovery of Valuable Materials

The first step in the recycling process is the disassembly of the e-waste, which most often is carried out manually using tools such as hammers, chisels, screwdrivers, and bare hands. According to a report by the Basel Action Network and the Silicon Valley Toxic Coalition [147], the following components are separated for further recycling.

- Materials containing copper (including motors, wires and cables, CRT yokes).
- Steel (including internal computer frames, power supply housings, printer parts etc.)
- Plastics (including housings of computers, printers, faxes, monitors, keyboards etc.)
- Aluminum (printer parts, etc.)
- Printer toners (from spent toner cartridges)
- PC-boards

At this stage, the disassembly and recovery of valuable components from CRTs and PC-boards are of particular concern. The lead loaded CRTs are thus broken to remove copper yokes that are collected for further treatment and copper recovery. The broken CRTs are often dumped on open land after removal of the yokes [147]. In India, CRTs were reportedly smelted for recovery of glass, but prior to the treatment they were stored in an open area [148]. The common method to recover solder and other valuables from PC-boards is by heating the boards until the connecting solder is melted. Heating is normally done using coal grills, propane torches, kerosene burners, or other simple devices. Melted solder is then collected and individual components attached to the PC-boards are manually removed with pliers. Chips and other components are then sorted between those valuable for re-sale and those to be sent to the acid chemical strippers for precious metal recovery. Often the pins of the components to be resold are straightened and dipped in fresh solder to make them look new before they are traded. The collected solder is also sold. Waste boards stripped of chips are further burnt or acid digested in order to recover the remaining metals [147].

Figure 2:3 Manual dissembling of electronic waste

2.5.2.2.Acid Extraction of Metals

In both China and India, primitive hydrometallurgical processes are used to recover metals from e-waste [147, 148]. PC-boards and other components are dissolved in strong acid solutions that are heated over small fires. The workers are then usually swirling the mixture for hours before the valuable metals can be precipitated and recovered from the solution. Common acids used are concentrated nitric acid and concentrated hydrochloric acid, either alone for extraction of copper and other metals, or in a 1:3 combinations (giving aqua regia) for extraction of gold. The waste acids and sludge's generated during these processes are often poured out and dumped on the open ground or into the water stream along which these facilities often are situated [148].

2.5.2.3.Shredding, Melting and Extrusion of Plastics

Plastics are normally shredded into smaller pieces, where after it is separated (e.g. by color or density) and further grinded. Usually, children are employed for these tasks. The plastics may then be melted and extruded in order to be used for new applications. These operations are often carried out in rooms with insufficient ventilation by workers using no respiratory protection [147, 148]. A large portion of the e-waste plastics are deemed unrecyclable because of impurities and unmatched colors. These are dumped on piles or burnt on open fires [148].

2.5.2.4.Burning of Plastics and Residual Materials

Some e-waste parts are burned on open fires to recover metals from the plastics in which they are encased. This includes plastic coated wires as well as other complex components [149]. This method is common by recyclers in both China and India, but is also used in African countries, such as Ghana [149], and also to some extent illegally in industrial countries [150]. In Ghana, it was reported that the main fuel used to sustain these fires was insulation foam, primarily polyurethane, from obsolete refrigerators [149], which likely in it will contribute to the emissions from these fires. Open burning of other wastes, unwanted scrap, and residues is also a common practice in many developing countries.

2.5.2.5.Toner Sweeping

Toner cartridges are taken apart with screwdrivers to get hold of the residual toner inside them. The toner is collected in buckets using paint 44brushes; where after the empty cartridges usually are discarded directly on the ground. The activity usually creates clouds of toner that surrounds the unprotected workers [147].

2.5.2.6.Dumping of Residual Materials

A large portion of the e-waste is not recycled but is dumped on fields and other open areas as well as along rivers and wetlands. This dumped material consists of leaded CRT glass, burned and acid-reduced PC-boards, toner cartridges, dirty or mixed plastics, residues from recycling operations (including ashes from open burning operations) and spent acid baths and sludge’s [147].

3. METHODOLOGY

3.1. Methodological framework

The focus of this thesis work is mainly on the assessment of the ongoing e-waste management in the ministry of information and communication technology and to recommend an appropriate and resent e-waste recycling approaches.

In doing so this research adopts qualitative and quantitative approaches to assess the existing e-waste management, review resent e-waste recycling approaches to recover precise metal from the e-waste (printed circuit board) from literature and investigate hydrometallurgy process to recover gold from the waste printed circuit boards at laboratory scale.

3.1.1. Technical Approach to Assess Waste Management System of MICT

Technically the study investigates as to how MICT collect, store, sort, select and recycle. The disposal activity was also investigated to ensure that the system follows environmentally friendly ways of collecting, storing, sorting and recycling. On this aspect the study refer the documentation of the MICT functions of its waste management system.

3.1.2. Technical Approach to Assess Waste Disposal of Waste Generator.

In this case, a sample of waste generator, prominently e-waste from institutions which can use bulk electronics material. A comparable size was determined on the basis of usage of computer technology among the different government organizations. On the study a sample of three institutions that may use the highest number of computer materials, with the assumption that the disposal of waste is also high was investigated.

3.2. Data Collection

The study applies both quantitative and qualitative data collection tools to generate data and information on the existing e-waste management and design strategy to recover precise metal from wasted printed circuit board available in all electronics materials. In order to reach at the intended objectives, the following tools for data collection was applied. These include:

- Document review;
- Qualitative data collection:

- Key informant interview
- Observation of the e-waste disposal site from the selected govermental organization and computer recycling and refurbishment center (CRTC) at Kality
- Case study at laboratory scale hydro-metallurgy to recover gold from waste printed circuit boards (PCB)

3.2.1. Document Review

The available document on e-Waste management was referred and synthesized, which can be used to revise and design technical approach and data collection instruments and tools as well. Key documents regarding literatures, more specifically on Global e-waste management System, e-waste management in Ethiopia, recent technologies to recycle precise metals from waste printed circuit boards (PCB) etc was reviewed and silent features was incorporated.

3.2.2. Key Informant Interview (KII)

Interviews are very important tools for gathering in-depth qualitative data. Key informants are individuals who are articulate and knowledgeable about the issue under discussion. This role gives them a special vantage point in describing the issues at concern. Key actors play a pivotal role in the theater of qualitative research, providing in-depth understanding of the topic of interest. Key informants represent an efficient source of invaluable information. They generally answer questions about the intent of the research in a comprehensive fashion.

KII was conducted with the concerned government officials and partners in e-waste management system. Interview was held with officials of the Ministry of Information Communication and Technology (MICT), interviewing technical laborers’ at the electronic dismantling and recycling site, interviewing governmental institutions (Addis Ababa university) who were disposing there e-waste on electronic dismantling and recycling site.

The first stage interview focuses on existing policies and strategies applicable to e-waste management in Ethiopia, and operational activities as part of ensuring its role to build a green economy in the country. Second, the second stage covers interviewing technical laborers at the electronic dismantling and recycling site, focusing on the current status of e-waste management activities, the availability of waste recycling techniques (mechanical, chemical and biological), the existing demand and potentials of the site. The third stage interview will address to collect pertinent information on the institutions who dispose their-waste. At this stage the interview is focused on the frequencies of the e-waste disposed by this institutions, types and volume of e-waste per annum, and their awareness towards e-waste.

Table 3:1 Selected Key Informants for the survey

	KII with	Number of Interviews per person	Points of discussion
MICT	Minister Department (concerned unit)	3	Policy and strategies related to e-waste management.
Waste generator	− Selected government offices (3)	3	− Types of e waste − Volume of waste being generated − Rule and procedure for managing and disposing e-waste − Methods of disposing the generated e-waste − place or site for disposing waste − cost of disposing waste − awareness on the e-waste management and use
Disposal site		1	− Types of e waste − Volume of waste being disposed − Volume of recycled waste − Facilities for disposing, dismantling and recycling − Methods of recycling e- waste − Selling price of the recycled wastes − awareness on the e-waste management and use
Total		6	

3.2.3. Observation

Observations on site levels are highly essential to get information on the type, volume of e-waste and available recycling technologies. For this the reasrech focus on e-waste storage facilities on the selected govermental offices, next to that e-waste recycling and refurbishing center at Kalite was observed.

3.3.Sample Size Determination

Sample size is the pivotal feature that governed the overall design of the sample. Computation of necessary sample size varied according to the measurement objective desired. The procedure will follow in computing the required sample size when key measurement objective will estimate changes that occurred between surveys, and the objective will be to provide baseline information (estimate) on e-waste generation and use.

I. E-waste Generators

This research was employed by adopting a multi-stage sampling technique. In the first stage, prominent governmental organization, which supposed to generate huge volume of e-wastes was targeted for this particular study. In the second stage the selected organizations were ranked based on the amount of e-wastes generated per-annum. From these data Adiss Abeba university was selected on the basis of accessibility of information and the amount e-waste generated.

II. E-waste Disposal and Recycling Sites

On this research disposal sites of the electronic wastes generated from the selected governmental organizations was surveyed.

3.4.Laboratory Scale Hydro-metallurgy to Recover Gold from Waste Printed Circuit Boards (PCB)

Hydrometallurgy a recent e-waste recycling approach can also be called as chemical leaching method. The method involves using a suitable chemical reagent for the dissolution of metals from e-waste.

