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Review

Potential Use of Industrial Biomass Waste as a Sustainable Energy Source in the Future

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Abstract: Aspects related to the growing pollution of the natural environment and depletion of conventional fossil fuels have become the motive for searching for ecofriendly, renewable, and sustainable alternative energy sources. Particular attention is paid to industrial waste, especially waste of biomass materials, which can be converted into biofuels and energy that meets the growing needs of humanity. The use of biomass for energy purposes is less damaging to the environment, the materials are low-cost, locally available in large quantities, and create employment opportunities for workers in suburban and rural areas around the world. This article discusses issues related to the use of waste biomass materials as renewable energy sources. The current energy situation in the world is analyzed in terms of production, consumption, and investments in green energy. Types of biomass and individual physicochemical and energy properties of waste plant materials obtained for energy purposes are described. Currently available methods of converting biomass into energy, including mechanical, thermal, and biochemical techniques are discussed. The conducted analysis indicates the possibility of using it as a competitive source of electricity and heat. Understanding the properties of biomass materials allows us to understand the right way to use them for energy and reduce the consumption of fossil fuels in the future.

Keywords: growing demand for energy; renewable energy sources; biomass waste materials; energy usefulness of biomass; alternative biofuels; sustainable energy economy

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1. Introduction

Fossil fuel resources are not renewable, but their amounts are limited and close to exhaustion due to overexploitation. According to analyses, global oil resources are extracted at a rate of approx. four billion tons per year. If currently known oil reserves continue to be exploited at or above current levels, it is predicted that all reserves could be exhausted within the next 40 years. The deadline may be slightly extended if new reserves are found [1]. The continuous exploitation of fossil fuels generates side effects for the environment. As a result of their combustion, approximately 21.3 billion tons of CO_2, along with other harmful gases, are released into the atmosphere globally, causing the greenhouse effect. It is estimated that natural processes can neutralize about half of this amount of gases. However, CO_2 emissions into the atmosphere, amounting to about 10.65 billion tons per year, are still a serious burden. Therefore, in order to ensure security, free life, and access to energy for future generations, it is necessary to search for new, alternative energy resources that will be environmentally friendly and meet the criteria of a sustainable economy and a zero-emission economy [2].

An opportunity for the energy sector is undoubtedly renewable energy, called bioenergy, which is stored in an organic form in a chemical state. The sustainable energy strategy in the European Union was launched by the European Commission in 1998 to implement Articles 2 and 6 of the European Treaty on sustainable development. This policy meant improving the well-being of society in the long term by striving to maintain a balance between energy security, meeting social needs, the competitiveness of the economy, and environmental protection. A sustainable energy system should ensure energy security, be competitive, effective, and support the dynamics of economic growth, and take into account human health and protect the environment [3,4]. Therefore, taking into account the aspirations in energy and environmental policy, renewable energy sources include biomass as the totality of organic animal or vegetable matter, including, in particular, the biodegradable fraction of products, wastes, and residues from agriculture, forestry, industry, households, as well as other substances obtained as a result of processing such biomass materials [5]. Agricultural biomass material has the advantage of absorbing the increasing levels of CO_2 in the atmosphere through biological CO_2 sequestration. Biomass waste as a renewable energy source can be converted into bioenergy using various technologies [6]. The European Union's strategy on biofuels states that new technologies for obtaining and using renewable fuels need to be developed, especially through the management of agricultural by-products and other waste, including biodegradable industrial waste [7].

Biomass material belongs to renewable energy resources due to the fact that CO_2 emitted in the processes of its combustion or thermal conversion does not increase the CO_2 content in the atmosphere. Biomass is an organic material obtained from plants growing through, among others, the process of photosynthesis. Plants assimilate CO_2 released into the environment as a result of the degradation processes of other plants as part of a closed cycle. Absorption of solar radiation by vegetation, CO_2 assimilation, and transformation into organic material is of great importance on many levels. Thanks to this, the life of terrestrial and aquatic organisms that use this energy is possible. Therefore, the use of biomass for energy purposes only leads to CO_2 emissions into the atmosphere, which will then be used by plants to reproduce biomass [8–10]. Plants in the form of biomass are decomposed by microorganisms or can be burned and turned into ashes in thermal incinerators and co-incineration in kilns, converting chemical energy into mechanical or electrical energy. If biomass undergoes natural biocomposting processes, it gives back carbon in the form of methane or CO_2 to the atmosphere. The general closed cycle of biomass energy circulation is shown in Figure 1 [11]. It is estimated that most developed countries will use biomass waste to meet more than 50% of their net energy needs by 2050. Agricultural biomass is rich in cellulosic raw materials, which are important in the production of biofuels, thereby reducing waste and meeting energy needs with no risk of losing valuable food [12].

From an energy point of view, biomass is composed of waste of plant and animal resources and at the same time, their energy potential. Using it for energy purposes will reduce dependence on traditional fossil fuels due to the abundance of resources, local availability, and lower costs. In many underdeveloped countries, large amounts of firewood are used for cooking and other household heating purposes, as well as other parts of agricultural and animal waste. Such large-scale unsustainable use of biomass resources may result in exposure to air pollution. Agricultural and food waste is locally also used to feed farm animals such as pigs, cows, bulls, chickens, ducks, and others [13].

Biomass waste is generated in huge amounts around the world, with rice straw (approx. 731.3 million tons), wheat straw (354.34 million tons), sugarcane bagasse (180.73 million tons), and corn stover (128.02 million tons) being the most produced annually [2]. The largest production of wheat and rice straw takes place in Asia, while the largest producer of corn straw and sugarcane bagasse is the United States [14]. According to statistics, approximately 950 million tons of biomass are produced annually in Europe, from which approximately 300 million tons of fuel equivalent to petroleum fuel can be produced. These data mean that biomass waste can provide around 65% of Europe's total oil consumption [15].

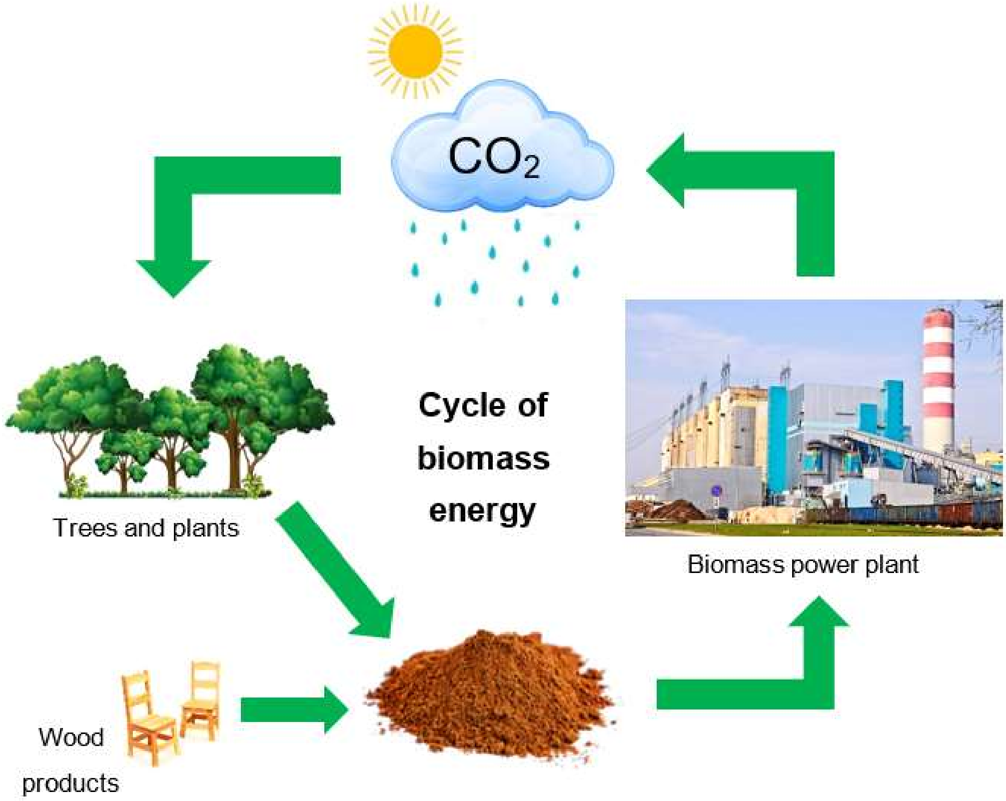

Figure 1. The general cycle of biomass energy.

The purpose of this study is to present an overview of the research conducted so far on the possibility of using biomass waste as a renewable energy source, to assess the current state of knowledge, and to indicate potential future research directions. Before undertaking research on the discussed problem, a number of questions regarding various aspects were asked. What is the current availability of biomass? What is the current energy situation in the world, including consumption and demand? What are the types and sources of biomass as a potential raw material? What methods of biomass conversion are available? What are the methods of energy characterization of biomass materials? Are there any barriers to the use of biomass materials? What is the future scope of biomass waste energy sources? There will be an attempt to find answers to all these questions and doubts with the support of the current literature, statistical data available through various databases, research results of investigators, and reports on available and new technologies. This study may help us to understand the current situation, the need to change the approach to the energy sector, and indicate future solutions in global terms. The above considerations were an inspiration to consider the energetic usefulness of waste biomass materials in this article.

2. Biomass Availability and the Current Global Energy Situation

Huge amounts of biomass are available in various natural terrestrial and aquatic areas, but also as waste from human industrial activities. In accordance with World Bioenergy Association, the total global aquatic and terrestrial biomass resources are approximately 4 billion tons and 1.8 trillion tons, respectively. It is estimated that the total biomass in the world has the potential to contribute to the production of around 33,000 EJ (exajoules), which is more than 80 times more energy than the world's annual energy consumption [16]. Fossil fuels (coal, oil, and natural gas) are still the dominant global energy source and account for approximately 81% of the total primary energy supply. Renewable energy technologies, such as solar, wind, water, biomass, geothermal, etc. had a share of 14.1% in the primary energy supply in 2019. Domestic biomass supply was 56.9 EJ, of which 85%

was solid biomass, including wood pellets, wood chips, and other biomass sources. Liquid biofuels accounted for 8%, municipal and industrial waste 5%, and biogas 2% [16].

Agriculture is a key area for increasing bioenergy potential in the future. There is a great opportunity for the growth of various crops in the world, which will allow increasing the production of not only food but also fuel using bioenergy. Another sector after forestry and agriculture is the production of energy from municipal and industrial waste, where the energy supply was 2.59 EJ in 2019 [16].

In 2019, 655 TWh of electricity was produced worldwide from biomass. Sources of solid biomass accounted for 68%, and municipal and industrial waste17%. Asia produced 39% of bioenergy (255 TWh), followed by Europe with 35% (229 TWh). It was estimated that, in total, the power plants produced around 428 TWh of bioenergy. In turn, 1.17 EJ of heat was produced from biomass raw materials, including 53% from solid biomass sources and 25% from solid municipal waste. Around the world, 1.35 EJ of heat was produced in CHP plants and 0.43 EJ in Europe, which is the world leader in the production of heat from biomass in power plants with a global share of 88% [16].

In such European countries as Poland, Denmark, and Sweden, 50% of energy demand is covered by renewable energy. In Poland, there is a growing trend for the increasing use of biomass materials for the production of biofuels for transport and electricity generation due to well-developed agriculture and food production in the country. In Poland, there are plans for at least 80% of total energy to come from renewable sources, including biomass, and as much as 75% of biomass energy is planned to be produced from agricultural biomass [17]. Austria, Sweden, and Finland use 13%, 17%, and 18% of biomass energy, respectively. Austria and Sweden are trying to use more firewood to produce heat, and there is a growing trend towards plantations of energy trees such as poplar or willow. Some countries have favorable policies in this regard; for example, France has introduced tax exemptions for the production of ethanol and biodiesel in order to encourage the development of biomass technologies. Great Britain has put emphasis on the development of effective biogas recovery systems from landfills for the production of electricity and heat. In comparison with representatives of other continents, the United States uses biomass for about 3% of its total energy demand, which corresponds to about 3.2 million TJ per year [18].

According to recent literature reports, global energy production is estimated at around 27,000 TWh/year and around 2664 TWh/year in the European Union (EU) [19,20]. Waste heat recovery of the industrial sector in the EU has been estimated at around 300 TWh/year, of which 30% of waste heat is low-temperature heat (<200 °C), 25% medium-temperature heat (200–500 °C), and 45% high-temperature heat (>500 °C) [21–24]. In 2020, global primary energy consumption decreased by 4% (564 EJ) compared to 2019 (Figure 2). This was due to the COVID-19 pandemic and its impact on fuel consumption for transport and other sectors of the economy. In 2021, a revival in energy consumption and its increase of 5.5% (595 EJ) compared to the previous year has been observed. However, global energy demand continues to grow and is unlikely to decline in this sector [25].

Global energy consumption continues to be concentrated around primary energy fuels such as coal and oil. The first place in terms of the largest consumption of primary energy in the world is occupied by China, consuming around 158 EJ in 2021 (Figure 3). The United States is in second place with an average consumption of around 93 EJ. It is followed by India, Russia, Japan, Canada, Germany, and other countries [26]. Renewable energy consumption is projected to increase annually and could reach around 247 EJ by 2050 (Figure 4) [27].

