Science World Journal Vol. 21(No 3) 2026 https://dx.doi.org/10.4314/swj.v21i3.12
www.scienceworldjournal.org
ISSN: 1597-6343 (Online), ISSN: 2756-391X (Print)
Published by Faculty of Science, Kaduna State University

Full Length Research Article

PRODUCTION OF PETROLEUM-BASED FUEL FROM MIXED PLASTIC WASTES WITHIN LAFIA METROPOLIS

*Agwale Edith Jonathan, Nasirudeen Mohammed Baba, Muhammad Etsuyankpa Binin

Department of Chemistry, Faculty of Physical Sciences, Federal University of Lafia, Nasarawa State, Nigeria

*Corresponding Author Email Address: agwaleedith@gmail.com

ABSTRACT
Mixed plastic waste was pyrolyzed to produce liquid fuel, and the resulting oil was characterized by FTIR, GC-MS, and physicochemical analyses. From 1000 g of feedstock, only 54.55 g of liquid oil was recovered (0.0606 liters), corresponding to a 5.5% yield, which is considerably lower than typical reported values. FTIR spectra indicated strong bands for aliphatic C-H, confirming a mixture of hydrocarbons and oxygenated compounds. GC-MS analysis showed the oil consists mainly of C_9-C_{16} hydrocarbons, including alkanes, alkenes, and cycloalkanes, with minor oxygenated products such as cyclohexanone, benzoic acid, and palmitic acid, Which Account for the measured acidity and stability. Physicochemical properties included a density of 0.911g/cm³, a viscosity of 1.3 cSt, a flash point of 187 °C, an acid value of 1.98 mg KOH/g, and a pH of 5.1, along with cold-flow properties (cloud point 2 °C, pour point 3 °C) comparable to diesel. The results suggest that the pyrolysis oil possesses diesel-like flow and energy characteristics. Its low yield, oxygenated content, and acidity necessitate further upgrading or blending before application as a fuel.

Keywords: Mixed plastic waste, Pyrolysis, Waste-to-energy, GC–MS, FTIR.