This research mainly focuses on the recovery of a precious metal (gold) from a wasted printed circuit board (PCB) by using a hydro-metallurgy technique. The methods for the extraction of the gold and the required apparatuses for the research are put as follows

i. Materials and Methods

Materials and methods referees the required laboratory setup for the resech.in this regard in order to undertake this research (Laboratory scale hydro-metallurgy to recover gold from waste printed circuit boards(PCB)) the following methods and laboratory equipment’s was deployed

ii. sampling

Sampling is a technique used to select, manipulate and analyze a representative subset of data points in order to identify patterns and trends in the larger data set being examined.as in the case of this research a sample represents an electronic waste's specifically printed circuit boards (PCB) will be used in this research.

iii. sample collection

for this research 225 printed circuit board (PCB) was used and this material was collected from electronic waste dismantling and recycling site (ministry of information communication and technology (MICT)) and the wasted PCB stored at room temperature until a laboratory test is carried on.

iv. Sample Preparation

The first stage of the sample preparation was manual disassembling of computers, separation of PCB and removal of the batteries and capacitors. Preparation was done by mechanical processing, i.e. by rejecting the parts without gold, for the purpose of less acid consumption required for dissolution. Then after the fingers which are gold plated was cuted by sheet metal sheers from the printed circuit board and collected for experimental analysis.

v. Materials

To extract gold from a wasted printed circuit board the following laboratory equipment's was deployed on this research.

- Sheet metal sheers
- beaker
- 5 gal bucket
- Coffee filter
- Filter paper

vi. Chemicals and Regents

Once the printed circuit board (sample) is prepared for analysis as explained earlier the next step will be addition of different chemicals and reagents for the recovery of the precious metal (gold). Therefore, the basic chemicals and reagents for this laboratory experiment are listed as follows.

- Hydro chloric acid (35%)
- Hydrogen per oxide. (15%)

3.5.Design of Experiments

Experimental design, design expert 7.0, was selected in order to design the experiments. This design is suitable for building quadratic and cubic models. The basic information to design the experiment listed as follows.

Treatments

Refers to the set of circumstances created for the experiment

Experimental Unit

In order to recover gold from the waste printed circuit board by using a hydro-metallurgy process this research will use fingers which are gold plated and cuted out from the mother printed circuit board as an experimental unit.

Response Variable

Refers to characteristics of an experiment unit measured after treatment and analyzed to address the objectives of the experiment. Therefore, on these research amount of gold recovered considered as the response variable

Factor

By taking four experiments at (1:1,0.5:0.5) HCl to H_2O_2 proportion, (2hr,24hr) retention time and the hydrochloric acid concentration was (35%).the experimental results at (1:1,2hr,35% and ,0.5:0.5,24hr,35%) was exothermic and most of the gold films was washed out of the bicker with the fume. The experimental results at (1:1,24hr,35% and,0.5:0.5,24hr,35%) the amount of gold recovered was very small. because of the above facts the following factors are selected.; (***HCl:H_2O_2) proportion (1:0.5,1:0.4,1:0.9), retention time(6hr,12hr,21hr) and HCl concentration (15%,10%,5%***) was considered for this research.

Levels

The number of levels of a factor or independent variable was 2

Replications

The number of replications of a factor or independent variable was 3

3.6.Experimental Procedures

Stage -1 Hydrochloric acid dilution and material preparation.

At the start of the experiment 20 gram of fingers was used for on batch.by weighing of the trimmed fingers it will be added on an empty beaker. The next step will be dilution of the hydrochloric acid, hydrochloric acid with the concentration of 35% will be diluted by adding 57 ml of water on the biker. Finally, we can get hydrochloric acid with the concentration of 15% with a volume of 43 ml.

Stage -2 hydrometallurgical reactions by the addition of hydrogen per oxide

Once the raw material is prepared and the available acid is poured on the biker, the next step will be the addition of hydrogen per oxide which has a concentration of 15% with a volume of 50 ml.

Stage-3 precious metal dissolution

The combination of hydrochloric acid and hydrogen per oxide will detached the gold fingers from the silicon chips and a film of gold fingers will float on the liquid chemicals and the rest will settle at the bottom of the biker.at this moment the liquid will turn in to light green and the reaction was proceeding for 6 hours.

$$SiO_2+HCl+H_2O_2 \rightarrow \quad SiCl+HO_2$$

Stage -4 Solution purification

Step one straining out the pieces of circuit card using a 5gal bucket and a kitchen strainer and rinse the jar completely with a wash bottle. Step two will be rinsing of the stripped fingers with water to remove the acid peroxide solution. Then after the rinsed fingers will be placed aside so to filter the gold foils out of the solution. Using another kitchen strainer and a large coffee filter the gold foils will be filtered out of the acid peroxide solution. Step three will be rinsing of the gold foils that will cling to the fingers with tap water in to the 5 gal bucket. After siphoning most of the clean water out of the bucket, the gold foils will be collected in a coffee filter.

3.7.Characterization of Gold

The recovered gold was characterized by using XRF EDX 2800 in the laboratory of geological survey of Ethiopia.

4. RESULT AND DISCUSSION

4.1.Qualitative Data Analysis

4.1.1. Assessment of Target Institutions

4.1.1.1.Consumption Trends

As the study reveals ICT penetration and Consumption of computers and other computing devices in the three campuses have been increasing year after year. This increasing trend is mainly triggered by the increasing number of departments and hence the number of academic and administrative staffs.

As of the number of academic and administrative staffs are increasing from time to time, it is no question that new electronic equipment's will be purchased. To this end, in the fact of the increasing demand for all kinds of computing devices the three campuses have no any environmental criteria on purchasing any automating and computing devices. According to different environmental approaches to E-waste, one of the strategies that can be done by the end user of the products is to pay money for environmentally sound products like products made from less hazardous and less toxic substances with power efficient eco-labeling marked on them. A key informant in Addis Ababa university (institute of technology campus) asked whether they have any environmental criteria on purchase of new EEES said:

Given low ICT penetration in the country in general, requirement of additional office automations in our campus and inadequate awareness about the issue of environment and insignificant impact of e-waste, so far, in the country, how can we have environmental criteria when we purchase new EEEs. Of course, we have criteria related to issues like Brand, Price and Specifications of the equipment's we purchase, but we never, so far, had any criteria related to environmental issues. On purchasing new equipment's, possibly, the issue of environment and waste will be one of our criteria if the government itself gives emphasis on it and install some directions on it.

Different computer manufacturers today have gone long in the effect of producing hazard free and power efficient products. Therefore, purchasers can eliminate environmental intensive manufacturers by purchasing products of pro-green and energy efficient products.

But, as the study reveals, this is not being practiced in the purchasing trends of all the three campuses of the study. They simply buy all computing devices and other electrical and electronic products based on the Performa collected on other criteria like price and specifications of the equipment's.

4.1.1.2.End of Life Management Practice.

According the result of the study, Re-using of computers and other computing devices has been practiced on the three campuses. According to main store keepers of the campuses, Computers that have been used in offices have been reused by other different offices that have never used any computing devices for extended periods. Yet again number of computers that have been used in different offices have been donated to different elementary schools, high schools,

Parallel to that used electronic wastes was classified as **class-A, Class-B** and **Class-C.** most the classification of the electronic wastes was done on the basis of their maintenance cost.as stated earlier most class-A electronic waste was maintained and donated for elementary and high schools in remote areas and the rest was donated for different governmental organizations in the cites.

Most Class-B electronic waste was sold for different buyers on the bases of their needs. the rest Class-C electronic appliances were collected by ministry of information communication and technology(MICT) finally stored at computer recycling and recovery center(CRTC) at Kalite.

Once the end life electronic appliances reach at CRTC, these electronic appliances were dismantled manually and the metal part and other parts of the electronic materials was selected and sorted separately. On the basis of the market need most metallic components of the electronic materials will be solid and the rest of the electronic materials was sorted simply.

Figure 4:1 Stored EoL computers and accessories in Addis Ababa university(AAIT)

Figure 4:2 Stored EoL computers and accessories in Addis Ababa university (collage natural science)

Figure 4:3 Stored EoL computers and accessories in Addis Ababa university (main campus)

4.1.1.3. Assessment of Degree of Awareness on E-waste Management at Addis Ababa University.

Awareness in solid waste management is measured in terms of behavioral change. Awareness creation activity requires appropriate approach with continuous effort. The approach may vary according to the different backgrounds of stakeholders like educational level, culture, language, understanding capacity of individuals, attitudes, interest, the nature of the waste and etc. the fact that stakeholders are informed about the issue does not guarantee their action accordingly. On the other hand, although stakeholders know and want to act positively, the mechanisms may not be available to help them implement what is required. For example, as the study reveals the majority of the university community knows that solid waste in general and E-waste in particular is resource for the others; but due to the lack of mechanisms and non-existence of market waste recovery, particularly for E-waste, the community are not sorting and carefully disposing to minimize waste. As awareness entails behavioral change, to act in the right direction enabling grounds should be set to help all act accordingly

4.2.Quantitative Data Analysis

4.2.1. Characterization of Gold

Geological survey of Ethiopia: geological laboratory directorate
Geochemical laboratory XRF EDX 2800 report format
Field ID 0586/17 PVT
Sample type: small size film
Preparation: no
Number of sample: 1
Analytical method: XRF EDX 2800
Analytical results in present: to determine precious element

Table 4:1 characterization of the gold.

