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Metal Extraction from Recycled E-waste and Its Future Prospects in Bangladesh: A Survey

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ABSTRACT
Around the world, 50 million tons of electronic waste (e-waste) is produced per year, with a 500% increasing rate in the years to come. Asia has a vast growing global economy and the total amount of e-waste is expected to rise to about 57.4 million tons by 2021. And that is more than 40% of the globally generated waste. Regarding environmental impact and increasing demand for raw materials and a gradual reduction in non-renewable sources, recycling can be a better secondary source of metals. In this paper, a survey is performed on all the existing processes of metal extraction from electronic-waste in Asia. The traditional metal separation techniques, pyrometallurgy, hydrometallurgy, electro-metallurgy, bioleaching, and mechanical processing are critically compared in this article. The introduction and future possibilities of several methods such as bio-hydrometallurgy, pyro-hydro hybrid metallurgical process, mechano-chemical technology, electro-chemical extraction are discussed. A comparison between different procedures leads to a decision on suggesting an efficient method applicable to Bangladesh. From the context of the recycling of e-waste in Bangladesh, an efficient e-waste management route is identified with defining the suitable metal extraction process.

Keywords: E-waste, Recycling, Metal extraction, Environmental Preservation

1. Introduction

Circular Economy- sustainable materials management emergence has become an essential move around the world. This is due to the vastly increasing electrical and electronic equipment (e-waste) waste and its potential risk to the eco-system [1]. For the sake of a circular economy, it is necessary to innovate to reduce the virgin material input and reduce waste output. Because of the global legislations and environmental issues, the treatment, including depositing in a landfill [2], combustion in incinerators, or even exporting overseas, is no longer a wise option. To encounter this problem systematically, the development and implementation of design strategies, business model, and policy formulation [3] of all the horsemen of Asia along with the collaboration of developing countries are necessary [4]. The focus of e-waste management should convert from the macroscopic level to the microscopic as recycling metals with a high recovery percentage can act as a secondary source of metals [5]. Metal substance extraction at the microscopic level can eradicate problems associated with e-waste recycling.

In 2019, the volume of e-waste generated in Asia is 24.9 MT (5.6 kg per capita), where only 11.7% (2.9Mt) has been reported as collected and recycled correctly [6]. Surprisingly, the %recovery of metals in e-waste is much higher than its content in metal ores [7]; a ton of PCB contains 30-40 times the amount of Cu and 40-800 times the amount of Au extracted from 1 ton of mining ore [4]. As the availability of metals is getting scarcer, we all have to find a sustainable framework to recycle metals from electronic scrap which is both profitable for the business and conserves the environment as well [8]. The traditional metal extraction route must be redefined with the collaborative [9] approach which should result in better efficiency, higher recovery rate, low energy consumption, and greater leaching speeds [10-12].

This paper delineates the wholesome status quo of the world, comparing with south-east Asia to select the suitable route for metal extraction in section 2. In section 3 a comparative approach is drawn among existing metal extraction processes. Section 4 follows the review of the recent innovations and advancements in these approaches. This paper focuses on assembling a few data on metal extraction to help novice researchers to choose the best possible way. This survey clarifies the best possible routes of handling vast e-waste based on the prospects of Bangladesh in section 5. Section 6 concludes this humble attempt by specifying the turnover of this survey. The main objective of this survey is to propose a sustainable e-waste management route for Bangladesh where e-waste reusing after repairing and recycling as an approach of retrieving new functional materials. This survey objectifies the most suitable method based on economic and environmental impact and availability by comparing all the traditional methods and recent innovations in this particular metal extraction e-waste recycling sector.

2. Regional E-waste Monitor: South-east Asia:

More prominent entrance to electrical and electronic equipment (EEE) is viewed as identical with economic improvement. New goods and promotions are continuously put on the business in reply to rapid technological advancement [4]. Globally, purchases of EEE have boomed in the later decades, and numerous Asian countries, as renowned EEE producers, have profited from this boom. Asia appears as the most extensive EEE consumer, considering nearly half of EEE placed on the run [3]. The more electronic equipment means more e-waste generation. The expanding amount of e-waste is mostly fueled by the higher expense of EEE, tiny life cycles, and a small number of replacement options. Production of E-waste

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has expanded to 53.6 million metric tons yearly in 2019 with an average of 7.3 kg per capita. The worldwide engendering of e-waste increased by 9.2 Mt since 2014 and is expected to rise to 74.7 Mt by 2030 – nearly doubling in just 16 years. Statistical data of globally generated e-waste is elaborately compared in fig.1 [6].