INTRODUCTION

Plastics are primarily composed of polymers; they are a wide range of synthetic or semisynthetic materials. They can be molded, extruded, or pressed into a wide range of solid forms due to their defining characteristic, plasticity (Millet *et al.,* 2018). Their adaptability, combined with other properties such as low weight, durability, flexibility, chemical resistance, low toxicity, and low-cost production, has led to their widespread use worldwide (Aimaadeed *et al.,* 2020). Plastics are mostly produced from natural gas and petroleum; growing minorities are produced from renewable resources like polylactic acid. These materials, classified as polymers and first produced by Alexander Parkes in 1862 (Dennis, 2024), consist of large molecules formed by repeatedly joining smaller molecular units. Plastics are organic molecules with long hydrocarbon chains. The demand for commodity plastics has increased due to the exponential growth in the world's population; by 2013, production had reached over 299 million tons (Kamarudin *et al.,* 2022; Almeida *et al.,* 2016). Plastic waste accumulation in landfills poses serious environmental problems due to its long decomposition times. As a result, turning this waste into useful resources has become a practical way to address waste management and the rising energy demand (Dey *et al.,* 2024). Pyrolysis is the thermochemical decomposition of organic material at elevated temperature (usually 400-1,000°C) in an oxygen-free environment (Aguado *et al.,* 2007; Alla *et al.,* 2014; Almeida *et al.,* 2016). The three main products of this process are Oil, gas, and char; each has significant value for refineries and other industrial uses. The environmentally friendly character of the resultant oil has attracted considerable attention, and it can be used directly in boilers, furnaces, turbines, and compression-ignition engines without modification (Kabeyi *et al.,* 2023). Reactor operating parameters such as temperature, residence time, and heating rate govern the ratios of gas, liquid, and solid char generation. Slow heating rates and long residence times favor the conversion of carbon to elemental form, as observed in the production of traditional charcoal (Antal *et al.,* 2003). Fast pyrolysis, which is characterized by rapid heating and shorter residence durations (less than 2 seconds) at about 500 °C, increases liquid yields by promoting the volatilization of chemicals created by polymer chain scission. Long-chain polymers are fragmented into shorter, lower-molecular-weight hydrocarbons during cracking, which serve as valuable fuels or chemical feedstocks (Vilela *et al.,* 2014; Kamarudin, 2022).Thermal cracking or thermolysis occurs without catalysts, whereas catalytic pyrolysis is a pyrolytic process that uses a catalyst to enhance the production of, and properties of, the resulting products, such as single-ring aromatic compounds and light olefins. The resulting volatile hydrocarbons condense into paraffin, isoparaffins, naphthenes, aromatics, and olefins, while non-condensable gases provide additional high-energy fuel. Product composition varies with the type of plastic waste, catalyst properties (e.g., type, size, and catalyst-to-polymer ratio), temperature, reactor design, and reaction duration. Interest in thermochemical conversion, particularly pyrolysis, has surged since China's 2018 ban on importing post-consumer plastic waste, which previously accounted for up to 45 % of global plastic waste management (Al-Salem *et al*., 2009; Chandrasekaran *et al*., 2019; Rajmohan *et al*., 2020). An estimated 8.3 billion metric tons of plastic waste have been produced globally since the 1950s; a large quantity of this garbage is currently found in landfills and marine ecosystems (Operato *et al.,* 2025). This environmental burden and the growing demand for petroleum-derived fuels underscore the urgent need for sustainable alternatives. One practical way to solve environmental and energy-related problems is to transform waste plastic into synthetic fuels. First and foremost, existing conversion methods frequently rely on environmentally damaging and energy-intensive processes such as incineration (Andrady, 2009), which result in greenhouse gas emissions, hazardous byproducts and less-than-ideal resource use. Furthermore, the efficiency and quality of the final fuel can be compromised by the variety of plastic compositions and the existence of contaminants in waste streams (Kehinde *et al.,* 2020). This study focuses on the synthesis of petroleum-based fuel from mixed plastic waste; this topic has been extensively studied. Characterization of mixed plastic waste fuel provides critical data on its energy potential, combustion behaviour, and environmental risks, particularly emissions associated with chlorine-containing plastics such as PVC (Verma *et al.,* 2016).

