Review

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# Plastics Are Paving the Way for a Greener Future and Accelerating Decarbonization

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*Review Paper*

# Plastics Are Paving the Way for a Greener Future and Accelerating Decarbonization

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**Abstract:** This Paper delves into the critical role played by fossil fuel-based polymers in promoting United Nations Sustainable Development Goals (SDGs) in the face of challenges brought about by swift population growth, suburbanization, and mechanization. It sheds light on the environmental and energy security recompences of converting plastic waste into biofuels and other valuable energy resources through state-of-the-art processes such as thermochemical conversion and pyrolysis. Besides, the research investigates the utilization of polymers in solar energy, energy storage, and low carbon transportation, emphasizing the inevitability of a dual approach that combines advancements in bio-based polymers and recycling technologies. It highlights the significance of collaborative endeavors involving governments, industries, and communities to overcome the technical, economic, and regulatory complications in transitioning towards a sustainable and circular plastic economy. Eventually, it showcases the potential of fossil fuel-based polymers in fostering a sustainable energy landscape, conducive to decarbonization efforts, and endorsing environmental sustainability.

**Keywords:** plastic; polymers; decarbonization; sustainability; sustainable future; green economy; renewable energy; material solutions;

## 1. Introduction

Accelerated urbanization, rapid population expansion, and increased industry continue to put a great deal of strain on the planet's resources. This growing demand has a significant influence on the limited resources, especially energy, which directly affects people. The substantial relationship that has been shown between industrialization, energy access, and quality of life is not surprising. Lack of access to enough energy sources and effective transformation systems continues to be a significant barrier to achieving abundant socioeconomic and human development in today's society. In order to reduce poverty, encourage industrialization, promote socioeconomic growth, and improve living conditions, access to energy is essential [1,2].

The percentage of people worldwide who have access to electricity for cooking and lighting has increased since 2010. Nevertheless, substantial geographical differences in the availability of renewable energy persist despite these advancements, impeding the attainment of universal coverage. For example, almost 50% of people in Sub-Saharan Africa do not have access to power, which makes up around 75% of the worldwide energy access gap [3]. Almost 20 million people worldwide still lack access to clean and healthy cooking fuels and technologies, mostly in Sub-Saharan Africa, Eastern Asia, South-eastern Asia, Central Asia, and Southern Asia. This is despite the fact that the percentage of the global population with these resources increased from 57% in 2010 to approximately 69% in 2020 [5]. One profitable approach to accomplishing SDG 7 is the conversion of waste into renewable fuels.

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Because plastic waste is thrown away and left behind, it damages ecosystems and presents a serious threat to the environment. These synthetic plastic items cause extensive environmental harm since they are not biodegradable. As a result, they linger in the environment for long periods of time. Plastic production has increased significantly worldwide, with 367 million metric tons (MMT) produced in 2020 and expected to reach 445 MMT and 590 MMT by 2025 and 2050, respectively [6,7].

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Remarkably, in 2016, the United States, China, and India were the top three manufacturers of plastic garbage, with respective amounts of 34 MMT, 26 MMT, and 21 MMT. [8]. Because plastics don't break down naturally, a lot of them end up in landfills and the ocean, which adds to the garbage buildup. Additionally, only 9% of plastic garbage is recycled, 19% is burned, and the remainder is dumped into the environment, which includes waterways and oceans. A significant global problem is plastic trash, with an estimated 850 million tons of greenhouse gases (GHGs) released into the atmosphere in 2019. By 2050, it is predicted that GHG emissions from plastic trash will exceed 2.8 billion tons if this worrying trend is not addressed immediately [9].

The surge in the need for plastic can be attributed to the growing preference for plastics as a primary material in various industries such as packaging, textiles, construction, and healthcare. In 2017, the packaging sector accounted for 115 MMT, followed by the building and construction sector with 64.1 MMT, and the transportation sector with 47.5 MMT, indicating their significant contribution to the overall plastic consumption [10].

