Romanian Journal of Ecology & Environmental Chemistry, 6(1), 2024

https://doi.org/10.21698/rjeec.2024.101

Review

Reviewing the progress and challenges of plastic waste recycling and management

MAJEDUL HOQUE*

Department of Pharmacy, Jahangirnagar University, Dhaka-1342, Bangladesh
**Corresponding author: majed.pharmju44@gmail.com*

Received:	Accepted:	Published:
06.02.2024	19.06.2024	04.07.2024

Abstract
Plastic waste is one of the biggest environmental threats since it is produced in large quantities and seriously harms both the environment and human beings. Plastic garbage generated on land frequently finds its way into water bodies, killing aquatic life and overloading the marine ecosystem. The main causes of this enormous mass of plastic garbage are a lack of technical expertise in handling hazardous waste, inadequate infrastructure development for recycling and recovery, and, most importantly, a lack of knowledge of the laws and regulations. The severity of plastic pollution harms the ecology as a whole. In this paper, a thorough investigation of the production of plastic garbage and its impact on humans and the environment are explored in terms of source identification concerning industrialized and developing nations. The article presents a thorough analysis of the current waste-to-energy and product conversion strategies. Additionally, this study clarifies sustainable waste management practices and pinpoints the major obstacles to implementing practical solutions to reduce the harmful effects of plastic trash.

Keywords: *plastic waste, mechanical recycling, management, impact, environment*

INTRODUCTION

Plastics are a versatile material that can be easily manufactured into a wide range of goods for use in a wide range of applications. They are lightweight, affordable, and durable. Plastics have evolved into an essential material in a variety of industries, including construction, engineering, medical, automotive, and aerospace, due to the prevalence of food packaging and everyday necessities all around us. Demand for and dependence on plastics have expanded as a result of economic development and progress, and during the past few decades, plastic production and consumption have rapidly increased globally. The majority of plastics manufactured each year are used to make disposable food packaging and other products with limited shelf lives that are thrown away after one year. Due to the exceptional durability of plastic, a large portion of this garbage is thrown in landfills or on to natural environments, where it accumulates significantly. It thus poses significant dangers to both human health and ecosystems, as well as substantial environmental pollution issues such groundwater contamination and hygiene-related issues. Additionally, a significant amount of plastic trash spills into the ocean as a result of improper waste disposal, creating a significant issue with marine plastic litter [1]. Solving these issues requires the effective and economical treatment of plastic trash, and interest in recycling plastic garbage has been rising quickly globally. The EU has advocated the idea of a circular economy based on the notion of using plastics in a cyclical fashion, and there are strong initiatives outside the European Union (EU) to pursue circular economies. With the assistance of numerous nations, the International Organization for Standardization (ISO) is developing global guidelines for the circular economy [2]. Despite the fact that researchers classify plastic recycling techniques differently, numerous publications on the topic have been published in this context. Primary recycling (re-extrusion), secondary recycling (mechanical), tertiary recycling (chemical), and quaternary recycling (energy recovery) are the four categories that some papers divide recycling into [3]. Although there are numerous studies that collectively refer to these as mechanical recycling, the difference between primary and secondary recycling is primarily attributable to the level of contamination of the plastic waste used. Energy recovery is typically characterized as recovery rather than recycling because it does not include the creation of new materials or raw materials but rather the extraction of energy in the form of heat. International standards for plastic waste disposal have been developed by the ISO, and there are three categories of plastic recycling: mechanical, chemical, and biological recycling [4].

Mechanical recycling is advantageous because it allows plastic waste to be converted back into plastics, but recycled plastics have drawbacks such worse quality and less strength when compared to virgin plastics [5]. Promoting public awareness of the benefits of recycled plastics for the environment is essential if we want to encourage consumers to switch from virgin to recycled plastics, especially in industrialized nations. Although chemical recycling is an efficient way to supplement mechanical recycling, it often only yields industrial items like fuel and ammonia, and it is challenging to make recycled polymers using this method. However, a method that can regenerate polymers from olefin plastic waste has just recently been discovered in several affluent nations, and its use is anticipated in the near future [6]. Plastic recycling has historically been done as part of the normal growth cycle in industrial businesses. For instance, where material and pollution limits are necessary, internal scrap will be reprocessed with virgin material to maximize the ultimate material output yield. Plastic garbage from industry and post-consumer use is disposed of in landfills [7, 8].

Polymeric materials have a wide range of applications in both domestic and industrial settings, and they are now a necessary element of modern life [9]. By 2050, it is predicted that there will be 1.1 billion tonnes of plastic produced globally [10]. According to the Environmental Protection Agency, only 7% of the tonnes of plastic garbage produced each year is recycled. Records showed that just 8% of the plastic being burned, with the remainder being dumped. These wastes are nevertheless released into aquatic bodies as a result of the energy and financial costs associated with landfilling [11, 12]. Wastes made of thermoset, thermoplastic, and elastomer plastic can seriously contaminate the environment [13, 14]. Therefore, addressing environmental and sustainability challenges requires proper management of plastic trash. The "take-make-consume-waste" technique is used in the conventional model to manage resources. The linear paradigm must be replaced with a generative and restorative model based on the circular economy concept. Thermal breakdown, landfills, mechanical pulverization, incineration, recycling, and microbiological degradation are common methods for managing plastic trash. The quick and accurate identification and sorting of waste plastic mixes is the key issue still facing the management of the waste plastic business [15].

In terms of the circular economy, landfilling is the least desired method of processing plastics, and the high rate of landfilling in the United States and Europa (particularly in Eastern and Southern European countries) is a significant problem [16, 17]. Secondary harm from landfilling includes ecological degradation and groundwater pollution. Recycling is strongly preferred over landfilling in industrialized nations. The percentage of energy recovery is high in Japan and several European nations. Energy recovery is a valuable technique for processing plastics since it is utilized for power generation, fossil resource replacements in industry, and it effectively lowers carbon dioxide emissions. However, mechanical and chemical recycling are preferable processing methods to energy recovery if generating recycled polymers is a top priority. The ability to recycle plastic effectively by a nation can lower environmental expenditures by an estimated 3.2 billion euros per year [18]. Since each technique has benefits and drawbacks, there is no one best way to recycle plastic garbage. Although mechanical recycling techniques utilizing wasted plastics, post-consumer plastic waste, or post-industry plastic waste are ideal, they have numerous drawbacks. Mechanical recycling has the drawback that recycled plastics don't perform as well as virgin plastics in terms of material attributes including strength, smell, purity, and color [19]. Pre-sorting of garbage is necessary due to the difficulties in recycling composite materials and filthy plastic waste, which raises prices [20].

Consequently, plastic garbage is typically thrown into landfills and released into the environment. Incineration is a common method for recycling energy from plastic trash, and it allows a substantial amount of energy to be created and used in a variety of applications [21]. Understanding the most effective separation techniques and recycling plastic trash are two of the most effective ways to reduce the buildup of huge waste stack in the environment. In order to reduce the buildup of plastic waste in the environment, this review will highlight the most cutting-edge mechanical and chemical recycling procedures for plastic trash. It is important to remember that breakdown of the polymer chains is necessary for chemical recycling of plastic waste [22].

