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Biomass – An Environmental Concern

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1.1 Introduction

Any biological organic matter derived from living or dead organisms can be called "biomass." Every type of biomass is directly or indirectly obtained from the photosynthesis process [1]. Thus, biomass is a natural material with an organic matrix obtained from plants and animals [2]. It encompasses various materials, like wood, agricultural and industrial remains, and animal and human waste. Due to its range, there are substantial differences in biomass composition, whether of industrial or domestic origin [3]. With this vast heterogeneity in the usage and origin of materials, the definition of "biomass" varies. There is a wide range of biomass materials that can be broadly grouped as raw or derived. Cellulose, hemicelluloses, lignin, starch, and proteins are some of the main elements of biomass [4–7]. Various biomass sources of diverse origins, like agricultural, forestry, industrial, and other sources, are presented in Table 1.1 and depicted in Figure 1.1.

Biomass is now primarily used for feed, followed by food, and finally for the production of energy, fuels, and chemical feedstock. It accounts for 13% of global final energy consumption (other renewables contribute another 5%). The industrial organic chemical sector produces 550 million tonnes of chemicals and 275 million tonnes of nitrogen fertilizer, but the chemicals contain only 500 million tonnes of carbon. Furthermore, organic compounds used in organic chemistry contain approximately 100 million tonnes of carbon [8]. Currently, sugar, starch, and vegetable oil are the primary sources of biofuels and biochemicals [9]. Consumers interest and the need for replacement of fossil fuels with renewable energy sources are driving up demand for bio-products. The price level of feedstocks, such as lignocellulose, sugars, starch, and oils, is another factor influencing the competitiveness of biochemical products [9]. Price comparisons of bio-based carbon to fossil-based carbon, as well as cost comparisons of processing bio-based materials with the corresponding fossil-based materials, are difficult to specify because they are dependent on raw materials and the molecular economy of the processes into the final products. The various advantages and disadvantages of biomass are depicted in Table 1.2.

Plant Biomass Derived Materials: Sources, Extractions, and Applications, First Edition.
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Table 1.1 Sources of biomass.

Woody biomass (WB)	Nonwoody biomass (NWB)	Animal biomass (AB)	Processed waste (PW)	Processed fuels (PF)
Shrubs	Energy crops	Animal waste	Sawmill wastes	Charcoal
Trees	Cereal straws	Animal residues	Plant oil cake	Briquette and densified biomass
Bushes	Plant fibers, leaves and roots	Animal remains	Fruit waste and nutshells	Biogas
Forest floor sweepings	Grasses	Decomposed animals	Flesh	Vegetable oil
Palms	Banana		Bagasse Producer gas	
Bamboo	Soft plant stems		Cereal husk	Methanol and ethanol
Forest residues	Water plants		Industrial wood, bark and logs	Industrial residues
	Agricultural residues		sewage and other municipal waste	

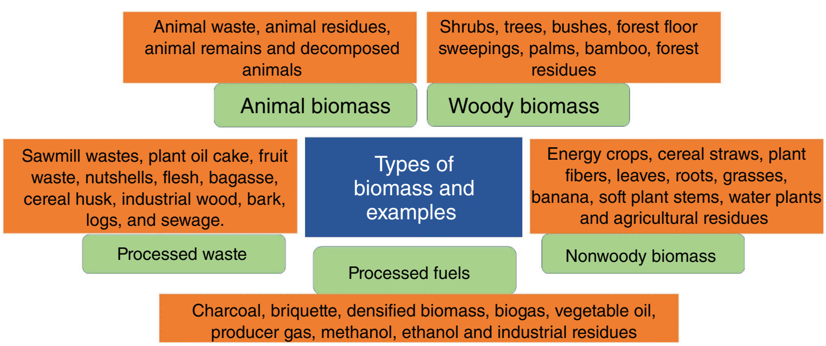


Figure 1.1 Types of biomass and examples.

Mineral oil is refined to produce fossil fuels and basic chemicals with very high carbon efficiency and low labor intensity. In contrast, biomass necessitates more processing steps, which increase the cost and labor requirements (see bioethanol production). Renewable energy sources such as solar, wind, hydro, and geothermal energy, as well as nuclear energy, are carbon-free in the energy industry. The transportation sector accounts for one-third of total final energy demand and 23% of global energy-related CO_2 emissions. Oil products meet approximately 96% of global transportation energy needs, with the remainder being met by electricity and biogas; thus increased use of renewables in the transportation sector is a high priority in the decarbonization of this sector.

The use of biofuels and other renewable energy sources, such as solar and wind, can help decarbonize the transportation sector [10]. The EU and the US have set limits on food-based biofuels. Although only 2% of global land is used for

Table 1.2 Advantages and limitations of biomass use.

