

The Transition to Green Energy: The Role of Biomass Energy in the Global Energy Structure

Xintong Lu *

College of Resources and Environment, Anhui Agricultural University, Hefei, Anhui, 230000, China

* Corresponding Author Email: 23114503@stu.ahau.edu.cn

Abstract. This article discusses the importance and role of biomass energy in the global energy transition. As a renewable, clean, and low-carbon energy source, biomass energy originates from the solar energy fixed by plants, animals, and microorganisms through photosynthesis and has a variety of utilization methods, including direct combustion, biofuels, biogas, etc. Its proportion in the global energy structure (GES) varies by region but accounts for 96% of global renewable heat production. Biomass energy technologies include power generation, solid fuels, liquid fuels, and gaseous fuels technologies, which can aid in lowering greenhouse gas emissions and reliance on fossil fuels. Although biomass energy has a place in the global GES, its development faces high costs, insufficient technical capabilities, and inadequate policy support. In the future, the biomass energy industry needs to build a low-carbon, circular, and sustainable development model, shift from solid utilization to gaseous utilization, and play a greater role in areas where electrification is difficult to decarbonize.

Keywords: Green Energy; Biomass Energy; Global Energy Structure.

1. Introduction

In the 21st century's energy transition, the rise of green energy has become a global consensus. As fossil fuels gradually deplete and environmental pollution worsens, the search for sustainable alternative energy sources becomes particularly urgent. Biomass energy, as a member of the green energy family, is becoming more and more significant in the GES.

Biomass energy, derived from the organic matter of plants, animals, and microorganisms that fix solar energy through photosynthesis, as well as the residues left after their death, serves not only as a source of energy but also as a bridge connecting agriculture, industry, and the environment. The utilization of biomass energy is diverse, including direct combustion, biofuels, and biogas, providing a variety of options for energy supply. Moreover, the development and utilization of biomass energy help reduce greenhouse gas emissions, promote the recycling of agricultural waste, and enhance energy security and economic sustainability. For instance, biomass power generation not only offers an effective way to handle agricultural and forestry waste, reducing environmental pollution, but also the ash and slag left after combustion can be used as organic fertilizers, achieving the recycling of resources. Additionally, one benefit of using biomass energy is that it can simultaneously solve the problems of heat and electricity, something that other renewable energy sources like solar and wind power cannot match. Globally, the utilization of biomass energy has already formed a diversified industry.

This article aims to explore the role of biomass energy in the GES, analyze its current application status in different countries and regions, assess its potential impacts on the environment, economy, and society, and propose strategies and recommendations to promote the development of biomass energy. Through in-depth research, we hope to provide new perspectives and ideas for the green transition of global energy.

2. Definition and Sources of Biomass Energy

2.1. Scientific Definition of Biomass Energy

Biomass energy refers to the energy produced through natural processes such as photosynthesis, respiration, and the decomposition of organic matter in plants, animals, and microorganisms (figure 1). It includes resources like wood, crops, animal manure, industrial organic waste, and municipal solid waste. Biomass energy can be converted into solid, liquid, or gaseous fuels for power generation, heating, or transportation. Since biomass energy originates from living organisms in nature, it is a renewable resource with lower greenhouse gas emissions, making it one of the important ways to address climate change and the energy crisis.

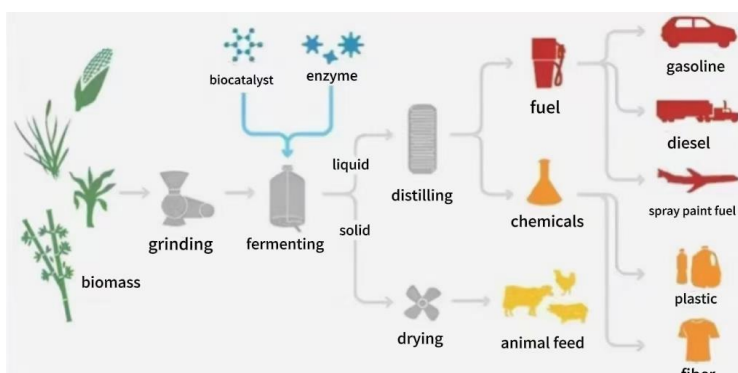


Fig 1. Schematic diagram of biomass energy utilization paths (original).