The effective management of the vast amount of plastic waste generated worldwide holds the potential to address the global energy demand. Numerous approaches have been employed to convert plastic waste into valuable energy resources. Among these methods, thermochemical conversion stands out as a promising pathway for transforming plastic waste into useful energy. In a different study, Liu et al. [11] used a nicke and ceramic-based catalyst at 700 °C to effectively transform waste polymers into carbon nanotubes. Another study looked examined the possibility of using thermal energy to turn waste plastic into biofuels. Despite the fact that the results of these investigations have been widely published in the literature, a thorough document that compiles the methods, procedures, end products, and results of diverse waste plastic conversion processes is still required. This document should specifically address strategies aimed at achieving SDG 7, which focuses on ensuring affordable, accessible, and sustainable energy for environmental preservation and national progress. However, it is worth noting that a recent analysis conducted by an author, while reviewing different instances of adapting plastic waste into biofuels, chemicals, and useful products, did not adequately establish a clear connection between waste plastic conversion and renewable energy, and in our perspective. This apparent gap highlights their failure to link the outcomes of these studies to the attainment of Sustainable Development Goal 7.

The main aim of this intervention is to provide updated information on the different approaches to achieving SDG 7 through waste plastic conversion. The main focus is on the relationship between converting waste plastic into biofuels and meeting SDG 7, which focuses on clean and affordable energy within a sustainable environment. This research seeks to conduct a thorough examination of the various pathways, tactics, and procedures involved in converting waste plastic into biofuels, with the ultimate objective of meeting the global demand for clean energy. The goal is to offer the most recent insights into waste-to-energy utilization, specifically emphasizing waste plastic, to equip international organizations, governments, policymakers, environmental advocates, energy producers, and consumers with valuable knowledge on the role of waste in fulfilling global energy needs. Furthermore, this study will be beneficial for researchers and energy experts dedicated to advancing knowledge in renewable energy studies and plastic waste management. By encouraging further innovative research, this study will contribute to the continuous efforts to achieve SDG 7 through waste conversion. This intervention provides a comprehensive overview of waste plastic categorization, different conversion pathways for waste plastic (with a specific focus on thermal conversion), and strategies for producing biooil, biohydrogen, and other valuable products from waste plastic. The implications and potential of converting waste plastic into biofuels and other value-added products are thoroughly explored and emphasized. The information used in this study is sourced from recent and pertinent published articles, as well as the expertise and experience of the authors [11].

## 2. Literature Review

### *2.1. Fossil Fuel-Based Polymers in Solar Energy Production*

Fossil fuels have long been used as the primary source of energy to meet the global energy demands. However, the growing population and economic development have intensified the pressure on these fuels, resulting in environmental challenges. As a result, there is a global push for clean and sustainable energy sources, leading to significant technological advancements in harnessing natural resources such as solar energy, tidal energy, wind energy, and geothermal energy. Among these, renewable energy as an abundant natural resource that can be stored as chemical or electrical energy. The process of converting solar energy into hydrogen fuel through photocatalytic or photoelectrochemical water splitting, and subsequently transforming it into chemical fuel through CO2 reduction, holds great potential. Hydrogen, known for its cleanliness and energy efficiency, is being utilized in various applications, ranging from small devices to the aviation industry, as a chemical fuel. The incorporation of polymers in this field is gradually expanding, opening up new opportunities in clean-energy fuel technologies. [12].

In light of the continuously increasing prices for crude oil, it is important to address another aspect. Fossil fuels serve as the primary raw material for the production of plastics on a global scale. Only a small portion, approximately 5%, of oil consumption is allocated to the manufacturing of plastics. The majority of oil resources, over 80%, are utilized for energy-related purposes such as powering vehicles, transportation systems, buildings, and industrial processes. While high oil prices or further increases may have some adverse effects on the plastics industry, it is anticipated that in the medium to long term, elevated oil prices will have a positive impact on the polymer industry. This projection is based on the idea that high oil prices will incentivize industries and society as a whole to adopt more efficient technologies, potentially transitioning towards renewable resources in the future. Due to their unique characteristics, including low density, customizable material properties, and the ability to combine structural and functional attributes, both existing and future plastics are expected to outperform other material classes in the market, even in a scenario of high oil prices [14].