For recycling filthy waste and composite materials, which are challenging to process mechanically, chemical recycling techniques involving pyrolysis [23] and gasification [24] are very useful. However, compared to mechanical recycling, it has the drawback of typically requiring a lot of energy, which leads to higher carbon dioxide emissions. In addition to the above listed methods, biological recycling is gaining popularity. Plastics made from petroleum can be organically broken down using microbes as one of the technique [25]. Another option, as some plastics are biodegradable, is a process of spontaneous disintegration under particular environmental circumstances [26]. Biological recycling has the benefit of having a low environmental impact because, depending on the circumstances for decomposition, it doesn't require a lot of energy. There are several different types of plastic garbage; polyethylene and polyethylene terephthalate (PET) are two of the most prevalent. Plastic waste recycling has been considered a convincing approach by scientists, and the packaging industry has offered numerous recycling techniques for this type of garbage. These technique aren't frequently used in the construction sector. As the most major industrial sector in many financial systems and the largest consumer of raw materials, the construction industry is actually a substantial and advantageous sector where plastic wastes add value and may be used for a variety of alternative uses and recycling. Plastic wastes can be used as insulation, filler, insulation bulk in asphalt and cementitious mixtures, and other civil building materials. Although the use of plastic trash in the building industry has a lot of promise, it is presently very underutilized [27÷29]. The process of heating materials to 400ºC to 650ºC in an atmosphere with little oxygen is known as pyrolysis. Organic compounds are broken down in this way without being burned. The technique can assist in recovering additional chemicals and materials, particularly from plastic trash, by incorporating cold plasma. Plastics can be pyrolyzed with cold plasma to produce ethylene, methane, and hydrogen. When burned, hydrogen and methane generate less carbon dioxide and emit more gas than fossil fuels. This makes them cleaner energy sources. This article provides brief summary about recent developments in materials and processes for recycling plastic trash. Additionally, about those research that has been done on polymeric waste found in common building materials as cementitious concrete and asphalt pavements, along with plastic management and some challenges. Figure 1 represents how devastating can be plastic disposal site.

Fig. 1. Devastating Plastic waste disposal site (Source: google)

METHODOLOGY

Data have been collected from different reputed international journals and literature like Scopus, PubMed and EBSCO etc.

DISCUSSIONS

Plastic materials

For proper use of a plastic material, it is crucial to understand what the substance is and if it will be employed. Plastics are created from chemicals and polymers. Depending on the product it is made for, the percentage of polymer inside a plastic material might range from around 100% to less than 20%. Figure 2 shows plastic input map into the ocean throughout the world. For the subject of recycling, these plastics should be classified into thermoplastics and thermosets, two primary types. This distinction affects both the production path and the recycling path and concerns the underlying molecular structure. In the initial application, a plastic is regarded as a new substance. When they are heated, they melt and float, and when they are subjected to cooling, they reformed. Refinishing a thermoplastic material is equally as crucial as repeatedly performing the heating and cooling cycle. Materials like HDPE, LDPE, PP, and PS are frequently utilized in the production of a variety of consumer goods, including apparel, carry bags, and quick snacks. PET is utilized in the bottles that hold carbonated beverages. PVC is used in the construction of the shoes, floors, and bottles. Similar to thermoplastics, thermosets cannot be remelted and initially processed thermosets disintegrate rather than fuse. That's because they become genetically entangled through a process termed treatment. This results in a hard and fragile chemical structure with a very high level of complexity. Examples of thermo-sets include thermosets, epoxy resins (adhesive, electrical isolation), melamine formaldehyde resin (heat-resistant laminate surfaces like kitchens), and phenolics (heat-strength doors, toasters, and irons). Reprocessing is significantly more difficult for thermosets because they are unlikely to be recycled by remelting. They are employed in smaller quantities to produce thermoplastic materials and have a lengthy shelf life (10 years). There have been a number of research projects to discover disposal methods for thermoset materials, some of which will be discussed later in this paper. As previously said, plastics are made up of polymers and additives, thus before examining recycling in more detail, it is crucial to talk about additives and their influence on this process. A thorough discussion of the several widely available plastic additives is outside the purview of this investigation. Plastic can have numerous chemicals added to it in a variety of quantities.

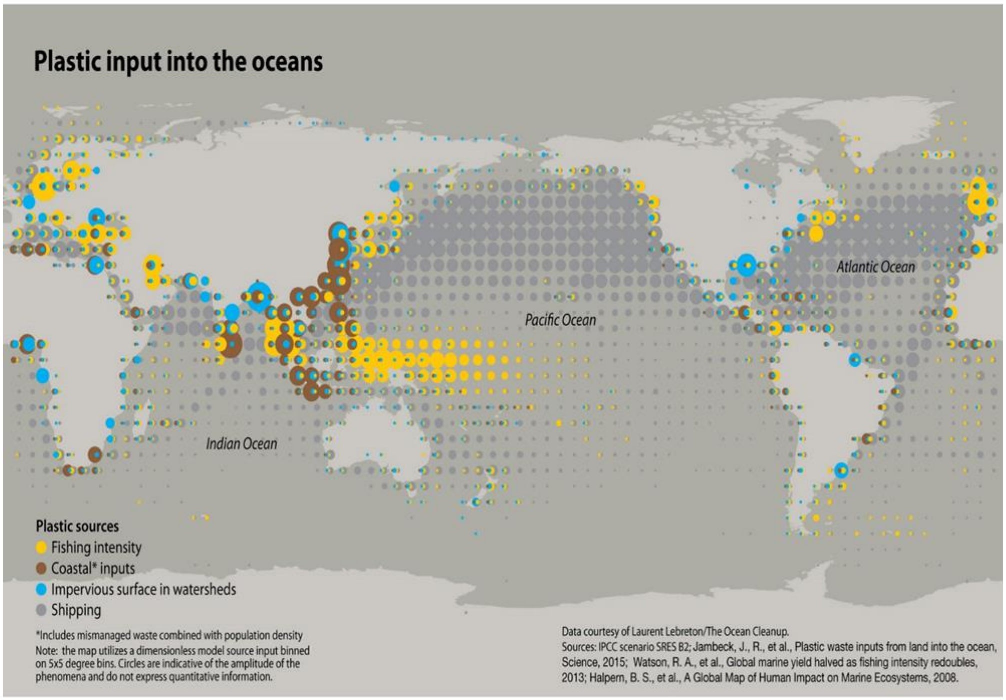

Fig. 2. Plastic input scenario into the ocean, (Source: IPCC scenario SRES B2)

Mechanics & recycling of plastic

Plastics are polymers, which are repeatedly arranged carbon and hydrogen atoms that can be converted into hydrocarbons like fuels, monomers, or intermediate chemicals. Figure 3 represents those countries with worst plastic management. Thermochemical recycling, which includes pyrolysis, gasification, depolymerization, and upcycling, is the term used to describe this process [28]. Pyrolysis is used here to refer to thermochemical recycling broadly. Mechanical recycling is the best kind of recycling since it uses waste plastic to recycle plastic. However, it has the drawback of being challenging to implement when recycling unclean plastic waste from food packaging and containers, as well as composite plastic trash [30]. Pyrolysis technology's global market size was around 972.8 million USD in 2019, and it is anticipated to increase at 8.2% CAGR between 2020 and 2027 [31]. Depending on the type of plastic, such as polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET), extensive research has been done to optimize reaction conditions (e.g., temperature, residence time, pressure, equipment, process), and suitable catalysts (e.g., cobalt, platinum, zeolite, aluminum chloride, organic matter) [23, 32÷35]. The regeneration of PS and PET from these wastes is being studied since PS and PET are extremely simple to monomerize [36, 37]. Commercial PET plants are available [37]. The main problem with pyrolysis is that it uses a lot of energy [38, 39], which can make it difficult to become carbon neutral. To counteract this, it is crucial to create a cheap, highly effective catalyst that can achieve thermal breakdown at lower temperatures.

