FOR PARTICIPANTS ONLY
8 March 2010
ENGLISH ONLY

UNITED NATIONS
DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS
In collaboration with
United Nations Centre for Regional Development (UNCRD)
Ministry of the Environment, Government of Japan

International Consultative Meeting on Expanding Waste Management Services in Developing Countries

18-19 March 2010
Tokyo

EMERGING ISSUES, CHALLENGES, AND OPPORTUNITIES IN ENVIRONMENTALLY SOUND MANAGEMENT OF E-WASTE

(Plenary Session 1(d) of the Provisional Programme)

Final Draft

This background paper was prepared with inputs from Dr. Sunil Herat, Griffith School of Engineering, Griffith University, for the International Consultative Meeting on Expanding Waste Management Services in Developing Countries ahead of the eighteenth session of the Commission on Sustainable Development. The views expressed herein are those of the authors only and do not necessarily reflect the views of the United Nations.

Abstract

Electronic and electrical waste (e-waste) is one of the fastest growing waste streams in the world today. It is estimated that the world generates around 20-50 million tonnes of e-waste annually. Globally, the use of electrical and electronics goods is set to rise sharply in the next 10 years especially in China and India and in African and Latin American continents. Improper handling of e-waste can cause harm to the environment and human health due to its toxic components. Several countries around the world are now developing policies and regulations to deal with this emerging threat. Although the current emphasise is on end-of-life management of e-waste activities such as reuse, servicing, remanufacturing, recycling and disposal, upstream reduction of e-waste generation through green design and cleaner production is gaining much attention. Environmentally sound management (ESM) of e-waste in the developing world is absent or very limited in most of the countries. There are significant numbers of challenges faced by these countries to achieve ESM of e-waste. The aim of this paper to provide an overview of current status, emerging issues, challenges and opportunities for environmentally sound management of e-waste. The paper will address the following areas of e-waste management in the context of developing countries:

- *Overall trends in the generation of e-waste*
- *Problems associated with e-waste*
- *International policies, regulations, conventions and initiatives to deal with e-waste*
- *End-of-life management techniques for managing e-waste*
- *Upstream reduction of e-waste generation*
- *Specific challenges, issues and opportunities related ESM of e-waste in developing countries*
- *Case Studies of issues and best practice*

1 Introduction

Electronic waste or E-waste is one of the fastest growing solid waste streams around the world today. According to the studies conducted in the European Union, e-waste is growing at a rate of 3-5% per annum or approximately three times faster than other individual waste streams in the solid waste sector (Schwarzer *et al.* 2005). Rapid uptake of information technology around the world coupled with the advent of new design and technology at regular intervals in the electronic sector is causing the early obsolescence many electronic items used around the world today. For example the average lifespan of a new model computer has decreased from 4.5 years in 1992 to an estimated 2 years in 2005 and is further decreasing (Widmer *et al.* 2005). In the United States, where it is believed to produce the largest amounts of e-waste in the world, it is estimated that over 100 million computers, monitors and televisions become obsolete each year and that amount is growing each year (United States Government Accountability Office 2005). Studies have also revealed that around 500 million computers were estimated to become obsolete in the United States alone between 1997 and 2007 (Yu *et al.* 2006). In the European Union (EU) the total generation of e-waste in 2005 was estimated to be 9.3 million tonnes which included 40 million personal computers and 32 million televisions (United Nations University 2007). It is estimated that in China 5 million new computers and 10 million new televisions are purchased every year since 2003 (Hicks *et al.* 2005) and around 1.11 million tonnes e-waste is generated every year coming mainly from electrical and electronic manufacturing and production processes, end-of-life of household appliances and information technology products and import from other countries

(Xuefeng *et al.* 2006). In Japan it is estimated that that some 9000 tonnes of home-used computers are scrapped every year, equivalent to 460,000 units, and this is expected to double or triple in next few years (Shimizu 2003). In Canada it is estimated that 140,000 tonnes of waste electrical and electronic equipment accumulate in Canadian landfills each year (Feszty and J. Calder 2007) while in Korea during 2004 over 3 million computers and 15 million mobile phones reached their end of life (Hyunmyung and Yong-Chul 2006).

The same scenario applies to mobile phones and other hand held electronic items used in the present society. Each year over 130 million mobile phones in the United States and over 105 million mobile phones in Europe reach their end-of-life and are thrown away (Canning 2006). As a result used Electronic and Electrical Equipment (EEE), commonly known as e-waste, have become a serious social problem and an environmental threat to many countries worldwide. United Nations estimate that collectively the world generates 20 to 50 million tonnes of e-waste every year (Schwarzer *et al.* 2005).

A latest report released by the United Nations (Schluep et al, 2009) predicts that by 2020 e-waste from old computers in South Africa and China will have jumped by 200-400% and by 500% in India from 2007 levels. It also states that by 2020 e-waste from discarded mobile phones will be about 7 times higher than 2007 in China and 18 higher in India. The report also cites that in the United States more than 150 million mobiles and pagers were sold in 2008, up from 90 million five years before and globally more than 1 billion mobile phones were sold in 2007, up from 896 million in 2006. The UN report also estimates that countries like Senegal and Uganda can expect e-waste flows from Personal computers alone to increase 4 to 8-fold by 2020.

There are growing concerns that most of the e-waste generated in developed countries is ending up in developing countries that are economically challenged and lack the infrastructure for ESM of e-waste resulting in adverse socio-economic, public health and environmental impact of toxics in e-waste.

The paper will address the following areas of e-waste management in the context of developing countries:

- Overall trends in the generation of e-waste
- Problems associated with e-waste
- International policies, regulations, conventions and initiatives to deal with e-waste
- End-of-life management techniques for managing e-waste
- Upstream reduction of e-waste generation
- Specific challenges, issues and opportunities related ESM of e-waste in developing countries
- Case Studies of best practice

This background paper would serve as a useful reference material to stimulate national governments, public waste utilities, city managers, private service providers, corporate sectors and various other important stakeholders to address sustainable management of e-waste and in the formulation and implementation of relevant and cost-effective waste management policies, programmes, institutions, partnerships (PPPs), and required social and physical infrastructures.

2 Problems Associated with E-waste

Problems associated with e-waste are becoming well known in the scientific literature. In general electrical and electronic equipment (EEE) is a complicated assembly of significant number of different materials, many of which are highly toxic. For example, the production of semiconductors, printed circuit boards, disk drives and monitors used in computer manufacture utilises many hazardous chemicals. Computer Central Processing Unit (CPU) contains heavy metals such as cadmium, lead and mercury. Printed Circuit Boards (PCB) contain heavy metals such as antimony, silver, chromium, zinc, lead, tin and copper. In EEE lead (Pb) is mainly used in cathode ray tubes (CRTs) in monitors, tin-lead solders, cabling, printed circuit boards and fluorescent tubes. The most significant use from the above list is the amount lead used in the manufacture of CRTs to shield the user from radiation. The main components of a CRT – the funnel, neck and the frit- contain between 0.4 kg and 3 kg of lead per monitor (Herat 2008d). Next to the CRTs, second largest source of lead in EEE can be found in tin-lead solders used to connect many components together. Lead is used in tin-lead solders (typically 60% tin and 40% lead) due to its good conductivity, high corrosion resistance and high melting point which are all essential factors for a sound connection between the components (Five Winds International 2001; Herat 2008b). Lead can affect almost every organ in the body including the nervous system, kidneys and reproductive system (ATSDR 2005).

Hexavalent chromium has applications in electronic industry as anticorrosive coatings on metals, primers for coated metals and hard chrome. The compounds of chromium such as calcium chromate, chromium trioxide and lead chromate are well known human carcinogens. Cadmium is classified as toxic with a possible risk of irreversible effects on human health. Like lead, cadmium can accumulate in the body over time causing long term damage to human parts. In e-waste cadmium occurs in certain components such as chip resistors, infrared detectors and semi conductors. Copper is used within printed wire boards to provide electrical connections to various layers in the boards. Copper has significant environmental problems during its whole life cycle from extraction to end-of-life disposal (Brigden *et al.* 2005).

The environmental and health impacts of e-waste recycling in the developing world are well documented in scientific literature. A study conducted in soil, air dust and human hair collected from an e-waste recycling site in Bangalore, India clearly found increased concentrations of the trace elements such as lead, zinc, silver, cadmium and copper compared to reference sites (Ha *et al.* 2009). A further study in China on human scalp hair to assess the extent of heavy metal exposure to workers and residents in areas with significantly high e-waste recycling operations found higher levels of cadmium, copper and lead confirming the previous findings (Wang *et al.*) A toxicity study of sediments collected from two rivers in Guiyu, China where significant amount of informal e-waste recycling is taking place showed that most sediments exhibited acute toxicity due to elevated levels of heavy metals and other chemicals and low pH caused by uncontrolled acid discharges (Wang *et al.*). Furthermore, a study of heavy metals (copper, cadmium, lead, zinc, arsenic, mercury) and persistent organic compounds including polycyclic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) conducted in Wenling, an emerging e-waste recycling facility in Taizhou area, China found high levels of the above compared to reference sites (Tang *et al.*)).

E-waste also contains brominated flame retardants (BFRs) such as polybrominated biphenyls (PBB) and polybrominated diphenylethers (PBDEs) which are used in printed circuit boards, connectors, covers and cables. There is growing body of literature suggesting that BFRs have negative environmental and health effects hence be limited or replaced altogether (Barontini and Cozzani 2006; Birnbaum and Staskal 2004; Herat 2008a). Exposure of PBDEs to personnel working in e-waste recycling facilities and people in surrounding areas has been studied by researchers worldwide (Cai and Jiang 2006; Jakobsson *et al.* 2002; Julander *et al.* 2005; Leung *et al.* 2006; Leung *et al.* 2007; Pettersson-Julander *et al.* 2004; Sjodin *et al.* 2001, (Tue *et al.*), (Han *et al.* 2009), (Wang *et al.* 2009) and (Liu *et al.* 2009).

3 International Policies, Regulations, Conventions and Initiatives related to E-waste

3.1 *Waste Electrical and Electronic Equipment (WEEE) Directive*

The aim of the WEEE Directive is to minimise the impact of electrical and electronic goods on the environment, by increasing re-use and recycling and reducing the amount of WEEE going to landfill. To achieve this producers are made responsible for financing the collection, treatment, and recovery of waste electrical equipment, and the distributors obliged to allow consumers to return their waste equipment free of charge. The directive was agreed by European Parliament on 13 February 2003, transposed into Member State legislation by 13 August 2004 and came into force by 13 August 2005 (European Union 2003b).

The main areas covered by the directive include product design, separate collection, treatment, recovery financing, information and transposition. The specific requirements of the directive include the following:

- Effective from 13 August 2005, WEEE must be collected separately from unsorted municipal waste. To achieve this producers are required to set up convenient public collection points so that private households are able to return their WEEE free of charge. The directive also requires that by 31 December 2006, above collection points much achieve a collection rate of at least 4 kg of WEEE per person per year.

- The directive makes the producers responsible for the costs of collection, treatment, recovery and disposal of their own products. The producers are also required to cover the above costs for products put on market prior to 13 August 2005 in proportion to their current market share by type of equipment.

The global impact of the WEEE Directive is very significant as this applies to worldwide producers and distributors who export EEE to the EU. These companies are concerned about additional costs that could incur due to lack of clarity and late implementation of the Directive in many EU countries. Furthermore, the member countries could adopt legislation that goes beyond restrictions and obligations provided by the EU legislation hence the harmonisation of the law among the EU member countries cannot be guaranteed, possibly adding to costs to non-EU manufacturers.

3.2 *Restriction of Hazardous Substances (RoHS) Directive*

The Restriction of Hazardous Substances (RoHS) Directive was created by the European Parliament in 2003 recognising the fact that not all hazardous substances in WEEE can be recycled or disposed of in an environmentally sound manner, thus imposing a ban on the use of certain substances in electrical and electronic equipment. The RoHS directive came into effect on 1 July 2006 and applies to new electrical and electronic equipment put on the European market on or after July 1st. It names six substances of immediate concern: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and ploybrominated diphenyl ethers (PBDE). The Directive has provisions for adaptation to scientific and technical progress such as establishing, as necessary, maximum concentration values, Exempting materials and components of electrical and electronic equipment and carrying out a review of each exemption at least every 4 years (European Union 2003a).

The maximum concentration values for RoHS substances were established in an amendment to the Directive on 18 August 2005. The maximum tolerated value for lead, mercury, hexavalent chromium, PBB and PBDE is 0.1% by weight in homogenous materials and 0.01% by weight in homogenous materials for cadmium (European Union 2005b).

RoHS has the same coverage of EEE as the WEEE Directive, with the exception of medical, monitoring and control equipment and number of specific exemptions declared as Annexes to the Directive. The amendments to the Directive to exempt these materials were made twice in October 2005 (European Union 2005a; c), once in April 2006 (European Union 2006d) and thrice in October 2006 (European Union 2006a; b; c), totalling the number of exemptions to twenty nine.

The global impact of WEEE and RoHS Directives is enormous with companies having to make significant investments to find substitutes for banned materials. The problem for most of these companies is that EU might make further exemptions for substances for which no substitutes exist, negating the effect of RoHS. The EU's RoHS has also driven authorities in other countries, especially the Asian sector (e.g. China and Korea), to develop their own version of the WEEE and RoHS as they are the largest exporters of EEE to EU.

The WEEE Directive has also attracted some criticisms from the stakeholders. (Huisman *et al.* 2006), for example, question that in the process of setting up the WEEE whether appropriate consideration was given to the environmental goals. They argue that WEEE Directive places heavy emphasise on weight based recovery of WEEE, thus making plastic for example the first priority whereas the focus should be to avoid the loss of precious metal values.

