SOLID-GASEOUS BIOFUELS PRODUCTION

Edited By
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Contents

Preface

Excessive energy demand in numerous sectors all over the world has resulted in maximal consumption of fossil fuels, which has led to their depletion. Furthermore, the study of different forms of energy is under consideration. In addition, research into diverse forms of energy is being examined for the future world. Biofuels are among the best substitutes for fossil fuels and for combating climate change to attain Net Zero Emissions by 2050. Furthermore, biofuels proved to be the most significant factor in boosting global alternative energies, accounting for approximately fifty percent of renewable energy and six percent of global energy stocks. Developing solid-gaseous-based biofuels requires a significant amount of time, effort, and resources, including the use of wastes and residual flows. Micro/macro-algae are the most diversified category of plants, flourishing in nearly most regions of the globe, and represent the third generation of biofuels. Algae are responsible for more than fifty percent of oxygen sources, and they also generate the feed as well as other essential health foods on a large scale. Although algae constitute the prominent starting substrates for producing biofuels, this issue focuses on advanced technology related to solid/gaseous biofuels. Furthermore, recent research and technological developments in algal biomass for refined biofuel generation, as well as various conversion processes for their prospects, are discussed. This book will help you explore the biofuel advancements of third-generation biomass, which is considered the leading alternative bio reserves business, as well as the related technologies and their many implementations. In the fields of sustainable renewable biofuel industries, it is a great reference tool for students, academics, researchers, professionals, and investors.

Chapter 1 The generation of biofuels has progressed from conventional processes like ethanol fermentation to cutting-edge approaches like enzymatic hydrolysis and algae culture. Modern technology focuses on increasing efficiency, minimizing environmental effects, and maximizing feedstock utilization. The development of biofuel production offers hope for more sustainable energy sources and lower carbon emissions.

Chapter 2 focuses on how algal biofuels can become a viable and sustainable option through bio-refineries. For that, biorefineries, algal, and biofuels are separately explained, then, the production of algal biofuels and other bioproducts are presented, along with data about them and the respective challenges and perspectives for the future.

Chapter 3 discusses the production of biofuel from waste materials like biomass feedstock, livestock waste materials, food processing waste etc. This chapter gives an overview of various biofuels such as bioethanol, biohydrogen, biodiesel, and biogas production. The classification of biofuels based on feedstock is also discussed in this chapter.

Chapter 4 portrays the essential elements required for the upgradation of biogas to biomethane, followed by its conversion to liquid biomethane (LBM). Various biogas to biomethane upgradation technologies through CH4 enrichment and salient features of practical biomethane liquefaction methodologies are also discussed.

Chapter 5 covers recent research and advancements in cost-effective biofuel production. It emphasizes the growing need for sustainable and economically viable biofuels to meet energy demands and reduce greenhouse gas emissions. Topics include utilizing non-edible and waste materials, algae as feedstock, genetic engineering, nanotechnology, optimization, advanced fermentation, and policy support.

Chapter 6 discusses obtaining hydrogen through cyanobacteria. The biophotochemical processes capable of producing it are discussed. In addition, it refers to a small economic and environmental analysis of hydrogen production by cyanobacteria. Production setbacks and an overview of patents are presented.

Chapter 7 has been focused on microstructural engineering used for bioenergy production. Also It has been detailed Microbial Engineering, Plant Cell Wall Engineering and Nanotechnology for Bioenergy Production. On the other hand, It has been covered the subjects of Biomass Microstructure and Characterization and Microstructural Engineering for Bioreactors and Processing.

Chapter 8 explores the potential of lignocellulosic biomass as an affordable, abundant, and environmentally sustainable feedstock for biofuel production through fermentation. It delves into the structural chemistry of lignocellulosic biomass, discusses pre-treatment methods, and critically reviews the contemporary technologies used for the biochemical conversion of lignocellulosic biomass into biofuels.

