***J. Adv. Sci. Edu. Res.* 2021: 2: 170-185**, ISSN: 2583-0155 (ONLINE)

https://doi.org/10.56253/JASER.2.1.2021.178-193
Pubished: 25.12.2021(http://jaser.rkmvccrahara.org/)

RECYCLING OF PLASTICS: STATUS, PROCEDURE AND UTILITY IN THE PRESENT ERA

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ABSTRACT

Pollution associated with plastic wastes is increasing day by day. In spite of several government directives, restrictions in the use plastics, specially single used plastics, has not yet been executed, owing to its easy availability, light-weight and significantly low cost. But, problem appears when they are disposed after use. Most of the plastics, used in our daily life, are non-bio-degradable, and may take up to several thousand years to degrade. Recycling of plastics is considered to be the most viable and economical way to get rid of such pollution. In global scenario, governments as well as the pollution control boards are promoting recycling to manage the plastic wastes most effectively. In today's pandemic situation the plastic waste management scenario is facing challenges due to uncontrolled use of plastics in terms of personal protective equipment. This has led to scientific communities to give priority in the plastic waste management to save the earth. In this review we have enlighten the global scenario of plastic waste management and recycling as one of the effective way in this regard. The waste management scenario in the post-pandemic era and some remedies have also been explored.

Keywords: Plastic Waste, Recycling, Pollution, non-biodegradable, COVID

1. Introduction

Plastics have proved themselves as very promising contenders commercially in the last decades owing to their low-cost, easy process ability and light weight. Thus, they have replaced conventional metal due to consumer's preference towards them. The single used plastic bags are used widely worldwide. Problem arises when the plastics are disposed of to the environment after use. Plastic pollution is the accumulation of plastic objects and particles (e.g. plastic bottles, bags and micro beads) in the Earth's environment that adversely affects wildlife, wildlife habitat, and humans (Hammer et al., 2012).

Plastics that act as pollutants can be categorized into micro-, meso-, or macro debris, depending on their size. The durability, as well as, comparatively lower cost have made plastics adaptable for different uses. Most of the plastic bags are non-biodegradable, i.e., they are not degraded by the biological entities present in the soil and may take up to several thousand years to degrade (Zia et al., 2007). This facilitates enormous quantity of plastic to come into the environment as mismanaged waste and becomes a part of the ecosystem. Production of polymers has always been combined with the challenge to utilize it after use. Plastic is one of the most major innovations of 20th century and is an omnipresent material. There are three main avenues for managing end-of-life for plastic products. A slower expansion in the field of recycling aggravates the situation more: several million tons of used polymeric materials are being disposed of every year. The amount of plastics in flow is expected to increase from 236 to 417 million ton per year by 2030 (Lebreton and Andrady, 2019), which may lead to severely hurt the ecological balance and subsequently develop social problems. Waste management via landfilling have lost its glory in recent days due to its increasing cost, low sustainability, and limitation of spaces especially in urban areas. Dumping from ships at sea has already been prohibited in 1990 (Coe and Rogers, 1997). Moreover, unscientific discard methods lead to the elimination of significant quantity of materials in term of economy. The economic destruction from damage to infrastructure, on tourism, and cleanup liability is also projected to be added in billions every year (2009; 2014; 2014).

Recycling is considered to be the most economical and viable way to manage solid waste pollution. But, even after extensive encouragement for recycling it has not been practiced much worldwide. Very unfortunately, negligible amount of plastic wastes are recycled in present days. In 2016, only 16% of polymers in stream were collected for recycling while 40% were sent to landfill and 25% were incinerated (Hundertmark et al., 2020). Recently, European countries have increased efforts to improve recycling rates. In 2018, more than 29.1 million tonnes of post-consumer plastic wastes were collected in Europe, of which only 32.5% were being recycled, 42.6% were incinerated and were 24.9% landfilled (Eurostat, 2018). Though the data showing management of only one third of the total wastes through recycling, the recycling percentage was doubled compared to 2006, as reported by the European Union (EU). The plastic coming out from the packaging contributes much (39.9%) in the plastic waste disposal.

