International Journal of Multidisciplinary Research and Publications
ISSN (Online): 2581-6187

Industrial Plastic Waste Conversion into Added Value Products in View to Mitigate Plastic Pollution: A Review

Tatnkam Ernest Jefferson[1]*, Dolly Sharma[1], Gaurav Pandey[1,2], Avinash V. Palodkar[3,4], Asheesh Kumar[3,4], Nadezhda Molokitina[2]
[1]Department of Petroleum Engineering and Earth Sciences (Energy Cluster), School of Engineering, University of Petroleum and Energy Studies, Dehradun, Uttarakhand, 248007, India
[2]Earth Cryosphere Institute, Tyumen Scientific Center SB, RAS, Tyumen 625026, Russia
[3]Upstream and wax Rheology Division, CSIR-Indian Institute of Petroleum, Dehradun Dehradun-248005, India
[4]India and Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India
Email address: ernesttatnkam2@gmail.com

Abstract**—*Since century now, human health and environment are threatened by plastic wastes. Plastics are among the worldwide used products, but constitute a big pollution problem due to the long degradation period of its wastes. The pollution prevention strategy can be resumed into 4Rs which are: Refuse, Reduce, Reuse and Recycle. The life cycle stages of plastic propose in the disposal step three ways: incineration, landfills and recycling; among which the last (recycling; 9%) represents the environmentally friendly option. Landfilling representing the highest proportion (79%) of plastic disposal, causing land pollution, followed by incineration (12%) which contribute to atmospheric pollution, and together landfills and incineration constitute a threat to ecosystems and to the human health. Originating mainly from fossil energy sources, plastics can be reverted back to fossil derivatives depending on their chemical composition, and preparation. Pyrolysis is one of the most common method for plastic conversion; but aside, there is also chemolysis, gasification, hydrothermal liquefaction and more, which can also use for converting plastic wastes. In this review, different products obtained through plastic conversion have been discussed along with the processes and parameters involved*.

Keywords**—** *Added value products; Plastic conversion; Plastic waste; Pollution mitigation; Pyrolysis.*

I. INTRODUCTION

The 20th century marked the rise of entirely synthetic plastics industry. The first plastic that was fully synthetic was made in 1970 by Leo Baekeland, a chemist from Belgium. Christened “Bakelite”, that first synthetic plastic was the combination under heat and pressure of formaldehyde and phenol (*The Age of Plastic*, 2023). Series of test have been conducted in view to develop variety of polymers, and today, with the alliance of the petroleum and chemical industries, there is a multiplicity of plastics. The development of plastics industry raised with the creation of different methods to produce polymers through petrochemical raw material. The researched features in plastics are their lightness, lifespan and affordability compare to other material types (OECD, 2022). The Compound Annual Growth Rate is predicted by RESEARCHANDMARKET to increase by 3.98% (~4%) and will reach by 2030, USD 824.46 billion (Markets, 2023). The growth of plastic demand can be attributed to the increase in foreign investment in domestic building markets, electronic devices, but also for daily use purpose as plastic bag, cup, plates, and tools; without forgetting the car industry.

II. PLASTIC DEMAND, WASTE AND POLLUTION MANAGEMENT

A. *Plastic demand*

One of the greatest environmental challenge in this 21st century is inevitably plastics pollution, which is at the origin of important damages of the ecosystems and human wellbeing. Additionally, the fossil sources of most of the plastics produced, has considerable impact on climate change. Yet being used in almost all financial sectors, plastics have become a fundamental part of the world economy (OECD, 2022). In 2022, the global plastic demand has been estimated at 470MTpa, and is intended to rise up to at least 800MTpa by 2050.

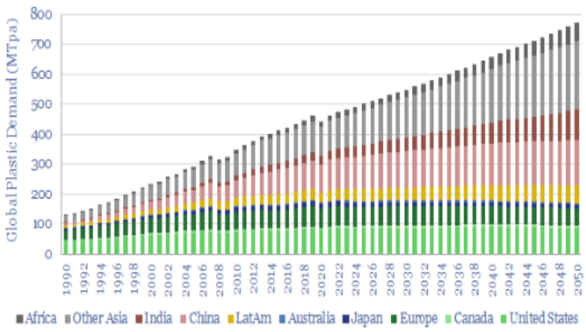

Fig. 1: Global plastic demand estimation between the years 1990-2050 (*Global Plastic Demand in Energy Transition?*, 2023.)

