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A Review on E-waste Management and Recycling Challenges in India

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Abstract- Electronics industry is the world's largest and fastest growing manufacturing industry. But the increase in sales of electronic equipments and their rapid obsolescence such as advancement in technology, change in fashion, style and status has resulted in generation of electronic waste which is popularly known as E-waste. E-waste contains many hazardous components that may negatively impact the environment and adversely affect human health if not properly managed. E-waste problem is of global concern due to the production and disposal of waste in a globalized world. In India, e-waste management has greater significance not only due to the generation of its own e-waste but also because of the dumping of e-waste from developed countries. This is coupled with India's lack of appropriate infrastructure and procedures for its disposal and recycling. The challenge is to develop innovative and cost- effective solutions to decontaminate polluted environments due to E-waste , to make them safe for human habitation and consumption, and to protect the functioning of the ecosystems which support life. This paper discusses the different categories of E-waste, categorization of different hazardous components present in e-waste, methods of E-waste management and an innovative bioremediation technologies which have become an eco-friendly and fruitful method to conventional clean up technologies to decontaminate e-waste from the soil-water environment, the challenges in which India is facing for the management of E-waste and suggestion for a formal method of E-waste recycling in India.

Index Terms - E-waste management, recycling, hazardous components, formal method, cost-effective solution, bioremediation

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1 INTRODUCTION

The production of electrical and electronic equipment (EEE) is one of the fastest growing global manufacturing activities. Rapid economic growth, urbanization and a growing demand for consumer goods, leads to the consumption and the production of EEE. E-waste comprises of wastes generated from used electronic devices and house hold appliances which are not fit for their original intended use and are destined for recovery, recycling or disposal(MoEF 2008).The Indian information technology(IT) industry has been one of the major drivers of change in the economy in the last decade and has contributed significantly to the digital revolution being experienced by the world(J. Zhang, X-J.Liang,2012et al ,Anwesha Borthakur,2012,S.B Wath,2010,Shalabh Agarwal ,2014). Even though electronic applications have infiltrated every aspect of our daily lives, such as comfort, health ,security ,easy information, data acquisition, the knowledge society is creating its own toxic footprints. As per D. Sinha-Khetriwal et al,(2005), while we are having some of the world's most advanced high-tech software and hardware developing facilities, India's recycling sector can be called medieval.

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The dumping of e-waste, particularly computer waste, into India from developed countries has further complicated the problems with the management of E-Waste, P.Kiddee et al(2013).The increased 'market penetration' into the developing countries and 'high obsolescence rate' make e-waste one of the fastest growing waste streams all over the world. Thus e-waste management has become not only an issue of environment but also human health. It also possesses a series challenge in disposal and recycling to both developed and developing countries (Zhang et al.,2012,Nguyen Minh Tue,2014,Xiaofeng Wang,2012,Pucket et al 2002).

In accordance with the national development policy (NDP) and for sustainable development, there is a greater need to improve the recovery and/or reuse of useful materials from waste generated from a process and/or from the use of any material and thus to reduce the waste destined for final disposal and to ensure the environmentally sound management of all materials (MoEF 2008).

As per global report Live science.com World's E-Waste grow to 33% by 2017.As per United Nations University 2013, E-Waste can fill a line of 40-ton trucks end-to-end on a highway straddling three quarters of the equator.

In USA-According to Environment protection act (EPA) in 2008, 3.16 million tones of E-waste were generated and only 13.6% of this amount was recycled. The rest was trashed in landfills or incinerators. Nearly 80% of all the E-waste are exported to Asia (MoEF 2008)

Sixty-five cities in India generate more than 60% of the total WEEE/ E-waste is generated in India.10 states generates 70% of the total WEEE/E-waste generated in India. Maharashtra ranks first followed by Tamilnadu, Andhra Pradesh, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh and Punjab in the list of WEEE/E-waste generating states in India(Shalabh Agarwal,2014,MoEF 2008).

