Production of Biochar from Waste Biomass Feedstock and its Applications in Sustainable Construction

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Abstract

Pyrolysis may turn fuel or waste material into biochar. It has certain constraints that may impede its development in improving fuel quality and quantity. Combustion occurs in an oxygen-deficient environment due to a number of processes utilizing biomass fuel. Burning the material produces biochar. Because biochar burns so readily, it is ideal for enterprises that utilize coal. It has a big influence on the ecology. The formation of biochar may significantly increase biomass usage. Modifications to the kind of material used, as well as future process modifications, must still be handled. Because biochar is rapidly replacing traditional charcoal and coal as a fuel source, this research focuses on biochar. Recycling and composting may be less efficient than previously thought. Diverse variables must be considered while recycling. In the long run, composting may produce high-quality soil nutrients. To get the greatest benefits, manage compost properly. Recent research has revealed that pyrolysis, gasification, and plasma technologies may be used to treat agricultural wastes. Each garbage disposal process has benefits and drawbacks. Research on pyrolysis and the use of biochar in building. A review of the various biomass waste sources utilized in the production of biochar is presented here. Qualitative research, closely related to secondary research, is used to examine in depth. Data gathering is crucial in qualitative research since it helps to better comprehend the study's goals and generate new ones. Findings from the research show a clear impact on biochar properties when the pyrolysis process parameters are altered. The types of biomass used for pyrolysis significantly affect the constituents of biochar produced. But the carbon percentage always remains at the maximum because thermal conversion converts complex compounds into elemental carbon and gases, which escape in the pyrolysis process. Further, biochar can be produced with a maximum yield with a fast pyrolysis process. The construction industry has prominent applications for biochar in the filler material. Substantial modification, soil stabilization, and pavement modification can be done economically, but more research is needed to impact construction parameters like durability and strength positively. Similarly, the cost benefits are also high in producing biochar as it can be used as an alternate form of fuel for energy generation. Overall, positive prospects exist in the conversion of biomass waste into biochar, and more research is needed involving innovative materials to get sustainable benefits from using biochar in productive applications.

Keywords: biochar, pyrolysis, biochar in construction and biomass thermal conversion

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Contents

1 Introduction

The agriculture sector is a key contributor to the generation of waste biomass from crops that have been harvested. The biomass of plants and animals is a naturally occurring organic and renewable source. As a result of improper biomass management and processing, pollutants such as greenhouse gases and surface and groundwater contamination may be produced. Slow pyrolysis is being used to make biochar from biomass even though it hasn't been fully commercialized yet. Malaysia's economy has historically depended on the construction sector, and the nation is now experiencing a new industrial revolution. Increasing construction and industrial activity levels produce toxic wastes that affect the environment [153].

Additionally, recycling and composting may not be as effective as expected. When it comes to recycling, several aspects need to be considered. Composting procedures that take weeks or more may turn biomass-based waste into high-quality soil nutrients. Y. Wang et al. (2020) concluded that it's also critical that all compost be handled properly to ensure the desired end product is achieved. Recent discoveries in agricultural waste treatment include anaerobic digestion and thermochemical methods like pyrolysis, gasification, and plasma technology [193]. When dealing with waste, each method has its own set of benefits and drawbacks. The detailed literature review of the pyrolysis process, biomass feedstock, production, and biochar application in construction.

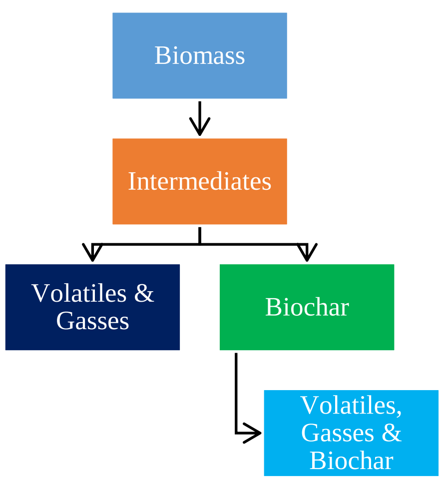

Figure 1 Production of biochar

Increasing energy demand has necessitated the development of environmentally acceptable green energy sources that can at least complement fossil fuels in most countries while retaining sustainability. It has long been known that biomass is one of the most promising resources for generating energy, heat, transportation fuels, and high-value bio-chemicals [38]. To manufacture biofuels and other bio-based products, biomass may be exploited. Approaches based on biochemistry and those based on thermochemistry are the most common. With thermochemical processes, it is feasible to process huge amounts of feedstock in a shorter period than is possible with biological processes. Pyrolysis, one of the most often encountered thermochemical methods for biomass, has drawn much interest for its ability to produce transportable high-density bio-oil or biochar [211]. Biosynthetic cellulosic materials are linear polymers made up of glucose units and amorphous cellulosic polymers consisting of five- and six-carbon sugars. Phenolic macromolecule that is not crystallized Aromatic structures, including sinapyl, coniferyl, and coumaryl alcohols, are found in lignin. Lignin Organically bound sodium, potassium, calcium, silicon, phosphorus, magnesia salts and water-soluble salts and minerals are among the inorganic species found in biomass. Materials derived from different types of biomass have other chemical structures and compositions. The models used to simulate biomass pyrolysis frequently contain cellulose, hemicellulose, and lignin [34].

In many models, biomass is represented as a superposition of its component elements, with no attention to the interactions between those parts. These types of biomass may be processed via pyrolysis. Soil amendment, cooking oil, and fine chemicals all employ charcoal, produced this way since the dawn of time [156]. Charcoal is still widely used in households today because it has a higher energy density than raw biomass and burns more consistently and cleanly. Less smoke is created as a result of the increased fixed carbon content. Increasing the residence time in the vapor phase and pre-drying biomass to prevent volatile components from being removed during moisture removal are two more well-known methods of increasing charcoal production. Charcoal yields may be increased by increasing operational pressure and particle size. Unfortunately, these systems can't be easily incorporated into current production processes since they need complex process control and heavy capital equipment [144]. Using fresh wood rather than waste-derived chips or pellets is preferable for big biomass particles.

Biomass macromolecules' polymer chains are broken down using externally given heat in an inert atmosphere to produce condensable volatiles, noncondensable gases, and charcoal. The final product of biomass pyrolysis greatly depends on the reaction conditions that exist throughout the whole operation. "Slow pyrolysis," which employs low heating rates and long residence durations to accomplish this aim, produces biochar as the main product. Fast pyrolysis necessitates high heating rates and short residence times to make bio-oil. The pyrolyzed crude bio-oil may be used to make biofuels and biobased chemicals [32]. Renewable energy, nuclear power, and fossil fuels all contribute to the overall energy supply. Renewable energy sources like biomass have seen a considerable surge in use, accounting for 70-80% of all renewable energy production during the last decade or so. A major acceleration in biomass and renewable energy technology development is required to accomplish the shift from conventional to "green" power engineering. Biomass's contribution to global energy generation is now just keeping pace with the overall development. It is often difficult to mill in its natural condition because of its low density, low moisture content, and other difficulties in processing biomass into usable fuel [104]. Depending on where it originates from, biomass may have a wide variety of properties and, as a consequence, issues. A wide range of methods are available to treat biomass as a consequence, and it is generally recommended. Thermal technologies seem to be the most promising environmental effects since they may be utilized to produce heat from renewable sources. Thermal processes may change the physical and chemical properties of the original material, making it more valuable or usable. Many scientists are intrigued by using biomass as a heat source [41]. Commercial adoption of biomass quality improvement technologies will help make biomass more widely accessible and easier to use, contributing to an increase in the quantity of biomass utilized in global energy production. This paper presents the detailed overview of the production of biochar from pyrolysis by using variety of materials and the possible applications in construction.

2 Methodology and framework

The current paper presents an overview of the utilization of different biomass waste materials in developing biochar that could be used in potential applications like construction. The qualitative research methodology is adopted for the detailed review because it involves the interpretivism research philosophy that is directly related to the secondary research approach. For the qualitative study design, the main element is to collect the information because the integrity and validity of the information published in the previous studies are important to practically improve the understanding of research objectives and develop prospects based on their overview. Evaluation of the information above is very helpful when it comes to the impact of neutralization of the different ways of items in the production of biochar because it is the main product being produced in the modern context to meet energy demand and handle the waste problem [23]. Furthermore, the research involves different materials, which come under the evolution of theoretical and quantitative information provided by the previous studies. However, it is still the entire summarization of the results based on arguments raised by the earlier researchers.

Table 1 Journals of selected articles

Research Journal	**Articles**	**Percentage**
Biochar	3	1.50%
Energy and Fuels	3	1.50%
Environment International	3	1.50%
Fuel	3	1.50%
SN Applied Sciences	3	1.50%
Biomass and Bioenergy	4	2.00%
Biomass Conversion and *Bio refinery*	4	2.00%
Catalysts	4	2.00%
Journal of Energy Chemistry	4	2.00%
Journal of Environmental Management	4	2.00%
Journal of Hazardous Materials	4	2.00%
Journal of Industrial and Engineering Chemistry	4	2.00%
Polymers	4	2.00%
ACS Sustainable Chemistry and Engineering	5	2.50%
Chemical Engineering Journal	5	2.50%
Chemosphere	5	2.50%
Energies	5	2.50%
GCB Bioenergy	5	2.50%
Sustainability (Switzerland)	5	2.50%
Journal of Cleaner Production	6	3.00%
Renewable Energy	6	3.00%
Bio resource Technology	9	4.50%
Energy	9	4.50%
Renewable and Sustainable Energy Reviews	12	6.00%
Science of the Total Environment	12	6.00%
Journal of Analytical and Applied Pyrolysis	13	6.50%
Others	56	28.00%

Therefore, an extensive literature review was carried out for which the main keywords were "production of biochar by pyrolysis process and biomass feedstock." Both of the keywords are utilized to investigate the existing literature, and the combination of the two keywords was also adopted to study the literature at least 10 years old. The general information needed to be collected for the expensive literature review was investigated from reputed journals. The primary focus of the study was to find out the most important aspects of biochar and the different factors that could affect its production properties. However, other materials used to produce biochar are also investigated and summarised from the perspective of their innovation and impact on the final quality of biochar. The databases were used to find out the research papers, of which the most prominent ones are Scopus, Elsevier, Springer, Google Scholar, etc. Overall, the inductive and deductive parameters were used to ensure that only research papers with any element of the research topic were selected. For these reasons, the induction characteristics for the entire project are related to the utilization of the biomass foot stock in the production of biochar, which only involves the pyrolysis process. There are many studies investigating the other functions, but only studies involving biochar production from the pyrolysis process were included. After shortlisting and further detection of the research papers, the final 200 were selected, and their literature was removed from the perspective of the interpretative research approach, which is very helpful in finding the most crucial arguments raised by the previous researchers and also in establishing the inappropriate relationship between the different factors that can contribute to the production of biochar and also various elements that can help to produce biochar that is sustainable for construction. The standard secondary approach highly adopts the evolution mechanism and overall study design. All the reliability and validity characteristics were investigated for each referenced paper. The summarized output may provide practical implications regarding the current progress of the pyrolysis process and biochar production.