3.3 *EU Directive on Energy-using-Products (EuP)*

On 6 July 2005, the European Parliament issued a Directive on establishing a framework for introducing ecodesign requirements for energy-using-products (European Union 2005d). The initial focus of the Directive is on products having high potential for a cost-effective greenhouse gas reduction such as consumer electronics, electric motor systems, water heaters, office equipment and lighting. The Directive provides legislative criteria and framework for life cycle ecodesign practices and declaration of conformity by the manufacturers.

3.4 *EU Directive on Registration, Evaluation and Authorisation of Chemicals (REACH)*

On 30 December 2006, the European Parliament issued the Directive on Registration, Evaluation and Authorisation of Chemicals (REACH) which was published in 849 pages of the Official Journal of the European Union (European Union 2006e). Its purposes include establishing a comprehensive database of chemical substances in the European Community, motivate manufacturers to seek cost-effective and safer alternatives to hazardous substances, shifting the testing and risk evaluation from regulatory authorities to the manufacturer, establishing graduated requirements for testing and risk evaluation and establishing a mechanism for controlling or restricting the use of hazardous substances. The regulation came into force on 1 June 2007.

3.5 E-waste Regulations in Japan

Japanese government has formulated several laws to promote waste recycling within Japan. In 2000, Japanese government passed the ‘Basic Act for Establishing a Sound Material-Cycle Society’ which sets basic principles for national government for establishing a sound material-cycle society. This law also declares the adoption of ‘extended producer responsibility’. The ‘Law for the Promotion of Effective Utilisation of Resources’ which was enacted in 1991 and amended in 2002 provides recycling requirements for wide ranging products. In addition Japanese government has recently passed several laws targeting recycling in specific industries such as packaging, home appliances, construction, food and end of life vehicles.

The Home Appliance Recycling Law (HARL) was enacted in 1998 and came in to effect in April 2001. It requires manufacturers and importers to collect and recycle products such as air conditioners, refrigerators, televisions and washing machines with obligation to finance the recycling of their own products.

The HARL imposes an ‘old for new’ requirement where Japanese retailers are required take back from the consumer the used product every time a sell a new product. The law also permits manufacturers to contract a trade group such as the Association for Electric Home Appliances (AEHA) to collect items on their behalf or use the services provided by the local government. The collection establishment is then required to transport the collected material to consolidation centres operated by two manufacturer consortia comprising of major manufacturing companies. Each consortium operates several consolidation centres and recycling facilities around Japan. Instead of front-end financing of the recycling costs, the HARL depends upon end-of-life fees paid by the consumers to finance the collection, transport and recycling operational costs. The consumers are required to pay a collection fee when they drop off their used product.

Japan’s Law for the Promotion of Effective Utilisation of Resources which was enacted in 1991 was revised in 2001 to accommodate personal computers. According to (INFORM 2004), it is estimated that 51% of households in Japan own personal computers amounting to total of 24 million units with several of these being discarded each year. To address this issue the law requires that as of April 2001 for businesses to recycle all their discarded PCs while as of October 2003 it requires recycling of PCs discarded by the households. The Japanese Electronics and Information Technology Association (JEITA) has taken role of implementing the legislation by operating the recycling program for PCs on behalf of manufacturers. JEITA estimates that some 9000 tonnes of home-used computers are scrapped every year, equivalent to 460,000 units, and this is expected to double or triple in next few years (Shimizu 2003).

The revised law states two different financial structures for used PCs. For PCs purchased prior to October 1, 2003, the recycling is financed by an end-of-life fee ranging from $27 to $37 whereas for PCs bought after this date, the recycling costs are included in the price of the product, effectively a front end fee. To operate the system the Japan Post acts on behalf of JEITA where collection of discarded PCs take place at 20,000 post offices nationwide. PCs purchased after October 1, 2003 are collected free of charge by Japan Post (INFORM 2004).

An amendment to the Law for the Promotion of Effective Utilisation of Resources took place on 1 July 2006 when the Japanese version of the RoHS (also known as J-Moss or JIS C 0950) was introduced. This amendment mandates that manufacturers provide material content declarations for certain categories of electronic products from sold after 1 July 2006. Manufacturers and importers are required to label their products and provide information on the six EU RoHS substances: lead, mercury, chromium VI, cadmium, PBB and PBDE. Apart from manufacturers, importers of the items listed above must meet the Design for Environment (DfE) criteria, which are required for domestic manufacturers. The Japan RoHS does not ban products containing restricted substances.

3.6 E-waste Regulations in China

China is considered to be one of the fastest growing economies in the world the largest exporter of information and communication technology products to the world surpassing Japan, European Union and United States. It is also estimated that total amount of e-waste generated in China is around 1.11 million tonnes per year mainly coming from EEE manufacturing and production processes, end-of-life of household appliances and information technology products and import from other countries (Xuefeng *et al.* 2006). China has become a key player in the global e-waste recycling system by employing over 0.7 million people in 2007 of which 98% in the informal recycling sector (Jinglei *et al.* 2009).

The environmental and health impacts of e-waste generated in China and also imported other countries are becoming well known in the general media and scientific literature. One of the first studies to document the environmental and health impacts of improper management of e-waste in China was conducted by the Silicon Valley

Toxics Coalition (SVTC) and the Basel Action Network (BAN) published in 2002 through a now well known document ‘Exporting Harm: The High-Tech Trashing of Asia’. This report asserts that 50 to 80 % of e-waste collected for recycling in the United States is exported to developing nations. BAN produced a film on the report which shows the Guiyu village in Guangdong province in China as ‘electronics junkyard’. The findings include 100,000 men, women and children making $1.50 a day to dismantle e-waste by bare hands to retrieve the valuable metals and materials, circuit boards being melted over coal grills to release valuable metals giving highly toxic dioxin fumes, riverbank acid baths used to extract gold and toner cartridges pulled apart manually sending clouds of toner dust into the air. Soil and drinking water at Guiyu are contaminated by lead much above WHO limits- soil by 200 times and water by 2,400 times. (Puckett *et al.* 2002).

Since the publication of SVTC/BAN report in 2002, several studies have been conducted in the area to investigate the health and environmental impacts of unsustainable recycling practices. The town of Guiyu located in the Chaoyang District Southeast of China has been the centre of attention to most of these studies. (Yu *et al.* 2006) studied the concentration, distribution, profile and possible sources of polycyclic aromatic hydrocarbons (PAHs) in soils in this area. They found very high concentrations (2065 µg per kg) of PAH in soils near burning sites suggesting soil in Guiyu may be affected by the primitive e-waste recycling activities around the area. A similar study was conducted by (Deng *et al.* 2006) to study the PAH levels and heavy metals in total suspended particles with aerodynamic diameter smaller than 2.5 µm ($PM_{2.5}$) found 2-6 times higher PAH concentrations and 4-33 times higher chromium, copper and zinc concentrations than other Asian countries further confirming that high concentrations of PAHs and heavy metals in air in Guiyu could pose a serious environmental and health concerns. A study conducted by (Wong *et al.* 2007) of the sediment samples taken of Lianjiang and Nanyang rivers, both flowing past Guiyu, found contaminated cadmium (up to 10.3 mg/kg), copper (17.0-4540 mg/kg), nickel (12.4-543 mg/kg), lead (28.6-590 mg/kg) and zinc (51.3-324 mg/kg) indicating significant high levels compared to uncontaminated sediments. As a result of these studies there is strong evidence that atmospheric air, soil and water in Guiyu area are all contaminated with chemical and metals due to e-waste recycling operations. A more general study by (Wang and Guo 2006) on surface water, ground water and sediment samples in Guiyu area confirmed these findings.

China’s problem with e-waste has come about mainly due to recycling operations conducted by labour intensive small and informal business sectors which lack the capacity to handle such wastes in a proper manner. The application of primitive technology to recover only the valuable metals while disposing other heavy mentals and toxic chemicals and low awareness of health and environmental aspects have all led to deterioration of the problem. Unfortunately the current legal framework in China lacks a clear prescription to manage the e-waste stream. At present governments at different level are paying attention to the problems caused by e-waste. However, there are still problems caused by inadequate measures, In order to legalize the management of waste electrical and electronic products and promote the comprehensive utilization of resources and development of circular economy as well as protecting environment, on March 5, 2009 the State Council adopted and promulgated the " *The Regulation on the Administration of the Recovery and Disposal* *of Waste Electrical and Electronic Products*", namely China WEEE. The regulations will come into effect in January 2011 (Streicher-Porte and Geering).

3.7 E-waste Regulations in India

In India e-waste is a major issue due to the generation of domestic e-waste as well as imports from developed countries. India's electronic industry is one of the fastest growing industries in the world. It is estimated that per capita ownership of personal computers grew by 604% during the period 1993 – 2000 compared to the world average of 181% increase during this period (Dwivedy and Mittal). Studies have estimated that total annual e-waste generation in India is between 1,46,000 – 3,30,000 tonnes and is expected to reach 4,70,000 tonnes by year 2011(Pinto, 2008). Formal WEEE recycling sector in India is currently being developed in major cities. However, informal recycling operations have been in place for a long time in India with over 1 million poor people in India being involved in the manual recycling operations (Pinto, 2008). Most of these people have very low literacy levels with little awareness of dangers of the operations. One of the well known activist groups (Toxics Link) in India with a mission for environmental justice and freedom from toxics has conducted number of assessments and published several reports urging the authorities to combat the e-waste issue in India (www.toxicslink.org).

India currently has no official regulatory framework to manage the e-waste problem at national levels although it has some of the world's most developed high-tech software and hardware facilities. The Central Pollution Control Board has developed guidelines for environmentally sound management of e-waste in India. This can be accessed via their website (http://www.cpcb.nic.in/e_Waste.php). The government has also taken some steps to deal with the issue of old EEE being imported to India. The Department of Information Technology under the Ministry of Communications & Information Technology has developed policies prohibiting the import of second hand computers including personal computers and laptops. However, such items can be imported freely as donations by certain category of donees provided they are not used for commercial purposes (www.mit.gov.in).

3.8 E-waste Regulations in Korea

Korea is among the largest exporters of electronics and information technology products in the world. In 2005, over 30% of Korea's manufactured exports consisted of high technology items such as televisions, mobile phones and refrigerators. It was also estimated that in 2003 over 25 million computers were being used in Korea with 60% of the population having access to the Internet and in 2004 over 3 million computers and 15 million mobile phones reached their end of life (Hyunmyung and Yong-Chul 2006).

Korea's regulations related to e-waste dates back to 1992 where, based on the waste control act, the waste deposit–refund system was introduced. In this system a deposit is imposed at a constant rate on products and packages that are readily recyclable. By 1997 televisions, washing machines, air conditioners and refrigerators were included in the system. Then in 2003 extended producer responsibility was introduced to these items to hold producers accountable for the entire life cycle of their products. Initially televisions, refrigerators, washing machines, air conditioners and computers were selected as primary targets followed by audio equipment and mobile phones in 2005 and fax machines and printers in 2006 (Lee *et al.* 2007). On 2 April 2007, On April 2, Korea's National Assembly passed the 'Act Concerning the Resource Recycling of Electrical/Electronic Products and Automobiles' which has similarities to EU's RoHS, WEE and ELV (End of Life Vehicles) Directives but also containing items specific to Korea. Also known as Korea's RoHS this regulation came into force on January 1, 2008 (Jun-sik Yun and Park 2007).

3.9 E-waste Regulations in Canada

The management of e-waste is rapidly growing public policy issue in Canada. It is estimated that 140,000 tonnes of EEE accumulate in Canadian landfills each year (Feszty and J. Calder 2007). To address the issue Canadian Council of Ministers of the Environment (CCME) endorsed the 'Canada-wide principles for electronic product stewardship' in 2004 (Canadian Council of Ministers of the Environment 2004).

Several leading information technology and electronic companies have joined together form a non-profit organisation called 'Electronics Product Stewardship Canada (EPSC)'. Its mission is to design, promote, and implement sustainable solutions to Canada's e-waste problem. The legislative authority to deal with e-waste in Canada lies with the provinces and territories. Alberta was Canada's first province to implement its own e-waste recycling program. The Alberta Recycling Management Authority manages the scheme and collects fees from retailers, wholesalers, distributors and manufacturers. Several collection points and drop-off locations have been established under this program with no cost to consumers at the time of disposal. The Advance Disposal Surcharge (ADS) has been collected at the retail level since February 2005.

Canada's first industry-led electronics stewardship program, 'Saskatchewan Waste Electronic Equipment Program (SWEEP)' , was launched on February 1, 2007 in Saskatchewan which became the first province in Canada to have an industry-led stewardship program for environmentally responsible recycling of e-waste The scheme was created by the consumer electronics and information technology industries and operates through a comprehensive network of depots across the province accepting selected electronics for recycling. The system is funded by an Advance Recycling Fee (ARF). As of August 1, 2007 consumers and businesses in the province of British Columbia will be able to drop off their e-waste at no charge. Introduced by the Electronics Stewardship Association of British Columbia (ESABC) and managed by Encorp Pacific, an environmental handling fee (EHF) will be levied on the sale of new products in the designated categories to fund the program. Several EU type WEEE management schemes are being rolled out in other provinces to address the mounting problem of e-waste in Canada.

3.10 E-waste Regulations in the United States

It is widely known that the United States (US) is one of the largest producers of e-waste in the world. According one estimate in year 2000, US generated 2.2 million tonnes on e-waste which included 859,000 tonnes of video products, 348,000 tonnes of audio products and 917.000 tonnes of information technology products (Gibson and Tierney 2006). The US Government Accountability Office (GAO) reports that over 100 million computers, monitors and televisions become obsolete in the US each year and that number is growing. It also refers to a National Safety Council forecast that in 2003 about 70 million computers became obsolete of which only 7 million were recycled and an International Association of Electronics Recyclers (IAER) report that estimated about 20 million televisions become obsolete each year, a number that is expected to grow significantly as cathode ray tube (CRT) technology is rapidly replaced by plasma technology. The GAO report also refers to US Environmental Protection Agency (US EPA) data which indicate that less than 4 million computer monitors and 8 million televisions are disposed of in landfills each year and only 19 million computers were recycled in 2005 (United States Government Accountability Office 2005).

