E-Waste Management

Ankur Budhraja[*]
Virtusa Polaris Consulting Services Pvt. Ltd,
India

Abstract— "E-waste" describes discarded electrical or electronic devices nearing the end of their "useful life". E-wastes are considered dangerous, as certain components of some electronic products contain materials that are hazardous, depending on their condition and density. The hazardous content of these materials pose a threat to human health and environment. Discarded computers, televisions, VCRs, stereos, copiers, fax machines, electric lamps, cell phones, audio equipment and batteries if improperly disposed can leach lead and other substances into soil and groundwater. Many of these products can be reused, refurbished, or recycled in an environmentally sound manner so that they are less harmful to the ecosystem. This paper highlights the hazards of e-wastes, the need for its appropriate management and options that can be implemented.

Keywords— electronic devices, dangerous, hazardous, threat, harmful, reused, recycled.

I.   INTRODUCTION

Electronic waste, e-waste, e-scrap or Electronic-disposal, is a term used to cover almost all types of electrical and electronic equipment (EEE) that has or could enter the waste stream. Although e waste is a general term, it can be considered to cover TVs, computers, mobile phones, white goods (e.g. fridges, washing machines, dryers etc), home entertainment and stereo systems, toys, toasters, kettles – almost any household or business item with circuitry or electrical components with power or battery supply.

E-wastes are considered dangerous, as certain components of some electronic products contain materials that are hazardous, depending on their condition and density. The hazardous content of these materials pose a threat to human health and environment.

A.   Objectives of study

The main objective of the study is to understand the disposal of end of life appliances which includes their collection, financing and recycling through the description, analysis and comparison of the prevalent practices. The other objectives are explained as follows:
1. Identify the actual quantity of e-waste.
2. Study the present e-waste management practices and different risks associated with it.
3. Estimate the future e-waste generation.
4. Suggest alternative solutions for end users, manufacturers and producers of e-waste.

B.   Statistics

1. 80 to 85 percent of electronic products were discarded in landfills or incinerators, which can release certain toxics into the air.
2. E-waste represents 2 percent of America's trash in landfills, but it equals 70 percent of overall toxic waste. The extreme amount of lead in electronics alone causes damage in the central and peripheral nervous systems, the blood and the kidneys.
3. 20 to 50 million metric tons of e-waste are disposed worldwide every year.
4. Cell phones and other electronic items contain high amounts of precious metals like gold or silver. Americans dump phones containing over $60 million in gold/silver every year.
5. Only 12.5 percent of e-waste is currently recycled.
6. For every 1 million cell phones that are recycled, 35,274 pounds of copper, 772 pounds of silver, 75 pounds of gold, and 33 pounds of palladium can be recovered.
7. Recycling 1 million laptops saves the energy equivalent to the electricity used by 3,657 U.S. homes in a year.
8. E-waste is still the fastest growing municipal waste stream in America, according to the EPA.
9. A large number of what is labeled as "e-waste" is actually not waste at all, but rather whole electronic equipment or parts that are readily marketable for reuse or can be recycled for materials recovery.
10. It takes 539 pounds of fossil fuel, 48 pounds of chemicals, and 1.5 tons of water to manufacture one computer and monitor.
11. Electronic items that are considered to be hazardous include, but are not limited to:

(i) Television and computer CRT monitors   (ii) LCD desktop monitors
(iii) Laptop computers with LCD displays   (iv) LCD televisions
(v) Plasma televisions   (vi) Portable DVD players with LCD screens

C. Sources of e-Waste
- IT and Telecom Equipments
- Large Household Appliances
- Small Household Appliances
- Consumer and Lighting Equipments
- Elecrical and Electronic Tools
- Toys and Sports Equipments
- Medical Equipments
- Monitor and Control Instruments

II. E-WASTE GROWTH

E-waste is growing exponentially simply because the markets in which these products are produced are also growing rapidly as many parts of the world cross over to the other side of the 'Digital Divide'. For example, between 2000 and 2005, the Organization for Economic Co-operation and Development (OECD) notes a 22% growth in Information and Communications Technology (ICT) in China. Furthermore, China was the 6th largest ICT market in 2006, after the US, Japan, Germany, UK and France. This is astounding when one considers that just ten years ago, under 1% of China's population owned a computer.