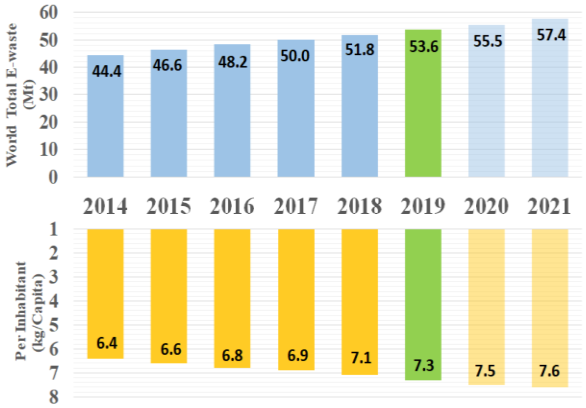

Fig.1 Comparison of globally generated and per inhabated (kg/capita) generated e-waste from 2014 to 2021, note: 2020, 2021 is estimated [6]

With the 49 countries, Asia originated the highest volume of e-waste in 2019 at 24.9 Mt because of having inhabitants of about 4.6 billion, whereas America and Europe produced 13.1 Mt and 12 Mt respectively. Africa and Oceania produced 2.9 Mt and 0.7 Mt respectively which is shown in fig.3. It is approximately 50% of the globally produced e-waste and the growth rate is 500% in some cases. Only 11.7% of e-waste is recycled properly according to statistics [6]. China is on the top in both Asia and the world for generating the highest (10.1 Mt) e-waste quantity. India made 3.2 Mt, and Japan produced 2.6 Mt. China performs a crucial role in the global EEE trade for several reasons [3]. This is the most crowded country globally, so the need for EEE is enormous, and it has an excellent EEE manufacturing capital. China has a notable performance also in this reuse, recycling, and refurbishment of e-waste [5].

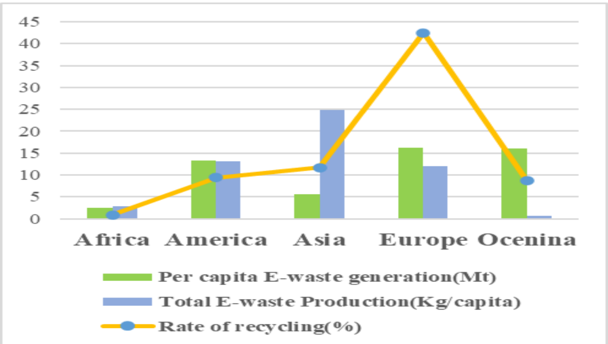

Fig.2 Regional E-waste Comparison on the metric of per capita e-waste generation, total e-waste production, and recycling rate[3, 6].

Other developed countries like Japan and South Korea have propelled e-waste ordinance. Japan was one of the world's leading countries to implement an EPR (Extended Producer Responsibility) based system for e-waste [5]. Japan relies on a robust legal framework, an exceptional take-back system, and improved processing infrastructure. In the southeastern zone of Asia, India plays a crucial role in the national production of e-waste (3.2 Mt in 2019) due to the vast population. Most of the citizens have light consciousness of the hazards of the proceedings [15].

3. Traditional Metal Extraction Methods:

Metal extraction from e-waste is now the alternative source of natural sources for example ores. The recovery of deposited metal in e-waste has some methods which are used traditionally. Those methods have some individual pros and cons [9]. Pyrometallurgy is the process of extracting value materials from ores using heat. It is a thermodynamic approach that quickens the chemical reactions. The creates flue of zinc (Zn), lead (Pb), silver (Ag) and gaseous residue for example Chlorinated, Brominated dioxins. Hydrometallurgy is another renowned metal extraction process where metals are extracted at room temperature by leaching ores with liquid solvents. It is a method that involves aqueous chemistry in order to extract metals. Unlike pyrometallurgy, hydrometallurgy excludes the heating process making it a more convenient method [13]. Electrometallurgy is the technique of extracting metals through electricity. When other methods require heavy machinery, electrometallurgy has a piece of compact equipment and generates a low amount of residue that is less harmful which gives it an edge. The method does not show high flexibility. Electrometallurgy can be approached in two steps and those are (1) selective dissolution of the metal e-waste and (2) selective recovery of the metal from solution. Bioleaching is the process where metal is extracted by utilizing living organisms. In this process the elements that are used can be found in the environment such as air, water and an element that can be grown in vast within small time is a microorganism. The leaching process is simply eco-friendly. On this basis, bioleaching can become the best on some metrics like environmental aspects. Lastly, the Mechanical approach is mainly a pre-treatment process that is really necessary for almost all the methods because it helps to trigger reactions to a certain level. But research [14] shows that following some mechanical steps can also extract metals from e-waste, which is also eco-friendly. The process is not so efficient and flexible but can be really effective as a companion with any other methods.

