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Future renewable energy uses, biomass combustion challenges in boiler power systems, and pollution concerns resulting from combustion

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Abstract

This study analyzes the challenges of biomass combustion in boiler power systems and details the possible uses of renewable energy sources to replace the combustion of fossil fuels as the primary energy sources in different nations. Here, biomass refers to both photosynthesis-produced organic matter and other types of organic waste from human and animal activities. Short explanations of the fundamental ideas behind the burning of biomass fuels are provided. Fourteen percent of the world's energy demand is met by renewable energy sources (RES). Renewable energy sources (RES) include those derived from plants, animals, the sun, the wind, the sea, and other bodies of water. Primary, domestic, clean, or infinite energy sources are renewables. As of 1995, bioenergy accounted for 62.1% of all renewable energy sources. We report experimental findings for a wide range of biomass fuels and operating circumstances. The use of numerical research is also covered. Being a renewable resource, biomass is a desirable option for use in industrial and municipal boilers. Biomass fuels may have a wide range of biomass constituents. The composition of ash produced by biomass is quite different from that of coal. Particularly inorganic components lead to severe issues with poisonous emissions, fouling, and slagging. Ash contains metals that, when combined with chlorine and other fuel ingredients like silica and sulfur, may cause a number of undesired reactions in the combustion furnace or power boiler. Ash fouling and slagging in biomass combustors are the result of chemical reactions involving a number of elements, including potassium, sodium, chlorine, phosphorus, calcium, magnesium, iron, and silicon. Corrosion caused by chlorine in biomass might disrupt operations. Heat transport is impeded by ash deposits, and serious corrosion may occur at high temperatures. Combustion rates and pollutant emissions also seem to be affected by biomass content. Systems that burn biomass produce no harmful emissions and hence greatly reduce environmental damage. Using biomass energy has several benefits, the most notable being a decrease in pollution caused by greenhouse gases.

Keywords: Slagging, fouling, alkalinity, corrosion, silica, sludge, biomass, and emissions are all terms associated with the renewable energy sector.

1. Introduction

The world's energy resources will be crucial moving forward. Energy is regarded a major agent in the formation of wealth and a vital role in economic growth. In place of traditional and fossil fuels, there are a plethora of new and renewable energy options to choose from. Fossil fuels, renewables, and nuclear power are the three types of energy resources that have been identified and categorized [1]. The choice as to what sorts of energy source should be employed must, in each situation, be taken on the basis of economic, social, environmental and safety concerns. There is widespread agreement that energy is crucial to economic growth, and evidence from the past supports the claim that there is a close connection between energy accessibility and economic activity [2].

The term "renewable energy resource" may also refer to conventional energy sources that are not fossil fuels. Using renewable energy resources that are produced on-site reduces or eliminates emissions of air pollutants and greenhouse gases. Ecology-friendly power

Marketable energy is generated using technological means that transform energy from natural sources. Alternative energy sources use the sun's rays and their effects on Earth (solar radiation, wind, falling water, and different plants; together referred to as "biomass"); gravitational forces (tides); and the heat of the earth's core (geothermal) to generate usable energy [2].

A global research and development in the area of renewable energy sources (RES) and systems is carried out throughout the previous two decades. By the end of 2001 the total installed capacity of renewable energy systems was comparable to 9% of the total power output [3]. By 2050, the world might use 318 exajoules (1 exajouleZ1018 J) of renewable energy in a scenario that emphasizes their use [4].

2. Renewable energy resources

wind, geothermal, other RES or on using energy more

Biomass fuel combustion is one method for recovering this lost energy [9]. Wood and wood wastes account for 64% of all biomass energy production, followed by solid waste (24%), agricultural waste (5%), and landfill gases (5%). Perennial crops provide for cost-effective biomass production with neutral or even beneficial effects on the environment.

Combustion occurs when biomass is burned as fuel in an energy application without first being chemically processed. It's possible to induce a conversion using thermochemical, biological, or chemical mechanisms. Direct combustion, pyrolysis, gasification, liquefaction, extraction using supercritical fluids, anaerobic digestion, fermentation, acid hydrolysis, enzyme hydrolysis, and esterification are all examples. It has been determined that in the near future, direct combustion and co-firing with coal for energy generation from biomass will be a promising technology. Around 97% of the world's bio-energy output comes from combustion [11], thus biomass thermo-chemical conversion methods like pyrolysis and gasification are not the most essential possibilities at the moment. Traditional biomass used for cooking and heating, particularly in rural parts of poor nations, makes up the vast majority of the supply. Traditional biomass use for heating and cooking results in substantial pollution.

