Review Article

Pelletization Process for the Production of Fuel Pellets from Various Surplus Biomass: A Review

---

Abstract

The increasing demand for renewable and sustainable energy sources has led to a growing interest in utilizing surplus biomass for the production of fuel pellets. Pelletization is a promising process that converts biomass into compact and uniform fuel pellets, which can be used as an alternative to fossil fuels. (The importance of biomass as a renewable energy source and the need to utilize surplus biomass for fuel pellet production) It also discusses the different types of biomass feedstocks that can be used for pelletization, including their availability, properties, and suitability for pellet production. The review further delves into the pelletization process, covering the key steps, such as size reduction, drying, conditioning, pelletization, and cooling. The influence of process parameters on pellet quality, including pellet durability, density, moisture content, and energy content, is also discussed in detail. The information presented in this review can serve as a valuable resource for researchers, engineers, and policymakers interested in biomass pelletization for renewable energy production.

Comment [A1]: Incomplete sentence

Comment [A2]: Please specify what the word it refers to

Keywords: Biomass, Fuel pellet, Drying, Size reduction, Durability, Economics

1. Introduction

The world's increasing demand for energy has resulted in the extensive usage of fossil fuels, such as coal, oil, and gas, which emit significant amounts of carbon dioxide (CO_2) into the atmosphere (IEA, 2021; Chen *et al.*, 2022). The increasing demand for energy presents both challenges and opportunities. On one hand, meeting the rising energy demand can strain existing energy infrastructure, pose environmental concerns, and impact climate change due to greenhouse gas emissions from burning fossil fuels. On the other hand, it creates opportunities for innovation, technological advancements, and investment in renewable energy sources such as solar, wind, hydropower, bioenergy, and geothermal energy, as well as energy efficiency measures and sustainable practices.

The World Energy Forum has predicted that fossil-based oil, coal and gas reserves will be exhausted in less than another 10 decades. Fossil fuels account for over 79% of the primary energy consumed in the world, and 57.7% of that amount is used in the transport sector and are diminishing rapidly (Kumar *et al.*, 2010). The exhaustion of natural resources and the accelerated demand of conventional energy have forced planners and policy makers to look for alternate sources. Renewable energy is energy derived from resources that are regenerative, and do not deplete over time. Renewable energy offers our planet a chance to reduce carbon emissions, clean the air, and put our civilization on a more sustainable footing. It also offers countries around the world the chance to improve their energy security and spur economic development. Modern biomass encompasses a range of products derived from photosynthesis and is essentially chemical solar energy storage.

Comment [A3]: Transportation??

Biomass has emerged as a promising substitute for fossil fuels in the production of solid, liquid, and gaseous energy carriers. Unlike other renewable sources such as solar, tidal, wind, and geothermal, biomass offers versatility and significant potential. Notably, the utilization of agricultural residues and organic wastes as substrates for biofuel production can contribute to reducing greenhouse gas emissions from landfills and open burning, while also creating a revenue stream for biomass suppliers (Demirbus, 2009). Biofuels are energy carriers that can be obtained from various biomass sources through mechanical, thermal, and biological conversion processes. Biofuels derived from raw biomass give direct and long-term environmental benefits, making them a crucial component of sustainability (Osman *et al.*, 2021).

The direct use of biomass for the generation of biofuels has been limited by some inherent characteristics of the material, such as its high volume, low density, hydrophilicity, high volatile content, high moisture content, low energy content, and heterogeneity. Low density and bulky biomass demand large amounts of storage space and expensive transportation. Increasing the bulk densities of biomass through densification lowers the cost of transporting raw biomass and allows long-term storage (Song *et al.*, 2023). Compared to alternative biofuels, biomass pellets have a number of benefits in the broad market currently, including a straightforward manufacturing process and an abundance of feedstock (Kang *et al.*, 2019). Additionally, both rural and urban populations worldwide are seeing a steady increase in the demand for wood pellets for power generation and heating. In 2027, it is anticipated that the world's demand for wood pellets for heating will exceed 26 million metric tonnes. Europe produced the most pellets in the world in 2020, followed by North America, China, and South America, with 13, 11, 10, and 4.4 million metric tonnes, respectively (Sarkar*et al.*, 2023).