Furthermore, converting mixed plastic waste into fuel suggests a cheap, feasible and environmentally sustainable solution for managing non-recyclable plastics while reducing dependence on fossil fuels (Hopewell *et al.,* 2009). Therefore, this study contributes to waste-to-energy research by addressing the technical, environmental, and economic challenges associated with mixed plastic waste, rather than idealized single-polymer plastic wastes. The American Society for Testing and Materials (ASTM) standard was followed in determining the physical parameters (Faujdar *et al.,* 2020). According to Andrady and Neal (2009), Plastics are primarily classified by their thermal properties into thermoplastics (re-moldable) and thermosets (non-re-moldable), and by resin identification codes (1-7) based on resin type. Key categories include PET (1), HDPE (2), PVC (3), LDPE (4), PP (5), and PS (6) and others. Plastics are primarily derived from petrochemicals; however, innovative bioplastics are also made from renewable resources (Nanda *et al.,* 2022). Crude oil, a fossil resource made from ancient organic matter, is the source of petroleum-based fuels (Kuppusamy *et al.,* 2020). Crude oil is refined to produce products such as diesel, gasoline, and jet fuel that power industry and transportation (Speight *et al.,* 2014). Pyrolysis is a thermochemical process that uses high temperatures or heat-induced chemical changes, typically between 400 and 1,000 degrees Celsius, to break down organic molecules in an oxygen-free environment (Sharma *et al.,* 2026). It is recognized that this method is a viable approach to converting waste plastic into high-energy-density fuels. In an oxygen-free environment, a complex web of chemical and thermal reactions, known as the pyrolytic process, breaks down polymeric structures to prevent burning (Kabeyi *et al.,* 2021). The components of plastic feedstock are volatilized by the high thermal energy generated during pyrolysis. The various types of pyrolysis processes include catalytic, flash, quick, and slow pyrolysis (Dennis *et al.,* 2024; Kabeyi *et al.,* 2021). At a low heating rate, slow or conventional pyrolysis produces significant volumes of solid, liquid, and gaseous products. It has historically been used in the charcoal-making process. Fast pyrolysis produces tar and other condensable compounds at moderate temperatures (850–1250 K) or at higher temperatures (1050–1300 K), with rapid vapor removal (Uddin *et al.,* 2024). The potential of the pyrolysis-derived gas as an alternative energy source has been highlighted by empirical research showing that its physicochemical characteristics, such as density, viscosity, and calorific value, are similar to those of commercial fuels like liquefied petroleum gas (LPG) (Otitoju *et al.,* 2023). A high-quality, high-yield fuel with physicochemical characteristics similar to diesel is produced by pyrolyzing mixed plastic waste at 450 °C, making it a viable replacement for diesel engine applications (Attia, 2025). One of the main benefits of pyrolysis over conventional recycling is that it does not require precise segregation of different polymer types. A small amount of PVC contamination in a PET recycling stream will weaken the PET resin, causing it to become discolored and brittle; the plastics cannot be recycled together (Hopewell, 2009). The plastic kinds with the highest liquid yield were polystyrene (PS), and the lowest were polyethylene terephthalate (PET). Because it produces dangerous hydrogen chloride (HCl) fumes, pyrolysis of polyvinyl chloride (PVC) is discouraged. Petroleum-based plastics have calorific values similar to those of gasoline, diesel, and liquefied petroleum gas (LPG). Instead of employing continuous systems, this research primarily used batch or semi-batch laboratory-scale reactors, focusing on how temperature, heating rate, and catalysts affect product yields. The end products are extremely complex and often contain more than 100 hydrocarbon components, including isomers, paraffins, and olefins. Petroleum hydrocarbons are commonly characterized using the PONA categorization system, which includes paraffins, olefins, naphthenics, and aromatics (Scheirs, 2006). Saturated hydrocarbons with linear or branched carbon chains are called alkanes; another name is paraffins. The chain structure of olefins is similar to that of paraffins, but they have one or more double or triple bonds between carbon atoms. Despite having cyclic carbon chains, naphthenic hydrocarbons are saturated, just like paraffins. A benzene ring is a component of the molecular structure of aromatics. An additional popular method for characterizing hydrocarbons is counting the number of carbon atoms in their molecular structures; this method is especially applicable to petroleum fuels (Ruiz-Morales, 2022).

MATERIALS AND METHODS

Mixed plastic waste comprising polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and polyvinyl chloride (PVC) was collected from households, supermarkets, and educational institutions within Lafia Metropolis, Nasarawa State, Nigeria. The selected plastics were chosen because they constitute a significant proportion of municipal solid waste generated within the study area. After collection, the plastics were manually sorted to remove non-plastic contaminants such as paper, metals, and glass.

Sample Preparation

The plastic materials were washed thoroughly with a detergent solution, then rinsed with distilled water to remove dirt, labels, and other surface impurities. The cleaned samples were air-dried before being mechanically shredded to 1 cm^2 to improve heat transfer during pyrolysis.

Pyrolysis Experimental Procedure

Pyrolysis experiments were conducted in a laboratory-scale fixed-bed stainless steel batch reactor with an effective capacity of 2 L. The reactor was equipped with an electrically heated furnace, a digital temperature controller, a gas outlet, and a water-cooled condenser to collect condensable products. Before each experimental run, approximately 50 g of the prepared mixed plastic feedstock (PE, PP, PS, PET, and PVC) was introduced into the reactor. To establish an oxygen-free atmosphere, nitrogen gas (99.9% purity) was continuously supplied at a flow rate of 100 mL min^{-1} for each run. The reactor temperature was increased from ambient temperature to 500 °C at a constant heating rate of 10 °C min^{-1} and 1atm. The reaction temperature was maintained for 60 min to ensure adequate thermal degradation of the polymeric materials. The volatile products generated during pyrolysis passed through a water-cooled condenser maintained at 10- 15 °C, where they were collected as liquid pyrolysis oil. Non-condensable gases exited through the gas outlet and were safely flared, while the solid carbonaceous residue (char) remained inside the reactor after cooling. After the 60-minute pyrolysis period at 500 °C, the reactor was allowed to cool naturally to a safe temperature under an inert nitrogen atmosphere. The reactor was not opened while it was still hot. After cooling, the reactor was opened, and the remaining solid residue was collected. The experiment was carried out in 20 runs. (Miandad *et al*., 2017).