As an alternative to coal, biomass has a lot going for it as a boiler fuel for utility companies. Forest debris, short-rotation woody crops, short-rotation herbaceous crops, alfalfa stems, and other forms of manure, landfill gas, and wastewater treatment gas are all potential biomass fuels for co-firing. Nowadays, solid waste is a cheap fuel only if it is accessible as a byproduct of something else. The solid wastes are a resource that may be used indefinitely.

Biomass fuels may replace fossil fuels in many applications. All across the globe, you may easily find them. Biomass is still widely used as a primary energy source in the developing nations. A significant fraction of Brazil's automobile fleet uses alcohol as fuel. In the West, efforts are being made to convert biomass into a usable fuel source. In Sweden, a massive biomass plant provides electricity to the country, while in the United Kingdom, efforts are being made to construct a power plant that will function purely on wood from a neighboring farm. Biomass output is estimated annually at 146 billion metric tons, with most of it coming from uncultivated plant growth. Biomass yields from certain crops and trees may reach 20 metric tons per acre per year. 50 metric tons per year might be produced by some species of algae and grasses [12]. In emerging nations, biomass is responsible for 35% of primary energy consumption, bringing the global total to 14%. Biomass has the ability to offer a low-cost, long-term energy source while also helping governments reach their greenhouse gas reduction goals. Biomass fuels have a significant impact on international trade and GDP. Yet, just 3% of primary energy consumption in developed nations comes from biomass sources.

Half of the world's population lives in rural areas, and most of them burn wood or other forms of biomass for energy [13].

More than double the percentage of coal (12%) and on par with the shares of gas (15%) and electricity (14%), biomass energy today accounts for around 14% of global final energy consumption. Several poor nations rely heavily on non-commercial biomass as their primary energy source. For this reason, collecting accurate statistics on biomass energy is a monumental challenge. However reliable information is required for performing tasks like examining past tendencies and present consumption habits, predicting future developments, and developing consistent plans of action.

The potential expanded use of this source as a significant alternative to solve the global warming problem is closely connected to the energy aspect of biomass utilization. In terms of carbon dioxide emissions, biomass is often thought of as an energy source. Assumption #1 is that the quantity of CO2 consumed in manufacturing is equal to the amount emitted into the atmosphere. Nevertheless, this is only the case if biomass energy is utilized in a sustainable manner, which would mean that the stock of biomass would not decrease over time. In many third-world nations, this may not be the case.

Table 6 details the significance of biomass in various global areas. The significance of biomass is shown to vary greatly among areas in Table 6. Biomass accounts for only about 3% of final energy consumption in Europe, North America, and the Middle East, but for the three-quarters of the world's population that lives in Africa, Asia, and Latin America, biomass provides a significant portion of the energy needs: about 33% on average, but as much as 80%-90% in some of the poorest countries in Africa and Asia (e.g. Angola, Ethiopia, Mozambique, Tanzania, Democratic Republic of Congo, Nepal and Myanmar). Furthermore, biomass is sometimes the only accessible and economical source of energy for basic necessities such as cooking and heating, especially for the poorest sectors of metropolitan populations.

By using a direct combustion process, biomass is converted into steam, which in turn powers a turbine, which in turn drives a generator.

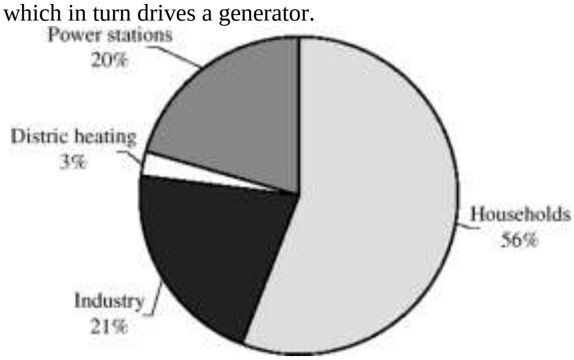

Fig. 1. Use of wood and wood waste as fuel in 1995. (Source: IEA).

one that creates power by use of a generator. Putting biomass through a gasifier allows for its transformation into a fuel gas (biogas). A high efficiency, mixed cycle gas turbine is then powered by the biogas [14]. In 1996, just 1.7% of Europe's energy came from renewable sources like biomass, but that number has steadily increased over the years. Figure 1 depicts the amount of wood and wood waste used for energy in 1995.