There is a lot of literature on the densification of various biomasses for the production of fuel pellets, but little on standardizing the densification process, optimizing its parameters, types of equipment used, the mechanisms of pellet formation, and characterization techniques for determining pellet quality. Additionally, the literature on the value-added utilisation of densified biomass, factors influencing biomass the pelletization process and pellet quality, detailed binding mechanisms during densification, and economic feasibility needs to be comprehensively revised with the latest findings in these fields. This paper offers a comprehensive examination of pellet quality evaluation methods in an effort to fill in any knowledge gaps that may exist. The paper also explores the use of binders, additives, and lubricants in the densification of biomass and their usage in the manufacture of fuel pellets.

Comment [A4]: Please delete the word “the”

2. Biomass potential in India

Fig. 1 shows the biomass resources for biofuel application. It is noteworthy that cellulose-based materials including grains, potatoes, cassava, and maize are classified as first-generation biomass. First-generation feedstocks face conflicts over food vs fuel, competition for arable land, irrigation water, and nutrient utilisation. Due to their predominant composition of inedible residues from agriculture, forestry, cattle farming, marine habitats, municipal solid trash, and waste management facilities, the second- and third-generation feedstocks do not compete with the food supply, cultivable areas, and accessible water (Sarkar*et al.*, 2023).Lignocellulosic biomass, which is made up of cellulose, hemicellulose, lignin, and extractives, is the term most often used to describe agricultural and woody biomasses (Kaloudas*et al.*,2021). With the use of thermochemical, hydrothermal, chemical, mechanical, and biological conversion methods, the feedstocks from the second and third generations can be transformed into a variety of biofuels, biochemicals, and bioproducts (Arvind*et al.*, 2020).

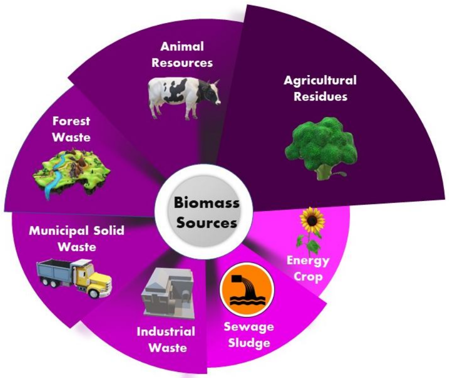

Fig. 1 Availability of biomass resources for biofuel production

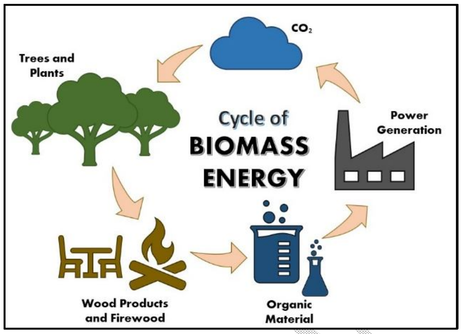

Fig. 2 Carbon-neutral and carbon-negative methods for harvesting biomass and using it to make biofuels

As can be seen in Fig. 2 Carbon-neutral and carbon-negative methods for harvesting biomass and using it to make biofuels. Several of the Goals for Sustainable Development of the UN, especially Goal 7 (Affordable and Clean Energy), Goal 12 (Responsible Consumption and Production), and Goal 13 (Climate Action), can be supported by the valorisation of unused biomass to generate bioenergy in order to promote clean energy and greenhouse gas emissions (Sarkar*et al.*, 2023). Due to their ease of grinding, pellets are a practical means of lowering CO2 emissions from coal-fired power stations. They are suited for co-firing with coal and direct burning in coal pulverisation systems (Smith *et al.*, 2019). Pellets, however, disintegrate into smaller particles and fines due to their composition when they are either manufactured improperly with inferior binder and filler or improperly stored to absorb moisture. The char or biomass fines produced by biomass pellets can seriously impact their health and safety. When these particulates are accumulated in dust on hot surfaces, it might result in explosions during bulk storage and transportation. The processes used throughout the pellet's manufacture operations determine its quality.