Science World Journal Vol. 21(No 3) 2026 https://dx.doi.org/10.4314/swj.v21i3.12
www.scienceworldjournal.org
ISSN: 1597-6343 (Online), ISSN: 2756-391X (Print)
Published by Faculty of Science, Kaduna State University

RESULTS AND DISCUSSION

Pyrolysis Oil Yield

W1 = Initial weight of reactor
W2= Reactor + Plastic before heating
W3= Reactor + Plastic after Heating
W4= Weight of Oil Obtained
At 500 °C

Table 1: Yield of Pyrolysis Oil

RUN	W1(g)	W2(g)	W3(g)	W4(g)
1	500	550	520	4.15
2	500	550	522	3.32
3	500	550	525	2.08
4	500	550	526	1.66
5	500	550	523	2.91
6	500	550	521	3.74
7	500	550	524	2.49
8	500	550	527	1.25
9	500	550	520	4.15
10	500	550	513	3.20
11	500	550	532	2.22
12	500	550	514	1.63
13	500	550	531	3.05
14	500	550	520	3.53
15	500	550	522	2.83
16	500	550	517	2.73
17	500	550	529	2.32
18	500	550	516	3.65
19	500	550	515	3.07
20	500	550	527	1.06

Yield of the oil

Total Mass of Plastic Waste = 1,000 g…….....M1

Total Mass of oil = 54.55 g…….....M2

Yield of Oil (liquid) = M2/M1×100

Yield of Oil = 54.55÷1000×100

Yield of Oil = 5.5 %

From 1000 g of plastic waste, only 54.55 g (0.0606 L) of oil was obtained, giving a 5.5% oil yield. This implies that there was poor condensation (oil was lost to uncollected condensate).

Physicochemical Characterization of Pyrolysis Oil

The recovered pyrolysis oil was characterized following ASTM D1500, ASTM D4052, ASTM D664, ASTM D445, ASTM D5768, ASTM D1298, ASTM D86, ASTM D6304, ASTM D5558, AOAC, ASTM D664, ASTM D97 and ASTM D2500 methods to determine its suitability as an alternative transportation fuel.

Table 2: Physicochemical Properties of Pyrolysis Oil

S/NO Parameters	Sample	Method Used	Values of Conventional Petroleum-Based Fuel
1. Color	Reddish Orange	ASTM D1500	0.86(Diesel)
2. Density (g/cm³)	0.911	ASTM D4052	0.86(Diesel)
3. Acid Value (mgKOH/g)	1.980	ASTM D664	≤0.50 mg/KOH/g(Diesel)
4. Viscosity (mm²/s)	1.300	ASTM D445	0.4-0.8(Gasoline)
5. Iodine value (mg/g)	57.147	ASTM D5768	N/A
6. Gravity	0.802	ASTM D1298	0.72-0.78(Gasoline)
7. Boiling point (°C)	83.600	ASTM D86	30-210°C (Gasoline)
8. Moisture (%)	0.850	ASTM D6304	≤0.05%
9. Saponification value mgKOH/g	187.14	ASTM D5558	N/A
10. Peroxide value (mg/dm³)	6.600	AOAC N/A	
11. Free fatty Acid	0.990	AOAC N/A	
12. Flash point (°C)	187	AOAC	38-72°C (Kerosene)
13. pH	5.1	ASTM D664	N/A
14. Pour point (°C)	3	ASTM D97	-15 to 15°C (Diesel)
15. Cloud point (°C)	2	ASTM D2500	-15 to 5°C (Diesel)