Concerns were raised in 2002 by the environmental groups estimating that between 50 to 80% of the e-waste collected in the US for recycling are nor recycled domestically but exported to developing countries such a China and India (Puckett *et al.* 2002). Although it appears that the situation has improved since 2002, GAO argues that there is still a lack of economic incentives to promote recycling and re-use of electronic equipment in the United States which is also compounded by the absence of federal regulations that either encourage recycling or avoid their disposal in landfills (United States Government Accountability Office 2005). It further argues that current federal laws allow hazardous used electronics to be disposed in landfills, do not provide a financing system to support recycling and do not preclude e-waste being exported to developing countries. Furthermore, e-waste recycling facilities in the US are finding it difficult to obtain enough inputs for their operations due to the economics of external disposal.

In the absence of Federal legislation, the individual States have begun to address the issue by developing and adopting their own e-waste legislation covering areas such as e-waste landfill disposal bans and comprehensive recycling legislation. As of April 2007, at least seven States (Arkansas, California, Maine, Massachusetts, Minnesota, New Hampshire and Rhode Island) have banned the landfill disposal of various types of electronic waste and four States (California, Maine, Maryland and Washington) have passed comprehensive recycling legislation. While California has adopted an advanced recycling fee system the other three States have settled for an extended producer responsibility systems. Furthermore, at least 16 States and New York City proposed recycling legislation in 2007 to adopt either an advanced recovery fee or an extended producer responsibility scheme (Solmer and Stoll 2007).

California was the first State to introduce e-waste recycling laws in the United States in January 2005 when it introduced an advanced recovery fee on all new televisions and computers sold within the State. Implementing the California Electronic Waste Recycling Act of 2003 (SB20), a fee ranging from \$6 to \$10 depending on the size of the device and is used to reimburse non-profit and commercial recyclers at a rate of 48 cents per pound. The recyclers in turn reimburse the e-waste collectors at a rate of 20 cents per pound giving them an incentive to provide a free service to the community (Hileman 2006). The California’s Electronic Waste Recycling Act also has a mandate to reduce the use of hazardous substances in electronic products sold within the State. Accordingly California RoHS (SB50) came into effect on 1 January 2007.

Although the United States Federal government has not implemented legislation for a national e-waste recycling system, it has initiated number of programs to encourage the recycling and re-use of used electronic equipment. Such programs include the National Electronics Product Stewardship Initiative (NEPSI), EPA eCycling Pilot, Best Buy Pilot, Electronic Product Environmental Assessment Tool (EPEAT), Federal Electronics Challenge, The Green Supply Network and the Design for Environment Program. The complete details of these programs and several other government/industry programs can be found in (Daly 2006).

One of the most recent developments in e-waste in the United States is the framework released by the Electronics Industries Alliance (EIA) on 25 May 2007 which paves the way for Federal legislation establishing a national program for recycling household televisions and information technology products like computers and computer monitors. It proposes a two-part financing approach, separating televisions from desktop computers, laptops and computer monitors to reflect their divergent business models, market composition and consumer base (Electronic Industries Alliance 2007).

3.11 E-waste Regulations in Australia

The Australian Government recently reported that in 2007/08, 31.7 million new televisions, computers and computed products were sold in Australia. Also during this period 16.8 million units of this equipment reached their end of life with 88% of them sent to landfill and only 9% recycled. Also the Government estimates that number of televisions, computers and computer products reaching their end of life is expected to grow to 44 million by 2027/28. Australian state and federal governments are currently working together to impose regulations directed towards extended producer responsibility upon computer manufacturers and retailers with a view to managing this huge and growing waste stream. In Australia the Environmental Protection Heritage Council (EPHC) is charged with the responsibility of dealing with environmental impacts of various businesses in Australia. EPHC is a council made up of all Australian environment ministers and powered with responsibility of environment and heritage protection in Australia and New Zealand (Environmental Protection Heritage Council 2007).

Co-regulation for product stewardship is a process where some form of government regulatory intervention is used in conjunction with specific industry product stewardship schemes. In December 2004 EPHC released an industry discussion paper on ‘Co-regulatory Frameworks for Product Stewardship’ (Environment Protection and Heritage Council 2004) where the framework for co-regulation of a particular sector was described as made up of two main parts; a voluntary product stewardship agreement negotiated and signed by the industry or the industry association through EPHC and a regulatory safety net comprising laws that would be implemented through the government.

Negotiations with the government (through EPHC) and the industry (through Australian Information Industry Association) to formulate a sustainable solution to the e-waste problem has taken place since 2004 but with limited success. In October 2005 national environment ministers, through EPHC, concluded that co-regulatory approaches proposed so far may not be suitable for computers and requested the officials to look at other options, including the regulatory options. In June 2006 Australian environment ministers directed their officials to report on regulatory options for product stewardship for computers by November 2006 taking into account this area presents significant challenges given the structure of the industry. At its meeting in Christchurch, New Zealand in November 2006, EPHC applauded Australian computer industry's efforts to develop a voluntary national computer recycling scheme. However, as the scheme has failed to engage with small importers and component distributors, EPHC recommended that introduction of a government-imposed regulatory national scheme for recycling be developed and introduced in 2007.

Australia is still to adopt a national framework for dealing with e-waste. Australian state and Federal Governments are currently working together to impose regulations directed towards extended producer responsibility upon computer and television manufacturers and retailers with a view to managing this huge and growing waste stream. After a long period of consultation with key stakeholders, the Australian Government through the Environment Protection and Heritage Council (EPHC) has put out a Consultation Regulatory Impact Statement for end of life televisions and computers and invited the public to comment. The purpose of this document is to examine the impacts of implementing consistent national arrangements for end of life televisions and computers and to consult the community and key stakeholders on these impacts. The document which is available at EPHC website (http://ephc.gov.au/taxonomy/term/51) provides an excellent analysis of various scenarios of regulatory instruments and their impacts.

On 5 November 2009 the Australian Government formally endorsed a new National Waste Policy charting a ten-year vision for resource recovery and waste management. As part of this policy the government announced a new national television and computer recycling scheme which will develop and implement requirements under the National Product Stewardship Framework to ensure that manufacturers and importers of televisions and computers establish an efficient and effective national schemes for collecting and recycling their end of life products. Under the proposed scheme, the manufacturers and importers will be responsible for recycling all products they sell in Australia. The regulatory support will ensure industry non-participants comply with the same standards as voluntary industry participants. It is expected that scheme will be up and running in or before 2011.

3.12 Basel Convention

Officially known as the 'Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal', the Basel Convention is the most comprehensive global environmental agreement on hazardous wastes ever developed (www.basel.int). Its main aim is to protect the human health and the environment from adverse impacts resulting from the generation, management, transboundary movements and disposal of hazardous and toxic wastes. It entered into force on 5 May 1992 in accordance with article 25(1) of the Convention. As at March 2009 there are 172 parties to the Convention. At its second meeting of the governing body, the Conference of the Parties (COP – 2) in March 1994, Parties agreed to an immediate ban on the export from OECD to non-OECD countries of hazardous wastes intended for final disposal. They also agreed to ban, by 31 December 1997, the export of wastes intended for recovery and recycling. During COP-3 in 1995, it was proposed that the ban be formally incorporated in the Basel Convention as an amendment, now referred to as 'Basel Ban Amendment'. As at April 2007, number of United Nations members who are Party to the Amendment stood at 63 (United Nations 2007). The Ban Amendment is still not in force as it needs to be ratified by three-fourths of the Parties who accepted it in order to enter into force.

The Basel Convention's Conference of the Parties (COP) has made several decisions to achieve environmentally sound management of electrical and electronic waste. Commencing from its 6th meeting (COP6) in December 2002 where it identified electronic wastes as a priority waste stream in the strategic plan for the implementation of the Basel Convention to 2010. In 2006 Basel Convention's 8th meeting of the Conference of the Parties (COP8) was held in Nairobi on the theme 'Creating innovative solutions through Basel Convention for the environmentally sound management of electronic wastes'. During this meeting ministers, executive officers, civil-society representatives and other relevant participants from around the world participated in a high level world forum on e-wastes. As a result, the 'Nairobi declaration on the Environmentally Sound Management of Electrical and Electronic Waste' was adopted by COP8 as decision VIII/2. The details of this declaration are found in Annexes I and II of (UNEP 2007a) and Annex IV of (UNEP 2007b). Basel Convention has conducted number of workshops on environmentally sound management of e-waste in the Asia Pacific region. Under the Basel Convention Partnership program, Japan and Vietnam hosted the latest training workshop in Vietnam in 2009 with two Basel Convention Regional Centers (BCRCs).

One of the obstacles for adopting the Basel Convention for used EEE is the use of common Harmonised System (HS) Code for both new and old EEE. This is being currently addressed by the World Customs Organisation (WCO). Japan has already developed different HS Codes for number of used EEEs and has been applied since January 2008 (Yoshida and Kojima, 2008).

The Basel Convention has developed three important initiatives to encourage private sector participation in ESM of e-waste. Launched in 2002 the 'Mobile Phone Partnership Initiative' (MPPI) has overall objectives for better product stewardship, changing consumer behaviour, promoting best reuse, refurbishing, material recovery, recycling and disposal options and mobilising political and institutional support for environmentally sound management. A guidance document on the environmentally sound management of used and end-of-life mobile phone was adopted by the 8th Conference of the Parties (http://www.basel.int/industry/mppi.html).

In 2005 Basel Convention with the support from the Japanese Government launched the Basel Convention Partnership on the Environmentally Sound Management of Electrical and Electronic Wastes for Asia Pacific Region (http://www.ntn.org.au/cchandbook/library/documents/leaflet%20asia%20ewaste.pdf). Its objectives include assessment of the current situation, prevention and minimisation of e-waste ending up in the landfills, introduction of cleaner production approaches to minimise the generation of e-waste and environmentally sound management by promoting best practices.

Most recently the Partnership for Action on Computing Equipment (PACE) was adopted in June 2008. The main objective of the PACE is to provide new and innovative approaches for addressing emerging issues on used and end of life computing equipment (http://www.basel.int/industry/compartnership/index.html).

3.13 Other International Treaties related to E-waste

The Basel Convention Partnership on the Environmentally Sound Management of E-waste in Asia Pacific Region was launched in 2005 by the secretariat of the Basel Convention with funding from the Government of Japan. Its goal is to enhance the capacity of Parties to manage e-waste in an environmentally sound manner through the building up of public-private partnerships and by preventing illegal traffic.

To address the issue of transboundary movement of e-waste, the Government of Japan in 2003 proposed the development of the 'Asian Network for Prevention of Illegal Transboundary Movement of Hazardous Wastes'. The network aims at facilitating the exchange and dissemination of information on transboundary movements of hazardous wastes and selected used products among the North-East and South-East Asian countries and assists in formulating appropriate legislative responses (http://www.env.go.jp/en/recycle/asian_net/).

The 'Solving the E-Waste Problem (StEP)' initiative, officially launched on 7 March 2007, aims to standardise the global e-waste recycling processes to harvest valuable components of WEEE, extend the life of products and markets for their re-use and to harmonise world legislative and policy approaches to e-waste management (http://www.step-initiative.org). The initiative is a new global public-private partnership with the participation of major high-tech manufacturers, governmental organisations, academic and research institutions and non-governmental organisations (United Nations University 2007).

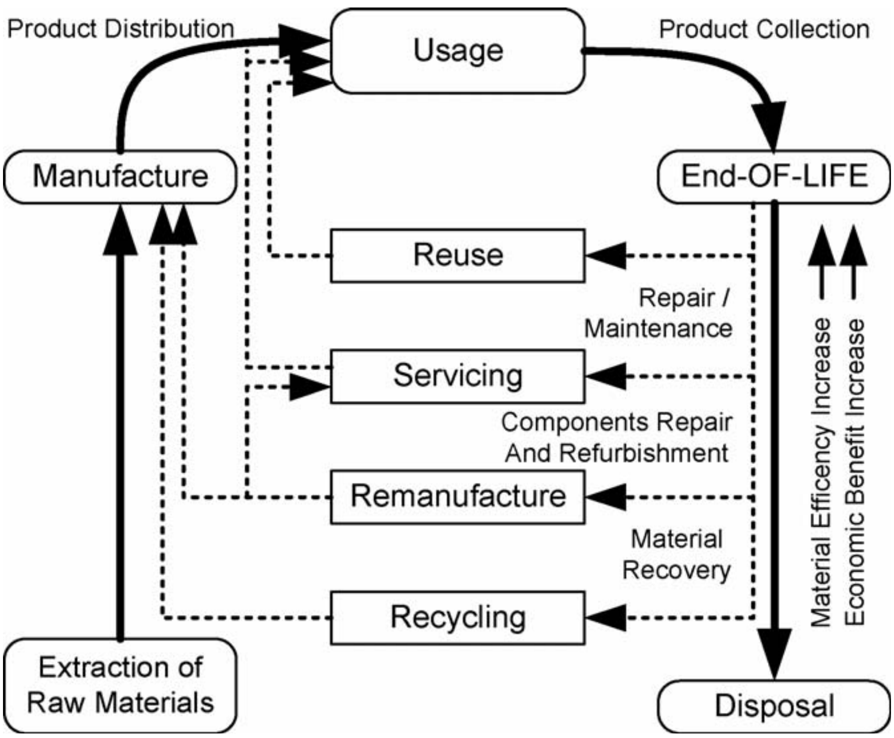
UNEP's Division of Technology, Industry and Economics (DTIE) has worked closely with the Information and Communication Technology (ICT) sector through the Global e-Sustainability Initiative (GeSI) since 2001 (http://www.gesi.org). One of the important outputs of GeSI is the tool referred to as E-TASC (Electronics – Tool for Accountable Supply Chains) which is a web based system for ICT companies to manage corporate responsibility throughout their supply chains. UNEP DTIE has also published two useful E-waste Manuals which are available at http://www.unep.or.jp/ietc/SPC/Publications.asp.