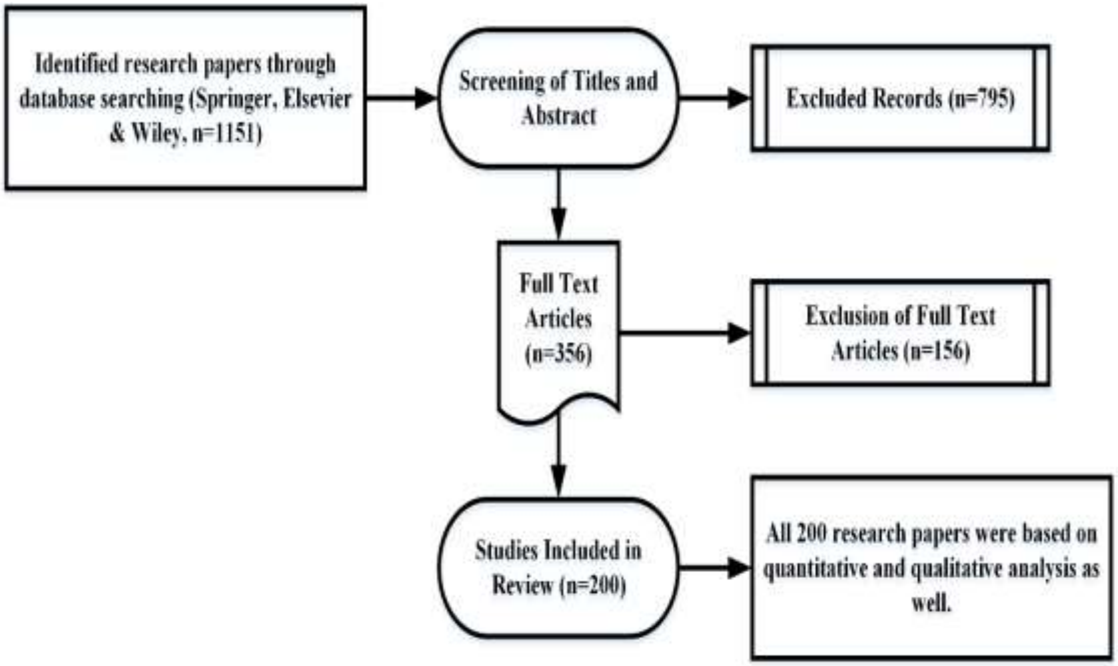

Figure 2 Selection of research papers

3 Problem statement

With the development of industries and the expansion of the human population, there is a consistent increase in waste. Any waste is always damaging to the environment because it disturbs the natural process. The increasing intervention of human beings in the development of synthetic methods has increased the accommodation of the west in an environment that is a growing threat to its sustainability and the future existence of human beings on this planet. The 21st century has given rise to products that are being used by human beings for a short period, after which there is a problem with the landfills and other areas that are highly contaminated. There is always a life cycle for everything. Still, most products take a long time before they are completely degraded and decomposed into favorable constituents for the environment [77].

Similarly, the combination of waste products creates problems for sustainable societies as they contribute to making the processes that further contaminate the environment and, ultimately, impact all living things. Increased waste is also one of the major reasons behind global warming. It is increasingly releasing harmful gases into the atmosphere like methane and carbon dioxide that are very dangerous for the future of the Earth [4]. On the other hand, human beings have increased energy consumption because of industrial expansion, which is further increasing the demand for energy in the form of electricity and fossil fuels. Fossil fuels are always known for their bad impact on the environment because they produce gases that cannot be eradicated from the atmosphere after combustion. Because of that, they create a highly contagious greenhouse effect. All the industrial progress currently being seen in the 21st century is entirely dependent on fossil fuels [206]. But again, it is not a reliable source to fill the increasing demand of industry in the future because the world needs to move toward alternative sources of renewable energy. There are plenty of resources that can be utilized from nature to produce fuel products that are very helpful for the development of industry and handling the electricity demand because it is one of the rising problems in modern societies that can affect the future of humanity. The fourth industrial revolution and the circular economy concept have given rise to the demand for fossil fuels and alternate sources of energy because there is no way by which development could be stopped [68].

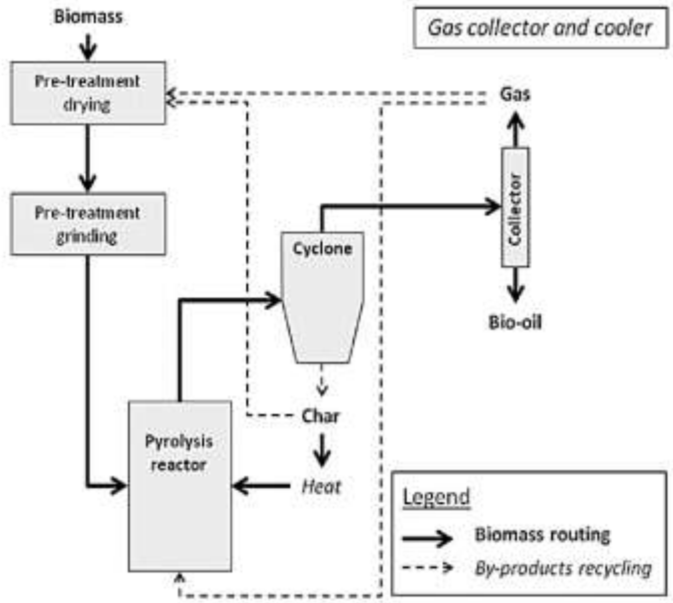

Figure 3 Generation of Biochar from biomass

Therefore, it is important to consider that the increasing waste items and the increasing demand for fossil fuels are two significant problems for the whole world, which means there is a potential need to investigate other sources that could provide a more reliable way of handling both issues. The most important quality of fossil fuel products that have been used for centuries is the presence of carbon, and the carbon itself is abundantly present in all kinds of biomass waste.

Suppose the waste products could be used to fulfil the increasing energy demand of modern industrial progress. In that case, it could be a potential solution to the growing problem of waste expansion and the increasing demand for energy. According to the latest studies, it is evident that more than 30% of the waste produced by humans can be regarded as biomass waste. This waste can be very helpful in eradicating the negative impact on the environment and utilizing the waste properly in developing processes that could meet the energy demand [65]. The simplest kind of biomass waste is material like wood, which breaks down after industrial processing into small chips that can be effectively converted into fuel to positively impact the environment and make sure that energy demand is being fulfilled. As a prominent example, agricultural waste can be considered a major development in the modern world, giving researchers hope to build more sustainable energy generation methods effectively. Hundreds of studies have utilized biomass products to produce fuels such as biochar and bio-oil, which are not very beneficial for the full film demand of the modern industry, but still, the challenges are huge [81].

The pyrolysis process is mostly used to convert biomass feedstock or waste products to items like biochar. It has specific limitations due to which its progress regarding the fuel quality and quantity can be affected. The biomass feedstock goes through a series of processes in which combustion takes place in the environment in which oxygen is depleted. Ultimately, after burning, the material can be obtained as biochar, in which the percentage of carbon is normal, above 50%. Biochar is an excellent material for charcoal because it can easily burn further and help fulfill the increasing demand of industries where coal is already being used. It has a significant impact on the environment [103]. The potential for increasing the consumption of biomass products in the development of biochar is huge. Still, the changes need to be handled specifically related to the type of material and further process changes that could alter the quality and constituents of biochar at the end of the process. The main focus of this research is biochar because, in the growing world, biochar applications are also increasing as it is an alternate material to normal charcoal and coal [139]. It is evident from the research that there is still a need for increased efficiency in the paralysis process because the ultimate impact of the conversion of the biomass waste product into the helpful biochar is not fully efficient, and it also needs to be investigated from the perspective of circular economy and development of further applications.

However, biochar can be used effectively in applications where the soil needs to be modified for agricultural use and has considerable application in the construction industry. The ultimate impact of biochar in the construction industry is to let it go by using it as a filler. But the constituents of biochar have a significant effect on the application because when the pyrolysis process is applied, the ultimate members of biochar are highly affected. After all, they depend on the constituents of waste biomass items. The different compositions of the biochar can produce unexpected outcomes in the application [98]. Therefore, there is a need for a comprehensive investigation to understand a better arrangement of the material and its impact on the pyrolysis process. For these reasons, there is a need to investigate the potential factors that play significant roles in producing biochar from waste biomass feedstock and its applications in construction. The economy is considerably dependent on the construction industry and has a lot of biomass waste produced from activities like deforestation and agricultural waste products. Besides this, the availability of the biomass heat stock from the resultant process of the industry is also increasing, which creates potential problems for the environment. For these reasons, the potential impact of biochar being produced from biomass feedstock can help the construction industry be more sustainable and help the environment prevent further degradation.

4 Pyrolysis

To use pyrolysis, researchers must have an organic substance that can be heated. It may be used for both pure and mixed items. Because of this property, pyrolysis is becoming an increasingly important process in today's business, as it enables ordinary resources and trash to be considerably more valuable. Kan et al. (2016) found that thermal treatment is usually linked to pyrolysis.

While combustion and gasification processes rely on the complete or partial oxidation of materials, pyrolysis relies on heating without the presence of air [87].

Thus, the process is mostly endothermic, resulting in high-energy products. Biochar, liquids, and non-condensable gases are all results of pyrolysis. Wang et al. (2017) stated the directions for using hot syngas. Pyrolysis raises a material's temperature from room temperature to a predetermined level. The material is kept within the pyrolysis unit and transferred via a screw conveyor at a set speed until the pyrolysis process is complete [192]. The composition and yield of a given product are directly related to the pyrolysis temperature. Using pyrolysis, researchers can turn organic materials into ash and carbon residue and trace amounts of liquid and gas.

On the other hand, carbonization is a by-product of very high temperatures and pressures of pyrolysis. Hydrolysis and combustion need water, oxygen, and other reagents in their reactions; pyrolysis does not. Czajczyńska et al. (2017) found that in every pyrolysis system, some oxidation is inevitable because it is impossible to operate in an oxygen-free atmosphere [31]. When the heating rate is slow, and the temperature is below 450 0C, pyrolysis produces mostly charcoal; when the pace is fast, and the temperature is over 800 0C, pyrolysis produces mostly gases. According to Kawamoto (2017), Bio-oil is the primary product at moderate temperatures and high heating rates. This technique may be used for a wide variety of biomass feedstock [88]. For pyrolysis to work well, the feedstock must have no more than 10% moisture content. Small particles up to 2 mm can only be processed by most pyrolysis methods because of the necessity for fast heat transfer. Small particle sizes necessitate that the feedstock for pyrolysis decreases in size first [52].

Efforts have been made to find ways to utilize biomass and pyrolysis oil as sources of renewable energy via catalytic cracking. A wide range of reactor designs may be incompatible with the current models to improve pyrolysis product yields. Primary degradation and secondary tar cracking kinetics models cannot usually accurately predict the pyrolysis rate [93,219]. The lack of consideration of Biochar's role in secondary tar cracking processes is one of the main reasons for this disadvantage. Because of the significant increase in the synthesis of Biochar's volatiles, reactor size models do not adequately analyze its in-situ catalytic activity, which reduces residence time. When the hydrodynamics of the reactor is altered as a consequence of this, it results in inaccurate product yield predictions [96].

To improve the amount of atomic carbon in the pyrolysis process, bio-oil yields, and bio-oil quality, physical and thermal approaches are utilized to reinforce biomass structure. Biomass feedstocks may be ground up to maximize heat flow and reduce polymerization of biomass components during pyrolysis, which in turn affects bio-oil production and composition. Biomass density and moisture content may impact pyrolysis product distribution and mass transfer efficiency. This is especially true when the biomass is densified [129]. When biomass is torrefied, it yields a higher-quality biofuel and increases the economic viability of the pyrolysis process. There is evidence that torrefaction may improve bio-oil quality, including decreasing oxygen concentration and boosting the heating value and the number of hydrocarbons in the oil. The activation energy for pyrolysis may be reduced as a result of this. Acidic and alkaline chemicals have been used with biomass before extraction to eliminate inorganic minerals and improve the bio-quality [70,168]. Oil's Acid pretreatment of biomass increases pore width and energy density and modifies its chemical makeup. The effectiveness of pyrolysis may be enhanced by utilizing white-rot fungus for biological treatment, which has been shown to increase the quantity of bio-oil hydrocarbons compared to untreated biomass [129].

Because of climate change, clean energy is becoming more important across the world. Environmental concerns have shifted the focus away from fossil fuels, despite their increasing depletion, due to their role in accelerating climate change. To produce solar energy and biofuel, the key renewable energy sources are the conversion of solar and biomass [10,66]. There is long-term potential for both of these techniques to address the world's future energy needs. It's also possible to transform agricultural waste and other agro-related trash into cash, which is another advantage. It will be possible to dispose of hazardous garbage in this way. Methane, bio-oil, and charcoal are all byproducts of biofuel production. In terms of biofuel production, this is a negative, but it's a good thing in terms of biochar enrichment [76]. Due to its low energy density and sporadic nature, solar insolation is ineffective for pyrolysis. Due to the installation's location, the biomass was exposed to direct radiation. The reactor was kept clean and inert by utilizing argon gas to keep it sanitized. Increase the quantity of Biochar we can make by adjusting the heating rate and residence time (1–2 h) [76].