Table 3: Major compounds identified in the oil sample by GC-MS

Peak No.	Retention Time (min)	Tentative Compound Identification	Area (%)
1	3.673	Oxazine and Oxathiolane derivatives(Heterocyclic Compounds)	5.70
2	10.003	Butanediol and cyclohexanone derivatives (Alcohols, Ketones)	5.67
3	10.226	β-Bisabolene and related terpenoids (Terpenoids)	6.73
4	13.096	Polyethylene Glycol Derivatives (Polyesters)	1.56
5	17.324	Tetradecanoic and Pentadecanoic acids (Carboxylic Acids/Fatty Acids)	10.40
6	19.135	Dodecene, tridecadiene, and oxirane derivatives(Alkenes)	8.84
7	19.327	Diisooctyl phthalate/ Bis(2-ethylhexyl) phthalate(Esters)	47.01
8	20.837	Aromatic ketones and alcohol derivatives	14.10

Interpretation of GC-MS Analysis Result

The chemical composition of the oil sample was determined by Gas Chromatography-Mass Spectrometry (GC-MS). Total ion chromatogram (TIC) revealed the presence of several volatile and semi-volatile organic compounds eluting within a retention time range of approximately 3.7 to 20.8 minutes. Eight major peaks were observed, indicating that the oil sample is a complex mixture of hydrocarbons, plastic-derived additives, fatty acids, ketones, and other oxygenated compounds. The TIC obtained from the GC-MS analysis showed well-resolved peaks, suggesting effective separation of the components present in the oil sample. The relative abundance of each compound was determined using the percentage-of-peak-area normalization method. Table 3 presents the major peaks detected, their retention times, tentative compound identifications, and relative area percentages.

Identified Compounds

1. Plasticizer Compounds: The dominant peak observed at a retention time of 19.327 minutes accounted for approximately 47.01% of the total chromatographic area. Based on mass spectral library matching, this peak was identified as Diisooctyl phthalate and Bis(2-ethylhexyl) phthalate (Esters). During the production of polyvinyl chloride (PVC) and other polymers, phthalate esters are frequently used as plasticizers. The high concentration of oil in the plastic garbage sample strongly suggests that the oil is contaminated by or generated from plastic waste.

2. Fatty Acids: A retention time of 17.324 minutes and a combined area percentage of 10.40% were observed; saturated fatty acids of medium-chain, specifically tetradecanoic acid and pentadecanoic acid, were found. These fatty acids may be present due to contamination from biological sources, secondary processes that occur during heat processing, or a heterogeneous feedstock composition. Plastic waste-derived oils are frequently reported to contain fatty acids.

3. Hydrocarbons and Alkenes: Retention time of 19.135 minutes; hydrocarbon components such as tridecadiene and dodecene were found. These substances are common byproducts of heat cracking and polymer chain scission during plastic waste pyrolysis. Their presence provides evidence that the oil sample is derived from plastic waste.

4. Oxygenated Compounds and Ketones: With retention durations of 10.003 and 20.837 minutes, several oxygenated compounds were detected, including ketones and alcohol derivatives. These substances could result from partial oxidation events that occur during the oil's thermal breakdown or during storage after processing. By altering characteristics such as calorific value and stability, oxygenated molecules can affect fuel quality.

5. Terpenoid Compounds: Retention period of 10.226 minutes, β-Bisabolene and related terpenoid compounds were found to make up 6.73% of the entire region. Terpenoids are frequently associated with plant-derived products; however, their presence in the oil sample could result from handling and processing contaminants, lubricants, or additives. The oil sample's overall GC-MS profile shows a complex mixture dominated by breakdown products and additives generated from plastic. The rise in phthalate levels occurs when alkenes and other hydrocarbons are present; esters are consistently found in oils derived from thermally converted mixed plastic waste. These findings indicate that the oil sample could be used as a chemical feedstock or fuel, but further refinement and assessment of its physicochemical properties would be necessary.