The G8 3Rs Initiative (Reduce, Reuse and Recycle) was introduced by Japan during the G8 (group of eight major industrial nations consisting of Japan, Russia, UK, France, Italy, Germany, USA and Canada) Summit in June 2004. During the Asia 3Rs Conference held in Tokyo during November 2006 where 20 Asian countries, six G8 countries and eight international organisations participated, progress and issues related to environmentally sound management of e-waste in the Asian region were discussed and delegates from Asian countries and experts made presentations on case studies of E-waste management. The Regional 3R Forum in Asia established in 2009 by the joint effort of the United Nations Centre for Regional Development (UNCRD) and the Ministry of the Environment, Government of Japan (http://www.env.go.jp/recycle/3r/en/index.html) aims to enhance current activities on e-waste in the region and focus on 3R especially the reduction of e-waste.

4 End-of-Life Management of E-waste

Given its environmental problems and high residual value, any management system related WEEE should consider extending the life cycle of EEE. This management system comprises end-of-life treatment strategies. In accordance with the potential economic and environmental efficiency, following are the strategies categorized by He et al (2006):

- **Reuse:** the recovery and trade of used products or their components as originally designed;
- **Servicing:** a strategy aimed at extending the usage stage of a product by repair or maintenance;
- **Remanufacturing:** the process of removing specific parts of the waste product for further reuse in new products;
- **Recycling:** Recycling can be done with or without disassembly, including the treatment, recovery, and reprocessing of materials contained in the used products or components in order to replace the virgin materials in the production of new goods;
- **Disposal:** the processes of incineration with or without energy recovery or landfill. Following Figure shows the lifecycle of EE equipments.



Lifecycle of EEE (He et al., 2006).

4.1 Reuse

According to EU (2003) the term ‘Reuse’ means any operation by which WEEE or components thereof are used for the same purpose for which they were conceived, including the continued use of the equipments or components thereof which are returned to collection points, distributors, recyclers or manufacturers. Reuse affects environmental, social and economic benefits and also cost of the recycling materials. Reuse affects the flows of computers to landfill and informal recyclers. The best way of reuse is that computers can be sold to employees of organisations or students of institutions at very reasonable price or donated to charitable organisations. The reuse method is important to minimise the land filling and recycling of e-waste techniques.

4.2 Remanufacturing

While it is necessary to examine closed systems as a whole and account for energy expended and any externalities that create an environmental impact, they should also be more eco-efficient than linear systems. In a study of Fuji-Xerox in Australia and accounting for all aspects of the supply chain process, it was found that remanufacturing is able to make a significant contribution to the eco-efficiency of a product system. Up to factor 3 reductions in energy consumption were achieved. However, the current model for remanufacturing exemplified by Fuji-Xerox is not necessarily a suitable model for future remanufacturing systems where factors of four to ten are seen as requisite target outcomes. To achieve this level of factor 3 efficiencies, substantial investment was made by Fuji-Xerox over the ten year period up to the study and most importantly, design for disassembly was incorporated into the product in order to achieve the savings desired (Kerr and Ryan, 2001).

Of importance to e-Waste, the high rate of technological change in the electronics industry presents a critical challenge for the process of remanufacturing and particularly DfE. With only a three year average life span for computers, there is a “technological pull away from the environmental principles of longevity, reuse and resource productivity” and remanufacturing runs the risk of prolonging the life of already obsolete product (Kerr and Ryan, 2001).

However, GAO argues that whilst remanufacturing may run the risk of extending the life of a technologically obsolete product, the energy saved by reuse or refurbishment is huge. Up to 80 percent of the energy utilised in the life cycle of a computer can be saved in this way instead of manufacturing a new unit from raw materials. Recycling and reuse also provides substantial savings over the manufacture of a new product (GAO, 2005).

4.3 Recycling

In general recycling refers to the reuse of materials and involves taking apart an old product and using the material it contains to make a new product through reprocessing. For computer products, this is generally a “down-cycling” process as material that would otherwise have been thrown away is being manufactured into other different products and generally only delaying its entry into the waste stream. E-Waste product is one that is not only at the end of its life, but also one that is obsolete in terms of the technology and outdated in its architecture.

There are a number of international programmes designed to dramatically increase collection and reuse/recycling of e-Waste. Especially the implementation of *WEEE* Directive in the EU has a huge potential for an increased rate of recycling in the EU which will lead to a large reduction in pollution. In the short-term there is a need to prioritise recycling as waste prevention though various EPR related DfE measures is a long-term process and will not be able to resolve issues associated with current level of existing and potential e-Waste generation.

Recycling is very important process of the end-of-life strategies for WEEE. The maximization of precious material recovery and the consequent minimization of disposal rely on the technologies used in the process.

The valuable metal oriented recovery techniques, such as hydrometallurgy and pyrometallurgy, are facing great challenges with the steadily decreasing amounts of the important materials in EEE. He et al. (2006) has specified different technique such as mechanical or physical recycling of WEEE, due to its better environmental properties. Mechanical or physical recycling process mainly includes three stages of the process.

Disassembly: Disassembly is a systematic process that removes a component or a part, or a group of parts from products. This process involves dismantling of hazardous or valuable components such as PCBs, cables and engineering plastics in order to simplify the subsequent recovery of materials (He et al., 2006).

Upgrading**:** Upgrading is the process of separating metals (e.g. copper, aluminium and gold) and non metal components from WEEE. Separation in the form of magnetic separation, electric separation and density based separation is common in this process. Magnetic separation is widely used for the recovery of ferromagnetic metals from non ferrous metals and other non magnetic wastes. Electric conductivity based separation is used to separate materials of different electric conductivity and resistivity density based separation is used to separate metals in WEEE powders and heavy metal materials (He et al., 2006).

Refining**:** Refining is the last stage where recovered materials from the process return to in their lifecycle. In the last step, recovered materials are retreated or purified by using chemical (metallurgical) processing so as to be acceptable for their original using (Cui et al., 2008).

4.4 Land filling

E-waste contains materials such as plastics and steel casing, circuit boards, glass tubes, wires, resistors, capacitors and other assorted parts and materials. In fact e-waste is a hazardous waste and its safe management by disposal in secured landfills a highly technical job and incurs heavy cost all social, economic and environmental.

Kahhat and his colleagues (2008) studied that e-waste landfill disposal is a threat to the environment and human health. Land filling may lead to the leaching of lead (Pb) and other heavy metals into ground water supplies. Lead is commonly used in solders for circuit boards and in cathode ray tube (CRT) glass.

4.5 *Incineration*

The process of destroying waste through burning is called as incineration. However, the variety of substances found in e-waste, incineration is associated with a major risk of generating and dispersing contaminants and toxic substances. The gases released during the burning and the residue ash is frequently toxic. This is especially true for incineration or co-incineration of e-waste with neither prior treatment nor sophisticated flue gas purification. Incineration results in the formation of ashes such as ‘bottom ash’ from the primary residues and the ‘fly ash’ from the flue gas emissions (Ecke et al., 2000).

Bottom ash has been disposed into land and results in ground water pollution. Fly ash results in air pollution. Municipal solid waste incineration plants have shown that copper, which is present in printed circuit boards and cables, acts a catalyst for dioxin formation when flame retardants are incinerated. These brominated flame retardants when exposed to low temperature (600-800°C) can lead to the generation of extremely toxic polybrominated dioxins (PBDDs) and furans (PBDFs). Incineration also leads to the loss valuable of trace elements which could have been recovered, sorted and processed separately (E-waste, 2008).

4.6 *Open Burning*

For developing countries (e.g. China, India), open burning is the largest known method for the management of e-waste. Open burning of e-waste may significantly contribute to emissions of PCDD/Fs to air. This is a major issue considering e-waste contains large amount of plastics used in electronics manufacturing (Zheng et al., 2008). Burning PVC releases hydrogen chloride, which on inhalation mixes with water in the lung to form hydrochloric acid and affects the respiratory system causing asthma, lung cancer (E-waste, 2008).

5 Upstream Reduction of E-waste

Currently, a major problem that exists in the manufacturing process of computer equipment is that of its design. The manufacturing process in the electronics industry is linear in nature and adheres to the standard “profit” focused approach which Doppelt (2003) labels one of “take-make and waste”. A computer manufacturer or other industry player may well have an environmentally certified manufacturing plant and be extremely mindful of its eco-responsibility. However, if the end product is not “clean” in process, then the impact of any improvement through accreditation is weakened. It must be recognised that accreditation is but the first step towards sustainability. It is not an end in itself. Once a product is out on the market, the ability to improve its environmental performance is essentially eliminated. Resources may be expended on attempting to do so but it will be relatively ineffective and environmental impact and degradation will not be reduced.

A product is like a messenger between the acts of production and consumption. They are “the carriers of material’s flow, energy usage, functional performance and environmental impacts”. Products then are one key by which progress can be made towards sustainability (Li 2005). The challenge is to ensure that an integrated circular "whole systems design" or as Doppelt (2003) argues, for a borrow-use-return approach to be taken and the linear method abandoned. This process incorporates design-for-the-environment (DfE).

DfE or eco-design, at times also refer to as cleaner production, as a result of major regulatory changes that have and are taking place internationally and together with pressure from end-users, is becoming an increasingly important priority for manufacturers of electronic equipment. DfE is not a compliance activity, but an integrated, cross-functional strategy. DfE is an integrated strategy that has the goal of reducing the environmental impact of a product at the design stage. DfE begins with research and development using environmental impact as the basis for the product whilst procurement and quality assurance work closely with suppliers by ensuring they meet or exceed the criteria for environmental performance. DfE will not only see the elimination of toxic products from the system altogether, better disassembly, lower weight and smaller footprints, it will enable manufacturers to achieve a level of competitive advantage over more conventional manufacturers that do not follow this path. It will also eventually eliminate these conventional manufacturers from the largest markets.

The introduction of legislation resulting in two major regulations in the European Union (EU), those of the WEEE and the RoHS Directives are now combining with market forces and lean manufacturing to force manufacturers to undertake a totally new and integrated approach to design. The directive on the RoHS has changed the whole process of interaction along the supply chain and is causing original equipment manufacturers (OEMs) to implement closer interaction between customers and suppliers as well as a reduction in the number of component suppliers. Further directives including the *Energy-using-Products* (EuP) *Directive*, restrictions on chemicals (REACH) and an updated battery directive will further reinforce this DfE push. These directives, particularly the EuP, encompass the full life cycle of product from component manufacture to disposal and establish legal parameters for the eco-design of products. The People's Republic of China, US states including California and Massachusetts, Korea have all formulated their own RoHS and WEEE legislation as a direct result of the EU Directives. Directives from the EU have effectively become international directives as OEMs cannot afford to run both compliant and non-compliant manufacturing lines so in effect these DfE changes are implemented globally.

DfE is not only an issue for the manufacturer; the consumer also has a part to play in the process. The consumer is the key to initiation and implementation of DfE at points along the supply chain. The consumer, particularly larger organisations such as government departments, through the implementation of purchasing policies, is in a position to encourage OEMs to implement DfE by specifying criteria in contracts. This is known as environmentally responsible product purchasing (ERPP).

5.1 Extended Producer Responsibility

In order to assist in improving environmental performance within the electronics industry, there has been a growing perception of the need to introduce measures that will improve the ability of governments and corporations to improve environmental performance. This includes a variety of initiatives and legislation that has been introduced internationally. These include global guidance standards as published by the International Standards Organisation (ISO) and work by the Organisation for Economic Cooperation and Development (OECD) and the United Nations Environment Programme towards providing information on product stewardship and extended producer responsibility (EPR) and guidance on public procurement with a view to improving environmental performance.

A definition of EPR is as:

> *"…a policy principle to promote total life cycle environmental improvements of product systems by extending the responsibilities of the manufacturer of the product to various parts of the product's life cycle and especially to the take-back, recovery and final disposal of the product"(Li 2005).*

The goal of EPR is to prioritise three major areas. These are prevention, life-cycle thinking and incentive mechanisms for industry to conduct ongoing improvement in processes and product design. This is not just about simply setting up a recycling system that does not encourage manufacturers to examine their own processes. The most comprehensive use of EPR is that it is the principle that producers should bear responsibility for all the environmental impacts of their products at all stages of the life cycle. This includes upstream impacts arising from the choice of materials, from the manufacturing process and downstream impacts and from the use and disposal of products.

Producers will only accept their responsibility when they assume legal, physical, and/or financial responsibility for the environmental impacts of their products (Tojo, 2005). By linking both the upstream phase of the product's life cycle with the downstream phase, EPR internalises costs and both provides the incentive and emphasises the need for manufacturers to design products that enable a transformation from the liner production model to a sustainable "borrow-use-return" cycle as highlighted by (Tojo, 2005).

A number of key features of EPR are outlined by (Tojo, 2005). These include:

- It is a product policy – not a waste policy;
- It gives priority to prevention over end-of-pipe pollution control;
- It aims to reduce the environmental impact of products and product systems throughout their life cycle instead of focusing on point sources, such as production sites;
- It seeks to prevent environmental problems at source by providing incentives for changes at the product design phase, without prescribing what should be done;
- It enacts the 'polluter pays principle' and attempts to internalise waste management costs into the product price

5.2 Developments in Green Electronics

Lead-free Soldering

Green electronic through lead-free soldering is gaining momentum worldwide. EEE contains over 1000 materials of which lead (Pb) has been one of the targets of the regulators forcing manufacturers to adopt lead free products. Industry has come up with several lead free solders with preference given to alloys containing tin, silver and copper but there is no ‘drop-in' substitute to leaded solder. Issues with lead free solders such as temperature, intermetallics, tin whisker, tin pest and reliability are yet to be resolved (Herat 2008c).