Biochemical and thermochemical methods are the two most frequent ways. It is feasible to process huge amounts of feedstock in a shorter period than is possible with biological processes with thermochemical processes [178,202]. Pyrolysis, one of the most often encountered thermochemical methods for biomass, has drawn much interest for its ability to produce transportable high-density bio-oil or Biochar [86]. By its position at the beginning of the process, pyrolysis has an outsized influence on the subsequent stages of combustion and gasification. Biomass macromolecules' polymer chains are broken down using externally given heat in an inert atmosphere to produce condensable volatiles, noncondensable gases, and charcoal. Using pyrolysis, biomass may be efficiently transformed into liquid fuel in high-value systems [86].

Pyrolysis may be divided into two categories: slow and fast. Slow pyrolysis produces Biochar, which may take hours to make. For biofuel, rapid pyrolysis may create bio-oil within a few minutes. High heating rates, short residence times, and finely ground feed are required for fast pyrolysis systems to perform [154]. The protein+lipid concentration of a biomass feedstock dictates the quantity of pyrolysis oil generated, while the cellulose, hemicellulose, and lignin content determine the number of solids. Gelatin is the most difficult material to convert to lignin [26,27]. The gas emission was lowest in CH_4 atmospheres. CO_2 was consistently the most common gaseous product, regardless of the kind of biomass or reaction conditions. The C and H content of all pyrolysis oils was higher than that of biomass feedstocks, although the O and S content was lower than that of the latter [10].

4.1 Impact factors of pyrolysis

- Biomass and garbage have a variety of thermal breakdown temperatures, which implies that each contributes differently to the final product. A pilot test is usually required to accurately anticipate the pyrolysis process performance due to the wide range of materials.
- The process temperature strongly influences the treatment outcomes. Dhyani & Bhaskar (2018) found that non-condensable gases are produced at higher temperatures during pyrolysis, whereas solid charcoal and other products are produced at lower temperatures [35].
- The amount of thermal conversion of a solid product and the amount of time vapour spends in the pyrolysis chamber impact the composition of vapours produced.
- The speed at which material is pyrolyzed depends on the size and structure of the particles. Pyrolysis oil production may be increased by using smaller particle size materials since the heat breakdown process more easily impacts them.

4.2 Types of Pyrolysis

4.2.1 Slow pyrolysis

Long residence durations, low temperatures, and sluggish biomass heating rates are hallmarks of slow pyrolysis. From 0.01 to 2 °C every second, the prevalent temperatures reach almost 500°C in this mode. Fahmy et al. (2020) found that the residence period may be as long as a few hundred microseconds for gas, whereas, for biomass, it can be as short as a few hours. Slow pyrolysis produces tar and char as the biomass devolatilizes over time [46]. In addition to main events, secondary processes such as re-polymerization and recombination also occur.

4.2.2 Flash pyrolysis

Flash pyrolysis occurs at temperatures between 400 and 600 °C at high heating rates. On the other hand, this method has a vapor residence time of less than 2s. When compared to slow pyrolysis, flash pyrolysis generates less gas and tar.

4.2.3 Fast pyrolysis

Bio-oil and gas are the primary products of this procedure. Depending on the intended yield of bio-oil or gas, biomass is quickly heated to temperatures ranging from 650 to 1000 degrees Celsius throughout the process. Char builds up rapidly, necessitating regular cleaning.

4.3 Methods commonly used in the industry

4.3.1 Bubbling Fluidized Bed Pyrolyzers

Because fluidized beds are very easy to build and design, they are often preferred over alternative reactors. There is a huge amount of heat storage capacity, greater temperature control, and better gas-solids interaction with a bubbling fluidized bed pyrolyzed. Tomczyk et al. (2020) biochar functions as a catalyst for the cracking of gasses during the pyrolysis phase. Entrainment procedures are ultimately responsible for collecting the char [175].

4.3.2 Circulating Fluid Beds and Transported Bed

High gas velocities reduce residence time for vapors and char, but they have comparable features to bubbling bed pyrolyzers. For example, these pyrolyzers feature a more direct gas-solid contact, a higher processing capacity, and the ability to handle hard-to-fluidity materials.

4.3.3 Ablative Pyrolyzer

Heat is transported directly from the heated reactor wall to the feedstock in an ablative pyrolyzer. Particles of large feedstock may be pyrolyzed since heat transport is not a factor in reaction rates.

5 Characteristics of biomass feedstock

Agricultural mulch films and crop waste may be valorized by pyrolysis, reducing waste and creating a more circular economy. Different pyrolysis procedures produce various by-products, which should be considered. Y. Wang et al. (2020) found that compared to fast-pyrolysis processes, such as charcoal and gas, this approach has low-value energy products. Many organic wastes, such as food scraps and yard trimmings, may be used to make bio-oil [193]. Co-pyrolysis of biomass feedstock with polyethylene, polypropylene, and styrene increases oil yield and calorific value while lowering water content.

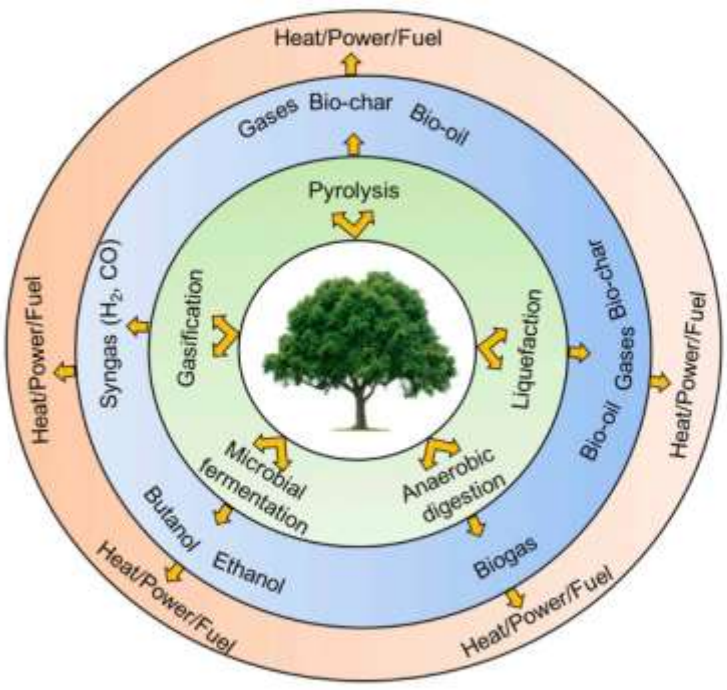

Figure 4 Methods of conversion of biomass feedstock into fuel and biochar [135]

Several agricultural applications for pyrolysis-produced biochar include soil amendment and carbon sequestration medium. This biochar may also be used to create a circular economy by turning garbage into value-added items. Hu et al. (2021) concluded that previously, research on plastics and agricultural waste co-pyrolysis focused on developing and recovering bio-oil by fast pyrolysis and then using this oil to replace conventional crude oil like petroleum in long-term transportation [75]. The feedstock may be pyrolyzed into value-added charcoal and electricity. Agricultural plastic sheets and waste streams containing crop remains may be used to generate a significant amount of energy. Using pyrolysis-based biomass co-processing of plastics will be a feasible value-adding technique because of the enhanced process performance and higher processing flexibility it offers.

To put it another way, it measures how much carbon will be turned into biocoal. Volatile matter, or biomass, is released during the pyrolysis and carbonization processes. Biochar will directly impact the generation of biocoal since it contains carbon. Ash content refers to the mineral residue found intangible goods. The ash content in the biocoal feedstock must be maintained at an ideal level to retain control over the biocoal's burning process. Kenney et al. (2013) found that a biocoal's calorie value, which defines how much energy it releases during production and how it will be sold, is a key consideration in the construction of a plant and the business model chosen [89]. It takes more energy to evaporate water from biomass if the moisture content is higher. The product's quality relies heavily on being able to regulate the quantity of moisture it contains. When the inflow moisture content of the biocoal production kiln is too high, it will affect efficiency and costs. Su et al. (2020) found that the optimal moisture content is between 5% and 15% for manufacturing. The syngas generated by operation is an excellent heat source for drying and normalizing moisture before biocoal synthesis [170]. The system's throughput will increase due to increasing the bulk density, which will enhance the product's durability and reduce transportation costs. The feedstock's particle size influences the quality and homogeneity of the end product. Hence biomass particle size should be kept below 10mm.

Consequently, to produce Biochar with a wide range of properties, multiple feedstocks have to be used. Co-pyrolysis, which has been found to improve biochar properties, is one technology that might improve biomass pyrolysis. Co-pyrolysis has been utilized to create Biochar and increase its properties by combining ligno- and macroalgal biomasses. Carbon sequestration and improved food production via biochar application have prompted worldwide interest in biomass utilization for long-term energy generation and a better environment [212]. Biochar manufacture is a prominent issue because of its energy and environmental benefits. Lignocellulose and macroalgae biomass may be combined in the energy biorefinery to produce Biochar. The quality of the biomass and the Biochar produced depends heavily on the pretreatment of the feedstock. Analysis of Biochar, including its physical and chemical properties and its usage in a variety of contexts, may be facilitated by biochar characterization. Additionally, a thorough sensitivity analysis of the biochar manufacturing process is required to determine the degree to which it is susceptible to changes in the market over time [212].

6 Properties of Biochar resulting from pyrolysis

Biochar has a lot of promise for lowering GHG emissions, enhancing soil quality, and minimizing trash. Pyrolysis, or controlled burning of organic wastes, creates biochar. Thus, unlike regular charcoal, biochar is not polluted by the carbon it contains. Pyrolysis decomposes organic materials like wood chips, leaves, and dead plants. The materials burn cleanly with no harmful fumes. According to Liu et al. (2020), the pyrolysis process creates biochar, a kind of carbon that cannot readily escape into the atmosphere. To produce renewable energy from pyrolysis by-products. Biochar converts carbon into a stable form faster and cleaner than conventional charcoals [112].

Biochar is absorbent, light, and finely powdered. Carbon makes about 2/3 of its bulk. The rest of the makeup is nitrogen, hydrogen, oxygen, and other elements. Based on the feedstocks and heating processes, biochar has many chemical compositions. Biochar composition is very diverse, having both stable and labile components. Most scientists agree that carbon, volatile matter, mineral matter, and water vapor make up the bulk of its composition. Sekar et al. (2021) found that the chemical and physical behavior and function of biochar as a whole and transport and destiny in the environment are determined by the relative percentage of biochar components [161]. For biochar production and transportation costs, moisture is another key component since greater levels raise the price per unit of biochar produced. Kan et al. (2016) found that according to a survey of relevant literature, there is still a lack of understanding of how biochar as a soil amendment is impacted by its composition and soil function. Charcoal with high carbon and low ash percentage has been the focus of most characterization studies since this is what the activated carbon market requires [87].

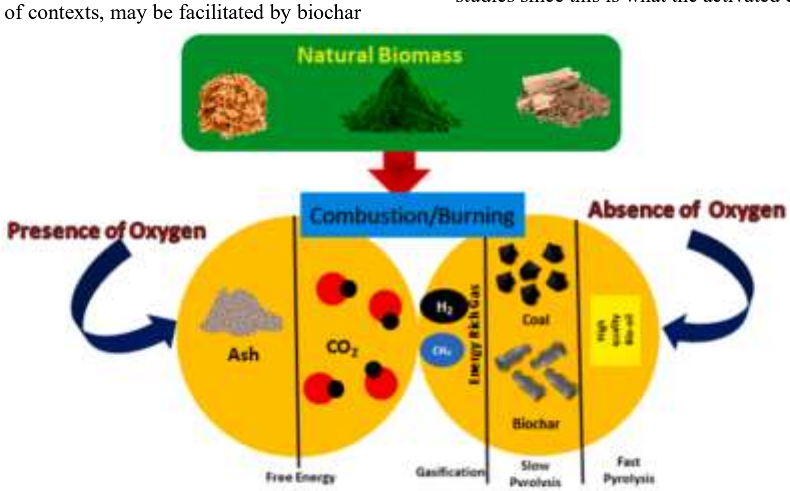

Figure 5 Comparison of burning of biomass with and without oxygen [63]

Additionally, the vast range of processing conditions and raw materials should be considered. This lack of standards is primarily because soil scientists do not fully understand the relationship between biochar content and its behavior and function. Tomczyk et al. (2020) found that speeding up the composting process encourages microbial activity. Additionally, it aids in reducing ammonia losses, bulk density, and odor in the compost [175]. Increased yield, product quality, or disease resistance may be achieved by either pre-treating the biomass before pyrolysis or using hot or cold biochar to improve and activate nutrients after pyrolysis. An increase in beneficial micro-organisms may also result from these improvements.