The top states, in order of highest contribution to WEEE, include Maharashtra, Andhra Pradesh, Tamil Nadu, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh, and Punjab. The city-wise ranking of largest WEEE generators is Mumbai, Delhi ,Bangalore,Chennai, Kolkata, Ahmadabad, Hyderabad, Pune, Surat, and Nagpur. This may be due to the presence of a large number of Info Tech Parks & electronic products manufacturing companies situated in these areas, which plays the main role in E-waste generation

2 Purpose of study

The components present in the E-waste are highly toxic in nature, Present treatment techniques such as Land filling, Incineration, Recycling which has been adopted in India will cause adverse impacts for both human beings and Environment. In India around 95% of the E-waste that is recycled goes through informal sectors. Children are often found to be dismantling E-waste which contains hazardous chemicals which is very dangerous for child health. This paper points out the proper treatment technique which has to be adopted for Environmental Sustainability and also the need for a formal methods of recycling.

3 Literature review

D. Sinha-Khetriwal et al.2005 presents a comparison of the end- of-life treatment of the life treatment of electronics in two countries, Switzerland and India.S. B Wath.2010 gives an idea of E-waste composition, categorization, Global and Indian E-waste scenarios, prospects of recoverable, recyclable and recovery processes followed, and their environmental and occupational hazards. P. Kiddee et al.2013 presents an overview of toxic substances present in the E-waste, their potential environmental and human health impacts together with management strategies currently being used in certain countries. Maria-Chrysovalantou Emmanouil et al.2013 analyzed the flow in an E-waste management system, present the processes included and the necessary information that interrelate and affect the processes. Pinto,2008 provides a concise overview of India's current E-waste scenario, namely magnitude of the problem, environmental and health hazards, current disposal and recycling operations, existing legal frame work organizations working on this issue and recommendations for action. Pamela Chawla and Neelu Jain,2012 categorized future trends in obsolete computer generation in India in the next fifteen years using logistic model based approach.

E-waste is divided into different categories according to Environmental Protection Act,1986.(EU 2002,S.B Wath,2010), which is shown in table 1

Table 1: Different categories of E-Waste

Classification	Examples
Large and small household appliances	refrigerator,freezer,washing machine,cooking appliances,grinders,watches etc.
Lighting equipments	bulb,CFL
IT and telecommunication	PCs,Printers,telephones
Consumer equipment	TV,radio,video camera,amplifiers
Electrical and electronic tools	drills,saws,sewing machine
Toys leisure,and sport equipment	computer/video games,electric trains
Medical devices	with the exception of all implanted and infected products radiotherapy equipment, dialysis, nuclear medicine
Monitoring and control instruments	smoke detector,heating regulators,thermostat
Automatic dispensers	for hot drinks,money,hot and cold bottles

3 Methodology

This descriptive type article purely based on review of literatures. The data collected for this review article consisted of secondary data through literature survey.

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Literatures are collected to study the hazardous effect due to the Components present in E-Waste and the treatment techniques adopted presently and tables were drawn highlighting the salient features. From the literature survey it is clearly noted that bioremediation can be a effective method of E-Waste treatment.

Current system of E-waste recycling system in India was studied and appropriate flow charts were drawn related to recycling and the challenges on which India is facing for the proper management of E-Waste. Drawbacks of current E-Waste management systems in India has been noted and its solutions were given as findings.

4 Objective

- To study the effect of E-waste impacts for both human beings as well as environment.
- To study the methods which are available for the management of E-Waste in India and to find the hazardous effects associated with it.
- To find out the challenges in which India is facing during recycling and to suggest a formal method of recycling

5 Data and Discussion:

5.1Impacts due to Hazardous Components Present in E-Waste

E-Waste consists of both toxic and valuable materials in them (EU 2009). The fraction including iron, copper, aluminium, gold and other metals in E-waste is over 60%,while plastics account for about 30% and hazardous pollutants comprise only about 2.7%.