Biomass may be put to three different uses. It may be used as a liquid fuel, converted to gaseous fuels like methane, hydrogen, and carbon monoxide, or burnt to generate heat and power. Ethanol and methanol are the two most common types of alcohol used in liquid fuels, often known as bio-fuels. Ethanol, made from sugarcane, maize, and other grains, is the most widely used bio-fuel. In areas where air pollution is very bad, people are already using gasoline mixed with ethanol.

2.1. Hydropower

Hydropower, often known as hydroelectric power, is generated by harnessing the flow of water in rivers and streams. Almost a quarter of the world's total electrical supply, all of Norway's electricity, and more than 40 percent of the electricity consumed in developing nations comes from large-scale hydro power. It is believed that only around 25% of the theoretically viable global potential of large-scale hydro is being used at now.

Micro hydropower systems (MHP) have a capacity of less than 100 kW, while small hydropower systems (SHP) have a capacity of between 101 kW and 1 MW, making them two distinct types of small-scale hydropower systems. Around 20% of the world's energy comes from large-scale hydropower. Large hydropower projects may confront financial, environmental, and societal obstacles [5], but there is still considerable potential in underdeveloped nations.

Sites with capacities below 100 kW (micro hydropower systems) and sites with capacities between 101 kW and 1 MW (small hydropower plants) are mentioned in this section (referred to as small hydropower systems). Cross-flow turbines and pelton wheels used in micro hydro-power (MHP) systems provide both direct mechanical energy (for agricultural processing) and electricity. Design limitations mean that turbines with a maximum output of 30 kW are currently feasible. ideal for mechanical energy extraction. Around 6 MW of the 12 MW of MHP systems in operation worldwide are dedicated to the processing of agricultural products. The peltric set, which combines a pelton turbine and an electrical generator into a single device with a typical output of 1 kilowatt, is the most often used micro hydro power system. Small hydropower (SHP) plants are those that generate between 1 and 30 MW, micro hydropower (MHP) systems are those with capacities between 100 and 1000 kW, and large hydropower (LHP) systems generate more than 30 MW.

Dams are one-of-a-kind man-made marvels, and their construction is the largest single component of fundamental infrastructure in any country [15]. Currently, reservoirs have submerged over 500,000 km2 of land in the world, capable of storing 6000 km^3 of water. As a result of this distribution of fresh water in the reservoirs, small but measurable changes have occurred in the world. The total installed capacity of hydropower is 640,000 MW (26% of the theoretical potantial) generating an estimated 2380 TWh/year in the world, producing nearly 20% of the world’s total supply of electricity. The current and estimated electricity generation of the world from the hydropower is given in Table 7. 27,900 MW of the total hydropower is at small scale sites, generating 115 TWh/year [16–18]. The NAFTA countries are, now, the biggest producers, with Latin America and EU/EFTA regions, but it is estimated that Asia will be generating more hydroelectricty than NAFTA countries at the end of the next decade

2.2. records of geothermal energy use that have been quantified for 58 nations. The current state of geothermal power is shown in Table 9.

2.3. Space heating and domestic hot water supply, CO_2 and dry-ice production process, heat pumps, greenhouse heating, swimming and balneology (therapeutic baths), industrial processes, and electricity generation are just some of the many applications for geothermal energy, which is clean, cheap, and renewable. Most people utilize it for its intended purpose, with 42% doing so for bathing, swimming, and balneology, 35% for space heating, 9% for greenhouses, 6% for fish farming, and 6% for industry [8]. Electricity production, direct consumption, space heating, heat pumps, greenhouse heating, and industrial use are only some of the many possible applications of geothermal energy. Geothermal steam is used to generate electricity in 21 nations on all seven continents. Low-temperature geothermal energy is used to create heat in several nations, with an estimated thermal capacity of about 10,000 MW.