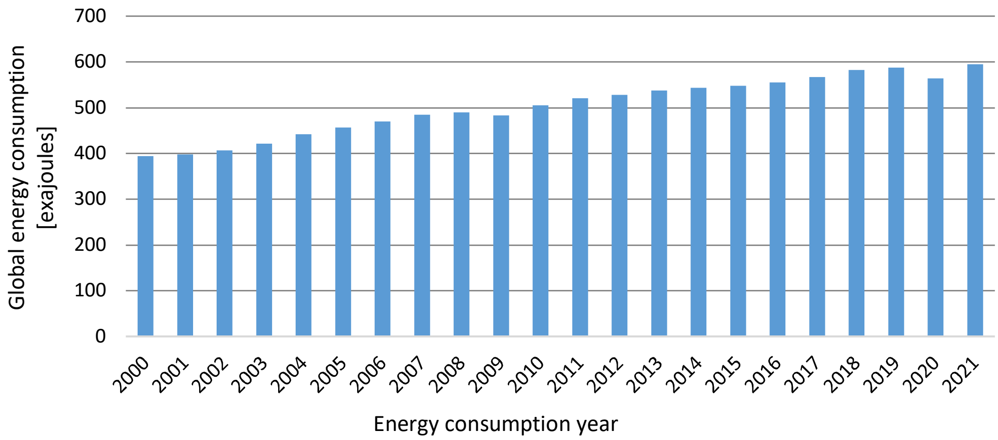

Figure 2. Global primary energy consumption (2000–2021) [25].

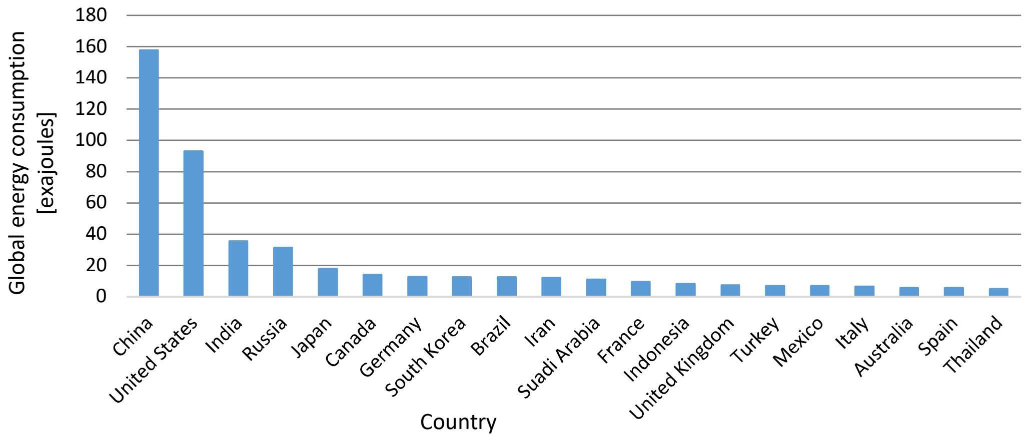

Figure 3. Global primary energy consumption in 2021 by country [26].

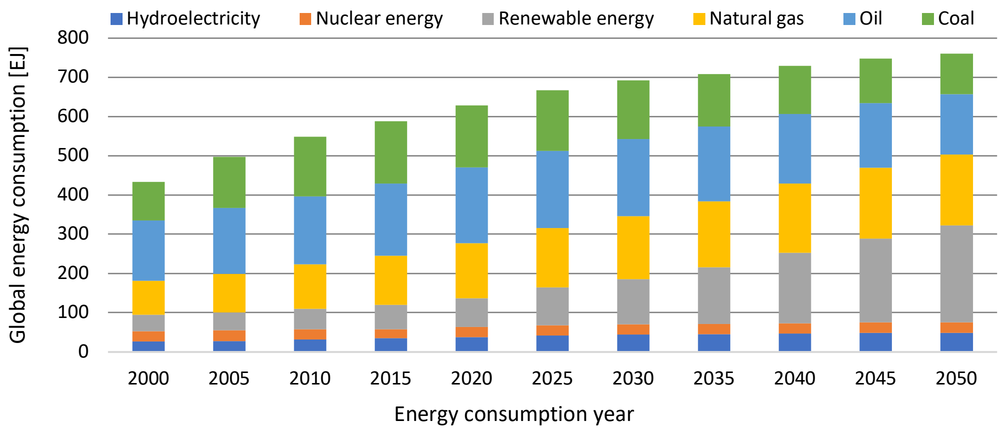

Figure 4. Global energy consumption (2000–2019) and a forecast until 2050 [27].

According to statistical data, in 2020, global bioenergy production was approximately 584 terawatt hours (Figure 5). The trend is still upward due to the changing energy sector toward the use of renewable energy sources from organic, biological, and waste materials. Bioenergy can come from combustion processes of biomass in the form of natural or waste wood, sawdust, straw and other agricultural waste, animal excrement, sewage sludge, seaweed, sugar cane, and other plants, organic waste (e.g., beet pulp, corn stalks, grass, etc.), vegetable oils, or animal fats. The share of global energy from renewable sources is growing every year. In 2018, 2.36 terawatts of cumulative renewable energy capacity were recorded. Despite a steady increase in the consumption of renewable energy, unfortunately, it is still a small amount compared to the consumption of fossil fuels [28]. The global supply of biomass for primary energy is steadily increasing from 41.6 EJ in 2000 to 57 EJ in 2019 (Figure 6) [29]. Similarly, there is an increase in the global production of electricity from biomass, and in 2019, it amounted to 655 TWh (Figure 7) [30].

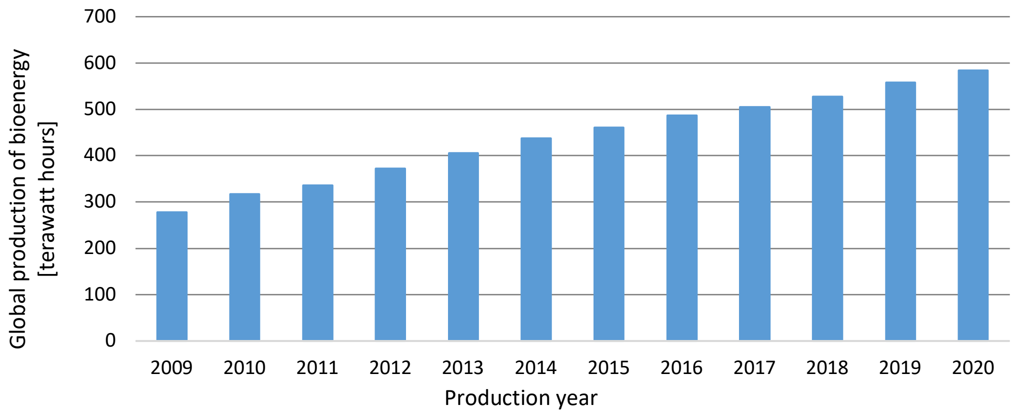

Figure 5. Global production of bioenergy (2009–2020) [28].

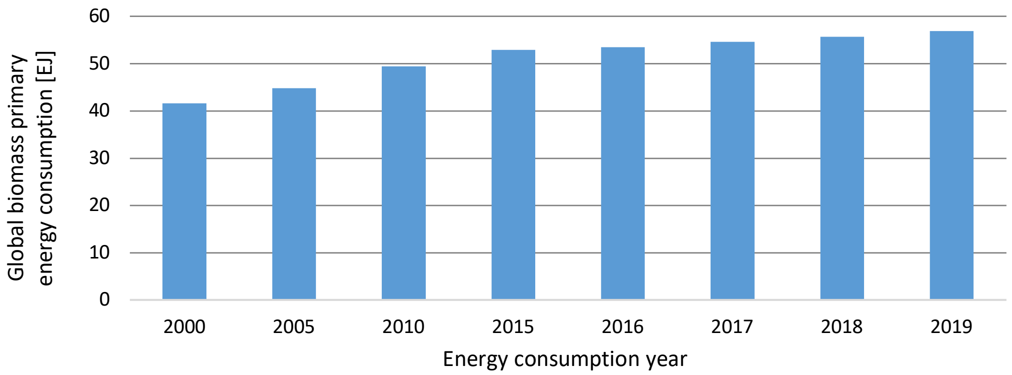

Figure 6. Global biomass primary energy consumption (2000–2019) [29].

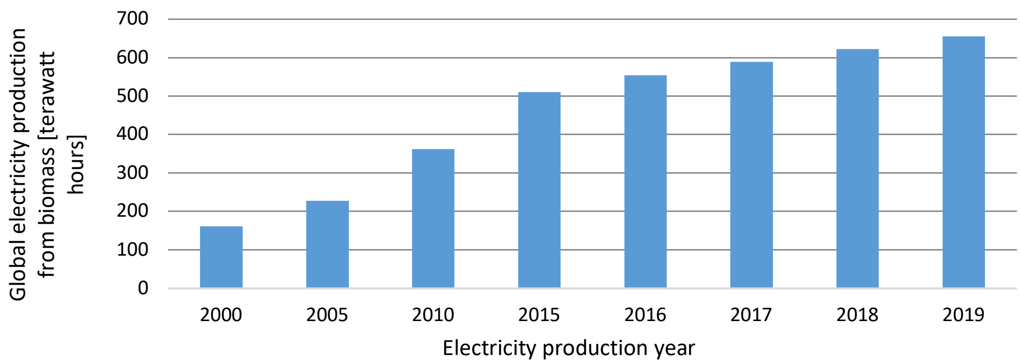

Figure 7. Global electricity production from biomass (2000–2019) [30].

In recent years, incineration of municipal solid sewage sludge using circulating fluidized bed combustion (CFBC) technology at temperatures up to 1000 °C has become increasingly popular in the European Union, China, and Japan. Modern incineration plants do not emit large amounts of pollutants into the environment and atmosphere compared to old ones due to increasingly strict legislation. As a result, it is possible to recover thermal energy and reduce methane emissions released from landfills. It should also be emphasized that innovative gas purification technologies are being developed both during and after the combustion process in order to reduce pollutants harmful to the environment [31,32]. In 2019, the global value of the waste-to-energy market was

USD 35.1 billion (Figure 8). According to estimates, this market could have reached USD 50.1 billion by 2027, assuming constant growth of 4.6% [33]. Global production of heat and electricity from waste amounted to 2.59 EJ in 2019 (Figure 9) [34]. World total energy supply from renewable energy sources and waste continues to grow and in 2019 amounted to 85,425 PJ (Figure 10) [35]. Energy generation from waste-to-energy systems is reported to have increased from 221 TWh in 2010 to 283 TWh in 2022 [36].

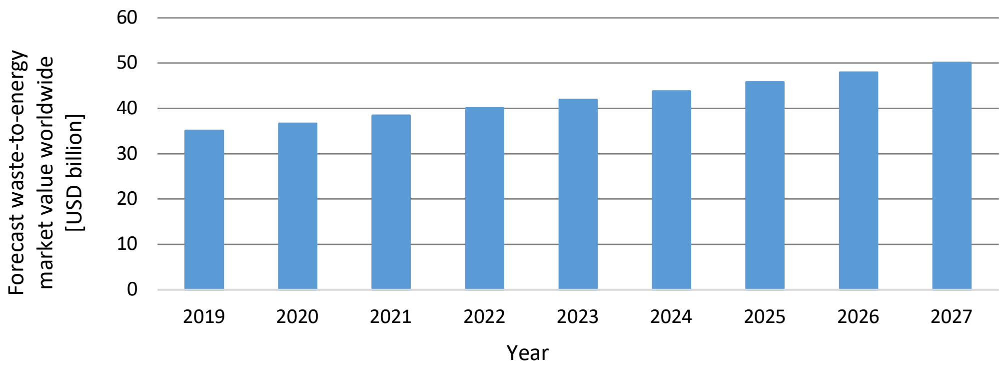

Figure 8. Global waste-to-energy market value forecast (2019–2027) [33].

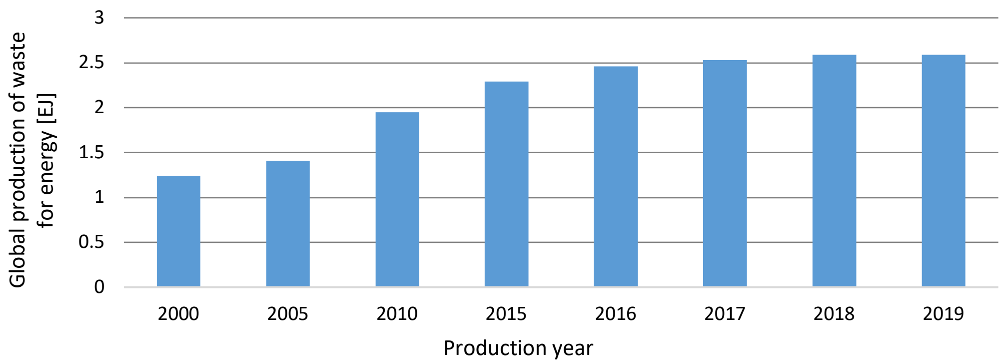

Figure 9. Global production of waste for energy (2000–2019) [34].