A mathematical model for an engineering application must balance the accuracy of the calculations, their time, preparation, and analysis requirements [25,125]. Precise predictions of the pyrolysis process were restricted by the time and precision required to calculate changes in chemical reactions and changes in heat transport conditions, such as moisture evaporation or bed shrinkage. However, when it comes to sourcing biomass material, complex kinetic models are more flexible. Each research scenario calls for a delicate balance between calculation speed and accuracy [122].

For example, Biochar made from agricultural waste may be used to decrease waste and protect the environment from the contaminants often present in farming. There are several variables to consider when designing a biochar application, including the specific demands of a particular project and the characteristics of biochars [210,216]. When low-grade feedstocks are used to complement biochar synthesis, new procedures are required. Feedstocks made from low-grade biomass offer both benefits and drawbacks. To get the highest possible concentration of carbon, biochars must be subjected to many different conditions, including temperature, pyrolysis duration, moisture content, and whether or not the biomass used is mostly cellulosic lignocellulosic or includes very little of either [75].

In lignocellulosic biomass, the amount of cellulose, hemicellulose, and lignin affects the hydrothermal liquefaction process's ability to produce a useful product. According to research, the amount of lignin in the biomass and Biochar paid is directly proportional. When lignin is heated above 220 °C and water is present, the lignin hydrolysis process begins. Several hydrolyses and dealkylation reactions rapidly transform the polyphenolic chemicals in the lignin into catechols, phenols, and others. Solid phenolic chemical leftovers are then produced by polymerization activities but at a slower rate than hydrolysis events. Char may also be formed from insoluble lignin during solid-solid conversion [89].

In the same way that lignin is formed from cellulose and hemicellulose in a series of steps, this process is analogous. Algae may also be used as a feedstock for hydrothermal liquefaction. Hydrolysis of algal polysaccharides produces monosaccharides and oligosaccharides. All three pyrolysis processes take place at temperatures between 300 and 1300 °C [61,190]. It uses lower temperatures than pyrolysis and delivers 2 to 70% more char. Most researchers believe that biomass polymers undergo less solid-phase conversion in hydrothermal procedures than in more traditional thermochemical processes like pyrolysis. An estimated 70% biochar yield challenges this widely held belief [161].

Diverse forms of biomass waste may be converted into Biochar, which has a wide variety of characteristics and uses possibilities in the soil. Brassard et al. claim that biochars with lower nitrogen concentrations are more suited to lowering soil N2O emissions. According to the research, Wetland and eutrophic water waste were used to make 500°C biochar, which had a C/N ratio of less than 30. While their higher nitrogen and other mineral content may help improve soil fertility, this is not the only benefit they may have [175]. When it comes to planting biomass waste, aquatic plants have the lowest fixed carbon content of biomass waste. Because of their high ash concentration, sludge, animal dung, and aquatic plant-based Biochar have high pH values [59,179]. There are significant carbon and oxygen concentrations in woody pruning debris, agricultural waste, and fruit and nutshells, contributing to increased biochar formation. As a result, various sorts of trash are ideal candidates for the production of Biochar. The private feedstock content and the resulting biochar yields of each form of Biochar were displayed in a triangle plot, which may be used to drive biochar application and selection for certain soils [175].

There is a growing need for lignocellulosic biomass because of its availability, cheap cost, and recyclability as a fuel source. Lignocellulosic biomass is mostly produced in agriculture and forestry. The lignocellulosic feedstock determines the features of the Biochar [79]. Different lignocellulosic materials, different breakdown mechanisms, and other variables affect the overall carbon concentration of Biochar. A lignocellulosic substance comprises cellulose, hemicelluloses, and lignin, all of which break down in unique ways to produce a wide range of compounds. It's vital to look at how lignocellulosic biomass degrades if we want to know anything about it [192].

Repurposing renewable and sustainable biomass waste into value-added uses is essential. To put it another way, the use of biomass waste may both injure the environment and supply useful feedstocks without causing any damage. Pyrolysis seems to be the most promising of the thermochemical conversion processes that may be utilized to manufacture three different multifunctional products from biomass waste [54]. Various issues, such as inefficient heat transfer, low heat transfer efficiency, and high energy consumption, are associated with the conventional pyrolysis of biomass using fossil fuels or electricity. Since microwave pyrolysis is known for its quick heating, short processing time, and good heat transfer, it is viewed as a potential solution [83,208]. To meet the growing demand for designed activated Biochar with improved chemical compositions and porous properties, conventional Biochar may be chemically or physically activated to generate value-added engineering started Biochar. Because of this, a wide variety of uses, such as wastewater treatment and catalysis, are possible. Research into reactor architecture and biomass pyrolysis is required before microwave pyrolysis may be commercialized [54].

Researchers have shown the efficacy of the pyrolysis process for appreciating woody biomass to produce high-value biofuels and chemicals. Even though pre-treatment with ionic liquids has not been mentioned in any publication, this may have impacted pyrolysis efficiency [215]. Using crude bio-oil as a direct fuel in today's engines might be problematic due to high concentrations of phosphorus and water in the oil, which is a common issue with the pyrolysis process. An efficient method for extracting oxygen and water from bio-oil is needed to compete with petroleum fuels. Supercritical fluids, solvent extractions, emulsions, hydro-deoxygenation, steam reforming, and catalytic approaches have all been studied in this research.

7 Production of Biochar by pyrolysis of waste products

It's a treasure trove of value that other people consider worthless. Douvartzides et al. (2019) found that using garden waste for pyrolysis is a way to generate useful products from rubbish and promote a feeling of community. Biogreen's tiny pyrolysis device may be used to transform garden waste into useful bio-products and power [44]. The core of the pyrolysis process is a hollow shaft screw conveyor that heats and delivers material through the process. District heating systems may generate steam and heat with the production of biochar and calorific syngas. To reduce greenhouse gas emissions, garden waste may be treated close to where it is produced using the Biogreen system. Standard Biogreen garden waste solutions can valorize roughly 7,000 tons of garden waste annually, producing 1500 tons of biochar. Y. Wang et al. (2020) stated that this agronomic improvement product might be returned to the community and serve as an example of the circular economy in the region. For trash managers and collectors who deal with garden leftovers, such a solution helps them produce an essential value for their company by allowing them to recycle garbage [193]. If biochar were used instead, this might be prevented. Biochar is an excellent method of storing carbon. Biochar has a major impact on soil health, plant development, and crop nutrition when it comes to farming.

Fast growth and nutrient absorption made Kangkong an ideal candidate for use as a biochar test plant. As a result, the investigation might be finished in as little as four weeks, leading to concrete results. It's also an easy-to-grow plant that doesn't need much attention. Higher dosages of biochar harm the growth of plants. Su et al. (2020) concluded that biochars alkaline qualities, which cause the soil pH to increase when applied at higher rates, may explain why boron and manganese in the soil are less prone to precipitate [170]. Biochar made from banana peels contains a trace quantity of nitrogen. Because of its high nitrogen content, biochar may adsorb nitrogen from the soil when dosed at high levels. The excessive biochar application hinders plant roots because they tend to plug soil pores. Hu et al. (2021) concluded that banana peels have been discovered to contain biochar precursors. An appropriate amount of biochar may have a significant impact on agricultural production [75].

Due to its global production and the large variety of feedstocks, agricultural waste might significantly impact the environment. Feedstocks include dairy manure, food waste, solid waste, and plastics. Hu et al. (2021) found two popular ways to dispose of trash: landfilling and incineration. Both procedures increase greenhouse gas emissions [75]. Co-pyrolysis biochar from agricultural wastes and plastic wastes such as agricultural mulch films, which are utilized to improve crop quality, has received only a limited amount of published studies. Bio-oil and syngas may be produced more efficiently using the co-pyrolysis of this resource [24,186].

Production of raw biochar decreased with increasing pyrolysis intensity and biomass ash content. The biochars produced had less volatile matter but more ash and fixed carbon as the pyrolysis severity increased. While treatment temperature and residence time did not affect fixed carbon output, the heat treatment intensity significantly impacted selected carbon content in various biochars tested. Y. Wang et al. (2020) said that as a result, it's possible to make the inaccurate conclusion that, during slow pyrolysis, the thermochemical conversion of biomass' organic component is practically constant across the studied ranges of residence times [193].

This study found that biochars produced by pyrolysis at temperatures between 300 and 500 degrees Celsius may be useful for agricultural purposes. Vegetable waste biochar is a promising solution for reducing the environmental effect of food waste while simultaneously earning money from food waste valorization. According to this study, the final characteristics of biochar are most heavily influenced by low temperatures, which are excellent for slow pyrolysis [134,174]. Particle size showed a negligible influence on the biochar potential for biochar qualities. It is possible to reduce the amount of raw waste that must be pyrolyzed to minimize the energy needed. The vegetable waste did not significantly affect biochar properties, but mixed and individual vegetable garbage performed equally well. As a result of this confirmation, funding will be provided to facilitate the collecting of mixed vegetable food waste and the direct conversion of that waste to biochar [90,138].

For biomass resources that may be used as fuel or transformed into other types of energy, "feedstock" is often used. Y. Wang et al. (2020) concluded that it is common to grow non-food crops, such as dedicated energy crops, only to produce biomass in remote or underpopulated places [193]. The two primary classifications are herbaceous and woody. Herbaceous energy crops may be harvested annually after attaining peak production after two to three years of development. Among them are sycamore and sweetgum trees and poplar and willow hybrids. Eastern cottonwood and silver maple are also featured. Using a broad range of resources, no food, fibre, or forest product output is adversely affected. Stalks and leaves from crops may be found across the United States. Aside from unusable trees, the cutting of lumber leaves the forests strewn with dead, ill, and otherwise useless trees.

Additionally, this woody debris may act as a habitat and aid in maintaining water and nutrients in their proper locations. Hundreds of millions of forest acres might be utilized to generate biomass for energy. Forest restoration, production, vitality, and resilience may be improved through woody biomass harvesting, which reduces the risk of fire and pests. Su et al. (2020) concluded that depending on the strain, algae may develop in freshwater or saltwater. Aquaculture, industrial, municipal, and even oil and gas drilling-generated water all include the right conditions for their development [170]. There is a significant amount of energy potential in wood processing residues, which are the by-products and waste streams generated throughout the process. Examples of waste resources include yard garbage, paper and paperboard, plastics, rubber, leather, textiles, and food waste. Biofuels made from municipal solid waste have the additional advantage of minimizing landfill trash. Food waste, commercial, institutional, and residential bio solid wastes, manure from concentrated slurries, industrial organic wastes, and biogas from the above feedstock streams are all wet-waste feedstocks that may be used to generate biogas. It is possible to use "trash streams" as renewable power sources to boost rural economies and alleviate waste disposal concerns [76,220].