2.2. Sources of Biomass Energy

Forest resources include scattered wood from fuelwood forests, leftover branches, leaves, wood shavings, forest care, and thinning operations; branches, sawdust, wood shavings, tops, bark, and heads from the logging and processing of timber; and waste from forestry by-products, such as shells and pits (figure 2).

Agricultural resources include crops (including energy crops), and waste from agricultural production processes, such as crop residues (corn stalks, sorghum stalks, wheat straw, rice straw, bean straw, and cotton stalks, etc.) left in the fields after harvest; and waste from agricultural processing industries, such as residual rice husks from agricultural production processes.[1]

Domestic sewage is mainly composed of various discharges from urban residents' lives, commerce, and service industries, such as cooling water, bathwater, wash water, laundry water, kitchen wastewater, and fecal sewage. Municipal solid waste is primarily made up of solid waste from urban residents' lives, commercial and service industries, and a small amount of construction waste.

Livestock and poultry manure refers to the total excreta of livestock and poultry, which is a derivative of other biomass types, such as feces, urine, and the mixing of grain, crop straw, and fodder with bedding straw expelled by livestock and poultry.

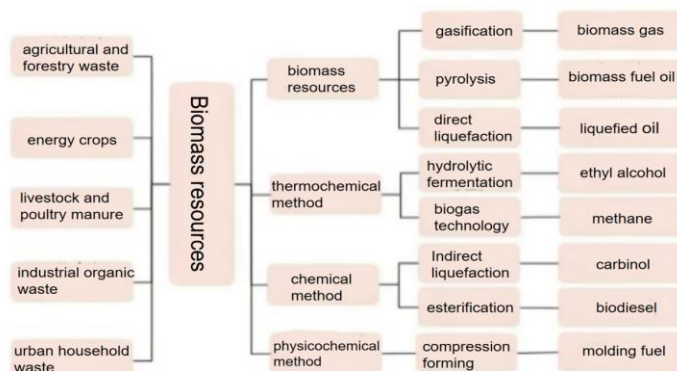


Fig 2. Classification and production methods of biomass energy resources (original)

3. Biomass Energy in the GES

3.1. Current Status of Global Energy Consumption

In 2023, global economic growth returned to the average trend from 2010 to 2019, but the growth rate of energy consumption exceeded this historical trend, indicating a failure of the decoupling of energy consumption from economic growth [2]. Multiple major energy regions around the world are facing energy shortages, and the rise in energy prices has increased production costs for downstream industries, adversely affecting electricity supply and winter heating. At the same time, renewable energy is developing rapidly, with more than 130 countries and regions proposing targets for net-zero emissions of carbon neutrality. In 2024, global investment in clean energy exceeded the \$3 trillion mark for the first time, with \$2 trillion allocated for clean energy technologies and infrastructure construction [3]. Expenditure on renewable energy, the grid, and energy storage has surpassed the total expenditure on oil, natural gas, and coal [3].

3.2. The proportion of biomass energy in the global energy mix

The proportion of bioenergy in the energy mix varies by region, with national and regional energy policies, resource endowments, and levels of technological development all influencing the utilization and share of bioenergy. In China, the status of bioenergy power generation is gradually rising. According to 2020 data, the cumulative installed capacity and power generation of bioenergy have increased to 2.96% and 5.68% of renewable energy, respectively [4]. Moreover, in 2023, China's non-fossil fuel power generation exceeded 3.3 trillion kilowatt-hours, with bioenergy power generation reaching approximately 198 billion kilowatt-hours, accounting for about 6.6% of the country's renewable energy power generation [4]. In the United States, bioenergy accounted for about 5% of the country's energy consumption in 2023, equivalent to approximately 4978TBtu (TBtu stands for one trillion British thermal units). In Europe, bioenergy has already made up 10% of the total energy consumption and 2/3 of renewable energy.