E-waste should not be combined with unsorted municipal waste destined for landfills because electronic waste can contain different substances, many of which are toxic, such as mercury, lead, arsenic, cadmium, etc. The table 2 below discusses about few of the toxic components present in e-waste as per Five winds International(2001), Puckett and smith(2002), P.kiddee et al (2013)

Table 2: The toxic components present in e-waste *Sources:*Five winds International(2001),Puckett and smith(2002),P.kiddee et al (2013)

Component	*E-waste product and operation disposal*	*Adverse Health Effects*
Chromium	Used to protect metal housings and plates in a computer from corrosion.	Inhaling hexavalent chromium or use bronchial maladies including asthmatic.
Cadmium	It is released as powder while crushing and milling of plastics, CRTs and circuit boards.	A carcinogen, long term exposure causes itai-itai,which affects kidneys and softens bones. It may be released with dust, entering surface water and groundwater.
Lead	Mechanical breaking of cathode ray tubes (CRTs) and removal of solder from microchips, releasing lead as powder and fumes.	A neurotoxin that affect kidneys and the reproductive system.High quantities can be fatal.It affects mental development in children.
Beryllium	Found in switch boards and printed Circuit boards.	It is a carcinogen and causing lung diseases.
Mercury	Released while breaking and burning of circuit boards and switches.	Damages brain and kidneys, impairs foetus growth and harm infants through mother's milk. Mercury in water bodies can form methylated mercury through microbial activity, which is toxic and can enter human food chain through aquatic life forms.
Plastics	Found in circuit boards, cabinets and cables. Burning PVC a component of plastics also produces dioxins. Even the dust on computer cabinets contains BFR.	They contain carcinogens. BFRs or *Brominated Flame retardants* give out carcinogenic brominated dioxins and furans. Dioxins can harm reproductive and immune systems.
Acids	Sulphuric and hydrochloric acids are often used to separate	Fumes contain chlorine and sulphur dioxide which cause respiratory problems.

	metals from circuit boards.	They are corrosive to the eye and skin.
Antimony	A metal agent in CRT glass, plastic computer housing, and a solder alloy in cabling.	It can cause stomach pain, vomiting, diarrhea and stomach ulcers through inhalation of high antimony levels over a long period of time.
Nickel	Batteries, computer housing, cathode ray tube and printed circuit boards.	Can cause allergic reaction, bronchitis and reduced lung function and lung cancers.
Selenium	Older photocopy machines.	High concentrations cause selenosis.

5.2Management Techniques of E-Waste in India

Landfilling: It is one of the most widely used methods for disposal of e-waste in India. Here, trenches are made on the flat surfaces and soil is excavated from the it. Then waste materials are buried in it, which is covered by a thick layer of soil.

Incineration: It is a controlled and complete combustion process, in which the waste material is burned in specially designed incinerators at a high temperature (900-1000^{0}C)(MoEF 2008). Some plants remove iron from the slag for recycling. By incineration some environmentally hazardous organic substances are converted into less hazardous compounds.

Recycling: Recycling is a process of dismantling ie, removal of different parts of e-waste containing dangerous substances like, PCB, Hg, separation of plastic, removal of CRT, segregation of ferrous and non-ferrous metals and printed circuit boards, hard drives, floppy drives, Compact disks, mobiles, fax machines, printers, CPUs, memory chips, connecting wires and cables can be recycled.

5.3 Environmental Impacts due to Present Management Techniques of E-Waste adopted in India

Hazards due to Landfilling: Land filling can leak. They are not completely tight throughout their lifetimes and a certain amount of chemical and metal leaching may occur. Mercury will leach when certain electronic devices, such as circuit breakers are destroyed, lead leachate occured from cathode ray tubes. The same is true for PCBs from a condenser. When brominated flame retarded plastics or cadmium containing plastics are landfilled, both PBDE and the cadmium may leach into the soil and groundwater (Schmidt,2002,Kasissi et al,2008,MoEF 2008,Valerie J Brown, 2004, research unit,Rajyasabha secretriate.2011, Shalabh Agarwal,2014).