Advantages	Limitations
Biomass is a renewable energy source	Biomass plants necessitate a large amount of space
It is available consistently and extensively	It could lead to deforestation
It is considered as carbon neutral.	It is not entirely clean
It helps to reduce our reliance on fossil fuels.	Biomass energy is inefficient compared to fossil fuels.
Is less costly than fossil fuels.	Biomass plants require a lot of space
It results in less garbage in landfills.	Huge requirement of resources like water
Biomass production generates revenue for manufacturers.	

Table 1.3 Biomass classification.

Type of biomass	Content	Utility	References
Wood and woody biomass	Logs, stems and branches Roots Foliage Bark Chips, pellets, and lumps Briquettes Sawdust	• Fuel in itself • Heat and electricity generation • Biogas generation • Fermentation for producing chemical products like alcohol and biodiesel • Manure as by-product	[3]
Herbaceous biomass	Grasses Straws Leaves Other residues like fruits, shells, and husks.		
Aquatic biomass	Algae Seaweed Lakeweed Kelp Water hyacinth, etc.		
Animal and human waste biomass	Excreta Dead and decaying animals Skin and bones, etc.		
Miscellaneous biomass	Food waste Food processing factory waste		

biofuel feedstock production, the "fuel versus food" debate shows that biomass used for industrial purposes is a sensitive issue in society. Some feedstocks (e.g. maize, oilseeds, sugarcane, and vegetable oil) have relatively high demand: biofuels consume 20% of global sugarcane, 12% of global vegetable oil, and 10% of global coarse grain production. Because biofuel accounts for a very small proportion of overall land use changes, crop competition may be reduced (as a percentage of total final energy consumption). Renewable energy sources play a critical role in the economy's "decarbonization," or the process of reducing the amount of greenhouse gas (GHG) emissions produced by the combustion of fossil fuels. These sources are called biomass only if they cannot be reused for subsequent processing [11]. The classification of biomass is presented in Table 1.3.

1.2 Biomass as an Energy Source

Factors that determine the usage of fuel are (i) cost, (ii) accessibility, (iii) stove type and technical features, (iv) cooking practices, (v) cultural preferences, and (vi) awareness about the potential health impacts [12]. Biomass is available on earth in many places, like agriculture, domestic farms, forests, and oceans. The total biomass reserves on land are estimated to be around 1.8 trillion tons, with an additional 4 billion tonnes in the ocean. Biomass is an enormously significant energy source, available everywhere, and bioenergy is the energy generated from biomass. About 33 000 EJ of energy can be produced by the total biomass present in the world. It is more than 80 times the total annual energy requirement of the world. Currently, biomass provides about 14% of the basic energy requirements of the world, i.e., 56.9 million exajoule per year globally (1230 million tonnes of oil equivalent per year) [8, 9]. About 159 billion liters of biofuel are produced each year globally from various biomass sources.

Solid biomass (wood, shrubs, herbs, wood chips, wood pellets, and other biomass sources) provides the majority of household biomass supply (85%). Biomass-based liquid biofuels contribute 8%, municipal and industrial waste contribute 5%, and biogas makes up a meager 2% of the total biomass supply. The utilization of biomass is not equal around the world. In some underdeveloped and developing countries, as much as 50% of the total energy needs are generated by wood combustion. In 2020, 1.93 billion m^3 of wood was produced globally as fuel. Africa and Asia had 36% and 37% of annual wood production, respectively. With 40.5 million tonnes produced globally, wood pellets are the most sought-after source. About 53.6 million metric tonnes of wood charcoal were produced in Africa, i.e. 65% of the total wood charcoal production globally.

In 2019, 2.59 EJ of energy was generated from municipal (56%, i.e. 1.45 EJ) and industrial waste (44%, i.e. 1.14 EJ). Globally, biomass was used to generate 655 terawatt-hours (TWh) of electricity. Of the total bioelectricity generated, 68% was from solid biomass sources, about 17% from municipal and industrial waste, and the remaining from other sources. Asia produced 39% (255 TWh), Europe produced 35% (230 TWh), and the rest of the world produced 35% (230 TWh). About 1.17 EJ of heat was produced from biomass-based sources in 2019. About 53% of the heat energy was produced from solid biomass sources, 25% from municipal solid waste, and the remainder from other biomass sources [10]. According to the 2018