In electrical and electronic equipment (EEE), lead is mainly used in cathode ray tubes (CRTs) in monitors, tin-lead solders, cabling printed circuit boards and fluorescent tubes. The most significant use from the above list is the amount lead used in the manufacture of CRTs to shield the user from radiation. The main components of a CRT – the funnel, neck and the frit- contain between 0.4 kg and 3 kg of lead per monitor. In a typical CRT 65-75% of the lead could be found in the frit while 22-25% of the lead in the funnel glass and 30% in the neck (Five Winds International, 2001). In a typical desktop personal computer (including the monitor), lead amounts to 6.3% by weight (MCC, 1996). Next to the CRTs, second largest source of lead in EEE can be found in tin-lead solders used to connect many components together. Lead is used in tin-lead solders (typically 60% tin and 40% lead) due to its good conductivity, high corrosion resistance and high melting point which are all essential factors for a sound connection between the components. It is estimated that the amount of lead used in soldering is about 50 g/m2 of the printed circuit boards (Five Winds International, 2001).

The main environmental effect of lead is the leaching of lead ions from the broken lead containing glass (e.g. broken cone glass of CRTs) when mixed with acid waters in waste landfills. It is estimated that 40% of lead found in US landfills come from EEE (Widmer, 2005). When printed circuit boards are heated to soften the lead solder during certain recycling operations, lead is released to the environment as fumes or as fine particulate dusts if they are shredded during the recycling operations. A recent study in EEE recycling workplaces in China and India found that concentrations of lead recorded in indoor dust samples in China are hundreds of times higher than typical levels recorded for indoor dusts in other parts of the world .

Lead-based solders have been used for a time in the electronics industry with most common being 63% tin (Sn) and 37% lead (Pb) by weight referred to as Sn63Pb37. Mechanically and electrically lead-based solders make an excellent choice in the electronics industry but due to the environmental reasons described above regulators now require the manufacturers to find suitable alternatives.

The substitutes to Sn-Pb solders must satisfy various engineering and other criteria which includes similar properties to current alloys, same temperature range as Sn-Pb, same or better reliability and equal or lower cost, compatibility with standard finishes, ease of application with wetting properties similar to current Sn-Pb including fluidity and cohesive force and stability. Technically, lead-free solders must have a coefficient of thermal expansion (CTE) that matches the joining components, must be able to resist thermal cycling, have sufficient creep resistance to maintain thermomechanical loading in the longer periods in the field of use . In general, materials used in lead free alternatives must be readily available, be economical and should not have any negative environmental impact now or in the future.

Although number of lead-free substitutes has been developed by the industry, finding a suitable substitute which satisfies all the requirements is not a simple matter. The industry is now favouring Sn-Ag-Cu (SAC) alloy for reflow and SAC and Sn-Cu alloys for wave soldering (Shangguan, 2004). In the United States, the National Electronics Manufacturing Initiative (NEMI) launched a project to determine the most suitable alloy for a lead free substitute. Their extensive research into processing and reliability of lead free solder joints resulted in the alloy 95.5Sn/3.9Ag/0.6Cu for reflow soldering and 99.3Sn/0.7Cu for wave soldering (Rae, 2004). In the European Community, a project was undertaken by Marconi Materials Technology Group under the heading ‘Improved Design Life and Environmentally Aware Manufacturing of Electronics Assemblies by Lead-Free Soldering or IDEALS'. In an extensive study lasting over 3 years this group studied several candidate solders under extensive assembly trials and came out with 95.5Sn/3.8Ag/0.7Cu eutectic alloy for reflow soldering and 95.25Sn/3.8Ag/0.7Cu/0.25Sb for wave soldering (Marconi Materials Technology, 1999). Furthermore, at the European level ELFNET (European Lead Free soldering NETwork) has been developed which is a network of the national organisations, technical experts and industry bodies in micro-electronics. It provides support to European Union electronics producers comply with the EU directive to introduce lead-free soldering (http://www.europeanleadfree.net/). Even before the regulations came into force, the Japanese electronic manufacturers have attempted to adopt lead free electronic to satisfy the demand for green products in the market. The Japanese Electronic Industry Development Association (JEIDA) has developed a roadmap towards the introduction of the lead-free soldering to gradually introduce the lead free soldering in the industry (Japanese Electronic Industry Development Association, 2000). JEIDA also recommended 96.5Sn/3Ag/0.5Cu for wave soldering and 96.5Sn/3Ag/0.5Cu, 99Sn/8Zn/3Bi and 48Sn/57Bi/1Ag as strong candidates for reflow soldering.

Alternatives to Brominated-Flame Retardants (BFRs)

BFR is the group of brominated organic substances that inhibits the ignition of combustible materials and is commonly used in the manufacture of EEE to reduce the flammability of the product. BFRs are manufactured synthetically and following are the major classes of them:

1. TBBPA: Tetrabromobisphenol -A
2. HBCD: Hexabromocyclododecane
3. PBDEs: Polybrominated diphenyl ethers consisting of Deca-BDE (Decabromodiphenyl ether), Octa-BDE (Octabromodiphenyl ether) And Penta-BDE (Pentabromodiphenyl ether)
4. PBB: Polybrominated biphenyls

The manufacture of EEE consumes a major portion of the global BFR market by accounting for 56% of the product. Nearly two thirds (59%) of the EEE industry's BFR consumption is destined for housings followed by the printed wiring boards (30%), connectors & relays (9%) and wire & cabling (2%). The BFR group TBBPA represents a half of BFR volumes and is contained in 96% of printed wiring boards (Bromine Science and Environmental Forum 2000).

It is estimated that around 200,000 tonnes of BFRs are produced globally each year with Asia being the largest consumer. According to the studies undertaken in 2001, Asian region consumed 56% of the total market demand followed by Americas (29%) and Europe (15%) (Birnbaum and Staskal 2004).

BFRs such as polybrominated biphenyls (PBB) and polybrominated diphenylethers (PBDEs) used in computer equipment are both an occupational and environmental health hazard (Kang and Schoenung 2005). One of the main reasons for the current concerns regarding the use of BFRs is that nearly all of the BFRs generate polybrominated dibenzo-dioxins and polybrominated dibenzo-furans (PBDDs/PDDFs) during the EOL processes such as heating of EEE.

China's e-waste recycling facilities have attracted significant attention worldwide due to their perceived unsustainable e-waste recycling operations. One of the first studies to document these practices was conducted by the Silicon Valley Toxics Coalition (SVTC) and the Basel Action Network (BAN) published in 2002 through a now well known document 'Exporting Harm: The High-Tech Trashing of Asia (Puckett *et al.* 2002). This report asserts that 50 to 80 % of e-waste collected for recycling in the developed countries end up in China and designated Guiyu village in Guangdong province in China as an 'electronics junkyard'. As a result significant amount of scientific research is being currently undertaken to assess the environmental impacts e-waste recycling operations in Guiyu area. (Wang *et al.* 2005) collected soil and sediment samples from the vicinity of an open e-waste recycling facility located in Guiyu and analyzed for the levels of PBDEs. They detected PBDEs levels in the soil and sediment samples at levels of 0.26–824 ng/g (nano gram per gram of dry weight). These findings were confirmed by (Cai and Jiang 2006) when they detected PBDE concentrations up to 600 parts per billion in soil samples collected from a similar e-waste recycling plant.

(Leung *et al.* 2006) conducted a detailed study in Guiyu area to identify the sources and quantify the pollution levels generated from e-waste. They found PBDE levels up to 1169 ng/g (dry weight) in soils near the plant which was 10-60 times higher than PBDE contaminated locations in the world. (Leung *et al.* 2007) extended this study to surface soils and combusted residue in Guiyu area and found total PBDE concentrations were highest in combusted residue of plastic chips and cables collected from a residential area (33 000-97 400 ng/g, dry wt), in soils from an acid leaching site (2720-4250 ng/g, dry w), and a printer roller dump site (593-2890 ng/g, dry wt). They also found that BDE congener 209 was the most dominant congener (35-82%) among the study sites confirming the existence of commercial Deca-BDE. Studies conducted by (Luo *et al.* 2007a; Luo *et al.* 2007b) further confirms the levels of PBDE in Guiyu area in their experiments on sediment and fish samples collected from rivers in Guiyu. The total concentrations of PBDE in this study ranged from 4434 to 16088 ng/g (dry weight) in Nanyang River bank sediment, from 55 to 445 ng/g in Nanyang River bottom sediment and 51.3 to 365 ng/g in Lianjiang River bottom sediment in Guiyu. The authors compared these findings with those from 16.1 to 21.4 ng/g in wastewater discharged from a vehicle repairing workshop in Hong Kong. They also found PBDE concentrations in sediment and fish in this area were 10 and 1000 times higher than other studies. In other parts of the world, (Binelli *et al.* 2007) conducted a study on a mangrove wetland in north-eastern part of Bay of Bengal in India and found concentrations of several PBDE congeners, however, they could not confirm the main source in this area which includes an e-waste dump site. There are also reports of incredibly high air concentrations of PBDD/Fs in Guiyu area, most likely due to the high PBDE levels.

Despite the uncertainties and knowledge gaps related to the environmental and health effects of BFRs used in the EEE manufacture, there is a significant effort within the electronics industry to find substitutes, particularly in Europe, United States and Japan. This is mainly driven by WEEE and RoHS regulations in the EU and the demand for green markets in Japan. Similar to the situation with lead-free soldering the challenge is to find a drop-in substitute for BFR which has the technical, environmental and economic edge to the material being substituted.

There are a large number of commercially available alternatives to BFRs mainly based upon inorganic compounds such as aluminium trihydrate, aluminium trihydroxide, magnesium hydroxide, ammonium polyphosphate, red phosphorous, zinc borate and antimony oxides, organophosphorous compounds such as resorcinol bis(diphenyl phosphate, nitrogen based melamine products such as melamine cyanurate, melamine polyphosphate and melamine pyrophosphate and nanoclays (Lincoln *et al.* 2005; Markarian 2005). Many of the major EEE manufacturers are currently using alternatives to BFRs.

6 Specific Challenges, Issues and Opportunities related to Developing Countries

The issue of ESM of e-waste is a global problem arising from transboundary movement among all countries and regions and thus requires global solutions. As noted elsewhere in this paper large amounts of e-waste are currently being exported to developing countries for the purpose of re-use, refurbishment, recycling and recovery of precious materials. Today India, China, Philippines, Hong Kong, Indonesia, Sri Lanka, Pakistan, Bangladesh, Malaysia, Vietnam and Nigeria are among the favourite destinations for e-waste. However, recycling and recovery facilities in these countries operate in an environmentally unsound manner causing significant environmental and health impacts. The operations in these countries are well documented. Significant amounts of e-waste containing hazardous materials can be seen dumped in open-land and waterways. The major environmental and health impact occur during open burning on e-waste to recover precious metals. In spite of these significant environmental and health impacts, the recycling and recovery operations have generated a huge informal employment sector in these countries. In addition to receiving e-waste from developed countries, developing countries are also emerging as significant generators of e-waste themselves. The highest growing consumption rates of electronics are in developing countries adding a further burden to already existing mountains of e-waste. Although the per capita generation of e-waste in developing countries is relatively small, populous and emerging economies such as China and India are already producers of e-waste in absolute terms.

According to the Secretariat of Basel Convention following are main pre-requisites for environmentally sound management (ESM) of e-waste:

- An appropriate legislative framework;
- Sustainable development policies, including policies on the collection, recycling and recovery of electronic and electrical wastes and ones that address the transboundary movements of such wastes;
- Economic incentives for environmentally sound practices and technologies;
- Green design aimed at reducing the use of hazardous materials in electrical and electronic products and enhancing their recyclability;
- Closing the loop for recyclables;
- Extending the life of products through reuse, refurbishment or repair;
- Elimination of hazardous constituents in products;
- Worldwide environmentally sound management standards or criteria for recycling and final disposal of electronic wastes;
- Action to prevent illegal traffic;
- Broad public awareness;
- Public-private partnerships to engage all stakeholders;
- Regional level playing field on how to deal with export and import of electronic and electrical wastes.

The adoption of ESM of e-waste in many developing countries around the world is either absent or limited. In this regard developing countries are facing number of issues and challenges as described below.

There is an increasing volume of e-waste imported illegally into developing countries. The issue of how much e-waste is generated and where it is moving around the world is difficult to answer. This is further worsened by the inability to make second hand electrical and electronic equipment (EEE) and waste products visible in systems that gather national statistics in production, sales and imports. Most of the second hand EEE imported to developing countries are rarely tested for functionality. In most cases the consignment of admixture of used EEE and e-waste are not shipped as wastes but as second hand EEEs. Therefore, technically they do not fall under the Basel Convention. However, some of these used EEE have already reached their end-of-life thus requiring the developing country to deal with the challenge of implementing the ESM of e-waste. This is not easy given that most developing countries have neither a well-established system for separation, storage, transportation, treatment and disposal of waste nor any effective enforcement related to managing e-waste. Thus, co-disposal of e-waste with domestic waste in open dumps is generally practiced in many developing countries causing severe damage to the environment and human health.