Comparing all five methods in the same metric is not logical because the methods have different approaches. Paralleling pyro, hydro, and electrometallurgy, we can draw a recommend one. Based on environmental preservation, bioleaching is preferred. The table-1 shows the pros and cons of the methods.

Table 1 Pros and cons of different methods [14-21].

Method	Advantages	Disadvantages
Pyrometallurgy	-Better suited for elevated temperature reaction. -Greater ease of physical separation -Lower capital cost due to faster reaction	-Requires mechanical pre-treatment. -Costly because small scale operation isn't possible -Lengthy engineering development.
Hydrometallurgy	-Potential low energy input and output is highly pure. -Process controlled environment and good recovery. -Ability of low-grade ore and complex extraction	-Highly corrosive solutions -From dissolved solution, valuable metal recovery is difficult. -Tedious, more time required for metal recovery. -Impurities problem in the purification process.
Electrometallurgy	-Small compact equipment in a little space -Utilizing and recycling radiation resistant reagent reduces waste volume.	-Can't handle all types of ore. -Inert atmosphere is necessary. -Often external potential is needed.
Mechanical	-Often used as pre-treatment - Can trigger many reactions and increase efficiency.	-Contamination is very high. -Solely cannot recover high volume of metal
Bioleaching	-Reduce production cost -Minimize the environmental effect - High efficiency, even in concentration in ore. - Leaching bacteria easily cultivated.	-Slower pace of metal recovery. -Sometimes create toxic chemicals as residue. -Lower profit margin because of lower recovery rate.

Utilizing pyro and hydrometallurgy, recovering different metals at the same time can bring complications and an increased amount of time but these methods recover successfully [13]. Hydrometallurgy consumes a low amount of energy [22] because pyrometallurgy requires heat energy and electrometallurgy needs electrical potential between electrodes [7]. That is why hydrometallurgy is the most beneficial among these three methods. Based on environmental aspects, all these methods create lethal residue but the residue generated in hydrometallurgy costs lower in recycling [23]. With the higher rate of metal extraction among traditional routes, hydrometallurgy is the most recommended one so far.

Table 2 The approximate amount of different metals in 1 kg of shredded PCBs and approximate recovery rate of different metals in different routes [8, 21, 24-26].

Metal	Amount	Recovery (%)		
		Pyro	Hydro	Electro
Cu	335.2g	90-93	85-90	75-82
Al	14.1gm	90-95	88-96	90-95
Fe	23.3gm	60-65	80-83	54-58
Sn	31.6gm	82-88	84-86	-
Ni	25.0gm	92-95	91-95	-
Zn	19.2gm	95-98	95-100	-
Cr	1.7gm	90-94	93-98	67-72
Pb	12gm	93-95	90-94	70-73
Co	0.21gm	84-90	88-94	77-80
Ag	3.6gm	94-98	98-100	60-65
Au	1.4gm	95-98	96-98	80-85
Pd	0.29gm	95-99	93-96	25-35
Pt	0.03 gm	88-92	87-95	47-52

From the table-2, we observe the flexibility of Pyro and Hydrometallurgy, but electrometallurgy does not work for all metals and shows a comparatively lower recovery rate. Electrometallurgy works well for those metals which have higher reactivity than Carbon(C). In some cases, pyrometallurgy shows slightly high recovery rates but the method is costly. That is why comparing different aspects; hydrometallurgy is the most recommended one [15]. Approaching a different metric which is environmental preservation, can give an edge to Bioleaching. The method is particularly exclusive because the leaching is done by bacteria such as Acidithiobacillus ferroxidans (A. ferroxidans) and Acidithiobacillus thiooxidans [20] The main advantage this method has is environmental friendliness. The process has a little amount of "secondary pollution" [20], but other methods have direct lethal impacts. Comparing extracted metals and the cost behind this, we reached the conclusion that the method is efficient, cost-effective and environment friendly. The drawbacks of this method are the lower rate of metal recovery [21] and getting the right bacteria can be challenging [13]. So, based on metric of environmental aspects this method is the best of one and also based on profitability the method is highly recommended. Lastly, the mechanical approach is vastly used in pretreatment, which is beneficial because the process triggers the reaction by bringing the physicochemical changes like structural defects, phase transformation [20]. A research [9], shows that residue from a leaching process can be used again for metal extraction after undergoing some mechanical process. It is a useful pretreatment but metal extraction only by mechanical process can be useful because the process is a dry route. That is why the generation of liquid effluent streams can be avoided [14]. In recent researches, these traditional routes are redefined with collaborative approach among the different metal extraction routes.