Computers are only one part of the e-waste stream though, as we see that in the EU in 2005, fridges and other cooling and freezing appliances, combined with large household appliances, accounted for 44% of total e-waste.

Rapid product innovations and replacement, especially in ICT and office equipment, combined with the migration from analogue to digital technologies and to flat-screen TVs and monitors, for example, are fuelling the increase. Additionally, economies of scale have given way to lower prices for many electrical goods, which has increased global demand for many products that eventually end up as e-waste.

A. Difference from General Municipal Waste

In addition to various hazardous materials, e-waste also contains many valuable and precious materials. In fact up to 60 elements from the periodic table can be found in complex electronics. Using the personal computer (PC) as an example – a normal Cathode Ray Tube (CRT) computer monitor contains many valuable but also many toxic substances. One of these toxic substances is cadmium (Cd), which is used in rechargeable computer batteries and contacts and switches in older CRT monitors.
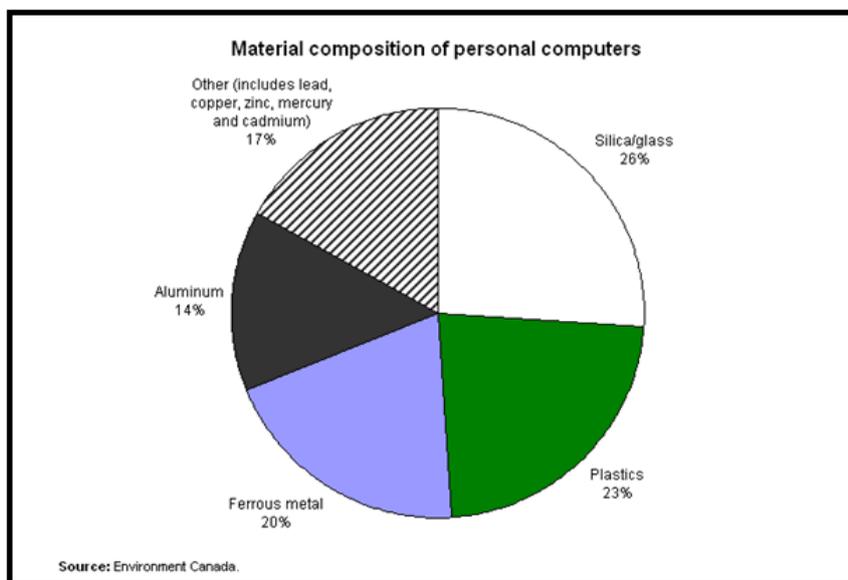

Fig. 1 Material composition of personal computers

Cadmium can bio-accumulate in the environment and is extremely toxic to humans, in particular adversely affecting kidneys and bones. It is also one of the six toxic substances that has been banned in the European Restriction on Hazardous Substances (RoHS) Directive. Beyond CRT monitors, plastics, including polyvinyl chloride (PVC) cabling is used for printed circuit boards, connectors, plastic covers and cables.

When burnt or land-filled, these PVCs release dioxins that have harmful effects on human reproductive and immune systems. Mercury (Hg), which is used in lighting devices in flat screen displays, can cause damage to the nervous system, kidneys and brain, and can even be passed on to infants through breast milk.

Electrical goods contain a range of other toxic substances such as lead (Pb), beryllium (Be), brominated flame retardants and polychlorinated biphenyls(PCB) just to name a few. Lead plays an important role in the overall metal production processes and while attempts to design-out lead from EEE does not necessarily mean that it is no longer used. Even the lead-free solder elements are co-produced with lead. This illustrates the need for a holistic view to be taken in analyzing the e-waste situation for working out possible solutions.