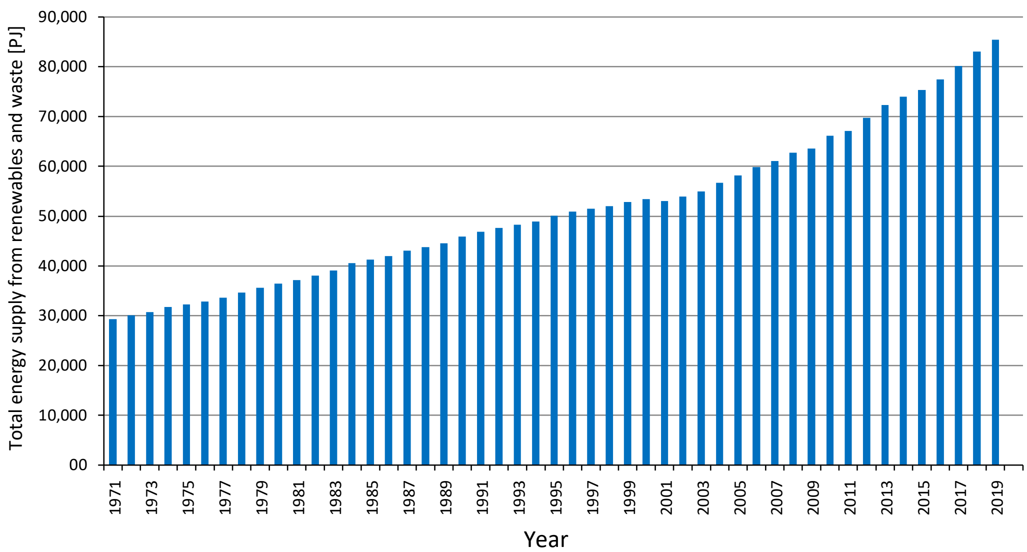

Figure 10. Global total energy supply from renewables and waste [35].

In the current energy crisis, clean energy is a great opportunity for economic growth in many countries, creating new jobs as well as the development of new international economic competition. By 2030, global investments in clean energy have been planned at the level of approx. USD 2 trillion, which is double compared to the current state of 2022 (Figure 11). It is estimated that the annual growth of solar and wind energy in the United States will increase by two and a half times and the production of electric cars by seven times. In China, the expansion of clean energy is planned, which means a gradual reduction in the consumption of coal and oil. The current energy crisis in the European Union has become a stimulus for the implementation of renewable energy sources, which may be associated with a reduction in demand for natural gas and oil by 20% and for coal by 50%. In Japan, a green transformation program is being implemented, ensuring an increase in funding for green and clean energy technologies, including nuclear energy, low-emission hydrogen, and ammonia. In India, due to the rapidly growing demand for electricity, it is planned to achieve the production of clean renewable energy at the level of 500 gigawatts in 2030 [37].

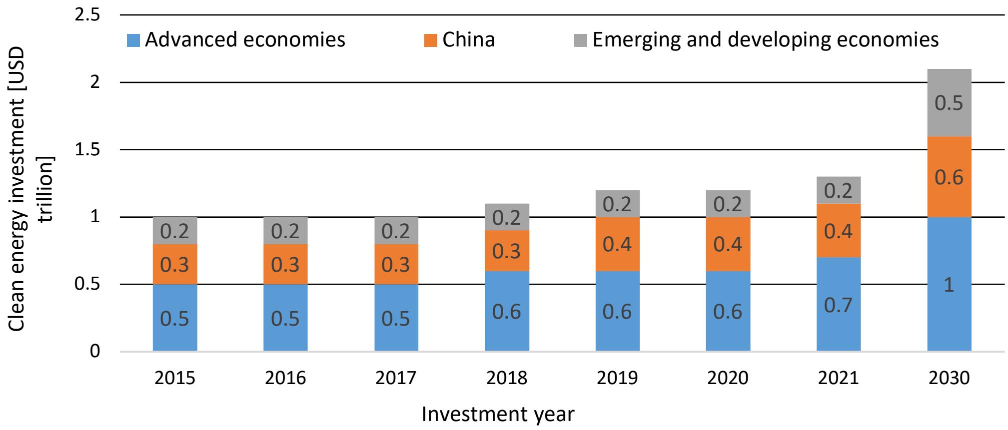

Figure 11. Global clean energy investment in the period 2015–2021 and forecasts for 2030 [37].

3. Classification, Types, and Sources of Biomass

Due to the origin, function, and final products, biomass can be divided into biomass existing in nature and the use of biomass as feedstock. The most commonly used classification is the division of biomass into different groups: wood and woody biomass, herbaceous biomass, aquatic biomass, animal and human waste biomass, and biomass mixtures (Tables 1 and 2) [38,39]. Other literature reports indicate that the main sources of biomass (Figure 12) include agricultural and forest residues (waste from the wood industry, e.g., sawdust, shavings, etc.), animal residues, sewage, algae, and aquatic crops. Biomass also includes municipal solid waste (MSW) and waste streams originating from anthropogenic activities in the absence of the possibility of their reuse [9].

Table 1. Types of biomass and examples [38].

Type of Biomass	Species and Varieties
Wood and woody biomass	Wood industrial waste, forest waste, branches, stems, chips, foliage, lumps, pellets, briquettes, sawdust, bark, sawmill, and others from various wood species
Herbaceous biomass	Flowers and grasses (bamboo, brassica, timothy, alfalfa, miscanthus, switchgrass, cane, arundo, bana, cynara, others); straws (sunflower, mint, bean, barley, flax, oat, sesame, wheat, corn, rice, rape, rye, others); other residues (husks, fruits, grains, vegetables, coir, pips, cakes, bagasse, fodder, pits, hulls, pulps, kernels, seeds, shells, stalks, cobs, food, etc.)

Table 1. *Cont.*

Type of Biomass	Species and Varieties
Aquatic biomass	Freshwater or marine algae, microalgae or macroalgae, kelp, lake weed, seaweed, water hyacinth, etc.
Animal and human waste biomass	Various manures, meat-bone meal, bones, etc.

Table 2. Range of chemical composition of different types of biomass [39].

Type of Biomass	C [%]	O [%]	H [%]	S [%]	N [%]	Volatile Matter [%]	Fixed Carbon [%]	Moisture [%]	Ash [%]
Wood and woody biomass	49–57	32–45	5–10	<1–1	<1–1	30–80	6–25	5–63	1–8
Herbaceous biomass	42–58	34–49	3–9	<1–1	<1–3	41–77	9–35	4–48	1–19
Aquatic biomass	27–43	34–46	4–6	1–3	1–3	42–53	22–33	8–14	11–38
Animal and human waste biomass	57–61	21–25	7–8	1–2	6–12	43–62	12–13	3–9	23–34
Biomass mixtures	45–71	16–46	6–11	<1–2	1–6	41–79	1–15	3–38	3–43

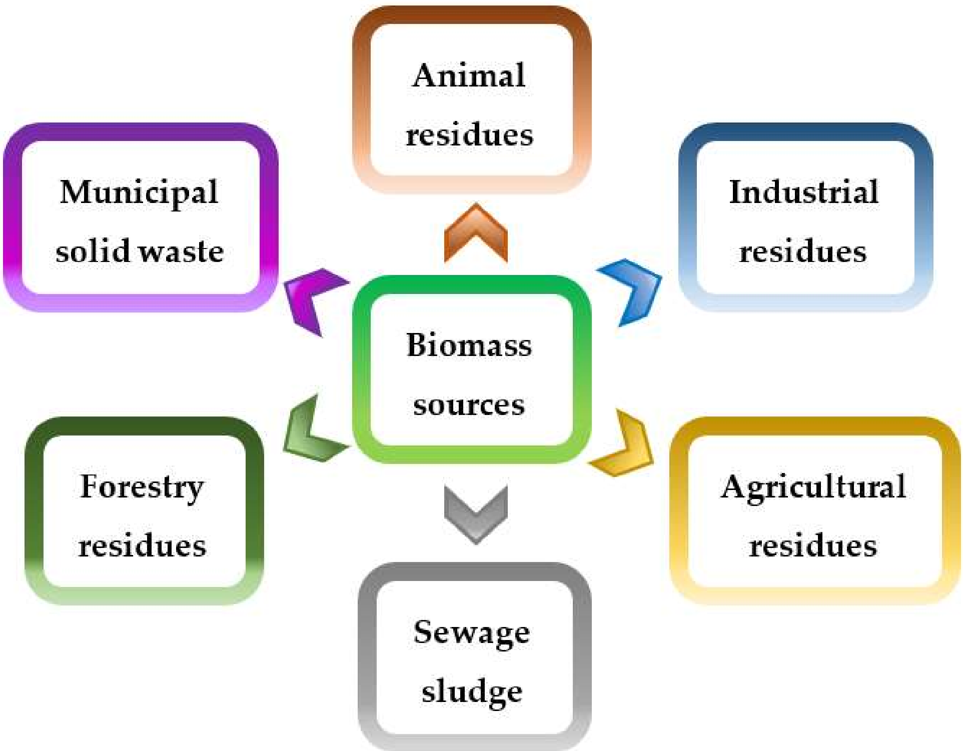

Figure 12. The main biomass sources [9].

Wood biomass consists mainly of cellulose (CE), hemicellulose (HCE), and lignin (LIG). Most often, these are wood and furniture industry waste, tree and root residues, bark, and leaves of woody shrubs, from which energy can be obtained as a result of combustion, gasification, or other thermal conversion processes. Production residues, non-commercial wood residues, post-consumer wood waste, municipal, and agricultural waste are often used for energy purposes [38].

Herbaceous biomass resources come mainly from agricultural residues and energy crops. Agricultural residues are by-products of food, textile, and other industries. Some of these wastes are used as animal feed. Their use as a source of bioenergy is not yet sufficiently known because their monitoring is not sufficient and there is a lack of studies in this area. On the other hand, energy crops are used for energy purposes [10].

Aquatic biomass includes macroalgae, microalgae, and emerging plants. Macroalgae are multicellular organisms that can reach up to tens of meters in length. They are mainly used in food production and hydrocolloid extraction. Microalgae are microscopic organisms such as diatoms, green algae, and golden algae. They are one of the largest sources of biomass on earth. They can be used to obtain starch, oils, or carbohydrates. Emerging plants occur partially submerged in swamps and marshes [40]. Aqueous biomass is a very good raw material for the production of biodiesel due to the fact that much larger amounts of biomass material per hectare can be used compared to land-based crops. However, the commercialization of biofuel from aquatic biomass is a huge challenge and requires a lot of technological research before successful implementation [41].

Sources of animal and human waste include various types of animal manure, human dung, meat meal, and bones. This waste is a source of pollution, unpleasant odors, and a threat to health; hence the relevant regulations have ordered the introduction of appropriate management methods. A useful technique is anaerobic digestion, which produces biogas as a potential source of energy in households or a source of electricity in power plants or internal combustion engines [42]. Sometimes biomass waste is in a mixed form, consisting of many raw materials of different types (Table 3).

Table 3. Higher heating values (HHV) of biomass waste samples.

Biomass Waste/Ref.	HHV [MJ/kg]	Biomass Waste/Ref.	HHV [MJ/kg]	Biomass Waste/Ref.	HHV [MJ/kg]
Corn stover [43]	17.8	Sugarcane bagasse [13]	20	Sugarcane leaves [13]	20
Corncob [43]	17.0	Sunflower shell [43]	18.0	Banana peel [13]	17.4
Beech wood [43]	19.2	Barley straw [13]	18.16	Ailanthus wood [43]	19.0
Wheat shoot [13]	17.15	Hazelnut shell [43]	20.2	Wood bark [43]	20.5
Olive husk [43]	20.9	Walnut shell [43]	21.6	Wood chips [44]	20.9
Bagasse [44]	21.2	Straw [44]	15.2	Rice husk [44]	15.1
Pine bark [44]	20.4	Cotton stalks [44]	19.0	Black coffee husks [44]	18.6
Pine sawdust [45]	18.3	Tucuma seed [45]	20.8	Ground nut shell [46]	19.7
Soya stalk [46]	19.1	Saw dust [46]	17.7	Palm frond [46]	14.5
Press mud [46]	14.9	Forest leaves [46]	12.2	Palm leaves [46]	15.4
Bamboo leaves [47]	15.7	Coconut husk [47]	15.9	Elephant grass [47]	15.1
Typha [47]	15.8	Castor stalk [47]	14.6	Ipomea [47]	15.3
Sunhemp [47]	15.9	Sesbania [47]	14.4	Bringle residue [47]	12.3
Tomato residue [47]	11.3	Capsicum residue [47]	13.0	Kanjaru weed [47]	9.8
Su baval [47]	16.8	Perry grass [47]	14.5	Okhara residue [47]	12.4
Eucheuma seaweed [47]	8.9	Spirullina powder [47]	19.5	Algae powder Spirogyra [47]	5.1

Generally speaking, sources of biomass waste for biofuel purposes may be agriculture, forestry, the agrifood industry, public utility facilities, and others. The content of the natural components (cellulose (CE), hemicellulose (HCE), and lignin (LIG)) varies depending on the type of biomass; examples include the following: wheat straw (38% CE, 30% HCE, 16.5% LIG), rice straw (39.04% CE, 20.9% HCE, 5.7% LIG), rice hull (33.47% CE, 21.03% HCE, 18.8% LIG), soft timber (35–40% CE, 25–30% HCE, 27–30% LIG), soybean hull (56.4% CE, 12.5% HCE, 18% LIG), rye straw (28.8% CE, 27.6% HCE, 2.8% LIG), sorghum straw (32% CE, 24% HCE, 13% LIG), barley straw (40% CE, 30% HCE, 15% LIG), peanut shell (40.5% CE, 14.7% HCE, 26.4% LIG), sugarcane bagasse (65% CE and HCE, 18.4% LIG), maize stover (12.4% CE, 30.8% HCE, 1.4% LIG), coconut husk (24.7% CE, 12.26% HCE, 40.1% LIG), rapeseed straw (32% CE, 16% HCE, 18% LIG), soybean straw (35% CE, 17% HCE, 21% LIG), sunflower straw (32% CE, 18% HCE, 22% LIG), energy plants (45% CE, 30% HCE, 15% LIG), grasses (39.7% CE, 16.9% HCE, 17.6% LIG), wood waste (50% CE, 23% HCE, 22% LIG), and municipal waste (45% CE, 9% HCE, 10% LIG) [48–58].