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### *2.2. Energy Storage Solutions Utilizing Polymers*

Conducting polymers have attracted significant interest from both academic and industrial sectors due to their unique ability to combine the electrical properties of semiconductors and metals with the advantageous characteristics of ordinary polymers, such as easy preparation and low-cost production. These polymers are known for their customizable electrical properties, excellent optical and mechanical capabilities, ease of synthesis and manufacturing, and superior environmental durability compared to traditional inorganic materials. This study specifically examines the molecular structures and behaviors of commonly found conducting polymers, including polyacetylene, polyaniline, polypyrrole, and polythiophene, as well as polythiophene derivatives. Furthermore, the review explores the transport phenomenon that plays a crucial role in understanding the conduction process. In order to assess their potential applications in supercapacitors and batteries, an extensive investigation is carried out on conducting polymer-based composites with carbon-based materials, metal oxides, transition metals, and inorganic particles. Recent advancements in the utilization of conducting polymers in energy storage systems, such as batteries and supercapacitors, are also discussed. Additionally, the review thoroughly examines the development of conducting polymers in energy storage devices, including supercapacitors, lithium-ion batteries, and other -ions batteries, while addressing current challenges and future prospects for advancing energy storage systems. The primary objective of this review is to deepen the understanding of conducting polymers and contribute to the exploration of new research avenues [16].

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### 2.3. Wind Energy Production

Cutting-edge materials play a crucial role in enhancing the effectiveness of wind power systems, enabling the harnessing and production of sustainable wind energy. Specifically, advanced materials such as composite materials like polymer-matrix reinforced with fiberglass or graphite fibers are commonly employed in fabricating rotor blades for wind turbines. Furthermore, the compact electrical generators within these turbines are equipped with powerful magnets made from rare earth materials. These generators are powered by the rotation of the turbine blades through a gearbox, which incorporates special alloys to accommodate a wide range of wind speeds. As wind turbine sizes continue to grow, particularly with the rise of offshore installations, the durability of turbine materials faces increasing challenges due to prolonged exposure to high stresses and harsh environmental conditions. It is crucial for turbine blades to maintain sufficient stiffness to prevent failure from deflection and buckling, as well as to possess long-term fatigue resistance in challenging conditions such as variable winds, ice loading, and lightning strikes. Therefore, the advancement of next-generation wind turbine components and materials necessitates research on advanced materials and critical components to enhance performance and reliability. This includes the development of new designs for larger, lightweight turbines that reduce overall mass, provide access to better wind resources through larger rotors and taller towers, and enhance system performance. Additionally, improvements in turbine cost, strength, weight, and fatigue are essential to decrease operations and maintenance expenses and minimize the failure rate of major components like blades, gearboxes, generators, power electronics, and collection systems. Innovations are also required to address the cost limitations associated with the transportation and installation of large-scale turbine systems and components[17].

### 2.4. Low Carbon Transportation and Polymers

This paper investigates how plastics and geopolymers might work together to create sustainable composite materials in response to the increasing demand for eco-friendly products and services around the world. Plastics are known for their flexibility and lightweight nature, but geopolymers provide a low-carbon substitute for traditional building materials. In order to achieve better mechanical, thermal, and chemical capabilities, the study focuses on examining the molecular-level interactions, improved material properties, and varied applications of this composite. The study also assesses the effects on the environment, including decreased energy use and carbon emissions, as well as the difficulties in manufacturing and scaling. This work opens the door for a new direction in material science that could greatly enhance the built environment's resilience and sustainability. It offers insightful information about recent accomplishments and potential future study areas [18].