Field no	LAB NO	Au	Ni	Cu	Weight(gm)
Sample 1	0586/17	99.71	0.12	0.16	1.66

N.B Au for gold, Ni nickel and Cu for copper

4.2.2. Experimental run

			factor1	**factor 2**	**factor 3**	**response**
Std	run	bolck	$HCl:H_2O_2$ Proportion	HCl Concentiration	retention time	gold (gm)
9	1	Block 1	2.00	0.00	0.00	0.0032
55	2	Block 1	0.00	0.00	2.00	0.0206
44	3	Block 1	2.00	1.00	1.00	0.2314
51	4	Block 1	1.00	2.00	1.00	0.0211
25	5	Block 1	2.00	2.00	0.00	0.0289
65	6	Block 1	0.00	1.00	2.00	0.002
38	7	Block 1	0.00	1.00	1.00	0.2454
70	8	Block 1	2.00	1.00	2.00	0.0102
56	9	Block 1	0.00	0.00	2.00	0.0205
20	10	Block 1	0.00	2.00	0.00	0.1071
3	11	Block 1	0.00	0.00	0.00	0.0052
37	12	Block 1	0.00	1.00	1.00	0.2453
75	13	Block 1	0.00	2.00	2.00	0.0053
74	14	Block 1	0.00	2.00	2.00	0.0051
27	15	Block 1	2.00	2.00	0.00	0.0287
32	16	Block 1	1.00	0.00	1.00	0.1436
61	17	Block 1	2.00	0.00	2.00	0.0081
72	18	Block 1	2.00	1.00	2.00	0.0101
68	19	Block 1	1.00	1.00	2.00	0.0032
28	20	Block 1	0.00	0.00	1.00	0.1095
8	21	Block 1	2.00	0.00	0.00	0.003
34	22	Block 1	2.00	0.00	1.00	0.0237
26	23	Block 1	2.00	2.00	0.00	0.0288
77	24	Block 1	1.00	2.00	2.00	0.0057
30	25	Block 1	0.00	0.00	1.00	0.1097
73	26	Block 1	0.00	2.00	2.00	0.0052
76	27	Block 1	1.00	2.00	2.00	0.0058
10	28	Block 1	0.00	1.00	0.00	0.0664
2	29	Block 1	0.00	0.00	0.00	0.0051
35	30	Block 1	2.00	0.00	1.00	0.0236
69	31	Block 1	1.00	1.00	2.00	0.0031
78	32	Block 1	1.00	2.00	2.00	0.0056
48	33	Block 1	0.00	2.00	1.00	0.0171
18	34	Block 1	2.00	1.00	0.00	0.0957
36	35	Block 1	2.00	0.00	1.00	0.0235
40	36	Block 1	1.00	1.00	1.00	0.2191
79	37	Block 1	2.00	2.00	2.00	0.1673
80	38	Block 1	2.00	2.00	2.00	0.1672
60	39	Block 1	1.00	0.00	2.00	0.0013
17	40	Block 1	2.00	1.00	0.00	0.0958
57	41	Block 1	0.00	0.00	2.00	0.0204

67	42	Block 1	1.00	1.00	2.00	0.0033
15	43	Block 1	1.00	1.00	0.00	0.0116
45	44	Block 1	2.00	1.00	1.00	0.2313
66	45	Block 1	0.00	1.00	2.00	0.003
54	46	Block 1	2.00	2.00	1.00	0.0456
5	47	Block 1	1.00	0.00	0.00	0.0043
42	48	Block 1	1.00	1.00	1.00	0.2193
41	49	Block 1	1.00	1.00	1.00	0.2192
46	50	Block 1	0.00	2.00	1.00	0.0173
19	51	Block 1	0.00	2.00	0.00	0.107
50	52	Block 1	1.00	2.00	1.00	0.0212
21	53	Block 1	0.00	2.00	0.00	0.1072
31	54	Block 1	1.00	0.00	1.00	0.1437
4	55	Block 1	1.00	0.00	0.00	0.0044
58	56	Block 1	1.00	0.00	2.00	0.0011
7	57	Block 1	2.00	0.00	0.00	0.0031
24	58	Block 1	1.00	2.00	0.00	0.0577
63	59	Block 1	2.00	0.00	2.00	0.0083
22	60	Block 1	1.00	2.00	0.00	0.0579
43	61	Block 1	2.00	1.00	1.00	0.2315
62	62	Block 1	2.00	0.00	2.00	0.0082
39	63	Block 1	0.00	1.00	1.00	0.2455
16	64	Block 1	2.00	1.00	0.00	0.0959
11	65	Block 1	0.00	1.00	0.00	0.0662
23	66	Block 1	1.00	2.00	0.00	0.0578
49	67	Block 1	1.00	2.00	1.00	0.0213
29	68	Block 1	0.00	0.00	1.00	0.1096
12	69	Block 1	0.00	1.00	0.00	0.0663
71	70	Block 1	2.00	1.00	2.00	0.0103
1	71	Block 1	0.00	0.00	0.00	0.005
6	72	Block 1	1.00	0.00	0.00	0.0042
33	73	Block 1	1.00	0.00	1.00	0.1438
14	74	Block 1	1.00	1.00	0.00	0.0118
13	75	Block 1	1.00	1.00	0.00	0.0117
47	76	Block 1	0.00	2.00	1.00	0.0172
52	77	Block 1	2.00	2.00	1.00	0.0458
53	78	Block 1	2.00	2.00	1.00	0.0457
81	79	Block 1	2.00	2.00	2.00	0.1671
59	80	Block 1	1.00	0.00	2.00	0.0012
64	81	Block 1	0.00	1.00	2.00	0.001

4.2.3. Experimental Design Results

The experimental results of the influence of the three factors which were (HCl:H_2O_2) proportion, retention time and HCl concentration on the response variable recovered gold were designed using general factorial of ANOVA and the results of the analysis of variance presented in the following table and discussed.

Table 4:2 Analysis of variance table [partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	0.46	26	0.018	3.802E+005	< 0.0001
A	*3.864E-003*	*2*	*1.932E-003*	*41394.67*	< 0.0001
B	*0.058*	*2*	*0.029*	*6.229E+005*	*< 0.0001*
C	*0.13*	*2*	*0.065*	*1.402E+006*	*< 0.0001*
AB	*0.023*	*4*	*5.712E-003*	*1.224E+005*	*< 0.0001*
AC	*0.024*	*4*	*6.092E-003*	*1.306E+005*	*< 0.0001*
BC	*0.17*	*4*	*0.043*	*9.299E+005*	*< 0.0001*
ABC	*0.048*	*8*	*5.964E-003*	*1.278E+005*	*< 0.0001*
residual	2.520E-006	54	4.667E-008		
Cor Total	0.46	80			

Accoding to the table ,the model F-value of 380243.79 implies the model is significant.there is only a 0.01% chance that a “Model F-value” this large couid occur due to noise.values of “prob>F” less than 0.0500 indicate model terms are significant,in this case A,B,C,AB,AC,BC and ABC($HCl:H_2O_2$ proportion,HCl concentration,retention time and there interaction effects) are siginificant model terms. values greter than 0.1000 indicate the model terms are not significant.if there are many insignificant model terms(not counting those required to suppoert hierarchy) model reduction may improve the model.

Another useful statistic here was the one labeled ‘Adeq precision’.this is a kind of signal to noise ratio that measures the ratio of the range of variation in the predicted response to an estimate of the standared error of the predictions and is obtained by subtracting the minimun predicted value from the maximum predicted value and then dividing by the average standard devation of a prediction.

A high value indicates that the varation that we are observing is large in relation to the underlying uncertinity of the fitted model.with respect to the following model adequecy signals,the “pred R-squared” of 1.0000 was in reasonable agreement with the”Adj R-squared” of 1.0000.a ratio greater than 4 is desirable.the ratio of 1957.956 indicates an adquate signal.this model can be used to navigate the design space.if the”pred R-squared” was not as close to the “Adj R-squared” it may have indicated us a large block effect or a possible problem with the model and or data.

Table 4:3 Model adequacy measures

Std. Dev	2.160E-004	R-squared	1.0000
Mean	0.061	Adj R-squared	1.0000
C.V.	0.35	Pred R-squared	1.0000
Press	5.670E-006	Adeq precision	1957.956

The following table shows the numerical coefficient estimates for all the single sources and interaction sources listed in the ANOVA table

Table 4:4 Coefficients of fitted model.

