IOSR Journal of Business and Management (IOSR-JBM)
e-ISSN: 2278-487X, p-ISSN: 2319-7668
PP 27-33
www.iosrjournals.org

E-Waste Management and Recovery of Valuable Metals

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Abstract:*With Rapid Growth Of Waste Electrical And Electronic Equipment (Weee), It Is Needed To Recycle The Electronic Waste (E-Waste). The Recycling Of Weee System Is Improved Day By Day In The World. The Aim Of The Paper Is To Give An Overview Of The Articles, Research Papers Related To Waste Management. Material Recovery And Review On Waste Management Are Found To Be The Leading Topics In This Area. Researchers Have Proved That Economically Viable Recycling Of Such Waste Is Possible In An Environmentally Friendly Manner.*
Keywords: *E-Waste, Generation, Management, Metal Recovery*

I. Introduction:

The Largest And Fastest Growing Waste Stream Among The Municipal Waste In The World Is Electronic Waste (E-Waste) Generation [1], [2], [3]. Waste Electrical And Electronic Equipment (WEEE) Is One Of The Most Important Part Of Household Waste. In WEEE, Various Types Of Easily Recyclable Materials Such As Metals, Plastics Or Glass [4], [5] And Also Some Hazardous Materials Which Are A Reason Of Environmental And Health Problem [6] Are Present. WEEE Management System Is Introduced In Developed And Developing Countries [7]For Disposing The Hazardous Substances. Mobile Phone Wastes Are One Of The Part Of WEEE.

It Is Estimated That The Usage Of Mobile Phone Increased From About 500 Million To 5000 Million In 1year (2010-2011) Worldwide [8], [9].Now A Days, The Number Of Mobile Phone Users Is Exponentially Growing. Globally, More Than 7 Billion Mobile Phone Subscriptions Will Be There By The End Of 2015, With A Population-Wise Penetration Rate Of 97% Is Calculated Bythe International Telecommunication Union (ITU) [10]. Due Torapid Change Of Mobile Phone Models With Advanced Technology Forces The Consumer To Change Their Phones More Frequently. Therefore, The Service Life Of Mobile Phones Becomes Too Short And Thereby Generating Large Amount Of Waste Streams [11]-[13].The Usage Period Of A Mobile Phone Is Less Than 3 Years In Developing Countries And Less Than 2 Years In Developed Countries. Thus It Can Be Predicted That Most Of The Mobile Phone Became Into Waste Stream May Still Have Performance Value. So These Can Be Recovered And Recycled[14].

The Presence Of Various Materials Such As Plastics, Glass, Metals And Ceramics In Large Quantities[15] Make Mobile Phones Are Very Complex Products For Recycling. A Typical Mobile Phone Consists Of Different Parts Like Display Unit, Battery, Front And Back Cases And Printed Circuit Boards (Pcbs).About 50% Of These Parts Are Made Up Of Plastics And The Rest Is The Other Materials [16], [17]. Pcbs Alone Contain Variety Of Metals Such As Gold, Silver, Copper, Iron, And Platinumetc[18]. From Surveys And Literatures, It Is Seen That About 80% Of The Materials Used In Mobile Phones Can Be Effectively Recycled [19]. In Mobile Phones, The Commonly Used Engineering Grade Polymers Are Polycarbonate (PC), Acrylonitrile–Butadiene–Styrene (ABS), PC/ABS Blends, And High Impact Polystyrene (HIPS). These Polymers Can Be Effectively Recycled And May Be Combined With Virgin Materials To Modify Into Application Needs [20], [21].

Potential Risk Of E-Waste To The Society Is Alarming As Toxic Materials Are Associated In Disposed Materials. The Risk Of Mercury, Lead, Cadmium Poisoning Is Increasing Due To Huge Amount Of E-Waste. The Possibility Of Ground Water Contamination Cannot Be Prevent Due To Stack Of E-Waste Without Proper Scientific Management. The Problem Is More Serious Where Degree Of Generating E-Waste Is Very High Like Big Cities In The Various States Or Cosmopolitan Town. In Some States, Throwing Toxic Gadgets In The Pond Is More Serious Problem, Leading To Environmental Pollution.