Chapter 9 focuses on the limitations of the first and second generation of solid-gaseous biofuels amidst the ongoing climate crisis. It deliberates on issues such as land-use changes, biodiversity loss, water security, and greenhouse gas emissions. Additionally, it highlights recent studies emphasizing the importance of diversifying feedstock for sustainable biofuel production.

Chapter 10 emphasizes on types of Agro-Processing wastes. The pre-treatment methods followed by supplementation of these wastes are discussed in detail. Additionally, the techniques used for fermenting these wastes are also covered. The main focus is to understand the substrate-microorganism combinations and pre-treatments performed to manufacture Ethanol and Butanol.

Chapter 11 discusses the current situation of biofuel production worldwide and draws the future perspective on the production and consumption of biofuel by 2030. Countries' goals for replacing fossil fuels with biofuels were also presented. Moreover, the advantages of green and sustainable feedstock compared to conventional feedstock were discussed.

Chapter 12 portrays various possibilities for generating bioenergy from carbon-based precursors and biomasses through microstructural maneuvering. Renewable energy production from carbon products, industrial wastes, agricultural crops, and municipal wastes offers a carbon-neutral future. The procedures of manipulating physico-chemical properties to augment bioenergy production from these precursors are discussed at length.

Chapter 13 discusses the crucial role of nanotechnology in enhancing the sustainable production of biofuel and bioenergy. It also emphasizes on the key factors that influence the performance of nanomaterials, their various advantages, disadvantages, and challenges for biofuel and bioenergy production.

Chapter 14 outlines the advancements in generating algal based bio-fuels through technological optimization. The ongoing research providing dynamical insight into various parameters that assists in overcoming the existing gaps between laboratory scale and industrial implementation in a cost effective manner remains the focal point of the chapter.

Chapter 15 talks about crop-based solid bio-fuels, the green alternative sources of energy against fossil fuel. There is a discussion on pellets, which are the way to store the solid bio-fuel. They contain the highest calorific values and burned with high combustion efficiency.

Chapter 16 discusses the process involved in the extraction, production, and storage of three vital gaseous biofuels namely bio-hydrogen, syngas, and biogas. The raw materials required for the production of these gaseous biofuels were also discussed, along with their applications and their role in limiting emissions and reducing pollution.

Chapter 17 discusses about the different types of biofuels. And various traditional and modern methodologies adopted to synthesize biofuels. Furthermore, the chapter also addresses the accessibility of feedstock supply and explores different catalysts used in the conversion process of biomass into biofuels. Additionally described in the chapter are contemporary extraction and purification methods along with their functions.

Chapter 18 details the processes to produce solid biofuels (SB). The main feed-stocks to produce SB, the physical and chemical processes, including dewatering and drying, size reduction and shredding, and microwave are also discussed. Also, the processes such as briquetting, pelletizing, pyrolysis, gasification and torrefaction and hydrothermal carbonization are discussed.

Chapter 19 details the application of coal for hydrogen production and storage. Industrial and economic production of hydrogen from coal pyrolysis, gasification, and coal slurry electrolysis are well-demonstrated. Similarly, the coal properties and their influence on hydrogen storage are elaborated to meet the energy demand of the upcoming hydrogen era.

Chapter 20 discusses various characteristics of solid and gaseous biofuels. Emphasis is on identifying standard methods used to establish these characteristics. The importance of understanding biofuel characteristics in energy mix decision making and process or equipment design is also included in the discussions.

