



## RESEARCH ARTICLE

### OPTIMIZING WASTE PLASTICS AND BIOMASS BY CO- PYROLYSIS PROCESS: A REVIEW

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#### ABSTRACT

Plastic waste from contemporary lifestyles has skyrocketed in recent years. Co-pyrolysis of these waste plastics and solid biomass feedstock combinations can boost fuels and value-added products in a synergistic way. The manufactured goods can be utilized as chemicals and pollutant sorbents to promote sustainable waste management practices. Elemental composition, proximate analysis, and heating value are the main topics of discussion when discussing the properties of distinctive solid feedstock combinations. Using TGA, pyrolyzer, fixed bed reactor, fluidized bed reactor, microwave, and multi-step reactors with GC, MS, and FTIR diagnostics, experimental techniques for co-pyrolysis study are thoroughly examined. Co-pyrolysis of waste plastic and solid biomass mixes is examined for insights into liquid products for chemicals and fuels, as well as yield and composition of gases and solid residues that evolved together with surface properties of the solid residues derived from the chosen configurations. With the addition of waste biomass for improved synergistic effects in waste disposal, the objective was to offer viable and advantageous routes for the clean and effective disposal of plastic waste.

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## INTRODUCTION

Because technology is developing at a rather sluggish pace, solid waste management is one of the most significant global concerns that humanity is currently confronting. Because landfills produce odors and byproducts that are harmful to the environment and human health, they are an unsustainable and costly activity in terms of environmental costs. Increasing the usage of solid organic waste can help support concerns related to energy needs, waste disposal, and waste management by providing valuable negative cost resources that are underutilized and can be turned into energy. Alternative energy sources must be taken into consideration because it is possible that non-renewable energy will eventually run out. Concerns over the depletion of non-renewable resources and their detrimental effects on the environment are growing globally. India, a developing country with a rapidly expanding population, is home to 1.366 billion people and is expanding at a pace of 1.58% annually. Given the overwhelming demand for coal—roughly 1300 million tons annually—India urgently needs to increase its imports of fossil fuels. These non-renewable sources are preferred above other renewable energy sources because of their greater accessibility, availability, and usability. However, excessive non-renewable resource combustion that results in greenhouse gas emissions today presents a possible hazard. Methane, carbon dioxide, and nitrous oxides are common suspects.

Ocean release, respiration, biological decomposition, and human activity are the primary sources of carbon dioxide emissions. Deforestation, which is carried out to satisfy the growing demand for wood products, releases this gas. Because of the significant expansion of civil society and the need for infrastructure, cement manufacturing is also a contributing factor to the rise in CO<sub>2</sub>. Therefore, excessive combustion of coal, natural gas, and petroleum is required to meet the energy requirements. Due to their higher extraction rate than formation rate, the widespread use of these naturally occurring resources over the past few decades is currently causing the rapid depletion of fossil fuels. As a result, energy prices have skyrocketed, creating energy instability. Therefore, it is imperative to transition to a renewable energy economy in order to replace these ephemeral and environmentally harmful fuels. Many nations have made use of renewable energy sources like solar, wind, and hydropower. However, the upkeep and maintenance of the equipment needed for these energy sources also has significant negative effects. Biomass and plastic trash are promising alternatives because they can be transformed into energy using thermochemical and biochemical processes that are helpful in turning raw materials into energy. With a focus on pyrolysis, this article attempts to demonstrate the many basic feedstocks accessible for pyrolysis, how they pyrolyze, and the composition of the final product. The review aims to illustrate the distinctions between biomass and plastics that have been pyrolyzed.

**Thermo chemical feedstock conversion:** Generally speaking, thermochemical or biological processes can be used to transform basic materials into energy. There are two groups of raw materials that are typically taken into consideration for the generation of renewable energy. They come from both biological and non-biological sources. Biomass is the term used to describe feed that comes from biological sources. Plastics and other waste items that can be converted into energy are included in the non-biological feed. Utilizing coal for energy production through methods that produce less pollution than traditional coal combustion is also of considerable interest. Therefore, feedstocks such as biomass and polymers and their thermochemical conversion to energy will be covered in this study. The majority of the feedstocks listed above are typically waste items. The process of turning so-called garbage into energy is good for the environment. Comparing and contrasting the product yield from different feedstocks is the specific area of interest. This aids in understanding the yield from different kinds of feedstocks and optimizes the feed composition.

**Pyrolysis and products:** The main goal of pyrolysis is to convert feedstock into energy. The pyrolysis process yields three main elements. These are pyro-oils (or bio-oils if the feed is organic), pyro-gas (biogas if the feed is organic), and char. Different fractions of oil, char, and gas products can be produced in the pyrolysis process by varying the temperature, reaction time, and heating rate. Therefore, these parameters can be used for certain purposes.