Hazards due to Incineration: Disadvantage of incineration are the emission of flue gases and the large amount of residues due to combustion. E-waste incineration leads to the annual emissions of cadmium and mercury. The incineration of brominated flame-retardants at a low temperature of 600-800^{0}C may lead to the generation of extremely toxic polybrominated dioxins (PBDDs) and Polybrominated furans (PBDfs). Significant quantity of PVC is contained in e-waste, which makes the flue gas residues and air emissions particularly dangerous (MoEF 2008, research unit,Rajyasabha secretriate.2011, Shalabh Agrawal 2012,Divya Gupta 2012).

Hazards due to Recycling: Recycling of hazardous products have environmental benefit, only if there is a goal to redesign the product to use non-hazardous materials. The hazard associated with disassembly stage is the possibility of accidental spillages of hazardous substances. For example, mercury, found within light sources(fluorescent tubes in scanners, photocopiers, etc.) as well as switches, could be released into the air of a recycling facility upon breakage of the shell(Puckett and Smith,2002).

A hazardous emission into the air also results from recycling of e-waste containing heavy metals, such as lead, cadmium etc(Asante et al,2012,Widmer et al 2005,Chen et al 2009, Wan et al,2009).Table 3 shows the hazardous effects due to E-Waste treatment.

Table 3: Hazardous effects due to E-Waste Treatment

Treatment	Hazards
Landfilling	Leakage of toxic substances
Recycling	Accidental spillage of hazardous substances
Incineration	Escaping of flue gases to the atmosphere

5.4 Environmental Friendly Methods of E-Waste Management

Approaches for Bioremediation : Bioremediation is a general concept which includes all the actions that take place in order to biotransform an environment which has

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already altered by contaminants, to its original state(Surajit Das et al.,2014).

Microbiological processes can be applied to mobilize metals from electronic waste materials. Bacteria-*Thiobacillus, thiooxidans, T.ferrooxidans and* fungi-*Aspergillus niger ,Penicillium simplicissimum* will grow in the presence of electronic scrap(S.Gouma et al.,2014,Yangvang Wang et al.,2014,Song Jin et al.,2014,John Geraldine Sandana Mala et al.,2014.). The formation of inorganic and organic acids caused the mobilization of metals. Both fungal strains were able to mobilize Cu and Su by 65%, and Al, Ni, Pb, and Zn by more than 95%. *Thiobacilli* were able to leach more than 90% of the available Cu, Zn, Ni, and Al. Pb precipitated as $PbSO_4$ while Sn precipitated probably as SnO.

Phytoremediation for Electronic waste: Phytoremediation might be a cost effective choice complementary to engineering based approaches. Phytoremediation is making use of vegetation for the treatment of soil, sediment, and water, which has been utilized successfully in sites contaminated by PCBs and other organic pollutants which is a harmful metal in E-Waste.(Hongyan Liu et al.,2014,Wojciech Dmuchowaki et al.,2014).

In the multi-component bioremediation which includes polycyclic aromatic hydrocarbon(PAH) degrading bacteria such as (*Acinetobacter sp.), (*Glomus mosseae) and ryegrass (Lolium multiflorum), AMF(Arbuscular mycorrhizal fungi) significantly improves the growth of PAH-degrading bacteria and increased peroxidase activities in soil(Hutchinson et al.,2003,Nan Xiao et al.,2014). Interactions of ryegrass with AMF or PAH degrading bacteria significantly accelerates the dissipation of phenanthrene (PHE) and pyrene(PYR) from soil. There will be a potential for the development of a multicomponent phytoremediation system for PAH contaminated soil, involving PAH degrading bacteria, AMF and plant(Nan Xiao et al.,2014,Chen et al,2003).

