MICROBIAL BIOTECHNOLOGY FOR BIOENERGY

Edited by
Naga Raju Maddela, Sesan Abiodun Aransiola
Chizoba I. Ezugwu, Lizziane Kretli Winkelstroter Eller,
Laura Scalvenzi and Fangang Meng

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Foreword

This book titled Microbial Biotechnology for Bioenergy highlights wholistic information on the role of microbial biotechnology in bioenergy. Going by the efforts of stakeholders in this area to make the global environment clean, save the ecosystem, and mitigate the climatic change for safe life, experts across the world were selected to contribute current information on issues surrounding bioenergy. This book is relevant, as efforts are currently being made to advance the various fields of science and engineering and overcome problems relating to the environment, health, food security, and energy crisis. The discoveries in this book, consequently, will help to proffer solutions to environmental hazard, including climate change, global warming, and pollution, thereby fostering environmental sustainability. Bioenergy appears to be the future for the power needs of humanity across the globe, as reliance on fossil fuels continues to diminish. As the drive toward clean, green, and renewable energy continues to advance, the cost will fall and work will be created to develop and install these new power solutions. More and more people are recognizing the environmental, societal, and economic benefits of bioenergy and, as more cities, states, and nations sign up to a green power agenda, this will continue to advance. There is therefore the need to know (in detail) the role and current biotechnological approaches of bioenergy. Furthermore, do microorganisms have a role to play in bioenergy? Does renewable energy solely depend on microbial activities? Could microorganisms solve the global warming problem? These questions are fully answered in this book. This book, going by the available facts and global trends, addresses the new emerging biotechnology and the microbial approaches in bioenergy and how these new areas affect or tend to affect the global community.

Aligning with the UN's Sustainable Development Goals and going by the recent statement by Anto´nio Guterres (the current Secretary-General of the United Nations) that "As we wean ourselves off fossil fuels, the benefits will be vast, and not just to the climate. Energy prices will be lower and more predictable, with positive knock-on effects for food and economic security. When energy prices rise, so do the costs of food and all the goods we rely on. So, let us all agree that a rapid renewables revolution is necessary and stop fiddling while our future burns." It is very certain that this book is valuable and will gain more reads and citations. To validate the three sections in this book, the editors have done a great job by inviting 98 experienced

experts from 12 different countries to con- engineers, researchers, industrialists, agritribute to this volume. Therefore I am fully culturists, and technicians for many years confident that the wealth of knowledge of to come. all the contributors of chapters in this book

Professor Fatimah Ja'afar Tahir is of

valuable importance and will have a

wide readership. Besides, it is a good source of information to students, scientists,

Vice chancellor, Bauchi State University Gadau (BASUG), Nigeria

Preface

Bioenergy has intrinsic cost-savings, as there is no need to exploit and transport fuels, such as with oil or coal, as the resources are replenished naturally. The future of bioenergy looks very bright, with recent years showing that more renewable energy capacity has been installed globally than new fossil fuel and nuclear capacity combined. As the world population continues to grow, there is an ever-increasing demand for energy, and renewable sources are the answer to providing sustainable energy solutions, while also protecting the planet from climate change. Of course, due to fossil fuels being a finite resource, it makes sense that the renewables are the future, and so it is expected that they will continue to increase in number, driving down the cost too. The contributions of biotechnology to the energy industry are not restricted to the production of biofuels, and the microbial production of methane may well be the largest contribution in the future.

Microbial Biotechnology for Bioenergy is an excellent book that gives appropriate information on the issue of global concern. The book addresses the general concept of the microbial biotechnological relationship with bioenergy. It reveals different sources of bioenergy, global statistics, challenges, and environmentalist projections of bioenergy. In addition, the book explains the role of biotechnology advances, the innovations of yesterday, today, and tomorrow, and the associated global politics and policies of bioenergy.

This book comprises three sections. Section 1, Sources, Challenges, and Environmental Views, has six chapters. Chapter 1 of Section 1 provides a general scope of bioenergy, the place of biotechnology in bioenergy, and the general perspectives. Chapters 28 discuss global advances in bioenergy production technologies, role of biotechnology and bioprocess in bioenergy, distributions of biomass sources for bioenergy production: challenges and benefits, decarbonization and the future fuels, bioenergy: the environmentalist perspectives, current trend of bioenergy of biogas, biomethane and hydrogen in developed country, emerging technology in global bioenergy generation, respectively. Section 2, Yesterday, Today, and Tomorrow Innovations of Bioenergy, includes Chapters 914, which reveal the bioconversion of biomass energy and biological residues: the role of microbes, potentials of organic waste to provide bioenergy, biotechnology of biofuels: bioethanol and biodiesel, sustainability of microbial fuel cells, marine energy and hydrogen, bioenergy as a global public tools and technology transfer, the past, present, and future of biotechnology in bioenergy. Section 3, Matter Arising in Bioenergy Advancement, has seven chapters, namely, the politics and policies of bioenergy advancement: global perspectives, biotechnology for renewable fuels and chemicals, the way forward in bioenergy technology for developing countries, bioenergy replacing fossil fuels and its role in global warming mitigation through climate change and economic growth in Turkey, economic perspective of bioenergy generation, genetically engineered marine microbes for the production of bioethanol, and future directions in the usage of organic waste for bioenergy.