Pyrolysis, a technique for recovering liquid fuel from waste polymers, offers a calculated way to lessen the impact on the environment and future need for fossil fuels. Pyrolysis is an effective method for turning waste polymers into pyrolysis oil (PO). Catalysts are added to the pyrolysis process to speed up the rate at which molecules fracture, produce more oil, and shorten processing times. The value and yield % of the extracted liquid are examined in this study as it explores the effects of Mg bentonite catalysts on the pyrolysis of low-density polyethylene (LDPE) with diverse weight percentages of 1, 2, 3, and 4. The studies are carried out at a constant temperature of 340˚C with varying catalyst concentrations. According to the results, using 1% and 2% catalysts during the pyrolysis process increases the pace at which PO is extracted and produces fuel with better qualities. Using 1% catalyst, for example, yields 77.97% PO, 14.23% residue, and 7.79% gas—higher PO extraction rates than other catalyst concentrations [19].

### 2.5. Lifecycle Assessment of Fossil Fuel-Based Polymers

This research study aims to compare the energy savings and greenhouse gas (GHG) emission reductions of biobased polymers and bioenergy on a per unit of agricultural land-use basis. The study extends existing life-cycle assessment (LCA) studies to include land demand in the evaluation of different biomass options. With the increasing focus on increasing the energy supply from biomass

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and the bulk production of biobased polymers, the availability of land for nonfood crop production could become a limiting factor. Therefore, it is important to consider land demand when comparing different biomass options, given the significance of energy and greenhouse gas issues in current environmental policy.

Though several life cycle assessments (LCAs) have been carried out on different kinds of bio-based polymers recently, the topic of land usage has not been covered in many of these studies. According to this comparison, the choices are ranked differently when the energy savings and GHG emission reductions of biobased polymers are expressed in terms of agricultural land instead of polymer produced. Thermoplastic starch and natural fiber composites perform better than bioenergy produced from energy crops when land usage is used as the comparative foundation. When it comes to energy savings and lowering greenhouse gas emissions, polyhydroxyalkanoates perform worse than polylactides. Moreover, adding agricultural leftovers to bio-based polymers for energy production greatly enhances their environmental performance. In the medium future, it is also expected that biobased polymers would reach improved manufacturing efficiencies, which will increase their ability to lessen dependency on nonrenewable energy sources and help mitigate greenhouse gas emissions. Given the possibility of finite land resources, biobased polymers provide intriguing prospects for environmentally friendly energy use [20].

In recent times, the field of functional materials and sustainability sciences has witnessed significant advancements, leading to the emergence of environmentally friendly and naturally derived technologies. These sustainable technologies aim to facilitate the transition from a wasteful fossil fuel-based economy to a more sustainable and circular economy. Biopolymers derived from plant materials and microbes have gained attention due to their sustainable nature, carbon neutrality, and renewable characteristics. These biopolymers can be grown indefinitely, offering the potential to establish a sustainable industry. Moreover, the successful utilization of biopolymers and the exploration of alternative pathways with reduced carbon footprint, utilizing green materials, hold great promise for the future development of increasingly sophisticated sustainable materials. This chapter provides an overview of the resources, demands, sustainability, and life cycle assessment of biopolymers. It serves as a guide for future research endeavors aimed at addressing ecological challenges and obtaining empirical evidence to support the establishment of a sustainable circular economy [21].

### *2.6. Recent Advancements*

Recycling and bio-based polymers are the two fundamental pillars that support the decarbonization of plastics. Utilizing biodegradable polymers has the potential to benefit society, the economy, and the environment through mechanical recycling. This study sought to determine if the power-driven and rheological characteristics of decomposable homopolymer blends might be substantially impacted by varying amounts of the same recycled biopolymer. Blends of monopolymers are made up of identical virgin and recycled polymers. A biodegradable blend that is commercially available was subjected to reprocessing in a single-screw extruder for two extrusion cycles. These samples were then ground and reprocessed in a melt using 75% and 90% of an identical virgin polymer. Tensile testing and rheological evaluations were then used to analyze the mixes. The results showed that while the polymer's mechanical and rheological properties were affected by several extrusions, the concentration of the reprocessed material in the blends had very little effect on the virgin material's characteristics. Additionally, the additive model that was used correctly predicted the patterns that were seen in the experiments [22].