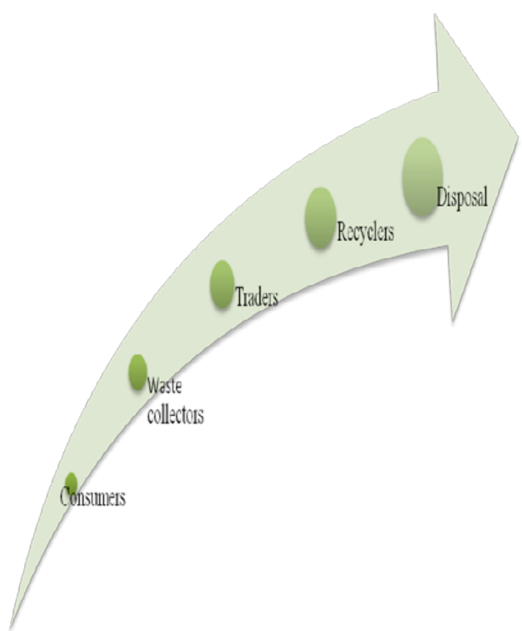
Comparing the phytoremediation potential of four plant species (rice, alfalfa, ryegrass and tall fescue) for PCBs contaminated soil from Taizhou city, which is one of the largest e-waste recycling centers in china. Higher PCBs removal percentages of 25.6-28.5% in rizosphere soil were observed after 120 days, compared with those of the nonrhizosphere(10.4-16.9%) and unplanted controls(7.3%)(Wu Qing et al.,2014).So that it can be effectively used for the neutralization of hazardous components such as PCBs.

5.5 E-waste recycling in India

India, with over 1.267 billion people, is the second most populous country in the world(World bank 2014).India is one of the fastest growing economies of the world. Unfortunately, economic growth and environmental protection indicators are at odds with one another. A report by a New Delhi based NGO, Toxics Link, on computer waste, estimated that in India business and individual households make approximately 1.38 million personal computers obsolete every year. There is also a large quantity of e-waste from manufacturing in the form of defective printed wiring boards, IC chips and other components discarded in the production process.

In India waste collectors pay consumers a positive price for their obsolete appliances (D.Sinha-Khetriwal et al, 2005). The waste collectors sell their collections to traders who aggregate and sort different kinds of waste and then sell in to recyclers, who recover the precious metals.

The entire industry is based on a network which consists of (a) collectors who collects E-Waste from primary generators such as offices, manufactures, organized market and importers.(b) traders who buy the E-Waste from collectors (c) Recyclers who dismantles waste for the reuse and precious metal extraction. Each has added values, and creating jobs, at every point in the chain. As the volume of e-waste has grown, some waste processors focus only on e-waste. Since a low level of initial investment is required to start a collection, dismantling, sorting or recovery business, it is attractive for small entrepreneurs to join the industry (D.Sinha-Khetriwal et al, 2005).



The main motive for the entrepreneurs is financial profit, not environmental or social awareness. But the trade and recycling alliances provide employment to many groups of