The chapters were contributed by 98 academicians/scientists/researchers from 12 different countries (China, Ecuador, India, Nigeria, Canada, Germany, the United States, United Kingdom, Malaysia, Hong Kong, Turkey, and France) across the globe.

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1. Sources, challenges and environmental views

CHAPTER

4

Distribution of biomass sources for bioenergy production: challenges and benefits

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4.1 Introduction

Producing bioenergy is important now because it can be used to address our energy needs in a sustainable and renewable way (Liu, Miao, Shi, Tang, & Yap, 2022). By harnessing the energy stored in organic matter, bioenergy can be used as a replacement for fossil fuels while also reducing emissions of greenhouse gases and helping to slow global warming. Bioenergy helps ensure our nation's continued access to reliable energy by providing an alternative to fossil fuels. Biomass in particular is important as a renewable energy source (M'Arimi, Mecha, Kiprop, & Ramkat, 2020).

Biomass refers to any organic stuff like plant matter, animal matter, or garbage. It consists of municipal, industrial, and agricultural organic waste as well as energy crops like switch grass and miscanthus and agricultural residues like corn stover and sugarcane bagasse. Benefits of biomass include its ubiquity and the possibility, with proper management, of its perpetual renewal (Robledo-Abad et al., 2017).

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Most of this increase in population is expected to occur in developing nations, with metropolitan regions seeing an increase of 50% (Hiloidhari et al., 2017). Because of this, urban areas are responsible for a growing share of the world's total energy use. Twothirds of the world's energy is used in urban areas, up from less than half in the early 1990s (Duque, A´ lvarez, Dome´nech, Manzanares, & Moreno, 2021). This would imply that the percentage of global energy consumption that comes from cities is growing at a rate greater than the percentage of the world's population that lives in cities. Energy sustainability is developing as a vital political answer to climate change concerns, even as cities continue to rely on fossil fuels as their primary source of energy (Guan, Tai, Cheng, Chen, & Yan, 2020). Indeed, cities are one of the most significant contributors to climate change, accounting for 70% of human-caused CO_2 emissions worldwide. Urban areas are also seeing the devastating effects of climate change. 70% of major cities are already feeling the effects of global warming. It is expected that the damage caused by rising sea levels will grow as 90% of all urban centers are located along the coast, with some developing country cities being particularly vulnerable. More people living in cities means more people breathing in polluted air. 90% of city dwellers are subjected to air pollution levels that are too high, according to the WHO (Hoang et al., 2021).

All plant and animal matter as well as organic elements obtained through natural or artificial modification are included in the definition of biomass (Guan et al., 2020; Leh-Togi Zobeashia, Aransiola, Ijah, & Abioye, 2018). Biomass-derived biofuels include wood shavings, firewood, pellets, various fruit stones like olive pits and avocado pits, and nutshells. Firewood, which is usually burned directly in home equipment like stoves and boilers, is the least treated of all. The biomass from farms and forests are crushed to make the chips, and their size might vary from batch to batch and from transformation to transformation (Aransiola, Victor-Ekwebelem, Leh-Togi Zobeashia, & Maddela, 2023). Pellets are considered to be the most intricate form of biofuel. The compressed biofuel cylinders have a length that ranges from 10 to 30 mm and a diameter that ranges from 6 to 12 mm. According to Gabisa and Gheewala (2018), pellets are considered to be a suitable form of low-density fuels due to their low energy density. Solid biofuels such as fruit stones, seeds, and husks are being utilized to a lesser degree compared to conventional fuels like fuelwood, wood chips, and pellets. In fact, it has been shown that the hulls of peanuts, sunflower seeds, and mangoes all have high heating value potentials, making them viable alternatives to other commercially available biofuels (Duque et al., 2021). That, plus the fact that production of these waste products is rising over the world, increases their potential for use in thermal energy generation and carbon dioxide (CO_2) reduction. Biomass is a heterogeneous group of materials that encompasses a diverse range of substances such as wood, sawdust, straw, seed waste, manure, paper waste, household trash, and wastewater, as reported by Liu et al. (2022).

Renewable heating energy can be produced either locally, using equipment installed in individual buildings, or globally, using centralized generating and distribution networks. The technology behind decentralized biomass boilers is relatively young and developing rapidly. Since biomass takes in carbon dioxide (CO_2) during photosynthesis and gives off CO_2 during combustion, it produces no net CO_2 emissions (Hoang et al., 2021). However, many industrial operations including electricity generation waste significant amounts of thermal energy. Cogeneration is the most popular method of recovering waste heat since it can generate both heat and electricity.