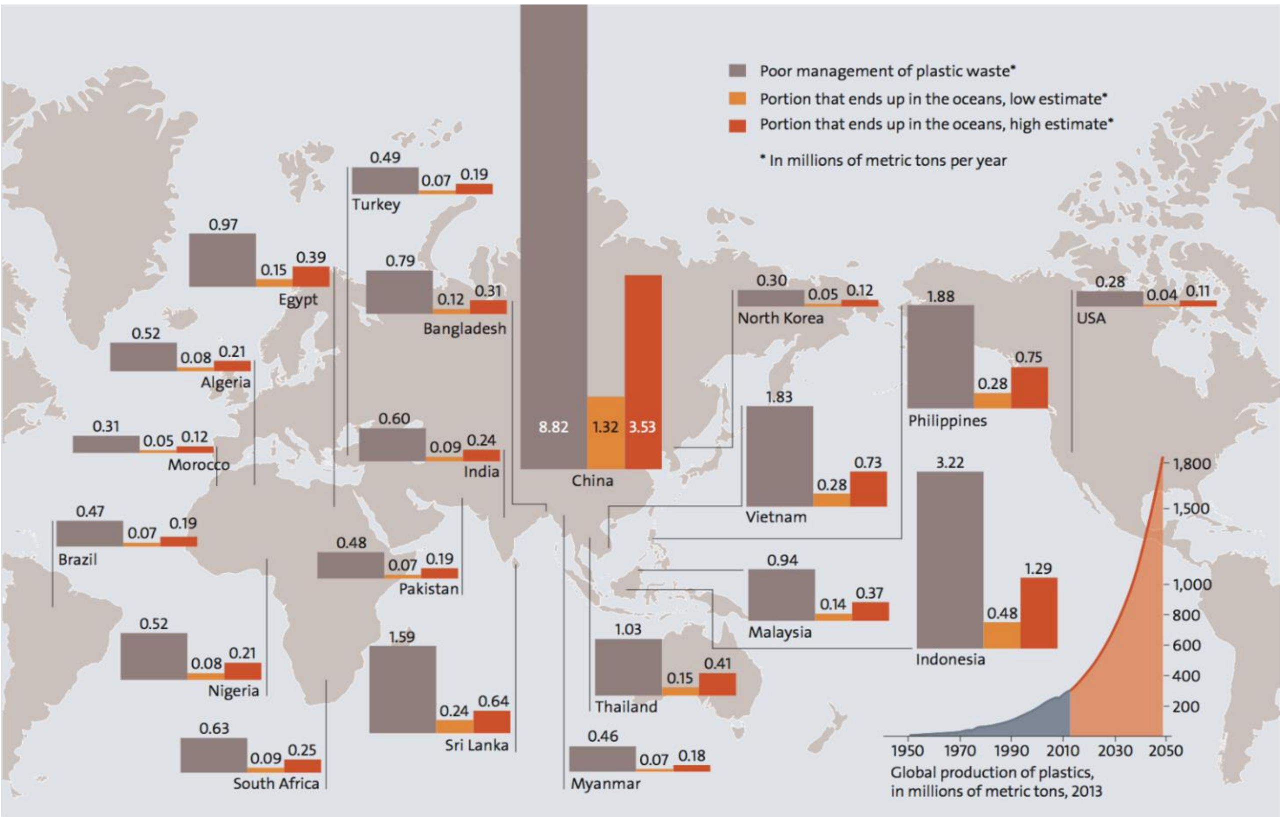

Fig. 3. Worst management of plastic by 20 countries, (Source: Gnda/Jambeck)

The specifics of waste and treatment operations, such as collection, transportation, and sorting techniques, vary depending on each country and location, and the LCA (life cycle assessment) of each prior study also takes these regional features into account [40, 41]. It is challenging to compare and condense the findings of each study in a strict sense because each study uses a different strategy for establishing system boundaries [41]. Despite these shortcomings, there are tendencies that are frequently seen in the literature. The differences between energy recovery and various treatment procedures are compared using the following metrics: global warming potential (GWP), energy use (EN), residual solid waste for disposal (SW), acidification potential (AP), and eutrophication potential

(EP). Mechanical recycling has a lower environmental impact in GWP, EN, SW, AP, and EP when compared to energy recovery [42, 43]. Comparing mechanical and chemical recycling, mechanical recycling has less impact on the environment in GWP, AP, EP, and EN, but a higher impact in SW [42]. Drawback of mechanical recycling is that it cannot recycle composite trash or unclean plastic waste. Therefore, it is not appropriate to compare mechanical and chemical recycling using LCA alone; it is preferable to use these two recycling techniques in conjunction with one another [44, 45]. Bioplastics-derived biodegradable polymers are also being industrialized. When compared to the current petroleum-derived polymers, polylactic acid (PLA), a biodegradable bioplastic, has poorer mechanical and barrier qualities. This restricts the uses for PLA. The fragility of PLA is increased by blending with hard polymers or by plasticizing block copolymerization [46]. Although the tensile strength is reduced, the strain at break is increased [47].

Bioplastics are polymers produced by microbial metabolism or from renewable materials and resources [48]. These are biomass-based and will be referred to as such from now on. The second definition states that, in addition to bio-based polymers, all biodegradable polymers—including those obtained from fossil fuels—are referred to as bioplastics [49]. The third definition states that the term "bioplastic" solely refers to bio-based and biodegradable polymers [46, 50]. Bio-PET and bio-PE are two types of bioplastics that are not biodegradable. Coca-Cola, Pepsi, and Nestle are those beverage corporations that already sell some beverages in bio-PET bottles to certain countries (30%) [51]. Terephthalic acid (TA), which serves as a starting point for the creation of bio-PET, is sourced from fossil resources; however, since the monomers required for production can be obtained from renewable resources, they can be referred to as bio-based PET [52]. Only one of the monomers in the majority of the bio-PET that is currently manufactured, ethylene glycol (EG), is derived from biomass, making bio-PET only partially bio-based. Only fossil fuels can be used to manufacture TA due to technical issues [53]. Making bio-TA from lignocellulosic biomass extracted from forest leftovers could be a way to make 100% bio-based PET [54, 55].