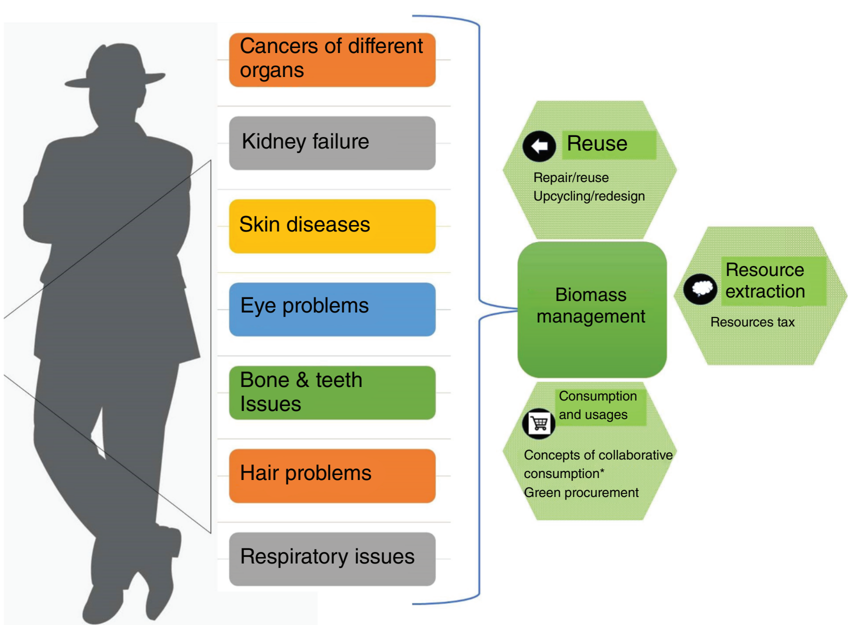
Table 1.4 Main conversion technologies and their corresponding products.

Process	Method	Biomass	Product	Concerns	References
Thermochemical conversion	Combustion	• Agricultural residues • Woody residues • Animal wastes	• Heat • Electricity	Air pollution by releasing gases such as CO_2, CO, nitrogen oxides, and volatile organic compounds	[3]
	Pyrolysis	• Agricultural residues • Woody residues	• Pyrolysis oil • Producer gas • Char	Pollution by synthetic gases and oils, ash, char, and heavy metals	
	Gasification	• Agricultural residues • Woody residues	• Producer gas • Liquid fuels • Char	Pollution by tars, heavy metals, halogens, and alkaline compounds	
	Liquefaction	• Agricultural residues • Algal biomass	• Fertilizer/biofuel • Syngas • Liquid fuels	Release of corrosive materials and salts	
Biochemical conversion	Anaerobic digestion	• Animal wastes • Sewage sludge	• Liquid fuels • Biogas • Electricity	Toxic and asphyxiant spills and gases. High COD liquids	
	Fermentation	• Agricultural residues • Sugars • Starch	• Liquid fuels (bioethanol)	Release of a high amount of CO_2	
Physicochemical conversion	Esterification/ Transesterification	• Vegetable oils • Animal fats • Waste oils	• Liquid fuels • Glycerol	Air water and soil pollution with the release of toxic chemicals	

World Biogas Association (WBA) report, biomass energy production in developed countries stands at 11% of the total energy produced [13]. In the USA, about 3% of energy demands (about 70 Mtoe yr^{-1}) are met by biomass. In Europe, 3.5% of its energy is derived from biomass (around 40 Mtoe yr^{-1}). European countries like Finland, Sweden, and Austria, with approximately 18%, 17%, and 13% of total energy generation from biomass, respectively, have a relatively high use of biomass energy in Europe [14]. Various methods of bioenergy generation and their concerns are presented in Table 1.4. [3, 15–17]

1.3 The Environmental Concern of Biomass

Burning fuels, fossils, or biomass releases carbon dioxide (CO_2). Apart from CO_2 emissions, burning any kind of biomass also emits other pollutants and particulate matter into the air, like CO, volatile organic compounds, and oxides of nitrogen. Sometimes, biomass can emit more pollutants than fossil fuels, and many of these pollutants cannot be sequestered by plants. Pollutants from biomass consumption can create environmental and human health problems if not properly controlled. During biomass processing, waste products like heavy metals, tar, alkaline compounds, and halogens are released, which cause environmental and health hazards. Because of the release of toxic exudates, gases, dust, and ash (both fly and bottom), biomass power generation has serious environmental consequences. It can also produce fire, explosions, high noise levels, odors, and other environmental hazards [18, 19]. Biomass, particularly biomass-based energy, is referred to as a carbon-neutral and nonpolluting energy source. This is not true; depending on the method of use and processing, biomass poses its own environmental risks. Although advanced processing can reduce emissions and subsequent pollution compared to fossil fuels, it cannot be considered environmentally safe [20–22]. Some of the environmental and health hazards of WB are discussed below.