Fossil-based polymers play a crucial role in the release of anthropogenic carbon dioxide into the atmosphere. This impact stems from various stages in the life cycle of the polymer, including oil extraction, cracking, polymerization, processing, and disposal. The reduction of carbon emissions from plastics can be accomplished through two key strategies: the utilization of bio-based or partially bio-based polymers, and the recycling of these bio-based materials. The disposal of these polymers, whether through biodegradation or energy recovery via combustion, does not introduce new carbon dioxide into the environment. Instead, carbon dioxide is utilized in the production of biomasses for

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bio-based polymers [23]. Furthermore, mechanical recycling, which extends the lifespan of polymers, can significantly contribute to reducing the vast quantities of plastics. Research findings show that while multiple extrusions have a notable impact on the mechanical and rheological properties, the presence of reprocessed material in the blends has minimal effects on the virgin material. These results suggest that the properties of the polymer blends closely resemble those of the virgin material. Additionally, the trends observed in experiments align well with predictions made by the additive model [24].

### *2.7. Challenges and Potential Solutions*

Numerous postconsumer recycling initiatives have been in operation for close to half a century, yet a considerable number of plastics still end up in landfills or are disposed of using other methods. Given the increasing concern over plastic pollution, particularly in oceans, there is a pressing need for innovative approaches and alternative methods to transform plastic waste into valuable products that can be efficiently utilized in a circular manner. This article initially outlines the technical and economic challenges associated with recycling postconsumer plastics, before delving into a discussion on emerging strategies aimed at recovering plastic waste through novel polymer designs, innovative recycling processes, and chemical conversions into high-value products. Key obstacles highlighted include the sorting and separation of plastic waste, the variability of products due to additives, and the cost-effectiveness of the petrochemical industry in producing virgin polymers, particularly polyolefins. While a wide array of technical solutions has been proposed for plastic recycling through mechanical and chemical processes, the commercial viability of these approaches is often hindered by performance issues, such as significant variations in key parameters, or economic constraints where the recycled products may match the performance of virgin materials but the recycling process itself is costly. The successful collection of postconsumer plastic waste for recycling is likely to hinge on economic incentives and governmental regulations [25].

Chemical recycling illustrates a promising solution for closing the carbon loop by transmuting plastic waste into valuable raw materials. However, it encounters various challenges. These challenges encompass intricate technological requirements that call for sophisticated processing methods, economic hurdles stemming from high operational expenses in comparison to producing new plastics, and the energy-intensive nature of certain recycling procedures that could offset environmental advantages. Furthermore, the effectiveness of chemical recycling is impeded by feedstock impurities, necessitating intricate sorting and pre-treatment procedures. The advancement and expansion of chemical recycling technologies are additionally limited by insufficient regulatory and policy frameworks that do not effectively encourage or back recycling endeavors. Moreover, establishing a strong market for recycled goods and dispelling public doubts regarding the quality and functionality of recycled materials are critical for positioning chemical recycling as a fundamental component of a circular economy. Tackling these impediments requires a collaborative approach involving industry, government, and society to promote technological innovation, bolster regulatory backing, boost market demand for recycled goods, and raise awareness among the public about the advantages of chemical recycling [26]. In order to efficiently address the challenges associated with recycling postconsumer plastics and converting them into valuable products, an inclusive approach is indispensable. This approach encompasses the integration of cutting-edge sorting technologies, innovative polymer designs that facilitate recycling or biodegradation, and the advancement of chemical and mechanical recycling processes capable of transforming plastic waste into valuable chemicals, fuels, or high-quality recycled materials. Accompanying these technical solutions with supportive policy frameworks, economic inducements such as taxes on virgin plastics and subsidies for recycled products, and the promotion of a circular economy through business models that prioritize the use of recycled materials, are central components. Additionally, education and public engagement are key aspects in increasing recycling rates and plummeting contamination. This multifaceted strategy requires collaboration among governments, industries, and communities to overwhelmed the economic and performance-related obstacles that currently hinder plastic recycling efforts, thus paving the way for a sustainable and circular plastic economy [27].