Comment [A5]: Incomplete sentence

Comment [A6]: Please correct the chemical symbol

3. Different types of pelletization technologies

Wood pellets are usually made from dry, untreated, industrial wood waste such as sawdust, shavings or ground wood chips. This material under high pressure and temperature is compressed into small pellets, cylindrical in shape. The manufacturing process is determined by the raw material but usually includes the following steps: reception of raw material, screening, grinding, drying, pelletizing, cooling, sifting and packaging (Peksa*et al.*, 2007).

- Feeding managing the feedstock is one of the greatest areas of concern for a pelletizing facility. Raw materials have to be sourced locally because their low bulk density makes them too costly to transport over long distances.
- Drying is a necessary part in the production of pellets. While some inputs, like planer shavings, do not need to be dried, most do. Drying consumes a large amount of energy. This raises concerns with the net energy value of wood pellets as a fuel source. Wood fiber can be pelletized at moisture contents as high as 17%. However, the optimal level is 12% or less if a final product with a moisture content of 6-8% is to be achieved.
- Grinding: The grinding process is also known as milling. Material should be ground to a size no bigger than the diameter of the pellet (~6 mm) producing a substance with a consistency similar to bread crumbs. Raw material should be filtered before grinding to remove materials like stone or metal (Peksa*et al.*, 2007).

- Conditioning: Many pelletizing machines come with a built-in steam conditioning chamber. Super-heated steam, at temperatures above 100°C (212 F), is used to soften the wood before it is compacted. Steam conditioning is not necessary but does make the raw material less abrasive to the pelletizing equipment. This helps reduce the maintenance costs (Peksa*et al.*, 2007).
- Pelletizing: Pelletizing machines, also known as extruders, are available in a range of sizes. Generally, every 100 horsepower provides a capacity of approximately one tonne of pellets per hour. Pelletizing machines come in two common forms (Peksa*et al.*, 2007):

1. Flat: where raw material is pressed through the top of a horizontally mounted die.
2. Rotary: where two (or more) rotary presses push raw material from inside a ring die to the outside where it can be cut into the desired length. Both systems create a pellet by using a great deal of pressure to force the raw material through holes in the die. As pressure and friction increase so does the temperature of the wood. This allows lignin to soften and the fiber to be reshaped into pellet form.

- Cooling the cooling process is critical to the pellets strength and durability. As pellets leave the extruder they are hot (90-95°C) and soft. They are gradually air cooled, which allows the lignin to solidify and strengthen the pellets. In contrast to the drying process, cooling does not involve the addition of the energy. There are three types of coolers: vertical, horizontal and continuous flow.

Comment [A7]: Please verify

- Screening once pellets have cooled, they are passed over a vibrating screen to remove any fine material. These “fines” are augured back into the pelletizing process to ensure that no raw material is wasted. Screening ensures the fuel source is clean and as near to dust free as possible. Once screened, pellets are ready to be packaged for the desired end use.

Comment [A8]: Please verify

- Distribution and storage Pellets can be distributed in bulk form, by truck, rail or ship or bagged in smaller quantities. Pellets can be purchased either bagged or in bulk and price can be calculated per total weight according to the moisture content.

Comment [A9]: Please verify

5. Effect of various parameters on quality of pellets

- **Moisture content**

The moisture content of biomass is a crucial factor in determining the quality of the fuel pellets, due to the direct impact it has on the mechanical strength and durability of the fuel pellets (Kaliyan and Morey, 2010). Pellets with a significant amount of moisture are more susceptible to microbiological activity, decay more quickly, and cost more to store and transport (Sheng and Yao, 2022). When pelletizing, moisture can serve as a natural binder by reducing friction through lubricating effects (Tumuluru*et al.*, 2011). Additionally, during pelletization, moisture content promotes the unfolding of proteins, the gelatinization of starches, and the solubilization of fibre (Samuelsson *et al.*, 2012). However, increasing moisture content after pellet produce allows for expansion, which reduces relaxed density and durability. A glass transition temperature of lignin dropped under high moisture content, enhancing the bonding between particles (Shelte*et al.*, 2011). In order to avoid deteriorating pellet quality, it is vital to determine the appropriate moisture content of feed ingredients before densification. It is suggested that wood pellets with moisture contents exceeding 20% become weaker as water molecule bonds take the place of hydrogen bridges between wood polymers (Borcsok and Pasztory, 2021).