Another major issue faced by developing countries in dealing with e-waste is how to tackle the emerging informal e-waste recycling sector. In most developing countries formal recycling of e-waste using best practice technologies in modern recycling facilities are rare to find As a result most of the e-waste is managed by using various improper methods such as open dumps, backyard recycling and disposal into surface water bodies. It is common to see open burning of plastics to reduce the e-waste volumes, copper wires to salvage valuable metals such as copper and acid leaching to recover precious metals from the printed circuit boards. Such operations have resulted in severe environmental pollution exposing millions of people living in developing countries to toxins in e-waste. Informal recycling takes place in developing countries using women, children and unemployed youths who are actively involved in crude processing methods without any personal protective gear and thereby exposing themselves to number of toxins in e-waste with potential adverse health impacts. The lack of awareness among the government officers and public in developing countries of hazardous nature of e-waste and the potential hazards of crude e-waste recycling activities to human health and the environment is very common. Unfortunately those involved in the dangerous crude e-waste recycling activities are also ignorant about the dangers of such activities or are forced to do so because of poverty. Although it can be argued that crude recycling of e-waste provides employment for youth in reality it may worsen their poverty if they are not protected from the impacts of hazardous substances. Crude recycling currently takes place in number of Asia Pacific countries such as India and China and in some African countries such as South Africa, Nigeria, Senegal and Ghana. It can be also argued that in many developing countries and countries with emerging economies, e-waste is both an emerging problem as well as an economic opportunity due to growth of e-waste that contain materials that are both hazardous and valuable.

Part of the problems faced by developing countries in achieving ESM of e-waste is due to lack of funds and investment to finance formal recycling infrastructures, and the absence of appropriate legislation to deal with the issue. The extended producer responsibility (EPR) is seen globally as one of the most effective ways of dealing with the e-waste issue. However unlike in the developed world implementing EPR in developing countries is a major challenge to policy makers. For example (Kojima *et al.* 2009) in their study into applying EPR policies in e-waste recycling in China and Thailand found two major difficulties to implement EPR in developing countries. The first difficulty is for the governments to collect funds from producers or imports if the goods are smuggled into the country or if the small sop-assembled products have a large share of the market. The second difficulty is the systems that create incentives for collectors and recyclers to over-report the amount of e-waste collected to gain extra subsidies from the fund. One of the other issues in implementing EPR in developing countries is the competition between the formal and informal recycling sector to gain access to e-waste.

(Nnorom and Osibanjo 2008) has also observed that in many developing countries used EEE flows from the cities to the countryside where the ownership of EEE is low. In many such cases reuse is the norm even with appliances that are beyond repair. Such scenarios make collection of e-waste difficult. Furthermore, recycling is undertaken by informal recyclers hence even the task is assigned to producers and importers, the collection of used EEE becomes very difficult. It is also difficult to assign the responsibility for products that have been repaired or modified and smuggled into the country. The question is whether responsibility lies with the producer or the importer. (Nnorom and Osibanjo 2008) also identify the following reasons behind the low-end management of used EEE and the existence of ineffective informal e-waste recycling sector in developing countries:

- Unwillingness of consumers to handout their used EEE or pay for the disposal of waste. This is because consumers regard used EEE as an income generating opportunity.
- There is some reluctance from the public to pay for e-waste recycling and disposal services as they can make money by selling used EEE instead.
- Emotional attachment to used EEE means that most of them are stored.
- Uncoordinated high levels of second hand EEE imports.
- Lack of funds to finance e-waste recycling infrastructures hence the absence of formal recycling sector.
- Absence of legislation dealing with e-waste and ineffective implementation of existing regulations on transboundary movement.

As seen from above there are numerous challenges to overcome before the developing countries achieve ESM of e-waste. Number of workshops and studies has been conducted by organisations such as Basel Convention to investigate the obstacles in developing countries to adopt ESM of e-waste. These have identified lack of e-waste inventories, lack of trained personnel to enforce ESM practices, lack of legislation including export and import rules, inadequate infrastructure to collect, handle, recycle and recover materials from e-waste and lack of awareness about the health and environmental impacts of unsound e-waste management practices as the main obstacles in achieving ESM of e-waste.

In order to address the issues related to e-waste management in the region, the Basel Convention Partnership on the 'Environmentally Sound Management of Electrical and Electronic Wastes for Asia Pacific Region' was officially launched in Tokyo, Japan in 2005 under auspicious of Japanese Government. Its strategic goals include assessment of the current situation through conduct of national inventories, prevention and minimisation of e-waste ending up in the landfills, introduction of cleaner production approaches to minimise the generation of e-waste, environmentally sound management by promoting best practices and use of sound recycling technologies and promotion of information and training through regional information clearinghouses. So far Cambodia, China, India, Indonesia, Malaysia, Philippines, Sri Lanka, Thailand and Vietnam have conducted the projects with financial support by the Japanese Government.

The policy makers in developing countries may find following activities useful in their attempt to achieve ESM of e-waste:

- Well defined regulatory procedure adequate enough to control illegal exports of e-waste and to ensure their environmentally sound management.
- Improve country's ability to gather data and inventory on e-waste generation including their transboundary movement and to access appropriate and cost effective technologies to manage e-waste within their own borders.
- Establishment of proper intuitional infrastructures for collection, storage, transportation, recovery, treatment and disposal of e-waste at regional and national levels.
- Development of scientific resources such as experts and laboratories to conduct environmental and human health impacts of e-waste

- Improving the working conditions and minimisation of work related toxic exposure at e-waste collection, processing, recovery and disposal facilities.
- Awareness raising programmes and activities on issues related to health and safety aspects of e-waste in order to encourage better management practices.
- Develop public-private-community partnerships to encourage the establishment of formal e-waste recycling and disposal enterprises.
- Address the obstacles related to implementing EPR and mandating producers, importers, retailers with cost of collecting, recycling and disposal of e-waste.
- Require the countries that export used EEE to developing countries to formally test the equipment prior to export.
- Prohibit import of e-waste if the receiving country does not possess adequate capacity to manage these wastes in an environmentally sound manner.
- Promote reduction and reuse of EEE.

Informal recycling of e-waste in developing countries is by far the biggest obstacle to achieve ESM of e-waste. It is necessary for informal sectors that are heavily involved in e-waste recycling to evolve into more formal sectors. However, this is a major challenge given that here are economic and social issues to deal with. Government should think of providing some incentives to informal sector in the form of tax reductions, low-interest loans, free expert advice on cleaner technologies etc. However, the challenge is the profit generated by remaining in the informal sector is greater than the benefits from government incentives.

Capacity building is a critical component of any sustainable management e-waste management system. One of the major events planned towards capacity building for e-waste management in the Asia Pacific region is the 1st Asia Pacific Conference on E-waste in July 2010 (Ewaste 2010). Participation from various UN organisations, global as well as regional manufacturing and recycling companies, government officials from number of Asia Pacific countries and researchers are expected to attend this event. This would be an ideal forum to discuss and solve various issues and challenges faced by developing countries towards ESM of e-waste. The complete details could be found in the event website (www.ewaste2010.org).

7 Case Studies on Issues or Best Practice of E-waste Management

The Section 3 of this background paper described regulations and current state of e-waste management in countries such as United Staes, Eupropran Union, Japan, China and India. The aim of this section is to describe case studies on best practice or issues of e-waste management from some countries in the Latin American and African region as well as the Small Islands Developing States (SIDS).

7.1 South Africa

Developing practical solutions to e-waste management is in the infancy in most countries in the African region. There is no specific legislation that deals with e-waste in South Africa. In 2009 The South African Parliament approved the National Environmental Management Waste Bill regulating waste management in order to protect health and the environment by providing reasonable measures for the prevention of pollution and ecological degradation and for securing ecologically sustainable development. This is the first time in South Africa that legislation has been developed to drive the waste minimisation agenda. This Bill has several definitions that have an impact on e-waste. The recycling of e-waste is well established in South Africa mainly through the informal sector. These recycling systems are not uniform and far from the solutions. As such e-waste is becoming a major social and environmental hazard. The e-Waste Association of South Africa with the support from SECO (Swiss State Secretariat for Economic Affairs) and EPMA (Federal Laboratories for Materials Testing and Research) conducted as assessment of e-waste in South Africa in 2008 (Finlay and Liechti 2008). Some of the findings from this study are:

- Between 1,129,000 and 2,108,000 tonnes of potential e-waste is estimated to be in South African households which includes white goods and consumer electronics.
- The major challenges facing e-waste recycling in South Africa include recycling of CRT glass and LCD monitors, disposal of rechargeable batteries and markets for flame-retardant plastics.
- Around 30% of all computer sales in South Africa are estimated to be refurbished PCs.
- Many e-waste recyclers and refurbishers are not yet ISO compliant. On-site incineration, exposed e-waste and insufficient containment of potential run-off are common in these oprtations.
- Informal recycling includes early stages of recycling such as collection, crude dismantling and sorting. Substantial burning of cables and other components is widespread.
- Logistics, especially transport costs, is a key challenge for ESM of e-waste.

7.2 Kenya

A baseline study into e-waste in Kenya was conducted in 2008 by the Kenya ICT Action Network (KICTANet) which was supported by Hewlett Packard (HP), EMPA and Digital Solidarity Fund (DSF). The following are some of the findings of this study (Mureithi *et al.* 2008):

- E-waste accumulated per year which includes only computers, monitors and printers in 2007 was around 3000 tonnes.
- E-waste is expected to be significant problem in the future given the rise in IT importation.
- E-waste management policies are lacking and there is no legislation governing e-waste.
- There are no regulatory and policy structures to safeguard health, environmental and social impacts of e-waste.
- Knowledge on where to discard e-waste is lacking from consume to the final disposer.
- There is a lack of mechanisms to separate e-waste from normal solid waste and systems to collect e-waste resulting in stockpiling of e-waste in homes and offices.

- Most EEE have a value to the owner even if they are broken. Hence public expects something in return when giving away for disposal.

7.3 Uganda

The most comprehensive study on e-waste scenario in Uganda has been completed by (Wasswa and Schluep 2008). Some of the findings of this study are:

- Uganda has no specific policy or legislation related to e-waste management.
- There is no formal infrastructure for formal collection and recycling of e-waste and also very small scale operations of informal recycling.
- There is a lack of awareness among the consumers and collectors of potential hazards of e-waste.
- Dumping of e-waste in formal landfills, informal dump sites or simply burying may lead to drinking water contamination.
- The total amount of installed computers in Uganda is relatively small (10 per 1,000 inhbaitants), the figure that may increase significantly in the coming years.

7.4 Senegal

An assessment of the e-waste situation in Senegal was conducted in 2008 with the support from DSF and EMPA. The following are some of the findings from this study (Wone *et al.* 2008):

- There is no specific legislation related e-waste in Senegal although several environmental legislations would apply to e-waste management.
- There is significant drive from the consumers to gain access to ICT equipment. In 2008 there were at least 4, 136, 000 mobile phone subscribers, 50,000 computers in government agencies and companies and 105,000 computers in the households. Senegal’s computer penetration is about 21.4 computers per 1000 inhabitants.
- There is no e-waste recycling sector with all the e-waste ending up in uncontrolled landfills.
- Estimated e-waste quantities are very low thus making recycling business non-viable.

7.5 Morocco

A study into e-waste in Morocco was conducted in 2008 by the Moroccan Cleaner Production Centre (CMPP) with the support from HP, EPMA and DSF (Laissaoui and Rochat 2008). Some of the major findings from this study are:

There is no specific legislation related to e-waste management in Morocco.
Both the government and private sector have elaborated strategies for development of ICT sector.
It was estimated e-waste resulting from computers, mobile phones and televisions amounted to 222,000 tonnes in 2007 with televisions sharing 68%, computers 30% and mobile phones only 2%. The households hold the largest share of e-waste (81%).
E-waste recycling sector is dominated by the informal sector with evidence of open-burning.

7.6 Colombia

Columbia is the fourth largest and second most populated country in South America. Colombia currently does not have any specific legislation covering e-waste. However the topic of e-waste has been in the political agenda for a long time with Ministry of Environment declaring e-waste as a high priority issue. The Ministry of Environment has signed voluntary agreements with the private sector to implement e-waste take-back schemes especially the mobile phone industry. Although there is significant interest to create recycling companies it is hindered by the lack of know-how. The large number of used EEE smuggled to the country is a serious problem.

After a prolong period discussions the Colombian Government has finally come up with its first formal proposal to regulate e-waste in the form of a Bill introduced in the Colombian Senate. The Bill is expected to be passed in 2010. The bill would require the importers, producers, distributors, wholesalers and retailers of EEE to

- establish take-back and collection plans for their end-of-life EEE, whether collective or single-company, without cost to the final user;
- inform users about the take-back and collection plans;
- assure and finance environmentally adequate and secure final disposal which can be done through third parties;
- provide e-waste managers the information necessary about the characteristics and composition of their equipment in order to facilitate environmentally secure reuse and recycling.

The bill would also lead to a national e-waste policy that will formulate economic and financial instruments that facilitate proper management of e-waste, and steps that promote the creation and formalization of e-waste recycling firms.

7.7 Brazil

Although accurate assessment of the e-waste situation relatively unknown Brazil has seen an immense increase in the production and consumption of EEE which generates high volumes of e-waste. Any recycling of e-waste is conducted by the informal sector in unsustainable manner. There is a general lack of information about the health and environmental issues among the actors and very limited public discussion on the topic. At the federal level there is no comprehensive law to mange e-waste. However, most recently in 2009 the state assembly of the state of Sao Paulo passed a new law that will make producers, importers and those who retail EEE products and components in Sao Paulo jointly responsible for ESM of e-waste. Under this law producers, importers and retailers are also required to maintain collection points to receive used EEE products and components from consumers. It also requires to include on the packaging or labels of EEE components and products sold in Sao Paulo the following information:

- warning that the item should not be disposed of with common trash;
- orientation on collection points for technological trash;

- the contact address and phone number of those responsible for collecting used EEE;
- an alert over the presence of heavy metals or toxic substances among product components.