CHP plants produce both electricity and heat at once, making them ideal for usage in both commercial and residential applications. All of the energy needs of industry are met, and any surplus is used mostly in the local community (Liu et al., 2022). On the other hand, district heating and cooling systems present a viable avenue for the exploitation of sustainable sources such as industrial and agricultural biomass, while concurrently enhancing energy efficiency. According to Manikandan et al. (2022), a distributed energy system employs underground insulated pipes to link to a central thermal or cold heat plant, which subsequently disseminates heated or cooled water to multiple buildings within a designated region.

Biomass, being a byproduct of various industrial and agricultural processes, presents itself as a viable and easily accessible source of renewable energy with considerable potential for expansion. Biomass has been identified as a viable energy source due to its ability to be utilized directly in waste conversion facilities for electricity generation or in boilers for industrial and domestic heating purposes, as noted by Manikandan et al. (2022). In order to align biomass with the standards of traditional fuels, it is frequently necessary to implement physicalchemical or biological alterations. It is important to note, however, that the current infrastructure may not always accommodate the direct combustion of biomass. Biomass district heating (BDH) is a highly effective approach to utilizing sustainable energy sources in urban regions. This is due to its ability to reduce carbon dioxide (CO_2) emissions by a significant margin, up to 100%, when compared to conventional fossil fuels. Additionally, BDH can improve energy efficiency by utilizing more affordable biofuels. Biomass is a heterogeneous group of materials that encompasses a broad range of substances, such as household waste, wood, straw, manure, seed waste, paper waste, wastewater and sawdust, as stated by Page-Dumroese et al. (2022). Some materials can be utilized as fuels in their natural state, while others require a sequence of pretreatments that necessitate specialized equipment. The advantages and disadvantages of biomass are of equivalent magnitude. The proposed initiative offers numerous advantages, such as the prospect of generating employment opportunities and utilizing the land for silviculture, thereby aiding in forest rejuvenation and mitigating the likelihood of wildfires. According to Page-Dumroese et al. (2022), biomass, which involves the collection of raw materials from rural and wild areas, is a dependable means of generating employment. The utilization of biomass as a biofuel has garnered significant attention from the scientific community.

Animal waste, wood, cereals, and seaweed are all examples of biomass that can be converted into usable energy. Biomass is the second-oldest energy source after the sun. For many centuries, people have relied on fires made from wood to warm their homes and prepare their meals. Biomass can only grow with the help of the sun. The sun's energy is contained within all living things. Through a process called photosynthesis, plants convert carbon dioxide and oxygen into oxygen and carbohydrates using only the energy from the sun.

Carbohydrates are a type of sugar that plants and herbivores use for fuel. Foods high in carbohydrates are an excellent source of fuel for the body. Biomass is considered a renewable energy source due to the fact that it does not have a finite supply. No matter how much we plant trees and harvest crops, trash will always be there (Wang, Wang, Zhang, & Grushecky, 2020).

Biomass refers to all plant-derived organic matter (such as algae, trees, and crops). All plant life on land or in water, as well as all organic waste products, are included in the term "biomass," which is formed when green plants convert sunlight into plant material via photosynthesis. Biomass is a renewable resource because it is made up of organic matter that stores solar energy in the form of chemical bonds. Chemical energy is released during digestion, combustion, or breakdown when bonds between nearby oxygen, carbon, hydrogen and molecules are broken. Humanity has long relied heavily on biomass as a source of energy, and recent estimates place its share of global energy production at anywhere from 10% to 14%.

Diverse methodologies can be employed for the purpose of deriving energy from biomass. For utilization in spark ignition petrol engines, a fuel must possess a gaseous or liquid state. The generation of gaseous fuel from biomass can be accomplished through various technologies, each possessing distinct prerequisites, benefits, and drawbacks (Yang et al., 2020).

Biomass is the organic matter derived from the process of photosynthesis, whereby carbon dioxide (CO_2) and water are converted into carbohydrates through the use of light energy and the release of oxygen (O_2). Photosynthesis has the capacity to convert a meager fraction of sunlight, specifically less than 1%, into chemical energy. The energy from the sun that fuels photosynthesis is stored within the chemical bonds of the structural components of biomass. The efficient digestion of biomass, whether through chemical or biological means, results in the liberation of energy that is stored within the chemical bonds. Upon combination with oxygen, this energy product undergoes oxidation, leading to the generation of carbon dioxide and water. The system in question is classified as a closed loop, given that the CO_2 that is recycled has the potential to serve as a source of fuel for further biomass growth. The valuation of biomass is contingent upon the chemical and physical attributes of its constituent large molecules. Throughout history, individuals have utilized the combustion of biomass as a source of fuel and have consumed plants for their sugar and starch content, thereby harnessing the potential energy stored within these chemical bonds. In recent years, the process of fossilizing biomass has resulted in the production of coal and oil. The conversion of biomass into fossil fuels is a time-intensive process that spans millions of years, rendering them nonrenewable within the context of human timescales. The combustion of fossil fuels not only reduces nonrenewable resources but also contributes to the greenhouse effect by transforming old biomass into new carbon dioxide. According to Brown (2019), the burning of fresh biomass does not result in the release of additional carbon dioxide into the atmosphere, as it is replanted after

harvesting.