Factor	Coefficient estimate	DF	Standard error	95% CI Low	95% CI High
Intercept	0.061	1	2.400E-005	0.061	0.062
A	2.770E-003	1	3.395E-005	2.770E-003	2.838E-003
A^2	-9.496E-003	1	3.395E-005	-9.569E-003	-9.428E-003
B	-0.026	1	3.395E-005	-0.026	-0.026
B^2	0.037	1	3.395E-005	0.037	0.037
C	-0.019	1	3.395E-005	-0.019	-0.019
C^2	0.056	1	3.395E-005	0.056	0.056
AB	6.819E-003	1	4.801E-005	6.722E-003	6.915E-

					003
A^2B	0.024	1	4.801E-005	0.024	0.024
AB^2	3.441E-003	1	4.801E-005	3.344E-003	3.537E-003
A^2B^2	-0.011	1	4.801E-005	-0.011	-0.011
AC	0.015	1	4.801E-005	0.014	0.015
A^2C	-8.126E-003	1	4.801E-005	-8.22E-003	-8.030E-003
AC^2	3.852E-003	1	4.801E-005	3.756E-003	3.948E-003
A^2C^2	0.020	1	4.801E-005	0.020	0.020
BC	-0.012	1	4.801E-005	-0.012	-0.012
B^2C	-0.021	1	4.801E-005	-0.021	-0.021
BC^2	8.741E-004	1	4.801E-005	7.778E-004	9.703E-004
B^2C^2	0.078	1	4.801E-005	0.078	0.078
ABC	-0.023	1	6.789E-005	-0.023	-0.023
A^2BC	-5.966E-003	1	6.789E-005	-6.132E-003	-5.860E-003
AB^2C	-0.012	1	6.789E-005	-0.012	-0.012
A^2B^2C	-0.018	1	6.789E-005	-0.018	-0.018
ABC^2	3.859E-003	1	6.789E-005	3.7273E-003	3.995E-003
A^2BC^2	0.017	1	6.789E-005	0.017	0.017
AB^2C^2	3.337E-003	1	6.789E-005	3.201E-003	3.473E-003
$A^2B^2C^2$	-0.013	1	6.789E-005	-0.013	-0.012

Final Equation in Terms of Coded Factors.

R.G=0.061+2.770E-003*A-9.496E-003*A^2-0.026*B+0.037*B^2-0.019*C+0.056*C^2+6.819E-003*AB+0.024*A^2B+3.441E-003*AB^2-0.011*A^2B^2+0.015*AC-8.126E-003-A^2C+3.852E-003*AC^2+0.02*A^2C^2-0.012*BC-0.021*B^2C+8.741E-004*BC^2+0.078*B^2C^2-0.023*ABC-5.996E-003*A^2BC-0.012*AB^2C-0.018*A^2B^2C+3.859E-003*ABC^2+0.017A^2BC^2+3.337E-003AB^2C^2-0.013*$A^2B^2C^2$.

The above mathematical equation was developed for the response variable (recovered gold) as a function of HCl:H_2O_2 proportion(A),HCl concentration(B) and retention time (C) and calculated as the sum of a constant,first order effects,second order effects and interaction effects.

Final Equation in Terms of Actual Factors.

Recoverdgold=0.0513240.061611*HCl:H_2O_2+0.10321*HClconcentration+0.14450*retention time+0.014244*HCl:$H_2O_2^2$0.055289*HClconcentiration^{2}0.083922*retentiontime^2+0.017708 *HCl:H_2O_2*HClconcentiration+0.017392*HCl:H_2O_2*retentiontime2.7500E003*HClconcentration*retention time.

4.2.4. Effects of Experimental Variables on the Amount of Recovered Gold

A. Effect of HCl:H_2O_2 Proportion on the Amount of Recovered Gold

HCl:H_2O_2 proportion was one of the factor that affect the amount of gold recovered. The effect of different proportion with a constant retention time and HCl concentration (6hr retention time and 15% HCl concentration) is shown in the following figure in order to know the influence of this single factore.as it can be observed from the graph, the amount of gold recovered increased as the proportion is 1:0.5 but an increase beyond the proportionality values of 1:0.4 and1:0.9 brought no significant improvement in the response variable. Therefore, this implies that the proportion of hydrochloric acid to hydrogen per oxide should be 1:0.5 in order to good result. This is because of H_2O_2 is a strong oxidizing agent in either acid or alkaline solution.

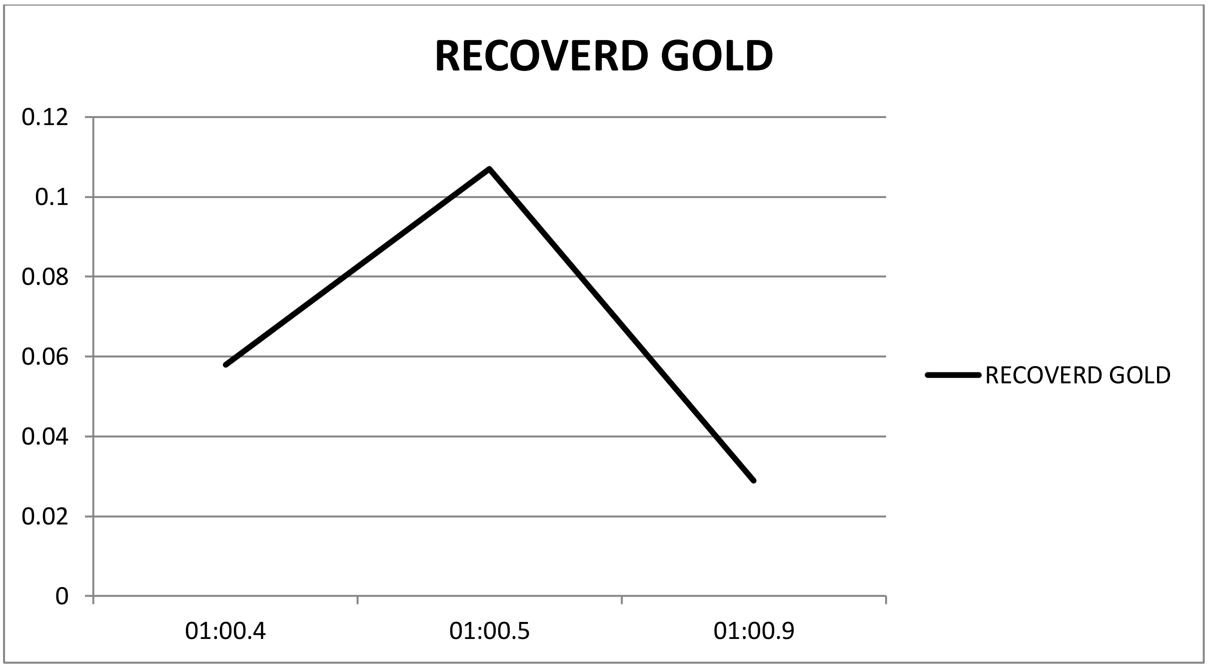

Figure 4:4 Effect of HCl: H_2O_2 proportion on the amount of recovered gold

B. Effect of Retention Time on The Amount of Recovered Gold

As we can observe from the figure, the retention time have a positive effect in the amount of gold recoverd.as we decrease the retention time to 6hr, a maximum value of gold 0.1g was obtained this is because the potency of the etchant tends to decline with time due to the formation of volatile products.

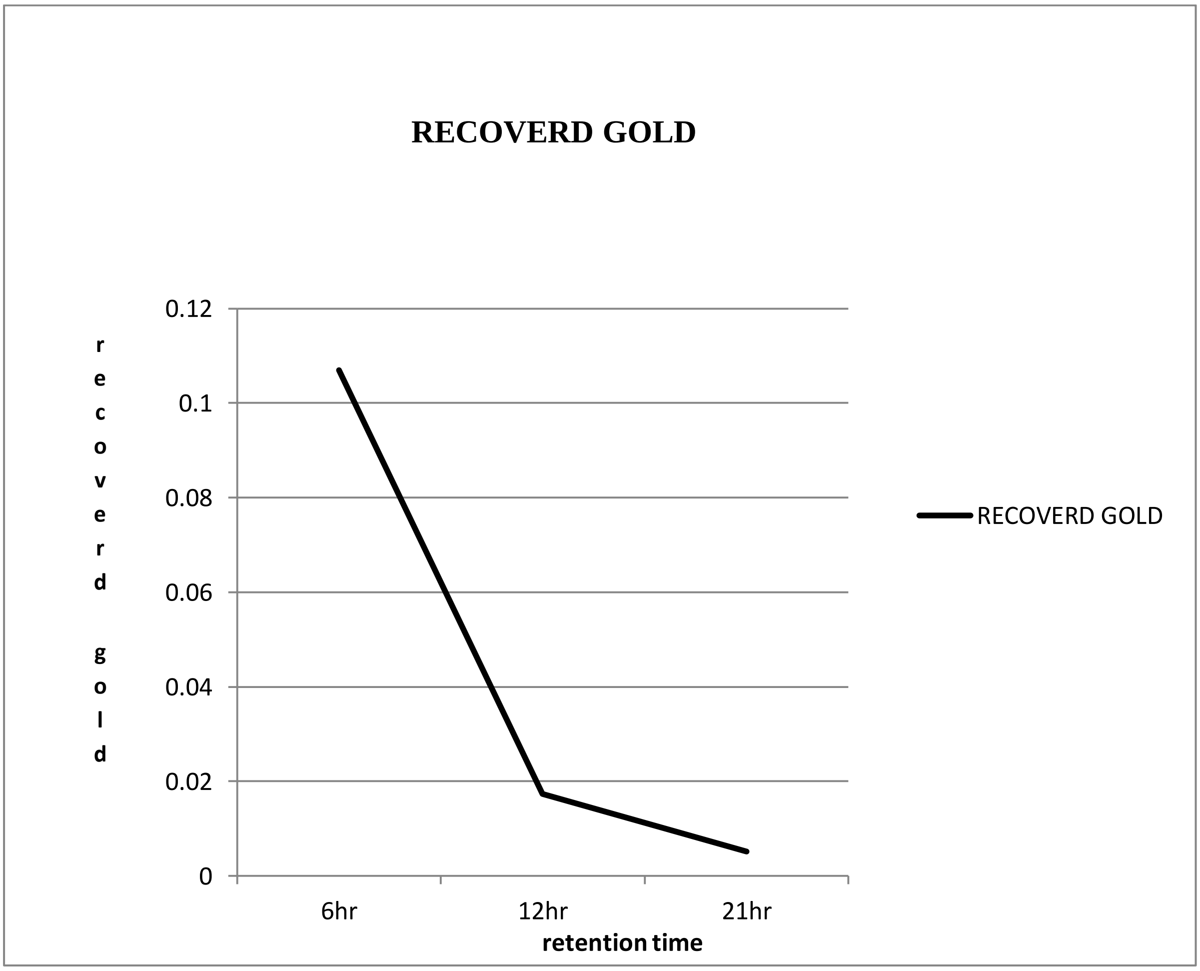

Figure 4:5 Effect of retention time on the amount of recovered gold

C. Effect of HCl Concentration on the Amount of Recovered Gold

The effect of hydrochloric acid concentration over the range of 5%-15% with a constant retention time and hydrochloric acid to hydrogen per oxide proportion is shown in the following figure in order to know the influence of this single factor.as it can be observed from the figure, the amount of gold recovered increases as the hydrochloric acid concentration increase. Therefore, this implied that the concentration of hydrochloric acid must be high in order to recover maximum amount of gold. Very strong acids such as