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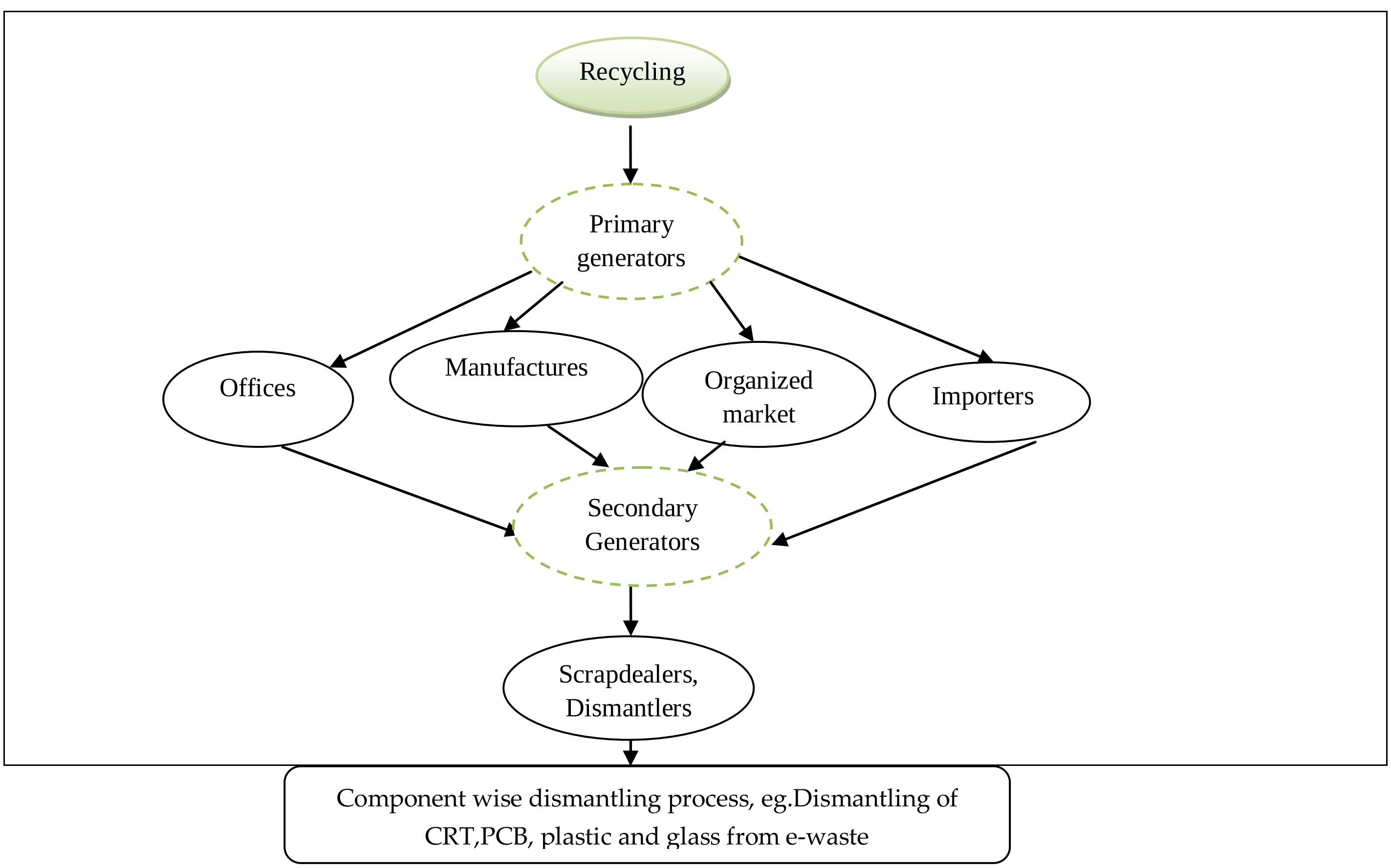
people (Baud et al,2001).E-waste recycling has become a profitable business, flourishing as an unorganized sector, mainly as backyard workshops (Empa, 2004).

For Delhi, study estimates the number of unskilled workers in recycling and recovering operations to be atleast 10,000 people (Empa 2004). The biggest drawback of the current Indian recycling system is the uncontrolled emission of hazardous toxics that are going into the air, water and soil. The health hazards from fumes, ashes and harmful chemicals affect not only the workers who come into contact with the e-waste, but also the environment.

The figure 1 below gives the flow chart showing the flow of E-Waste from orgin to destination during recycling process from primary generators to tertiary generators(MoEF 2008).



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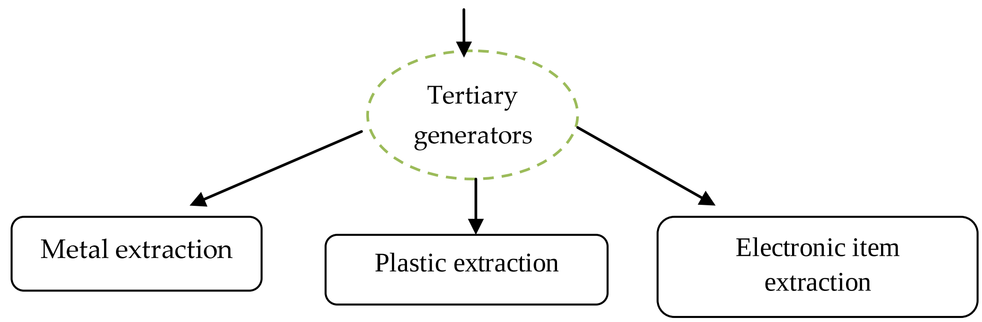

Fig: 1 Flow chart showing the flow of E-Waste from origin to destination during recycling

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5.6 E-waste recycling challenges in India