From the above charts, we can notice that 12% of the global population, representing developed countries, do have 40% of the global plastic demand. The emerging global demand is estimated to double from 300MTpa to 600MTpa and plus in coming years (OECD, 2022).

B. *Waste management*

Tatnkam Ernest Jefferson, Dolly Sharma, Gaurav Pandey, Avinash V. Palodkar, Asheesh Kumar, Nadezhda Molokitina, “Industrial Plastic Waste Conversion into Added Value Products in View to Mitigate Plastic Pollution: A Review,” *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 6, Issue 6, pp. 177-180, 2023.

Globally, some countries are giving their best to address the challenges of waste plastic through diverse methods and policies.

Due to the growing demand, plastic waste menace is becoming significant and should be sustainably addressed. The figure 2 below out show an overview on how plastic wastes are managed.

The steps involved in waste plastic recycling are the following:

- The collection of plastic wastes

Plastics are collected by the help of rag pickers, waste collectors, waste dealers and recycling enterprise. Then brought to the sorting facility.

- The sorting of plastic wastes

Collected plastics are sorted base on their colour, resin content and plastic recycling code. By sorting, identification and elimination of impurities is done.

- Impurities removal (cleaning through washing)

Remaining contaminants are removed through this process, with use of detergent. After what the clean plastics are washed.

- Shredding and resizing of cleaned plastic waste

The shredder has for function here to cut and grind the plastic into tiny pieces. After what, using a specially designed machine lighter and heavier pieces are separated.

- Plastic melting and pellet making

Under regulated temperature, to ensure melting without destruction; plastics melt down and are next extruded and resized into granules which are next compressed into pellets

- Re-use

For this part, it is important to note that the pellets from recycled plastics are repurposed and redesigned into other added value products.

Recycling is therefore the conversion process of plastics wastes into useful products. It is categorised as primary recycling, secondary recycling, tertiary recycling and quaternary recycling as depicted in the table 1 (Singh N, Hui D et al., 2017).

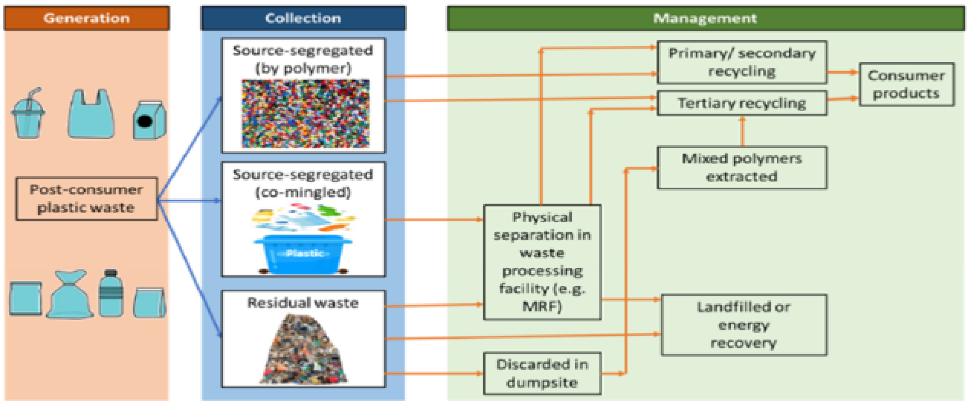

Fig. 2: Global view of plastic wastes managements (Kumar et al., 2023)

TABLE 1: Recycling categories (Hopewell et al., 2009)

Definitions by ASTM D5033	Definitions by Equivalent ISO 15270	Other similar terms
Primary recycling	Mechanical recycling	Closed-loop recycling
Secondary recycling	Mechanical recycling	Downgrading
Tertiary recycling	Chemical recycling	Feedstock recycling
Quaternary recycling	Recovery of energy	Valorisation