## LITERATURE REVIEW

F Paradelo et al. 2009 We look into using pyrolysis to recover two different kinds of garbage. The results obtained indicate that the slow pyrolysis of pine is more efficient overall when a plastic mix is included. Consequently, compared to the traditional slow pyrolysis carbonization of biomass, it was feasible to obtain greater liquid yields and less solid output. The liquids that were produced displayed heating values that were comparable to those of heated fuel oil. The resulting solid fractions displayed heating values higher than some coals, while the gas products had energetic contents higher than producing gas. Additionally, certain common byproducts of rapid biomass pyrolysis that are utilized as raw materials in a variety of industries were identified. Additionally, the impacts of experimental settings on product composition and yield were investigated. Reaction time on gas product composition (increasing alkane content) and on liquid composition (increasing aromatics content); reaction temperature on product yield (decreasing liquid yield with increasing solids and gases) and on gas product composition (increasing alkane content); initial pressure on liquid composition (increasing aromatics content); and primarily the pine content of the initial mixture on products yield (increasing gas and solid yield with decreasing liquids) and on the gas product composition (favoring CO and CO<sub>2</sub> formation). ÖÇepeliogullar et al. 2013 We examined the kinetics and co-pyrolysis properties of biomass-plastic blends. The desert land plant *Euphorbia rigida*, cotton stem, hazelnut shell, and sunflower residue were combined with polyvinyl chloride (PVC) and polyethylene terephthalate (PET) in a specific ratio (1:1, w/w). In the presence of N<sub>2</sub> at a flow rate of 100 cm<sup>3</sup> min<sup>-1</sup>, experiments were carried out with a heating rate of 10 °C min<sup>-1</sup> from room temperature to 800 °C. Following thermal breakdown in TGA,

a kinetic analysis was carried out to fit thermogravimetric data, leading to a thorough explanation of the co-pyrolysis mechanism. The findings of the experiments showed that the thermal decomposition behaviors of biomass and plastics are directly influenced by their structural differences. While the pyrolysis process for plastic materials produced two processes for PET and three steps for PVC, biomass pyrolysis is typically based on three primary steps. Additionally, it was discovered that plastic required higher activation energies than biomass materials to achieve thermal breakdown. Furthermore, it can be said that the assessment of plastic materials in conjunction with biomass produced notable modifications to both the thermal and kinetic behaviors. Burra K. G. et al 2018 In this work, we use polypropylene (PP), polyethylene terephthalate (PETE), and polycarbonate (BPC) to co-pyrolyze pinewood and other plastic wastes in various mass fractions. Co-pyrolysis had non-additive synergistic effects when compared to the pyrolysis of separate components. The results of differential thermography (DTG) revealed a prolonged evolution of syngas, a lowered peak of plastic polymers employing BPC or PETE, and enhanced decomposition peaks of biomass. When pyrolyzed with biomass, the char residue was non-additively decreased by around 5% (dry weight basis) using PP and BPC and by 2-3% with PETE. This implies higher volatile output and carbon conversion efficiency during co-pyrolysis as opposed to pyrolysis of individual components.

The synergistic effects of biomass with PP or PETE were primarily caused by the physical character of the polymers, as seen by the enhanced activation energy bandwidth of biomass degradation, according to first order distributed activation energy modeling (DAEM) with five pseudo-components. The activation energy distribution of BPC and pinewood mixes overlapped between 100 and 150 kJ/mol. Due to this overlap, a group of reactions with comparable energetics interacted chemically and improved the pyrolysis of the composite mixture. In comparison to the separately studied polymer breakdown, the activation energy of BPC in the presence of pinewood was lowered by about 50 kJ/mol. Compared to individual component pyrolysis, the quantitative synergistic kinetics findings in co-pyrolysis of biomass plastic waste combinations provide essential information towards the development of feed-flexible, clean pyrolysis and gasification system for efficient fuels production. Ann-Christine Johansson et al. 2018 In comparison to pyrolysis of the individual feedstocks, these investigations demonstrate that co-pyrolysis of biomass and plastics can increase the quantity and quality of the produced pyrolysis oil.

