A Review on Solid Biomass Fuel as a Sustainable Energy Source

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Abstract: This study delves into the potential of solid biomass as a sustainable energy source for power generation and various applications. It offers a comprehensive overview of diverse solid biomass sources, encompassing agricultural residues, forestry residues, and municipal solid waste. The study addresses the challenges and obstacles associated with current techniques and methodologies for promoting extensive solid biomass utilization, including issues related to availability, logistics, and economics. By offering a comparative analysis of different technologies and methods, along with their respective advantages and drawbacks, it provides valuable insights into their suitability for specific applications. The research underscores the importance of adopting a holistic approach that considers the entire biomass supply chain, from collection to conversion and utilization, to ensure the sustainable and efficient use of solid biomass as a renewable energy source. In conclusion, this review offers valuable insights into the potential of solid biomass for power generation and other applications, highlighting the need to consider various factors when selecting the most appropriate technologies and methods for biomass energy production.

Keywords: *solid biomass fuel, biomass gasification, briquettes, torrefaction, biochar, pyrolysis, sustainability, renewable energy*

1. Introduction

India significantly relies on solid biomass as an energy source, with 10,700 MW of biomass power capacity installed by March 2021, contributing 2% to the nation's electricity generation. Biomass finds applications in power generation, heating, and cooking, primarily in states like Karnataka, Andhra Pradesh, and Tamil Nadu. In northern states such as Rajasthan, Punjab, and Haryana, solid biomass offers an eco-friendly alternative to fossil fuels, reducing greenhouse gas emissions and enhancing energy security. Despite challenges like limited incentives and feedstock issues, India aims for 10 GW of biomass power capacity by 2022, with the government promoting biomass use through initiatives like the Biomass Power and Bagasse Cogeneration Program and the National Biomass Cookstoves Initiative. Sustainable biomass production and management practices are being encouraged to ensure a steady supply of biomass feedstock [1][2]. Solid biomass is a recognized, sustainable energy source, especially vital in low-income areas due to its affordability and accessibility. Its use has gained attention for its potential to combat deforestation, lower greenhouse gas emissions, and provide reliable off-grid energy.

Various articles have explored aspects of solid biomass, emphasizing its availability, cost-effectiveness, and eco-friendliness. They stress the significance of biomass briquettes as carbon-neutral, environmentally gentle energy sources. Encouraging off-grid communities to shift from round wood to loose biomass is vital, albeit challenging due to the need for enhanced energy density, handling, and storage. Production methods, such as using cow dung and cactus plants as binders, have been discussed. Additionally, studies evaluated factors like energy content, moisture content, particle size, and compaction pressure's impact on briquette quality [3].

In low-income communities and developing countries, solid biomass's importance is evident. It offers a readily available, low-cost, and sustainable energy source for cooking, heating, and lighting, particularly in areas with limited access to electricity. This shift from traditional biomass fuels like firewood and charcoal, which are expensive and environmentally harmful, can raise living standards. Solid biomass is carbon-neutral, reducing greenhouse gas emissions and supporting global climate efforts. It also has the potential to boost economic development by creating employment, generating income, reducing poverty, enhancing food security, and improving access to education and healthcare services.[4]

Solid biomass, including wood, agricultural residues, and animal waste, is readily available and cost-effective for households and small businesses. It provides a dependable energy source for cooking, heating, and lighting, elevating quality of life and supporting economic growth. Moreover, its use reduces reliance on expensive and remote fossil fuels, with minimal environmental impact. When biomass briquettes are produced from loose biomass residues, they mitigate deforestation by reducing the demand for round wood, further supporting sustainable forest management. In conclusion, solid biomass's potential as an affordable, eco-friendly, and sustainable energy source is clear. Nevertheless, more research is necessary to optimize biomass briquette production and enhance quality and efficiency [5].

Solid biomass, as an energy source, offers significant advantages for low-income communities and developing countries. It enhances energy access, fosters economic development, and supports sustainable forest management. To unlock its full potential, further research and initiatives are essential to promote its utilization and enhance storage and handling [6].

Biomass briquette production can create jobs and generate income in rural areas, while also contributing to greenhouse gas emission reduction and sustainable development. Encouraging off-grid communities to shift from traditional biomass fuels to freely available loose biomass for briquette production is crucial [7].

In summary, solid biomass plays a vital role in low-income communities and developing countries by providing a sustainable, cost-effective, and readily available energy source. It improves living standards, reduces greenhouse gas emissions, and fosters economic development in areas with limited or no access to modern energy services.

Traditional biomass use for cooking and heating is known to be inefficient and detrimental to public health, causing approximately 3.6 million premature deaths annually due to household air pollution. Despite being centuries-old, biomass remains a significant energy source, with approximately 25 EJ of modern solid bioenergy used for power generation and end-use sectors in 2021, highlighting its relevance.