7.8 Pacific Islands

In March 2008 National Toxic Network (NTN) and the Island Sustainability Alliance C.I (ISA CI) undertook a project to assess the current situation of e-waste management in the South Pacific Islands of Fiji and Samoa (National Toxic Network & Island Sustainability Alliance 2008). The aim of the study was to investigate the degree of awareness of the impacts of e-waste among all stakeholders and to determine the level of management. Field studies conducted in Fiji found that it has a growing problem of e-waste which is almost entirely landfilled or burnt. Waste burning at household level is common and frequent. The awareness about the impacts of e-waste on human health and environment is very low. The study also found that EEE imports to Fiji are on a sharp rise particularly the mobile phones but there are virtually no government policies or programmes in place to deal with the used EEE. The study observed that Fijian commercial enterprises are willing to participate in e-waste recycling provided there is clear government policy framework on the issue. The findings for Samoa were quite similar to what was found in Fiji meaning the same state of play in all the Pacific Island countries.

There is some on-going collaboration between the Japan International Co-operation Agency (JICA) and the Secretariat for the Pacific Regional Environment Program (SPREP) in developing a solid waste strategy action plans which also covers e-waste.

7.9 Jamaica

Jamaica is experiencing a high growth of e-waste generation due to liberalisation and continued expansion of the ICT sector. For example, Jamaica’s mobile phone penetration stood at 93% in 2007 representing a ten fold increase over the year 2000 (Planning Institute of Jamaica 2007). Jamaica has no comprehensive mechanisms or policies to deal with e-waste and no formal facilities to manage e-waste. This means most of the e-waste are either disposed at landfills, wetlands or in the sea.

7.10 Australia

In the absence of any national framework for EOL of e-waste in Australia and also due to lack of knowledge and infrastructure for collection, recovery and recycling, it is widely believed that most of the used computers in Australia are ending up in storage in homes or offices or dumped in landfills.

Re-use involves the transfer of ownership of the used computer for continued use by some one else. In Australia, according the household electrical and electronic waste survey, it was found that giving computers away to family and friends is the most common form of disposal followed by council pick-up collection schemes. Re-use could take various forms including a ‘closed system’ where computers are transferred to an immediate circle of influence or ‘open system’ where ownership is transferred via commercial or non-profit organisations. This is a viable option given that different people have different needs as far as the computing is concerned. The Australian government's 'Computer Technologies for Schools project' (CTFS) is a national project aimed at providing used computers to governmental and non-governmental schools around Australia. The program has delivered over 210,000 pieces of ICT since its inception (Australian Government, 2003).

Several non-profit organisations are involved in delivering the 'open' re-use of computers in Australia. For example *Computer Bank* operates in several States around Australia delivering computers to disadvantaged groups. *Green PC* is a similar organisation where computers are made available to low income communities. All these organisations rely upon volunteers and several organisations employ 'work-for-the-dole' staff providing additional benefit to the society.

Recycling and recovery of used computers involve disassembly of computers into constituent parts in order to recover raw materials such as metals and plastics that have been used in their manufacture. To date, Australia has not recycled much of its computers mainly due to lack of infrastructure due to not enough incentives to invest in reprocessing facilities. However, during last two years there has been a significant interest from major international companies to set up businesses in Australia.

In the absence of a national framework in Australia few computer take back schemes are currently operated by major manufacturers as well as industry led organisations as described below:

As of 2003, Dell is the world's leading supplier of PCs. Dell is a preferred supplier to a number of major organisations around Australia and appears to have a significant share of the Government/Institution PC market. Dell utilises MRI as a recycler, refurbisher and re-marketer for its computer take-back programme in Australia. The public relations material states that Dell is engaged in product development for the purposes of reducing the environmental impact through Design for Environment (DfE), consumer awareness and computer take back for recycling. Dell has offered recycling services to Australians since 2003 and has helped Australian customers reuse and recycle more than 800 tonnes of computer equipment. Dell currently offers number of computer recycling options for Australian customers. For home and small business customers, Dell will pick up any Dell-branded equipment from any location in Australia or New Zealand (metro, country and remote) free of charge. There is no need to purchase any new Dell equipment to qualify for this program. In addition, Dell will recycle any brand of personal computer on a one-for-one basis when you buy a new Dell XPS, Vostro or Inspiron desktop or notebook. Dell also provides a recycling service to consumers who are concerned about the environment but don't own a Dell product or haven't purchased a new Dell PC. They will pick up unwanted computer equipment at your nominated location for a flat fee of $10 plus $13 per item in metropolitan areas or $15.50 if you are more than 40 kms of the General Post Office in your capital city. Alternatively, customers can take their equipment to drop off points in Sydney and Melbourne for $8.50 per unit.

HP runs hardware take back programmes in Australia as well as ink and laser jet print cartridge take back. HP supports the rights of third-party re-manufacturers to compete in the marketplace with refilled product. It is recognised by HP that this is a specific market niche and HP does not design print cartridges to prevent remanufacturing. HP does believe that re-manufacturers should be responsible for the take back of their own product. HP also partners with eBay on the Rethink initiative which provides information, tools and solutions for selling, donating, or recycling used computers and electronics. The take back and recycling stance taken by HP provides them with a strong incentive to implement DfE. It operates two recycling plants in the US and one in Germany in partnership with Noranda Recycling. In Australia it cooperates with Sims E who takes its entire product. HP offers free recycling for commercial and enterprise customers in Australia provided they meet some minimum criteria. Relatively low volume users are able to drop off their used original HP inkjet or LaserJet cartridges at the centres such as Australia Post, Dick Smith Electronics, Dick Smith Powerhouse, Harvey Norman and Officeworks. HP offers hardware recycling services to small and medium business customers as well as consumers. HP takes back and recycles end-of-life HP branded personal computers, printers, scanners, fax machines, monitors, handheld devices, batteries and associated external components. To join this program, customers are required to drop off their end-of-life HP products at the designated drop-off points. In Victoria, HP partners with the state and local governments to provide the consumers options of returning their end-of-life computer hardware for recycling. A program called Byteback provides residents and small business owners in Victoria to dispose of their unwanted, old or unused computer hardware in a safe and environmentally responsible way

Apple runs a computer recycling program where customers who purchase any Apple computer or Apple Cinema Display from Apple Telesales, the Apple Online Store or one of their retail stores are eligible to recycle their old computer and monitor at no charge.

MobileMuster is the official national recycling program of the mobile phone industry in Australia. The program collects and recycles mobile phone handsets, batteries and accessories from a network of over 3500 mobile phone retailers, local council, government agencies and businesses drop off points across Australia. The program is fully funded by the Australian Mobile Telecommunications Association (AMTA) through its members and is free to consumers and retailers (Australian Mobile Telecommunications Association, 2007). As of the 31 March 2009 over 582 tonnes of mobile phone handsets, batteries and accessories had been collected or more than 4.01 million handsets and batteries.

Disposal of computers at landfills is widespread across Australia. Apart from the toxicity, waste computers also take up valuable landfill space. In Australia several major capital cities like Sydney and Melbourne are already facing landfill space problems. Unfortunately with landfill fees as little as $27 per tonne (Commonwealth of Australia 2006) there is not much of an incentive to move away from this practice.

The survey conducted recently on household electrical and electronic equipment revealed that 51% of used portable electrical and electronic items which include equipment such as walkmans and MP3 players were disposed of via the normal garbage bin collection system and essentially ending up in landfills (Katos and Hoye 2005). Therefore, the size of the equipment plays a key role in the disposal method used by the households.

8 Conclusions

E-waste is being generated around the world at a higher rate than most other waste streams. High uptake of information and communication technology products and the rapid development of newer designs by the producers on a regular basis make current electronic equipment obsolete much sooner than before contributing more and more towards e-waste generation. In order to address the issue, regulations and policies are being evaluated, developed or implemented urgently in many countries around the world largely driven by the European Union. However, it is also important that these regulations and policies do not differ substantially in scope from region to region making necessary some international standardisation process for the purpose of harmonisation.

Although number of initiatives have been implemented to achieve ESM of e-waste, there are significant number of issues and challenges to deal with. The following are seen as some of those issues and challenges:

- Regulatory instruments to address the ever increasing import of e-waste into developing countries from other parts of the world;
- Ability to gather data and inventory on e-waste generation including transboundary movements;
- Establishment of proper infrastructure for e-waste collection, transportation, storage, treatment, recovery and disposal;
- Improving the working conditions and minimisation of work-related hazardous exposure at e-waste management facilities;
- Raising awareness of health and environmental impacts of e-waste;
- Adoption of green product design practices by equipment manufacturers;
- Development of pool of experts and resources to deal with the e-waste issues;
- Development of public-private partnerships involving all the stakeholders.

Cooperation among the key stakeholders is the key to finding solutions to the above issues and challenges. Although currently there are number of activities conducted by various countries and donor agencies, harmonisation of these activities is needed to maximise the limited resources. There is a growing need to support the development of regulatory mechanisms and e-waste management infrastructures in developing countries including the small island development states as they are experiencing a significant growth in the ICT sector. In the absence of such support informal e-waste recycling would develop to deal with the e-waste which will have significant social, environmental and health impacts.

References

ATSDR. (2005) Lead: Agency for Toxic Substances and Disease Registry Fact Sheet. p. 2. United States Department of Health and Human Services.

Barontini F. & Cozzani V. (2006) Formation of hydrogen bromide and organobrominated compounds in the thermal degradation of electronic boards. *Journal of Analytical and Applied Pyrolysis* **77**, 41-55.

Binelli A., Sarkar S. K., Chatterjee M., Riva C., Parolini M., Bhattacharya B. d., Bhattacharya A. K. & Satpathy K. K. (2007) Concentration of polybrominated diphenyl ethers (PBDEs) in sediment cores of Sundarban mangrove wetland, northeastern part of Bay of Bengal (India). *Marine Pollution Bulletin*, **54**, 8, 1220-1229.

Birnbaum L. S. & Staskal D. F. (2004) Brominated flame retardants: Cause for concern? *Environmental Health Perspectives* **112**, 9-17.

Brigden K., Labunska I., Santillo D. & Allsopp M. (2005) Recycling of Electronic Wastes in China and India: Workplace & Environmental Contamination. p. 55. Greenpeace International.

Bromine Science and Environmental Forum. (2000) An Introduction to Brominated Flame Retardants. p. 29.

Cai Z. W. & Jiang G. B. (2006) Determination of polybrominated diphenyl ethers in soil from e-waste recycling site. *Talanta* **70**, 88-90.

Canadian Council of Ministers of the Environment. (2004) Canada Wide Principles for Electronics Products Stewardship.

Canning L. (2006) Rethinking market connections: mobile phone recovery, reuse and recycling in the UK. *Journal of Business & Industrial Marketing* **21**, 320-9.

Commonwealth of Australia. (2006) Waste Management - Productivity Commision Inquiry Report. p. 506.

Daly L. (2006) Recycling Technology Products: An Overview of E-Waste Policy Issues. p. 148. Office of Technology Policy, United States Department of Commerce.

Deng W. J., Louie P. K. K., Liu W. K., Bi X. H., Fu J. M. & Wong M. H. (2006) Atmospheric levels and cytotoxicity of PAHs and heavy metals in TSP and PM2.5 at an electronic waste recycling site in southeast China. *Atmospheric Environment* **40**, 6945-55.

Department of Environment and Conservation. (2006) NSW Extended Producer Responsibility Priority Statement for 2005-06. 34.

Doppelt,B., Leading Change Toward Sustainability: A Change-Management Guide for Business, Government and Civil Society. Greenleaf Publishing Limited, Sheffield UK**, 2003**

Dwivedy M. & Mittal R. K. Estimation of future outflows of e-waste in India. *Waste Management* **30**, 483-91.Electronic Industries Alliance. (2007) A Legislative Framework for Electronics Recycling. p. 4.

Environment Protection and Heritage Council. (2004) Industry Discussion Paper on Co-regulatory Frameworks for Product Stewardship. p. 18.

Environmental Protection Heritage Council. (2007) Product Stewardship.

European Commision. (2006) Implementation of the Waste Electric and Electronic Equipment Directive in the EU. p. 106.

European Union. (2003a) Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain

hazardous substances in electrical and electronic equipment. *Official Journal of the European Union* **46**, 19-23.
European Union. (2003b) Directive 2002/96/EC of the European Parliament and the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE). *Official Journal of the European Union* **46**, 24-39.
European Union. (2005a) Commission Decision of 13 October 2005 amending for the purposes of adapting to the technical progress the Annex to Directive 2002/95/EC of the European Parliament and of the Council on the restriction of the use of certain hazardous substances in electrical and electronic equipment. *Official Journal of the European Union* **48**, 48-50.
European Union. (2005b) Commission Decision of 18 August 2005 amending Directive 2002/95/EC of the European Parliament and of the Council for the purpose of establishing the maximum concentration values for certain hazardous substances in electrical and electronic equipment. *Official Journal of the European Union* **48**, 65.
European Union. (2005c) Commission Decision of 21 October 2005 amending for the purposes of adapting to technical progress the Annex to Directive 2002/95/EC of the European Parliament and of the Council on the restriction of the use of certain hazardous substances in electrical and electronic equipment. *Official Journal of the European Union* **48**, 18-9.
European Union. (2005d) Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council. *Official Journal of the European Union* **48**, 29-58.
European Union. (2006a) Commission Decision of 12 October 2006 amending, for the purposes of adapting to technical progress, the Annex to Directive 2002/95/EC of the European Parliament and of the Council as regards exemptions for applications of hexavalent chromium. *Official Journal of the European Union* **49**, 50-1.
European Union. (2006b) Commission Decision of 12 October 2006 amending, for the purposes of adapting to technical progress, the Annex to Directive 2002/95/EC of the European Parliament and of the Council as regards exemptions for applications of lead and cadmium *Official Journal of the European Union* **49**, 48-9.
European Union. (2006c) Commission Decision of 12 October 2006 amending, for the purposes of adapting to technical progress, the Annex to Directive 2002/95/EC of the European Parliament and of the Council as regards exemptions for applications of lead in crystal glass *Official Journal of the European Union* **49**, 47.
European Union. (2006d) Commission Decision of 21 April 2006 amending, for the purposes of adapting to the technical progress, the Annex to Directive 2002/95/EC of the European Parliament and of the Council as regards exemptions for applications of lead *Official Journal of the European Union* **49**, 38-9.
European Union. (2006e) Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC

and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC. *Official Journal of the European Union* **49**, 1-849.