It Was Observed That The Number Of Authorized Recyclers Is Very Few Compare To Un-Authorized Dealers. Few Authorized Dealers Managing E-Waste Are Tech-Logic, UPL Group And Various Municipal Bodies Of Big Cities. In Various Cities In India, Survey Reports Has Revealed That The Extent Of Electronic Waste Generated Is Of The Order Of 1000 Kg To 3000 Kg Per Month. An Awareness Programme Should Be Initiated With Major Waste Disposal Sector To Dispose E-Waste In Special Designed Bins Compare To General Bins. Special Drive Should Be Initiated Among School, College And Other Public Places To Control E-Waste Disposal And Conversion Of Waste Into Useful User. This Paper Represents An Overview Of E-Waste

Generation, Different Approaches For E-Waste Management And Finally Recovery Of Valuable Metals From E-Waste.

II. Generation Of E- Waste:

Changing Lifestyle And Urbanization Has Led To Higher Consumption Of Electronic Products. Huge Amounts Of Locally Generated And Internationally Imported Have Posed A Serious Threat To Human Health And The Environment. The Complexity Of The Issue Of E-Waste In India, Given Its Vast Geographical And Cultural Diversity And Economic Disparities, Makes Management Challenges In India Quite Unique.Fig 1 Shows The Summary Of The Generation Of E-Waste.

Fig 1: Flowchart Of Generation Of E-Waste

Several Researchers Have Focused On The Estimation Of Generation Of E-Waste. However, It Was Observed That The Most Of These Studies Pivoted On Their Local Waste Generation Statistics Only Rather Than A Global Representation.According To The Estimation By United Nation University That E-Waste Will Rise From The 41 Million Tonnes Currently Produced Each Year To 47 Million Tonnes In 2017 [8]. In The European Union (EU), E-Waste Is Growing At A Rate Of 3–5% Per Annum Which Is About Three Times Faster Than Other Individual Waste Streams In The Solid Waste Sector [22], [23]. It Is Estimated That In 2009 Around 5 Million Tonnes Of E-Waste Were In Storage And 2.37 Million Tonnes Of E-Waste Were Ready For Disposal, Which Represents An Increase Of Around 120% From 1999 Levels [24], [25].

Most Of The E-Waste Was Generated In Asia, 2016 Around 18.2 Mt, Or 4.2 Kg Per Inhabitant. Approximately 2.7 Mt Were Documented To Be Collected And Recycled Which Is Illustrated In Table 1. The Highest Quantity For Each Inhabitant 17.3 Kg/Inh Was Generated By Oceania. However, Oceania Generated The Lowest Quantity Of E-Waste In The World In 2016 At 0.7 Mt, And Could Only Document 6% Of Its E-Waste That Was Documented To Be Collected And Recycled (43 Kilotons (Kt)). Comparing To Oceania,The European Continent, Including Russia, Generated An Amount Of E-Waste Per Inhabitant (16.6 Kg/Inh). In Total, The E-Waste Generation For The Whole Region Is 12.3 Mt. Around4.3 Mt Of E-Waste Was Collected To Be Recycled In Europe, Showing The Highest Regional Collection Rate Of 35% Compared To E-Waste Generated. The Lowest Amount Of E-Waste Per Inhabitant Was Generated In Africa(1.9 Kg/Inh). The Whole Continent Generated 2.2 Mt Of E-Waste, And With Current Data, Only 4 Kt Were Documented As Collected And Recycled; This Is Less Than 1%. In 2016, The Americas Generated 11.3 Mt Of E-Waste 7 Mt For North America, 3 Mt For South America, 1.2 Mt For Central America. The Whole Continent Generated 11.6 Kg/Inh. Of E-Waste In 2016, And Approximately 1.9 Mt Of E-Waste Documented Was Collected And Recycled.

The Difference Of E-Waste Generated In Developed Versus Developing Countries Is Quite Large. The Richest Country In The World In 2016 Generated An Average Of 19.6 Kg/Inh, Whereas The Poorest Generated Only 0.6 Kg/Inh.[8].

Table 1: E-Waste Generation And Collection Per Continent[8]

Indicator	Africa	Americas	Asia	Europe	Oceania
Countries In Region	53	35	49	40	13
Population In Region (Millions)	1,174	977	4,364	738	39
WG (Kg/Inh)	1.9	11.6	4.2	16.6	17.3
Indication WG (Mt)	2.2	11.3	18.2	12.3	0.7
Documented To Be Collected And Recycled (Mt)	0.004	1.9	2.7	4.3	0.04
Collection Rate (In Region)	0%	17%	15%	35%	6%