Efforts to improve efficient and sustainable biomass use are ongoing. While the STEPS scenario predicts a 20% reduction in traditional biomass use by 2030, it may not fully address inefficiencies. The APS scenario presents a more optimistic outlook, aiming to reduce traditional biomass use by 60% to 75% by 2050 while achieving clean cooking targets, addressing energy crises, rural development, household air pollution, and climate change comprehensively. Furthermore, the NZE scenario goes a step further, aiming to phase out global traditional biomass use by 2030, relying on modern solid bioenergy and BECCS for emissions reduction. Achieving this ambitious scenario necessitates significant investment and collaboration between governments and private organizations, requiring a substantial effort from all stakeholders [8].

2. Different Sources of Biomass

Various renewable and sustainable fuel sources offer distinct advantages. Wood, agricultural residues, cattle dung, municipal solid waste (MSW), energy crops, livestock waste, and aquatic plants all feature high energy content, affordability, and low emissions. Repurposing waste materials can also create additional income for farmers, enhancing their appeal as fuel sources. Wood is abundant and boasts a high energy content and low ash content. It's versatile, easily processed into chips, pellets, or logs, and is a carbon-neutral, low-emission, and sustainable resource. Agricultural residues like straw, husk, and stalks are also energy-rich and cost-effective. They can be repurposed waste materials, offering farmers an additional income source. Cattle dung and MSW, widely available and high in energy content, serve as reliable and predictable low-cost fuel sources. Their use reduces landfill waste and emissions. Energy crops, such as switchgrass and miscanthus, yield well on marginal land, delivering extra income to farmers. They are renewable, sustainable, carbon-neutral, and produce minimal emissions. Livestock waste, like manure, is abundant, renewable, and cost-effective. Repurposing it as fuel reduces greenhouse gas emissions and is characterized by low emissions. Aquatic plants, including algae and water hyacinth, grow rapidly with high yields. They can be cultivated in wastewater or non-potable water sources, aiding in water purification. These plants are renewable, sustainable, carbon-neutral, and produce low emissions [9].

Table 1. Different sources of biomass energy and their properties

Biomass Source	Properties
Wood	High energy content, low ash content, widely available
Agricultural residues (e.g. straw, husk, stalks)	High energy content, abundant, low cost
Cattle Dung & Municipal solid waste (MSW)	High energy content, widely available, low cost
Energy crops (e.g. switchgrass, miscanthus)	High yield potential, low cost, can be grown on marginal land
Livestock waste (e.g. manure)	Abundant, renewable, low cost
Aquatic plants (e.g. algae, water hyacinth)	Fast-growing, high yield potential, can be grown in wastewater or other non-potable water sources

Each of the mentioned renewable fuel sources offers distinct advantages suitable for various applications. By embracing these renewable fuel sources, we can reduce dependence on fossil fuels, fostering a more sustainable energy future. Their carbon-neutral nature and low emissions make them attractive alternatives, further enhanced by the economic benefits of repurposing waste materials. Collaboratively developing and implementing sustainable energy solutions paves the way for a cleaner and sustainable future for generations to come.

3. Performance Parameters for Solid Biomass as Fuel

Biomass, as a renewable energy source, has gained prominence for its cleaner attributes in comparison to traditional fossil fuels. Nonetheless, its effectiveness hinges on various crucial parameters explored in this review. Moisture content is a significant factor impacting energy content and combustion efficiency. High moisture levels diminish energy content, lead to incomplete combustion, and raise emissions. Thus, meticulous moisture management is essential for optimal biomass performance. Ash content, influenced by biomass type and quality, affects equipment corrosion and efficiency. Optimal performance relies on low-ash biomass selection. Volatile matter, the combustible part of biomass, impacts energy content, combustion efficiency, and emissions. Managing volatile matter content is key to performance optimization. Carbon content, the primary biomass component, determines energy content and emissions. High carbon content enhances energy content and lowers emissions. Heating value signifies the heat released when biomass burns and determines its energy content. Effective heating value management is crucial. Particle size influences combustion efficiency and emissions. Balancing particle size is vital for performance optimization. Density affects biomass storage, transport, and handling convenience. Careful density management is essential. Chemical composition dictates combustion behavior and suitability for specific applications. Selecting biomass with the right chemical composition is crucial for optimal performance. Lastly, sustainability relies on source and production methods that minimize environmental and social impacts. Sustainable biomass selection minimizes negative environmental effects and ensures optimal performance. Overall, the efficacy of biomass as an energy source is contingent on these parameters. Thoughtful management can optimize performance and reduce environmental impacts, making biomass a valuable contender in our pursuit of cleaner energy sources amid growing climate change concerns [10].

4. Available Technologies for Biomass Energy Conversion

Biomass can be transformed into various energy forms through different technologies. Key methods include combustion, gasification, pyrolysis, anaerobic digestion, co-firing, briquetting, pelletization, biochar production, hydrothermal carbonization, and torrefaction.