In this study, three pertinent plastic wastes—paper reject, shredder light fraction, and cable plastics—were assessed using analytical pyrolysis, Py-GC-MS/FID, along with woody biomass (spruce and pine stem wood). Additionally, one verification experiment was carried out under conditions relevant to industry in a cyclone pyrolyser pilot plant. Hae Won Ryu et al. 2020 Utilizing sustainable energy sources is essential since the depletion of fossil resources and price variations for fossil fuels pose a threat to the world economy. Fossil fuels can be replaced by carbon-neutral fuels, such as bio-oil made from biomass pyrolysis. Because plastic promotes deoxygenation, co-pyrolysis of lignocellulosic biomass with plastic is an effective way to improve the quality of bio-oil. However, to create bio-oil that is appropriate for possible usage as fuel for transportation, catalysts are needed. From the standpoint of chemistry, catalyst, and feedstock pretreatment,

this paper provides an overview of current developments in catalytic co-pyrolysis of biomass and plastic. The results of recent studies on acid catalysts for catalytic co-pyrolysis are also presented in this review, along with new methods that make use of base catalysts. Future research directions are suggested for commercially feasible co-pyrolysis process. Khursheed B. Ansari 2021. The scientific community has been forced to search for technologies that can process and turn both biomass and plastic wastes into useful end products due to the unprecedented growth in mixed plastic and biomass wastes, including plastic bags, drinking water bottles, agro- and forestry waste, and COVID-19-driven waste (facemask, gloves, PPE kits, and surgical masks). Because of the synergy between the two reactants, co-pyrolysis of plastic and biomass has promise for producing high-quality liquid fuel (hydrocarbon-rich bio-oil). Several parallel processes, including depolymerization, dehydration, deoxygenation, hydrogenation, hydrodeoxygenation, aromatization, and condensation, are made possible by the addition of catalysts in a co-pyrolysis process.

This results in the production of hydrocarbon-rich bio-oil that can be used directly or blended with the current fuel. SBE Esso et al. 2022. In this work, we look into In recent years, there has been a notable increase in the amount of organic solid waste (OSW) released by the general public. Here, we look at plastic garbage and bio-waste. Biomass, another name for bio-waste, is a plentiful and sustainable energy source that comes in a variety of forms. One inexpensive source of hydrogen found in OSW is plastic garbage. Pyrolysis is a process that transforms OSW by thermochemically converting plastic and biomass. This conversion can reduce problems with waste accumulation and result in synergistic product enhancements for chemicals and fuels. the occurrence and magnitude of the interactive/synergistic impact during the co-pyrolysis of biomass and plastic waste. the impact of a number of variables, such as the kind of plastic, biomass, reactor type, mixing ratio, heating rate, reaction temperature, and catalysts on the synergistic effect is considered. Additionally, plausible interaction mechanisms pertaining to the co-pyrolysis synergistic impact are described. The results of this review showed that the catalytic activity of the alkali/alkaline earth metal species in biomass, the transfer of active hydrogen radicals from plastic to the biomass unstable oxygenated radicals, and the heat and mass transfer during the co-conversion are the interaction mechanisms by which the synergistic effect may occur. The interactions can be strengthened by pre-treating the biomass, using catalysts, and having a similar chemical structure to the plastic. At high temperatures, synergistic effects are likely to occur to a large extent at a low heating rate. There are conflicting findings about the blend ratio.

Zhiwei Wang et al. 2022. The properties of distinctive solid feedstock combinations are examined in this study, with particular attention paid to elemental composition, proximate analysis, and heating value. In order to determine the quality of petrochemical equivalent products made from the co-pyrolysis of biomass and plastic waste, the effective H to C ratio of the various feedstocks is assessed. With an emphasis on the synergistic effects that can be achieved by co-pyrolyzing them with biomass, the properties of polyethylene terephthalate (PET), high density and low density polyethylene (HDPE & LDPE), polyvinyl chloride (PVC), polypropylene (PP), polystyrene (PS), and other major plastic waste components

are discussed. Modern experimental techniques for co-pyrolysis research are thoroughly examined employing TGA, pyrolyzer, fixed bed reactor, fluidized bed reactor, microwave, and multi-step reactors with GC, MS, and FTIR diagnostics. Along with a thorough understanding of various catalytic processing (ZSM-5 based catalyst, transition metal based catalyst, multipurpose catalysts, and ex-situ catalyst) for favorable product yield, various catalytic co-pyrolysis reactors are also compared and discussed at various feedstock to catalyst ratios, reactor temperature, and other operational parameters. Co-pyrolysis of waste plastic and solid biomass mixes is examined for insights into liquid products for chemicals and fuels, as well as yield and composition of gases and solid residues that evolved together with surface properties of the solid residues derived from the chosen configurations. There is also discussion of the difficulties and prospects for the advancement of co-pyrolysis of various solid organic waste and plastic feedstock mixes. The objective was to offer viable and advantageous routes for the clean and effective disposal of plastic wastes, including waste biomass to improve waste disposal synergy and recover energy and value-added goods. Chiun Chao Seah et al. 2023. Co-pyrolysis of biomass and plastic benefits from synergistic interactions between both feedstocks, increasing the output and quality of biofuels. Pyrolysis stands out as a viable thermochemical approach to synthesis biofuels. The synergistic process of biomass and plastic co-pyrolysis is therefore explained in this paper, along with a thorough presentation of recent developments in this area. Additionally emphasized is the significance of using circular bioeconomy frameworks for biomass and plastic waste Ahmad Nawaz et al. 2024.