One of the most popular thermoplastic materials is PVC [56]. PVC has become a ubiquitous polymer as a result of its special features, excellent performance, low cost, and wide range of applications by various processing conditions and methodologies [57÷59]. PVC is used in many short-lived products, including textiles, medical equipment, cleaning supplies, beverage packaging, and food packaging. PVC is also used in durable goods like pipes, floors, window frames, wallpaper, cable insulation, and roofing sheets [60]. It is challenging to create cost-effective and efficient mechanical recycling since post-consumer PVC waste is combined with other plastic debris and sorting is still an issue [61]. In actuality, goods made mechanically from a mixture of waste materials have poor mechanical qualities and limited use [62]. A product with a low chlorinated compound content can be produced by using both low-temperature de-chlorination and mechanochemical treatment in base hydrolysis of PVC. The end product doesn't produce any harmful chemicals when chlorination occurs. The temperature and duration of the process can be greatly reduced by substituting an organic solvent and chlorine for the water-soluble medium [63÷67]. The fundamental benefit of treating PVC hydrothermally in subcritical water is that no chemicals that cause chlorination are created. This is because the chlorine produced from the PVC is changed into hydrogen chloride, which is completely soluble in water. This area of study is still being investigated [68÷75].

Electrical and electronic equipment (EEE) is made out of a variety of plastics, the most popular of which are acrylonitrile-butadiene-styrene (ABS), high impact polystyrene (HIPS), and polystyrene (PS). To comply with fire rules, EEE plastics employ flame retardants (FR). Chemicals called FR are added to polymer structures to prevent ignition and lessen product flammability [76]. In the process of treating EEE plastic trash, FR present a significant barrier. Chemicals of all kinds, both organic and inorganic, are employed as FR. There are two varieties of organic FR: halogen- and phosphorus-based FR. Chlorinated and brominated FR are examples of halogen-based FR [77]. FR is included in around 30% of the polymers used for EEE [78]. The abbreviation BFR stands for bromine-loaded FR. BFR include substances like aliphatic and aromatic substances. The primary distinction between the more than 75 different forms of BFR is where the bromine atom is located in the chemical structure [79]. The best way to handle EEE plastic waste is by mechanical recycling, which accounts for the majority of recycling done today [80, 81]. For mechanical recycling, BRF-containing plastics must first be separated, which raises the cost of production. Sorting by specific gravity is the most widely used automated sorting strategy [82]. A sorting method using infrared rays or X-rays has been extensively studied in recent years [83÷87]. For mechanical recycling, it is also necessary to presort by type of plastic such as ABS, HIPS, and PS, which increases the processing cost. For this reason, there are many studies that mechanically recycle the blended plastics, which are often used in EEE, without sorting them [84, 85, 88÷90].

A technique called flotation separation exploits the hydrophobicity of plastics to separate plastics depending on how differently they float on water. To limit its contact with air bubbles, the plastic surface is selectively made hydrophobic. For selected contact with air bubbles, the wettability of various plastics must be sufficiently different from one another [91]. There are two primary methods for flotation separation, one is to selectively make wettable polymers out of hydrophobic plastics [92].

Alternately, it is possible to selectively make wettable plastics hydrophobic [91]. Finding a useful method to effectively wet the polymers on a selective basis is the main challenge in plastic flotation. For instance, there are techniques for modifying chemical conditions, surface treatment, and techniques for lowering liquid-vapor surface tension (referred to as gamma flotation) [93].

It is widely accepted that when two materials with dissimilar surface qualities come into touch, they become charged. This is referred to as the tribo-charging phenomena, which is also referred to as frictional or contact electrification [94]. The tribo-charging principle is used to charge two distinct plastics positively and negatively in the process of electrostatic separation. Electrostatic separation can guarantee sorting of plastic trash since plastics typically have various surface characteristics (i.e., effective surface work functions) [95]. Electrostatic separation can only be employed to detect positive and negative charges due to the relative work function discrepancies between various plastic wastes, which make it impossible to measure the work function of all plastic wastes with rough surfaces accurately [96]. Typically, plastic trash is crushed to an appropriate size, sieved, and then charged using a triboelectric charger. Particles are then collected after applying an electric field to deflect them. Three collisions in particular - between particles made of different plastics, between particles made of the same plastic, and between particles and the device's wall material - affect the charge of the particles in the device [97]. Combinations of these three mechanisms, with contact between various types of plastics being the most significant, can alter the polarity and magnitude of charge on plastic surfaces. Tribo-charging actually only happens at a depth of 30 nm or less below the surface of plastics [98].

When plastics are used as an aggregate in concrete, heat generation and shrinkage are reduced, which reduces the risk of cracks. Additionally, since mixing plastics can reduce the amount of expensive raw materials utilized, such as cement paste and mortar, which are the primary ingredients in concrete, the cost of building can be lowered. There are few studies on the field applications of recycled plastics in concrete, despite the fact that there has been a lot of research on this topic. Global demand for concrete is strong, and processing a lot of plastic trash would be possible if recycled plastics could be utilized as aggregate. As a result, there is a substantial corpus of research in this area that is now being done [99÷101]. Concrete that uses plastics as aggregate has less slump, or flowability, and is more difficult to work with on building sites. Slump values have been shown to decrease by up to 50% when plastics are used to replace 20% of the fine aggregate [102]. The low density of plastics, the uneven shapes and sizes, and the pointed corners of recycled plastic fragments are assumed to be the causes of these features. Plastics don't mix well with the existing aggregates, and when plastic content rises, concrete's water absorption, permeability, and carbonation increase, severely affecting the material's durability [99].

Asphalt is a hydrocarbon-containing substance that shares chemical properties with polymers. Researchers agree that recycled plastics, when correctly combined with asphalt under ideal circumstances, greatly enhance the performance and lifetime of asphalt pavements [103]. For instance, ethylene vinyl acetate (EVA) has been used in road building for many years [104]. EVA is a class of polymers that modify asphalt by creating a hard, stiff, three-dimensional network that resists deformation. For complete LDPE dissolution into the asphalt, wet procedures that utilize LDPE need high shear rates and high temperatures. Although it is widely acknowledged that adding LDPE to asphalt enhances rutting, fatigue, and moisture resistance, the results of studies examining thermal cracking resistance vary [105]. The addition of PP to asphalt increases hardness and helps to boost rutting resistance. It is primarily employed in wet procedures. On the other side, PP makes asphalt less ductile, which causes more air voids. Increased air gaps were shown to hinder rutting resistance in one investigation [106].

Energy recovery

The burning of endogenous energy can be used to describe energy recovery. It is not surprising that polymers are excellent producers of fire when burned since they are composed of petrol. The amount of energy to be recovered is based on the material's heat content. According to published data, mixed plastic garbage has an average calorific value of 35 MJ/kg. It can be demonstrated that the energy return of plastics when burned is very high compared to paper (16 MJ/kg) and organic garbage (3MJ/kg). Different methods of energy recycling are employed. Incineration, the processing of spent coal, and gas recovery from pollutants from landfill sites are three sources of recycled energy. The United Kingdom continues to lag behind continental Europe, Japan, and the United States in the adoption of carbon storage technologies. For instance, China uses roughly 78% of its industrial waste, Denmark 58%, and the UK only 9% to create electricity. The distinction results primarily from the acceptance of trash disposal as a substitute. Alternative methods of disposal should emerge, though, as the costs and downsides of such disposal are expected to increase. Many nations in Europe use a large amount of municipal waste combustibles with cutting-edge carbon recycling and flue gas cleaning technologies to meet a significant portion of their home energy needs. When the combustion system is connected to a local heating system for the transport of hot water and process vapour, energy recovery becomes much more efficient. In some areas of Paris, France, homes are constructed using combustion plants.