Polák And Drápalová (2012) [26] Estimated The Generation Of Mobile Phone Waste In Czech Republic. They Used A Specific Methodinvolving Calculation Of Life Span And Volume Of Distribution Ofmobile Phones To Estimate The Existing And Near Future Mobilephone Waste Quantity. They Calculated The Amount Of Discardedmobile Phones And Reported The Quantity In Numbers That Is Only45 Thousand In The Decade 1990–2000, While It Was 6.5 Millionin The Next Decade, I.E., 2000–2010 And Projected Around 26 Millionin The Current Decade (2010–2020). They Also Compared Theirvalues With Other Countries Such As Japan, China, US, UK And Korea. Babatunde Et Al. (2014) [27] Focused More On The Mobile Phone Used Battery Disposal Behaviour In Nigeria. They Made An Interesting Observation Regarding Life Cycle Of Mobile Phones And Observed That Approximately 40% Of The Inhabitants Used The Mobile Phone Only For One Year. They Also Studied The Trends In Battery Usage By The Residents. Rahmani Et Al. (2014) [28] Estimated The Past And Future Trends In Generation Of Obsolete Computers And Mobile Phones In Iran. They Achieved This Through Different Models Such As Time-Series Multiple Life Span Model And Simplified Logistic Function Model. They Calculated That About 39 Million Mobile Phones Entered The Waste Stream Until 2014 And Proposed That This Figure Would Reach 90 Million By 2035. They Also Projected That The Saturation Level For Mobile Phone Waste Would Be 21 Years From 2014. Li Et Al. (2015) [13] Compared Several Methods Such As Market Supply Method, Consumption And Use Approach And Sales And New Method. They Found A Great Differentiation In Results Depending Upon The Method Chosen. They Observed That 47.92 Million Mobile Phones Retired In 2002, And It Reached To 739.98 Million In China In 2012 Which Was The Result Of Applying The New & Sale Method. Therefore It Is Prior To Select The Proper And Most Appropriate Method To Get Accurate Values Of Mobile Phone Waste Generation.

III. Management Of E- Waste:

Managing Electronic Waste (Or E-Waste) Is One Of The Most Rapidlygrowing Pollution Problems Worldwide. Management Of Mobile Phone Waste Comes On Light After Establishment Of E-Waste Handling Regulations And Rohs (Restriction Of Hazardous Substances) Directive By EU In 2011.

The Major E-Waste Problem In Developing Countries Arises From Theimportation Of E-Waste And Electronic Goods From Developed Countries. These Western Countries Exports Their Older, Less Ecologically Friendly Equipment To The Developing Countries And Resulting 80% 0f All E-Waste [29].

Comparing Several Mobile Phones, Tanskanen And Butler (2007) [30] Concluded That There Is A Huge Potential For Mobile Phone Recycling Through Take Back Initiatives Which Is Taken By USA And Finland. The Success Of Such Take Back Systemsis The Ease Of Use, Strong Messaging And The Right Incentive For The Consumer. Sahu And Srinivasan (2008) [31] Discussed Several Concerns Related To Mobile Phone Waste Management In Asia–Pacific Region. They Quoted That There Was A 30% Increase In Mobile Phone Sales In The Year 2004 When Compared To 2003. Countries Like India, China, Korea And Malaysia Put Forward E-Waste Management Rules Recently In Response To Basel Convention And EU Directive On E-Waste. However, The Legislations Regarding E-Waste Are Yet To Be Set Up In Many Developing Countries. They Also Suggested That Without Proper Legislation, Effective Management Of Mobile Phone Waste Cannot Be Done Effectively.

Jang And Kim (2010) [32] Gave A Detailed Review On Management Of Mobile Phone Waste In Korea. The Methodology Of Their Study Included Gathering Data Associated With Annual Domestic Demands Of Mobile Phones, Questionnaire Surveys, Site Visits, Interviews And Conversations, And Review Of Available Literature. They Discussed On Features And Effectiveness On The Legislative Measures Taken By The Korean Government For Proper Disposal Of Mobile Phone Waste. One Interesting Aspect Of Their Work Includes A Methodology Divided Into Four Stages As Generation, Collection, Reuse/Recycling And Treatment, Employed For Mobile Phone Recycling. They Indicated That Combined Efforts From Producers, Mobile Phone Companies, Consumers, And Governments Will Be Required To Solve The Increasing Mobile Phone Waste Issue.