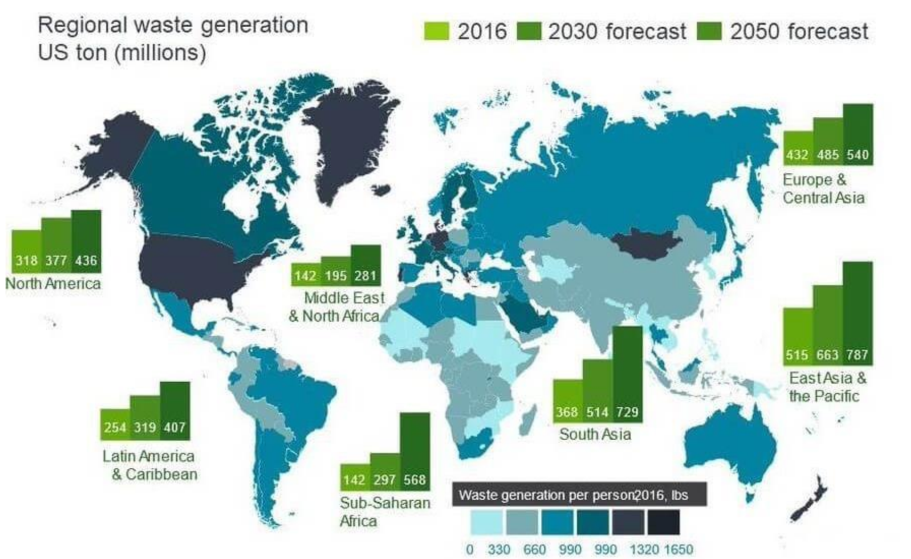
Thermoplastic polymers, such as, PE, PP, PS and PET are widely used commercially for packaging. Thermoplastics comprised of long, linear heat-responsive molecular hydrocarbon chains which allows the alternation of physical properties upon heating and cooling. Thermoplastics can be easily shaped by injection molding and other simple processes. The durability along with lower cost also facilitates their widespread applications (Michler and Balta-Calleja, 2016; Krevelen and Nijenhuis, 2019). Thus, thermoplastic materials are the most established material in single-use plastic waste. To diminish their deadly impact on the environment, numerous efforts have been made over the last few years, to increase the recovery of such products in an economically viable yet eco-friendly manner, with minimum compromise of their mechanical performances (Ribeiro et al., 2016; Yang et al., 2012). Incineration and recycling are the key recovery methods for treatment of polymer wastes with thermoplastics. Countries like Singapore and Japan have widely adopted waste-to-energy processes, which again necessitates addressing another set of environmental concerns such as the production of toxics gases and heavy metal-contaminated ash (Saleh and Danmaliki, 2017; Michael, 2013).

In this review, we enlighten the present global scenario of recycling and difficulties associated with it. Few recycling methodologies have also been explored. The applications of recycled plastics, as well as, the importance of recycling in the post-pandemic situation can also be found in the present review. Here, we have used Google scholar as the search engine for finding the literatures related to this mini review according to their relevance. Focus has been put in selecting the papers based on their merit in the present context. Several government reports, newspaper data, as well as, the data available in the web have also been considered in writing this review.

2. Global Status of Recycling

Until 2015, the total amount of plastic produced globally is estimated to be 8.3 billion tones (Geyer et al., 2017). By 2015 the worldwide production had reached some 381 Mt per year, greater than the combined weight of everyone on the Earth (Walpole, 2012). The recycling rate in that year was 19.5%, while incineration rate was 25.5% and the remaining 55% was disposed of mostly through landfill. These rates lag far below those of other recyclables, such as paper, metal and glass. Although the percentage of recycling or incineration is increasing each and every year, the mismanaged waste also continues to rise. This is due to the global plastic consumption is going on increasing year-on-year. Urban India generates 62 million tons of waste municipal solid waste (MSW) annually, and it has been expected to touch 165 million tons in 2030. 43 million tons of MSW were collected annually, out of which only 11.9 million was processed further while the rest 31 million was dumped into the landfill (Singh, 2020). Waste is not segregated in India after collecting, and huge quantities of plastic litter are found to clog public spaces, as well as, water bodies. In India, the segregation of wastes and its management through recycling is operated very casually in the most unscientific way.