III. Plastic Life Cycle Analysis

Petrochemicals Life Cycle Analyses (LCA) is a method that helps to evaluate environmental influence of a compound from production step, until the disposal of wastes (Gandhi N, et al. 2021). LCA has helped to analyse the impacts of different production modes as well as disposal for a clear comprehension of the environmental accumulation issue caused by wastes (Mishra A, et al., 2021). Plastics are known for having a slow rate of decomposition, causing their accumulation in natural environment for years (~10 to +100 years). Plastics fragment into smaller particles known as microplastics. According to recent studies, the consumption of an average human in microplastic particles is around 50,000 annually; this is done through air, water and food chain contamination. Among the chemicals composing those microplastics, BPA (Bisphenol A) is encountered, and is detrimental for human health.

IV. Conversion Processes Of Plastics Into Petroleum Derivatives

TABLE 2: Plastics conversion processes

Processes	Categories/types	Products
Thermochemical Processing	*Pyrolysis *Gasification *Hydrothermal liquefaction	Plastic fuel: -Light oil -Medium oil -Heavy oil -Sludge -Coke -…
Catalytic Conversion	* Mixed plastic waste's catalytic upgrading * plastics waste's catalytic pyrolysis	-Plastic fuel -Lubricants -…
Chemolysis	Combinations of chemistry, solvents and heat to break down polymers into monomers (cefic, 2023)	-Monomer reused to make polymers…
Carbonization	Plastic waste Conversion into carbon-based compounds at high temperature.	*Coke *H.C oil *Coke oven gas (COG)

TABLE 3: Physical properties registered from various plastic wastes oil (S. D. Anuar Sharuddin, 2016).

Properties	PET	HDPE	PVC	LDPE	PP	PS	Gasoline	Diesel
Calorific Value (MJ/Kg)	28.2	40.5	21.1	39.5	40.8	43.0	42.5	43.0
Density (g/cm^3 @ 15°C)	0.9	0.89	0.84	0.78	0.86	0.85	0.78	0.807
Viscosity (mm^2/s)	-	5.08	6.36	5.56	4.09	1.4	1.17	1.9-4.1
Flash Point (°C)	-	48	40	41	30	26.1	42	52

As shown in the figure (4) below and through the above table (3), there are many ways of transforming plastic wastes.

A. *Pyrolysis*

One of the promising method for transforming plastic wastes, with running installations all over the world is pyrolysis, which is a combined series of chemical and thermal reactions; initiated to depolymerize in absence of oxygen, organic materials [M. J. B. Kabeyi et al. 2020]. Table shows that, from different plastics, different products are obtain according to the constituents of the feedstock.

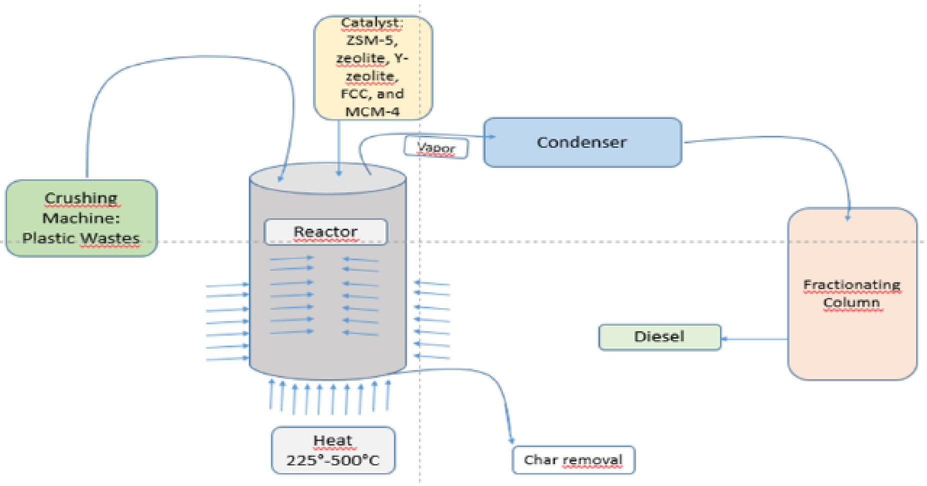

Fig 3: Plastic wastes pyrolysis process

TABLE 4: Opportunities and challenges of recycling

Opportunities	Challenges	References
Wastes becomes resources and there is pollution reduction	Difficulties in handling flexible and rigid plastic packaging simultaneously.	Hopewell et al., 2009 Local Government Association (UK) 2007 Shaxson, L. 2009 WRAP ,2006 WRAP, 2008
Production of high value material (biodiesel, wax, …)	Need for high quality product of highly conditioned feedstock.	
Creation of new industries and jobs	Price of recycled polymer compare to virgin polymer.	
Some governments elaborate policies to ease deployment of postconsumer recycling	Variation in supply of recycled polymer compare to virgin polymer	