$HClO_4$,HI, HCl or H_2SO_4 are almost completely dissociates in water, therefore as concentration increases the amount of gold recovered will increase.

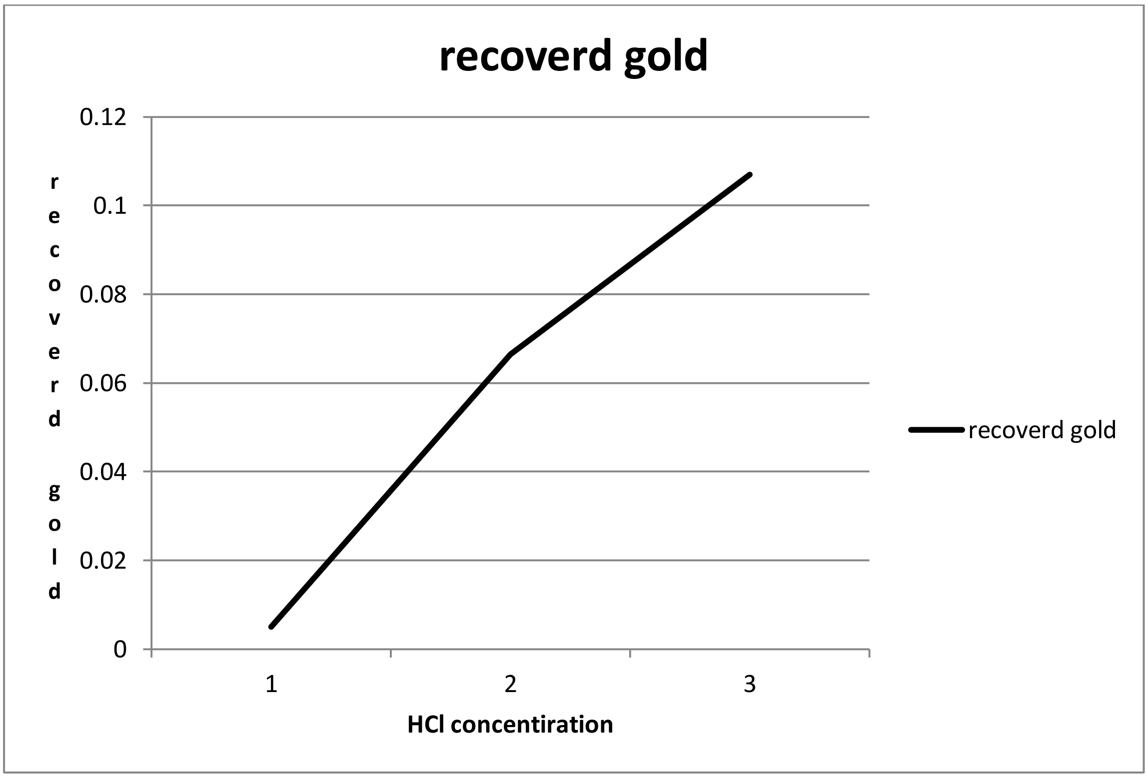

Figure 4:6 Effect of HCl concentration on the amount of recovered gold

D. Interaction Effect Among the Factors

According to the design of expert output, the interaction of HCl:H_2O_2 proportion,HCl concentration and retention time is observed in the following figure.design ponits are included in the plot.and these points are points in the graph which helps to develop mathimatical model of the pridected response based on these points. This interaction plot shows how the effect of changing one control variabile will change the second control variabile as it can be observed in the figure.the line on the interaction graph is single,this indicates that the effect of changing HCl concentiration or HCl:H_2O_2 proportion have a significant variation on the other parameter.this was also described in the ANOVA table that the interaction effect of the three variabiles was signifiant with a Prob>F value of 0.0001

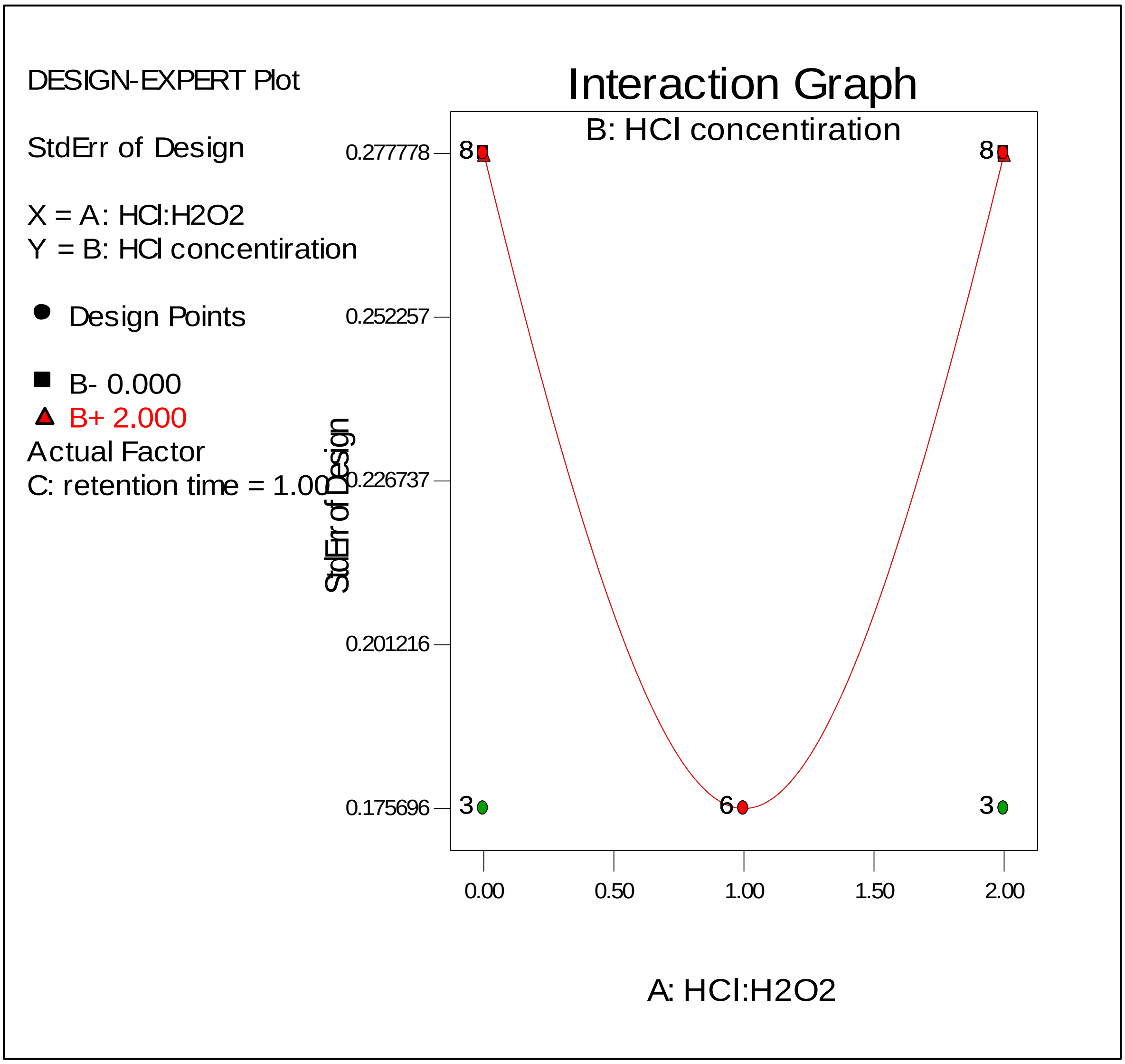

Figure 4:7 Interaction effect among the factors

4.2.5. Diagnostics and Contour Plots

Under this tab residual plots, Box-Cox plot of power transformations and plots of leverage and influence statistics are available. these residual plots are the main notes that offers the usual range of residual plots for checking assumptions such as normality and constant variance, the Box-Cox plot for power transformation help us to decide whether we could improve the fit of the model by measuring the response on a different scale e.g. by using the log of the response values. And plots of leverage and influence statistics show the influence of individual data points on the fitted model.so for standard designs such as factorials; these statistics will not usually be needed. Only the residual plots are included in here.