Recycling rates vary between the different types of plastic, reflecting the easy with which they can be sorted and reprocessed (2018). PET bottles and HDPE have the highest recycling rates, whereas others such as polystyrene foam are sometimes not recycled at all. According to the United Nations, .only 9% of the plastic waste ever produced globally is recycled (2021). Fig.



1 represents the global scenario of waste generation and its forecast.

Fig.1: *Generation of wastes and its forecast, globally (2021).*

3. Recycling Procedure

There are fundamentally two processes for recycling, namely, primary mechanical recycling and secondary mechanical recycling. Fig.2 represents different recycling procedures.

3.1. Primary Mechanical Recycling

In primary mechanical recycling, the discarded polymer is directly converted into a new product without negotiating with the performance of the polymer. The post industrial wastes are being recycled by most of the manufacturing units via this process, and thus primary mechanical recycling process is regarded as closed-loop process of recycling. But, difficulty arises when it comes to the post-consumer wastes as it faces several associated complications, such as, selective collection, manual sorting of wastes etc. Primary recycling thus becomes unattractive to the stakeholders due to significant increase in costs of the recycled products.

The used materials require several steps, such as, grinding, crushing, shredding, milling etc. before fabrication of the used material into a new product. These processes make the cleaning process easier. Moreover, the crushed material will be more homogeneous and thus the blending process will be more facile for further processing. The finely divided material will then be subjected to melt and the desired shaped recycled plastics can be obtained after molding.

The widely accepted primary mechanical recycling processes are extrusion, injection molding, roto-molding, and heat pressing. Thus, only thermoplastic polymers, such as PP, PE, PET, and PVC, can normally be mechanically recycled (Goodship, 2007).