Key features:

- Provides a broad overview of biofuels
- Outlook for the technological advancements in biofuel industries
- Discussion across a wide range of scopes and challenges related to biofuels
- Future trends of biofuels development

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1

Biofuel Production: Past to Present Technologies

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Abstract

Biofuels are renewable energy sources from biological materials such as plants, algae, and animal waste. These fuels are gaining popularity as a sustainable alternative to traditional fossil fuels, which are non-renewable and contribute significantly to climate change. The production of biofuels involves converting biological materials or biomass into usable fuels through various processes such as fermentation, pyrolysis, and transesterification. These processes can be conducted on a small scale, such as in a laboratory, or on a large scale, such as in industrial plants. Different generations of biofuels exist; the first-generation biofuels are typically made from corn, sugarcane, and soybeans, whereas the second-generation biofuels are made from non-food crops such as switchgrass and wood chips. The third-generation biofuels are produced from algae and other aquatic plants. Biofuels have the potential to reduce greenhouse gas emissions, create jobs, and increase energy security. However, there are also concerns about the environmental impact of biofuel production, such as land use changes and water usage. Therefore, it is essential to carefully consider biofuel production's benefits and drawbacks and to develop sustainable production practices.

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1.1 Introduction

The world's population is increasing fast and is projected to reach 9.7 billion by the year 2050, so there is an increase in energy demand [1]. By 2050, global energy demand will increase by 50%, existing at around 900 quadrillion Bt [2]. It is necessary to satisfy the rising energy needs of the globe with resources. Fossil fuels have the largest share (84.3%) of the global energy mix [3]. It is a fretting situation because burning fossil fuel sources creates problems for human health and the environment, atmospheric issues, global warming, and climatic changes due to greenhouse gas emissions [4, 5]. After the 20th century, due to industrialization and globalization, energy demand increased exponentially, resulting in the availability of this fuel, which is also one of the concerns [4]. Awareness has shifted to using sustainable and alternative energy sources to address the above issues [5, 6].

Nowadays, several alternative solutions are available for energy recovery, which are renewable in nature. It includes solar, wind, ocean, geothermal, and bioenergy [7, 8]. Among them, biomass or bioenergy has excellent potential for developing sustainable energy solutions [9]. Green plants absorb the energy from the sun during the photosynthesis process. Biomass is widely accessible, inexpensive, carbon neutral, and low in sulfur and chlorine; has a decentralized supply; and has a short life cycle for non-woody biomasses [10]. Biomass energies are harvested using various conversion processes, i.e., physical, thermochemical, and biochemical [1, 11]. The generated biofuels can be used for transport, heat, and electricity generation. Biofuel production from biomass feedstock gained more attention in the energy sector due to its reliability and positive role in reducing CO_2 levels in the atmosphere compared to conventional sources [12, 13].

The first-, second-, third-, and fourth-generation biofuels are the four categories into which biofuels are divided on the basis of the kind of feedstock [14]. Food-vs.-fuel problems may result from the first-generation biofuels from eatable feedstock [15]. Cellulosic waste that cannot be consumed is used to create the second-generation biofuels [16]. Of the four generations of biofuels, only the first and second generations are produced commercially. Algae-based fuels are categorized as the third-generation biofuels, whereas genetically modified (GM) organisms are used to produce the fourth-generation biofuels. Large-scale commercialized production of the third- and fourth-generation biofuels is less due to high production cost and low biomass production. The feedstock used for biofuel generation can be agricultural waste, forest waste, sewage sludge, wastewater, processed industrial waste, and kitchen food waste [17–19]. So, simultaneously utilizing this waste will solve waste management issues by converting them into value-added products [20]. Thus, generations of biofuels from destruction will help to develop sustainable green cities in the future, as per the Paris Agreement [21].

As per the bibliometric study of Hasan *et al.* [22] in a study period of 2001 to 2022, after 2006, the publication in the biofuels area increased substantially. This is because the governments have taken initiatives to increase renewable energy areas, climate change issues, and increasing energy demand and consumption—the increased production of biofuel-initiated concept of biofuel economy. The idea of a sustainable biofuel economy is directly correlated with the sustainable development goals (SDGs) of the United States. For example, the use of biofuels ensures good health and well-being of people (SDG3); biofuels provide clean and sustainable energy (SDG7); biofuel generation increases employment opportunities and economic growth of agricultural people and industries (SDG8); biofuel generation assures secure, resilient, and sustainable cities and communities for everyone (SDG11); and biofuel generation ensures taking immediate action to tackle climate change challenge (SDG13) [22, 23].