- **4.1 Combustion**: This widely-used method involves burning solid biomass for heat or electricity. It's a common approach in power plants, and the biomass generates steam to drive turbines.
- **4.2 Gasification**: Solid biomass undergoes partial oxidation to produce syngas, a mix of carbon monoxide, hydrogen, and other gases. Syngas can be used in turbines or converted into liquid biofuels.
- **4.3 Pyrolysis**: This process heats biomass in the absence of oxygen, yielding bio-oil, solid char, and burnable gas. Bio-oil can become transportation fuels, and char can improve soil quality.
- **4.4 Anaerobic Digestion**: It breaks down organic matter, like food waste, into biogas (methane and carbon dioxide) for energy or conversion into compressed natural gas.
- **4.5 Co-firing**: Combines biomass with coal to cut emissions and enhance renewable energy, primarily in power plants.
- **4.6 Torrefaction**: Biomass is heated in the absence of oxygen, resulting in a more energy-dense material suitable for energy production or other applications.
- **4.7 Direct Combustion Stoves**: These stoves are prevalent in developing countries for cooking and heating. However, they have drawbacks like fuel inefficiency and indoor air pollution.
- **4.8 Briquetting**: Solid biomass is compressed into dense blocks or briquettes for efficient transportation and storage, offering higher energy density.
- **4.9 Pelletization**: Biomass is compacted into uniform pellets for convenient handling and transportation, commonly used for heating or electricity generation.
- **4.10 Biochar Production**: Pyrolysis creates biochar, enhancing soil fertility, sequestering carbon, and generating bio-oil and gas for energy.
- **4.11 Co-firing**: Combining biomass with coal to reduce emissions in power plants, but constrained by supply chain sustainability.
- **4.12 Hydrothermal Carbonization (HTC)**: Converts wet biomass into hydrochar through a high-temperature, high-pressure process. Hydrochar can serve as bio-coal for energy or bio-oil for biofuel production, offering a means to process wet biomasses, sequester carbon, and

reduce emissions, but it requires significant energy input.

Overall, these technologies offer diverse ways to harness biomass for sustainable energy production and environmental benefit. Several issues and challenges are associated with the different technologies used for solid biomass energy production. Table 2 shows challenges associated with technologies available to convert biomass into different forms of energy [11].

Table 2. Challenges associated with technologies available to convert biomass into different forms of energy

Technology	Issues/Challenges/Barriers
Combustion	Emissions of air pollutants and greenhouse gases, ash disposal, low efficiency, high capital cost
Gasification	High capital cost, technical complexity, gas cleaning, feedstock variability, slagging, and fouling
Pyrolysis	High capital and operational cost, technical complexity, feedstock variability, bio-oil stability, and upgrading
Anaerobic digestion	Feedstock preparation, process instability, reactor design, and maintenance, low conversion efficiency, and gas cleaning
Co-firing	Low energy density, combustion instability, ash handling, fuel blending, and limited feedstock availability
Torrefaction	High capital cost, energy-intensive, feedstock variability, limited scalability, and material handling
Direct combustion stove	Indoor air pollution, health hazards, inefficient combustion, and fuel supply
Briquetting	High capital cost, feedstock availability, limited markets, and briquette quality
Pelletization	High capital cost, feedstock availability, limited markets, and pellet quality
Biochar production	High capital and operational cost, feedstock availability, biochar quality, and markets for the product
Hydrothermal Carbonization	High Energy input, High capital and operational cost, feedstock availability

Implementing biomass as a sustainable energy source faces multiple barriers hindering its growth. Lack of awareness about solid biomass energy's potential, high initial costs, limited and competitive feedstock supply, inefficient conversion technologies, variable biomass quality affecting energy output, environmental concerns, inadequate regulations, infrastructural limitations, socio-economic issues, competition with other uses, and technological barriers all impede biomass's adoption as a sustainable fuel.

4. Conclusion and Future Directions

In conclusion, solid biomass has emerged as a viable and sustainable option for renewable energy, particularly in low-income communities. The use of biomass briquettes can play a significant role in mitigating deforestation and reducing reliance on round wood as an energy source. However, there are significant challenges associated with bioenergy, including land use conflicts, competition with food production, and sustainability concerns. Careful planning and management of bioenergy systems is needed, including selection of appropriate feedstocks, sustainable production systems, and effective policies and governance frameworks. It is imperative to have research and development efforts to improve the efficiency and sustainability of bioenergy technologies and to develop new feedstocks and production systems.

Further studies are needed to explore the potential of solid biomass as a sustainable energy source in specific regions such as Rajasthan, Madhya Pradesh, Punjab, Haryana, Gujarat, and Uttar Pradesh. Additionally, research gaps such as the economic feasibility of biomass briquettes, the impact of bioenergy on biodiversity and ecosystem services, and the integration of bioenergy into energy systems need to be addressed. Therefore, there is a need for increased research and investment in the bioenergy sector to ensure its sustainable development and deployment. It is important to acknowledge that the use of solid biomass as an energy source can only be truly sustainable if implemented with a comprehensive and integrated approach that considers environmental, social, and economic factors.

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