Conclusion

The present study successfully demonstrated the production and characterization of pyrolysis oil derived from plastic waste. It evaluated its suitability as an alternative liquid fuel through physicochemical characterization, Fourier Transform Infrared (FTIR) spectroscopy, and Gas Chromatography–Mass Spectrometry (GC–MS) analysis. The results confirmed that the pyrolysis oil possesses several characteristics comparable to conventional petroleum fuels while also exhibiting compositional features that distinguish it from commercially refined fuels. The physicochemical properties showed that the oil has relatively low viscosity and acceptable cloud and pour points, indicating favorable atomization, pumpability and cold-flow characteristics similar to those of diesel fuel under moderate climatic conditions. However, the comparatively higher density, acid value, free fatty acid content, moisture content, peroxide value, and moderate iodine value indicate the presence of oxygenated compounds and unsaturated species, which reduce oxidative stability and increase the oil's corrosivity. These properties suggest that, although the oil has promising fuel characteristics, it would require upgrading before direct application in internal combustion engines or long-term storage. The FTIR analysis confirmed that the oil is predominantly composed of hydrocarbons, with strong absorption bands corresponding to aliphatic C–H stretching vibrations characteristic of paraffinic hydrocarbons found in conventional gasoline, diesel, and kerosene. Nevertheless, the detection of carbonyl (C=O) and C–O functional groups revealed the presence of oxygenated compounds such as ketones, aldehydes, alcohols, and esters, which account for the observed acidity and lower chemical stability of the oil. The presence of aromatic C–H vibrations further indicated that the oil contains aromatic hydrocarbons that can enhance combustion performance. However, their concentrations would need to be controlled to meet commercial fuel specifications. GC–MS analysis further established that the pyrolysis oil is a complex mixture of hydrocarbons, oxygenated compounds, plastic-derived additives, fatty acids, and aromatic compounds. The predominance of phthalate esters confirmed the plastic origin of the feedstock. At the same time, the identification of alkenes and other hydrocarbon compounds verified that thermal cracking effectively converted long-chain polymer molecules into lower-molecular-weight fuel-range hydrocarbons. The detection of ketones, alcohols, esters, and fatty acids corroborated the FTIR findings and explained the elevated acid value, peroxide value, and acidic pH measured during physicochemical characterization. These complementary analytical techniques collectively demonstrate that the oil contains both desirable fuel-range hydrocarbons and undesirable oxygenated species that influence its overall fuel quality. Comparison with conventional petroleum fuels revealed that the pyrolysis oil exhibits several advantageous characteristics, including favorable viscosity and satisfactory low-temperature flow behavior. However, unlike commercial gasoline and diesel, the oil contains higher concentrations of oxygenated compounds, exhibits greater acidity and density, and possesses lower oxidative stability. These differences arise primarily from incomplete removal of oxygen-containing compounds during pyrolysis and the complex composition of mixed plastic-derived products. Consequently, although the oil possesses considerable potential as an alternative liquid fuel, it does not yet satisfy the quality requirements for direct use in commercial engines without further processing. Overall, the

findings demonstrate that plastic waste pyrolysis represents a viable and sustainable pathway for converting non-biodegradable plastic waste into valuable liquid hydrocarbons, thereby contributing to waste management, resource recovery, and the development of alternative energy sources. The production of pyrolysis oil offers significant environmental benefits by reducing the volume of plastic waste destined for landfills and open burning while simultaneously recovering energy from discarded materials. This approach supports circular economy principles by transforming waste into value-added products and reducing dependence on finite petroleum resources. To maximize its commercial potential, further research should focus on improving the quality of the pyrolysis oil through catalytic upgrading, hydro treatment, deoxygenation, fractional distillation, moisture removal, and blending with conventional petroleum fuels or renewable biofuels. Future investigations should also evaluate the fuel's cetane number, octane rating, Sulphur content, emissions profile, storage stability, engine performance, long-term material compatibility, and life-cycle environmental impacts. Optimization of feedstock selection, catalyst type, reactor design, and operating conditions will also be essential for enhancing product quality, increasing fuel yield, and achieving compliance with international fuel specifications. With appropriate upgrading and process optimization, plastic waste-derived pyrolysis oil has significant potential to serve as a sustainable supplementary fuel and chemical feedstock, contributing to cleaner waste management practices, enhanced energy security, and the transition towards a more sustainable and circular energy economy. (Sogancioglu et al., 2017).