On the other hand, the huge impact of EEE on valuable metals resources must not be neglected. A mobile phone e.g. can contain over 40 elements including base metals (copper (Cu), tin (Sn),..), special metals (cobalt (Co), indium (In), antimony (Sb), ..), and precious metals (silver (Ag), gold (Au), palladium (Pd),

Similar calculations can be made for computers or other complex electronics and the increasing functionality of EEE products is largely achieved using the unique properties of precious and special metals. For example 80% of the world indium demand is used for LCD screens, over 80% of ruthenium is used for hard disks and 50% of the worldwide demand for antimony is used for flame retardants. Taking into account the highly dynamic growth rates of EEE, it becomes clear that they are a major driver for the development of demand and prices of certain metals.

Because of this complex composition of valuable and hazardous substances, specialized, often "high-tech" methods are required to process e-waste in ways that maximize resource recovery and minimize potential harm to humans or the environment.

III. ESTIMATION OF E-WASTE

Because so much of the planet's e-waste is unaccounted for, it is difficult to quantify e-waste amounts. Moreover, the types of e-waste included in government-initiated analyses and collection programs vary from country to country. Under the current version of the WEEE Directive, the EU has ten distinct product categories, whereas in North America it is typically limited to Information and Communications Technology (ICT) products and televisions and in Japan to four product categories including TVs, air conditioners, refrigerators and washing machines.

The deviation in categorization of e-waste notwithstanding, reasonable estimates are in the order of 40 million tons p.a., which is enough to fill a line of dump-trucks stretching half way around the globe.

Rapid changes in technology, changes in media (tapes, software, MP3), falling prices, and planned obsolescence have resulted in a fast-growing surplus of electronic waste around the globe. Display units (CRT, LCD, LED monitors), Processors (CPU, GPU, or APU chips), memory (DRAM or SRAM), and audio components have different useful lives. Processors are most frequently out-dated (by software no longer being optimized) and are more likely to become "e-waste", while display units are most often replaced while working without repair attempts, due to changes in wealthy nation appetites for new display technology.

An estimated 50 million tons of E-waste are produced each year. The USA discards 30 million computers each year and 100 million phones are disposed of in Europe each year. The Environmental Protection Agency estimates that only 15-20% of e-waste is recycled, the rest of these electronics go directly into landfills and incinerators.

According to a report by UNEP titled, "Recycling - from E-Waste to Resources," the amount of e-waste being produced - including mobile phones and computers - could rise by as much as 500 percent over the next decade in some countries, such as India. The United States is the world leader in producing electronic waste, tossing away about 3 million tons each year. China already produces about 2.3 million tons (2010 estimate) domestically, second only to the United States. And, despite having banned e-waste imports, China remains a major e-waste dumping ground for developed countries.

In the United States, an estimated 70% of heavy metals in landfills comes from discarded electronics.

Electrical waste contains hazardous but also valuable and scarce materials. Up to 60 elements can be found in complex electronics.

A. Economical Method
Econometric method to estimate the e-waste is as follows,

$$\sum_{t=1}^{i} ew = \sum_{t=1}^{i} (P + S + I + A + T + H) * C$$

Where,

ew: It is e-waste generated in region at time t

S: Shops and malls in region

A: Number of Schools, colleges,et

H: Health care institutions in all municipal corporations

C: E-Waste generarion capacity (i.e. percentage of e-waste w.r.t. solid waste in the region)

P: Population of region at time t

I: Number of industrial units in region

T: Theaters in region

IV. EFFECTS
The processes of dismantling and disposing of electronic waste in the third world lead to a number of health and environmental impacts as illustrated in the graphic. Liquid and atmospheric releases end up in bodies of water, groundwater, soil and air and therefore in land and sea animals – both domesticated and wild, in crops eaten by both animals and human, and in drinking water.