- **Temperature**

During the process of densifying biomass, temperature has the greatest impact on the mechanical strength and density of the resulting pellets (Cao *et al.*, 2020). Natural binding agents, particularly lignin, extractives, or other supplementary binder, exhibit deformation at an adequate range of temperatures, improving interparticle bonding (Reza *et al.*, 2012). The amount of lignin in the biomass plays an important role for improving the binding process (Yoo*et al.*, 2020). Lignin contributes to the binding structure of particles by melting at a temperature higher than its glass transition temperature, and after cooling, it repolymerizes (Liu *et al.*, 2019). As a result, the extruder die's temperature must be greater than the glass transition point of lignin (Tang *et al.*, 2021).Pelletization temperature and density have a positive linear relationship on durability and mechanical strength. Ma *et al.*, (2021) studied that the impact of biomass pelletization temperature on the extruder die (60-160 °C). At higher temperatures, they observed that the abrasion index decreased although a minor decrease in density was observed at temperatures beyond 120 °C.

- **Pressure**

One of the most important factors to take into consideration is pelleting pressure. The pelletizing pressure is the maximum compressive force that the machine can exert on the biomass material. Additionally, pressure develops as a result of the resistance that forms when feedstock is compressed between the extruder die and roller and the press channels in the die (Nielsen *et al.*, 2020). The two basic methods by which pressure is created during compression are internal friction caused by the breaking of inter-particle linkages and exterior friction between the biomass particles and the extruder die surface (Tumuluru*et al.*, 2011). Herbaceous biomass is easier to compress than woody biomass, therefore it takes less energy to pelletize them (Cui *et al.*, 2021). The ideal pressure for a pellet of the highest quality was 150 MPa, with pressures ranging from 3 MPa to 150 MPa. As pressure increased, density and compression strength both increased significantly. Ma *et al.*, (2022) investigated the impact of pelleting pressure and found that as pressure increases, both Meyer hardness and density as well. However, the increase in density was minimal until the pressure was reached (100 MPa). Therefore, for an experimental pressure range of 10-150 MPa, the appropriate pressure for pelleting corn cob was 100 MPa.

- **Particle size**

Pellet properties are also influenced by biomass particle size and shape. The biomass particle size has an impact on the mechanical strength and density of the pellets because smaller particle size offers more surface area during pelletization. Small to medium-sized particles offer a greater surface area for moisture addition during steam conditioning, which improves starch gelatinization and strengthens the binding mechanism. A certain amount of fines to medium particle sizes improves pelleting effectiveness and cost. Particles that are too small, however, might block pellet mills and lower production rates. Labbe*et al.*, (2020) studied that the biomass with the largest particle size has highest durability. They also looked into the combustion emission and found that the lowest CO emission was produced by particles with a size between 3.2 and 6.3 mm. They observed no relationship between pellet density and biomass particle size. Yilzme*et al.*, (2021) studied that melon stem biomass from greenhouses was used to study the effects of particle size on pellet qualities. Particle sizes ranged from 4 to 6 mm, and it was shown that 4 mm particles produced the best pellet quality. Additionally, they revealed that particle size has no impact on durable of pellet.

6. Application

Fuel pellets have a wide range of uses, including industrial-scale power plants as well as domestic cooking and heating.