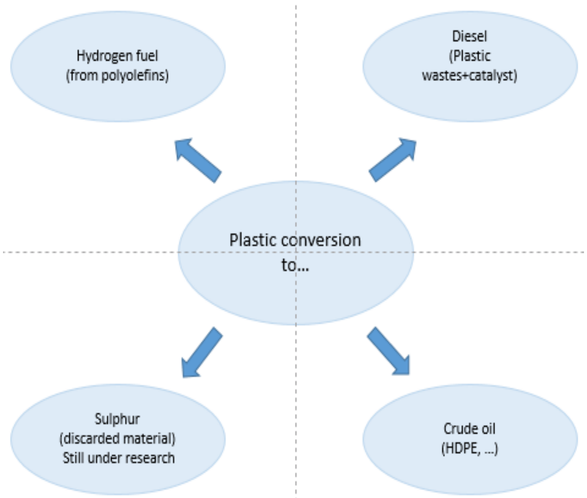

Fig. 4: Transformation ways of plastic wastes

V. Plastic Wastes Recycling Impact

The high demand in plastics and continuous production of plastic wastes in ecosystems and their negative impacts on health are among major issues today. Furthermore, avoiding incineration or landfill requires the circular economy to be seen as the appropriate option from an economic, social, environmental, and legal perspective (Spreafico C, et al., 2021). This concept of circular economy considers the recovery of resource means: recycling, reusing, and upcycling; while joining at the same time, operational waste management process in the supply chain (Hossain R, et al., 2022).

VI. Conclusion

Plastics have gain great importance now our days and are widely used in different domain because of the following properties: lightweight; resistivity to degradation or environmental rusting; low price; recyclability; and their socioeconomic impact. However, some of this properties like their non-biodegradability, and the increasing in demand have in parallel increased the amount of wastes. Making of plastic a nuisance to human and to the environment. Furthermore, we also saw that sustainable reuse and recycling of plastic wastes should be encouraged for they help to palliate to a certain extent, the environmental problems caused by plastic wastes. Despite the existence of some challenges; from technological factors, to economic or social behaviour issues, recycling of waste plastics stand as the best option to improve the eco-friendly action of the polymer or plastic industry.