1.4 Air Pollution

During the processing and burning of biomass, pollutants like gases, dust, biomass ash, fly ash, and char are released into the air, adversely affecting the environment by polluting the air and subsequently human health.

1.4.1 Gaseous Emissions

Gaseous emission is the main drawback of biomass utilization when used directly for energy, i.e. burning or processing to obtain a somewhat more efficient biofuel or energy source. Biomass utilization is one of the major sources of GHGemissions. The most common gases emitted are CO_2, NO_2, CO, and other nitric oxides. Though CO_2 is considered the main GHG responsible for global warming and other environmental problems, NO_2, which is produced during biomass generation, processing, and usage, is more harmful to the cause of global warming, i.e. 298 times that of CO_2. The point here is that relatively less NO_2 is released by fossil fuels as compared to biomass-based energy sources [23, 24]. It is reported that if we use NWB for processing, then relatively high levels of sulfur, chlorine, and ash are generated compared to processing WB [25]. It is well established that sulfur and chlorine have many hazardous effects on health and the environment. Sulfur as well as nitrogen are present in the majority of biomass, and their oxides (NO_x and SO_x) produced as by-products of processing have a huge negative impact on the environment [26].

1.4.2 Dust

Dust is generally generated during most of the stages of biomass production, handling, and processing [27]. The handling of dry and friable solid biomass is a major source of airborne particles. When viewed in isolation, biomass appears to be a minor source of dust particles that pollute the environment. But collective dust production by total biomass production, processing, and utilization is very high. Limits for particulate emission are (i) 0.60 g kg^{-1} of air for rural areas or urban areas with a population of 50 000 and (ii) 0.20 g particulates kg^{-1} of air for urban areas with a population of 50 000 [28]. Common agricultural biomass produces approximately 8% (ranging from 6% to14%) of the world's dust [29]. Persons dealing with biomass, in general, are exposed to and inhale >10 mg m^{-3} of dust, which is much higher than the limits of 1.5 mg m^{-3}, said to be acceptable by environmental groups [30]. Inhalation of dust can cause lung damage, interstitial lung disease, COPD (chronic obstructive pulmonary disease), asthma, pneumonitis, cancer, and irritation of the skin and eyes [31]. The size range of 0.2–5 m of dust is considered the most dangerous, causing serious health problems for humans and other living organisms.

1.4.3 Biomass Ash (Bottom Ash)

Ash is the residue left after the combustion of biomass. Materials like ash pose great risks to our health and the environment. But most of the attention is paid to gaseous emissions and other pollutants. Ash content can reach up to 20% in mass for some biomasses. Deposition and uncontrolled release of ash can result in extensive pollution of water sources, air, and soil. The ash can contain toxic elements like arsenic, chromium, lead, barium, cadmium, nickel, and others. These elements have been linked to cancer, neurological disorders, and lung and heart diseases. When exposed in large quantities, they can cause serious health problems and even death. The problem with ash is that it is not classified as hazardous waste, so there are no guidelines for its safe disposal. Even though there are no standards for the leaching of chemicals from it into the environment, ashes are fouling and slagging [32].

1.4.4 Fly Ash

Apart from residue ash, biomass can generate fly ash. It is called fly ash because it is released from gases, especially during combustion. It is a fine powder consisting of noncombustible matter that remains after incomplete combustion. Fly ash comprises spherical and irregular particles with diameters less than 10 μm. The fly ash has a higher concentration of heavy metals and other harmful elemental contaminants than the bottom ash. Based on the variety and source of biomass, the composition of biomass varies. The fly ash not only contaminates the air by releasing hazardous pollutants but also gets deposited in or mixed with water bodies, making them unsafe for drinking. Compared to bottom ash, the potential for health hazards with fly ash is multiplied. [33–35]

1.4.5 Carbon Monoxide Poisoning

It has been known since long that the leading product of biomass burning is carbon monoxide (CO), a colorless and odorless gas. CO is the most common cause of gas poisoning and has very hazardous effects [36]. CO enters the bloodstream after inhalation and binds with hemoglobin to form carboxyhemoglobin (COHb). CO has a great affinity for hemoglobin, and as much as 80–90% of absorbed CO binds with hemoglobin, thus declining the oxygen-carrying capacity of the blood and causing severe hypoxia. Compared to oxygen, hemoglobin has 200–250 times more affinity for CO than for oxygen [37, 38].

1.5 Water Use and Water Pollution

The commercial production of biomass uses a huge quantity of water. [39] Biomass cultivation needs a continuous water supply, and irrigating biomass fields for commercial purposes uses groundwater and surface water. Evan plants, which generate energy from biomass, consume a great deal of water. For example, ethanol production facilities require approximately 3–4 gallons of water per liter. Another critical point is that these processes require pure water, which is pumped from a very deep source [40]. These all have a significant impact not only on surface water but also on groundwater levels. Thus, increased biomass production can produce drought-like conditions, affect aquatic habitats, and affect water availability for other purposes like food crops, drinking, hydropower, and fish farming.