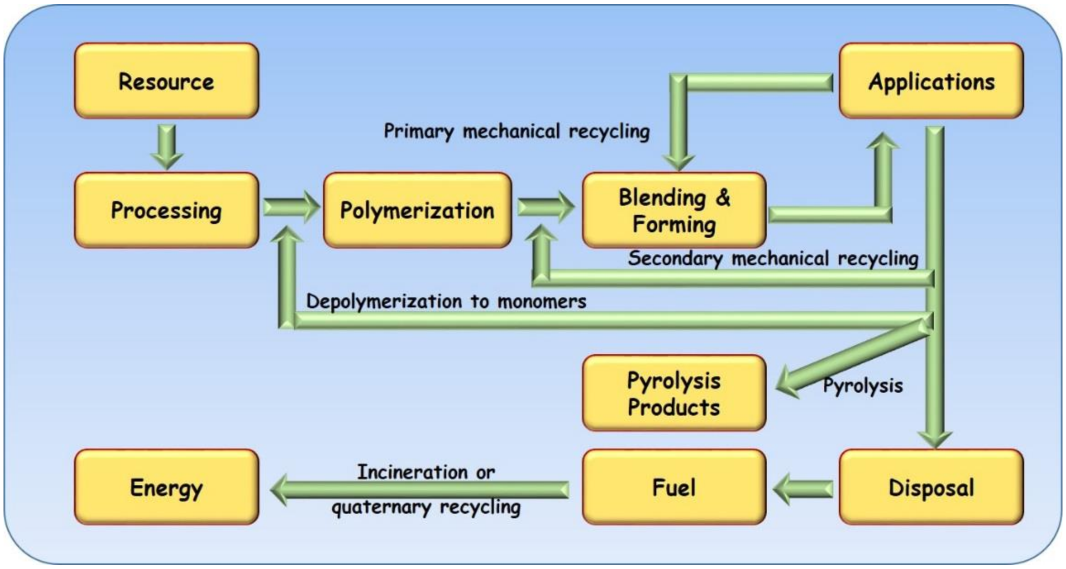


Fig.2: *Most commonly used polymer recycling procedures and their utilization*

3.2. Secondary Mechanical Recycling

Primary mechanical recycling faces numerous difficulties associated with the limited knowledge about the purity grade of the polymer used. Secondary recycling thus found to be effective as it involve additional separation and purification steps before further processing. Thermoplastics are generally processed through primary recycling procedure. As the primary recycling procedure involve direct processing it leads to decrease in molecular weight due to the chain scission reactions in the presence of water and traces of acids present in the waste plastics. It may lead to the reduction of mechanical performance of the recycled plastics formed. In contrary, the secondary recycling procedure involves several purification steps, such as, intensive drying, vacuum degassing, and stabilization by adding suitable additives, which facilitates to retain the mechanical performance of the recycled polymer. Moreover, various polymers are found to be not compatible with the matrix polymers and thus appeared as phase separated and thus displays very poor mechanical performance in the blends or composites form. Secondary mechanical recycling offers efficient separation of the constituent materials before incorporating in the same composite.

Several sophisticated techniques, such as, Fourier-transform and near-infrared spectroscopy and optical recognition are generally utilized to identify and separate the waste polymers in secondary mechanical recycling. X-ray diffraction is utilized in the identification and isolation of PVC to eliminate the unwanted formation of HCl during reprocessing at higher temperatures (Hopewell et al., 2009).

The secondary recycling procedures depends on several factors, such as, logistics of high volume waste materials, costs of selective collection, storing of waste materials, composition and purity of waste plastics. The price difference between virgin and recycled materials, existence of undesired additives, availability and costs of recycling techniques aggravates the situation more.

In automobile industry, shredded car components coming out from the automotive shredder are generally utilized in the fabrication of new car components via secondary recycling procedure. Secondary recycling process is also widely applied in the recycling of post-consumer polyurethane (PU) foam. In PU recycling, the foam is first disintegrated to form flakes and then transformed into a new form by remolding. However, due to polymer degradation, the quality of the end product is often not satisfactory (Yang et al. 2012).

3.3. Tertiary and Quaternary Recycling

Tertiary recycling involves production of fuels and chemicals by using waste plastics as feedstock. This process is utilized in the glycolysis of poly ethylene terephthalate (PET) into diols and dimethyl terephthalate, which can again be utilized in making virgin PET. In quaternary recycling process waste materials energy is recovered from the waste materials during incineration. One classic example of quaternary recycling process is tire-derived fuel (TDF) (Merrington, 2017).

Incineration is considered to be the most viable way to recover energy by reducing the volume of organic material. This method is considered to be very fruitful as it generates considerable energy from polymers. However, the health hazards associated with the airborne toxic substances, for example, dioxins (in the case of heavy metals, chlorine-containing polymers, toxic carbon, and oxygen-based free radicals) limits its application.

4. Difficulties in Recycling

There are several complications associated with recycling which have restricted its widespread applications; only 9% of the plastic wastes are recycled globally. In this part we will try to find out the underlying difficulties and suitable pathways to manage them.

- *<u>Greater cost of recycled plastics:</u>* The value of plastics wastes depend on the quality as well as disposal of plastics after use from the end of consumer. As it come into the market, the price of the recycled plastics is determined by the demand-supply chain as well as the local authorities. It is very much obvious that the quality of the recycled plastics are lower as compared to the virgin plastics. Yet, it appears to be of comparable price to that of a brand new material. It is thus difficult to create business of recycled plastics.
- *<u>Difficulties in segregation:</u>* Most of us are not willing to sort or clean waste plastics before their disposal into the trash. However, if small effort is given towards cleaning and sorting before disposing of waste plastics, the recycling process will be easier and economical.
- *<u>Difficulties associated with paint:</u>* Paint is another material which makes the recycling difficult. Before recycling paint should be removed and thus the recycling process becomes complicated and costly.
- *<u>Complicated processing for composites:</u>* Most of the plastics used in our daily life are composite materials. Composite materials contain polymers as well as reinforcements, which make the processing difficult. In some fields, ternary and quaternary composites are used, which make the recycling process complicated. These composites are least recycled, owing to the complexity associated with their recycling. Recycled plastic again faces weak demand towards the consumers due to its virgin counterpart appeared as cheaper as well as of superior quality (Hopewel et al., 2009)
- *<u>Lack of proper plan:</u>* No global action plan for plastic waste management has also restricted the global drive of recycling.
- *<u>Cheaper alternative ways:</u>* Manufacturing of cheap composite materials using less amount of plastics has aggravates the situation by lowering down the plastic cost and thus plastics are being used in extensive levels without caring the environmental factors.