- **Residential heating and domestic purposes**

Boilers and stoves in homes frequently use fuel pellets. Wood pellets are the primary fuel source for home stoves in a lot of European nations. Recently, the potential of agricultural biomass pellets for use in household stoves has drawn the attention of numerous researchers. To do this, nevertheless, needs understanding of how pellet quality and operating circumstances affect gas, particulate matter, and ash emissions. According to reports, the quality of the fuel pellet has a significant impact on the released emissions that include gaseous and fine particles (Garcia-Maraver*et al.*, 2014). The amount of CO emissions from biomass pellets are significantly influenced by the particle density and the length-to-diameter ratio of the fuel pellets. Cardozo *et al.*, (2014) revealed that 6 mm diameter of fuel pellets made from sunflower husk, bagasse and Brazil nuts were compared to wood pellets of the same size. It was shown that using non-woody fuel pellets resulted in increased oxygen content in the flue gas, faster ash removal cycles and lower fuel power input. They also stated that compared to other biomass pellets, wood-based pellets had a higher relative conversion of elemental nitrogen to NO and elemental sulphur to SO_2.

- **Power generation**

Pellets made from wood are a major component of the world's industrial renewable energy production. This compares with the production of energy from coal and petrol, which simultaneously emits significant amounts of greenhouse gas emissions and other pollutants. Utilising biomass pellets in combustion or co-firing thermal energy production systems can be a long-term, sustainable solution to reducing industrial emissions. As a result, changing the fuel supply of industrial power plants to renewable sources rather than fossil fuels requires high-quality coal-like fuel pellets. However, due to high ash content, which causes agglomeration and clinker forms, the use of nonwoody biomass pellets in industrial applications is prohibited. Proskurina*et al.*, (2017) evaluated the potential of biomass that has been torrefied in a variety of industries, including the electricity and non-power sectors. They suggested that torrefied products could effectively take the place of fossil fuel on a large scale. In addition to combustion and co-firing, biomass pellets can be utilised in a variety of other industries, including paper and pulp, ceramic, glass, metallurgy, and cement production, resulting in lower emissions of greenhouse gases and particulates. Wang *et al.*, (2015) revealed that the use of biomass, such as char, wood pellets, and torrefied material, in place of pulverised coal in steel industry blast furnaces.According to their analysis, charcoal alone can lower emissions by 28%, compared to 6% for wood pellets.

7. Economic analysis

The market for wood pellets has been gradually expanding in both the commercial and domestic sectors, so there is a lot of opportunity for producing fuel pellets from various types of waste biomass. The logistical and operational costs of pelletization, storage, transportation, and conversion as well as the environmental advantages and risks associated with emissions of greenhouse gases, particulate matter, and by-products are all important considerations in the economic analysis, which is crucial to determining the economic feasibility of the densification and conversion processes. Pradhan*et al.*, (2018) the feasibility of producing 2 tonnes per day of fuel pellets from agricultural waste using a pelletizer. They came to the conclusion that pelletization is profitable when pellet prices are greater than $120 per tonne. The cost of raw materials, however, had the greatest impact on the cost analysis. Agar, (2017) assessed the costs associated with producing raw vstorrefied pellets. The annual production cost of conventional raw pellets was greater than that of torrefied pellets (€7.05 M vs. €6.11 M). Additionally, the specific cost of torrefied pellets was €95.54/ton greater than that of raw pellets. Chai and Saffron, (2016) revealed that the three alternative pellet manufacturing scenarios, such as raw pellets, lightly torrefied pellets, and severely torrefied pellets, were evaluated in terms of production costs. In comparison to other cases, they reported the cost of producing pellets that had been slightly torrefied. Climate and biomass field conditions are important factors that affect the cost and quality of pellet manufacturing. Due to the expense of pre-treatment, torrefied pellets have a greater production cost than raw pellets.

Conclusion

In conclusion, the pelletization process for the production of fuel pellets from various surplus biomass feedstocks offers a promising solution for renewable energy production. The utilization of surplus biomass through pelletization can contribute to reducing greenhouse gas emissions, decreasing dependence on fossil fuels, and addressing issues related to agricultural and forestry residues, energy crops, and municipal solid waste management. The review highlighted the importance of understanding the properties and suitability of different biomass feedstocks for pellet production, as well as the key steps involved in the pelletization process, including size reduction, drying, conditioning, pelletization, and cooling. However, challenges associated with feedstock variability, pellet quality consistency, and emissions during the process were identified. Overall, the pelletization process for the production of fuel pellets from surplus biomass has significant potential for renewable energy production, but further research and development are needed to address the challenges and optimize the process. This review serves as a comprehensive resource for researchers, engineers, and policymakers interested in biomass pelletization as a sustainable energy production option, and it calls for continued efforts towards developing efficient and environmentally friendly pelletization processes for surplus biomass utilization.