As a by-product of biomass processing, wastewater is produced as effluent. Various toxic pollutants like phenolic components, polycyclic aromatic hydrocarbons, benzene, toluene, ethylbenzene, and xylene are present in the released wastewater from biomass processing units. Apart from contaminating water and rendering it unsafe for domestic, agricultural, or fishery use, improper, unregulated disposal of these effluents causes other environmental problems. Biomass burning also leads to excessive fume production, which is released into the atmosphere, thus affecting the quality of not only the air but also increasing the incidence of acidic rain with a pH ranging from 3 to 6. Also, rainwater contains higher concentrations of ions like SO_4^{2-}, NO_3^-, and NH_4^+ in areas where biomass burning is more prevalent [41].

1.6 Impact on Soil

The presence of hazardous pollutants or contaminants in soil is termed "soil pollution." The presence of pollutants in high concentrations in soil poses a great risk to the ecosystem and human health. The high level of naturally occurring elements in the soil is also considered pollution. The direct use of biomass in agriculture not only increases the heavy metal concentration but also adds new heavy metals to the soil, which may lead to hazardous levels of heavy metal contamination. Because of the release of organic acids by biomass and the oxidative activation of compound heavy metals into molecular heavy metals, biomass activity activates heavy metals [42]. Soil pollution by biomass also alters the microbial content of soil and thus affects the basic nature of soil, including its nutritional values and fertility [43]. It indirectly also affects basal soil respiration (BSR) and nematode populations. These are directly or indirectly related to changes in heavy metal concentrations in soil. The ash that is formed by biomass burning, especially by the process of converting biomass into bioenergy, is generally not handled properly and gets mixed with the soil. This ash is detrimental to soil quality and nature due to its high elemental content, including hazardous heavy metals. This contaminated soil also becomes a reason for leaching contaminants into surrounding water bodies and even groundwater. The problem with soil pollution is that it also leads to the accumulation of pollutants in the plants or crops grown on polluted soil, causing health hazards to humans and animals who consume them.

Soil erosion is an indirect effect of excessive biomass consumption. Soil erosion is a condition where soil particles get detached from the surface either by wind, rain, or flowing water. One cause of soil erosion is the removal of crop residue for biofuel production. Fast-growing crops need a lot of nutrients and are harvested in relatively less time than regular crops, thus making soil prone to erosion due to repeated planting and harvesting activity. Also, cutting wild trees for fuelwood results in the creation of bare land where soil erosion is most severe. The various health hazards of by-products of biomass processing are depicted in Table 1.5.

Table 1.5 Hazardous effects of by-products of biomass processing on health and environment.

Aromatic hydrocarbon	Effect on human	Effect on environment	References
Naphthalene (tertiary tar)	• Hemolytic anemia, • Hemolysis • Depletion of pulmonary glutathione. • Dose-dependent necrosis of bronchiolar epithelia. • Cause cataracts • Damages retina.	Poor air quality with increased polycyclic aromatic hydrocarbon in air and water. Toxic to animals and fish	[44, 45],
Benzene (secondary/tertiary tar)	• Anemia • Drowsiness • Dizziness • Headaches • Tremors and confusion • Cancer	Benzene in soil or water Contaminates groundwater leading to toxicity	[46]
Toluene (Secondary tar)	• Headaches • Intoxication • Convulsions • Narcosis • Death (on chronic exposure)	Toxic to small animals, fish, and other aquatic organisms	[47, 48]
Xylene (secondary tar)	• Irritation of skin, eyes, nose, and throat • Difficulty in breathing and headache • Reduced muscle coordination Dizziness • Confusion	Bio accumulates in fish High acute toxicity to aquatic organisms	[49, 50]
Ethyl benzene (secondary/tertiary tar)	• Paralysis • Trouble in breathing • Liver toxicity • Death (on chronic exposure)	Water contamination with high acute toxicity to animals, birds, and aquatic life causes death	[51]

1.7 Indoor Pollution

Burning biomass fuel in an open area or on traditional stoves produces huge amounts of fumes or smoke. It also releases gases like CO_2, CO, hydrocarbons, organic oxides, free radicals, chlorinated organics, and particulate matter. [52]. Some contain particulate matter, an inhalable material with a diameter of 10 μm. Acceptable MPM (mean particulate matter) levels, as per WHO guidelines, are 25–50 $g\,m^{-1}$ [53]. The average indoor PM concentration is generally above 2000 $g\,m^{-1}$ in developing or underdeveloped countries at peak times [54, 55].