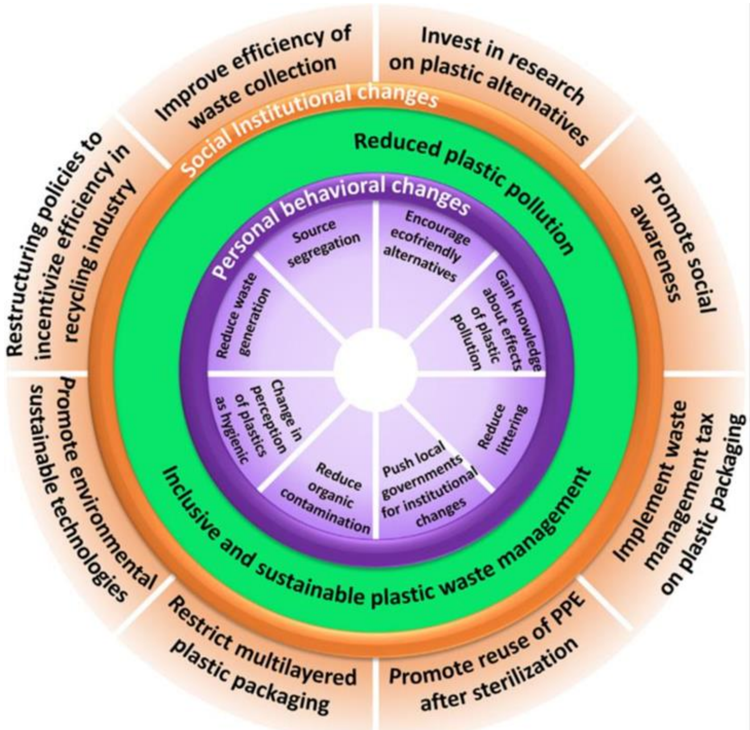


Fig.3: *Diagram illustrating an approach to reduce pollution associated with plastic wastes and sustainable management of plastic wastes (Vanapalli, 2021)*

The management of plastic wastes via recycling can only be achieved via global action plan, governments' initiative, and goodwill of industries and responsibility of common people. Fig.3 illustrates different approaches for plastic waste management.

- Global action plan should be made to fight against plastic waste pollution and promote recycling globally.
- Governments should frame strict directives to promote recycling. To make recycling more effective and viable, strict rule should be made in the fabrication of plastics. More virgin plastics should be used in making consumer product. This will not only increase the price of the plastic product but also will make the recycling feasible.
- Governments should promote recycling by subsidizing the recycling equipment and setting up recycling industry. More dedicated R&D should be developed and research projects should be sanctioned to develop novel technologies to utilize plastic wastes.
- Individuals also have their own responsibilities to make the plastic waste management process favorable. Mental set up is very much necessary in the consumer end that the

used plastics will be recycled and thus proper disposal is necessary. After using the plastic product it should be properly cleaned before their disposal. Plastic wastes should be disposed of at right place and should never be thrown as litters.

5. Applications of Recycled Plastics

Polymers used as consumer products are mainly of two types, viz., thermoplastics and thermosets. Thermosets are less attracting towards recycling as they cannot be processed thermally. The only things can be done with the thermosets are incineration and pyrolysis. The carbon residues left can be utilized in making concretes and roads. Recycled thermoplastics have wide variety of application. Table 1 summarizes the applications of different recycled thermoplastics.

Table 1: Common recycled plastics and their applications

Plastics	Applications	References
PET	Drink bottles, detergent bottles, clear film for packaging, carpet fibers	Siddique et al., 2008
PVC	Packaging for food, textile, medical materials, drink bottles	Zare, 2015
HDPE	Detergent bottles, mobile components, agricultural pipes, compost bins, pallets, toys	Rahimi and Garcia, 2017, Siddique et al., 2008
PP	Compost bins, kerbside recycling crates	Hopewell et al., 2009
PS	Disposable cutlery	Gallop, 2009
LDPE	Bottle, plastic tubes, food packaging	Rahimi and Garcia, 2017 Achilias et al., 2009

Composites with less process ability can be introduced in the incinerator, kiln and the residues can be utilized in making bricks and concrete. Roads can also be made by using waste plastics owing to the good hydrophobicity of plastics.