Feszty K. & J. Calder. (2007) E-Waste legislation grows in Canada. In: *Green Supply Line*. Green Supply Line.

Finlay A. & Liechti D. (2008) e-Waste Assessment South Africa. Report prepared by e-Waste Association of South Africa. p. 73.

Five Winds International. (2001) Toxic and Hazardous Materials in Electronics. p. 77. Environment Canada.

Gibson K. & Tierney J. K. (2006) Electronic waste management and disposal issues and alternatives. *Enviromental Claims Journal* **18**, 321-32.

Ha N. N., Agusa T., Ramu K., Tu N. P. C., Murata S., Bulbule K. A., Parthasaraty P., Takahashi S., Subramanian A. & Tanabe S. (2009) Contamination by trace elements at e-waste recycling sites in Bangalore, India. *Chemosphere* **76**, 9-15.

Han W., Feng J., Gu Z., Chen D., Wu M. & Fu J. (2009) Polybrominated Diphenyl Ethers in the Atmosphere of Taizhou, a Major E-Waste Dismantling Area in China. *Bull. Environ. Contam. Toxicol.* **83**, 783-8.

Herat S. (2008a) Environmental impacts and use of brominated flame retardants in electrical and electronic equipment. *The Environmentalist* **28**, 348-57.

Herat S. (2008b) Green electronics through legislation and lead free soldering. *Clean-Soil Air Water* **36**, 145-51.

Herat S. (2008c) Green Electronics through Legislation and Lead Free Soldering. *CLEAN - Soil, Air, Water* **36**, 145-51.

Herat S. (2008d) Recycling of cathode ray tubes (CRTs) in electronic waste. *Clean-Soil Air Water* **36**, 19-24.

Hicks C., Dietmar R. & Eugster M. (2005) The recycling and disposal of electrical and electronic waste in China - legislative and market responses. *Environmental Impact Assessment Review* **25**, 459-71.

Hileman B. (2006) Electronic waste. *Chemical & Engineering News* **84**, 18-21.

Huisman J., Stevels A., Marinelli T. & Magalini F. (2006) Where did WEEE go wrong in Europe? Practical and academic lessons for the US. In: *Proceedings of the 2006 IEEE International Symposium on Electronics and the Environment* pp. 6 pp.- pp. Ieee.

Hyunmyung Y. & Yong-Chul J. (2006) The practice and challenges of electronic waste recycling in Korea with emphasis on extended producer responsibility (EPR). In: *Proceedings of the 2006 IEEE International Symposium on Electronics and the Environment* pp. 5 pp.- pp. Ieee.

INFORM. (2004) PC Recycling in Japan.

Jakobsson K., Thuresson K., Rylander L., Sjodin A., Hagmar L. & Bergman A. (2002) Exposure to polybrominated diphenyl ethers and tetrabromobisphenol A among computer technicians. *Chemosphere* **46**, 709-16.

Jinglei Y., Meiting J. & Williams E. (2009) Waste electrical and electronic equipment recycling in China: Practices and strategies. In: *Sustainable Systems and Technology, 2009. ISSST '09. IEEE International Symposium on* pp. 1-.

Julander A., Karlsson M., Hagstrom K., Ohlson C. G., Engwall M., Bryngelsson I. L., Westberg H. & van Bavel B. (2005) Polybrominated diphenyl ethers - plasma levels and thyroid status of workers at an electronic recycling facility. *International Archives of Occupational and Environmental Health* **78**, 584-92.

Jun-sik Yun & Park I.-s. (2007) Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles. p. 27. ECO-FRONTIER.
Kang H. Y. & Schoenung J. M. (2005) Electronic waste recycling: A review of US infrastructure and technology options. *Resources Conservation and Recycling* **45**, 368-400.
Katos G. & Hoye J. (2005) Household Electrical & Electronic Waste Survey 2005: Report of Findings. p. 117. IPSOS.
Kojima M., Yoshida A. & Sasaki S. (2009) Difficulties in applying extended producer responsibility policies in developing countries: case studies in e-waste recycling in China and Thailand. *Journal of Material Cycles and Waste Management* **11**, 263-9.
Laissaoui S. E. & Rochat D. (2008) Morocco: E-waste Country Assessment. In: *19th Waste Management Conference of the Insitutute of Waste Management South Africa (WasteCon2008)* pp. 521-6, Durban, South AfricaLee J.-c., Song H. T. & Yoo J.-M. (2007) Present status of the recycling of waste electrical and electronic equipment in Korea. *Resources, Conservation and Recycling* **50**, 380-97.
Leung A., Cai Z. W. & Wong M. H. (2006) Environmental contamination from electronic waste recycling at Guiyu, southeast China. *Journal of Material Cycles and Waste Management* **8**, 21-33.
Leung A. O. W., Luksemburg W. J., Wong A. S. & Wong M. H. (2007) Spatial distribution of polybrominated diphenyl ethers and polychlorinated dibenzo-p-dioxins and dibenzofurans in soil and combusted residue at Guiyu, an electronic waste recycling site in southeast China. *Environmental Science & Technology* **41**, 2730-7.
Li L., Geiser, K. (2005) Environmentally reponsible public procurement (ERPP) and its implications for integrated product policy (IPP). *Journal of Cleaner Production* **13**, 705-12.
Lincoln J. D., Ogunseitan O. A., Saphores J.-D. M., Schoenung J. M., Nixon H. & Shapiro A. A. (2005) Environmentally benign materials for electronics: a review of current developments and emerging technologies. In: *Advanced Packaging Materials: Processes, Properties and Interfaces, 2005. Proceedings. International Symposium on* pp. 139-43.
Liu W. L., Shen C. F., Zhang Z. & Zhang C. B. (2009) Distribution of Phthalate Esters in Soil of E-Waste Recycling Sites from Taizhou City in China. *Bull. Environ. Contam. Toxicol.* **82**, 665-7.
Luo Q., Cai Z. W. & Wong M. H. (2007a) Polybrominated diphenyl ethers in fish and sediment from river polluted by electronic waste. *Science of The Total Environment ,* **383**, 115-127.
Luo Q., Wong M. & Cai Z. (2007b) Determination of polybrominated diphenyl ethers in freshwater fishes from a river polluted by e-wastes. *Talanta*, ***72****, 1644-1649*.
Markarian J. (2005) Flame retardants for polyamides - new developments and processing concerns. *Plastics, Additives and Compounding* **7**, 22-5.
Meinhardt Infrastructure & Environment Pty Ltd. (2004) Electronic Waste Recycling Development Strategy for Victoria. p. 41. Multimedia Victoria.
Mureithi M., T W., A W., A F. & Schluep M. (2008) E-waste in Kenya: Baseline Assessment. In: *19th Waste Management Conference of the Insitutute of Waste Management South Africa (WasteCon2008)* pp. 502-9, Durban, South Africa.

National Toxic Network & Island Sustainability Alliance. (2008) E-waste in the Pacific: The Rising Tide Fiji and Samoa. p. 20.
Nnorom I. C. & Osibanjo O. (2008) Overview of electronic waste (e-waste) management practices and legislations, and their poor applications in the developing countries. *Resources Conservation and Recycling* **52**, 843-58.
Perchards. (2005) Transposition of the WEEE and RoHS Directives in Other EU Member States. p. 104.
Pettersson-Julander A., van Bavel B., Engwall M. & Westberg H. (2004) Personal air sampling and analysis of polybrominated diphenyl ethers and other bromine containing compounds at an electronic recycling facility in Sweden. *Journal of Environmental Monitoring* **6**, 874-80.
Planning Institute of Jamiaca. (2007) Management of Hazardous & Solid Wastes in Jamaica. Reoprt prepared by the Sustainable Development and Regional Planning Division. p. 50.
Puckett J., Byster L., Westervelt S., Gutierrez R., Davis S., Hussain A. & Dutta M. (2002) Exporting Harm: The High-Tech Trashing of Asia. Basel Action Network and Silicon Valley Toxics Coalition.
Schluep M., Hageluken C., Kuehr R., Magalini F., Maurer C., Meskers C., Mueller E. & Wang F. (2009) Recycling - From E-waste to Resources. Report prepared by Swiss Federal Laboratories for Materials Testing and Research, Umicore Precious Metal Refining and the United Nations University.
Schwarzer S., Bono A. D., Peduzzi P., Giuliani G. & Kluser S. (2005) E-waste, the hidden side of IT equipment's manufacturing and use. In: *UNEP Early Warning on Emerging Environmental Threats No. 5*.
Shimizu K. (2003) New law requires recycling of PCs at consumers' expense. In: *The Japan Times*.
Sjodin A., Patterson D. G. & Bergman A. (2001) Brominated flame retardants in serum from US blood donors. *Environmental Science & Technology* **35**, 3830-3.
Solmer J. S. & Stoll R. G. (2007) United States: Electronic Waste - New Developments. In: *Folley and Lardner*. Folley and Lardner.
Streicher-Porte M. & Geering A. C. Opportunities and Threats of Current E-Waste Collection System in China: A Case Study from Taizhou with a Focus on Refrigerators, Washing Machines, and Televisions. *Environ. Eng. Sci.* **27**, 29-36.
Tang X. J., Shen C. F., Shi D. Z., Cheema S. A., Khan M. I., Zhang C. K. & Chen Y. X. Heavy metal and persistent organic compound contamination in soil from Wenling: An emerging e-waste recycling city in Taizhou area, China. *Journal of Hazardous Materials* **173**, 653-60.
Tojo,N. Extended Producer Responsibility. Presentation to Greenpeace Seminar on Extended Producer Responsibility, 11 April **2005**, Manila, Philippines.
Tue N. M., Sudaryanto A., Minh T. B., Isobe T., Takahashi S., Viet P. H. & Tanabe S. Accumulation of polychlorinated biphenyls and brominated flame retardants in breast milk from women living in Vietnamese e-waste recycling sites. *Science of The Total Environment* **In Press,** http://dx.doi.org/10.1016/j.scitotenv.2010.01.012
UNEP. (2007a) The Environmentally Sound Management of Electrical and Electronic Waste (E-waste) Under the Basel Convention. p. 13. Secretariat of the Basel Convention.

UNEP. (2007b) Report of the Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal on its eighth meeting. p. 109.
United Nations. (2007) Basel Convention Bulletin. p. 8. Secretariat of the Basel Convention.
United Nations University. (2007) UN, Industry, Others Partner to Create World Standards For E-Scrap Recycling, Harvest of Valuable Components. United Nations University, Office of Communications.
United Nations University. (2007) 2008 Review of Directive 2002/96 on Waste Electrical and Electronic Equipment (WEEE).
United States Government Accountability Office. (2005) Electronic Waste: Strengthening the Role of the Federal Government in Encouraging Recycling and Reuse. p. 57.
Wang D. L., Cai Z. W., Jiang G. B., Leung A., Wong M. H. & Wong W. K. (2005) Determination of polybrominated diphenyl ethers in soil and sediment from an electronic waste recycling facility. *Chemosphere* **60**, 810-6.
Wang F., Leung A. O. W., Wu S. C., Yang M. S. & Wong M. H. Chemical and ecotoxicological analyses of sediments and elutriates of contaminated rivers due to e-waste recycling activities using a diverse battery of bioassays. *Environmental Pollution* **In Press, Corrected Proof**.
Wang H. M., Yu Y. J., Han M., Yang S. W., li Q. & Yang Y. (2009) Estimated PBDE and PBB Congeners in Soil from an Electronics Waste Disposal Site. *Bull. Environ. Contam. Toxicol.* **83**, 789-93.
Wang J. P. & Guo X. K. (2006) Impact of electronic wastes recycling on environmental quality. *Biomedical and Environmental Sciences* **19**, 137-42.
Wang T., Fu J., Wang Y., Liao C., Tao Y. & Jiang G. Use of scalp hair as indicator of human exposure to heavy metals in an electronic waste recycling area. *Environmental Pollution* **In Press, Corrected Proof**.
Wasswa J. & Schluep M. (2008) e-Waste Assessment in Uganda. p. 35.
Widmer R., Oswald-Krapf H., Sinha-Khetriwal D., Schnellmann M. & Boni H. (2005) Global perspectives on e-waste. *Environmental Impact Assessment Review* **25**, 436-58.
Wone S. S., Rochat D., Gassama C. & Kane C. (2008) Senegal: E-waste Country Assessment. In: *19th Waste Management Conference of the Insitutute of Waste Management South Africa (WasteCon2008)* pp. 516-20, Durban, South Africa.
Wong C. S. C., Wu S. C., Duzgoren-Aydin N. S., Aydin A. & Wong M. H. (2007) Trace metal contamination of sediments in an e-waste processing village in China. *Environmental Pollution* **145**, 434-42.
Xuefeng W., Jinhui L., Liu H., Fengfii Y., Lixiao H., Heping L. & Zhenyu L. (2006) An agenda to move forward e-waste recycling and challenges in China. In: *Proceedings of the 2006 IEEE International Symposium on Electronics and the Environment* pp. 6 pp.- pp. Ieee.
Yu X. Z., Gao Y., Wu S. C., Zhang H. B., Cheung K. C. & Wong M. H. (2006) Distribution of polycyclic aromatic hydrocarbons in soils at Guiyu area of China, affected by recycling of electronic waste using primitive technologies. *Chemosphere* **65**, 1500-9.