Non-fossil, organic materials of biological origin constitute solid biomass that can be used to produce electricity and heat. Examples include firewood (e.g., pellets or briquettes produced from wood and paper industry waste and natural plant waste), energy crops grown on plantations, for instance, grasses (*Panicum virgatum*, *Andropogon gerardi*, *Miscanthus giganteus*, *reed canarygrass*, etc.), fast-growing trees and shrubs (*Acer negundo*, *Robinia pseudoacacia*, *willow*, *poplar*, *Rosa multiflora*, etc.), perennials (*Sakhalin knotweed*, *Jerusalem artichokes*, *Virginia mallow*, *Silphium perfoliatum*, etc.), annuals (energy crops: rye, beet, maize, rape), as well as residues from horticulture and agriculture [48]. Another classification includes the following division: processed waste (e.g., fruits and vegetable waste, sawmill wastes, plant oil cake, nutshells and flesh, bagasse, industrial wood waste), processed fuel (e.g., biogas, densified biomass, charcoal waste, briquette, pellets, plant oils, rape, sunflower, methanol, ethanol), woody biomass (e.g., wood waste, shrubs, bushes, forest floor, sweepings), non-woody biomass (energy crops, cereal straws, cassava, cotton, roots, tobacco, stems, grasses, and soft plant stems) [59].

The cultivation of energy crops is becoming an increasingly popular source of energy. The requirements are similar to those for agricultural crops, namely the right type of soil, climatic conditions, agronomic procedures, and others. In 2019, the global production volume of the most popular energy crops was as follows: wheat 733.4 million metric tons (MMT), coarse grain 1373.6 MMT, and rice 484.2 MMT. Their largest producers include China, India, and the United States [13].

There are six categories of crop groups with their residues: cereal (rice straw and husk, wheat shoot and pod, maize cob and shoot, bajra cob, husk and shoot, barley straw, ragi straw, and jowar cob, husk, and shoot), oilseeds (shoots of mustard, rapeseed, sesame, Niger, linseed, safflower, and groundnut), pulses (shoots of sunflower, tur, lentil, gaur, and gram), sugarcane (bagasse and leaves of sugarcane), horticultural (banana peel, coconut frond, and areca nut husk and frond), and others (cotton and jute shoots, husks, shells). Unfortunately, in developing countries, some farmers practice burning crop residues in their fields, wasting energy that could be used for energy purposes for many people [60].

According to the Food and Agriculture Organization (FAO), forest resources in terms of biomass are only considered in the range of material diameters equal to or greater than 10 cm. The following types of residues can be included in this category: processed forest residues (sawdust and logs) and unprocessed residues (trees, branches, and leaves). According to FAO statistics, about 25% of the world's forest land is about 5 billion hectares of forested land [61,62].

Municipal solid waste accounts for a huge amount of waste from urban and rural areas around the world. These include household waste, medical waste, or industrial waste, which are sometimes not all sorted, so they are stored in the same landfill. In order to be subjected to appropriate thermal, chemical, or biochemical processes, segregation is necessary. Then, it is possible to use the waste in a sustainable way to convert it into energy within the framework of a circular economy [63].

Inadequate and irresponsible management of solid waste may lead to increased pollution of the land, water, and air environment. The consequences for humanity can be catastrophic and related to the uncontrolled spread of many pathogenic microorganisms and, thus, the deterioration of public health (chronic, infectious diseases of the respiratory or digestive system). In addition, landfilled solid waste can produce huge amounts of methane, which contributes to significant emissions of greenhouse gases into the atmosphere as a result of global climate change. Therefore, in order to prevent the negative effects of the growing amount of solid waste, solutions such as segregation and recycling, combustion in boilers to produce heat and electricity, anaerobic digestion to produce compost, bioenergy, or electricity should be sought and implemented [64].

According to the literature on the analysis of global solid waste management, there has been a significant increase in the amount of waste generated annually in recent years. At the current rate of growth, it is estimated that the amount of waste could reach around 2.2 billion tons per year in 2025, and the costs could rise to around £302.67 billion [65].

Another group of biomass materials is those used to remove pollutants from the aquatic environment. Appropriate quality drinking water is a prerequisite for the proper and sustainable development of life and ecosystems. The natural nature of water is changing, and access to clean and healthy drinking water has become an issue in many emerging and developing countries. Water pollution is related to climate change but also to human activities, including intensive and rapid industrialization, urbanization, uncontrolled consumerism, water pollution from industrial wastewater, and household waste [66–69]. In accordance with the UN World Water Development Report (2018), nearly 47% of the global population lacks access to clean and reliable drinking water, and pursuant to estimates, this number may increase to 57% in 2050 (approx. 4 to 10.2 billion people) [70]. Large amounts of water are used by industrial plants, and after processing, contaminated water is discharged into land reclamation or rivers, causing pollution and a threat to aquatic life. Among the contaminants, there are often heavy metals that come from various industries, including mining, tanneries, untreated municipal sewage sludge, electroplating, industrial production such as textiles, smelters, foundries, dyeing, metallurgy, alloy industry, petrochemical plants, oil refineries, metal plating, chemical industry, chemical fertilizers, pesticides, radiator manufacturing, battery manufacturing, as well as metal piping, transport, fuel combustion, combustion by-products from coal-burning power stations, and many others [71]. Heavy metals (Cu, Cd, Zn, Pb, Cr, As, Hg, Ni, Co, etc.) are estimated to be the main pollutants in wastewater, and they are a threat due to such properties as non-biodegradability, toxicity, harmfulness to the health of living organisms, or carcinogenicity. Therefore, it is necessary to remove or reduce metal ions from industrial wastewater before they enter the aquatic environment (rivers, lakes, seas, oceans, or other water reservoirs) [72–75].

Among conventional methods, the most promising are adsorption and biosorption processes due to many benefits such as the low cost of adsorbents (for instance, industrial waste), low operating costs, simple operation, no need for additional chemical reagents, the small amount of sludge produced, low energy demand, no negative impact on the natural environment, high efficiency of the metal removal process, simultaneous adsorption of many metal ions, treatment of large volumes of wastewater, the possibility of adsorbent and biosorbent regeneration, the possibility of easy desorption of metals, being functional in a wide range of process conditions, including temperature, pH, concentration and presence of other metal ions, adsorbent dose, the reduction in the amount of waste, the possibility of metal removal in dilute concentrations at ppb level, and no increased chemical oxygen demand of water, which is a limitation of some conventional methods [76]. Appropriate adsorbents and biosorbents are selected on the basis of previously conducted laboratory experiments or literature reports. Commonly used commercial adsorbents are activated carbons, carbon nanotubes, or zeolites. However, the costs of adsorption processes using activated carbons are high and continue to increase due to the rising prices of fossil fuels and the depletion of coal-derived activated carbon [77]. Due to these obstacles, cheap adsorbents with high adsorption capacity and minimal environmental impact are sought. Of particular interest are raw materials and natural resources, low-cost biomaterials derived from agricultural by-products, available agricultural waste, terrestrial and aquatic biomass, as well as by-products of industrial processes. The effectiveness of ecological adsorbents varies and depends on the composition, process conditions, or type of metal ions. Sometimes biosorbents are highly effective and comparable to expensive commercial ones (e.g., composites based on biopolymers), and sometimes their effectiveness is at an average or low level. However, waste adsorbents from industry and agriculture are certainly an ecological and economical solution for new technologies for removing heavy metal ions from wastewater. In addition, secondary raw materials from waste are a valuable energy source of biomass [78].

4. Biomass Energy Classification and Conversion Methods

The term bioenergy is an increasingly popular term used in the literature and means energy from various sources of biomass. Current technological progress creates many opportunities for the implementation of new alternative energy sources. The use of biomass resources is a promising direction for the management of waste collected daily in huge amounts in many urban and rural areas. Bioenergy can be produced in the form of heat, electricity, or biofuels (gaseous, liquid, solid) in thermochemical or biochemical processes as a result of biomass treatment (Figure 13). In order to produce bioenergy, bioproducts, or biofuels, pretreatment of biomass is necessary [79–81].

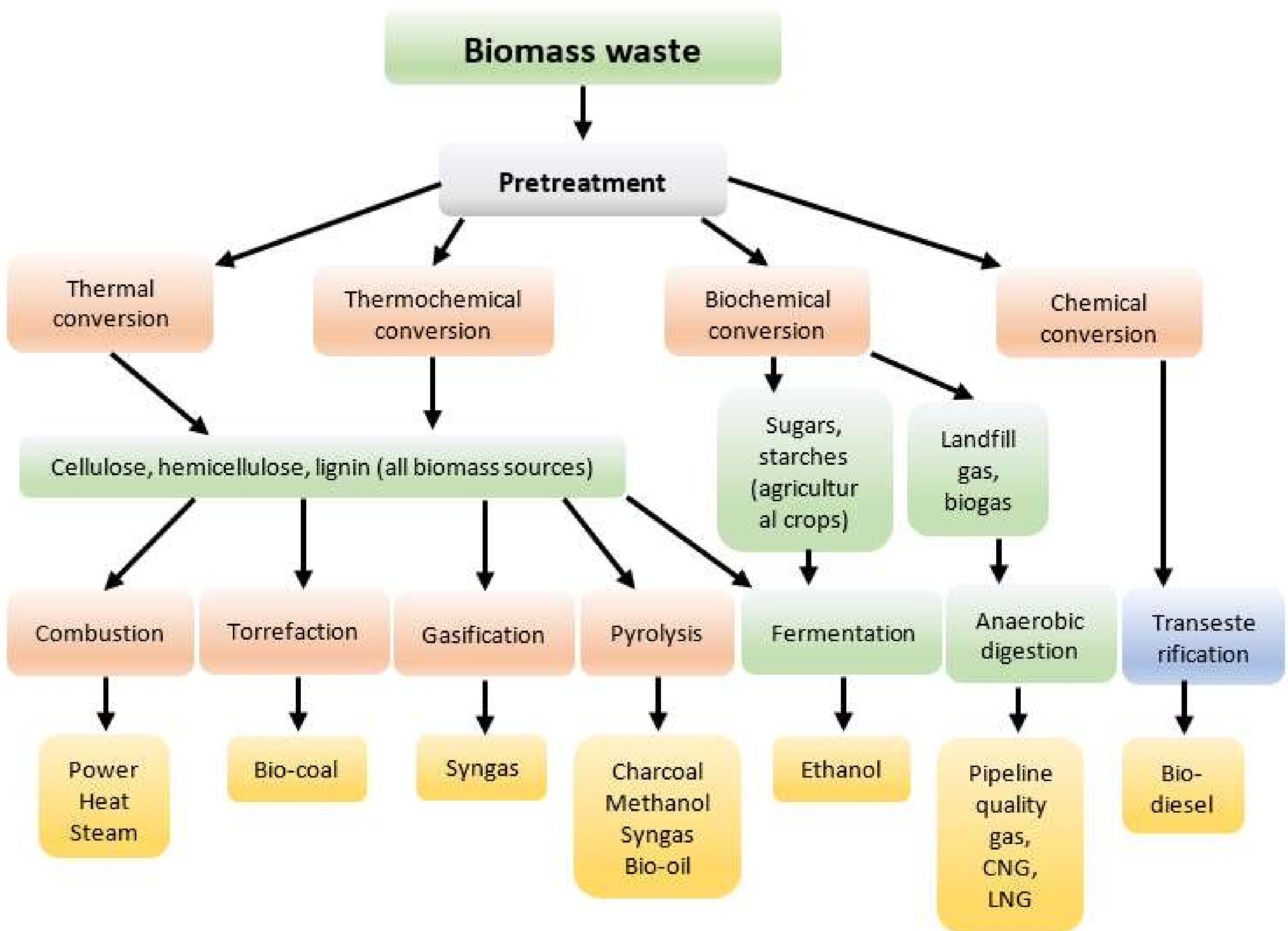

Figure 13. Biomass conversion into bioproducts [79–81].

Biomass can be converted into such forms of energy as liquid biofuels (methanol, ethanol, etc.), gases (hydrogen, synthesis gas, etc.), and electricity through biochemical or thermochemical processes. Vegetable oil, rapeseed, soybean, and waste fats can be used to produce biodiesel, while corn or sugar cane can be used to produce bioethanol [82].

Bioenergy production is associated with varying degrees of biomass consumption, depending on its energy characteristics. Thermal energy can be the result directly from the combustion of biomass, and the heat generated can be used to produce steam, which can provide heat for the production processes of specific products, or it can be converted into energy by delivering it using a steam turbine. Sometimes the low characteristics (low energy density) of biomass fuel material require conversion. The purpose of the conversion is to adapt biomass fuels to the requirements of the high-energy density fuel market, where traditional gaseous, liquid, and solid fuels are used. In recent years, the wood industry has provided waste wood biomass for bioenergy production in the amount of almost half of the total energy supplied to the market [83].