One critical yet often neglected aspect to contemplate in utilizing biomass as a means to mitigate global warming is the temporal delay between the initial release of CO_2 resulting from the combustion of fossil fuels and its eventual absorption as biomass, which may span multiple years. The identification of this temporal discrepancy and the implementation of measures to reduce it constitutes a significant obstacle confronting the industrialized nations in contemporary times. The developing nations encounter comparable predicaments as they resort to the combustion of their biomass reserves for energy without implementing a synchronized reforestation initiative (Brown, 2019).

Numerous crop varieties have been suggested or are presently under investigation for utilization in commercial energy farming. Energy crops encompass a variety of plant species, including perennial flora such as trees and grasses, herbaceous plants, annual crops like sugarcane and maize, as well as oil seeds.

The subsequent features represent the overarching attributes of an optimal energy crop:

- Low cost.
- Low nutrient requirements.
- Composition with the least contaminants.
- High yield (maximum production of dry matter per hectare).
- Low energy input to produce.

Both the weather and the soil can have an effect on the final product's quality. In many regions of the world, water consumption is very limited, hence the ability to withstand drought is essential (Arpia, Chen, Lam, Rousset, & De Luna, 2021).

Important characteristics also include the need for fertilizer and tolerance to pests. In this analysis, we only considered weather patterns in the United Kingdom.

In the last 10 years, there has been increasing global interest in biomass as an energy source. This scenario is caused by a number of factors, including the following:

- To begin with, developments in conversion, crop production, and other areas promise cheaper and more efficient use of biomass than was previously possible. For example, the price of energy is now often competitive with the cost of energy generated using fossil fuels, when cheap biomass waste is used as fuel. Newer methods of generating power, such as the production of methanol and hydrogen via gasification processes, show promise and allow for the efficient use of energy crops.
- The second is the food surplus produced by agriculture in Western Europe and the United States. A solution to this problem has been to reserve tracts of land in order to cut down on surpluses. The introduction of nonfood crops is desirable due to challenges like rural depopulation and the provision of large subsidies to keep land barren. Energy crops grown on such (potentially) surplus land will have access to a nearly infinite market as a result of rising energy demand.
- The agricultural industry in Western Europe and the United States, which generates an excess of food, serves as a significant contributing factor. This situation has led to the implementation of a tactic involving the allocation of land for the purpose of mitigating excess supply. The introduction of nonfood crops is deemed desirable due to related issues such as rural depopulation and the payment of substantial subsidies to maintain fallow land. The demand for energy is expected to generate a vast market for energy crops cultivated on potentially surplus land.

However, it should be noted that the three aforementioned primary concerns are not the sole drivers. Biomass, as an autochthonous energy resource, is widely accessible in numerous nations, and its utilization has the potential to broaden the range of fuel supply in various scenarios, thereby contributing to a more dependable energy supply. The production of biomass has the potential to create employment opportunities. Furthermore, if energy crops that are managed with less intensity are used to replace intensive agriculture, there may be environmental advantages, such as a decrease in the leaching of fertilizers and a reduction in the use of pesticides (Arpia et al., 2021).

In addition, it may be feasible to restore degraded lands by selecting suitable crops. Enhanced biodiversity can be achieved through the utilization of diverse crops and cultivation techniques for biomass production, in contrast to prevailing agricultural methodologies. Biomass is a sustainable resource that can be obtained through natural processes or as a secondary output of human activities, such as organic waste. The global estimate for the capacity of biomass energy obtained from agricultural and forest residues is approximately 30 EJ/yr, in contrast to the annual global energy requirement of more than 400 EJ. In order for biomass to make a significant contribution to the global energy supply, it will be necessary to engage in energy farming, which involves cultivating specialized crops for energy production. This will involve utilizing both fallow land and marginal lands, which are typically not suitable for food crop cultivation. Upon considering energy crops as a potential source of biomass, it is evident that the overall energy potential for biomass-based energy production may be significantly greater than that of biomass residues. During the Rio United Nations Conference on environment and development in 1992, the Renewable Intensive Global Energy Scenario (RIGES) proposed that biomass could potentially meet around 50% of the world's current primary energy consumption of approximately 400 EJ/yr by 2050. Additionally, RIGES suggested that renewables, including biomass, could supply up to 60% of the world's electricity market (Arpia et al., 2021).