REFERENCES

1. A. Antelava, S. Damilos, S. Hafeez et al., "Plastic solid waste (PSW) in the context of life cycle assessment (LCA) and sustainable management," Environmental Management, vol. 64, no. 2, pp. 230–244, 2019.
2. Al-Salem S, Lettieri P, Baeyens J. The valorization of plastic solid waste (PSW) by primary to quaternary routes: from re-use to energy and chemicals. Prog Energy Combust Sci 2010; 36(1):103–29. https://doi.org/10.1016/J.PECS.2009.09.001.
3. Gandhi N, Farfaras N, Linda Wang N-H, Chen W-T, Wang N-HL, Chen W-T. Life cycle assessment of recycling high-density polyethylene plastic waste. J Renew Mater 2021;9(8):1463–83. https://doi.org/10.32604/jrm.2021.015529.
4. *Global plastic demand in energy transition?*. Thunder Said Energy. Retrieved 8 October 2023, from https://thundersaidenergy.com/downloads/global-plastics-an-overview/
5. GreenSutra; Plastic Recyclin Process: All You Need to Know; Oct 2023;
6. Hopewell, J., Dvorak, R., & Kosior, E.. Plastics recycling: Challenges and opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences* 2009, *364*(1526), 2115–2126.
7. Hossain R, Islam MT, Ghose A, Sahajwalla V. Full circle: Challenges and prospects for plastic waste management in Australia to achieve circular economy. J Clean Prod 2022;368:133127. https://doi.org/10.1016/j.jclepro.2022.133127
8. Kumar M, Xiong X, He M, Tsang DCW, Gupta J, Khan E, et al. Microplastics as pollutants in agricultural soils. Environ Pollut 2020; 265:114980. https://doi.org/ 10.1016/j.envpol.2020.114980.
9. Local Government Association (UK) War on waste: food packaging study. UK: Local Government Authority. 2007.
10. M. J. B. Kabeyi and A. O. Oludolapo, "Design and Modelling of a Waste Heat Recovery System for a 250KW Diesel Engine for Cereals Drying," in 2nd African International Conference on Industrial Engineering and Operations Management Harare, Zimbabwe December 2020, http://www.ieomsociety.org/ harare2020/papers/78.pdf.
11. M. J. B. Kabeyi and O. A. Olanweraju, "Sustainability Assessment for Non-Combustible Renewable Power Generation," in Paper presented at the 12th Annual Istanbul International Conference on Industrial Engineering and Operations Management, pp. 2232–2244, IEOM Society International, Istanbul, Turkey, 2022.
12. M. S. Qureshi, A. Oasmaa, H. Pihkola et al., "Pyrolysis of plastic waste: opportunities and challenges," Journal of Analytical and Applied Pyrolysis, vol. 152, article 104804, 2020.
13. Mishra A, Kumar M, Bolan NS, Kapley A, Kumar R, Singh L. Multidimensional approaches of biogas production and up-gradation: opportunities and challenges. Bioresour Technol 2021;338:125514. https://doi.org/10.1016/j. biortech.2021.125514.
14. N. Patni, P. Shah, S. Agarwal, and P. Singhal, "Alternate strategies for conversion of waste plastic to fuels," ISRN Renewable Energy, vol. 2013, Article ID 902053, 7 pages, 2013.
15. Nganda A, Srivastava P, Lamba BY, Pandey A, Kumar M.; Advances in the Fabrication, Modification and Performance of Biochar, Red Mud, Calcium Oxide, and Bentonite Catalyst in Waste-to-fuel conversion. Environ Res. 2023 Sept 1; 116284. Doi: 10.1016/j.envers.2023.116284.
16. S. D. Anuar Sharuddin, F. Abnisa, W. M. A. Wan Daud, and M. K. Aroua, "A review on pyrolysis of plastic wastes," Energy Conversion and Management, 2016, vol. 115, pp. 308–326.
17. S. Devasahayam, G. Bhaskar Raju, and C. Mustansar Hussain, "Utilization and recycling of end of life plastics for sustainable and clean industrial processes including the iron and steel industry," Materials Science for Energy Technologies, vol. 2, no. 3, pp. 634–646, 2019.
18. Singh N, Hui D, Singh R, Ahuja I, Feo L, Fraternali F. Recycling of plastic solid waste: a state of art review and future applications. Compos B Eng 2017;115: 409–22. https://doi.org/10.1016/j.compositesb.2016.09.013.
19. Spreafico C, Spreafico M. Using text mining to retrieve information about circular economy. Comput Ind 2021;132:103525. https://doi.org/10.1016/j. compind.2021.103525.
20. WRAP food grade HDPE recycling process: commercial feasibility study. London, UK: Waste & Resources Action Programme; 2006.
21. WRAP Large-scale demonstration of viability of recycled PET (rPET) in retail packaging. 2008; http://www. wrap.org.uk/retail/case_studies_research/rpet_retail.html.
22. W. U. Eze, R. Umunakwe, H. C. Obasi, M. I. Ugbaja, C. C. Uche, and I. C. Madufor, "Plastics waste management: a review of pyrolysis technology," Clean Technologies and Recycling, vol. 1, no. 1, pp. 50–69, 2021.

Tatnkam Ernest Jefferson, Dolly Sharma, Gaurav Pandey, Avinash V. Palodkar, Asheesh Kumar, Nadezhda Molokitina, "Industrial Plastic Waste Conversion into Added Value Products in View to Mitigate Plastic Pollution: A Review," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 6, Issue 6, pp. 177-180, 2023.