According to the World Bioenergy Association's (WBA) "Global Bioenergy Statistics Report 2023," by 2020, bioenergy accounted for 96% of global renewable heat production. Despite bioenergy's presence in the global energy structure, its development across different countries and regions is uneven. In some countries, bioenergy has achieved industrialized development, whereas in developing countries like China, the bioenergy industry is still in development and requires policy support to achieve long-term growth. Additionally, the potential for bioenergy development is vast, but currently, the energy conversion volume is only 1% of the global annual renewable biomass resources.

4. Biomass Energy Technology

The conversion of biomass energy helps reduce human dependence on fossil fuels, lower greenhouse gas emissions, and promote the use of renewable energy sources.

4.1. Biomass Energy Power Generation Technology

Biomass energy power generation technology is a thermal power generation technology that utilizes biomass and its processed forms as solid, liquid, and gaseous fuels. Biomass energy power generation technology mainly includes the following methods.

Direct combustion power generation technology, which is the simplest and most direct method, involves sending biomass fuel into a steam boiler suitable for biomass combustion, using the high-temperature combustion process to convert the chemical energy in the biomass fuel into the internal energy of high-temperature, high-pressure steam, then converting this into mechanical energy through a steam power cycle, and finally transforming the mechanical energy into electrical energy through a generator. Coupled combustion power generation technology, which uses biomass fuel to partially replace other fuels (usually coal) for co-firing in power generation, can increase the flexibility of

biomass fuel while reducing coal consumption, achieving carbon dioxide emission reduction for coal-fired power units. Biogas power generation technology utilizes biogas produced from organic waste under anaerobic conditions through internal combustion engines or fuel cells to convert it into electrical energy.

Biomass energy power generation technology has plenty of advantages, as bioenergy power generation is the best way to deal with agricultural waste, which is beneficial for achieving a virtuous cycle in the rural economy [5]. At the same time, the electricity generated from biomass energy is of good quality, reliable, and has a stable output, capable of participating in power peaking, helping to reduce losses in the power grid, and improving energy efficiency. In terms of development trends, the biomass energy industry will build a low-carbon, circular, and sustainable development model, gradually transitioning from subsidy-driven to market-driven, with diversified utilization methods and non-electric utilization becoming a focus. The development of the biomass energy industry will progress from solid-state utilization (biomass thermoelectric/clean heating) to gaseous utilization (biomethane/pyrolysis gas), and in the future, in areas where decarbonization is difficult for electrification, advanced fuels such as bio-jet fuel and bio-methanol will play a significant role.

In addition, biomass energy power generation technology has a broad market prospect globally, especially in regions rich in agricultural and forestry waste. With technological advancements and cost reductions, biomass energy power generation is expected to play a more significant role in the future energy mix.

4.2. Production Technologies of Biofuel

Solid Fuel Technology (SFT): In terms of solid biofuels, China has developed ambient temperature biomass molding technology. In 2010, the Ministry of Agriculture of China promulgated and implemented the industry standard for biomass molding fuel, becoming China's first SFT standard. SFT mainly includes biomass molding fuel technology and biochar technology, among which, biomass molding fuel technology mainly includes the manufacturing technology of biomass pellets, biomass blocks, and molding equipment. Factors affecting biomass solidification and molding include the type of raw materials, particle shape, moisture content, temperature, etc., which are the main factors determining the development of biomass molding fuel technology. Biochar refers to a highly aromatic, refractory, carbon-rich substance produced by biomass under complete or partial oxygen-deficient conditions through high-temperature pyrolysis, mainly consisting of ash, fixed carbon, and volatile matter. Hydrothermal carbonization and pyrolysis carbonization are the two main categories of biomass carbonization technology based on the carbonization process, flash carbonization technologies, etc [6]. Currently, European countries are developing the fastest in the field of biomass solid fuels, and therefore, they are the most mature in terms of SFT overall. Japan's dense molding technology has led the world. China still needs to make breakthroughs in key technologies of biomass solid molding fuel to achieve large-scale development.