The UK government has set a goal to produce 10% of the country's annual electricity demand of 60 GW from renewable sources, with a notable contribution from biomass. Currently, there are approximately 10 biomass projects in operation or in the process of being constructed, which are expected to produce a total of approximately 100 MW of energy. Three primary categories of products can be derived from biomass conversion:

- chemical feedstock,
- electrical/heat energy,
- transport fuel.

Of particular interest in this study is the generation of electricity but the two other endproducts will be examined briefly.

4.2 Types of biomass

4.2.1 Agricultural products and wood

The predominant source of biomass utilized in contemporary times is domestically cultivated energy. Approximately 44% of biomass energy is derived from wood logs, chips, bark, and sawdust. However, it is noteworthy that any organic material has the potential to generate energy in the form of biomass. Additional biomass sources comprise of agricultural byproducts such as corncobs and fruit pits. Electricity generation is facilitated through the utilization of wood and wood waste. A significant proportion of the electrical energy is consumed by industrial sectors engaged in waste production, and this energy is not dispensed by public utilities. Instead, it is generated through a process known as cogeneration. According to Avitabile and Camia (2018), paper mills and saw mills utilize a significant portion of their waste materials to produce steam and electricity for their internal operations. Nevertheless, owing to their high energy consumption, it becomes necessary for them to procure supplementary electricity from utility providers.

4.2.2 Solid waste

The process of incinerating waste materials results in the conversion of refuse into a viable source of energy. A quantity of waste weighing 1 ton, equivalent to 2000 pounds, possesses a comparable amount of thermal energy to that of 500 pounds of coal. The energy content of garbage is not solely derived from biomass, as approximately 50% of its composition is attributed to plastics, which are derived from petroleum and natural gas. Facilities that generate energy by incinerating waste materials are commonly referred to as waste-to-energy plants (Chen et al., 2022).

4.2.3 Landfill gas and biogas

Bacteria and fungi exhibit a nondiscriminatory feeding behavior. They consume deceased flora and fauna, resulting in putrefaction or decomposition. The cellulose present in a decaying log is being enzymatically broken down by a fungus in order to obtain a source of nourishment in the form of sugars. Despite the deceleration of this process within a landfill, the decay of waste still generates a compound known as methane gas. Recent regulations mandate the collection of methane gas from landfills due to concerns regarding safety and the environment. Methane gas is a compound that lacks both color and odor; however, it is not devoid of potential hazards. The gas possesses the potential to result in fires or detonations in the event of its infiltration into adjacent residential structures and subsequent ignition. Methane gas can be extracted from landfills, subjected to purification processes, and subsequently utilized as a source of fuel. Methane has the potential to be generated through the utilization of energy derived from both agricultural and human waste sources. Biogas digesters are enclosed structures that are impermeable to air and can be constructed using materials such as steel or bricks. The waste material deposited into the receptacles undergoes anaerobic fermentation, resulting in the generation of a gas that is predominantly composed of methane. According to Chen et al. (2022), this particular gas has the potential to serve as a source of energy for both electricity generation and household applications such as cooking and lighting.

4.2.4 Ethanol

Ethanol is a type of alcohol fuel, specifically ethyl alcohol, which is produced through the process of fermentation of the sugars and starches present in various plant sources, followed by distillation. Ethanol can be produced from any organic matter that comprises cellulose, starch, or sugar. Corn is the primary source of ethanol production in the United States. Recent technological advancements have enabled the production of ethanol from cellulose present in lignocellulosic biomass, such as woody bars derived from trees, grasses, and crop residues (Chen et al., 2022).

Presently, the majority of petrol retailed in the United States comprises approximately 10% ethanol and is commonly referred to as E10. The United States Environmental Protection Agency granted approval for the utilization of E15 (a fuel blend consisting of 15% ethanol and 85% petrol) in passenger vehicles manufactured from the year 2001 to 2011. According to Duque et al. (2021), fuel that comprises 85% ethanol and 15% petrol, commonly known as E85, is considered a viable alternative fuel (Aransiola, Falade, Obagunwa, & Babaniyi, 2016).

4.2.5 Biodiesel

Biodiesel is a type of fuel that is produced through the chemical reaction between alcohol and various sources of oils, fats, or greases, including but not limited to vegetable oils, animal fats, and recycled restaurant grease. The predominant source of biodiesel in contemporary times is derived from soybean oil. Biodiesel is commonly incorporated into petroleum diesel at varying proportions of 2% (B2), 5% (B5), or 20% (B20). B100, a pure form of biodiesel, can also be utilized in a refined manner. Biodiesel fuels exhibit compatibility with unmodified diesel engines and can be readily utilized within the current fueling infrastructure. According to Duque et al. (2021), the utilization of this transportation fuel has experienced rapid growth in the United States.