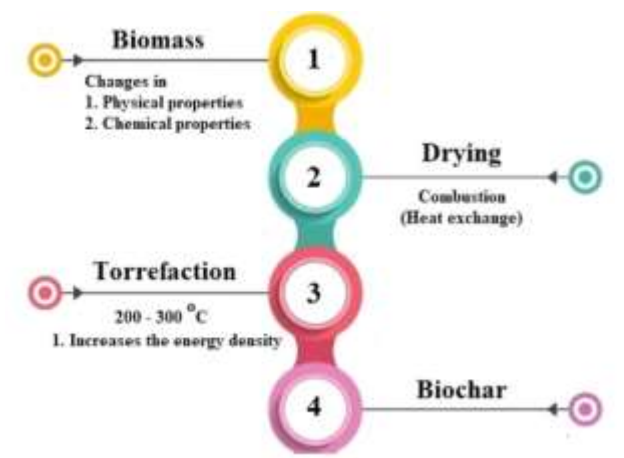

Figure 6 Example of torrefacation process of biomass [204]

Cafeterias and other food service facilities produce the bulk of these wastes, which are a combination of plastics and organic trash. Despite the availability of technology for the independent management of various waste streams, significant issues persist. Even while food waste may be composted, this method can be stinky and take a long time to decompose. Thermochemical conversion processes may be used to use a range of lignocellulosic biomass. It is possible to produce biochar and other useful byproducts via pyrolysis, one of the most widely used thermochemical conversion methods [21,84].

Different reactors have been used to study the pyrolysis of agricultural biomass waste, such as rice straw or sugar cane bagasse. Scientists studied both trunk and stump wood in order to better understand the bio-oils created by pyrolysis. According to the study's findings, liquids made from stump wood were 31.6% lighter and 11.8% heavier than those made from trunk wood, with a difference of 34.1% lighter and 13.0% heavier. In N2 and N2 atmospheres, rice straw pyrolysis produced bio-oils with 12.8% and 31% yields, respectively. There was a greater concentration of liquid products in the nitrogen atmosphere than the hydrogen one. Dhyani & Bhaskar (2018) stated that the gaseous product and losses yields were calculated using the mass difference between the bio-char products in the reactor and the gaseous product and losses yields [35]. To collect bio-oil products, dichloromethane was utilized as a solvent. The solvent was taken from the biooil and weighed in order to determine the amount of solvent that had been extracted. There are three processes in thermogravimetric testing for all four types of biomass, such as eucalyptus, sunflower shell, peanut shell and wheat straw biomass. The thermochemical decomposition of biomasses differed depending on the kind of agricultural biomass waste [42,127].

Another research study focuses on the co-pyrolysis of swine wastes and used mulch films. To generate 25 percent m/m energy, just 10% SPM is required. In the 10% SPM scenario, excess energy is generated for power generation. Comparing co-pyrolyzed biochars with biochar produced from porcine waste, we employed surface area and 1H NMR spectra. Douvartzides et al. (2019) focused on the fast pyrolysis of co-pyrolysis feedstocks from agricultural biomass wastes that include polymers at 650°C [44]. Catalytic fast pyrolysis of lignocellulosic biomass may produce hydrogen-rich co-reaction by adding co-reactants such waste plastics and tires. Aromatic hydrocarbons may be increased by including these co-reactants into the process. Additionally, the study sheds light on how to dispose of waste polymers from landfills.

Analyses using catalytic fast pyrolysis were carried out on red oak biomass in conjunction with high-density polyethylene. Pyrolysis temperatures as high as 625 °C were investigated. The pyrolysis oil production increased by 57.6 percent by weight. High temperatures resulted in the formation of a light hydrocarbon-rich gas during the cracking of pyrolysis oil. Adding HDPE resulted in a heating value of up to 36.6 MJ/kg, which was an extra benefit. Y. Wang et al. (2020) concluded that with HZMS-5 as a catalyst, co-pyrolysis enhances the yield of aromatic hydrocarbon. Increased aromatic hydrocarbon production was achieved when switchgrass and high-density polyethylene were mixed [193]. The pyrolysis of switchgrass was examined utilizing tail gas-reactive pyrolysis in this research to see how polyethylene and switchgrass affected it. Waxy material production is down. At 70 percent tail gas ambient pressure, noncondensable gases and substantially deoxygenated and aromatized pyrolysis oil were produced [14,16].

The kinetic properties of co-pyrolysis products of PET, PLA, and rice straw were determined using proximate and thermogravimetric studies. When rice straw was added, the pyrolysis activation and breakdown temperatures of PLA and PET were decreased. It has a temperature range of 560 to 900 degrees F. Biochar was also studied for its physical properties. According to the results, biochar's sorbent characteristics may be improved by the use of PET and agricultural wastes in its production. Tomczyk et al. (2020) found that polyethylene and acid-treated maize stover were tested for synergistic interactions with and without zeolite catalysts [175]. The quality and amount of pyrolysis oil generated from CS has also improved. A drop-down tube reactor was used to co-pyrolyze LDPE, wood, and straw. Pyrolysis took place at temperatures ranging from 500 to 600 degrees Celsius. A co-pyrolysis temperature of 600 °C gave the largest oil output compared to biomass or LDPE pyrolysis, by far [187,195].

On the other hand, lumpy biomass that is rich in cellophane yields an oil richer in ketones than that which is richer in cellophane. Numerous sample transfers are required to separate the product fractions and eliminate solvents from the soil samples [94,184]. There is going to be some weight reduction as a consequence of this. As a result of the pyrolysis of biomass that could not be collected during the solvent extraction process, water was also created, lowering the mass balance closure. The CH4 atmosphere always resulted in the lowest mass balance closure when employing the same biomass supply [170].

Biomass has the potential to make a significant impact in terms of environmental friendliness since it is a renewable energy source. Although pollution is a problem, biomass conversion technology provides a solution and creates new job possibilities in the agricultural waste use industry via revolutionary developments in biomass conversion technology. Biomass conversion also reduces the amount of biomass and improves the compactness of biomass [51,113,147]. Temperature, residence time, moisture content, and biomass particle size fluctuation impact product yield [80]. The effect of biomass moisture content on heating rate was explored in previous research. This study found that biomass particle size had no impact on syngas production since it wasn't a component, although increased moisture content may have had a role. In this study, the conditions and procedures for traditional and fast pyrolysis are identical. Nothing else has changed but the duration of stay and the cost of heating. Each of our trials yielded a loss. However, despite the condensed volatile products describing the losses, both approaches resulted in less than 15% losses [89].

In contrast, the classic pyrolysis procedure resulted in more than 15% losses because of its prolonged residence period. Increased temperature enhances syngas production in classical pyrolysis, but it also increases solid yield and losses in rapid pyrolysis [19,85,218]. Traditional pyrolysis results in a greater material loss, even though both processes lose less than 15% of the original material. These losses are the result of volatile chemicals condensing inside connected tubes [99,158]. Traditional pyrolysis may be to blame for the longer stay because of the higher concentrations. The most hydrogen was produced by fast pyrolysis at 953K. However, the amount of methane produced by either technique fluctuates depending on temperature and process type [169].

There are several key elements to successful fast pyrolysis, including high heat transfer rates and heating rates, rapid cooling of vapours and aerosols, and accurate temperature control to produce high levels of bio-oil. Fast-pyrolysis technology makes it easier to produce liquid fuels and a broad range of specialty and commodity chemicals [163]. Because the transportation and storage of this liquid product are less expensive than the handling of solid biomass, the two operations may be separated. It doesn't only fuel that has the potential to be more valuable than other useful molecules. Even on a small scale, fast pyrolysis technology may provide low investment costs and high energy efficiency. Due to the following advantages, bio-oil production utilizing fast pyrolysis has recently attracted a lot of attention [36,200]. The potential of pyrolysis technology for the generation of bio-oil from biomass necessitates extensive study and development. Several technical and economic challenges must be overcome before pyrolysis bio-oil technology can be economically viable [67].

Despite the apparent simplicity of slow pyrolysis, operating variables may substantially impact biochar yields and quality, contrary to common assumptions. A considerable influence on the production and quality of Biochar comes from the kind of biomass employed in its manufacture. An exciting possibility for increasing carbonization efficiency is the use of increased pressure. The biochar generation was unaffected by the carrier gas composition [15,20,71]. It seems reasonable to continue investigating the benefits of pressured slow pyrolysis in a CO2 atmosphere for biomass processing. Research into the ideal operating parameters for a certain application and the unique biomass feedstock is vital [176].

Electrode material, supercapacitor, soil ameliorant, catalyst, and so on all use this material because of the special features it receives from the biomass source. The Biochar's porosity is improved by removing pore-blocking substances from the surface area due to the breakdown of aliphatic alkyls and ester groups in organic molecules. At high pyrolysis temperatures, Biochar is hydrophilic; at lower temperatures, hydrophobic Biochar is formed [87]. Carboxyl and pyridine functional groups may also be added to the surface at higher temperatures. Electrons may be exchanged between these functional groups on the surface [152,177]. Increased molecular absorption and catalytic activity are the consequence of the abundance of oxygen in Biochar, which is composed of phenolic and carboxylic acid groups and sulfonic acid groups. Biochar is a carbon-based substance with various applications because of its stability, porosity, disobedience, and CO2 sequestration. Formed in low- or no-oxygen settings by the thermal decomposition of biomass, this material has a carbon content of roughly 65%. Charred biomass is composed mostly of carbon, hydrogen, nitrogen, sulfur, and oxygen, although the amounts vary depending on biomass [74].

Future studies may learn about the composition of Biochar by going through the process of analyzing it. Paddle kilns and bubbling fluidized beds are only a few of the reactors that are used in the process of making Biochar. Classifying pyrolysis as quick or slow depends on many factors, including but not limited to temperature, contact time, surface temperature, rate of combustion, and pressure. Biochar is a particularly good option for cleaning up pollutants [23]. A wide variety of features and several methods for establishing waste management and energy generation solutions alter the interaction between the two. There are certain drawbacks to using the approach proposed here, such as a lack of flexibility compared to an open waste management model. This circular economy model has the potential to improve energy recovery rates [53,55,121].

Because of its many applications in agriculture and the environment, Biochar has garnered much attention in the last several years. There has been an explosion in the amount of biochar-related literature recently due to the material's wide variety of uses and environmental friendliness, which has attracted many scientists to the topic. Biochar may be made from a broad range of biomass, but the quality of the finished product will be highly determined by the kind of feedstock and the processing method [40]. The reduced surface area and limited functionalities of as-prepared Biochar make it less efficient than activated carbon in eliminating soil and water contaminants. Because of this limitation, many subsequent studies have focused on improving material properties by adding essential functionality [3,198]. These efforts have resulted in a better-performing, more flexible Biochar. Biochar has a wide variety of qualities depending on the kind of feedstock. The feedstock must be carefully selected for making Biochar with appropriate properties as the feedstock's fixed carbon content increases, biochar production, whereas volatile matter content decreases. Biochar may be made from a wide variety of biomass, although crop residue is the most common source [146,224]. Lignocellulosic materials, such as wood pulp or straw make up the bulk of agricultural biomass. The breakdown of cellulose, hemicellulose and lignin usually starts around 340, 240, and 370 degrees Celsius. Respectively [172]. Degrees Celsius. Temperature and biomass content determine the characteristics of Biochar according to thermal decomposition data. Because of this, little research has been done on the impact of biomass components on biochar production.

It's termed bioenergy conversion when biomass is used to generate electricity. Bioenergy may be used to transform biomass into several energy-dense products. The kind of biomass utilized in the manufacture of Biochar influences the final product. Lignin's presence encourages the synthesis of charcoal, while this aids in the production of tar. Moisture in the biomass hinders char formation, which requires more energy to achieve pyrolysis temperature. Yields may be significantly affected by process factors [155]. It is important to note that temperature is a crucial process variable that influences the formation and quality of Biochar. Depending on the kind and content of the biomass, the optimal temperature for making Biochar is between 450 and 600 degrees Celsius. The greater the temperature, the less Biochar is produced, and the more gas and liquid are produced [133,160]. Despite the comparatively low temperature and low heating rate, low temperatures and long residence durations are conducive to char growth. Developing solid char requires a temperature differential between the biomass's inner core and outer surface, which a bigger particle size provides. Product distribution is also impacted by altering reactor pressure [88].