Consumer & citizens

According to a research carboxy-methyl cellulose film can be excellent substitute of plastic material, it has a great deal of potential to replace petroleum-based polymers that are non-biodegradable because of its low cost and biodegradability [107]. Changes in the needs and habits of the final consumer may also influence manufacturers to use more recycled plastic in their goods. Figure 4 shows following six level pyramid of plastic waste management can help in reducing plastic residue. This problem is common in the food business, which is directly affected by the seas' plastic contamination. Brands are under pressure from customers and civil society to use more recycled plastic in their packaging. Finally, by properly classifying their waste, consumers must also take on a portion of the duty for separated collection. The quality of streams that are available for recycling directly depends on how carefully sorting standards are followed. Public authorities must clarify the rules and standardize them in order to improve the sorting of domestic waste, which is a challenge (Figure 5).

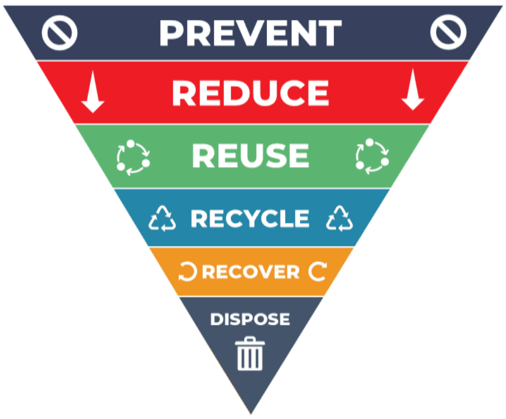

Fig. 4. Six level pyramids to reduce plastic wastes

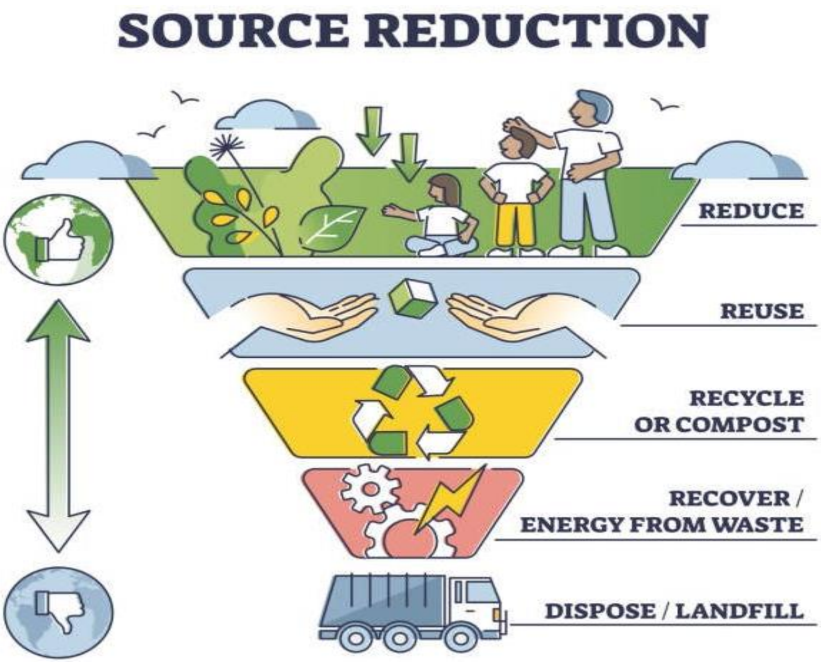

Fig. 5. Plastic waste management (Source: Getty images)

Challenges

Several hardship are related to the following issues:

- *variable composition*: plastic wastes come in a range of sorts and grades, which could cause them to function differently when used for building;
- *harvesting*: before the recycling process, this is regarded as the main constraint of plastic trash*;*
- *low density*: this may lead to some restrictions where a higher elasticity and toughness modulus are needed;
- *lack of knowledge*: the contractors' ability to accept and utilize plastic waste (PW) was constrained by their insufficient knowledge of the long-term performance of recycled plastics*;*
- *low surface energy*: this causes poor mechanical bonding during incorporation into the composites and greatly lowers the final composite's overall mechanical characteristics.

CONCLUSIONS

Plastics are indispensable to our daily lives, and when they are no longer needed, plastic garbage will inevitably be produced. As a result, their employment in the construction industry is a viable alternative that contributes to the sustainable management of plastic trash. The negative impact of plastic garbage is now a global issue because it contributes to climate change and global warming by releasing pollutants and poisonous gases into the environment. In addition to impairing soil fertility and tainting groundwater, the growing amount of plastic waste also seriously harms nearby ecosystems and the marine environment. But traditional methods of managing plastic trash primarily require open dumping or landfilling, burning, etc, and these actions ultimately harm the environment rather than meeting sustainable waste management objectives. This paper provides insight into the thorough examination of cutting-edge technologies for managing plastic trash and discusses the most resource- and environmentally-conscious approaches to handle plastic waste.

ACKNOWLEDGEMENTS

The data and materials used to support the findings of this study are publicly available.

REFERENCES

[1] HOPEWELL, J., DVORAK, R., KOSIOR, E., Philos. Trans. R. Soc. B Biol. Sci., 364, 2009, p. 2115.