Biodiesel is characterized by a negligible amount of sulfur content, which makes it capable of mitigating the levels of sulfur present in the diesel fuel supply of the country. This effect is even more pronounced when compared to the presently available low sulfur fuels. The elimination of sulfur from diesel fuel derived from petroleum has been observed to cause a decline in lubrication. However, biodiesel has been found to possess superior lubricating properties and can effectively decrease the friction of diesel fuel when blended in proportions as low as 1% or 2%. The significance of this trait lies in the fact that the Environmental Protection Agency has mandated a 97% reduction in sulfur levels in diesel fuel since 2006, as reported by Duque et al. (2021).

4.3 Overview of biomass sources

Biomass sources for bioenergy production can be categorized according to their origin and composition. Plants like dedicated grasses, fast-growing trees, and oilseed crops are examples of energy crops. These plants generate a lot of power and can be cultivated on underutilized land without displacing food crops (McKendry, 2002).

Corncobs, wheat straw, and rice husks are all examples of agricultural remnants. These byproducts are often wasted, but they can be put to good use as biomass feedstock, providing farmers with an additional revenue source (Tun, Juchelkova, Win, Thu, & Puchor, 2019). The term “forestry residues” refers to the waste materials left over from logging and wood processing. In order to reduce waste and put otherwise unused materials to good use, branches, bark, and sawdust can be converted into bioenergy (Bonechi et al., 2017). Bioenergy can be produced from a wide variety of organic waste streams, including municipal solid waste, food industry waste, and animal manure. By converting biological waste into energy, we can solve waste management problems while also producing sustainable power and heat (Abioye, Adeoye, Aransiola, & Oyewole, 2015; Rosillo-Calle, 2012).

Availability and distribution of biomass resources differed considerably between locations. Biomass potential is affected by a number of factors, including climate, land

availability, and agricultural practices. Agricultural and forestry hubs, as well as regions with ideal growing conditions for biofuels, are rich in biomass resources (Garcı´a, Pizarro, Lavı´n, & Bueno, 2017). By using a wide variety of biomass sources, we may tap into a sustainable and widely distributed energy source. In what follows, we will examine the pros and cons of distributing biomass for bioenergy generation (Tun et al., 2019).

4.4 Challenges in biomass distribution for bioenergy production

Distributing biomass for bioenergy production has many challenges. The wide variation in readily available biomass supply between regions is a major barrier. Because of differences in temperature, land use, and resource availability, the amount of readily available biomass differs from location to region. To establish which biomass sources are most suited to each region, careful planning and assessment are required (Ahorsu, Medina, & Constantı´, 2018).

Additional technological and logistical challenges arise when it comes to the collection and transport of biomass. Biomass resources are dispersed and hence require efficient collecting methods in order to be exploited, in contrast to the centralization of fossil fuels.

It is necessary to have logistical planning, the required equipment, and transportation infrastructure in order to harvest biomass, particularly from fields or forests (Fernand et al., 2017). This is because harvesting biomass requires transporting the biomass feedstock from the source to the bioenergy facility. Concerns for the environment and the ability to maintain operations over the long term are essential components of biomass distribution. To avoid negative environmental repercussions, sustainable biomass management practices must be used. This includes engaging in responsible land management practices, protecting biodiversity, and limiting soil degradation as much as possible. It is extremely important to strike a balance between the utilization of biomass resources for the production of bioenergy and the protection of ecosystems and natural habitats (Gabisa and Gheewala, 2018).

4.5 Benefits of biomass distribution for bioenergy production

Despite the drawbacks, there are several benefits to distributing biomass for bioenergy production. Enhanced energy security and diversity is a major perk. Using biomass as a sustainable energy source, countries can reduce their dependency on fossil fuels and the volatile global energy market. Biomass is widely available and can be used as a local, renewable energy source (Hoang et al., 2021). Reduced emissions of greenhouse gases and other negative environmental effects are another major benefit. Biomass is considered a carbon-neutral energy source since the carbon dioxide released during combustion is offset by the carbon taken in by plants during growth. This helps mitigate climate change and create a cleaner, more sustainable energy industry (Edrisi & Abhilash, 2016).

Producing bioenergy from biomass could also have financial and employment benefits. Employment opportunities in biomass production, processing, and bioenergy facility operations are created by locally based bioenergy projects, which are beneficial to rural economies. Wastes from agriculture and forestry can be used as biomass feedstock to increase their value and provide new income for farmers and forest owners (Wang et al., 2020).

The distributed nature of biomass-based bioenergy generation provides an additional benefit. By building smaller bioenergy facilities in outlying areas, we can reduce the need for costly and inefficient grid expansion and long-distance transportation. This decentralized approach not only makes the energy system more resilient and flexible, it also increases access to electricity in rural areas (Arpia et al., 2021). Considering these merits, it is evident that distributing biomass for bioenergy production holds great promise for resolving energy and environmental issues. Resource mapping, legislation and regulations, technological breakthroughs, and case studies are only some of the topics that will be explored in the sections that follow (Chen et al., 2022).