The biggest drawback of the current Indian recycling system is the uncontrolled emission of hazardous toxics that are going into the air, water and soil (D.Sinha-Khetriwal et al,2005).As per Sinha-Khetriwal, the hazards from the fumes, ashes and harmful chemicals affect not only the workers who come into contact with the E-waste, but also the environment. Over 95% of the E-waste handled by untrained workers without personal protective equipment during recycling. As global hazardous waste always flows from orgin to destinations with weaker environmental regulations, the dirty side of its recycling processes has to be properly noted. The policy should be designed and find out the effective ways to improve job quality in the recycling industry in India.(Empa et al 2004,D. Sinha-Khetriwal et al,2005). Figure 2 shows the challenges faced by India in managing E-waste (S.B Wath 2010).

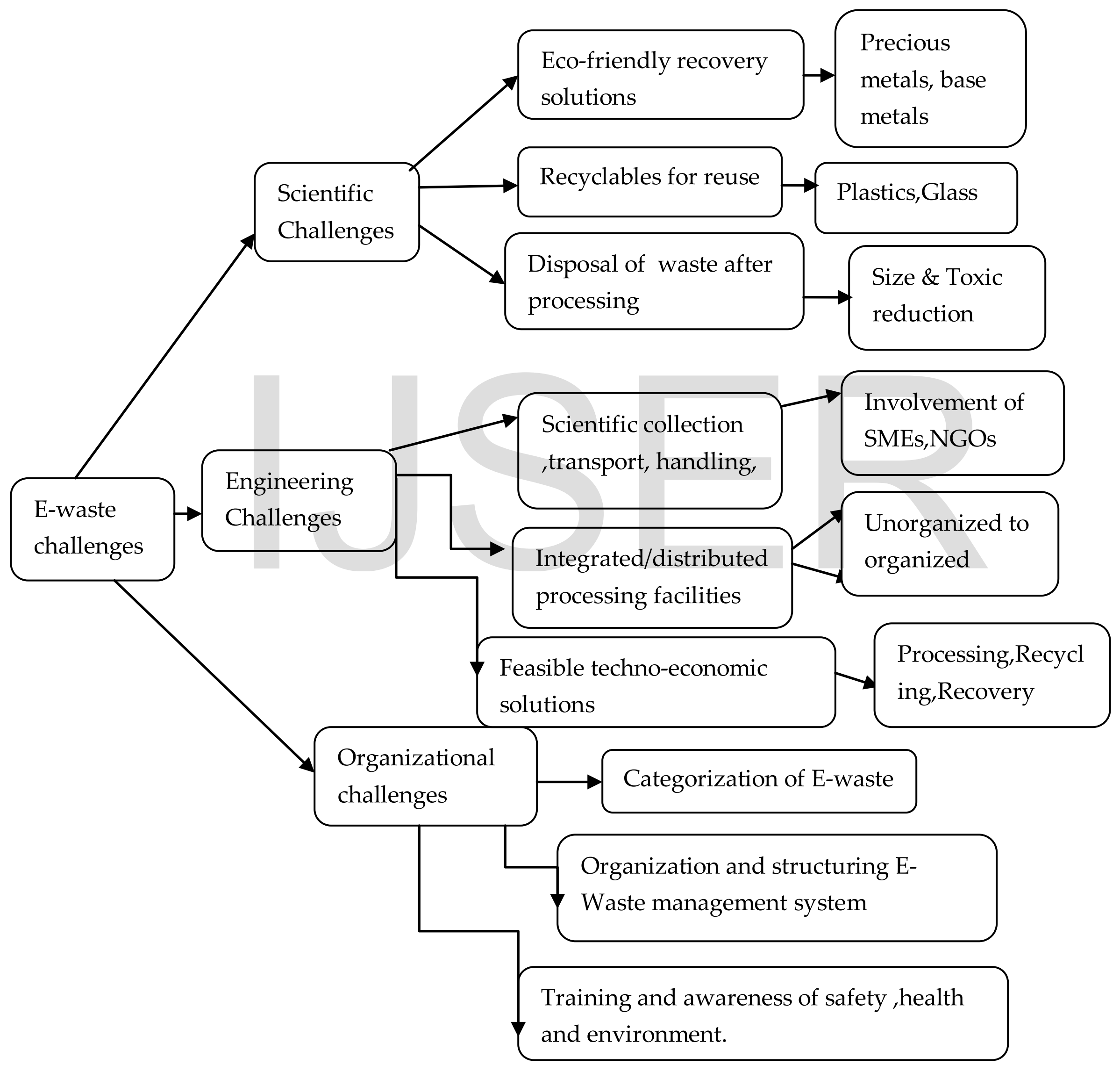

Fig 2: Flow chart showing the E-Waste challenges faced by India during E-Waste management

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5.6 Formal and Informal methods of recycling

Formal method of recycling has to be undertaken in an effective way so that it will be beneficial to the unorganized sectors. The table 4 given below discusses about the difference between present informal method of recycling system adopted in India and a formal method of Recycling.

Table 4: Difference between present informal method of recycling system adopted in India and a formal method of Recycling. *Source(research unit, Rajyasabha secretriate, New Delhi,2011)*

Informal	***Formal***
• Cathode ray tube are broken manually to separate its components – glass, metal and copper. The glass comprising lead is sold to bakeries or bangle makers. Since it retains heat, the glass goes into the base of ovens. Phosphorous if inhaled, can be toxic.The CRTs are sold to non branded television makers.	• **Components of CRT are separated by heating in a closed chamber, which sucks out phosphorous from the components. They are then crushed in shredder machines. Glass containing lead is sold to the companies that manufacture the CRTs.**
• Circuit boards have good plasted brass pins, microchips and condensers which are separated by heating. Fumes released during heating are toxic. Gold-plated brass pins are soaked in acid to recover the gold and brass separately. Microchips and condensers are heated in big containers filled with acid to extract metallic parts	• **Circuit boards are crushed in shredder machines. They are send to approved smelters abroad,where after smelting at 1200 ^{0}C, the metals in the circuit board collect together. Since smelting is carried out in a closed chamber at high temperature, it is not hazardous. The metals-Lead, copper, Nickel, Tin, silver, Palladium-are then separated by electro refining.**