The many social and environmental advantages have proven the recent headways in biofuel production. Still, its financial sustainability depends on feedstock availability, possible technology, design, project management, and production capacity [22, 24]. Recently, conversion technologies such as hydrothermal carbonization [25, 26], hydrothermal liquefaction [27, 28], pelletizing [29, 30], gasification [31, 32], fast pyrolysis [33, 34], bioethanol production [35, 36], and biodiesel production [37] under research in developed and developing countries to convert waste into biofuels. Thus, this article aims to provide knowledge on the production of biofuels from past to present by using different technologies within a sustainability and economic feasibility framework. This article will overview current research trends for producing solid, liquid, and gaseous biofuels with varying conversion pathways and future roadways for producing biofuels to fulfill global energy security.

1.2 Types of Biofuels

1.2.1 Solid Biofuels

Solid fuels are mainly used for heat and power generation. Conventionally, solid fuels are obtained from coals of lignite, bituminous, and sub-bituminous types [20]. Burning coal for energy has a negative impact as it increases CO_2 concentration in the atmosphere, which causes climate and global warming [38]. Several countries are finding it extremely challenging to minimize CO_2 emissions in the atmosphere. As a result, both developed and developing nations are working to establish sustainable energy systems to address the problems caused by the use of fossil fuels [9]. In addition, heavy dependency on fossil fuels also leads to low energy sustainability and security [10]. Among the different solutions, solid biofuels play a vital role in circular economy concepts by converting waste to wealth by implementing reduction, reuse, and recycling principles [31]. Solid biofuels can be obtained from agricultural residue, forest residue, food waste, municipal solid waste, and microalgae [20]. The socioeconomic development of so many developing countries relies mainly on agriculture and agro-based industries to meet the growing population's increasing demand. Consequently, the annual generation of agricultural waste is considerably high [39]. For example, India annually generates 550 Mt of agro residues [40]. The type and quantity of waste vary from ecological zones. The production of solid biofuels depends upon different factors like type of feedstock, feedstock availability, technique used, economic conditions, and energy required.

Solid waste has low bulk density, high moisture content, irregular shape, high volatile matter, heterogeneity, high hygroscopicity, and low calorific value [41, 42]. So, to improve the properties of feedstock, pretreatments such as drying, size reduction, microwave pretreatments, and dewatering are commonly given. To convert the raw feedstock to solid biofuels, different production techniques, i.e., briquetting/pelletizing/densification, torrefaction, pyrolysis, gasification, and hydrothermal carbonization, can be used as shown in Figure 1.1. Table 1.1 summarizes the common pretreatments given to feedstock to produce solid biofuels by using different technologies, such as microwave torrefaction [32], hydrothermal carbonization [43], vacuum pyrolysis [44], and microwave vacuum pyrolysis [45]. Integrating pretreatment with different technologies brings extra benefits of selective, homogeneous, rapid heating; low energy input; and processing time [43, 44]. The produced solid biofuels can be used as cooking fuel for domestic purposes, industrial boilers, biochar for soil amendment, and wastewater treatment [20]. Therefore, solid biofuels can replace fossil fuel consumption, supporting SDGs and a circular economy [46, 47].