4.6 Biomass resource mapping and assessment

In order to disperse biomass effectively for bioenergy production, it is necessary to first accurately map and appraise available resources. Many different methods and approaches are used in these procedures in order to calculate a region's biomass potential (Natarajan, Latva-Ka¨yra¨, Zyadin, & Pelkonen, 2016). Mapping biomass resources is a useful application of remote sensing technology. Land cover, vegetation density, and biomass productivity can all be learned from aerial and satellite imagery. By examining these images, researchers can locate areas with high biomass potential, including dense woods or agricultural regions with substantial crop leftovers. Monitoring land use changes and locating areas where biomass resources may be underutilized or threatened can also be accomplished through the use of remote sensing techniques (Avitabile & Camia, 2018).

Mapping and evaluating biomass resources typically employ geographic information systems (GIS). Through the use of GIS, geographical data including land cover, soil types, climate, and terrain may be integrated into comprehensive biomass resource maps. By superimposing these layers of data, researchers can identify optimal biome locations for biomass production. The viability of biomass distribution is affected by a number of factors, including the routes used to transport the material and the proximity to existing bioenergy facilities, all of which may be analyzed more easily with the help of GIS tools (Ukoba et al., 2023).

In order to accurately evaluate biomass resources, field surveys are essential. Researchers collect biomass quantity and quality data onsite to verify the results of remote sensing and GIS analyses. There are a number of factors that need to be computed, including biomass production and moisture content. In order to verify that the predicted biomass potential is in line with actual ground conditions, it is essential to conduct field surveys to gather ground truth data (Hiloidhari et al., 2017).

Potential biomass feedstocks for bioenergy production can be located with the help of biomass resource mapping. The location of potential biomass resources is useful for arranging its transit and subsequent processing (Ukoba et al., 2023). Biomass planning and optimization are greatly aided by knowing how much and what kind of biomass is readily available in a given area. To reduce waste and maximize energy production, bioenergy

projects can be designed to prioritize the use of local resources, such as agricultural leftovers, in regions where such resources are abundant (Ukoba et al., 2023).

Efficient distribution of biomass for bioenergy production relies heavily on accurate mapping and evaluation of available biomass resources. Using tools like remote sensing, GIS, and field surveys, stakeholders may locate feasible biomass sources, assess their amount and quality, and maximize their usage. Case studies provide valuable insights and provide real-world examples of effective approaches to mapping biomass resources. By continuously improving these mapping methodologies and sharing knowledge and best practices, we can guarantee the sustainable and efficient utilization of biomass resources for bioenergy production (Hiloidhari et al., 2017).

4.7 Policies and regulations for biomass distribution

Increasing biomass dispersion for bioenergy generation is greatly aided by governmental rules and restrictions. Bioenergy is a renewable and sustainable energy source, and thus many nations have enacted regulations and incentives to foster its growth (Singh, Christensen, & Panoutsou, 2021). Feed-in tariffs are a common policy tool used by governments to encourage biomass distribution. Biomass producers benefit from long-term price stability and investment certainty thanks to feed-in tariffs, which guarantee a fixed payment rate for bioenergy generated from biomass sources. According to a study by Yang et al. (2020), biomass distribution projects benefit from these tariffs because they encourage private investment and foster a positive market environment.

Rebates on taxes are another great legislative tool for spreading biomass. In order to make bioenergy projects more financially viable, governments may offer tax credits or exemptions to biomass producers. Such incentives can take the form of tax rebates on equipment purchases, income tax reductions, or property tax exemptions for biomass installations (Ebers, Malmsheimer, Volk, & Newman, 2016). Financial incentives are not the only thing governments offer to boost biomass distribution projects; they also offer grants and subsidies. Research and development, infrastructure construction, and skill development are all viable uses for these funds. Businesses and groups who are interested in entering the bioenergy sector might benefit from grants and subsidies that reduce the high upfront costs of distributing biomass (Bilgili, Koc¸ak, Bulut, & Kus¸kaya, 2017).

Long-term biomass management, environmental protection, and quality control can only be ensured with the help of regulatory frameworks and standards. Governments set up rules and regulations to ensure that biomass feedstocks are obtained, harvested, and transported in an environmentally responsible manner. These regulations contribute in avoiding the overexploitation of biomass resources, encouraging more sustainable land management, and safeguarding ecosystems and biodiversity (Page-Dumroese et al., 2022). International agreements and partnerships also facilitate the exchange of knowledge and the standardization of biomass distribution procedures. Countries can collaborate on R&D projects, share best practices, and share data on policy frameworks. Effective international transfers of biomass feedstocks and bioenergy products are facilitated by international agreements (Malladi & Sowlati, 2018). It is the responsibility of policymakers to create a conducive policy climate that takes into account the need for biomass distribution with social, economic, and environmental considerations. This includes setting clear goals for bioenergy research and development, conducting regular policy reviews and assessments, and holding stakeholder dialogs to make sure that policies are in line with the needs and desires of everyone who has a stake in the issue (Guan et al., 2020).