[2] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, ISO/TC 323; Circular Economy, https://www.iso.org/committee/7203984.html [24.08.2023].
[3] AL-SALEM, S.M., LETTIERI, P., BAEYENS, J., Waste Manag., 29, 2009, p. 2625.
[4] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, ISO 15270:2008-Plastics-Guidelines for the Recovery and Recycling of Plastics Waste, https://www.iso.org/standard/45089.html [24.08.2023].
[5] SCHYNS, Z.O.G., SHAVER, M.P., Macromol. Rapid Commun., 42, no. 3, 2021, https://doi.org/10.1002/marc.202000415.
[6] IDEMITSU KOSAN CO., L., Started Japan’s First Demonstration Study of Waste Plastic Recycling including Mixed waste Plastics at Chiba Complex—Construct a Waste Plastics Recycling System by New Liquefaction Technology and Our Petroleum Refining & Petrochemical Plants, https://www.idemitsu.com/en/news/2021/0507.html [24.08.2023].
[7] BALAKRISHNAN, A., FLORA, R.M.N., Int. J. Eng. Res. Rev., 15, no. 3, 2017, p. 231.
[8] THOMAS, N.L., CLARKE, J., MCLAUCHLIN, A.R., PATRICK, S.G., Proceedings of Institution of Civil Engineers: Waste and Resource Management, 2012, 165, no. 3, pp. 133, https://doi.org/10.1680/warm.11.00014.
[9] EVODE, N., QAMAR, S.A., BILAL, M., BARCELO, D., IQBAL, H.M., Case Studies in Chemical and Environmental Engineering 2021, 4, https://doi.org/10.1016/j.cscee.2021.100142.
[10] LAI, Y.-Y., LEE, Y.-M., Sustain. Environ. Res., 32, 2022, p.1, https://doi.org/10.1186/s42834-022-00123-0.
[11] YUAN, Z., NAG, R., CUMMINS, E., Sci. Total Environ., 2022, 823, https://doi.org/10.1016/j.scitotenv.2022.153730.
[12] EMENIKE, P., ARAOYE, O., ACADEME, S., UNOKIWEDI, P., OMOLE, D., 5th International Conference on Science and Sustainable Development (ICSSD 2021), 11 - 13 October 2021, Center for Research, Innovation and Discovery, Covenant University, Nigeria, in IOP conference series: earth and environmental science, 993, 2022, https://doi.org/10.1088/1755-1315/993/1/012019.
[13] CHEN, Y., SELVINSIMPSON, S., Plastic and Microplastic in the Environment: Management and Health Risks, John Wiley & Sons Publishing House, 2022, p. 205-221, https://doi.org/10.1002/9781119800897.ch11.
[14] PRAJAPATI, R., KOHLI, K., MAITY, S., SHARMA, B., Composites Science and Technology, Springer, 2021, p. 15–41, https://doi.org/10.1007/978-981-16-3627-1_2.
[15] PAN, D., SU, F., LIU, C., GUO, Z., Adv. Compos. Hybrid Mater., 3, 2020, p. 443, https://doi.org/10.1007/s42114-020-00190-0.
[16] UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data#PlasticsTableandGraph [24.08.2023].
[17] PLASTICS EUROPE. Plastics—The Facts 2020, Chrome extension://oemmndcbldboiebfnladdacbdfmadadm/https://plasticseurope.org/wp-content/uploads/2021/09/Plastics_the_facts-WEB-2020_versionJun21_final.pdf [24.08.2023]. [18] WEN, Z.G., XIE, Y.L., CHEN, M.H., DINGA, C.D., Nat. Commun., 12, 425, 2021, https://doi.org/10.1038/s41467-020-20741-9.
[19] SHAMSUYEVA, M., ENDRES, H.J., Compos. Part C Open Access, 6, 2021, https://doi.org/10.1016/j.jcomc.2021.100168.
[20] SONI, V.K., SINGH, G., VIJAYAN, B.K., CHOPRA, A., KAPUR, G.S., RAMAKUMAR, S.S.V., Energy Fuels, 35, no. 16, 2021, p. 12763, https://doi.org/10.1021/acs.energyfuels.1c01292.
[21] ASTRUP, T., MØLLER, J., FRUERGAARD, T., Waste Manag. Res., 27, no. 8, 2009, p. 789, https://doi.org/10.1177/0734242X09343774.
[22] SIWAL, S.S., KAUR, H., DENG, R., ZHANG, Q., Curr. Opin. Green Sustain. Chem., 39, 2023, https://doi.org/10.1016/j.cogsc.2022.100722.
[23] SHARUDDIN, S.D.A., ABNISA, F., DAUD, W., AROUA, M.K., Energy Convers. Manag., 115, 2016, p. 308, https://doi.org/10.1016/j.enconman.2016.02.037.

[24] LOPEZ, G., ARTETXE, M., AMUTIO, M., ALVAREZ, J., BILBAO, J., OLAZAR, M., Renew. Sustain. Energy Rev. 82, 2018, p. 576, https://doi.org/10.1016/j.rser.2017.09.032.
[25] MOHARIR, R.V., KUMAR, S., J. Clean. Prod., 208, 2019, p. 65, https://doi.org/10.1016/j.jclepro.2018.10.059.
[26] HOQUE, M., Int. J. Res. Publ. Rev., l4, no 8, 2023, p. 838, https://ijrpr.com/uploads/V4ISSUE8/IJRPR16131.pdf.
[27] DAMAYANTI, D., SAPUTRI, D.R., MARPAUNG, D.S.S., YUSUPANDI, F., SANJAYA, A., SIMBOLON, Y.M., ASMARANI, W., ULFA, M., WU, H.-S., Polymers, 14, no. 15, 2022, https://doi.org/10.3390/polym14153133.
[28] SONI, A., DAS, P.K., HASHMI, A.W., YUSUF, M., KAMYAB, H., CHELLIAPAN, S., Sustain. Chem. Pharm., 27, 2022, https://doi.org/10.1016/j.scp.2022.100706.
[29] AHMAD, J., MAJDI, A., BABEKER ELHAG, A., DEIFALLA, A.F., SOOMRO, M., ISLEEM, H.F., QAIDI, S., Crystals, 12, no. 7, 2022, https://doi.org/10.3390/cryst12070944.
[30] AL-SALEM, S.M., LETTIERI, P., BAEYENS, J., Prog. Energy Combust. Sci., 36, no.1, 2010, p. 103, https://doi.org/10.1016/j.pecs.2009.09.001.
[31] GRAND VIEW RESEARCH Inc. Plastic to Fuel Market Size, Share & Trends Analysis Report by Technology (Pyrolysis, Gasification, Depolymerization), by End-Fuel (Sulfur, Hydrogen, Crude Oil), by Region, and Segment Forcasts, 2021–2028, https://www.grandviewresearch.com/industry-analysis/plastic-to-fuel-market [24.08.2023].
[32] KUMAGAI, S., YOSHIOKA, T., Bull. Chem. Soc. Jpn., 94, no. 10, 2021, p. 2370, https://doi.org/10.1246/bcsj.20210219.
[33] KOSLOSKI-OH, S.C., WOOD, Z.A., MANJARREZ, Y., DE LOS RIOS, J.P., FIESER, M.E., Mater. Horiz., 8, no. 4, 2021, p. 1084–1129.
[33] AL-SALEM, S.M., ANTELAVA, A., CONSTANTINOU, A., MANOS, G., DUTTA, A., J. Environ. Manag. 197, 2017, p. 177, https://doi.org/10.1016/j.jenvman.2017.03.084.
[35] KUNWAR, B., CHENG, H.N., CHANDRASHEKARAN, S.R., SHARMA, B.K., Renew. Sustain. Energy Rev. 54, 2016, p. 421, https://doi.org/10.1016/j.rser.2015.10.015.
[36] CAPUTTO, M.D.D., NAVARRO, R.., VALENTIN, J.L., MARCOS-FERNANDEZ, A., J. Polym. Sci., 60, no. 24, 2022, https://doi.org/10.1002/pol.20220137.
[37] THIYAGARAJAN, S., MAASKANT-REILINK, E., EWING, T.A., JULSING, M.K., VAN HAVEREN, J., RSC Adv. 12, 2021, p. 947,
[38] KOSLOSKI-OH, S.C., WOOD, Z.A., MANJARREZ, Y., DE LOS RIOS, J.P., FIESER, M.E., Mater. Horiz., 8, 2021, p. 1084.
[39] ZHUO, C.W., LEVENDIS, Y.A., J. Appl. Polym. Sci., 2014, 131, https://doi.org/10.1002/APP.39931.
[40] MAJEDUL, H., Rom. J. Ecol. Environ. Chem., 5, no. 2, 2023, p. 17, https://doi.org/10.21698/rjeec.2023.202.
[41] ALHAZMI, H., ALMANSOUR, F.H., ALDHAFEERI, Z., Sustainability, 13, no. 10, 2021, https://doi.org/10.3390/su13105340.
[42] LAZAREVIC, D., AOUSTIN, E., BUCLET, N., BRANDT, N., Resour. Conserv. Recycl., 55, no. 2, 2010, p. 246, https://doi.org/10.1016/j.resconrec.2010.09.014.
[43] CHEN, Y.D., CUI, Z.J., CUI, X.W., LIU, W., WANG, X.L., LI, X.X., LI, S.X., Resour. Conserv. Recycl. 146, 2019, p. 348, https://doi.org/10.1016/j.resconrec.2019.03.011.
[44] DAVIDSON, M.G., FURLONG, R.A., MCMANUS, M.C., J. Clean. Prod. 293, 2021, https://doi.org/10.1016/j.jclepro.2021.126163.
[45] CHAUDHARI, U.S., LIN, Y.Q., THOMPSON, V.S., HANDLER, R.M., PEARCE, J.M., CANEBA, G., MUHURI, P., WATKINS, D., SHONNARD, D.R., ACS Sustain. Chem. Eng., 9, no. 22, 2021, p. 7403, https://doi.org/10.1021/acssuschemeng.0c08622.
[46] LAMBERTI, F.M., ROMAN-RAMIREZ, L.A., WOOD, J., J. Polym. Environ., 28, 2020, p. 2551, https://doi.org/10.1007/s10924-020-01795-8.