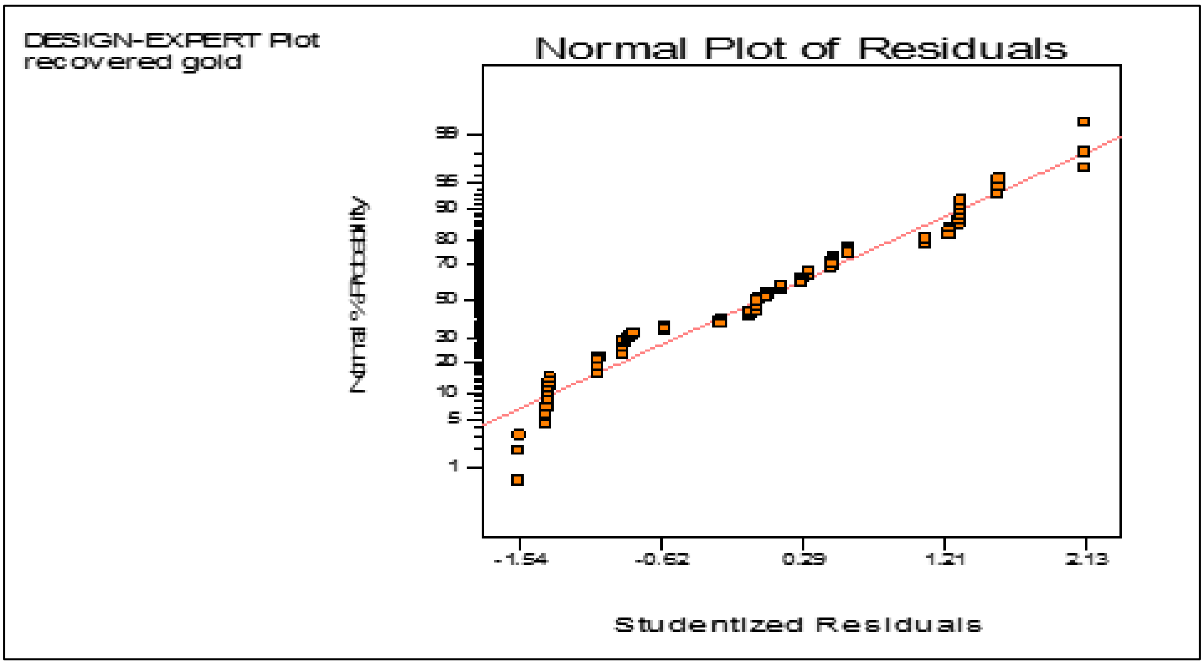

Figure 4:8 Normal plot of residuals

As it was already described in the above note, this residual analysis is necessary to confirm that whether the assumptions for the ANOVA are met and the above plot of studentized residuals showed that it is a good plot. According to [Shari Kraber, 2005], a good plot must be linear and normal.

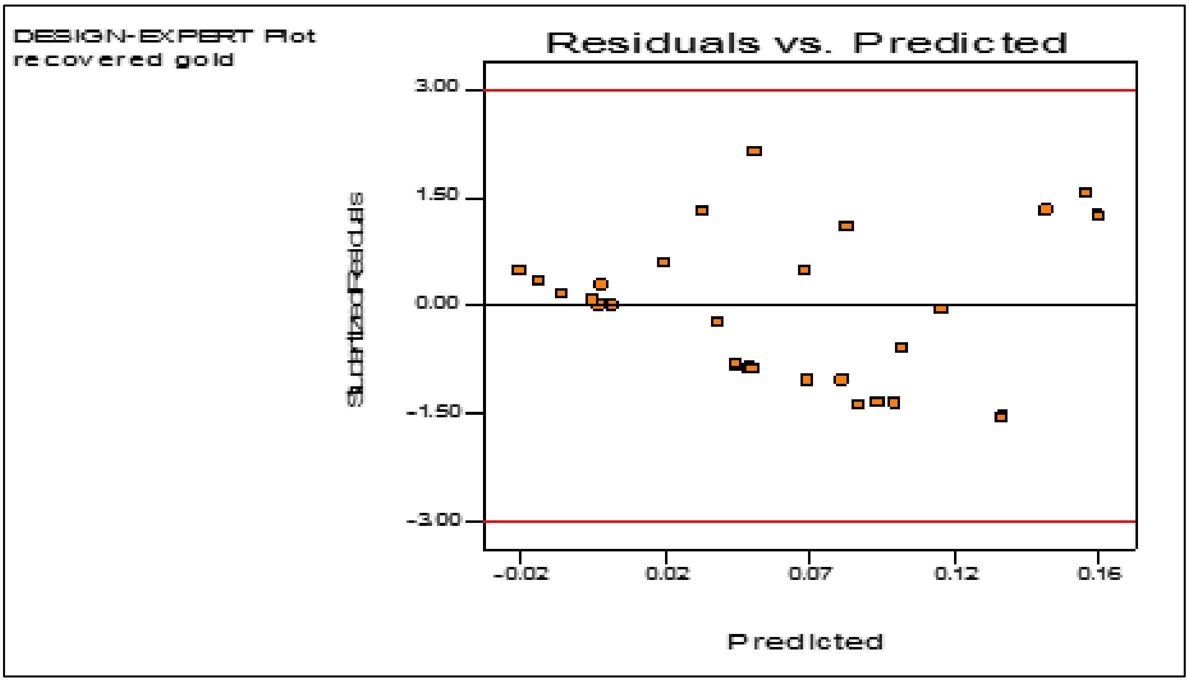

Figure 4:9 Studentized residuals versus predicted value

According to the above plot, the points in the figure are randomly scattered which indicates that it is a good plot [Shari Kraber,2005] and the assumptions for the ANOVA are met. With respect to the residual versus run number, the plot should also be in random scatter with no trends which indicated that the following plot is also good one.

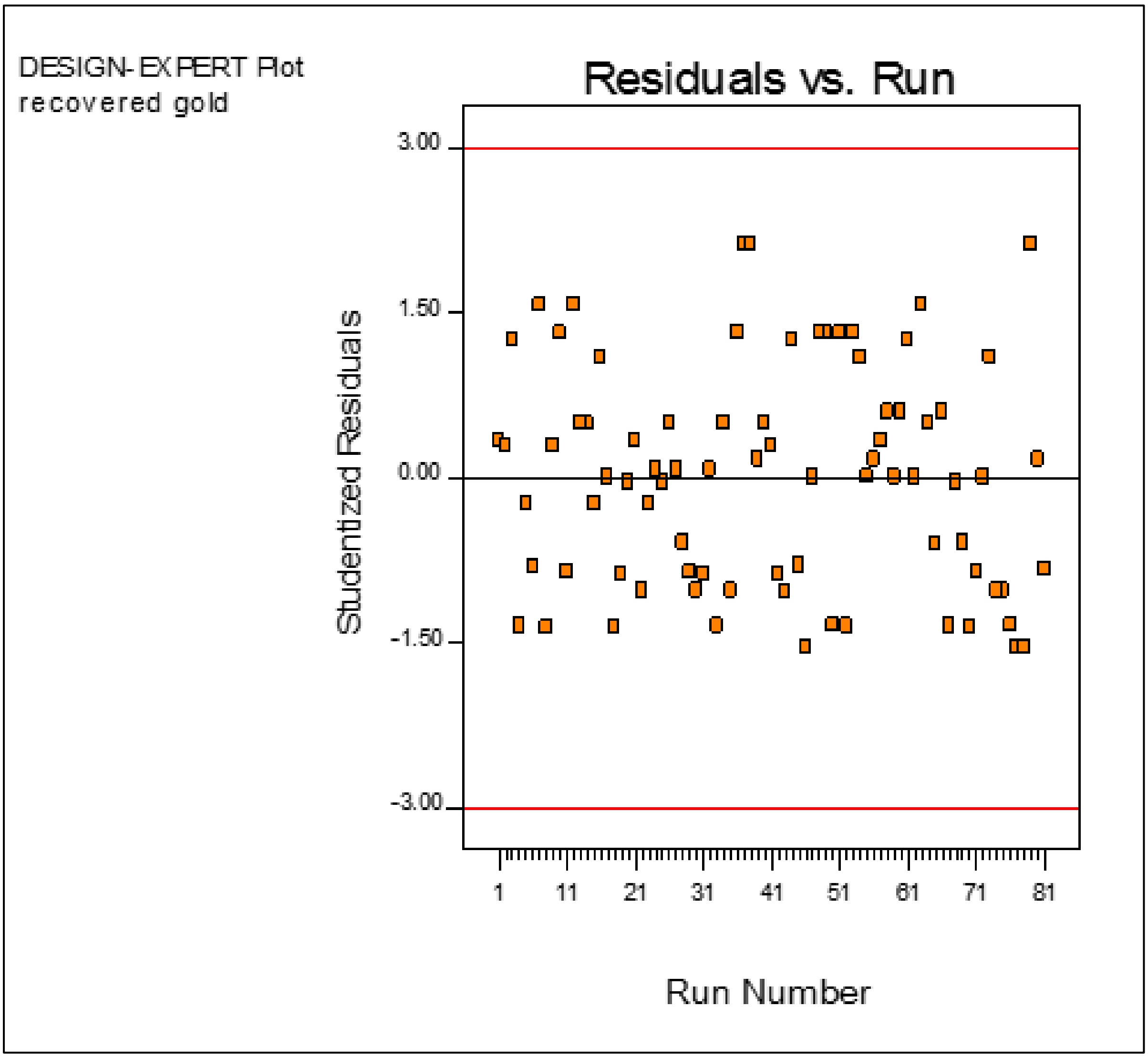

Figure 4:10 Studentized residuals versus run number

One of the aims of statistical design is to ensure that the models make good use of all observations and are not critically dependent on just a few points. The other range for checking assumptions was predicted versus actual and with respect to the figure below, the points are randomly scattered along the 45-degree line which implied that it is a better prediction [Shari Kraber, 2005]. Groups of points above or below the line indicate areas of over or under prediction.