Plant biomass obtained from different areas and changing weather conditions is characterized by increased humidity; hence the drying process is required. Drying of biomass is carried out before its storage in order to remove moisture and prepare it for further conversion processes. The first known conversion method is the mechanical processing of biomass through various processes, such as grinding (chipping, cutting) and next pressing, pelleting, or briquetting. In order to reduce transport costs and increase bulk density, biomass is shredded before transport. In turn, solid fuel (e.g., husks, hay, straw, sawdust, etc.) densification processes are used to improve physical and energy properties. Thanks to this, the shapes and sizes of converted biofuels to the required standards allow for distribution in the energy industry [48].

Another method is the thermal conversion of biomass, including pyrolysis, gasification, carbonization, or combustion. One of the most common and recommended combustion methods is incineration in fluidized bed boilers, which is highly efficient and allows energy recovery. Another method is the process of co-combustion of coal with biomass in specific proportions in boilers intended for coal combustion [84].

Co-combustion of biomass takes place in a furnace chamber in which biomass and coal are fed as a previously prepared mixture or separately. Indirect co-combustion, on the other hand, takes place in a gasifier after biomass gasification, and the resulting gas is transferred to a combustion chamber, where it is incinerated. When biomass and coal are burned in separate combustion chambers, this is parallel combustion. Thermal carbonization of biomass takes place under pressure close to atmospheric pressure and at higher temperatures (approx. 200–300 °C). As a result of this drying process, biofuel is obtained with physicochemical properties, such as hydrophobicity, increased calorific value, energy and physical properties similar to coal, resistance to biological degradation, and others. Another process is pyrolysis involving the thermal decomposition of biomass in anaerobic conditions or in a small amount of oxygen. As a result of rapid pyrolysis at high temperatures (approx. 500 °C), biomass decomposes into syngas and char. After cooling, an oily liquid with a good calorific value is formed. Slow pyrolysis generates charcoal, char with increased stability, low humidity, and high energy density. In addition, pyrolysis also produces pyrolysis oil or gas. Gasification of biomass consists of many thermal processes to which biomass is subjected in a gasifier. The stages include drying at a temperature of approx. 150 °C, formation of oxides, CO_2, and water vapor at a temperature above 600 °C (oxidation) and reduction of CO_2 and water vapor to CO and H_2. As a result of biomass gasification processes, the following products are generated: gaseous (wood gas), liquid (acids, alcohols, steam), tar, and solids (fly ash). Biochemical methods include the transesterification of animal fats and vegetable oils for the production of biodiesel, as well as anaerobic fermentation for the production of alcohols (e.g., methanol, ethanol) or biogas. Biomass components such as cellulose, hemicellulose, and lignin are converted into liquid fuel in subsequent processes into methanol, ethanol, or biogas [84].

5. Energy Aspects of Biomass

Biomass waste can potentially be used as an energy source in connection with the current trends in the demand for renewable energy sources [85]. In accordance with Directive 2001/77/EC, biomass is defined as "the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste" [86]. Other sources say that biomass is characterized as any organic matter of plant or animal origin, as well as materials obtained as a result of their transformation or processing [87,88]. The energy potential of biomass depends on the form of fuel, type of material, moisture content, or calorific value [48]. In addition, its positive value results from the quantity, availability, chemical composition, acquisition, and processing costs.

Biomass can be used for direct combustion or co-combustion in solid, liquid, or gaseous form. Biofuels derived from it can include pellets, wood shavings, firewood, various fruit stones, and nut shells. Wood chips can come from the processes of shredding forest and agricultural waste. Pellets have the appearance of small cylinders with a diameter of up to several millimeters and a length of several tens of millimeters. They are formed as a result of pressing biofuels with binding additives [43,89,90]. Pellets are an increasingly popular form of renewable energy due to the fact that they are considered ecological, economical, and available on the local market. They are pure, natural products obtained from plant stems, waste materials, straw, wood chips, processed sawdust, post-production waste, or agricultural food waste. The positive aspect is the fact that no chemicals are added to pellet production processes, and natural substances are used as binders when forming the round cylindrical shape, e.g., pectin of plant fiber or lignin contained in wood. Other advantages include the use of only natural and renewable raw materials for pelletization, no additional CO_2 emissions due to the introduction of ecological circulation of raw materials, high functionality of fuel combustion, and low costs of the pelletization process. Pellets formed as a result of carbonization are characterized by high energy density, higher hydrophobicity, resistance to moisture, better grinding properties, and greater resistance to biological degradation [91]. Unfortunately, biomass combustion also brings with it various operational problems, including the large number of volatile components released, which can cause the emission of organic and organochlorine compounds (e.g., dioxins, polycyclic organic hydrocarbons), high chlorine content causing corrosive damage to heating installations and HCl emission, high content of alkali metal oxides in fly ash causing the formation of deposits and smearing of heating surfaces, the low calorific value of biomass compared to fossil fuels, low biomass density hindering storage, transport, feeding to heating devices and adversely affecting the stability of the combustion process, variable humidity causing additional drying costs, and investment costs related to the purchase of biomass combustion boilers of special design [92]. An opportunity to reduce investment costs is the solution of mixing coal with biomass in the co-combustion process. Thanks to this, there are lower costs associated with the purchase of traditional fuel, a reduction of emission fees, and the possibility of using low-cost biomass. In addition, co-combustion can be carried out in grates, pulverized beds, and fluidized bed boilers, both of high and low power. The effectiveness of the co-combustion process depends on the proper selection of the proportions of the fuel composition components. It should be emphasized that the proportions depend on the properties of the specific biomass, and the maximum share of biomass in the composition should not exceed 30% [93].

Biomass is ecologically clean fuel, which means, among other things, that it does not contribute to the emission of excessive amounts of CO_2. Taking into account the overall balance, the CO_2 emission is taken as zero if only the amount of CO_2 emitted from combustion that will be assimilated in the process of plant growth is taken into account. Ecological purity is related to the situation when the emission of CO_2 in the combustion process is equal to its absorption during the renewal of biomass through photosynthesis. The overall balance should take into account energy flow in the whole cycle involving incineration or co-incineration processes [94].

It has been shown that biomass waste has a high energy potential and a higher heating value comparable to commercial fuels (for instance, the calorific value of coal is estimated in the range of 25–35 MJ/kg [95]) (Table 3). The global production of these by-products has a growing trend, which makes them attractive and competitive not only for the generation of heat and electricity but also for reducing carbon dioxide emissions into the atmosphere.

Biomass waste, which is a potentially renewable source of energy, contains energy polysaccharide components; however, differences between individual materials occur in the elemental, chemical composition, and biomass energy capacity. The main measure of energy efficiency of biofuel is its calorific value, expressing the dependence of chemical composition on elementary components. Lowering calorific value is affected by moisture and ash content. Therefore, in order to obtain reliable results comparing the energy potential of biomass, the state of dry matter should be taken into account. Energy potential is determined on the basis of net calorific value (NCV) and gross calorific value (GCV). GCV refers to the amount of energy released (per unit volume or mass) during the stoichiometric combustion of a material. Generally speaking, the higher GCV, the more efficient the combustion process. Assessment of the energy properties of materials is necessary when estimating the use of biomass waste as a potential source of renewable energy. By knowing these properties, biomass production yields can also be optimized and product quality improved. The following properties should be determined: basic density [kg/m^3], ash and volatile matter content [%], solid carbon content [%], moisture content [%], moisture absorption capacity [mg/g], particle size [nm] and shape, resistance to processing, calorific value [MJ/kg], the heat of combustion [MJ/kg], the content of ash and combustible sulfur [%], and the content of hydrogen, nitrogen, oxygen, and chlorine [%] [96]. Energy density is calculated from the relationship between the gross calorific value and the material's basic density, according to Equation (1):

$$BED = \frac{(GCV)}{Bd} \div 1000 \quad (1)$$

where BED = basic energy density [GJ/m^3], GCV = gross calorific value [MJ/kg], Bd = basic density [kg/m^3] [25].

In order to determine the volume of emissions of individual gases and dust from renewable energy sources, the method of emission factors is used. The emission can be determined according to Equation (2):

$$Emission = A \cdot EF \quad (2)$$

where A = activity [Mg], EF = emission factor [kg/Mg].

The amount of fuel burned per hour can be determined according to Equation (3):

$$B = \frac{3600 \cdot NP}{\eta \cdot CV} \quad (3)$$

where B = fuel consumption [kg/h], NP = nominal boiler power [kW], η = combustion efficiency, CV = calorific value [kJ/kg].

In food processing plants, pollution abatement equipment is used for the amount of dust. Hence, a dust drift factor that corresponds to an emission factor can be used. The CO emission factor can be calculated from Equation (4):

$$EF_{CO} = \frac{28}{12} \cdot EF_C \cdot (C\_CO/C) \quad (4)$$

where EF_{CO} = carbon monoxide emission factor [kg/kg], 28/12=the ratio of molar masses of carbon monoxide and carbon, EF_C = emission factor of chemically clean coal [kg/kg], C_CO/C = part of the carbon emitted as carbon monoxide (average value of 0.06 can be assumed for agricultural waste).

$$EF_C = c \cdot p_c \quad (5)$$

where c = carbon content in biomass in working condition [kg/kg], p_c = part of coal oxidized in a combustion process (for agricultural waste, the average value can be taken as 0.88)

CO_2 emission factor can be calculated from Equation (5), taking into account the total carbon balance:

$$EF_{CO_2} = \frac{44}{12} \cdot \left(EF_C - \frac{12}{28} \cdot EF_{CO} - \frac{12}{16} \cdot EF_{CH_4} - \frac{26.4}{31.4} \cdot EF_{NMVOC} \right) \quad (6)$$

where EF_{CO2} = CO_2 emission factor [kg/kg], 44/12=the ratio of molar masses of carbon dioxide and carbon, 12/28 = the ratio of molar masses of carbon and carbon monoxide, 12/16 is the ratio of molar masses of carbon and methane, EF_{CH4} = CH_4 emission factor [kg/kg], EF_{NMVOC} = emission factor of volatile organic compounds (except CH_4, value for field and orchard yields can be assumed to 0.009 and 0.004, respectively).

CH_4 emission factor can be calculated based on Equation (7):

$$EF_{CH_4} = \frac{16}{12} \cdot EF_c \cdot (C\_CH_4/C) \tag{7}$$

where EF_{CH4} = CH_4 emission factor [kg/kg], 16/12r = the ratio of molar masses of methane and carbon, C_CH_4/C = part of the carbon emitted as CH_4 (average value of 0.005 can be assumed for agricultural waste).

NO_x emission factor is the sum of nitrogen dioxide and nitrogen oxide emission factors and can be calculated from Equation (8):

$$EF_{NO_x} = \frac{46}{14} \cdot EF_C \cdot (N/C) \cdot (N\_NO_x/N) \tag{8}$$

where EF_{NOx} = NO_x emission factor [kg/kg], 46/14 = the ratio of molar masses of nitrogen dioxide and nitrogen, N/C = the nitrogen to carbon ratio in biomass, N_NO_x/N = part of the nitrogen emitted as NO_x (average value of 0.122 can be assumed for agricultural waste).

SO_x emission factor is the sum of SO_2 and SO_3 emission factors and can be calculated from Equation (9):

$$EF_{SO_2} = \frac{2S}{100} \cdot (1 - r) \tag{9}$$

where EF_{SO2} = SO_2 emission factor [kg/kg], 2 = the ratio of molar masses of SO_2 and sulfur, S = sulfur content in fuel [%], r = coefficient determining the proportion of total sulfur remaining in fly ash.

The amount of fly ash lifted over the furnace depends on the conditions of the combustion process. It is estimated that 30% of ash generated is fly ash raised above the furnace in the case of hard coal combustion for a mechanical grate and steam output of $\geq$20 Mg/h. However, in the case of co-combustion of conventional fuel with the addition of biomass waste, the value of 15% to the fly ash removal from ash generated can be used to determine the dust emission factor. Dust emission factor for coal and biomass can be calculated from Equation (10):

$$EF_{dust} = 1.5 \cdot C_{FA} \cdot \frac{100 - \eta_0}{100 - k} \tag{10}$$

where 1.5 = the coefficient representing 15% ash lift in the form of fly ash, C_{FA} = fly ash content in fuel [%], $(1.5 \cdot C_{FA})$ = drift indicator determining the amount of dust generated during combustion [kg/Mg], η_0 = dedusting efficiency (assumed 20%), k = the content of combustible parts in the dust (assumed 25% for coal and 5% for biomass).

The emission of gases and dust is directly proportional to the content of fly ash and sulfur in a fuel mass unit. The calorific value of fuel should be taken into account when estimating emissions per unit of energy. The emissions of sulfur dioxide, nitrogen dioxide, carbon monoxide, carbon dioxide, and dust can be determined from the following Equations (11)–(15):

$$E_{SO_2} = B \cdot 16 \cdot S \tag{11}$$

$$E_{NO_2} = B \cdot 1 \tag{12}$$

$$E_{CO} = B \cdot 100 \tag{13}$$

$$E_{CO_2} = B \cdot 1850 \tag{14}$$

$$E_D = B \cdot 1.5 \cdot C_{FA} \frac{100 - \eta_0}{100 - k} \tag{15}$$

where E_{SO2} = SO_2 emission [kg/h], B = fuel consumption [kg/h], S = sulfur content in fuel [%], E_{NO2} = NO_2 emission [kg/h], E_{CO} = $C\,O$ emission [kg/h], E_{CO2} = CO_2 emission [kg/h],

E_D = dust emission [kg/h], C_{FA} = fly ash content [%], η_0 = dedusting efficiency (assumed 20%), k = content of combustible parts in the dust (assumed 25% for coal).