[47] LEMMOUCHI, Y., MURARIU, M., DOS SANTOS, A.M., AMASS, A.J., SCHACHT, E., DUBOIS, P., Eur. Polym. J. 45, no. 10, 2009, p. 2839, https://doi.org/10.1016/j.eurpolymj.2009.07.006.
[48] QIN, Z.H., MOU, J.H., CHAO, C.Y.H., CHOPRA, S.S., DAOUD, W., LEU, S.Y., NING, Z., TSO, C.Y., CHAN, C.K., TANG, S.X., HATHI, Z.J., HAGUE, A., WANG, X., LIU, C.S.K., Chemsuschem 14, no. 19, 2021, p. 4103, https://doi.org/10.1002/cssc.202101825.
[49] RAMESH KUMAR, S., SHAIJU, P., O'CONNOR, K.E., BABU, P.R., Curr. Opin. Green Sustain. Chem., 21, 2020, p. 75, https://doi.org/10.1016/j.cogsc.2019.12.005.
[50] RUJNIC-SOKELE, M., PILIPOVIC, A., Waste Manag. Res., 35, no. 2, 2017, p. 132, https://doi.org/10.1177/0734242X16683272.
[51] BARRETT, A., PepsiCo Goes for Bioplastic Bottles, https://bioplasticsnews.com/2018/09/10/pepsico-goes-forbioplastic-bottles/ [24.08.2023].
[52] SHEN, L., WORRELL, E., PATEL, M.K., Biofuels Bioprod. Biorefining, 6, no. 6, 2012, p. 625, https://doi.org/10.1002/bbb.1368.
[53] TABONE, M.D., CREGG, J.J., BECKMAN, E.J., LANDIS, A.E., Environ. Sci. Technol., 44, no. 21, 2010, p. 8264, https://doi.org/10.1021/es101640n.
[54] REPO, A., KANKANEN, R., TUOVINEN, J.P., ANTIKAINEN, R., TUOMI, M., VANHALA, P., LISKI, J., Glob. Chang. Biol. Bioenergy, 4, no. 2, 2012, p. 202, https://doi.org/10.1111/j.1757-1707.2011.01124.x.
[55] PETERS, M., TAYLOR, J.D., JENNI, M., MANZER, L.E., HENTON, D.E., Integrated Process to Selectively Convert Renewable Isobutanol to p-Xylene. WO2011044243A1, 14 April 2011.
[56] OUR WORLD IN DATA, Primary Plastic Production by Polymer Type, 2015, https://ourworldindata.org/grapher/plastic-production-polymer [24.08.2023].
[57] GARCIA, D., BALART, R., CRESPO, J.E., LOPEZ, J., J. Appl. Polym. Sci., 101, no. 4, 2006, p. 2464, https://doi.org/10.1002/app.23484.
[58] YARAHMADI, N., JAKUBOWICZ, I., MARTINSSON, L., Polym. Degrad. Stab., 79, no. 3, 2003, p. 439, https://doi.org/10.1016/S0141-3910(02)00360-9.
[59] BRAUN, D. PVC—Origin, growth, and future. J. Vinyl Addit. Technol. 2001, 7, 168–176.
[60] SADAT-SHOJAI, M., BAKHSHANDEH, G.R., Polym. Degrad. Stab., 96, no. 4, 2011, p. 404, https://doi.org/10.1016/j.polymdegradstab.2010.12.001.
[61] DITTA, A.S., WILKINSON, A.J., MCNALLY, G.M., MURPHY, W.R., J. Vinyl Addit. Technol., 10, no. 4, 2004, p. 174, https://doi.org/10.1002/vnl.20026.
[62] GARCIA, D., BALART, R., SANCHEZ, L., LOPEZ, J., Polym. Eng. Sci., 47, no. 6, 2007, p. 789, https://doi.org/10.1002/pen.20755.
[63] SINGH, R., PANT, D., Chem. Eng. Res. Des., 132, 2018, p. 505, https://doi.org/10.1016/j.cherd.2018.01.043.
[64] YOSHIOKA, T., KAMEDA, T., GRAUSE, G., IMAI, S., OKUWAKI, A., J. Polym. Res., 17, 2010, p. 489, https://doi.org/10.1007/s10965-009-9335-2.
[65] GUO, L., SHI, G.Q., LIANG, Y.Q., Eur. Polym. J., 35, no. 2, 1999, p. 215, https://doi.org/10.1016/S0014-3057(98)00130-X.
[66] WU, Y.H., ZHOU, Q., ZHAO, T., DENG, M.L., ZHANG, J., WANG, Y.Z., J. Hazard. Mater., 163, no 2-3, 2009, p. 1408, https://doi.org/10.1016/j.jhazmat.2008.07.047.
[67] GHAEMY, M., GHARAEBI, I., Eur. Polym. J., 36, no. 9, 2000, p. 1967, https://doi.org/10.1016/S0014-3057(99)00264-5.
[68] SHEN, Y.F., Biomass Bioenergy, 134, 2020, https://doi.org/10.1016/j.biombioe.2020.105479.
[69] NAGAI, Y., SMITH, R.L., INOMATA, H., ARAI, K., J. Appl. Polym. Sci., 106, no. 2, 2007, p. 1075, https://doi.org/10.1002/app.26790.
[70] POERSCHMANN, J.; WEINER, B.; KOEHLER, R.; KOPINKE, F.D., Chemosphere, 131, 2015, p. 71, https://doi.org/10.1016/j.chemosphere.2015.02.057.
[71] SOLER, A., CONESA, J.A., ORTUNO, N., Chemosphere, 186, 2017, p. 167, https://doi.org/10.1016/j.chemosphere.2017.07.146.