A. *Effects on Human Health*

Table I The Health Effects Of The Processing Of Different Electronic Waste Components

Source of e-wastes	Constituent	Health effects
Solder in printed circuit boards, glass panels and gaskets in computer monitors	Lead (PB)	Damage to central and peripheral nervous systems, blood systems and kidney damage. Affects brain development of children.
Chip resistors and semiconductors	Cadmium (CD)	Toxic irreversible effects on human health. Accumulates in kidney and liver. Causes neural damage. Teratogenic.
Relays and switches, printed circuit boards	Mercury (Hg)	Chronic damage to the brain. Respiratory and skin disorders due to bioaccumulation in fishes.
Corrosion protection of untreated and galvanized steel plates, decorator or hardner for steel housings	Hexavalent chromium (Cr) VI	Asthmatic bronchitis. DNA damage.
Cabling and computer housing	Plastics including PVC	Burning produces dioxin. It causes Reproductive and developmental problems; Immune system damage; Interfere with regulatory hormones
Plastic housing of electronic equipments and circuit boards.	Brominated flame retardants (BFR)	Disrupts endocrine system functions
Front panel of CRTs	Barium (Ba)	Short term exposure causes: Muscle weakness; Damage to heart, liver and spleen.
Motherboard	Beryllium (Be)	Carcinogenic (lung cancer), Inhalation of fumes and dust. Causes chronic beryllium disease or beryllicosis. Skin diseases such as warts.

B. *Effects on Environment*

Table III The Environmental Impact Of The Processing Of Different Electronic Waste Components

E-Waste Component	Process Used	Potential Environmental Hazard
Cathode ray tubes (used in TVs, computer monitors, ATM, video cameras, and more)	Breaking and removal of yoke, then dumping	Lead, barium and other heavy metals leaching into the ground water and release of toxic phosphor
Printed circuit board (image behind table - a thin plate on which chips and other electronic components are placed)	De-soldering and removal of computer chips; open burning and acid baths to remove final metals after chips are removed.	Air emissions as well as discharge into rivers of glass dust, tin, lead, brominated dioxin, beryllium cadmium, and mercury
Chips and other gold plated components	Chemical stripping using nitric and hydrochloric acid and burning of chips	Hydrocarbons, heavy metals, brominated substances discharged directly to rivers acidifying fish and flora. Tin and lead contamination of surface and groundwater. Air emissions of brominated dioxins,heavy metals, hydrocarbons
Plastics from printers, keyboards, monitors, etc.	Shredding and low temp melting to be reused	Emissions of brominated dioxins, heavy metals and hydrocarbons
Computer wires	Open burning to remove copper	Hydrocarbon ashes released into air, water and soil.

C. *Information Security*

E-waste presents a potential security threat to individuals and exporting countries. Hard drives that are not properly erased before the computer is disposed of can be reopened, exposing sensitive information. Credit card numbers, private financial data, account information and records of online transactions can be accessed by most willing individuals. Organized criminals in Ghana commonly search the drives for information to use in local scams.

V.   MANAGEMENT OF E-WASTE

It is estimated that 75% of electronic items are stored due to uncertainty of how to manage it. These electronic junks lie unattended in houses, offices, warehouses etc. and normally mixed with household wastes, which are finally disposed off at landfills. This necessitates implementable management measures.

In industries management of e-waste should begin at the point of generation. This can be done by waste minimization techniques and by sustainable product design. Waste minimization in industries involves adopting:

- inventory management
- production-process modification
- volume reduction
- recovery and reuse

A.   *Inventory Management*

Proper control over the materials used in the manufacturing process is an important way to reduce waste generation. By reducing both the quantity of hazardous materials used in the process and the amount of excess raw materials in stock, the quantity of waste generated can be reduced. This can be done in two ways i.e. establishing material-purchase review and control procedures and inventory tracking system.

Developing review procedures for all material purchased is the first step in establishing an inventory management program. Procedures should require that all materials be approved prior to purchase. In the approval process all production materials are evaluated to examine if they contain hazardous constituents and whether alternative non-hazardous materials are available.

Another inventory management procedure for waste reduction is to ensure that only the needed quantity of a material is ordered. This will require the establishment of a strict inventory tracking system.

B.   *Production-process Modification*

Changes can be made in the production process, which will reduce waste generation. This reduction can be accomplished by changing the materials used to make the product or by the more efficient use of input materials in the production process or both. Potential waste minimization techniques can be broken down into three categories:

i) Improved operating and maintenance procedures,
ii) Material change and
iii) Process-equipment modification.