The Ministry Of Environment In Norway Signed An Agreement To Set Up Take Back Companies With The Producers And Importers Of Electronic Waste As Early As 1998. It Was A Voluntary Agreement And Was Later Followed By An E-Waste Regulation In 1999. Like The Rules In India, Management Of E-Waste In Norway Is Also A Producer Responsibility And Producers Are Defined As Norwegian Manufacturers And Importers Of EEE.

India Plays An Important Role In The Domestic Generation Of E-Waste (2 Mt In 2016) Due To The Large Population, But The Country Also Imports From Developed Countries. India's Electronics Industry Is One Of The Fastest Growing Industries In The World. The Formal E-Waste Recycling Sector In India Is Currently Being Developed In Major Cities. However, Informal Recycling Operations Have Been In Place For A Long Time, With Over 1 Million Poor People In India Involved In Manual Recycling Operations. Most Of These People Have Very Low Literacy Levels With Little Awareness Of The Dangers Of The Operations. Severe Health Impacts And Environmental Damage Are Widespread In India, Due To The Final Step Of The E-

Waste Processing By The Informal Sector. India Has Had The E-Waste Rules In Effect Since 2011. The Rule Mandates Producers To Be Responsible For The Collection And Financing Of Systems According To The Extended Producer Responsibility (EPR) Concept. Further Amendment To This Rule Came In 2015, Which Resulted In The E-Waste (Management) Rule In 2016. The Main Feature Of This Rule Is EPR. The Amended Rule Has Provisions For Producer Responsibility Organisations (Pros) And Deposit Refund Scheme Under EPR [8].

Sixty-Five Cities In India Generate More Than 60% Of The Total E-Waste Generated In India. Ten States Generate 70% Of The Total E-Waste Generated In India. Maharashtra Ranks First Followed By Tamil Nadu, Andhra Pradesh, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh And Punjab In The List Of E-Waste Generating States In India. Among Top Ten Cities Generating E-Waste, Mumbai Ranks First Followed By Delhi, Bangalore, Chennai, Kolkata, Ahmadabad, Hyderabad, Pune, Surat And Nagpur. There Are Two Small E-Waste Dismantling Facilities Are Functioning In Chennai And Bangalore. There Is No Large Scale Organized E-Waste Recycling Facility In India And The Entire Recycling Exists In Unorganized Sector.

The Central Zone Bench (Bhopal) Of National Green Tribunal (NGT) Recently Ordered All Producers And Manufactures Of Electrical And Electronic Equipment (EEE) In Madhya Pradesh, Chhattisgarh And Rajasthan To Set Up Collection Centres And Take Back Systems For Discarded Electronic Goods. The Bench Came Down Heavily On Producers And Manufacturers For Failing To Implement Extended Producer Responsibility (EPR), Under E-Waste Rules 2011. There Is Only One E-Waste Collection Centre In The Whole Of Madhya Pradesh. The Situation Is No Different For Most Of The States Of The Country.

EPR Is The Most Defining Provision In The E-Waste Regulation Of Our Country. According To EPR, Manufacturers Are Responsible For The Post-Consumer Waste Of Their Respective EEE Products. The E-Waste Rules Were Notified In 2011 And Came Into Effect In 2012. It Has Been Three Years Since The Rules Were Notified And Two Years Since They Came Into Force But Only A Handful Of Companies Have Come Forward To Manage The End Of Life Cycle Of The Products That Have Been Put By Them In The Market. EPR Approaches To E-Waste Management At A National Scale Are Summarised In Table 2.

Table 2: E-Waste Management Approaches To EPR[33]

Country	Policy	Target	References
The Netherlands	Take Back (Large Household Appliances And IT Equipment)	Recycling Rate 45–75% By Weight	[34]
United Kingdom	Take Back (Electronic Appliances)	Recycle And Recovery 50–80%	[35], [36]
Germany	Take Back (Electronic Appliances)	_	[37]
Switzerland	Take Back (Electronic Appliances) Disposal Ban In Landfill Advance Recycling Fees	_	[38], [39], [40]
Japan	Take Back (Four Large Household Appliances: TV Sets, Refrigerators,P[Air Conditioners And Washing Machines) Product Re-Design (Lead Free Solders And Bromine Free Printed Circuit Boards)	Recycling Rate 50–60% By Weight	[39], [34]
United States	Take Back Household Appliances In Some States, Such As Maine (Take Back Only Televisions And Computer Monitors)	_	[41], [42]
Canada	Take Back Household Appliance In Some Provinces, Including Alberta And Ontario Develop Advanced EPR Program	_	[43]
India	Feasibility Study	_	[44]
Thailand	Developing Legal Framework	Collection And Recycling	[45]

India Can Take A Cue From Norway Which Has E-Waste Take Back System In Place For More Than A Decade Now. When The E-Waste Rules Were Introduced In Norway, The Country Faced Similar Questions. The Authorities Were Finding It Extremely Difficult To Enforce And Follow Up So Many Entities Producing And Importing Electronics In The Country. The Deliberations Conceptualised The Idea Of EPR Which Culminated In E-Waste Regulation.