1.8 Deforestation and Land Degradation

Biomass energy consumption constitutes about 50–90% of total energy consumption in some parts of the world. Fuelwood is the primary domestic fuel and the main source of energy in these countries. In many of these countries, fuelwood is also used commercially to produce coal as an industrial energy source. Forests, agricultural or village trees, and forest residues are the main sources of fuelwood. To satisfy this huge need for biomass, these countries are dependent on their forests. Also, forest land is cleared for agriculture, animal husbandry, and cattle feeding. This takes a heavy toll on forests and woodlands. It results in the cutting of trees around villages and a decrease in forest area, leading to deforestation. Deforestation, in turn, leads to soil erosion, increased flood risks, and even desertification. Even if NWB fuels are used, they cause problems with insufficient fodder for animals, both wild and domestic. The reason is that wild animals feed on grass and shrubs, while domestic animals mainly feed on crop residues, grass, and shrubs [56].

1.9 Health Hazards

Biofuels and bioenergy, though allegedly believed to be clean and safe, are the main cause of indoor air pollution. The prolonged use of this form of energy results in respiratory infections and many other disorders that pose a serious threat to humans [57]. There are many incidences of respiratory and other diseases reported in poor and underdeveloped Asian and African countries. Some of the health hazards caused by biomass energy are discussed below.

1.10 Non-respiratory Illness

1.10.1 In Children

1.10.1.1 Lower Birth Weight

It has been reported that the inhalation of smoke by pregnant women from biofuel burning affects the growth of the fetus. The babies of mothers who use traditional methods of biofuel burning for daily household chores have low weights when compared with babies born to mothers using cleaner fuels [58].

1.10.1.2 Nutritional Deficiency

Biomass fuel also affects the growth of babies exposed to biomass smoke. Long-term exposure to biomass fuel smoke may lead to nutritional insufficiencies and anemia. It may even cause underdevelopment in children, thus affecting their growth [59, 60].

1.10.2 Respiratory Illness in Adults

1.10.2.1 Interstitial Lung Disease

Women from developing countries, especially those living in rural areas, suffer from severe interstitial lung disease. It has been dubbed "hut lung" because most of the women who suffer from it are poor and live in small houses where biofuels are burned indoors for cooking and other purposes [61]. Interstitial lung disease is a form of pneumoconiosis in which the lungs are damaged by prolonged exposure to smoke and particulate matter.

1.10.2.2 Chronic Obstructive Pulmonary Disease (COPD)

Biomass smoke is one of the major causes of COPD, especially in nonsmoking men and women living in rural areas of developing and underdeveloped countries. [62–64]. Exposure to biomass smoke causes COPD with clinical features that necessitate hospitalization and reduce the quality of sufferers' lives. COPD patients have a mortality rate comparable to tobacco smokers [65, 66]. The BMF is a major contributor to the pathogenesis of COPD, which has the highest global disease burden.

1.10.2.3 Tuberculosis

Tuberculosis (TB) is still a life-threatening disease in many countries like Asia and Africa. It is already proven that TB infection is increasing, especially in women periodically exposed to biomass fuel. Several studies have found a link between biomass smoke exposure and TB [67, 68]. BMF smoke harms the lungs and the function of alveolar macrophages [69–71]. Damaged alveolar macrophages are an easy target for *Mycobacterium tuberculosis*. The healthy alveolar macrophages act as an early defense mechanism against bacteria.

1.10.2.4 Lung Cancer

Biomass smoke has been identified as a "probable carcinogen" (Group 2a) by the IARC (International Agency for Research on Cancer). IARC also classified coal, a common household fuel, as carcinogenic. (Group 1) [72]. Prolonged exposure to biomass fuel smoke may develop adenocarcinoma of the lungs [73, 74]. Inhalation of biomass smoke from the burning of coal and wood is a major lung cancer-causing factor in the nonsmoking population.

1.10.3 Non-respiratory Illness in Adults

1.10.3.1 Cardiovascular Disease

Particulate air pollution is proven to increase the incidence of cardiovascular diseases. Particulate air pollution causes rapid increase in fibrinogen, plasma viscosity, platelet activation, and endothelin release. These changes have been found to be statistically significant in the development of cardiovascular diseases [75]. BMF smoke contains up to 20% less than 3 particulate matter. The people who inhale the BMF smoke are exposed to hazardous levels of PM, thus making them highly susceptible to cardiovascular diseases.