According to this report, industrialization and population growth have boosted global energy consumption, which has resulted in a number of issues like pollution, power shortages, and the depletion of fossil fuels. These difficulties made it imperative to find and use plentiful renewable energy sources, particularly biomass, employing thermochemical conversion techniques like co-pyrolysis. Plastic waste and solid biomass feedstock combinations can be used to increase fuel and value-added products in a synergistic way. The current study offers a glimpse of past research, present-day successes, and future potential in the co-pyrolysis of solid biomass and plastic trash to produce high-quality biofuels. The characteristics of important components of plastic trash are discussed, with a focus on the potential synergistic advantages of co-pyrolyzing them with biomass. For the co-pyrolysis investigation, a variety of cutting-edge experimental approaches are evaluated employing various reactor types. Additionally highlighted are the challenges and opportunities for progress in the co-pyrolysis of different solid biomass and plastic waste combinations. According to this critical analysis, co-pyrolysis of solid biomass with plastic waste is a straightforward, efficient, and optional way to achieve efficient waste management, increase energy security, and reduce dependency on fossil fuels. It is also more beneficial than typical biomass pyrolysis alone.

**Future directions:** Catalytic co-pyrolysis, a new process, is thought to be an efficient way to turn biomass into premium bio-oils. However, several crucial elements must be emphasized for further study. Deoxygenation reactions and coke production are linked to the catalyst's acidity. Although high acidity increases affinity for coke formation, it also promotes the deoxygenation process over breaking the

pyrolysis vapor toward the synthesis of aromatic and olefins. To get the optimum yield of aromatics and olefins with the least amount of coke production, the catalyst's acidity (acid strength and number of acid sites) must be tuned during catalyst design. By regulating Si/Al, the catalyst's acidity can be changed. The textural architecture of the catalyst, which includes its particle size, surface area, and pore size distribution, also affects the product distribution that results from catalytic co-pyrolysis. The accessibility of reactants and products into and out of the inner pores of catalytic active sites is largely dependent on pore size. Smaller pores (less than 8.1 Å but more than 7.8 Å) can limit the formation of polyaromatic compounds, which serve as precursors to coke, and impede the passage of big molecules.

However, other researchers asserted that by passing through polymerization and dehydration reactions, phenol compounds and other big molecular weight products show a strong tendency to become adsorbed on the catalyst surface and have a high affinity to create coke. Larger pore size catalysts would be advantageous in this case since they can let big molecules into the catalytic side. Therefore, it is recommended that the pore aperture be large enough (24) to for large molecules to access the catalytic side and proceed through the deoxygenation process without being transformed into coke by polymerization and dehydration reactions outside of the catalyst. Due to these catalysts' superior performance in increasing the production of aromatics and olefins, the usage of multifunctional catalysts by metal inclusion has attracted a lot of interest lately. The type of metal, the amount of metal loading, and the manner of metal inclusion are important factors to take into account because they affect the final product's selectivity. The intricacy of different feedstock compositions during catalytic co-pyrolysis will be revealed by activation energy, pre-exponential factor, and reaction mechanism. In order to comprehend the transient behavior of catalytic co-pyrolysis and investigate the applicability with different kinds of kinetic models, a kinetic study is recommended.

## CONCLUSION

The investigation of co-pyrolysis methods to create high-grade pyrolysis oil has been the main focus of this review. The analysis and discussion in this paper are supported by the studies found in the literature. Without the use of any catalysts, solvents, or free hydrogen pressure, numerous researchers have found that the co-pyrolysis method can greatly increase the amount and quality of pyrolysis oil. As a result, this approach can be regarded as an easy, affordable, and efficient way to produce high-grade pyrolysis oil. Additionally, this method helps to raise the caloric value of gas and char, which are byproducts of co-pyrolysis. The availability of tire and plastic waste as an additional material in co-pyrolysis is crucial to the technique's sustainability. Co-pyrolysis is a viable option for converting biomass into pyrolysis oil from an economic perspective. Co-pyrolysis offers enormous potential for development in many nations because biomass wastes are readily available and in large quantities worldwide. Additionally, this technology makes it easy to control the volume of biomass wastes. The production of pyrolysis oil from biomass wastes may eliminate the need for landfills, lower waste treatment costs, and address some environmental issues. Furthermore, it can also be noted that this is an optional solution to increase energy security of the nation and reduce dependence on fossil fuel.

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