The distribution of biomass for bioenergy generation is greatly aided by governmental rules and restrictions. Feed-in tariffs, tax incentives, grants, and subsidies are all examples of government policies that encourage investment in the bioenergy sector and foster a favorable market environment for biomass distribution (Ren, Yu, & Xu, 2019). Protecting the environment and ensuring its sustainable use over time and regulatory frameworks and standards are essential for biomass management. Information may be shared more effectively and biomass distribution practices can be standardized, thanks to international collaborations and agreements. By developing well-rounded policies, governments may help speed up the adoption of bioenergy technology and pave the way toward a lowcarbon energy future (Page-Dumroese et al., 2022).

4.8 Technological advances in biomass conversion

The efficiency and effectiveness of biomass conversion procedures have been greatly enhanced by technological advancements, allowing biomass to be transformed into bioenergy. There is a wide variety of conversion techniques that can be used to transform various biomass feedstocks into useful products (Adams, Bridgwater, Lea-Langton, Ross, & Watson, 2018).

Combustion, gasification, and pyrolysis are all examples of thermochemical processes that have seen extensive usage for biomass conversion. Directly igniting biomass to generate thermal and mechanical energy is known as combustion. Biomass gasification results in syngas, a gaseous fuel that can be further processed into different types of biofuels. According to Brown (2019), pyrolysis is the practice of heating biomass without oxygen in order to create biooil, charcoal, and syngas. Technologies such as fluidized bed reactors, integrated gasification combined cycle systems, and improved control systems have considerably advanced these thermochemical processes. As a result of these innovations, energy conversion efficiency has increased, emissions have decreased, and processes have become more versatile (Pang, 2019).

Biochemical processes, such as anaerobic digestion and fermentation, have also benefited from technological developments. Biogas (a combination of methane and carbon dioxide) is produced when bacteria decompose biomass in anaerobic conditions (Ahorsu et al., 2018). Fermentation is the process by which certain bacteria transform sugars present in biomass into biofuels like ethanol and butanol (Bonechi et al., 2017). Sugars in biomass can now be more easily transformed because of recent developments in pretreatment processes such as steam explosion and acid hydrolysis. More efficient and cheaper enzymatic hydrolysis has enhanced the entire conversion procedure (Gouveia & Passarinho, 2017).

Rapid advancements in biomass conversion have been made possible by the merging of bioenergy production with other industries, such as biorefineries. To produce biofuels, bioproducts, and bioenergy, among other things, biorefineries process a wide range of

biomass feedstocks in a number of ways (Yamakawa, Qin, & Mussatto, 2018). By combining multiple conversion processes and making use of a wide range of biomass components, biorefineries boost the value of biomass resources as a whole. The sugars taken from biomass during processing can be used to produce bioethanol, and the residual biomass can be used to produce heat and electricity (Duque et al., 2021).

Technology advancements have also targeted making biomass conversion methods more environmentally friendly. Greenhouse gas and pollutant emissions are two negative outcomes of biomass conversion that researchers and developers are working to mitigate. Improved performance and less wasteful resource use are the results of the use of modern process monitoring and control systems in biomass conversion facilities (Aransiola, VictorEkwebelem, Ikhumetse, & Abioye, 2021; Hoang et al., 2021). Biomass conversion technologies for bioenergy generation have benefited greatly from technological advancements in recent years. Biochemical operations like anaerobic digestion and fermentation use microbes to convert biomass into valuable energy products, while thermochemical processes like combustion, gasification, and pyrolysis provide a wide range of biomass conversion options. When bioenergy production is combined with other industries, such biorefineries, the total value of biomass resources rises. These advancements in technology, along with a focus on sustainability, pave the way for a bioenergy industry that is both effective and environmentally beneficial (Manikandan et al., 2022).

4.9 Conclusion

There are positive and negative aspects associated with the distribution of biomass for the production of bioenergy. The elimination of regional variability, the surmounting of technological and logistical hurdles, and the upkeep of environmental sustainability are among the primary challenges. On the other hand, the advantages of biomass distribution, which include improved energy security, reduced emissions of greenhouse gases, improved economic prospects, and decentralized generation of energy, make it an attractive option. By leveraging biomass resources in the form of effective resource mapping, supportive legislation, technological advancements, and knowledge exchange through case studies, we can both maximize the distribution of biomass for the production of bioenergy and pave the way for a future that is both sustainable and dependent on renewable energy sources.

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