4. Advancements in Metal Extraction Technology:

The innovation of new technology with new forms of engagement is necessary to maintain a circular economy. Extracting methods should be more efficient and less time consuming because the e-waste is piling up at a high rate, but the recycling rate is slow. It also demands the issue of environmental preservation. Not only that, but the methods should also be economically profitable so that companies can pursue them. In recent times researchers have found tremendous positive results on the collaborative approach of metal extraction among various methods. The target behind these is to make the recovery greener, more efficient, less time-consuming.

A researcher group of India has constructed a new method called pyro-hydro hybrid metallurgical process in which from PCB Cu, Ni and Fe are recovered at a high amount. From the leach liquor, acid recovery up to 99.99% makes this process even more beneficial for circulatory industrial approach by using 70% TEHA diluted in kerosene at the pregnant leachate after beneficiation. The process starts with crushing, then pyrolysis, beneficiation, leaching and ends with solvent extraction. After pyrolysis and beneficiation, doing air sparging, Fe precipitate is found. Challenges with solely going with pyrolysis, beneficiation after first stage recovery was required, the amount of metal recovery is not possible as well as acid waste in leach liquor. To the rescue of this problem, they suggest that recovered acid be used further, and then 99% Cu is recoverable from the 2nd stage. Using 1% LIX (Liquid Ion Exchanger) 841C at pH 4.58 is beneficial for 2nd stage Ni recovery. Electrolysis, evaporation and crystallization are used to recover metal from metallic solution. This combinational hybrid process of pyro and hydrometallurgical has found to be successful concerning leaching agent recovery within 5 min, more efficient metal recovery, higher leaching speed as well as circulative industrially profitable [10].

In recent work [12], have revealed a novel approach of two-step leaching process with the collaboration of bioleaching and hydrometallurgy, biohydrometallurgy. To extract metal from waste printed board and steel pickling waste, they have found that using SPWL (Steel pickling waste liquor) as a leaching agent at the first step and A. ferroxidans at last, makes it possible to recover 100% Cu and 51.94% iron. This simultaneous two-step leaching process is beneficial because of its simplicity, low cost, low energy consumption, and most importantly, no hazards towards the environment. The use of microorganism (A. ferroxidans) for extracting Cu makes possible its positive impact on environmental preservation. Because of using microorganisms, this process is satisfying the goal of environmental preservation. Using microorganism does not generate harmful residue but using chemical does. Pyrometallurgical has a colossal limit that is high temperature. This limit can be overcome by this. Combining these two methods merges the advantages of these methods, which is why this hybrid method is efficient, cost-effective and eco-friendly [10].

Precious metals like tungsten, palladium, gold, silver recovery are not possible with hydrometallurgy due to excessive use of acid. The solution to this challenge can be avoided by using a method called mechano-chemical technology which is discussed by a research [11]. From an e-waste concentrate, they used ball milling with $K_2S_2O_8$ and NaCl as a reagent in 0.5 mol/L dil HCl. Ball milling creates the oxidation state which fastens the leaching speed and makes a possible higher recovery. This method's use can avoid the traditional use of HNO_3 or $HNO_3.H_2SO_4$, which adds value to its eco-friendly impact [11]. In order to make the recycling process more efficient, there is a method called mechano-bioleaching process. With the advantages of bioleaching, additional mechanical activation increases efficiency. This activation triggers some physiochemical changes [20]. The mechanical process is activated by structural defects or phase transformation, which brings improvement in leaching efficiency of various metals.