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## 3. Discussion

The exploration of utilizing polymers derived from fossil fuels to advance a sustainable and eco-friendly future presents an intriguing narrative that intertwines environmental conservation with technological progress. Through processes like thermochemical conversion and pyrolysis, plastic waste can be converted into biofuels and other energy sources, showcasing a practical approach to curbing carbon emissions, combating plastic pollution, and enhancing energy stability. Furthermore, the integration of polymers in solar energy, energy storage, and eco-friendly transportation exemplifies the versatile nature of these materials in promoting a sustainable energy infrastructure.

The findings also emphasize specific constraints, especially concerning technical, economic, and regulatory challenges that impede the broad adoption of these innovative methods. Enhancing the effectiveness and expandability of waste-to-energy conversion technologies is essential for addressing the rising worldwide energy demands sustainably. Furthermore, the evaluation of petroleum-based polymers highlights the necessity of a well-rounded approach that not only takes into account disposal options but also underscores the importance of bio-based polymers and recycling technologies in minimizing the total carbon footprint.

Incapacitating these challenges will be essential for the future development of this field, necessitating collaborative efforts in research and development, policy-making, and partnerships between the public and private sectors. Capitalizing in the advancement of scalable and economically feasible conversion technologies, as well as endorsing progress in bio-based polymers, are key steps towards establishing a circular plastic economy. Moreover, improving recycling infrastructure and inspiring the use of renewable energy sources are perilous for creating a more environmentally friendly and sustainable future.

This comprehensive examination establishes the groundwork for a transformation in our perception and utilization of fossil fuel-derived polymers, endorsing an integrated strategy that leverages the distinctive characteristics of polymers to tackle environmental concerns. Through promoting innovation and collaboration across diverse industries, a hopeful trajectory emerges towards attaining Sustainable Development Goal 7 and steering the international community towards a future that is both sustainable and decarbonized

## 4. Conclusions

The importance of fossil fuel-based polymers in promoting a more environmentally friendly future and expediting decarbonization initiatives is highlighted through an extensive examination. These substances show great potential in meeting Sustainable Development Goal 7 by undergoing creative conversion methods such as thermochemical conversion and pyrolysis, which convert waste plastics into valuable biofuels and other energy sources. This vitrine a feasible route towards lessening the environmental impact of plastic waste and bolstering global energy security. The flexibility and promise of polymers are further underscored by their integration into solar energy generation, energy storage solutions, and low-carbon transportation, so cultivation a sustainable energy environment. Moreover, a two-pronged strategy is convincing to diminish the carbon footprint linked with plastic production and utilization. This dictate conducting a comprehensive evaluation of fossil fuel-based polymers' life cycle, in conjunction with advancements in bio-based polymers and recycling technologies. By concentrating on creating sustainable, renewable, easily recyclable, or biodegradable polymers, as well as ornamental post-consumer recycling endeavors, the polymer sector can make significant strides in contending climate change and advocating for environmental sustainability. Nevertheless, the path towards an eco-friendlier future, as demarcated in this research, presents obstacles that must be surmounted. Technical, economic, and regulatory encounters ought to be tackled to fully harness the potential of these groundbreaking technologies and materials. Accomplishing a successful shift towards a more sustainable and circular plastic economy demands collaborative actions from governments, industries, and communities worldwide. By implementation a comprehensive approach that participates advanced sorting technologies, innovative polymer designs, and supportive policy frameworks, we can pave the way for a future where fossil fuel-based polymers assume a crucial role in attaining global sustainability objectives.

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