From an ecological point of view, an important component of biomass fuel is sulfur. In fuel combustion processes, sulfur is transformed into sulfur oxides, which are emitted into the atmosphere and pollute the environment, as well as irritating the respiratory system of animals and humans. Hence, the determination of sulfur content is one of the basic analyses of biomass for fuel, and the result gives toxicological information and information about the possible impact on the environment. During combustion, nitrogen is converted into nitrogen oxides (NO_x), which are released into the atmosphere. High concentrations of NO_x are toxic and irritating to the respiratory system. The sulfur and nitrogen content in coal varies and depends on the type and origin, but most often, it ranges from 0.5% to 5% of total sulfur [97] and from 0.5% to 2% of total nitrogen, respectively [98]. On the other hand, S and N content in biomass waste is considered low and, according to the literature, examples are as follows: coffee husk (0.67% S, 1.55% N), rice husk (0.59% S, 0.31% N) [46], burley stalk (0.55% S, 0.89% N), Virginia stalk (0.48% S, 0,85% N), corn cob (0.1% S, 0.4% N), corn stalk (0.05%S, 1.28% N), wheat straw (0.1% S, 1.65% N), sunflower stalk (0.12% S, 2% N), barley stalk (0.06% S, 0.41% N), and oat stalk (0.11% S, 0.69% N) [99].

6. Barriers to the Use of Biomass Materials

In most literature studies, opinions about the positive aspects of using biomass can be found, and indeed this direction should still be developed. However, these are materials with different characteristics and physicochemical properties than crude oil, hard coal, or lignite; hence there may be various barriers or challenges during their operation. Firstly, the high moisture content of biomass makes it unsuitable for thermal conversion processes such as pyrolysis or gasification, as it significantly reduces its efficiency. In addition, biofuels obtained as a result of conversion may contain moisture, which is naturally undesirable in combustion processes. Therefore, to increase a calorific value, pre-drying should be carried out. Unfortunately, the drying process is associated with additional high costs and energy input. High moisture content affects biological degradation, the development of fungi, mold, bacteria, and other microorganisms, as well as the loss of organic substances. The disadvantage of high water content can be solved by densifying the material in pressing processes. Increasing bulk density reduces storage capacity and transport costs, but unfortunately, the compaction process itself generates additional costs. Sometimes high moisture content is beneficial, for example, in hydrothermal conversion processes during the production of alcohol from carbohydrates with the use of hydrolysis and fermentation of biomass. Then water is an important reagent during the conversion [100,101].

Another disadvantage is the bulk density of biomass, which is mostly low, and for woody and grassy biomass, it is usually in the range of 160–220 kg/m^3 and 80–150 kg/m^3, respectively. As a result, there are difficulties in exploiting large amounts of biomass, and higher storage and transport costs [102]. Densification by mechanical pressing is used to increase bulk density. Cubing, pelleting, or briquetting are used to give uniform shapes and dimensions. Thanks to these processes, it is possible to increase the density of biomass materials many times, depending on its type, moisture, properties, densification technique, etc. The costs of storage, transport, and handling can be significantly reduced [103].

The proportions between cellulose, hemicellulose, and lignin in the composition are different for different types of biomass. For example, hardwood biomass contains more cellulose, and hemicellulose has D-xylose structures such as arabinoglucuronoxylan. Straw, on the other hand, has more hemicellulose. Such diversity in the composition of biomass materials has an impact on the fact that the technology of their conversion to the production of biofuels and other products must be properly designed to ensure the maximization of the efficiency of these processes [104]. The possibility of effective use of biomass depends on its physicochemical properties, methods of initial preparation, or optimization of the conditions of the production process. The diversity in the composition affects the initial preparation and, in subsequent stages, the dissolution of biomass. Properties such as the hydrophobicity of lignin, crystalline arrangement of cellulose, location of cellulose in the hemicellulose–lignin zone, and difficulties in cleaving hydrogen, ether, and other bonds make biomass materials resistant to dissolution. Cellulose is difficult to hydrolyze because it is contained in a lignin matrix. These barriers mean that biomass should first be broken down into lower molecular weight substances in order to be processed into various products. Then, hydrolysates from shredded biomass can be used for the production of solvents, sugars, sugar alcohols, or biofuels such as hydrogen, ethanol, methanol, etc. However, hydrolysis processes are also burdensome for the environment because toxic chemicals such as mineral acids and hydroxides are used, or the process is lengthy in the case of enzymatic hydrolysis [101,105]. In addition, obtaining glucose from biomass sometimes requires high-temperature conditions or high concentrations of acids. In turn, at high temperatures, by-products (tar) are formed during pyrolysis and other processes. The use of concentrated acids generates higher energy consumption, affects the corrosion of the installation, requires chemical neutralization, and causes the formation of by-products. Hydrolysis processes are time-consuming and generate high costs. An additional disadvantage is the fact that under difficult dissolution conditions, carbohydrates may be degraded. An alternative environmentally friendly solution may be the hydrolysis of biomass using subcritical water obtained under changed conditions of temperature and pressure [101].

The demand for electricity and heat is constant throughout the year, while the availability of different types of biomass materials is only seasonal. Perennial energetic plants (e.g., kenaf, miscanthus, miscanthus, etc.) are available for longer periods, do not require annual replanting, and their growth does not require specialized and high maintenance and investment expenditures. On the other hand, food crops (e.g., sugar beet, sugar cane, corn, etc.) are seasonal and require favorable climatic conditions, fertilization, or other types of care. The advantage is that the remains of agricultural biomass, such as pulp, peelings, rice husks, wheat, rye, and corn straw, etc., are a low-cost waste materials, because no additional land is required for their cultivation. Another valuable source of energy is forest biomass waste; however, their harvesting and transport generate additional high costs. The above-mentioned barriers to the use of biomass materials for energy and product purposes have a negative impact on the success and development of this sector. However, in order to reduce all these obstacles, new solutions should be sought, including, for example, standardization systems [101].

7. The Future Scope of Biomass Waste Energy Source

It is inevitable that industry will continue to develop and it is difficult to predict its pace and direction of development, as well as the consequences for the natural environment and humans. Among all these unknowns, it is certain that agricultural and industrial waste will continue to be generated, which requires appropriate and useful management. Recent years of research have proven that the use of biomass waste for energy purposes is a promising and innovative direction of development, using environmentally friendly technologies that reduce the emission of harmful substances and are neutral in terms of carbon dioxide emissions. Such biomass materials as wood, forest residues (sawdust, branches, wood pellets), perennial grasses, post-production waste, or landfill gases can be a valuable source of energy, heat, and liquid fuels. The main benefit is that biomass cannot be exhausted, unlike fossil fuels. This feature makes renewable energy from all biomass sources inevitable [10,85,106].

The currently available biomass conversion technologies are diverse due to the goals to be achieved, such as reducing the impact on the environment and climate change, the use of individual types of biomass waste resources, or economic efficiency. Thermal conversion of biomass waste into products, electricity, or heat is mainly achieved through such processes as combustion, pyrolysis, gasification, fermentation, or transesterification. Direct combustion of biomass in the presence of air with oxygen is used to generate electricity and heat. For example, based on research conducted in Pakistan, it was shown that the use of 70% of rice hulls during combustion generated approximately 1328 GWh of electricity, which was estimated at approximately 47.36 cents/kWh. This is a cheaper option compared to the cost of generating electricity using coal, which was estimated at 55.22 cents/kWh [107]. According to the literature, the efficiency of electricity production from burning biomass itself oscillates between 20 and 40% [108]. An opportunity is co-combustion with coal, which may increase the efficiency of the process. In the near future, many studies should be carried out to determine the costs and the amount of electricity generated as a result of the combustion or co-incineration of various types of biomass waste from various industries and then compare them with the results of the combustion of conventional fuels. As a result of pyrolysis, i.e., thermal decomposition, bio-char or bio-oil can be produced, which are the basis for obtaining oxygenated high-octane products, including diesel oil, kerosene, or gasoline. Thanks to the increased oxygen content, these biofuels achieve high efficiency during combustion [109]. The next process is gasification, which consists in converting biomass into a combustible gas mixture consisting mainly of CH_4, CO, CO_2, and H_2 [110]. The resulting hydrogen fuel releases energy and water (H_2O) during combustion and does not generate greenhouse gases in the atmosphere [111]. It is known from literature reports that the process of atmospheric oxidation of agricultural biomass (cereal straw) was used for the chemical production of fuel biogas with a lower calorific value. Another process concerned the gasification of carbonization pyrolysis, during which straw tar and charcoal were obtained [112]. A chance potential application may be gasification using the method of distributed power generation. Unfortunately, the large-scale application is limited by the high dissipation of energy and the small volume of biomass waste. Other promising technologies could be supercritical water gasification (SCWG) for wet biomass and plasma gasification for the treatment of toxic organic waste [113]. The development of biomass gasification would be more dynamic if there was greater support from the legislative side, the social environment as well as the willingness of various investors to invest in order to accelerate commercialization.

8. Conclusions

The issues of increasing pollutant emissions related to human industrial activity, the use and depletion of conventional fossil fuels, as well as the need to protect the environment, contribute to the search for ecological renewable energy sources. A significant reduction in the number of harmful substances emitted to the environment is possible thanks to the use of biomass for energy purposes. The use of biomass waste as an alternative source of energy seems to be a real solution, which is already being used effectively by many countries around the world. Currently, the main use of biomass is the production of biofuels by mechanical, thermochemical, or biochemical conversion processes. Moreover, it provides a sustainable fuel source that can gradually replace depleting fossil fuel resources and minimize the amount of solid waste generated and greenhouse gas emissions. Due to the fact that the biomass material is diverse and its characteristics depend on local climatic conditions, each region of the world can look for optimal technological solutions in the use of its types of biomass for cleaning the aquatic environment from pollutants, including heavy metals, as well as for conversion into biofuels and then converted into electricity and heat. In order to effectively and efficiently use biomass waste for energy production, it is necessary to develop appropriate technology. On the other hand, the use of agricultural biomass from energy crops can create new prospects for farmers to allocate part of their land to the cultivation of these crops. The production of bioenergy from agricultural biomass not only has a positive effect on the natural environment but also generates profits in the economic and social spheres. New technologies and solutions mean more employment, revitalize the local economy, and increase farmers' income. However, the obstacle is still insufficient knowledge about the energy characteristics of biomass materials found locally in different regions of the world, insufficient knowledge about the technology of converting biomass into energy, equipment requirements, installation, efficiency, and many other obstacles that slow down the development of effective use of biomass in the near future.

As a result of the literature research studies, the paper presents:

- An analysis of the cycle of biomass energy,
- biomass availability and the current global energy situation,
- the growing global demand for energy,
- the increasing shift from conventional fossil sources to renewable biomass energy,
- the growing volume of bioenergy production in the world,
- the growing use of waste for energy production,
- the growing total energy supply from renewable energy sources and waste,
- the growing global volume of investment in green energy technologies,
- types and sources of biomass materials,
- benefits of using biomass waste materials,
- the possibility of using various types of waste materials from biomass for the purification of the aquatic environment,
- an energy analysis of biomass materials,
- available biomass conversion technologies, including mechanical, thermal and biochemical,
- barriers to the use of biomass materials,
- the future scope of biomass waste energy sources.

The future of obtaining energy belongs to the use of renewable energy sources. Fossil fuels have limited resources and need to be gradually replaced by other resources such as agricultural, industrial, and other waste. Their resources will not end, hence they will require continuous appropriate and useful management. The use of biomass waste for energy production is a promising direction of development, where the technologies used reduce the emission of harmful substances into the environment and are neutral in terms of CO_2 emissions. Currently, available technologies are differentiated due to specific goals to be achieved. These include reducing the impact on the environment and climate change, the use of specific types of biomass waste resources, or economic and energy efficiency. Processes such as direct combustion, pyrolysis, gasification, fermentation, or transesterification are methods of thermal transformation of biomass waste into products, heat, and electricity. The large variety of biomass materials makes it necessary to conduct a lot of research on their energy usage, and on determining the costs and the amount of electricity or heat generated as a result of combustion or co-incineration of various types of biomass waste from various industries.

According to studies published in the literature, greenhouse gas emissions from the production and use of biomass turned out to be lower than emissions from coal for electricity production. Therefore, these ecological premises are one of many strong arguments justifying the rightness of using biomass as a renewable energy source. This literature review clearly indicates the need to continue and expand research on the development of the bioenergy economy sector. In order to accelerate the development of the energy sector in this direction, legislative changes and appropriate political decisions are necessary.