Improvements in the operation and maintenance of process equipment can result in significant waste reduction. This can be accomplished by reviewing current operational procedures or lack of procedures and examination of the production process for ways to improve its efficiency. Instituting standard operation procedures can optimise the use of raw materials in the production process and reduce the potential for materials to be lost through leaks and spills. A strict maintenance program, which stresses corrective maintenance, can reduce waste generation caused by equipment failure. An employee-training program is a key element of any waste reduction program. Training should include correct operating and handling procedures, proper equipment use, recommended maintenance and inspection schedules, correct process control specifications and proper management of waste materials.

Hazardous materials used in either a product formulation or a production process may be replaced with a less hazardous or non-hazardous material. This is a very widely used technique and is applicable to most manufacturing processes. Implementation of this waste reduction technique may require only some minor process adjustments or it may require extensive new process equipment. For example, a circuit board manufacturer can replace solvent-based product with water-based flux and simultaneously replace solventvapor degreaser with detergent parts washer.

Installing more efficient process equipment or modifying existing equipment to take advantage of better production techniques can significantly reduce waste generation. New or updated equipment can use process materials more efficiently producing less waste. Additionally such efficiency reduces the number of rejected or off-specification products, thereby reducing the amount of material which has to be reworked or disposed of.

C.   *Volume Reduction*

Volume reduction includes those techniques that remove the hazardous portion of a waste from a non-hazardous portion. These techniques are usually to reduce the volume, and thus the cost of disposing of a waste material. The techniques that can be used to reduce waste-stream volume can be divided into two general categories: source segregation and waste concentration. Segregation of wastes is in many cases a simple and economical technique for waste reduction. Wastes containing different types of metals can be treated separately so that the metal value in the sludge can be recovered. Concentration of a waste stream may increase the likelihood that the material can be recycled or reused. Methods include gravity and vacuum filtration, ultra filtration, reverse osmosis, freeze vaporization etc.

For example, an electronic component manufacturer can use compaction equipments to reduce volume of waste cathode ray-tube.

D.   *Recovery and Reuse*

Recycling raw materials from end-of-life electronics is an effective solution to the growing e-waste problem. Most electronic devices contain a variety of materials, including metals that can be recovered for future uses. By dismantling

and providing reuse possibilities, intact natural resources are conserved and air and water pollution caused by hazardous disposal is avoided.

This technique could eliminate waste disposal costs,
reduce raw material costs and provide income from a salable waste. A number of physical and chemical techniques are available to reclaim a waste material such as reverse osmosis, electrolysis, condensation, electrolytic recovery, filtration, centrifugation etc. For example, a printed-circuit board manufacturer can use electrolytic recovery to reclaim metals from copper and tin-lead plating bath.

However recycling of hazardous products has little environmental benefit if it simply moves the hazards into secondary products that eventually have to be disposed of. Unless the goal is to redesign the product to use nonhazardous materials, such recycling is a false solution.
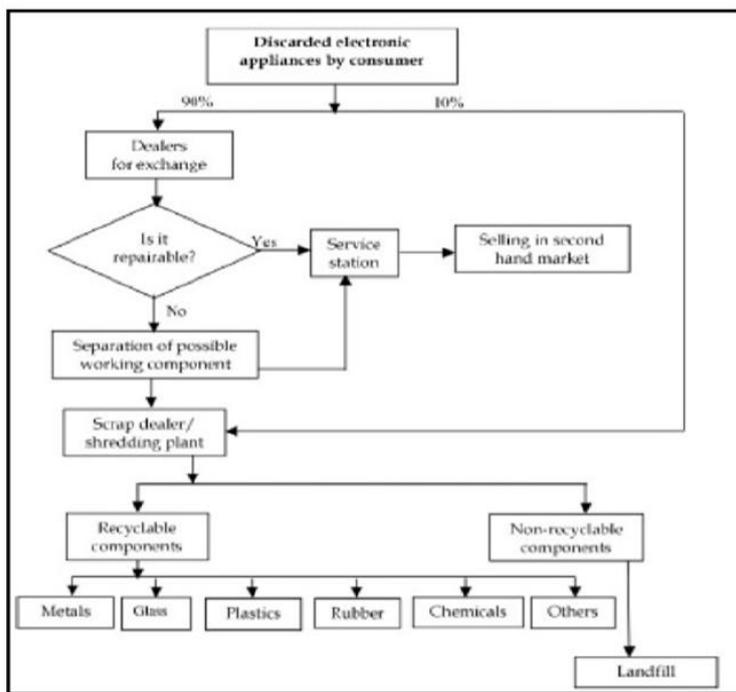