Since 1999, When Reporting On The Collection Of E-Waste Was Initiated In Norway, The Collection Rate Has Risen Continuously. More Than 143,790 Tonnes Of E-Waste Was Collected In Norway In 2012. In 2013, The Collection Increased To 146,018 Tonnes.

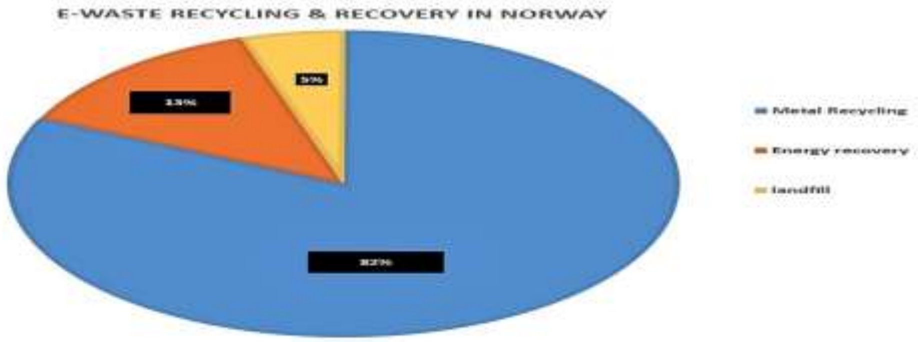

Fig 2: A Diagram Of E-Waste Recycling And Recovery In Norway (From Norwegian Environment Agency, 2014)

So, Both The Government And Mobile Phone Manufacturer Has To Work Together With Recycling Industries To Develop A Proper Waste Recycling System.

IV. Metal Recovery From E-Waste:

For The Recovery Of Metals From WEEE, Various Treatment Options Based On Conventional Physical, Hydrometallurgical And Pyrometallurgical Processes Are Available. Hagelüken And Corti, 2010 [46] Estimated That 1000 Kg Of Waste Mobile Phones Can Yield About 300–350 G Of Gold Along With Other Metals. The Interesting Fact Here Is That Only About 5 G Of Gold Is Present In A Ton Of Ore From A Gold Mine. Hence, Leaching Out The Precious And Other Metals From Mobile Phone Waste Become A Broad Are Of Research. Ha Et Al. (2010) [47] Used A Less Hazardous Cupric-Thiosulfate – Ammonia Solution In Place Of Traditional Cyanide Solution For Leaching Gold From Mobile Scrap. They Could Extract 98% Of Total Gold From The Scrap. Similar Studies And Observations Were Made By Tripathi Et Al. (2012) [48], Ha Et Al. (2014) [49], Petter Et Al. (2014) [50].

We Leach Out The Metals From The Mobile Printed Circuit Board (Pcbs) Through Hydrometallurgical Process. In Acidic Solution The Metal Ions Are Rapidly Dissolved Into The Solution. HNO_3 Is Strong Oxidizing Agent Which Oxidise The Metals Into Nitrates. Fig 3 Shows Thatat 30℃ Temperature, 0.5423% Of Cu, 0.013% Of Ni And 0.0201% Of Au Is Extracted Using Nitric Acid For 20 Min.

