Arizona State University

Review Article

Biomass Power Generation: Costs, Technologies, and Market Trends

MAE 582 Renewable Energy-Mech Systems

By

Pradnesh Mhatre - 1226479399

Submitted to

Prof. Ronald Calhoun

Associate Professor
School of Engineering of Matter, Transport, and Energy
Arizona State University

Abstract

This review synthesizes key insights from the IRENA report on biomass for power generation. Biomass energy, as a versatile and renewable resource, offers substantial potential in supporting global energy transitions. The article explores biomass conversion technologies, feedstock dynamics, cost structures, levelized cost of electricity (LCOE), and global deployment trends. It concludes by evaluating economic viability, technical maturity, and the policy implications of biomass power systems.

Introduction

Biomass energy represents a critical component of the global renewable energy mix, especially in rural and decentralized settings. This review aims to provide a cohesive understanding of biomass power generation's technological frameworks, economic feasibility, and global development patterns based on IRENA's in-depth analysis.

Biomass Conversion Technologies

Biomass can be converted into electricity through:

- **Direct Combustion**: Mature and widespread, with over 90% of biomass energy derived from combustion systems such as stokers and fluidized bed boilers.
- **Anaerobic Digestion**: Suitable for high-moisture feedstocks, producing biogas usable in engines and turbines.
- **Gasification**: Offers higher efficiency, converting biomass into syngas usable in advanced power cycles.
- **Co-firing**: Involves burning biomass alongside coal, reducing fossil fuel dependency with relatively low capital investment.

Emerging technologies like pyrolysis and biomass integrated gasification combined cycle (BIGCC) offer potential efficiency gains but face economic and scalability challenges.

Biomass Feedstocks

Feedstocks range from forest and agricultural residues to municipal solid waste and energy crops. Key attributes affecting their utility include:

- **Moisture content**: High levels reduce energy density and increase transport costs.
- **Ash and slagging potential**: Can affect combustion performance and maintenance needs.
- **Energy content**: Varies significantly across feedstock types, impacting overall efficiency.

Cost Analysis

Capital Costs

Capital costs for biomass power generation vary widely depending on the technology, plant scale, and regional factors. For example, stoker boilers range from USD 1,880 to 4,260 per kW, while more advanced systems like gasifiers can cost between USD 2,140 and 5,700 per kW. Anaerobic digesters are relatively expensive, with capital costs between USD 2,570 and 6,100 per kW, and combined heat and power (CHP) configurations can be significantly higher. Co-firing biomass in existing coal plants is the most cost-effective option, requiring as little as USD 140 to 850 per kW. These capital investments are influenced by feedstock type, site-specific infrastructure needs, and technology maturity.

Capital investments vary based on technology and scale:

Technology	**Capital Cost (USD/kW)**
Stoker Boiler	1,880–4,260
CFB Boiler	2,170–4,500
Anaerobic Digesters	2,570–6,100
Gasifiers	2,140–5,700
Co-firing	140–850

Operating and Maintenance Costs

Operating and Maintenance (O&M) costs are a significant component of the total expenses in biomass power generation, typically accounting for 9% to 20% of the Levelized Cost of Electricity (LCOE). These costs vary depending on the technology used, with higher expenses observed in systems requiring extensive fuel preparation or handling. Fixed O&M costs generally range from 2% to 7% of the installed capital cost annually, while variable O&M costs average around USD 0.005 per kWh. Landfill gas systems, due to their specific operational needs, can have even higher fixed O&M costs—up to 20% of capital investment per year. Efficient O&M management is essential for ensuring the economic viability and reliability of biomass power plants.

Levelized Cost of Electricity (LCOE)

The levelized Cost of Electricity (LCOE) for biomass power generation reflects the average cost of producing electricity over a plant's lifetime, accounting for capital, operational, and fuel expenses. Biomass LCOE ranges from USD 0.06 to 0.29 per kWh, depending on factors like feedstock cost, technology type, and plant efficiency. Co-firing and digestion systems tend to have lower LCOEs, while advanced technologies like gasification or CHP systems have higher costs due to greater capital and operational complexity. When low-cost or on-site feedstocks are available, biomass can be a highly competitive alternative, especially in off-grid or diesel-reliant regions.

LCOE varies significantly:

Technology	LCOE (USD/kWh)
Stoker Boiler	0.06–0.21
Gasifier CHP	0.11–0.28
Anaerobic Digesters	0.06–0.15
Co-firing	0.04–0.13

Biomass is competitive with diesel in off-grid areas and, when using low-cost feedstock, can rival conventional grid electricity prices.

Global Market Trends

As of 2010:

- Installed capacity was concentrated in Europe and North America.
- Biomass projects in Asia and Latin America are gaining momentum, often leveraging agricultural residues.
- By 2030, the global capacity is expected to rise sharply with increased investment in sustainable feedstock supply chains and distributed generation systems.

Challenges and Opportunities

Challenges:

- Feedstock supply logistics and sustainability.
- High capital and feedstock transport costs.
- Regulatory and policy inconsistency.

Opportunities:

- Rural electrification and energy security.
- Waste-to-energy integration.
- Industrial symbiosis in pulp/paper and sugar sectors.

Conclusion

In conclusion, biomass power generation presents a versatile and sustainable energy solution with the potential to complement both grid-connected and off-grid systems. While capital and operational costs vary across technologies, the use of locally available, low-cost feedstocks can make biomass highly cost-effective. Mature technologies like direct combustion and anaerobic digestion offer immediate deployment opportunities, whereas emerging options like gasification and pyrolysis hold long-term promise. With supportive policies, reliable feedstock supply, and continued innovation, biomass can play a critical role in diversifying energy sources and advancing global renewable energy goals.

References

International Renewable Energy Agency. (2012). *Renewable energy cost analysis: Biomass for power generation*. IRENA. https://www.irena.org/publications