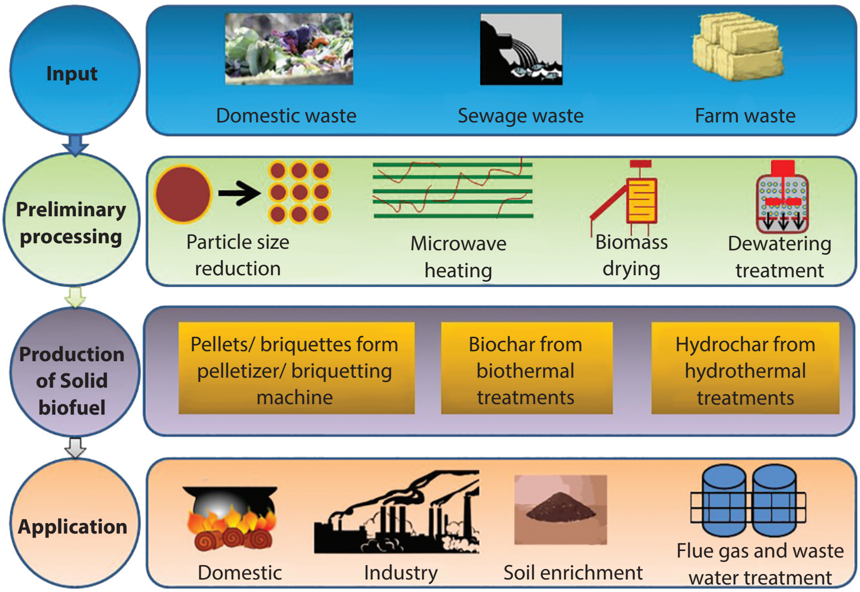

Figure 1.1 Overview of solid biofuel production and its application.

1.2.2 Liquid Biofuels

Liquid fuels are majorly used for transport purposes. According to the International Energy Agency [2], total transport emissions increased by 2.1% (or 137 Mt) in 2022. However, due to the increasing population, the global demand for transport continues expanding (40% by 2035). So, at the world level, efforts are being made to reduce emissions due to transport by replacing fossil fuels with renewable, sustainable, and carbon-neutral liquid biofuels [15]. Biomass may be converted into ethanol, methanol, butanol, biodiesel, and Fischer–Tropsch diesel, among other fuels [4]. With a global yearly production of 200 billion tons, liquid biofuels may be produced from natural, renewable, and sustainable feedstocks already in the environment [48]. These different sources include residue from the agricultural sector, forest sector, food-industrial sector, non-food energy crops, solid waste, and algal biomass.

To convert the raw feedstock to liquid biofuels, different production techniques, i.e., torrefaction, pyrolysis, gasification, hydrothermal carbonization, and aerobic and anaerobic fermentation, can be used, as shown

Table 1.1 Solid biofuels from different wastes.

Raw material	Pretreatment	Technology used	Product	Properties	Scale	HHV, MJ/kg	Application	Ref.
Rice husk	Size reduction	Pelletizing (water as a binder)	Pellets	Y, 65%; BD, 650 kg/m^3; AC, 18%	Pilot	12–13.5	Thermochemical application for the generation of energy	[92]
Banana stalk	Drying and grinding	Hydrothermal carbonization (180°C, 1–3 h)	Hydro char	EY, 57.8% to 75.3%; FC, 16–44; VM, 48–73; AC, 6–10	Lab	18.1–18.9	Potential raw material for energy production	[93]
Oil palm trunk	Drying, grinding, and sieving	Pyrolysis (300°C–350°C)	Bio-coal	EY, 27.8%; BD, 87.7 kg/m^3; FC, 51.8; VM, 39.4; AC, 15.5	Pilot	19.6	Co-combustion in coal-firing power plants; keywords	[94]
Jute sticks	Drying, grinding, and sieving	Torrefactions (150°C–350°C)	Solid fuel	EY, 94.03%; EF, 1.18; FR, 0.64	Lab	19.32	Pelletizing and gasification	[95]
Cornstalk	Microwave pretreatment	Hydrothermal carbonization	Hydro char	FC, 9.8%–18%; VM, 74.3–81.3; AC, 3.1–4.0	Lab	22.82	Direct solid fuel or auxiliary fuel	[96]

Y, yield; EY, energy yield; BD, pellet density; AC, ash content; FC, fixed carbon; FR, fuel ratio; EF, enhancement factor; VM, volatile matter.