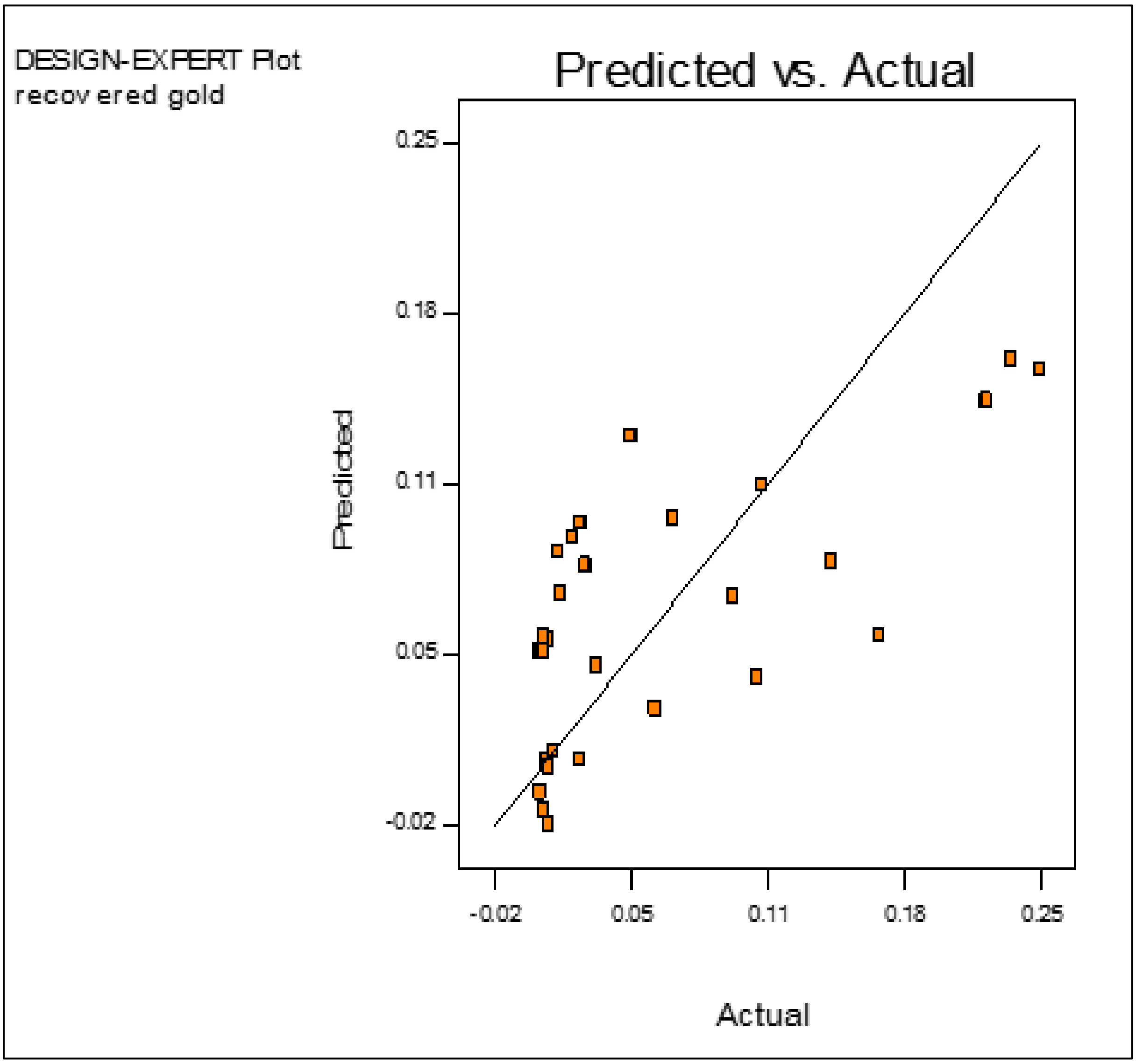

Figure 4:11 Predicted versus actual

The contour plots in design expert are useful to explore design space, slicing on the factors or components identified from the perturbation or trace plots as well as any categorical factors. The following contour plot is sliced in order to show the different points. the red points in the plot showed the design points with in each of the factors.

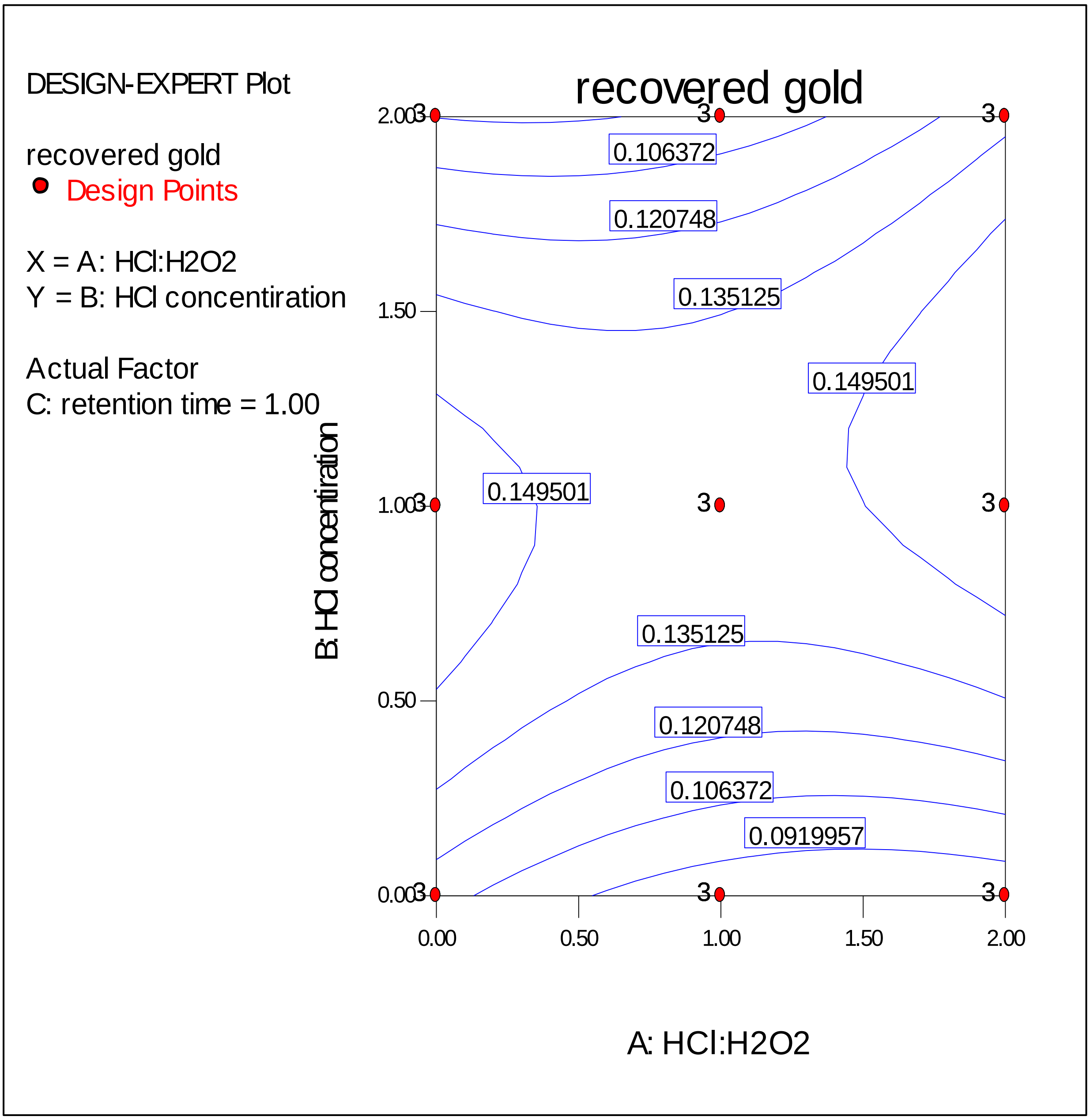

Figure 4:12 Contour plot of recovered gold

5. CONCLUSION

Generally, as per the results of the study and based on its specific objectives the following conclusions are drawn

- Waste printed circuit boards contain valuable materials such as gold, palladium and silver. this research focuses on the gold in high purities. Hydrochloric acid and hydrogen per oxide was used as a leaching agent. Hydrochloric acid to hydrogen per oxide proportion (1:0.5,1:0.4,1:0.9), retention time(6hr,12hr,21hr) and hydrochloric acid concentration of (5%,10%,15%) was considered as factors for the experimental analysis and by taking the amount of gold as a response variable 99.71% Au,0.12% Ni,0.16% Cu with total weight 1.66 gm sample was recovered from 500 gm of printed circuit board fingers which was characterized at geological survey of Ethiopia.