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References

1. Saleem, M. Possibility of utilizing agriculture biomass as a renewable and sustainable future energy source. *Heliyon* **2022**, *8*, e08905. [CrossRef] [PubMed]
2. Sarkar, N.; Ghosh, S.K.; Bannerjee, S.; Aikat, K. Bioethanol production from agricultural wastes: An overview. *Renew. Energy* **2012**, *37*, 19–27. [CrossRef]
3. Cardiff European Council. Presidency Conclusions. Available online: https://www.europarl.europa.eu/summits/car1_en.htm (accessed on 16 November 2022).
4. Decision No 2179/98/EC of the European Parliament and of the Council of 24 September 1998 on the Review of the European Community Programme of Policy and Action in Relation to the Environment and Sustainable Development towards Sustainability. Available online: https://eur-lex.europa.eu/ (accessed on 16 November 2022).
5. Drożyner, P.; Rejmer, W.; Starowicz, P.; Klasa, A.; Skibniewska, K.A. Biomass as a renewable source of Energy. *Tech. Sci.* **2013**, *16*, 211–220.
6. Kumar, M.; Sundaram, S.; Gnansounou, E.; Larroche, C.; Thakur, I.S. Carbon dioxide capture, storage and production of biofuel and biomaterials by bacteria: A review. *Bioresour. Technol.* **2018**, *247*, 1059–1068. [CrossRef]
7. Commission Communication of 8 February 2006 Entitled "An EU Strategy for Biofuels" [COM(2006) 34 Final—Official Journal C 67 of 18 March 2006]. Available online: https://eur-lex.europa.eu/ (accessed on 16 November 2022).
8. Tkemaladze, G.S.; Makhashvili, K.A. Climate changes and photosynthesis. *Ann. Agrar. Sci.* **2016**, *14*, 119–126. [CrossRef]
9. Kaltschmitt, M. Renewable energy from biomass, Introduction. In *Renewable Energy Systems*; Kaltschmitt, M., Themelis, N.J., Bronicki, L.Y., Söder, L., Vega, L.A., Eds.; Springer: New York, NY, USA, 2013; pp. 45–71.
10. Tursi, A. A review on biomass: Importance, chemistry, classification, and conversion. *Biofuel Res. J.* **2019**, *6*, 962–979. [CrossRef]
11. Parmar, K. Biomass—An overview on composition characteristics and properties. *IRA-Int. J. Appl. Sci.* **2017**, *7*, 42–51. [CrossRef]
12. Demirbas, A. Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. *Energy Convers. Manag.* **2008**, *49*, 2106–2116. [CrossRef]
13. Sivabalan, K.; Hassan, S.; Ya, H.; Pasupuleti, J. A review on the characteristic of biomass and classification of bioenergy through direct combustion and gasification as an alternative power supply. *J. Phys. Conf. Ser.* **2021**, *1831*, 012033. [CrossRef]
14. Saini, J.K.; Saini, R.; Tewari, L. Lignocellulosic agriculture wastes as biomass feedstocks for second-generation bioethanol production: Concepts and recent developments. *3 Biotech* **2015**, *5*, 337–353. [CrossRef]
15. Stout, B.A. *Handbook of Energy for World Agriculture*; Elsevier Applied Science: London, UK; New York, NY, USA, 2012.
16. World Bioenergy Association. WBA Global Bioenergy Statistics 2018, Summary Report. Available online: https://www.worldbioenergy.org/ (accessed on 10 January 2023).
17. Wyszyński, Z.; Michalska-Klimczak, B.; Pągowski, K.; Kamińska, S. Biomass as the main source of renewable energy in Poland. In *Renewable Energy and Energy Efficiency. Biogas and Biofuel Production Technologies*; Latvia University of Agriculture, REE Conference: Jelgava, Latvia, 2012.
18. Habert, G.; Bouzidi, Y.; Chen, C.; Jullien, A. Development of a depletion indicator for natural resources used in concrete. *Resour. Conserv. Recycl.* **2010**, *54*, 364–376. [CrossRef]
19. Enerdata. Electricity Production. Available online: https://yearbook.enerdata.net/electricity/world-electricity-production-statistics.html (accessed on 16 November 2022).
20. Eurostat. Electricity Production, Consumption and Market Overview. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_production,_consumption_and_market_overview (accessed on 16 November 2022).
21. Bonaccorsi, L.; Antonio Fotia, A.; Malara, A.; Frontera, P. Advanced Adsorbent Materials for Waste Energy Recovery. *Energies* **2020**, *13*, 4299. [CrossRef]
22. Ziemele, J.; Kalnins, R.; Vigants, G.; Vigants, E.; Veidenbergs, I. Evaluation of the industrial waste heat potential for its recovery and integration into a fourth generation district heating system. *Energy Procedia* **2018**, *147*, 315–321. [CrossRef]
23. Papapetrou, M.; Kosmadakis, G.; Cipollina, A.; La Commare, U.; Micale, G. Industrial waste heat: Estimation of the technically available resource in the EU per industrial sector, temperature level and country. *Appl. Therm. Eng.* **2018**, *138*, 207–216. [CrossRef]
24. Agathokleous, R.; Bianchi, G.; Panayiotou, G.; Arestia, L.; Argyrou, M.C.; Georgiou, G.S.; Tassou, S.A.; Jouhara, H.; Kalogirou, S.A.; Florides, G.A.; et al. Waste heat recovery in the EU industry and proposed new technologies. *Energy Procedia* **2019**, *161*, 489–496. [CrossRef]
25. Sönnichsen, N. Global Primary Energy Consumption 2000–2021. Available online: https://www.statista.com/statistics/265598/consumption-of-primary-energy-worldwide/ (accessed on 16 November 2022).
26. Sönnichsen, N. Global Primary Energy Consumption 2021, by Country. Available online: https://www.statista.com/statistics/263455/primary-energy-consumption-of-selected-countries/ (accessed on 16 November 2022).
27. Sönnichsen, N. Energy Consumption Worldwide from 2000 to 2019, with a Forecast until 2050, by Energy Source. Available online: https://www-1statista-1com-1s8fui2pq12ae.han3.ue.poznan.pl/statistics/222066/projected-global-energy-consumption-by-source/ (accessed on 16 November 2022).
28. Jaganmohan, M. Global Bioenergy Production 2009–2020. Available online: https://www.statista.com/statistics/1032907/bioenergy-production-globally/ (accessed on 16 November 2022).

29. Jaganmohan, M. Supply of Biomass Primary Energy Worldwide from 2000 to 2019. Available online: https://www-1statista-1com-1s8fui2pq12bd.han3.ue.poznan.pl/statistics/481628/biomass-primary-energy-supply-worldwide/ (accessed on 16 November 2022).
30. Alves, B. Biomass Electricity Generation Worldwide from 2000 to 2019. Available online: https://www-1statista-1com-1s8fui2pq12bd.han3.ue.poznan.pl/statistics/481743/biomass-electricity-production-worldwide/ (accessed on 16 November 2022).
31. Mukherjee, A.; Debnath, B.; Kumar Ghosh, S. A Review on Technologies of Removal of Dioxins and Furans from Incinerator Flue Gas. *Procedia Environ. Sci.* **2016**, *35*, 528–540. [CrossRef]
32. Zhu, Z.; Xu, B. Purification Technologies for NOx Removal from Flue Gas: A Review. *Separations* **2022**, *9*, 307. [CrossRef]
33. Tiseo, I. Global Outlook on Waste to Energy Market Value 2019–2027. Available online: https://www-1statista-1com-1s8fui2pq1202.han3.ue.poznan.pl/statistics/480452/market-value-of-waste-to-energy-globally-projection/ (accessed on 16 November 2022).
34. Sönnichsen, N. Production of Waste for Energy Worldwide from 2000 to 2019. Available online: https://www-1statista-1com-1s8fui2pq12bd.han3.ue.poznan.pl/statistics/481716/waste-to-energyl-production-globally/ (accessed on 16 November 2022).
35. IEA. World Energy Balances and World Energy Statistics. Available online: https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances (accessed on 10 January 2023).
36. Statista Research Department. Power Generation of Waste-to-Energy Systems in 2010 and 2022. Available online: https://www-1statista-1com-1s8fui2pq12bd.han3.ue.poznan.pl/statistics/240057/worldwide-power-generation-of-waste-to-energy-systems/ (accessed on 16 November 2022).
37. IEA. Clean Energy Investment in the Stated Policies Scenario, 2015–2030. Available online: https://www.iea.org/data-and-statistics/charts/clean-energy-investment-in-the-stated-policies-scenario-2015-2030 (accessed on 16 November 2022).
38. Vassilev, S.D.; Andersen, L.; Vassileva, C.; Morgan, T. An overview of the organic and inorganic phase composition of biomass. *Fuel* **2012**, *94*, 1–33. [CrossRef]
39. Vassilev, S.V.; Baxter, D.; Andersen, L.K.; Vassileva, C.G. An overview of the chemical composition of biomass. *Fuel* **2010**, *89*, 913–933. [CrossRef]
40. Dibenedetto, A. The potential of aquatic biomass for CO_2-enhanced fixation and energy production. *Greenhouse Gases Sci. Technol.* **2011**, *1*, 58–71. [CrossRef]
41. Strezov, V. Properties of biomass fuels. In *Biomass Processing Technologies*; Strezov, V., Evans, T.J., Eds.; CRC Press: Boca Raton, FL, USA, 2014; pp. 1–32.
42. Horan, N.J. Introduction. In *Anaerobic Digestion Processes*; Horan, N., Yaser, A., Wid, N., Eds.; Green Energy and Technology; Springer: Singapore, 2018; pp. 1–7.
43. Acar, S.; Ayanoglu, A. Determination of higher heating values (HHVs) of biomass fuels. *Energy Educ. Sci. Technol. A Energy Sci. Res.* **2012**, *28*, 749–758.
44. Patro, B. Efficiency studies of combination tube boilers. *AEJ-Alex. Eng. J.* **2016**, *55*, 193–202. [CrossRef]
45. Pecora, A.; Avila, I.; Lira, C.; Cruz, G.; Crnkovic, P.M. Prediction of the combustion process in fluidized bed based on physical–chemical properties of biomass particles and their hydrodynamic behaviors. *Fuel Process. Technol.* **2014**, *124*, 188–197. [CrossRef]
46. Subramaniam, R.S.; Sarode, D. Study of Suitability of Biomass Wastes as Sustainable Fuel. In Proceedings of the 1st International Conference on Sustainable Waste Management through Design, Ludhiana, Punjab, India, 2–3 November 2018; Springer: Berlin/Heidelberg, Germany, 2019; pp. 562–568.
47. Patel, B.; Gami, B. Biomass Characterization and its Use as Solid Fuel for Combustion. *Iran. J. Energy Environ.* **2012**, *3*, 123–128. [CrossRef]
48. Niedziółka, I.; Szpryngiel, M.; Zaklika, B. Possibilities of using biomass for energy purposes. *Agric. Eng.* **2014**, *1*, 155–163.
49. Huang, C.; Han, L.; Liu, X.; Ma, L. The rapid estimation of cellulose, hemicellulose, and lignin contents in rice straw by near infrared spectroscopy. *Energy Sources A Recovery Util. Environ. Eff.* **2010**, *33*, 114–120. [CrossRef]
50. Mansaray, K.G.; Ghaly, A.E. Determination of kinetic parameters of rice husks in oxygen using thermogravimetric analysis. *Biomass Bioenergy* **1999**, *17*, 19–31. [CrossRef]
51. Alemdar, A.; Sain, M. Isolation and characterization of nanofibers from agricultural residues—Wheat straw and soy hulls. *Bioresour. Technol.* **2008**, *99*, 1664–1671. [CrossRef]
52. Cabral, M.M.S.; Abud, A.K.S.; Silva, C.E.F.; Almeida, R.M.R.G. Bioethanol production from coconut husk fiber. *Ciênc. Rural.* **2016**, *46*, 1872–1877. [CrossRef]
53. Thygesen, A.; Vahlgren, L.; Frederiksen, J.H.; Linnane, W.; Thomsen, M.H. SSF fermentation of rape straw and the effects of inhibitory stress on yeast. In *Bioethanol*; Lima, M.A.P., Natalense, A.P.P., Eds.; IntechOpen: Rijeka, Croatia, 2012; Volume 1, pp. 209–222.
54. Martelli-Tosi, M.; Torricillas, M.D.S.; Martins, M.A.; Assis, O.B.G.D.; Tapia-Blácido, D.R. Using commercial enzymes to produce cellulose nanofibers from soybean straw. *J. Nanomater.* **2016**, *2016*, 8106814. [CrossRef]
55. Antonopoulou, G.; Dimitrellos, G.; Beobide, A.S.; Vayenas, D.; Lyberatos, G. Chemical pretreatment of sunflower straw biomass: The effect on chemical composition and structural changes. *Waste Biomass Valori* **2015**, *6*, 733–746. [CrossRef]
56. Bharthare, P.; Shrivastava, P.; Singh, P.; Ttiwari, A. Peanut shell as renewable energy source and their utility in production of ethanol. *Int. J. Adv. Res.* **2014**, *2*, 1–4.