A study [13] shows that combining different processes can be more profitable. In this study, CPU PCBs are used for gold recovery by electrowinning and copper and nickel recovery by leaching of solid residue. This method can become sustainable as gold is recovered as precious metal and residue are used in order to recover copper and nickel. As the residue and leaching solution also are used to recover metal, it has proven to be a greener method with the maximum use that makes the process cost-efficient and profitable. [9] For a greener world with a circular economy along with sustainable material management, these collaborative methods are best suited for adopting, especially in countries like Bangladesh where regulations with e-waste are still not that constructive [3].

5. Future Prospects of Bangladesh:

Bangladesh is a developing country with a highly dense population with growing demand in each and every field. With growing demand, Bangladesh generates a massive amount of e-waste from shipyards, mobile phones, CPU and other living appliances. Most of the e-wastes are filling the land, and the molecules of metals and plastics get mixed with food harming the wildlife, domestic and human life also. Besides, e-waste management flow is not well organized and systematic. A minimal amount of e-waste is reported (only 5%) to be collected and recycled, and the rest is burnt even after applying the national 3R (reduce, reuse and recycle) strategy. With an up growing population, Bangladesh has cheap labor and many opportunities in this recycling field. Increasing recycling factories by the government or private sector can have an impact on unemployment issues[27]. It costs only $2 to recycle a PC in Bangladesh whereas it costs a minimum of $20 in the US or other developed countries [8]. Bangladesh should have organized systems for the collection, segregation, recycling, disposal, and monitoring of such wastes.

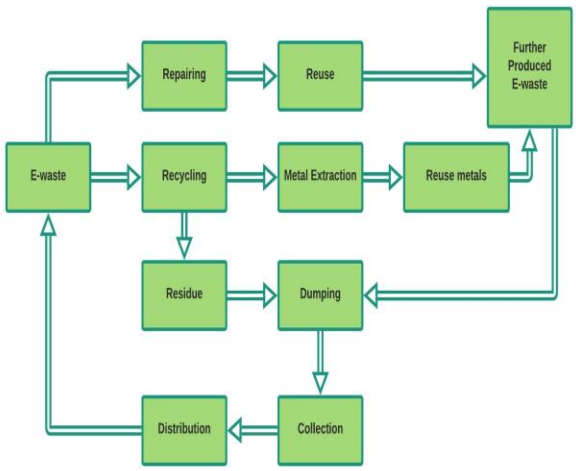

Fig 3: Proposed e-waste management route for developing countries like Bangladesh with the concept of circular economy

By making the process systematic, it can be profitable for Bangladesh in several matrices. For Bangladesh making a perfect law for e-waste management should be the first step as there are policies, acts, rules for environment [28] but no specific law or action plan regarding e-waste management [27]. Next, a proper guideline should be followed and one is introduced by Environmental and Social Development Organization (ESDO) in 2012 [28]. Hawker can collect the e-waste from dumps in different landfills or different places. These people can sell them to some particular local dealers at a fixed price. In the process of being developed, there may be some digital way of collecting this from users directly to increase efficiency. After collecting and selling to local dealers, the e-waste can be divided in any particular way so that it can be easy to distribute among the recyclers according to their choice as different recyclers may have different sets of choices of e-waste according to their targeted metal. After collecting the e-waste, local dealers can transport this e-waste to the recycler. Recyclers can use any method according to their policy and can make a profit, creating a balance with environmental effects. Recovering different base metals such as copper, tin, and zinc which are so much useful or some precious metals such as gold, silver which have high economic value can be so much beneficial. [8] For countries like Bangladesh following a mix-up method such as Bio-hydrometallurgy can be helpful for the balance as they are cost effective, efficient and creates a lesser harming residue. If one wants to go with the plain method then hydrometallurgy is suitable because raw materials of bioleaching are still not widely available.

6. Conclusion:

This survey research justifies the emergence of sustainable e-waste management for maintaining the paradigm of a circular economy. An efficient sustainable e-waste management has proposed for Bangladesh which must be followed by regulations of ESDO. Considering the economic assessment and environmental preservation are greatly dependent on volumetric electronic scrap, the article has assembled a redefinition of existing metal extraction routes. The study has focused on the metal extraction collaborative approach based on recent research. It is clear from the aforementioned study that hydrometallurgy is the best suited route for metal extraction from e-waste in Bangladesh. Bio-hydrometallurgy is another alternative yet sustainable approach if appropriate raw bio-agents are available. With the huge amount of e-waste produced, Bangladesh has a great possibility for e-waste recycling and getting profited, both economically and environmentally.

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