1.10.3.2 Cataracts

Studies have found a significant association between exposure to BMF smoke and cataracts or blindness [76, 77]. This was especially significant for patients who engaged in indoor cooking with BMF. BMF smoke and fumes induce oxidative stress. It also lowers plasma ascorbate levels, carotenoids, and glutathione below the normal range. These plasma constituents are very strong indigenous antioxidants that prevent cataract formation. Increased oxidative stress with a depleted defense mechanism leads to higher cases of cataracts in people who use BMF regularly.

1.11 Safe Disposal of Biomass

Due to the rising generation of biomass wastes and the absence of practical and effective methods to recycle these biomass waste resources, the disposal, usage, and management concerns of biomass wastes are becoming an increasingly serious problem for cities, particularly in developing nations. As a result, the sensible reuse of them has garnered considerable interest globally. Biomass is a kind of solar energy that has been stored. It was first gathered by plants through photosynthesis, in which CO_2 is taken in and converted to plant materials. It encompasses a wide range of organic components derived from plants and animals fed on the plant sand, and it can be transformed into several valuable sources of bioenergy. Today, biomass energy has overtaken coal, oil, and natural gas as the fourth-largest source of energy in the world [78].

Several processes, ranging from ordinary combustion to cutting-edge thermal depolymerization, can convert biomass wastes into clean energy and/or fuels. In addition to recovering a significant amount of energy, these technologies can result in a significant decrease in the total amount of trash that needs to be disposed of in the final stage. This allows for safer disposal in a controlled manner while still adhering to pollution control regulations [79].

In two different methods, the conversion of biomass waste into energy lowers GHG emissions. The production of heat and electricity lessens the reliance on fossil fuel-powered power plants. By limiting methane emissions from landfills, GHG emissions are considerably decreased. Additionally, waste-to-energy facilities are quite effective at extracting previously untapped energy from garbage [80].

Technology based on biomass is naturally adaptable. Due to the range of technological possibilities available, it can be utilized to generate baseload power on a much larger scale while simultaneously creating heat on a small and localized scale. Thus, biomass generation can be adapted to urban or rural settings and used in residential, commercial, or industrial settings. For maximizing the potential of biomass waste as an energy source, a wide range of technologies are available, from very basic systems for getting rid of dry waste to more sophisticated ones that can handle significant volumes of industrial waste [81].

By simple combustion, co-firing with other fuels, or through a middle phase like gasification, biomass can be turned into energy. The energy generated can be heat, electricity, or both (combined heat and power or CHP). The benefit of using heat in addition to, or instead of, electrical power is the noticeable increase in conversion efficiency. Electrical generating typically has an efficiency of around 30%, but when heat is employed, efficiencies can increase to more than 85% [82].

Clean energy can also be produced via biochemical processes like anerobic digestion in the form of biogas, which can then be used in a gas engine to generate electricity and heat. Additionally, wastes can produce liquid fuels like cellulosic ethanol, which can take the place of fuels derived from petroleum. As a natural source of oil that can be converted into jet fuel or diesel by conventional refineries, algae biomass is also gaining popularity as a reliable energy source [83].

Since the construction industry must constantly address issues related to GHG emissions, the disposal and recycling of raw materials, and sustainable development, the use of biomass wastes like rice husk, rice straw, flax, and fly ash as unconventional construction materials is an intriguing solution. Utilizing a combustion method they created themselves, Hu et al. produced reactive rice husk ash and used it in cement-based materials. It was discovered that raising the rice husk ash content increased the compressive strength of motors. The use of rice husk ash was also an environmentally friendly strategy, as shown by a sustainability analysis. Martinez–Lage et al. reported that adding biomass ash to composite mortars made them stronger in terms of compressive strength but reduced their flexural strengths [84].

The carbon-based materials made from biomass wastes were widely employed to give composite materials various functional features, such as conductivity, adsorption, hydrophobicity, and so on, in addition to their usage in buildings. To create carbon microtube anodes for Li batteries that were graphitic, porous, and co-doped with heteroatoms from hair debris, Zhu et al. designed an interfacial catalytic engineering procedure. During the graphitization of biomass, Ni-based nanofilm was a key catalyst in the Li+ diffusions and the formation of deep pores. The anodic behaviors of the microtube were discovered to be superior in terms of rate capabilities, active utilization effectiveness, long-term cyclic stability, and recycling capacity. However, its use is restricted due to its difficult preparation and the presence of hazardous and unsustainable compounds. To increase the rate ability and cycle stability of Li–S batteries, the interlayer – a carbon film inserted between the separator and sulfur cathode – is therefore proposed. Reusing the active chemicals during energy storage benefits from adding an interlayer. Nitrogen and boron dual-doped aerogel (NB-PPCA) was made from pomelo peel by Zhu et al. using a hydrothermal, freeze-drying, and pyrolysis procedure. It served as an interlayer on the pristine separator in Li batteries and outperformed other cells with a PPCA separator and pristine separator in terms of initial discharge capacity, high specific capacity, and higher cycle stability and rate ability [85].