Utilizing algae that can survive high amounts of CO2 in flue gas, this carbon capture technology uses microalgae to collect the CO2. Biomass yields are significant because they fix carbon more efficiently than terrestrial plants via photosynthetic activities [1,137,173]. Microalgae properties minimize greenhouse gas emissions while providing a sustainable source for biofuels at the same time. There is an alternative to landfilling and using wastewater biosolids directly on agricultural land: the carbonization process [192]. When pyrolysis is used to treat wastewater biosolids before disposal, metals, organic and inorganic components may be liberated. Wastewater treatment plants were responsible for 2.8% of global GHG emissions. Plant-level energy integration on biosolid management may lower the carbon footprint of wastewater treatment facilities by employing Biochar to reduce GHG emissions from landfills [78,159]. To reduce the number of antimicrobials and surfactants, which are often found in wastewater treatment, pyrolysis, a process that creates value-added Biochar, might be a significant asset in treating biosolids [150]. Reduces the cost of wastewater treatment by carbonizing biosolids Moving wastewater treatment plant biosolids also saves a lot of money because of the reduced weight and volume.

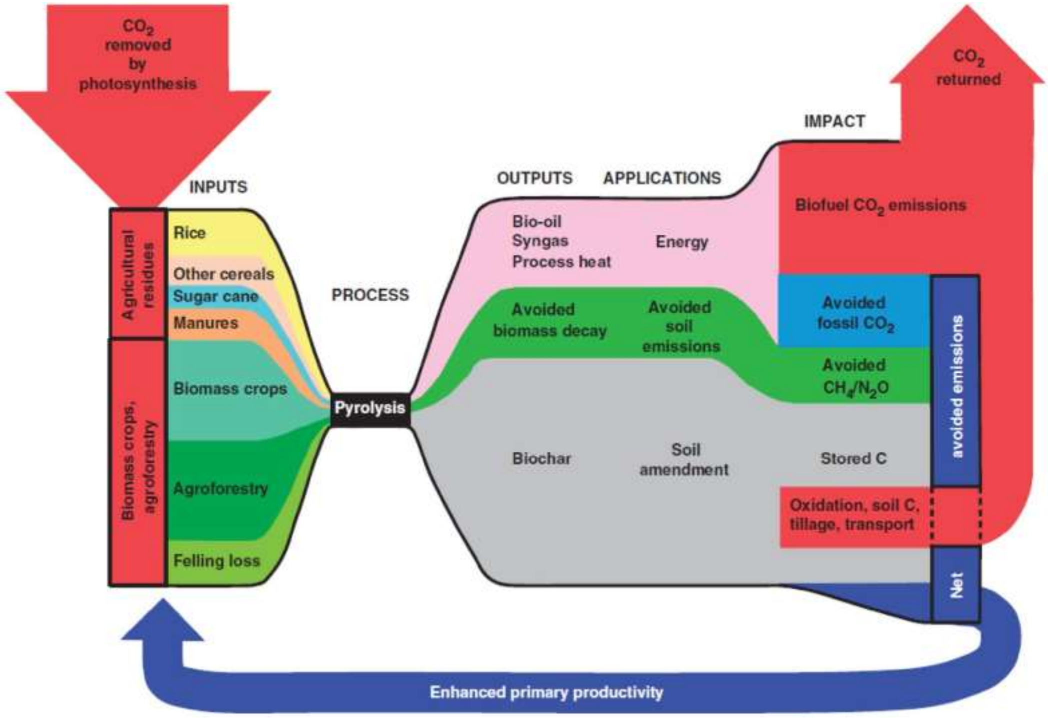

Figure 7 Conversion of biomass into Biochar by pyrolysis and its energy distribution [197]

Pyrolysis and carbonization are two thermochemical processes that may be used to manufacture biofuels and other energy products from biomass. During the pyrolysis process, the biomass is thermochemically transformed in the absence of air to produce the solid Biochar. Carbonization has been used for thousands of years to gently pyrolyze organic materials to create Biochar [212]. Slow pyrolysis warms biomass to a low temperature without the presence or absence of air over a long period. High-quality Biochar with a high fixed carbon content may be produced by keeping the reactor temperature between 400 and 600 °C [31]. Porosity and surface area allow more nutrients to be absorbed into the soil, allowing beneficial bacteria to flourish. Soil microbial biomass carbon is greatly increased when compared to chemical fertilizers.

Low-temperature biomass decomposition, known as slow pyrolysis, is a technique in which the pyrolysis vapor is allowed to settle and increase the secondary cracking threshold over time. To get high-quality Biochar, need to use a process known as "slow pyrolysis," which is crucial. To improve biochar production, it is necessary to reduce the rate at which heat is created. Charcoal and bio-oil are possible outcomes of slow pyrolysis [92,116]. During the slow pyrolysis process, both condensable and noncondensable components are formed in the pyrolysis vapors, which have a relatively high temperature [35]. It is possible to extract bio-oil, which is frequently referred to as "wood vinegar," due to the presence of acetic acid from condensable components. Bio-organic oil is mostly composed of acids, esters, ketones, and phenols. Isolated bioproducts from bio-oil include a wide variety of chemicals [122].

Given how closely pyrolysis parameters are connected to feedstock and biochar characterization, it is critical to characterize both to understand the long-term viability of Biochar as an agronomic and environmental input. Many ecological and toxicological problems must be considered before deciding which feedstock to utilize for biochar production. Slow pyrolysis in charcoal produces stable carbon [10]. For example, colonization of tiny structures by microorganisms may be an effective way to store nutrients and sequester atmospheric CO2. Using it on the ground might increase soil fertility and quality while sequestering carbon and adsorbing various harmful pollutants [100,114]. The selection of four distinct kinds of feedstock for pyrolysis determines the features of Biochar. Classification of appropriate feedstocks for biochar synthesis is required even if Biochar cannot be utilized in crops or food production. According to various production techniques, the chemical, physical, and structural characteristics of feedstock materials and Biochar formed are summarized [66].

This caused the pH to rise. Bio-oil production peaks at 500°C because cracking occurs at higher temperatures. The low-temperature environment in the reactor boosts the quantity of charcoal generated by slow pyrolysis. However, char production rose with decreasing temperature rise rate only at lower temperatures (below 650°C) [57,108,151]. Cracking occurs at low temperatures, whereas oxygenated hydrocarbon decarbonylation processes occur at high temperatures. Biochar formed at a rapid rate of temperature rise has less volatile materials and more ash [72]. As a result, high-temperature rising Biochar has a higher quality. This effect of an increase in temperature rate was not seen at high pyrolysis temperatures. To get a high output of liquid, fast pyrolysis is often used [37,119].

Biochar production processes are always being made to boost production and improve quality. There have been several ways lately outlined, but a comprehensive categorization of them has yet to be done. Despite this, we've categorized all key biochar manufacturing procedures into two basic categories [107,110,213]. In creating Biochar, the preparation technique and the kind of feedstock used considerably influence its qualities and applications. A fundamental challenge is that biochar applications must be assessed in their field efficiency and economic feasibility as part of continuing research [205].

Using Biochar as a pollutant adsorbent, catalyst, and energy storage is summarized in this report. Biochar's structure and application are demonstrated to be intertwined. More study is required to produce a wide variety of biochars for particular applications, such as better control over the design and features of Biochar. Biochar is produced by a combination of intermolecular and intramolecular reactions [205]. Temperature causes the hemicellulose components to become porous and smooth, resulting in a loss of functional groups in the material. Lignocellulosic biomass has a broad range of hemicellulose, cellulose, lignin concentration, interrelationships, and crystallinity [2,117,201]. The thermal degradation behavior may be affected by structural or chemical changes in raw material components. Lignin is the main precursor to Biochar in biomass pyrolysis because of its aromatic structure, which aids in the synthesis of Biochar. Because of its high cellulose loss rate, pyrolysis biochar may have a larger porosity [76].

By the temperature at which it is produced and where it comes from, the physical and chemical qualities of soil are influenced by the texture of Biochar. As a result of the larger surface area created by the higher temperatures, they have a lower nutritional value than biochars made from manure or agricultural residues but a higher sorption capability. A coarser texture reduces the microbial population and enzyme activity in these soils [138]. When biochars are introduced to soils with a fine texture, the microbial population does not alter in abundance. Fresh biochar-supplemented soil had enhanced C mineralization, but microbial abundance didn't change, suggesting that older Biochar augmented earth had more efficient microorganisms [62,95].

Byproducts of biomass waste gasification and pyrolysis may be employed in various industries, including agriculture, construction, and industry. Biochar Byproducts such as bio-oil/syngas may be utilized to power turbines or heat water and steam. Biochar production and consumption have increased dramatically over the world in recent years [44]. To make Biochar, the breakdown, depolymerization, and condensation of biomass under anoxic, high-temperature conditions necessitates a lengthy chemical process [43,64,69]. For each crop and growing medium, the pH of BLC has to be adjusted to meet specific needs. According to prior research on biochar performance, there are standards for appropriate techniques for pyrolysis and gasification settings. Biochar may include high concentrations of heavy metals and organic contaminants. However, these toxins may not be absorbed by the body [191].

In pilot-scale operations needing large feedstock, clean and "field-run" feedstock differ significantly. Species variety, production conditions, harvesting, collecting, and storing practices all impact the ultimate product quality when comparing feld-run biomass to research feedstocks that have been meticulously maintained [107]. Cut and placed on the ground emits ash and other pollutants, which may happen even before it is gathered. Soil contamination may introduce ash to biomass feedstock during harvest and collection procedures, but intrinsic ash also includes vascular and structural ash. Selecting and fractionating feedstock, using best management practices to minimize soil entrainment, and using preprocessing technologies to remove entrained soil and physiological ash from vessels or structural elements are all ways to reduce ash content [204].

Typically, the moisture content of charcoal is between 15% and 20%. The feed may range in size from little briquettes to large logs. Slow-pyrolysis methods might also use cashew nut shells and palm kernels as feedstocks and wood. Lignocellulosic biomass may be used as a pyrolysis feedstock to produce both environmentally friendly and cost-effective biofuels. In the case of wood biomass and agricultural waste, pelletization may be utilized to generate power [97].

Additionally, several reactor designs of different shapes and sizes have been studied. Biodiesel yields a lower-quality bio-oil than conventional fossil fuels because of the biomass's moisture content, uneven distribution, and wide range of feedstock [22,111]. Large-scale pyrolysis has extra difficulties due to phosphorus compounds, unstable bio-oil, and oxygen. It's possible that bio-refineries, with their high-energy feedstock production and process intensification, might help solve these challenges by reducing production costs [185]. Suppose pyrolytic oils are to survive in the long run. In that case, they will need to be supplied by bio-refineries that can provide high oil-yielding feedstock, affordable catalysts, reactors with high thermal efficiency, and an adaptive energy market [214].

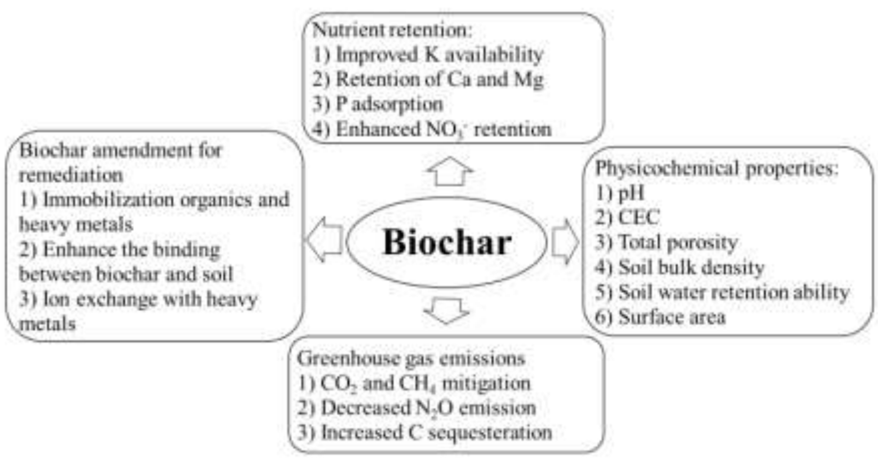

Figure 8 Biochar advantages

During the pyrolysis process, the quantity of moisture in the biomass must be taken into account. Feed source, manufacturing process, and mode of collection all affect how much water is in bio-oil. The liquid's water content is due to the pyrolysis process and subsequent dehydration operations in the raw materials [217,222]. To keep the produced oil's water content as low as possible, the biomass feedstock is often specified to have a moisture level of no more than 10%. High moisture content may increase the bio-oils calorific value, stability, and viscosity. Continuous pyrolysis relies heavily on the feeding rate. The reactor configuration has a major impact on the distribution of products and the qualities of bio-oil.