Liquid Fuel Technology: In terms of liquid biofuels, there are two technologies: biodiesel and fuel ethanol. Among them, biodiesel includes conventional alkali (acid) catalytic technology, high-pressure alcoholysis technology, and supercritical (or subcritical) technology. Fuel ethanol mainly includes cassava ethanol, sweet sorghum ethanol, and cellulosic ethanol. Overall, starch (including sugar), lignocellulose, and oils are three types of biomass resources suitable for the preparation of liquid fuels. Oils are mainly prepared into biodiesel or bio-gasoline through processes such as thermal cracking, transesterification, or catalytic hydrogenation. Lignocellulose is mainly used to prepare liquid fuels through fermentation, gas-Fischer-Tropsch synthesis, liquefaction-refining, and selective synthesis of platform compound intermediates. In the United States, there is a greater tendency to study the first-generation and second-generation raw materials for biomass ethanol production (namely starch biomass and wood fiber biomass). At the current technological level, the large-scale production of ethanol in the United States and globally is mostly derived from the former. Cellulosic raw materials, such as agricultural and forestry residues, perennial grasslands, and solid waste, have advantages because they do not need to compete with food, feed, and fiber production. Compared to

corn and other commodity crops, they require less input (such as water, nutrients, and land). However, due to immature technology, production costs are still high and not suitable for large-scale industrial production [7]. At present, various countries in Europe, the United States, and China have matured in liquid fuel technology using grain as raw materials. In terms of liquid fuel technology using cellulose as raw materials, the United States and Europe have made significant progress, and China has also achieved certain results, but there is still a distance between the United States and Europe. At present, 18 provinces in northern China can grow sweet sorghum for ethanol production, while cellulosic ethanol technology faces three major technical bottlenecks: efficient pretreatment technology for straw-type plant biomass; high cost of enzymes for cellulose degradation into glucose; and the lack of microbial strains with high conversion rates for utilizing pentose and hexose to produce ethanol. In terms of biodiesel, the technology using herbaceous oil as raw materials has matured and is now shifting towards fuel development technology using woody oils.

Gas Fuel Technology: Existing biomass gas fuel technologies mainly include biodegradation, high-temperature pyrolysis, plasma pyrolysis, molten metal gasification, and supercritical water gasification, with equipment mainly including fixed beds, fluidized beds, and gas flow beds, divided into single-bed and double-bed types. Among them, gasification reactions without gasification agents are called pyrolytic gasification, while gasification with gasification agents can be divided into oxygen gasification, steam gasification, air gasification, and composite gas gasification. Biomass gasification technology can also be applied to centralized gas supply, cogeneration of heat and electricity, synthetic natural gas, synthetic liquid fuels, and hydrogen production. The process of producing synthetic natural gas from biomass through thermochemical gasification includes biomass pretreatment, gasification, purification and adjustment, methanation, and gas purification, among which, methanation is the key technology, mainly involving methanation reactors and catalysts. Methanation reactors used in synthesis gas methanation mainly include fixed beds and fluidized beds, and the commonly used methanation catalysts are transition metals supported on oxide carriers. In fermentation technology, biogas production involves providing a specific environment for living microorganisms to function optimally, thus often distinguishing between mesophilic and thermophilic production, wet slurry production, and dry production. The current gas fuel technology mainly focuses on biogas technology, and the technologies of various countries have basically matured. China has also begun to operate some large-scale biogas production projects. The latest research progress is the gasification of algal biomass to produce methane, with various countries having started technology research and development, such as China's research on blue-green algae fermentation to produce methane, Japan's research on seaweed fermentation to produce methane, and Spain's research on algae cracking to produce methane, etc.

5. Challenges and Opportunities of Bioenergy

5.1. Issues Facing the Application of Bioenergy

Bioenergy still faces some serious problems in practical applications.

The application cost of bioenergy is relatively high. Among the costs of biomass power generation, fuel costs account for the highest proportion, directly affecting the profitability of enterprises. Acquisition costs have the largest share in fuel costs, with direct combustion power generation at 70% and gasification power generation at 80% [8]. The reasons for the high cost of raw material collection include the difficulty in collecting dispersed straw, the lack of integrity among some straw brokers, the low enthusiasm of farmers for collection, and the clustering of biomass power plants. Compared with conventional thermal power, the characteristics of biomass fuels determine that the investment per kilowatt is large. At present, the cost per kilowatt is above 10,000 yuan, and the cost per kilowatt of the first national-level demonstration project built and put into production is as high as 13,000 yuan [8]. The maintenance costs of related connection equipment for bioenergy are relatively high, especially for the transmission and distribution lines of biomass power generation, which are built by the power generation companies themselves. If there are problems with the lines during operation,

the power generation companies have to pay for the power grid enterprises to repair them. These costs are also a considerable burden for the bioenergy power generation industry, which is already not very profitable. The low energy density, dispersed resource distribution, and low collection and storage efficiency of bioenergy are also among the reasons for the high costs.