References

Agar DA. A comparative economic analysis of torrefied pellet production based on state-of-the-art pellets. Biomass and bioenergy. 2017; 97:155-161.

Aravind S, Kumar PS, Kumar NS and Siddarth N. Conversion of green algal biomass into bioenergy by pyrolysis. A review. Environmental Chemistry Letters. 2020;18:829-849.

Borcsok Z and Pasztory Z. The role of lignin in wood working processes using elevated temperatures: an abbreviated literature survey. European Journal of Wood and Wood Products. 2021;79:511-526.

Cao Z, Zhang S, Huang X, Liu H, Sun M and Lyu J. Correlations between the compressive strength of the hydrochar pellets and the chemical components: Evolution and densification mechanism. Journal of Analytical and Applied Pyrolysis. 2020;152: 104956.

Cardozo E, Erlich C, Alejo L and Fransson TH. Combustion of agricultural residues: An experimental study for small-scale applications. Fuel2014;115:778-787.

Chai L and Saffron CM. Comparing pelletization and torrefaction depots: Optimization of depot capacity and biomass moisture to determine the minimum production cost. Applied Energy. 2016; 163:387-395.

Chen C, Yang R, Wang X, Qu B, Zhang M, Ji G and Li A. Effect of in-situ torrefaction and densification on the properties of pellets from rice husk and rice straw. Chemosphere. 2022; 289:133009.

Cui X, Yang J, Wang Z and Shi X, Better use of bioenergy: A critical review of co-pelletizing for biofuel manufacturing. Carbon Capture Science & Technology. 2021; 1:100005.

Demirbas MF.Biorefineries for biofuel upgrading: a critical review. Appl Energy.2009; 86: S151–S161. https:// doi. org/ 10. 1016/j.apenergy. 2009. 04. 043

Garcia-Maraver A, Zamorano M, Fernandes U, Rabacal M and Costa M. Relationship between fuel quality and gaseous and particulate matter emissions in a domestic pellet-fired boiler. Fuel. 2014; 119:141-152.

International Energy Agency. 2021. Global Energy Review 2021. International Energy Agency.https://www.iea.org/reports/global-energy-review-2021

Kaliyan N and Morey RV. Natural binders and solid bridge type binding mechanisms in briquettes and pellets made from corn stover and switchgrass. Bioresource technology. 2010; 101(3):1082-1090.

Kaloudas D, Pavlova N and Penchovsky R. Lignocellulose, algal biomass, biofuels and biohydrogen: a review. Environmental Chemistry Letters. 2021; 19:2809-2824.

Kang K, Qiu L, Sun G, Zhu M, Yang X, Yao Y, Sun R. Co-densification technology as a critical strategy for energy recovery from biomass and other resources-a review. Renew Sustain Energy Rev. 2019; 116:109414. https:// doi. org/ 10. 1016/j. rser. 2019. 109414

Kumar A, Kumar K, Kaushik N, Sharma S and Mishra S. Renewable energy in India: current status and future potentials. Renewable and sustainable energy reviews. 2010; 14(8): 2434-2442.

Labbe R, Paczkowski S, Knappe V, Russ M, Wohler M and Pelz S. Effect of feedstock particle size distribution and feedstock moisture content on pellet production efficiency, pellet quality, transport and combustion emissions. Fuel. 2020; 263:116662.

Liu R, Long L, Sheng Y, Xu J, Qiu H, Li X, Wang Y and Wu H. Preparation of a kind of novel sustainable mycelium/cotton stalk composites and effects of pressing temperature on the properties. Industrial Crops and Products. 2019; 141:111732.

Ma J, Feng S, Shen X, Zhang Z, Wang Z, Kong W, Yuan P, Shen B and Mu L. Integration of the pelletization and combustion of biodried products derived from municipal organic wastes: The influences of compression temperature and pressure. Energy. 2021; 219: 119614.