Fig.2 Recycling and Disposal of Electronic Appliances

VI. MANAGEMENT OPTIONS

Considering the severity of the problem, it is imperative that certain management options be adopted to handle the bulk e-wastes. Following are some of the management options suggested for the government, industries and the public.

A. *Responsibilities of the Government*

- Government should set up regulatory agencies in each district, which are vested with the responsibility of coordinating and consolidating the regulatory functions of the various government authorities regarding hazardous substances.
- Government should be responsible for providing an adequate system of laws, controls and administrative procedures for hazardous waste management. A comprehensive law that provides e-waste regulation and management and proper disposal of hazardous wastes is required. Under this law, the agency concerned should:
  ✓ Collect basic information on the materials from manufacturers, processors and importers and to maintain an inventory of these materials. The information should include toxicity and potential harmful effects.
  ✓ Identify potentially harmful substances and require the industry to test them for adverse health and environmental effects.
  ✓ Control risks from manufacture, processing, distribution, use and disposal of electronic wastes.
  ✓ Encourage beneficial reuse of "e-waste" and encouraging business activities that use waste". Set up programs so as to promote recycling among citizens and businesses.
  ✓ Educate e-waste generators on reuse/recycling options
- Government must encourage research into the development and standard of hazardous waste management, environmental monitoring and the regulation of hazardous waste-disposal.
- Government should enforce strict regulations and heavy fines levied on industries, which do not practice waste prevention and recovery in the production facilities.
- Polluter pays principle and extended producer responsibility should be adopted.
- Government should encourage and support NGOs and other organizations to involve actively in solving the nation's e-waste problems.

B. Responsibility and role of Industries
- Generators of wastes should take responsibility to determine the output characteristics of wastes and if hazardous, should provide management options.
- All personnel involved in handling e-waste in industries should be properly qualified and trained. Companies can adopt their own policies while handling e-wastes.
    - ✓ Use label materials to assist in recycling (particularly plastics).
    - ✓ Standardize components for easy disassembly.
    - ✓ Re-evaluate 'cheap products' use, make product cycle 'cheap' and so that it has no inherent value that would encourage a recycling infrastructure.
    - ✓ Create computer components and peripherals of biodegradable materials.
    - ✓ Encourage / promote / require green procurement for corporate buyers.
    - ✓ Look at green packaging options.
- Companies can and should adopt waste minimization techniques, which will make a significant reduction in the quantity of e-waste generated. It is a "reverse production" system that designs infrastructure to recover and reuse every material contained within e-wastes metals such as lead, copper, aluminum and gold, and various plastics, glass and wire. Such a "closed loop" manufacturing and recovery system offers a win-win situation for everyone.
- Manufacturers and distributors should undertake the responsibility of recycling/disposal of their own products.
- Manufacturers of computer monitors, television sets and other electronic devices containing hazardous materials must be responsible for educating consumers and the general public regarding the potential threat to public health and the environment posed by their products.

C. Responsibilities of the Citizen

Waste prevention is perhaps more preferred to any other waste management option including recycling. Donating electronics for reuse extends the lives of valuable products and keeps them out of the waste management system for a longer time. Reuse, in addition to being an environmentally preferable alternative, also benefits society. By donating used electronics, schools, non-profit organizations, and lower-income families can afford to use equipment that they otherwise could not afford.

E-wastes should never be disposed with garbage and other household wastes. This should be segregated at the site and sold or donated to various organizations.

While buying electronic products opt for those that:
- ✓ are made with fewer toxic constituents
- ✓ use recycled content
- ✓ are energy efficient
- ✓ are designed for easy upgrading or disassembly
- ✓ utilize minimal packaging
- ✓ offer leasing or take back options
- ✓ have been certified by regulatory authorities,

NGOs should adopt a participatory approach in management of e-wastes.