Insufficient technological capabilities and inadequate scientific research support for bioenergy. At present, China lacks relevant research and development capabilities, and equipment manufacturing capabilities are weak. Technology and equipment production relies heavily on imports, and the technological level and production capacity are far behind the advanced levels abroad. This leads to insufficient innovation capacity in the bioenergy industry, limited investment of social capital, and an imperfect industrial system and policy support.

Insufficient policy measures and market confidence. The original business model of the bioenergy industry no longer meets the requirements of the new era, especially after the decline in electricity price subsidies, how to explore new profit models has become key. The ecological and environmental value and green value of bioenergy are often overlooked by the market and need further recognition and attention from within and outside the industry.

5.2. Future Development Trends of Bioenergy

As internationally recognized zero-carbon renewable energy, bioenergy has enormous potential and advantages in the process of green development. China's bioenergy industry will build a low-carbon circular sustainable development model of agriculture-environment-energy-agriculture, gradually shifting from solid-state utilization (biomass power/thermal power) to gaseous utilization (biogas/thermolysis gas), and playing a significant role in areas where electrification is difficult to decarbonize, such as bio-jet fuel and bio-methanol. The development of the bioenergy industry will gradually shift from subsidy-driven to market-driven, with diversified development in utilization methods, and non-electric utilization becoming a focus. With continuous technological innovation and breakthroughs, the efficiency of bioenergy utilization will continue to improve, and production costs will be further reduced. Power generation will also develop towards diversified utilization, including heating, gas supply, and the production of by-products such as ethanol and biogas. More and larger professional companies are joining the field of bioenergy, driving the development of the entire industry, and making the industry's development more professional and large-scale. It is expected that the future market size of bioenergy will continue to expand, and market share will gradually increase.

6. Conclusion

Biomass plays an increasingly important role in the GES today. Despite challenges such as high costs and policy support deficiencies, the future of biomass energy lies in transitioning from solid to gaseous utilization and expanding its role in hard-to-decarbonize sectors. As a form of renewable clean energy, bioenergy plays a key role in promoting energy development and achieving sustainable development. This article discusses the production and sources of bioenergy, its proportion in the GES, the technologies and applications of bioenergy production, and the challenges and opportunities it faces in future development.

References

- [1] Wang K, Sun L, Wang J, et al. The electricity, industrial, and agricultural sectors under changing climate: Adaptation and mitigation in China. *National Science Open*, 2024, 3(01):100-146.
- [2] Romeo L M N. Research on Multi-Objective Optimization of Investment and Financing for Photovoltaic Power Generation Projects in Cameroon. North China Electric Power University (Beijing), 2023.
- [3] Shinechimeg K. Regional Energy Cooperation in Northeast Asia: the Current Dynamics and the Future Prospects. Shandong University, 2023.

- [4] Boyang H. Effect of Photovoltaic Power Generation on Carbon Dioxide Emission Reduction under Double Carbon Background. *China Petroleum Processing & Petrochemical Technology*, 2023, 25(04): 164-174.
- [5] Liu Y, Chen L, Yang L, et al. Porous framework materials for energy & environment relevant applications: A systematic review. *Green Energy & Environment*, 2024, 9(02): 217-310.
- [6] Guo Z, Han X, Zhang C, et al. Activation of biomass-derived porous carbon for supercapacitors: A review. *Chinese Chemical Letters*, 2024, 35(07): 147-164.
- [7] Ajayo C P. Research on the Process of Producing Bioethanol from the Whole Biomass of *Broussonetia papyrifera* and Optimization of the Process Flow. Sichuan Agricultural University, 2023.
- [8] Shoaib M. Socio-Economic Impacts of the CPEC in Rural Pakistan: A Case Study of M5 Motorway. Shandong University, 2023.