



PYROLYSIS OF BIOMASS AS A SUSTAINABLE ALTERNATIVE TO FOSSIL FUELS: A REVIEW OF THERMOCHEMICAL CONVERSION PROCESSES

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Abstract. *The energy crisis is a major issue of concern which is mainly associated with rapid population and economic growth. With the increasing trend in annual energy demand, there is a high dependence on fossil fuels to meet this expected increase in energy demand. However, the use of fossil fuels results in a substantial amount of environmental pollution, and this is why nowadays, a lot of researches are geared towards the generation of green and renewable energy. As such, thermochemical processes, particularly the pyrolysis process, are getting a lot of recognition lately. In this chapter, slow, fast and flash pyrolysis is reviewed. For the production of biochar, a low heating rate and temperature are employed. Bio-oil production is favoured at a high temperature together with a high heating rate. A short vapour residence time is also employed for bio-oil production. While for gas production, a long vapour residence time is favoured. This is employed together with a high temperature and a high heating rate. The operating conditions to be employed will depend on the final product desired. Pyrolysis effect on biochar properties and characterisation of biomass and biochar are included here. As thermochemical processes claim to be carbon neutral processes, investing in those technologies for biofuel production will help achieve a sustainable and green future.*

Keywords: *Pyrolysis, Biomass, Agricultural wastes, Renewable energy, Biochar, Thermochemical conversion,*

Introduction. Current energy provision is almost totally dependent on fossil fuel, which is non-renewable. According to the International Energy Agency (2024), 81.4 % of the world energy needs in year 2023 were covered by fossil

resources such as petroleum, natural gas and coal. Rapid industrialisation and highly increasing world's population are the major causes for the high demand in energy. Fossil fuel combustion products are causing global problems. Some of the major global problems are global warming, acid rain, ozone layer depletion and urban air pollution (Veziroglu and Sahin [2018](#)). It was stated by Lancaster ([2022](#)) that the main driver for moving away from fossil resources, other than long-term supply issues, is pollution. Eventually, global problems adversely affect our environment, which leads to negative impacts on the living creatures on earth. The availability of fossil energy is predicted to last only for a few more decades. In recent years, interest in alternative energy sources has increased tremendously. The awareness of the need for a sustainable future, and in recent years, is being fostered due to the rapid exhaustion of fossil fuel. Thus, it is important to consider alternative fuels that can sustain rapid development and also substitute fossil fuel when its reserves are exhausted.

Biomass is considered to be among the most viable renewable sources of energy due to its abundance (Sumathi et al. [2018](#)). However, biomass is usually not suitable for direct energy production in its initial state due to its high moisture content and low bulk energy density (Chin et al. [2023](#)). As such, energy is derived from biomass through various conversion technologies. The two main categories of biomass conversion technologies are thermochemical conversion and biological conversion. Pyrolysis is one of the several thermochemical methods to degrade the biomass. Without the presence of oxygen, the biomass is degraded by heat. The products of this biomass thermochemical conversion are char, bio-oil and gases (Hosseini et al. [2025](#)). Char is the solid product while bio-oil is the liquid product. Another thermochemical method which is used to derive gaseous products from solid or liquid fuel is called gasification. High yield of gaseous products which are rich in carbon monoxide, carbon dioxide and methane can further be processed to produce hydrogen. Liquefaction is also a thermochemical process converting lignocellulose

material, woodchips, organic wastes and other renewable fuels into liquid and solid fractions. The liquid fraction undergoes neutralisation, fermentation and distillation processes for the production of ethanol. Lignin components resulting from fermentation process are used for the generation of process heat and electricity (Lee [2017](#)). Biological conversion includes two process options, digestion and fermentation. Digestion process converts biomass using bacteria. Biogases which consist of a mixture of methane and carbon dioxide are produced in an anaerobic environment. Fermentation process produces ethanol from starch crops and sugar. The starch is converted to sugars by enzymes with yeast once the biomass is ground. Then the sugars are converted to ethanol with the help of yeast. This process has been commercialised in various countries at a very large scale ([2022](#)).

Biomass as Alternative Energy

Energy from biomass is considered renewable as plants obtain their energy through photosynthesis from the sun, an inexhaustible source. Biomass is considered important since it can be cultivated almost anywhere and, therefore, provides social and economic development. Currently biomass is the fourth largest energy source. Biomass represents 10 % of the world's total primary energy supply and 54.6 % of the global renewable energy supply (International Energy Agency [2024](#)). Tremendously abundant crop residues are readily available in the agriculture-based countries. However, the residues from agriculture are not well utilised for alternative fuel production.

The energy derived from biomass is gaining importance. Depleting supply of fossil fuels is the main reason driving the interest on biomass energy. Together with rising environmental concerns, there is a need to shift away from the conventional fossil fuel. Generally, the conversions of biomass into fuels are done through thermochemical processes. Gasification, pyrolysis and liquefaction are mainly the processes involved. Biochar is a by-product in all of these conversion processes. According to the International Biochar Initiative Organization, about 80 % of all

crop and forestry residues may be converted to biochar and energy, an estimation by the year 2050. Most companies are repeatedly searching for fuels that are less expensive than coal, oil and gas. Biochar can be produced from biomass during the thermochemical conversion process. When biomass is burnt or biochar being used, the carbon in the parent biomass or the biochar reacts with oxygen in the air to form carbon dioxide (CO₂) which is released into the atmosphere. The amount of CO₂ which is taken from the atmosphere during growing stage is equal to amount of carbon dioxide produced if fully combusted. So biomass can be considered as a carbon sink as there is no net addition of CO₂.

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