Ma J, Feng S, Zhang Z, Wang Z, Kong W, Yuan P, Shen B and Mu L. Effect of torrefactionpretreatment on the combustion characteristics of the biodried products derived from municipal organic wastes. Energy. 2022; 239: 122358.

Nielsen SK, Mando M and Rosenorn AB. Review of die design and process parameters in the biomass pelleting process. Powder Technology. 2020; 364:971-985.

Osman AI, Mehta N, Elgarahy AM, Al-Hinai A, Al-Muhtaseb AH, Rooney DW. Conversion of biomass to biofuels and life cycle assessment: a review. Environ ChemLett. 2021; 19: 4075-4118. https:// doi. org/ 10. 1007/ s10311- 021- 01273-0

Peksa M, Dolzan P, Grassi A, Heinimo J, Junginger HM, Ranta TM and Walter A. Global wood pellets markets and industry: policy drivers, market status and raw material potential.2007; 1-120

Pradhan P, Mahajani SM and Arora A. Production and utilization of fuel pellets from biomass: A review. Fuel Processing Technology. 2018; 181:215-232.

Proskurina S, Heinimo J, Schipfer F and Vakkilainen E. Biomass for industrial applications: The role of torrefaction. Renewable Energy. 2017; 111:265-274.

Reza MT, Lynam JG, Vasquez VR and Coronella CJ. Pelletization of biochar from hydrothermally carbonized wood. Environmental Progress & Sustainable Energy. 2012; 31(2):225-234.

Samuelsson R, Larsson SH, Thyrel M and Lestander TA. Moisture content and storage time influence the binding mechanisms in biofuel wood pellets. Applied energy. 2012; 99:109-115.

Sarker TR, Nanda S, Meda V and Dalai AK. Densification of waste biomass for manufacturing solid biofuel pellets: a review. Environmental Chemistry Letters. 2023; 21(1):231-264.

Sheng C and Yao C. Review on self-heating of biomass materials: understanding and description. Energy & Fuels. 2022; 36(2):731-761.

Smith JS, Safferman SI and Saffron CM. Development and application of a decision support tool for biomass co-firing in existing coal-fired power plants. Journal of Cleaner Production. 2019; 236:117375.

Song B, Cooke-Willis M, Van Leeuwen R, Fahmy M and Hall P. Insights into the swelling behaviours of biomass and biomass/thermoplastic briquettes under water penetration and moisture adsorption. Biomass and Bioenergy. 2023; 168: 106673.

Stelte W, Holm JK, Sanadi AR, Barsberg S, Ahrenfeldt J and Henriksen UB. Fuel pellets from biomass: The importance of the pelletizing pressure and its dependency on the processing conditions. Fuel. 2011; 90(11):3285-3290.

Tang Y, Jean M, Pourebrahimi S, Rodrigue D and Ye Z. Influence of lignin structure change during extrusion on properties and recycling of lignin-polyethylene thermoplastic composites. The Canadian Journal of Chemical Engineering. 2021; 99:S27-S38.

Tumuluru JS, Wright CT, Hess JR and Kenney KL. A review of biomass densification systems to develop uniform feedstock commodities for bioenergy application. Biofuels, Bioproducts and Biorefining. 2011; 5(6):683-707.

Wang C, Mellin P, Lovgren J, Nilsson L, Yang W, Salman H, Hultgren A and Larsson M.Biomass as blast furnace injectant–Considering availability, pretreatment and deployment in the Swedish steel industry. Energy Conversion and Management. 2015; 102:217-226.

Yilmaz H, Canakci M, Topakci M and Karayel D. The effect of raw material moisture and particle size on agri-pellet production parameters and physical properties: A case study for greenhouse melon residues. Biomass and Bioenergy. 2021; 150:106125.

Yoo CG, Meng X, Pu Y and Ragauskas AJ. The critical role of lignin in lignocellulosic biomass conversion and recent pretreatment strategies: A comprehensive review. Bioresource technology. 2020; 301: 122784.