- E-waste will be a huge problem in the future, given the rise in consumption trend of the target institutions and the general importation trend of the country. It is, therefore, imperative that measures are put in place to address the emerging challenge
- The current trend of lifecycle management of this electronic waste at CRTC and at Adiss Abeba University is out date and the precious metals like that of gold and palladium are not properly recycled.

6. RECOMMENDATION

Based on the results of the study and conclusions reached together with lessons drawn from literatures on experiences of other countries to mitigate the major challenges of e-waste and hence achieve sustainable and opportunistic e-waste management, the following key remarks are recommended.

- The government through its instruments-the federal and regional EPAs-should put a system in place where institutions and households can handle the cradle-to grave management of EEEs separately from solid waste. In doing so, the process should be job opportunistic for small scale enterpriser's in each of the stages through the entire process; for example, this enterpriser's working on e-waste collection can be created to collect e-waste from the source-institutions or households. E-waste should be sorted at source by the institutions or the households.

- The EPA and other governmental stakeholders should encourage and acknowledge the likely role of civil society stakeholders in creating awareness and conducting research on e-waste

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Appendix

Annex I: Interview and discussion guide questions for ministry of information and communication technology.

1. በየጊዜው እየጨመረ የመጣውን የኤሌክትሮኒክስ መሳሪያዎች አጠቃቀም ከግምት ውስጥ በማስገባት እና እነዚህ መሳሪያዎች ጊዜያቸውን ጨርሰው ሲወገዱ መወሰድ ያለበት የአወጋገድ ስርአት በፖሊሲ ደረጃ ተቀርፆል?ከተቀረፀ የሚኒስተር መስራቤቱ ሀላፊነት ምንድንው?

2. በተመረጡ ከተሞች ውስጥ ግልጋሎት ላይ የዋሉ የኤሌክትሮኒክስ መሳሪያዎች አወጋገድ ስርአት ተግባራዊ ማድረግ አስፈላጊነቱ ምንድን ነው?

ከዚህ በታች ለተቀመጡት ጥያቄዎች መልስ በሳጥኖቹ ውስጥ √ አስቀምጡ

3. ግልጋሎት ላይ ለዋሉ የኤሌክትሮኒክስ መሳሪያዎች ተገቢ የሆነ የአወጋገድ ስርአት በሀገሪቱ ውስጥ ለመዘርጋት ክፍተቱ ምንድን ነው?
   - በቂጥናቶች አለመኖር ☐
   - የግንዛቤ ማነስ ☐
   - ለስራው ተገቢ የሆነ በጀት አለመኖር ☐
   - የባለሙያ እጥረት ☐

4. በተመረጡ ሰባት ከተሞች ውስጥ ግልጋሎት ላይ ለዋሉ መሳሪያዎችየተደራጀ የአወጋገድ ስርአት ተግባሪዊ ለማድረግ የትኞቹ ሀሳቦች በመሰረታዊነት ያስፈልጋሉ
   - በቂጥናቶች ☐
   - ለስራው ተገቢ የሆነ በጀት ☐
   - ☐

የተደራጀ የባለሙያ አወቃቀር

ተጨማሪ ሀሳብ

5. ግልጋሎት ላይ የዋሉ የኤሌክትሮኒክስ መሳሪያዎችን በተገቢው መልኩ አለማስወገድ በመሳሪያዎቹ ውስጥ ያሉት ኬሚካሎች በጊዜ ብዛት የአካባቢውን አየር፣አፈር እና ውሀ ይበክላሉ፤ ለዚህም በመሰረታዊነት ይህን ለመከላከል ምን ማድረግ ይቻላል

በጥናት የታገዙ የአወጋገድ ስርአቶችን መተግበር ☐

ዘመናዊ የሆኑ መሳሪያዎችን በመጠቀም በድጋሚ አገልግሎት የሚሰጡትን በመለየት የማያስፈልጉትንማስወገድ ☐

ትርፋማነቱን በማጥናት እና የቢዝነስ ፕላን በማዘጋጀት ወጣቶችን አደራጅቶ ወደ ስራ ማስገባት ☐

አቅም ያላቸውን ባለሀብቶች በማወዳደር ወደ ተግባር መቀየር ☐

ተጨማሪ ሀሳብ

6. በኢትዮጵያ ውስጥ የተደራጀ ግልጋሎት ላይ የዋሉ የኤሌክትሮኒክስ መሳሪያዎች አወጋገድ ስርአት ተግባራዊ ለማድረግ እና በቀጣይነት ወደ ተግባር ለመቀየር ጥናቶች ምን ያህል አስተዋጽኦ አላቸው?

ከፍተኛ ☐

መካከለኛ ☐

አነስ ☐

Annex II: Interview and discussion guide questions for Adiss Abeba university

ቀን:	የስራ ቦታ:	ቃለ መጠይት አቅራቢ:

መግቢያ
እኔ ተማሪ... በአዲስ አበባ ዩኒቨርስቲ ኢኒስቲቲዩት ኦፍ ቴክኖሎጂ በአካባቢ ምህንድስና የድህረ ምረቃ ተማሪ ስሆን ግልጋሎት ላይ የዋሉ የኤሌክትሮኒክስ መሳሪያዎች አወጋገድ ላይ ጥናት እያደረኩ ነው። ለጥናቱ ማሟያ ከዚህ በታች የተቀመጡትን ጥያቂዎች እንዲመልሱ በአክብሮት እጠይቃለሁ።/በቃለ መጠይቁ ላይ ስለተሳተፉ አመሰግናለሁ

ቃለ መጠይቅ የተደረገለት ሰራተኛ	
ስም	

የስራ ሀላፊነት	
የስራ ክፍል	
ስልክ ቁጥር	

1. ሰራተኞች ግልጋሎት ላይ የዋሉ የኤሌክትሮኒክስ መሳሪያዎች ላይ ያላቸውን ግንዛቤ የመለኪያ ጥያቂዎች		
1.1	ግልጋሎት ላይ የዋሉ የኤሌክትሮኒክስ መሳሪያዎች ለአካባቢ እና ለጤና ጎጂ የሆኑ ኬሜካሎች አላቸው፤እነዚህ ኬሚካሎች ሳይንሱን ተከትሎ መወገድ ያለባቸው ሲሆን ከዚህ ጋር ተያይዞ ያለህ/ሽ ግንዛቤ	☐ ከፍተኛ ☐ መካከለኛ ☐ አነስተኛ

1.2	ግልጋሎት ላይ የዋሉ የኤሌክትሪክ መሳሪያዎች ን መስሪያቤቱ የሚያስወግደው እንዴት ነው?	☐ ግምጃ ቤት ውስጥ ይቀመጣል ☐ የሚመለከተው የሚኒስቴር መስራቤት ያስወግዳል ☐ መረጃው የለኝም

1.3	ሀ) መስሪያ ቤቱ እየተከተለ ያለው ግልጋሎት ላይ የዋሉ የኤሌክትሮኒክስ መሳሪያዎች አወጋገድ በቂ ነው? ለ) ምን አይነት ማሻሺያዎች መደረግ አለበት	ሀ) ☐ አዎ ☐ አይደለም	ለ)

2.ግልጋሎት ላይ ያሉ በኤሌክትሪክ ሀይል የሚሰሩ መሳሪያዎች
በስራ ክፍሉ ውስጥ አገልግሎት የሚሰጡ መሳሪያዎች

ለስራው አስፈላጊ የሆኑ ማሳሪያዎች	
ኣይነት	#
ፐርሰናል ኮምፒውተር (PCs* central unit)	
ላፕቶፕ (Laptops*)	
ተንቀሳቃሽ ስልክ (Mobile phones*)	
የማይንቀሳቀሱ ስልኮች	

ፕሪንተር (Printers)		
ኮፒ ማሽን (Copy machines)		
እስካነር (Scanners)		
የፋክስ ማሽን (Fax machines)		

አይነት	#
ፍሎረሰንት (**Fluorescent tubes*)**	
ሀይል ቆጣቢ መብራቶች (Long life light bulbs (energy saving))	
ቻርጅ የሚደረጉ መብራቶች (Rechargeable lamps)	

4.የማጠቃለያ ጥያቄዎች		
4.1	ግልጋሎት ላይ የዋሉ የኤሌክትሪክ መሳሪያዎች ለጤና በማይጎዱ እና የአካባቢ አየር በማይበክል መልኩ ቢወገዱ፡፡በዚህ በተጨማሪ እነዚህ መሳሪያዎች ሳይንሳዊ ሂደቱን ተከትሎ በድጋሚ አገልግሎት እንዲሰጡ ቢደረግ መሳሪያዎቹን ያለ ክፍያ ለሚያስወግደው አካል መስጠት አለበት**?**	☐ አዎ ☐ አይደለም
4.2	መስሪያ ቤቱ አሁን እየተከተለ ካለው ግልጋሎት ላይ የዋሉ የኤሌክትሪክ መሳሪያዎች አወጋገድ ስርአት በተሻለ መልኩ ማስወገድ ይቻላል ? ከቻለ በምን መልኩ?	

Annex III: experimental results


1:05
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