D. Consumer Awareness Efforts
- The U.S. Environmental Protection Agency (USEPA) encourages electronic recyclers to become certified by demonstrating to an accredited, independent third party auditor that they meet specific standards to safely recycle and manage electronics. This works to ensure the highest environmental standards are being maintained.
- e-Cycle, LLC: e-Cycle, LLC is the first mobile buyback and recycling company in the world to be e-Stewards, R2 and ISO 14001 certified. They work with the largest organizations in the world to raise awareness on the global e-waste crisis.
- Best Buy: Best Buy accepts electronic items for recycling, even if they were not purchased at Best Buy. For a full list of acceptable items and locations, visit Best Buy's Recycling information page.
- Staples: Staples also accepts electronic items for recycling at no additional cost. They also accept ink and printer toner cartridges. For a full list of acceptable items and locations, visit the Staples Recycling information page.
- In the US, the Consumer Electronics Association (CEA) urges consumers to dispose properly of end-of-life electronics through its recycling locator at www.GreenerGadgets.org. This list only includes manufacturer and retailer programs that use the strictest standards and third-party certified recycling locations, to provide consumers assurance that their products will be recycled safely and responsibly.
- AddressTheMess.com is a Comedy Central pro-social campaign that seeks to increase awareness of the dangers of electronic waste and to encourage recycling.
- The grassroots Silicon Valley Toxics Coalition (svtc.org) focuses on promoting human health and addresses environmental justice problems resulting from toxins in technologies.
- Basel Action Network (BAN.org) is uniquely focused on addressing global environmental injustices as a result of the global toxic trade. It works for human rights and the environment by preventing disproportionate dumping of hazardous waste on developing countries, on a large scale

- [Texas Campaign for the Environment](texasenvironment.org) (texasenvironment.org) works to build grassroots support for e-waste recycling and uses community organizing to pressure electronics manufacturers and elected officials to enact producer takeback recycling policies and commit to responsible recycling programs.
- The World Reuse, Repair, and Recycling Association (wr3a.org) is an organization dedicated to improving the quality of exported electronics and encouraging better recycling standards in importing countries
- TakeBack My TV is a project of The Electronics TakeBack Coalition and grades television manufacturers to find out which are responsible and which are not.
- E-Cycling Central is a website from the Electronic Industry Alliance which allows you to search for electronic recycling programs in your state. Ewaste.guide.info is a Switzerland-based website dedicated to improving the e-waste situation in developing and transitioning countries. The site contains news, events, case studies, and more.
- STEP: Solving the E-Waste Problem, STEP, is an initiative founded by various UN organizations to develop strategies to solve the e-waste problem, follows its activities and programs.

VII. CONCLUSION

In summary one can clearly grasp and understand the e-waste problem is of global concern because of the nature of production and disposal of waste in a globalized world. Although it is difficult to quantify global e-waste amounts, we do know that large amounts are ending up in places where processing occurs at a very rudimentary level. This raises concerns about resource efficiency and also the immediate concerns of the dangers to humans and the environment.

REFERENCES
[1]   Freeman M.H.(1989) *Standard Handbook of Hazardous Waste Treatment & Disposal*, McGrawHill Company, USA
[2]   Cedric Gossart and Jaco Huisman (2011) "*Improving e-waste policies: The role of post Normal indicators*" presented at the 2011 ESEE conference
[3]   UNEP, *Call for Global Action on E-waste*, United Nations Environment Programme (2006)
[4]   Ronald E. Hester and Roy M. Harrison, *Electronic Waste Management*
[5]   Rakesh Johri, *E-waste: Implications, regulations, and management in India and current global best practices*
[6]   R E Hester and R M Harrison, *Electronic Waste Management*

WEBSITES
[1]   http://en.wikipedia.org/wiki/Electronic_waste
[2]   http://www.ces.iisc.ernet.in/
[3]   http://www.step-initiative.org/index.php/Initiative_WhatIsEwaste.html
[4]   http://www.ewaste.in