Faster devolatilization occurs when the feeding speed is lowered, resulting in gas and organic vapor formation [175].

On the other hand, slower feed rates result in a longer volatile residence time due to a slower pace of gas-phase production. More volatiles is recombined with char if the volatile-char interaction is longer. This helped split organic vapor secondary into gas even if the vapor residence period was lengthened [183]. Feeding at a greater rate reduces char and gas yields because the vapor residence time is reduced, hindering the further breakdown of vapor to gas and polymerization to form secondary chars.

Catalysts and oxygen-rich atmospheres help produce syngas at high temperatures in pyrolysis reactors. Biomass pretreatments may considerably enhance the pyrolysis process. Commercial bio-oil production utilizes woody biomass in bubbling and cycling fluidized-bed processes. Circulating fluidized bed reactors have better throughput than bubbling reactors, despite the greater complexity of the hydrodynamics [112]. The biomass particles grow increasingly difficult throughout the pyrolysis process because of their anisotropic structure and the fractures and comminutions. To accurately predict fast pyrolysis processes, significant attention must be given to the features of biomass and char as the process develops [29,164,165].

As an example, there exist models for biomass pyrolysis reaction kinetics. Reactor design relies heavily on kinetic models, which may be readily linked to other heat and mass transport models. The accuracy of pyrolysis models based on structural deformation, which might vary depending on the feedstock, is high [18,142,180]. However, the generation of char, tar, and volatiles may be accurately predicted using network models [46]. Biomass pyrolysis has been widely researched in the literature, and biofuel pyrolysis technologies that are close to commercialization have been developed. Modeling biomass pyrolysis is becoming more important. Unresolved concerns included the need for a more exact model of bed gas and particle behavior and the mechanisms behind first- and second-order reactions [13,143,209]. A flurry of probes has now addressed this lack of information. Model-based understanding of response mechanisms has seen some recent advancements [170]. Biomass pyrolysis's intrinsic inorganic species are examined in this research project. Multiscale models that account for the interactions between all of the biomass components should be developed by researchers to understand better how biomass is pyrolyzed [105,115,162].

The addition of clay mineral bentonite to biomass pyrolysis resulted in increased yields, whereas heavy oils were decreased. In the future, this clay charcoal mixture might be employed as an additive to soil and as a fuel source. When the clay was added, lighter percentages of the leftover oils became more noticeable. The greater the temperature of pyrolysis and the greater the concentration of clay material, the greater the degree of the reaction. The exact extent of this response can only be discovered by additional testing [47]. The findings are consistent with earlier research and add to them. Charcoal production may also be increased by altering the heating rate, allowing volatile compounds to remain in the fixed carbon structure for a longer time. Increasing the residence time in the vapor phase and pre-drying biomass to prevent volatile components from being removed during moisture removal are two more well-known methods of increasing charcoal production [17,128]. Charcoal yields may be increased by increasing operational pressure and particle size. Unfortunately, these systems can't be easily incorporated into current production processes since they need complex process control and heavy capital equipment [96]. Using fresh wood rather than waste-derived chips or pellets is preferable for big biomass particles.

To enhance pyrolysis product yields, it is advised to add internals to the spouted bed reactor or optimize the fountain area, as explained in this work. The primary reaction has high noncondensable gas and tar concentration in the region where biomass particles preferentially collect. Gas near the top of the annulus has a very low temperature. Noncondensable vapor and tar from the biomass particles' preferred distribution cause this area to be very low-temperature and high-gas-density [86]. The secondary reaction gas is concentrated in the bed's upper part, where it can't be condensed. Increased input velocity and pyrolysis temperature lead to a turbulent gas-phase flow inside the spout region. It could not get microscopic readings from the reactor's output due to difficult operating circumstances and complex interphase flow patterns [45,60,106].

The pyrolysis method used to boost the value of a phytoextraction feedstock has several elements to consider. Progress in phytoextraction and pyrolysis process design should generate consistent and reliable phytoextraction valorization processes. Pyrolysis settings should consider the intended products, inorganic content, and heating method [193]. Flash pyrolysis should be employed for high liquid yields and heavy metal separation from the char produced during the pyrolysis process to optimize fast and flash pyrolysis. The kind of pyrolysis reactor, intended product quality, and organic degradation processes all play a role in choosing the optimal temperature in this range [215].

In contrast, there is no impact on inorganic pollutants. Fluidized bed reactors seem to operate at higher temperatures while still maintaining harmful metals in the solid products they make, in contrast to ablative reactors, which can only keep toxic metals in the char when the temperature is lower [56]. Other than calorific and organic content, the operational temperature is also considered. The char of phytoextractors grown for soil cleaning must be properly evaluated for metal and metalloid pollutants in future studies [50,118,136]. The ultimate objective would be to compare their pollution levels to those with stricter environmental regulations in other nations [141]. A range of products may be produced by pyrolysis, which can be used to valorize biomass in a variety of ways.

8 Construction using Biochar

Traditional biochar production methods may be combined with current biomass pyrolysis technologies to create carbon-rich, fine-grained residue. A significant quantity of carbon dioxide is released when biomass and agricultural leftovers are burned and decomposed. Soil biochar may help reduce GHG emissions while also improving soil fertility. According to Dhyani & Bhaskar (2018), food insecurity, deforestation, water pollution, and climate change are all concerns that biochar may help to address. Biochar has the potential to help address these and other human development issues. Some of the most promising biochar will be examined in this article [35]. This high percentage is possible because biochar may completely replace sand, and the resultant plaster is five times lighter than the conventional form due to the high porosity of the substance. Tomczyk et al. (2020) found that the biochar-clay application has excellent insulating qualities, humidity-regulation, and electromagnetic radiation-mitigation capabilities as a carbon store. Reusing the biochar-based application in the soil as a compost supplement extends the building's carbon-trapping potential when it's finally dismantled [175].

Bricks and tiles may also be made from biochar and other building materials. According to the study, the biochar-cement bricks might reduce CO2 emissions from cement manufacture by 6% if utilized worldwide [120,126,182]. While carbon capture and storage is a viable option, we might have a more visible and functional effect by employing stored carbon in buildings, such as green walls and roofs, which may play a new role after a building's useful life has expired. Liu et al. (2020) concluded that biochar's poor heat conductivity and water absorption capacity of up to five times its weight are two unique qualities. Because of these characteristics, biochar is an excellent choice for building insulation and humidity control [112]. Using biochar to add plaster, bricks, and concrete components is possible by mixing it up to 80% with clay or lime/cement mortar. Because of this merging, interior walls now have great insulation and breathing qualities to keep a room's humidity between 45 and 70% year-round [58,131,148]. This helps keep the air in the rooms from becoming excessively dry, which may contribute to respiratory difficulties and allergies, and mold growth around thermal bridges and on exterior walls. Sekar et al. (2021) found that standard plaster spraying or rendering equipment may apply biochar to a building's outer walls. Houses may serve as long-term carbon sinks and provide a better interior temperature at the same time by using biochar-based insulation [161]. And if the home is subsequently destroyed, the biochar-clay or biochar-lime plaster may be utilized as a compost addition, thereby completing the natural carbon cycle. For those who cook and smoke, biochar-clay plasters are a welcome addition. It is also an excellent electromagnetic radiation absorber due to the employment of both wireless technology and main power.

Biochar is the revolution as a construction material because it can be effectively used as the pillar material which contain a significant percentage of carbon as the major constituent element. The expected impact on the CBR of soil when the biochar is added in moderate percentage as the pillar material will be positive. Fahmy et al. (2020) concluded that it is because the strengthening property of the biochar plays a critical tall in the development of matrix of soil that is further enhanced with the presence of ash in the biochar obtained from pyrolysis [46]. The temperature is also found to be a major variable that can modify the impact of biochar on the soil properties and it is prone that when the paralysis is done at higher temperatures the carbon content in the biochar increases [33,82,171]. This remains true for all the biomass feedstock that is added into the pyrolysis reactor. But it is also providing that the higher temperature are very damaging for the biochar strategic capabilities because if the carbon percentage increases above than 85% then it is also no longer possible to get the effective improvement in the mechanical properties of soil as most of the material is just carbon.

Additionally, Biochar is a suitable area for carbon sequestration since it absorbs CO2 from the atmosphere. Biochar is well-known for being produced by burning biomass and generating a large amount of smoke. This needs a well-ventilated workspace. Biochar should be made and applied to reduce the need for respirators, they said. It is also suggested that Biochar be slurried and mixed with the soil to minimize secondary dust formation [30].

Biochar's physical and chemical properties are influenced by the kind of biomass used to make it. A soil amendment, not a nutrition supply, is what Biochar made from woody biomass is for. Biochar generated from animal dung, for example, is higher in mineral content. Even if the same feedstock is used, the temperature at which Biochar is carbonized may substantially influence its properties. Temperatures that rise during carbonization enhance Biochar's specific surface area and decrease its nitrogen content. An essential role might be played by rhizobacteria or diazotrophic endophytes in increasing nitrogen fixation and compost mineralization. According to a study, many different biochars exist and choosing the proper one is critical to a suggested technique's effectiveness [54].

The main element in biochar is carbon, which is not very beneficial for the soil. As an organic compound, it can provide the required level of conditioning and stabilization to enhance further its ability to promote strength and integrity. One of the unique characteristics of biochar is that it is not a binder, which means that it cannot directly help the other constituents of the soil to bind together. Still, it acts as a major that can promote the load resistance and make sure that the earth is fully stabilized because it can easily absorb water [140,149]. It is always accepted that biochar is a similar product to simple charcoal. Still, it has the characteristic of water absorption that can be further explained by the unique features of material produced through pyrolysis. Water in large percentage is very bad for the soil. In the construction of a road, if the percentage of water is considerably high, it can easily affect the stabilization property of the earth and even cause the ground not to handle the required level of design load as the road can exert on the soil.

A variety of stabilizers are being used in the development of soil. Some of them are very expensive because they use materials produced by the industry or are very expensive concerning the expected property of the ground. Biochar is already proven to be very beneficial for the soil's agriculture and capability. For these reasons, it is usually used as an alternative to fertilizer to enhance the ground's fertility. But there are always certain factors that could affect biochar application in construction [28,124,189]. These factors closely depend on their constituents. The other important elements like sulfur and nitrogen present in the biochar can react with soil compounds and even help bind the soil together. It has achieved significant capability in concrete applications because it can replace the normal sand and even bring the characteristic durability requirements to the concrete that is already prone to previous studies. Therefore, the future applications of biochar will considerably increase, specifically the improvement of soil and concrete, because both are important in the construction sector worldwide, and they can adopt the waste material. However, some arguments are also evident from the study that increased carbon in the soil may result in the release of methane gas after certain reactions happen between the soil additives [48,166,188]. The methane gas is very limiting to the atmosphere, and therefore, one of the best examples of that type of soil could be given as peat. To strengthen this type of soil, it is always very important to add the binder and filler materials that can help to mitigate the voids. Biochar can be considered an important alternative to the other expensive materials available for solid stabilization as it can considerably improve the CBR of soil. However, its negative impact on the environment also needs to be considered because increased biochar production can negatively affect the environment [6,49,123].