1.12 The Bioeconomy of the Biomass Utilization

Around 50 countries have implemented carbon pricing systems, accounting for more than 20% of annual GHG emissions. Between 2017 and 2019, the price of CO_2 European Emission Allowances increased from €4 to €25/t [86]. According to estimates, EU carbon markets saved approximately 1.2 billion tonnes of CO_2 from 2008 to 2016, or 3.8% of total emissions during this time period. Carbon markets can function even when prices are low; however, current EU debates center on including the transportation and housing sectors in European emissions trading. Since January 2021, CO_2 emissions in the heat and transport sectors that are not covered by the EU Emissions Trading System (ETS) in Germany will be priced at €25/t. The EC intends to revise the current ETS rules, which will go into effect in 2023. Biotechnological innovation in the energy and chemical sectors has reduced reliance on petroleum and fossil fuels, benefiting the environment. The bioeconomy and circular economy are merging due to the integration of the circular economy's economic aspects and the economy's sustainability. Internationalization of various bioeconomics is a top priority in developing the circular bioeconomy [87].

1.13 Biowaste-Derived Functional Materials

Despite being excellent sources of natural polymers, biomass wastes possess functional groups and distinctive qualities that allow for direct reuse, particularly as adsorbents and building materials. They can also be utilized as a base or precursor for the pyrolysis and hydrothermal, physical, and chemical activations that have gained a lot of interest in the past five years to create functional carbon-based materials [88].

Carbon-based products have been created in many different forms up to this point, including biochar, activated carbon (AC), graphitic carbon, and others. Although pyrolysis is used to create both biochar and AC, there are some key differences between the two, including feedstock, pyrolysis temperatures, activation treatments, porous architectures, and uses. Various biomass wastes, including peanut shells, cornstalks, and some animal wastes, are used as feedstock for biochar. Organic materials are pyrolyzed at temperatures below 700 °C under oxygen-restricted circumstances in a heated, sealed reactor to produce biochar. Because the reactors are nontoxic and recyclable, this approach is more environmentally friendly, accessible, and effective than those used to produce other charcoals. The temperature and ramping rate during pyrolysis had a considerable impact on the microstructures of biochar, giving it a variety of functional qualities. As a result, biochar has demonstrated considerable promise for the catalytic oxidation of organic contaminants, soil amendment, and water treatment [89].

However, incomplete pyrolysis will result in the formation and release of pollutants that have an adverse effect on the environment and human health, including NO_x, SO_x, smoke, aerosols, and unburned hydrocarbons. By pyrolyzing biomass or other carbonaceous materials (like coal) at a temperature above 700 °C, AC can be created.

Compared to charcoal, AC often has a smaller microporous structure and a larger specific surface area. It is important to note that by using an activation procedure (such as chemical and physical activation with KOH and NaOH), biochar can be transformed into AC with an optimum porosity structure and specific surface area. Consequently, the electrochemical double-layer capacitor was used with the biochar-based AC that had been created.

The direct use of raw biomass wastes as adsorbents has some disadvantages. For instance, the sluggish diffusion or small number of surface-active sites contribute to the comparatively poor clearance rate of heavy metals. The process of separating absorbents from solutions and recycling them for subsequent use is similarly challenging. In order to create novel carbon-based materials with improved adsorption capacities, biomass wastes have been converted into various types of research during the past five years [90].

Heavy metals can be removed from wastewater using biochar, which is a common adsorbent. To remove 1-butyl-3-methyl-imidazolium chloride ([BMIM] [Cl]), Yu et al. created three different types of biochar from peanut shell, maize stalk, and wheat straw. Similar microporous structures and a significant number of functional groups that include oxygen were discovered in these biochars [91].

1.14 Conclusion

Biomass is an integral part of human life as an energy source, cattle feed, and raw material for many processes and products. It is generally considered “common man’s fuel” as it is abundant and comparatively cheaper. It was also considered very safe and environmentally friendly. But direct or indirect biomass usage produces gaseous, solid, and liquid pollutants that pollute the air, water, and land resources. This not only adversely affects the environment but also poses serious health hazards to the flora and fauna of the surrounding area, including severe health problems for humans. The areas where biomass energy is the primary source show a high amount of particulate matter and increased levels of GHGs (CO, CO_2, and other gases), leading to a weakened ozone layer. Though biomass utilization is a necessity due to various factors, it must be used and exploited wisely. The public should be aware of its proper use and processing to minimize the harmful effects of biomass on the environment and health.

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