6. Utility of Recycling in the COVID Pandemic

The situation of plastic waste management has become more complex due to COVID 19 outbreaks spread around the world in the early 2020. We are writing this review when the world has suffered almost 1.5 year in this pandemic situation. The COVID 19 pandemic has promoted the use of uncountable plastic as personal protective equipment (PPE). Face masks, face-shields, aprons, gloves, caps, sanitizer bottles have been widely used to fight against the pandemic. Single used PPEs are of great headache considering their disposal after use. The incineration as well as other solid waste managements of every country is facing challenges. The pandemic has also increased the use of single used food packaging materials, cutlery sets, plates etc. Most of the groceries and other consumables are being purchased from e-commerce sites and all of them are being packed by single used plastic bags owing to the safety of the items. Fig.4 depicts different types of waste generated during COVID 19 pandemic.

The medical wastes have been increased tremendously owing to the large number of COVID 19 affected people. To date (2nd June, 2021), 183,440,159 people are reported to be affected with COVID 19, with total deaths of 3,971,870 worldwide (2021). The infectious wastes are being directed to dispose by incineration, but the facility available has become inadequate to handle such large amount of wastes. Major amounts of these plastic wastes are being managed most unprofessional means, like, open air burning, landfilling. This may lead to another epidemic associated with mismanagement in the plastic waste disposal.

To fight against the plastic waste pollution the following suggestions may work:

- Infectious biomedical wastes should be incinerated or introduced into the kiln.
- Non-infectious or UV-sterilized plastic wastes may be pyrolized and the remaining carbon may be utilized in construction material.
- The use of bio-plastics in PPEs as well as in packaging may reduce the waste generation.
- The single used plastics for packaging may be utilized multiple times and disposed of in proper place after sufficient use.
- Governments should take initiation in recycling the plastic bags, cutlery, sanitizer bottle, face shield etc.
- COVID 19 waste treatment plan should be planned globally and implemented in the municipal scale.
- In the post-pandemic era the use of plastics should be more strictly handled by the government to compensate the high amount of consumption of plastics during COVID-19 pandemic

Fig.4: *Different Plastic Waste Generation during COVID-19 Pandemic (Vanapalli, 2021)*

7. Future Challenges

To save the earth governments and stakeholders should put their hands together to save our earth from the plastic waste pollution. Plastic waste management is considered to be an important waste management stream. Proper and systematic utilization of plastic wastes may lead to useful bye products such as fuel. Planning and professionalism are thus very much required in this regard.

Plastic wastes should be segregated first to make useful products. PET, PS, PMMA, PP, HDPE, LDPE based material can be recycled easily if they are in virgin form or having definite composite composition. The thermosets used in several purposes are difficult to process and thus can be utilized in the construction fields, as well as, in fuel manufacturing. Thus, wastes can be widely used in the generation of economical products, sometimes referred as 'Waste to Wealth'.

8. Conclusion

Plastic wastes have proved themselves as a field of immense attention owing to the existence of our environment for indefinite period after disposal. Lots of plastics are used globally and disposed of to the environment without further treating which in turn leads to severe plastic waste based pollution. Here, we have discussed recycling to be an effective way to get rid of this plastic waste pollution. Different recycling procedures along with difficulties of recycling has been discussed. The difficulties of recycling as well as applications of recycled plastics have also been summarized. The waste management scenario is facing more challenges due to COVID-19 pandemics, which has increased the disposal of single used plastics extensively. The biomedical plastic wastes has challenged the plastic waste management capacity of any government around the globe. Though it seems to aggravate the waste management scenario, accurate planning, professional management can lead to generate economical products without harming the environment. Governments and stakeholders should put hands together to get rid of this plastic waste pollution.

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