REFERENCES

Adamu, J., Ejilah, I. R., Sintali, I. S., & Dandakouta, H. (2025). AN INTEGRATED STUDY ON BIODIESEL PRODUCTION FROM FLAMBOYANT (DELONIX REGIA) SEED OIL: EXTRACTION, PHYSICOCHEMICAL, FUEL PROPERTIES AND ASTM COMPLIANCE ASSESSMENT. *Nigerian Journal of Tropical Engineering*, *19*(1), 80–93.

Aguado, J., Serrano, D. P., Miguel, G.S., Escola, & Rodríguez, J.M. (2007). *Journal of Analytical and Applied Pyrolysis,* 78,153-161.

Aimaadeed, M. A. A., Ponnamma, D., & El-Samak, A. A. (2020). Polymers to improve the world and lifestyle: physical, mechanical, and chemical needs. In *Polymer science and innovative applications* (pp. 1–19). Elsevier.

Alla, M. M. G., Ahmed, A. I., & Abdalla, B. K. (2014). *Conversion of plastic waste to liquid fuel. International Journal of Technical Research and Application, 2*(3), 29–31.

Almeida, D., & Maria de Fátima Marques (2016). *"Thermal and catalytic pyrolysis of plastic waste." Polímeros* 26.1 44-51.

Al-Salem, S. M., Lettieri, P., Baeyens, J., & Janssen, M. (2009). *Recycling and recovery routes of plastic solid waste (PSW): A review. Waste Management*, 29(10), 2625–2643.

Andrady, A.L., and Neal, M.A. (2009). *Applications and societal benefits of plastics. Philosophical Transactions of the Royal Society B: Biological Sciences,* 364(1526), 1977-1984.

Antal, M. J., & Grønli, M. (2003). The art, science, and technology of charcoal production. *Industrial & Engineering Chemistry Research*, *42*(8), 1619–1640.

Attia, A. (2025). Integrating medical plastic waste pyrolysis with the circular economy for environmental sustainability.

Butler, E, Devlin, G, & McDonnell, K (2011). *Waste and Biomass Valorization,* 2, 222–255.

Chandrasekaran, S.R. & Sharma, B.K. (2019). *From Waste to Resources; Elsevier BV: Amsterdam, the Netherlands*.345–364.

Dennis, L. (2024). A brief history of the use of plastics. *Cambridge Prisms: Plastics*, *2*, e19.

Dey, S., Veerendra, G. T. N., Babu, P. A., Manoj, A. P., & Nagarjuna, K. (2024). Degradation of plastic waste and its effects on biological ecosystems: A scientific analysis and comprehensive review. *Biomedical Materials & Devices*, *2*(1), 70-112.

Faujdar, E., Negi, H., Singh, R. K., & Varshney, V. K. (2020). Study of biodegradable poly(α-olefins–co–α-pinene) architectures as pour-point depressants and viscosity-index improvers for lubricating oils. *Journal of Polymers and the Environment*, *28*(11), 3019–3027.

Hopewell, J., Dvorak, R., and Kosior, E. (2009). *Plastics recycling: challenges and opportunities. Philosophical Transactions of the Royal Society B,* 364(1526), 2115–2126.

Kabeyi M.J.K., and Olanrewaju O.A., (2021). *Hydrogen and Carbon Nanotubes from Pyrolysis-Catalysis of Waste Plastics: A Review, Waste and Biomass Valorization.* 12, no.1, 1–28.

Kabeyi, M. J. B., & Olanrewaju, O. A. (2023). Review and design overview of plastic waste-to-pyrolysis oil conversion with implications on the energy transition—Journal *of Energy*, *2023*(1), 1821129.

Kamarudin, S. H., Rayung, M., Abu, F., Ahmad, S. B., Fadil, F., Karim, A. A., ... & Abdullah, L. C. (2022). A review on antimicrobial packaging from biodegradable polymer composites. *Polymers*, *14*(1), 174.