Biochar may lower the net greenhouse gas emissions of concrete projects when it is used with cementitious material. Our study is focused on the use of biochar generated from mixed-wood sawdust in place of cement. According to experimental results, biochar's small particle size and microfiller influence may have led to a moderate improvement in compressive strength while decreasing sorptivity by around 70 percent after 28 days of curing. Because of its improved strength and permeability, biochar may be employed as a carbon-sequestering concrete construction material. If the infrastructure is well-built and resistant to degradation, it will need less maintenance during its operating life. As a consequence, buildings will be more ecologically and economically sound. According to the findings of this study, biochar may replace 2 to 4 percent of the cement in mortar while boosting the compressive strength. The micro-filler effect may not be created by lesser percentages, but larger percentages have been found to affect the mortar's strength and permeability [9,11,102]. Biochar increased the combination's impermeability compared to the control mixture. Biochar replaced 2-4 percent of the cement in the sorptivity test, producing the same level of permeability as a pozzolanic alternative. Future research might focus on improving biochar-mortar paste bonding and dispersing biochar in mortar mix more uniformly. One technique to improve the strength and permeability of biochar-based mortar mixes is to examine the form and size of the biochar particles themselves [12,39,199].

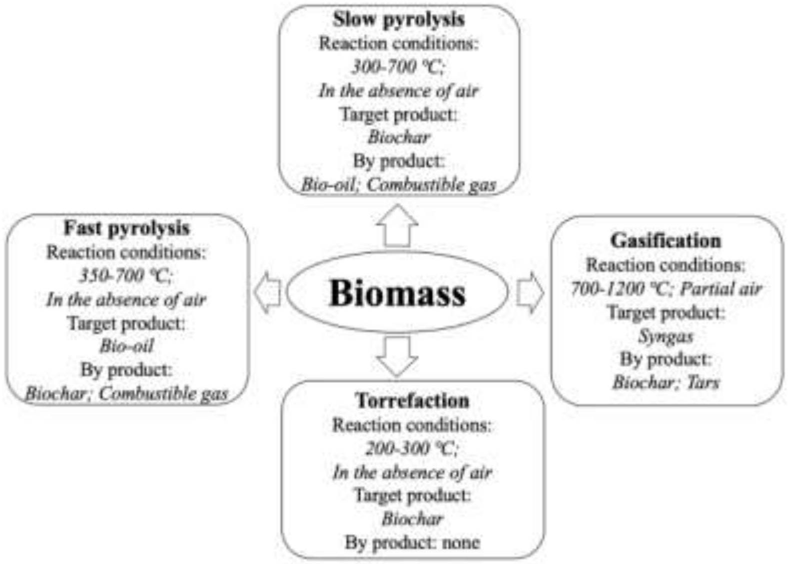

Figure 9 Biomass and its possible processes for thermal conversion

Biochar is a well-known technique for improving soil. lately it has become a construction material. Although biochar has been used in road construction, it is now being employed as a cement component. While mining and constructing to capture and store carbon would result in higher emissions of greenhouse gases, this method of using biochar will produce reduced emissions. There are a variety of products manufactured from this substance, including biochar-lime bricks. When it comes to insulating properties and humidity control, this biochar-plaster combination seems to be a promising candidate [130,157,194]. Excessive drying of the interior air is a main source of respiratory problems, which may be avoided by using the composite. It may also help to prevent mold growth on the outside walls by preventing moisture from forming. Temperatures in pyrolysis are more stable at higher temperatures. Because it has fewer reactive sites than concrete or asphalt, biochar is less likely to react negatively. Biochar's flammability must be considered when utilizing it as a construction material. These free radicals react with the oxygen in the atmosphere, as well as other elements such as metals, to produce a wide range of chemical reactions. Slow biochar pyrolysis has two benefits over fast pyrolysis: a smaller surface area and a greater ability to reduce carbon-free radicals [91,196,203].

Adding char particles to cement at a 1 percent mass concentration either inhibited fracture propagation or broke a single break into many smaller cracks under stress, as seen by scanning electron microscopy images. Flexural strength and toughness of the concrete were both increased by the char particles' crack propagation resistance. Char particles are more effective in shielding against electromagnetic interference than concrete containing carbon nanotubes at the same dosage. The pace at which the biochar is heated affects how much is created. The biomass contains cellulose, hemicelluloses, and lignin. Oil, gas, or char are all products of the breakdown of these components at different temperatures [5,181,223].

In addition, it's not cost-effective to continuously re-coating the walls in order to ensure that they continue to absorb. This means that further research should be done on this subject in the future. Construction and civil engineering projects may also benefit from its utilization. As a result of the addition of biochar to concrete and subsequent addition of carbon dioxide gas, the trapped carbon dioxide is permanently sealed inside these structures [101,109]. A concept like this might result in the long-term storage of a significant quantity of greenhouse emissions. Whether carbonation in biochar with adsorbed CO_2 impacts the durability of reinforced concrete still has to be studied further. Due to the heat of hydration, some CO_2 from biochar may be absorbed by fresh concrete. Carbon dioxide that has been absorbed into the new concrete may result in the formation of $CaCO_3$, which is beneficial since it minimizes porosity. Carbonation, on the other hand, may shorten the lifespan of reinforced concrete by corroding the embedded reinforcing bars.

9 Cost analysis of Biochar

The bioenergy production process's most costly stage, pyrolysis, accounts for 36% of total system costs. Even though pyrolysis has been around for some time, more efficient and effective equipment is needed. For Biochar, bio-oil, and syngas, the pyrolyzer is the most energy-intensive phase and the most labor-intensive. Even though running a 1-MWh pyrolyzer costs more than a portable one, it is less expensive than the bio-oil pyrolysis system utilized in the United Kingdom. No existing enterprises could provide a stable feedstock supply for such an endeavor since gathering this kind of material would be a whole new undertaking [161]. An entirely new approach to the region's social and economic well-being is introduced. It is hard to ignore the social aspects of the system, notably macroeconomic demand and supply consequences while evaluating the carbon footprint and costs of specific bioenergy projects. As a result, the biochar-based bioenergy system's evident job generation potential was not considered in this study [75].

However, no one in the biomass pyrolysis field can agree on how to swiftly and economically do this. Because of the lack of demand, a large-scale biomass pyrolysis plant was not developed. Commercially available ones tend to be of a set size. Consequently, a well-positioned ad will help to showcase its advantages. To enhance bio-techno economics, further study is required after the pyrolysis experiment. Several studies looked at the oil's Co-pyrolysis of biomass with other pollutants, such as plastics and tire debris [132]. Several studies have demonstrated that a coprocessing waste is required to pyrolyze diverse biomasses successfully. If biomasses are to be treated alongside other materials, further investigation into the pyrolysis kinetics of diverse biomasses and the interactions between the intermediates formed during co-pyrolysis is required [7,73,145]. An interaction between reaction intermediates may affect pyrolysis process efficiency and the bio-content oils and properties [207]. All that has been written about biomass-based fuel production being cost-competitive with fossil fuels is still in the early stages. The fundamental chemistry of the pyrolysis process must be studied further to make the technology commercially viable [129].

Biochar is expected to remain a high-end specialty product for the foreseeable future, although new products using biochar's unique chemical properties are gaining appeal. Every year, activated carbon is used in wastewater treatment facilities to remove contaminants and reduce odors. Biochar is a realistic choice when it comes to conserving money [8,167,221]. System profitability may be determined if carbon sequestration costs are more than a typical per-tonne cost of comparable carbon and the distance traveled is significant, as well as the different values of C offset. Between 12 and 13 years is the break-even point for land application scenarios. Biochar and bioenergy may be produced in tandem to save money and store carbon for the long term, making it a viable alternative to burning fossil fuels. Consequently, it is possible that the policy on harvesting forest biomass has to be amended. An entirely new approach to the region's social and economic well-being is being introduced..

10 Conclusions and recommendations

The predicted products, inorganic content, and heating method should be considered. To get the most out of pyrolysis, combine high liquid yields and metal separation from char with fast and flash pyrolysis. Biochar is a great carbon sink because it can absorb CO2. Biochar is made by burning biomass, which produces a lot of smoke. This process requires enough ventilation. They recommended making and using Biochar to lessen the requirement for respiratory protection. Biochar should be slurred and blended into the soil to avoid secondary dust. To better understand how biomass is pyrolyzed, researchers should construct multiscale models that include all biomass components. Pretreatment and posttreatment of biomass pyrolysis products must be coordinated before and after pyrolysis. To improve biomass pyrolysis performance, pretreatments such as torrefaction and biological pretreatment should be investigated. A catalytic system and pyrolysis parameters may create more complex liquid fuels like aromatic/aliphatic hydrocarbons, chemicals with added value like anhydrosugars, and biochars with unique properties for pyrolysis products. When volatile molecules are allowed to stay in the fixed carbon structure for a long time, more charcoal is generated.

It's also common to pre-dry biomass to avoid volatile components from being lost during moisture removal. Raising the pressure and particle size may enhance charcoal production. Biomass pyrolysis has been extensively studied in the literature, with entire pyrolysis systems built to generate biofuels. The importance of biomass pyrolysis modeling has increased. Unsolved challenges included first and second-order reaction processes, bed gas, and particle dynamics. Throughout the pyrolysis process, the biomass' moisture content must be considered. The amount of water in bio-oil varies on the feedstock, production, and collection methods. Pyrolysis and dehydration of the fundamental constituents resulted in a high water content liquid. Phosphorus compounds, volatile bio-oil, and oxygen hamper large-scale pyrolysis. Process intensification and high-energy feedstocks may help bio-refineries reduce production costs. Components and containers that are preprocessed before use may assist minimize the quantity of carbon black in the final product. The pyrolysis and gasification parameters may be standardized based on previous research. Heavy metals and organic pollutants are common in Biochar. Biochar made from manure or agricultural waste has a larger surface area and better absorption capacity. Structure or chemical changes in raw materials might impact thermal deterioration. Its aromatic nature makes it an ideal Biochar source in biomass pyrolysis. Fast-forming Biochar has less volatile components and more ash than slow-forming Biochar.

This improves the quality of high-temperature rising Biochar. Higher pyrolysis temperatures did not result in temperature rises. Fast pyrolysis is utilized for large volumes of liquid. Biochar is made by pyrolyzing four different types of raw materials. Even though Biochar cannot be used in agriculture or food production, categorization of feedstocks is critical. Slow pyrolysis heats biomass slowly without using air. A high-temperature reactor may create high-quality Biochar with high fixed carbon content. As temperatures increase, gas and liquid output outpace biochar production. Char may occur even at low temperatures and heating rates. These adjustments improved Biochar's performance and adaptability. The properties of Biochar vary depending on the fuel used. Agricultural waste is the most frequent biomass used to make Biochar. There are certain disadvantages to open trash management.

The breakdown of aliphatic alkyls and ester groups in organic molecules removes pore-blocking compounds from Biochar. The higher the pyrolysis temperature, the more hydrophilic Biochar is generated. Fast-pyrolysis technique facilitates the production of liquid fuels and specialty and commodity chemicals. Concerns concerning environmental pollution have been addressed, and agricultural waste usage has created new work opportunities. Less biomass is needed for conversion, and it is compressed. Temperature, moisture content, and particle size variation affect biomass product production. This requires numerous sample transfers to remove solvents from soil samples. As a consequence, you will lose weight. Water was created by burning non-solvent biomass. This harmed the mass balance. Despite the existence of waste separation technologies, substantial issues continue. Food waste may be composted instead of rotting in a septic tank. Some lignocellulosic biomass may be thermochemically transformed. Pyrolysis, a common thermochemical conversion process, may yield Biochar and other significant byproducts. Materials such as food scraps and yard debris are examples of waste resources. Biofuels derived from municipal solid waste help the environment and save money. Food waste, biosolids, manure concentrated slurries, industrial organic waste, and biogas derived from the above feedstocks are all acceptable wet-waste feedstocks. Rural areas may grow while lowering garbage disposal worries by producing renewable energy from "trash streams." The particle size of Biochar does not affect its quality. Reduce the quantity of raw waste that must be pyrolyzed to conserve energy. Neither combined nor individual vegetable waste affected the characteristics of Biochar. The ash concentration of the biocoal feedstock must be maintained for proper combustion. This strategy will improve the area's social and economic well-being. When evaluating the carbon footprint and costs of individual bioenergy projects, societal factors such as macroeconomic demand and supply must be considered. Due to its lack of binding properties, Biochar cannot help the soil's other components create a cohesive whole. It increases load resistance, and so increases ground safety and stability. Charcoal has long been considered a relative of Biochar. The specific qualities of pyrolysis-derived materials explain their water absorption characteristics.

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