[72] KUBATOVA, A., LAGADEC, A.J.M., HAWTHORNE, S.B., Environ. Sci. Technol., 36, no. 6, 2002, p. 1337, https://doi.org/10.1021/es011186k.
[73] YAO, Z.L., MA, X.Q., Energy, 141, 2017, p. 1156, https://doi.org/10.1016/j.energy.2017.10.008.
[74] NING, X.J., TENG, H.P., WANG, G.W., ZHANG, J.L., ZHANG, N., HUANG, C.C., WANG, C., Fuel, 270, 2020, https://doi.org/10.1016/j.fuel.2020.117526.
[75] TAKESHITA, Y., KATO, K., TAKAHASHI, K., SATO, Y., NISHI, S., J. Supercrit. Fluids. 31, no. 2, 2004, p. 185, https://doi.org/10.1016/j.supflu.2003.10.006.
[76] COVACI, A., HARRAD, S., ABDALLAH, M.A.E., ALI, N., LAW, R.J., HERZKE, D., DEWIT, C.A., Environ. Int., 37, no. 2, 2011, p. 532, https://doi.org/10.1016/j.envint.2010.11.007.
[77] SCHREDER, E.D., UDING, N., LA GUARDIA, M.J., Chemosphere, 150, 2016, p. 499, https://doi.org/10.1016/j.chemosphere.2015.11.084.
[78] PEETERS, J.R., VANEGAS, P., TANGE, L., VAN HOUWELINGEN, J., DUFLOU, J.R., Resour. Conserv. Recycl., 84, 2014, p. 35, https://doi.org/10.1016/j.resconrec.2013.12.006.
[79] HOQUE, M., RAFI, I.K., GSC Biol. Pharm. Sci., 24, no. 03, 2023, p. 132, https://doi.org/10.30574/gscbps.2023.24.3.0377.
[80] JAIDEV, K., BISWAL, M., MOHANTY, S., NAYAK, S.K., J. Polym. Environ., 29, 2021, p. 1763, https://doi.org/10.1007/s10924-020-01998-z.
[81] TURNER, A., FILELLA, M., Sci. Total Environ., 601-602, 2017, p. 374, https://doi.org/10.1016/j.scitotenv.2017.05.173.
[82] THE INTERNATIONAL BROMINE COUNCIL, Impact of Brominated Flame Retardants on the Recycling of WEEE Plastics, https://www.bsef.com/ [24.08.2023].
[83] TAURINO, R., POZZI, P., ZANASI, T., Waste Manag., 30, no. 12, 2010, p. 2601, https://doi.org/10.1016/j.wasman.2010.07.014
[84] DE SOUZA, A.M.C., CUCCHIARA, M.G., EREIO, A.V., J. Appl. Polym. Sci., 133, no. 34, 2016, https://doi.org/10.1002/app.43831.
[85] HIRAYAMA, D., SARON, C., Waste Manag. Res., 33, no. 6, 2015, p. 543, https://doi.org/10.1177/0734242X15584845.
[86] MENAD, N GUIGNOT, S., VAN HOUWELINGEN, J.A., Waste Manag., 33, no. 3, 2013, p. 706, https://doi.org/10.1016/j.wasman.2012.04.007.
[87] ARENDS, D., SCHLUMMER, M., MAURER, A., MARKOWSKI, J., WAGENKNECHT, U., Waste Manag. Res., 33, no. 9, 2015, p. 775, https://doi.org/10.1177/0734242X15588585.
[88] BRENNAN, L.B., ISAAC, D.H., ARNOLD, J.C., J. Appl. Polym. Sci., 86, 2002, p. 572, https://doi.org/10.1002/APP.10833.
[89] HIRAYAMA, D., SARON, C., Polymer, 135, 2018, p. 271, https://doi.org/10.1016/j.polymer.2017.12.038.
[90] VAZQUEZ, Y.V., BARBOSA, S.E., Waste Manag., 59, 2017, p. 403, https://doi.org/10.1016/j.wasman.2016.10.021.
[91] WANG, C.Q., WANG, H., FU, J.G., LIU, Y.N., Waste Manag., 41, 2015, p. 28, https://doi.org/10.1016/j.wasman.2015.03.027.
[92] FRAUNHOLCZ, N., Miner. Eng., 17, no. 2, 2004, p. 261, https://doi.org/10.1016/j.mineng.2003.10.028.
[93] ALTER, H. Resour. Conserv. Recycl., 43, no. 2, 2005, p. 119, https://doi.org/10.1016/j.resconrec.2004.05.003.
[94] LOWELL, J., ROSE-INNES, A.C., Adv. Phys., 29, no 6, 1980, p. 947, https://doi.org/10.1080/00018738000101466.
[95] WU, G.Q., LI, J., XU, Z.M., Waste Manag., 33, no. 3, 2013, p. 585, https://doi.org/10.1016/j.wasman.2012.10.014.
[96] PARK, C.H., PARK, J.K., JEON, H.S., CHUN, B.C., J. Electrost., 66, no. 11-12, 2008, p. 578, https://doi.org/10.1016/j.elstat.2008.07.001.

[97] CALIN, L., CALIAP, L., NEAMTU, V., MORAR, R., IUGA, A., SAMUILA, A., DASCALESCU, L., IEEE Trans. Ind. Appl., 44, no. 4, 2008, p. 1045, https://doi.org/10.1109/TIA.2008.926689
[98] WATSON, P.K., YU, Z.Z., J. Electrost. 40–41, 1997, p. 67, https://doi.org/10.1016/S0304-3886(97)00016-8.
[99] ALMESHAL, I., TAYEH, B.A., ALYOUSEF, R., ALABDULJABBAR, H., MOHAMED, A.M., ALASKAR, A., Constr. Build. Mater., 253, 2020, https://doi.org/10.1016/j.conbuildmat.2020.119146.
[100] BABAFEMI, A.J., SAVIJA, B., PAUL, S.C., ANGGRAINI, V., Sustainability, 10, no. 11, 2018, https://doi.org/10.3390/su10113875.
[101] FARAJ, R.H., ALI, H.F.H., SHERWANI, A.F.H., HASSAN, B.R., KARIM, H., J. Build. Eng., 30, 2020, https://doi.org/10.1016/j.jobe.2020.101283.
[102] MUSTAFA, M.A.T., HANAFI, I., MAHMOUD, R., TAYEH, B.A., Structures, 20, 2019, p. 519, https://doi.org/10.1016/j.istruc.2019.06.008.
[103] KALANTAR, Z.N., KARIM, M.R., MAHREZ, A., Constr. Build. Mater., 33, 2012, p. 55, https://doi.org/10.1016/j.conbuildmat.2012.01.009.
[104] AMERI, M., MANSOURIAN, A., SHEIKHMOTEVALI, A.H., Constr. Build. Mater., 40, 2013, p. 438, https://doi.org/10.1016/j.conbuildmat.2012.09.109.
[105] WU, S.H., MONTALVO, L., J. Clean. Prod., 280, part 2, 2021, https://doi.org/10.1016/j.jclepro.2020.124355.
[106] OTUOZE, H.S., EJEH, S.P., AMARTEY, Y.D., JOEL, M., SHUAIBU, A.A., YUSUF, K.O., Jordan J. Civ. Eng., 12, no.1, 2018, p. 35.
[107] HOQUE, M., HOSSAIN, M.S., HASSAN, N., JUBAYER, A., AKTARUZZAMAN, M., GSC Biol. Pharm. Sci., 24, no. 03, 2023 ,p. 193, https://doi.org/10.30574/gscbps.2023.24.3.0386.

Citation: Majedul, H., Reviewing the progress and challenges of plastic waste recycling and management, *Rom. J. Ecol. Environ. Chem*., **2024**, 6, no.1, pp. 6÷19.