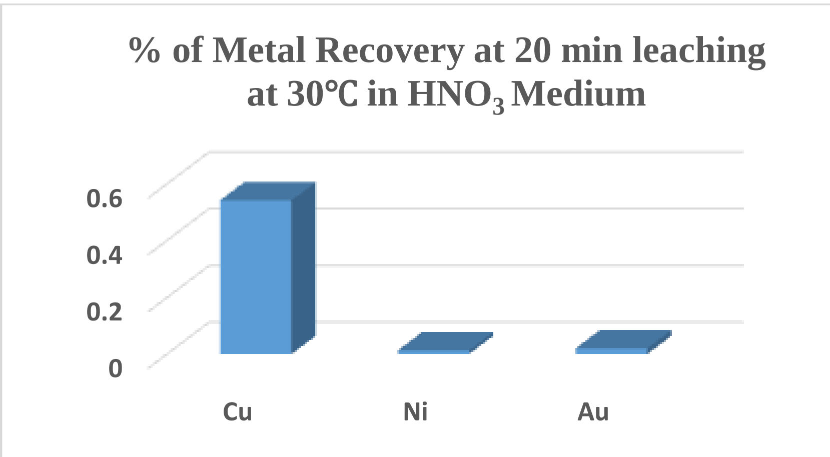

Fig 3: A Diagram Of Recovery Cu, Ni And Au At 20 Min Leaching At 30℃ Temperature In HNO_3 Medium

Chi Et Al. (2011) [51] Used A Bioleaching Process To Extract Gold And Copper From Waste Mobile Phone Pcbs. The Bioleaching Was Effected By Using Chromobacteriumviolaceum (C. Violaceum), A Cyanide Generating Bacterium In A Yeast-Polypeptone With Glycine Medium. They Achieved Recovery Rates Of 24% And 11% For Copper And Gold Respectively. Kim Et Al. (2011) [52] Selectively Recovered Gold From Waste Mobile Phone Pcbs Using A Hydro-Metallurgical Process. They Could Extract More Than 95% Gold With Purity As High As 99.9%. They Found Out That The Leaching Efficiency Of Gold Increased With Increase In Temperature And Initial Chlorine Concentration.

Sakultung Et Al. (2007) [53] Extracted Cobalt And Nickel From Waste Mobile Phone Batteries. Sulfuric, Nitric And Hydrochloric Acids Were Employed For The Leaching Process. More Than 90% Recovery

Of Nickel And 80% Recovery Of Cobalt Were Achieved. They Also Noted That The Hydrochloric Acid Provided Best Recovery Efficiency At All Concentrations Than Other Acids. Hanafi Et Al. (2012) [54] Analyzed The Composition Of Waste Mobile Phone Pcbs Using EDX (Energy Dispersive X-Ray Spectroscopy). The PCB Samples Were Disassembled, Pulverized And Density Separated Into Light And Heavy Fractions. The Compositions Of Each Class Were Identified By EDX. The Copper Was Extracted As Copper Sulfate Hydrate With 98.82% Purity.

V. Conclusion:

Electronic Waste Has Become The Largest Andfastest Waste Stream All Over The World. Potential Risk Of Associated E-Waste Is Very Alarming To The Environment And Mankind As It Contains Harmful Materials Like Mercury, Lead, Cadmium Etc. Due To Rapid Change Of Technology Leads To Better Gadgets Resulting More Generation Of E-Waste. A Comparative Study Of E-Waste Generation Among The Continents Has Been Done By Baldé Et Al., 2015 [8]And It Shows That E-Waste Generation Is Maximum In The Developed Countries. Americas, Europe Andoceania Contain Generally 11.8, 16.6, 17.3 Kg/Inhabitant E-Waste. India Is Among The Leading Country In The E-Waste Generation With 2 Mt E-Waste Generated In 2016.

Management Of E-Waste Based On Collection And Take Back Of Household Electric Or Electronic Appliances And IT Equipments During Purchase Of The New One Than Recycling And Recovery Of Precious Metals From E-Waste. Developed Countries Like Netherlands, UK, Germany, Switzerland, Japan And USA Have Already Developed A System And Achieved Good Success With 45-75% Recycling And 50-80% Recovery Of The Metals. However, In Developing Countries Like India, This Management Is Still In The Nascent State. Proper Government Policies Like E-Waste Rule 2016 Along With Collaborative Work Of Govt., Electronic Goods Manufacturer And Recycling Industries Can Develop A Proper Waste Recycling System In India To Control The E-Waste Pollution.

Another Aspect Of E-Waste Management Is Recovery Of Precious Metals From E-Waste. Leaching Of Metal Portion Of E-Waste With Ammonium Thiosulphate, Cyanide Solution Or Different Inorganic Acids Likehcl, H_2SO_4 And HNO_3can Recover Considerable Amount Of Metals From The E-Waste. Bioleaching Using Chromobacteriumviolaceum, A Cyanide Generating Bacterium Shows Effective Leaching With 24% And 11% Of Cu And Au Recovery Is Reported By Chi Et Al. 2011 [51].

Acknowledgement:

The Author Is Grateful To DST INSPIRE FELLOWSHIP For Financial Support For Research Work.

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