Kehinde, O., Ramonu, O. J., Babaremu, K. O., & Justin, L. D. (2020). *Plastic waste: an environmental hazard and an instrument for wealth creation in Nigeria. Heliyon, 6(10).*

Kuppusamy, S., Maddela, N. R., Megharaj, M., & Venkateswarlu, K. (2020). Total petroleum hydrocarbons. *Environ. Fate Toxic. Remediat*, *2*, 20–26.

Latimer Jr, G. W. (2023). *Official methods of analysis of AOAC INTERNATIONAL: 3-volume set*. Oxford University Press.

Miandad, R., Barakat, M. A., Rehan, M., Aburiazaiza, A. S., Ismail, I. M. I., & Nizami, A. S. (2017). Plastic waste to liquid oil through catalytic pyrolysis using natural and synthetic zeolite catalysts. *Waste Management*, *69*, 66–78.

Millet, H., Vangheluwe, P., Block, C., Sevenster, A., Garcia, L., & Antonopoulos, R. (2018). The nature of plastics and their societal usage.

Nanda, S., Patra, B. R., Patel, R., Bakos, J., & Dalai, A. K. (2022). Innovations in applications and prospects of bioplastics and biopolymers: a review. *Environmental Chemistry Letters*, *20*(1), 379–395.

NNPC (2018). *NNPC Product Quality Specifications. Nigerian National Petroleum Corporation.*

Operato, L., Panzeri, A., Masoero, G., Gallo, A., Gomes, L., & Hamd, W. (2025). Food packaging use and post-

consumer plastic waste management: a comprehensive review. *Frontiers in Food Science and Technology*, *5*, 1520532.

Otitoju, M. A., Olawoye, T., Abiola, S. S., Ahmed, S., & Okoma, O. (2023). Plastic waste management and recycling: A review. *Journal of Global Social Sciences*, *4*(16), 60–71.

Rajmohan, K. S., Yadav, H., Vaishnavi, S., Gopinath, M., & Varjani, S. (2020). *Perspectives on bio-oil recovery from plastic waste. In Current developments in biotechnology and bioengineering* (pp. 459–480).

Ruiz-Morales, Y. (2022). Application of the Y-rule and theoretical study to understand the topological and electronic structures of polycyclic aromatic hydrocarbons from atomic force microscopy images of soot, coal asphaltenes, and petroleum asphaltenes. *Energy & Fuels*, *36*(16), 8725–8748.

Scheirs, J., & Kaminsky, W. (2006). *Feedstock recycling and pyrolysis of waste plastics. Chichester, UK; Hoboken, NJ: J. Wiley & Sons.*

Sharma, M., Manna, S., Kamboj, N., Behera, A. K., & Suthar, S. S. (Eds.). (2026). *Energy Recovery from Organic Waste: Thermochemical and Biochemical Processes*. CRC Press.

Shoor, S.S., & Lodise, M. (2006). *Rapid synthesis of Au, Ag, and bimetallic Au core-Ag shell nanoparticles using Neem (Azadirachta indica) leaf broth. Journal of Colloid and Interface Science.* 275(2): 496–502.

Sogancioglu, M., Yel, E., & Ahmetli, G. (2017). *Pyrolysis of waste high-density polyethylene (HDPE) and low-density polyethylene (LDPE) plastics and production of epoxy composites with their pyrolysis chars.* Journal of Cleaner Production, 165, 369–381.

Speight, J. (2014). *The Chemistry and Technology of Petroleum. CRC Press.*

Uddin, M. N., & Wang, F. (2024). A Review on the Production of Sustainable Aviation Fuels from Biomass and Wastes using Pyrolysis Technologies.

Verma, R., Vinoda, K.S., Papireddy, M., and Gowda, A.N.S (2016). Toxic pollutants from plastic waste-A review. *Procedia Environmental Sciences*, 35, 701–708. Vilela, C., Sousa, A. F., Fonseca, A. C., Serra, A. C., Coelho, J. F., Freire, C. S., & Silvestre, A. J. (2014). The quest for sustainable polyesters–insights into the future. *Polymer Chemistry*, *5*(9), 3119–3141.