• No safety precautions followed informal recyclers paid Rs 200-300 daily in seelampur: Rs 100-150 in Moradabad.	• **Protective equipments- Gloves, masks, shoes, caps-are provided to the employees.Rs.5000 per month paid to the unskilled workers.**
• Minimum capital investment required. Cost includes price of e-scrap, bribes to transfer it across slate borders and set up and run shops, and rent for the work space.	• **Investment for a dismantler is about Rs 30 lakh and for a recycling plant, about Rs 25 crore.**

6 Findings

- E-waste should not be combined with unsorted municipal waste destined for landfills because electronic waste can contain different substances, many of which are toxic, such as lead, mercury, arsenic, cadmium, etc.
- Bioremediation might be an environmental friendly and fruitful method complementary to engineering based approaches which is also a effective solution for environmental Sustainability.
- Informal recycling leads to uncontrolled emission of hazardous toxics that are going into the air, water and soil. The health hazards from fumes, ashes and harmful chemicals affect not only the workers who come

into contact with the e-waste, but also the environment.

- As global hazardous waste always flows from origin to destinations with weaker environmental regulations, the dirty side of its recycling processes would never be properly addressed.
- A policy should be designed and find out the effective ways to improve job quality in the recycling industry in India. A formal method of recycling will be a better option.

7 Conclusion

The problem of E-waste is growing tremendously not only in India but all over the world. Improper handling and management of e-waste during recycling and other end-of-life treatment options may develop potentially significant risks to both human health and environment. In India consumers is expected to receive payment for their E-waste, which is viewed as a potentially valuable resource. If management of E-waste is properly carried out, is an opportunity as it is often called as “urban mining”. Bioremediation methods can improve the scenario of current treatment practices available for e-waste. Current informal method of E-waste management in India is causing risks that could to a large extent, and this could be rectified by using a formal method of E-waste recycling.

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