57. Fu, F.; Wang, Q. Removal of heavy metal ions from wastewaters: A review. *J. Environ. Manag.* **2011**, *92*, 407–418. [CrossRef]
58. Chen, Q.; Yao, Y.; Li, X.; Lu, J.; Zhou, J.; Huang, Z. Comparison of heavy metal removals from aqueous solutions by chemical precipitation and characteristics of precipitates. *J. Water Process Eng.* **2018**, *26*, 289–300. [CrossRef]
59. Dukhnytskyi, B. World agricultural production. *Ekon. APK* **2019**, *7*, 59–65. [CrossRef]
60. Schnepf, R. CRS Report for Congress Energy Use in Agriculture. 19 November 2004. Available online: https://nationalaglawcenter.org/wp-content/uploads/assets/crs/RL32677.pdf (accessed on 16 November 2022).
61. Grainger, A. An evaluation of the FAO tropical forest resource assessment 1990. *Geogr. J.* **1996**, *162*, 73–79. [CrossRef]
62. Woo, H.; Acuna, M.; Cho, S.; Park, J. Assessment techniques in forest biomass along the timber supply chain. *Forests* **2019**, *10*, 1018. [CrossRef]
63. Vongdala, N.; Tran, H.D.; Xuan, T.D.; Teschke, R.; Khanh, T.D. Heavy metal accumulation in water, soil, and plants of municipal solid waste landfill in Vientiane, Laos. *Int. J. Environ. Res. Public Health* **2019**, *16*, 22. [CrossRef]
64. Seruga, P.; Krzywonos, M.; Seruga, A.; Niedźwiecki, Ł.; Pawlak-Kruczek, H.; Urbanowska, A. Anaerobic Digestion Performance: Separate Collected vs. Mechanical Segregated Organic Fractions of Municipal Solid Waste as Feedstock. *Energies* **2020**, *13*, 3768. [CrossRef]
65. Burke, C.S.; Salas, E.; Smith-Jentsch, K.; Rosen, M.A. *What a Waste: A Global Review of Solid Waste Management*; Urban Development Series; World Bank: Washington, DC, USA, 2012; Volume 15, pp. 1–116.
66. Harsha, K.; Senthil, P.; Panda, R.C. A review on heavy metal pollution, toxicity and remedial measures: Current trends and future perspectives. *J. Mol. Liq.* **2019**, *290*, 111197.
67. Kalak, T.; Tachibana, Y. Removal of lithium and uranium from seawater using fly ash and slag generated in the CFBC technology. *RSC Adv.* **2021**, *11*, 21964–21978. [CrossRef] [PubMed]
68. Kalak, T.; Marciszewicz, K.; Piepiorka-Stepuk, J. Highly effective adsorption process of Ni(II) ions with the use of sewage sludge fly ash generated by circulating fluidized bed combustion (CFBC) technology. *Materials* **2021**, *14*, 3106. [CrossRef] [PubMed]
69. Bilal, M.; Ihsanullah, I.; Younas, M.; Ul Hassan Shah, M. Recent advances in applications of low-cost adsorbents for the removal of heavy metals from water: A critical review. *Sep. Purif. Technol.* **2021**, *278*, 119510. [CrossRef]
70. World Water Assessment Programme (Nations Unies). The United Nations World Water Development Report 2018 (United Nations Educational, Scientific and Cultural Organization, New York, United States). Available online: www.unwater.org/publications/world-water-development-report (accessed on 30 October 2022).
71. Narjala, J. Heavy Metal Sources and Their Effects on Human Health. In *Heavy Metals: Their Environmental Impacts and Mitigation*; Nazal, M., Zhao, H., Eds.; IntechOpen: London, UK, 2020; pp. 1–12.
72. Mitra, S.; Chakraborty, A.J.; Tareq, A.M.; Emran, T.B.; Nainu, F.; Khusro, A.; Idris, A.M.; Khandaker, M.U.; Osman, H.; Alhumaydhi, F.A.; et al. Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. *J. King Saud Univ. Sci.* **2022**, *34*, 101865. [CrossRef]
73. Kalak, T.; Walczak, J.; Ulewicz, M. Adsorptive recovery of Cd(II) ions with the use of post-production waste generated in the brewing industry. *Energies* **2021**, *14*, 5543. [CrossRef]
74. Kalak, T. High efficiency of the bioremoval process of Cu(II) ions with blackberry (Rubus L.) residues generated in the food industry. *Des. Water Treat.* **2021**, *238*, 174–197. [CrossRef]
75. Kalak, T.; Dudczak-Hałabuda, J.; Tachibana, Y.; Cierpiszewski, R. Effective bioremoval of Fe(III) ions using paprika (*Capsicum annuum* L.) pomace generated in the food industry. *J. Mater. Cycles Waste Manag.* **2021**, *23*, 248–258. [CrossRef]
76. Shamim, S. Biosorption of Heavy Metals. In *Biosorption*; Derco, J., Vrana, B., Eds.; IntechOpen: London, UK, 2018; pp. 21–49.
77. Elkady, M.; Shokry, H.; Hamad, H. New Activated Carbon from Mine Coal for Adsorption of Dye in Simulated Water or Multiple Heavy Metals in Real Wastewater. *Materials* **2020**, *13*, 2498. [CrossRef]
78. Thakur, A.K.; Singh, R.; Pullela, R.T.; Pundir, V. Green adsorbents for the removal of heavy metals from Wastewater: A review. *Mater. Today Proc.* **2022**, *57*, 1468–1472. [CrossRef]
79. Clauser, N.M.; González, G.; Mendieta, C.M.; Kruyeniski, J.; Area, M.C.; Vallejos, M.E. Biomass Waste as Sustainable Raw Material for Energy and Fuels. *Sustainability* **2021**, *13*, 794. [CrossRef]
80. Chung, J.N. Grand challenges in bioenergy and biofuel research: Engineering and technology development, environmental impact, and sustainability. *Front. Energy Res.* **2013**, *1*, 4. [CrossRef]
81. Fiala, M.; Nonini, L. Biomass and biofuels. *EPJ Web Conf.* **2018**, *189*, 1–35. [CrossRef]
82. Naik, S.N.; Goud, V.V.; Rout, P.K.; Dalai, A.K. Production of first and second generation biofuels: A comprehensive review. *Renew. Sustain. Energy Rev.* **2010**, *14*, 578–597. [CrossRef]
83. Gielen, D.; Boshell, F.; Saygin, D.; Bazilian, M.D.; Wagner, N.; Gorini, R. The role of renewable energy in the global energy transformation. *Energy Strateg. Rev.* **2019**, *24*, 38–50. [CrossRef]
84. Panwar, N.L.; Kothari, R.; Tyagi, V.V. Thermo chemical conversion of biomass—Eco friendly energy routes. *Renew. Sustain. Energy Rev.* **2012**, *16*, 1801–1816. [CrossRef]
85. Perea-Moreno, M.-A.; Samerón-Manzano, E.; Perea-Moreno, A.-J. Biomass as Renewable Energy: Worldwide Research Trends. *Sustainability* **2019**, *11*, 863. [CrossRef]
86. Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market. Available online: https://eur-lex.europa.eu/ (accessed on 16 November 2022).

87. Mehedintu, A.; Sterpu, M.; Soava, G. Estimation and forecasts for the share of renewable energy consumption in final energy consumption by 2020 in the european union. *Sustainability* **2018**, *10*, 1515. [CrossRef]
88. Contescu, C.I.; Adhikari, S.P.; Gallego, N.C.; Evans, N.D.; Biss, B.E. Activated Carbons Derived from High-Temperature Pyrolysis of Lignocellulosic Biomass. *C J. Carbon Res.* **2018**, *4*, 51. [CrossRef]
89. Li, G.; Liu, C.; Yu, Z.; Rao, M.; Zhong, Q.; Zhang, Y.; Jiang, T. Energy saving of composite agglomeration process (CAP) by optimized distribution of pelletized feed. *Energies* **2018**, *11*, 2382. [CrossRef]
90. Williams, O.; Taylor, S.; Lester, E.; Kingman, S.; Giddings, D.; Eastwick, C. Applicability of mechanical tests for biomass pellet characterisation for bioenergy applications. *Materials* **2018**, *11*, 1329. [CrossRef] [PubMed]
91. Pradhan, P.; Mahajani, S.M.; Arora, A. Production and utilization of fuel pellets from biomass: A review. *Fuel Process. Technol.* **2018**, *181*, 215–232. [CrossRef]
92. Rosillo-Calle, F. A review of biomass energy—Shortcomings and concerns. *J. Chem. Technol. Biotechnol.* **2016**, *91*, 1933–1945. [CrossRef]
93. Munir, S. A review on biomass-coal co-combustion: Current state of knowledge. *Proc. Pak. Acad. Sci.* **2010**, *47*, 265–287.
94. Chen, J.; Li, C.; Ristovski, Z.; Milic, A.; Gu, Y.; Islam, M.S.; Wang, S.; Hao, J.; Zhang, H.; He, C.; et al. A review of biomass burning: Emissions and impacts on air quality, health and climate in China. *Sci. Total Environ.* **2017**, *579*, 1000–1034. [CrossRef]
95. Dincer, I.; Rosen, M.A.; Khalid, F. Thermal Energy Production. In *Comprehensive Energy Systems*; Dincer, I., Ed.; Elsevier: Toronto, ON, Canada, 2018; Volume 3, pp. 673–706.
96. Rusch, F.; de Abreu Neto, R.; de Moraes Lúcio, D.; Hillig, É. Energy properties of bamboo biomass and mate co-products. *SN Appl. Sci.* **2021**, *3*, 602. [CrossRef]
97. Chou, C.-L. Sulfur in coals: A review of geochemistry and origins. *Int. J. Coal Geol.* **2012**, *100*, 1–13. [CrossRef]
98. Gil, S. Fuel-N Conversion to NO, N_2O and N_2 during Coal Combustion. In *Fossil Fuel and the Environment*; Khan, S., Ed.; IntechOpen: London, UK, 2012; pp. 37–62.
99. Mijailovic, I.; Radojicic, V.; Olivera, E.-D.; Stefanović, G.; Kulic, G. Energy potential of tobacco stalks in briquettes and pellets production. *J. Environ. Prot. Ecol.* **2014**, *15*, 1034–1041.
100. Johansson, J.; Liss, J.; Gullberg, T.; Bjorheden, R. Transport and handling of forest energy bundles-advantages and problems. *Biomass Bioenergy* **2006**, *30*, 334–341. [CrossRef]
101. Irmak, S. Challenges of Biomass Utilization for Biofuels. In *Biomass for Bioenergy—Recent Trends and Future Challenges*; Abomohra, A.E., Ed.; IntechOpen: London, UK, 2019; pp. 1–11.
102. Sokhansanj, S.; Fenton, J. *Cost Benefits of Biomass Supply and Pre-Processing*; A BIOCAP Research Integration Program Synthesis Paper; BIOCAP Foundation: Edmonton, AB, Canada, 2006; pp. 1–61.
103. Sokhansanj, S.; Turhollow, A.F. Biomass densification—Cubing operations and costs for corn stover. *Appl. Eng. Agric.* **2004**, *20*, 495–499. [CrossRef]
104. Puls, J. Chemistry and biochemistry of hemicelluloses. Relationship between hemicellulose structure and enzymes required for hydrolysis. *Macromol. Symp.* **1997**, *120*, 183–196. [CrossRef]
105. Alvira, P.; Tomás-Pejó, E.; Ballesteros, M.; Negro, M. Pretreatment technologies for an efficient bioethanol production process based on enzymatic hydrolysis: A review. *Bioresour. Technol.* **2010**, *101*, 4851–4861. [CrossRef]
106. Alper, K.; Tekin, K.; Karagöz, S.; Ragauskas, A.J. Sustainable energy and fuels from biomass: A review focusing on hydrothermal biomass processing. *Sustain. Energy Fuels* **2020**, *4*, 4390–4414. [CrossRef]
107. Mohiuddin, O.; Asumadu-Sarkodie, S.; Obaidullah, M. The relationship between carbon dioxide emissions, energy consumption, and GDP: A recent evidence from Pakistan. *Cogent Eng.* **2016**, *3*, 1210–1491. [CrossRef]
108. Demirbaş, A. Biomass resource facilities and biomass conversion processing for fuels and chemicals. *Energy Convers. Manag.* **2001**, *42*, 1357–1378. [CrossRef]
109. Larsson, T.; Mahendar, S.K.; Christiansen-Erlandsson, A.; Olofsson, U. The Effect of Pure Oxygenated Biofuels on Efficiency and Emissions in a Gasoline Optimised DISI Engine. *Energies* **2021**, *14*, 3908. [CrossRef]
110. Bolan, N.; Hoang, S.A.; Beiyuan, J.; Gupta, S.; Hou, D.; Karakoti, A.; Joseph, S.; Jung, S.; Kim, K.H.; Kirkham, M.B.; et al. Multifunctional applications of biochar beyond carbon storage. *Int. Mater. Rev.* **2022**, *67*, 150–200. [CrossRef]
111. Saleem, M.; Chakrabarti, M.H.; Abdul Raman, A.A.; Hasan, D.B.; Wan Daud, A.W.M.; Mustafa, A. Hydrogen production by Chlamydomonas reinhardtii in a two-stage process with and without illumination at alkaline pH. *Int. J. Hydrog. Energy* **2012**, *37*, 4930–4934. [CrossRef]
112. Zhang, Z.; Zhao, W.; Zhao, W. Commercialization development of crop straw gasification technologies in China. *Sustainability* **2014**, *6*, 9159–9178. [CrossRef]
113. Luo, X.; Wu, T.; Shi, K.; Song, M.; Rao, Y. Biomass Gasification: An Overview of Technological Barriers and Socio-Environmental Impact. In *Gasification for Low-Grade Feedstock*; Yun, Y., Ed.; IntechOpen: London, UK, 2018; pp. 3–17.