2.4. Geothermal energy

Solar energy

Solar thermal electric power (STEP) occurs when the sun's energy is concentrated to heat water and produce steam, which is then used to produce electricity. Other forms of solar energy include solar water heating (SWH), solar photovoltaic (SPV): converting sunlight directly into electricity, and solar heating (SH, SHH, SD, SC, and SWH). The solar collector is the main part of a solar energy system. Collectors for solar power convert the heat from the sun into the thermal energy of the material they are transported through, making them a subset of heat exchangers. Dehydrated herbs and produce may be stored for longer periods of time with the help of solar dryers. Box types, cabinet types, and tunnel types of SD are the three most common. Direct heat is used in a box style to dehydrate food. Cabinet dryers employ collector-heated air to dehydrate food, whereas tunnel dryers use forced air circulation to disperse heat. Compared to box type dryers, cabinet and tunnel type dryers are cumbersome and expensive, but the dried materials they produce are of a higher quality. Thus far, 760 of the roughly 800 dryers distributed are box dryers [27].

There are many different types of solar energy systems, including solar thermal, solar photovoltaic, solar water heating, sun drying, and solar cooking. Often, these are systems that a family or a small community sets up and maintains alone. For residential use, the maximum allowable PV system output is 40 W. A single family or a small community may install and maintain such a system.

Other than solar hot water (SHH) systems, photovoltaic (PV) systems are utilized for telecommunications, water pumping for drinking and agriculture, and energy production. Markets for photovoltaic (PV) panels have also expanded rapidly, with prices dropping considerably. It is anticipated that about 1 GW of such systems have been built at this point. There is a 30% annual increase in the installed capacity of solar photovoltaics and grid-connected wind turbines [5]. Figure 2 displays global exports of PV modules from 1990 to 2000.

Solar water splitting is an appealing method for converting solar energy into chemical energy [28].

whenever the wind blows (at night and also during the day). In theory, wind systems can produce electricity 24 h every day, unlike PV systems that cannot make power at night. However, even in the windiest places, the wind does not blow all the time. So while wind farms do not need batteries for backup storage of electricity, small wind systems do need backup batteries.

Wind power in coastal and other windy regions is promising as well. By any measure the power in the wind is no longer an alternative source of energy. Wind energy has limitations based on geography and meteorology, plus there may be political or environmental problems (e.g. dead birds)with putting turbines in.

2.5. Other renewable energy sources

Marine energy, biogas from animal wastes, landfill gas, hydrogen and peat energy are the other RES. Marine energy sources are current, tidal, ocean thermal energy conversion (OTEC) and wave technologies. The world wave resource is between 200 and 5000 GW mostly found in offshore locations [29]. Wave energy converters fixed to the shore- line are likely to be the first to be fully developed and deployed, but waves are typically 2–3 times more powerful in deep offshore waters than at the shoreline. Wave energy can be harnessed in coastal areas, close to the shore. The first patent for a wave energy device was filed in Paris in 1799, and by 1973 there were 340 British patents for wave energy devices. By comparison to wind and PV, wave energy and tidal stream are very much in their infancy. Currently, around 1 MW of wave energy devices is installed world- wide, mainly from demonstration projects.

The OTEC is an energy technology that converts solar radiation to electric power. OTEC systems use the ocean’s natural thermal gradient to drive a power-producing cycle. As long as the temperature between the warm surface water and the cold deep water differs by about 20 K, an OTEC system can produce a significant amount of power. The oceans are thus a vast renewable resource, with the potential to help us produce billions of watts of electric power.

Landfill gas contains about 50% by volume methane. Producing energy from landfill gas improves local air quality, eliminates a potential explosion hazard and reduces greenhouse gas emissions to the atmosphere. Hydrogen, produced by passing an electrical current through water, can be used to store solar energy and regenerate it when needed for night-time energy requirements. Hydrogen can be produced by pyrolysis from biomass [30]. It can be burned to produce heat or passed through a fuel cell to produce electricity.

3. Biomass combustion

The price of generating energy from fossil fuels has finally risen beyond the price of biomass fuels.

With a few notable exceptions, the cost of producing the same amount of energy from fossil fuels is higher than the cost of producing the same amount of energy via biomass conversion. Concern about climate change has sparked widespread interest in developing new uses for renewable energy sources like biomass fuels. As a fuel source, biomass not only shows great promise, but also a relatively low price tag in contrast to other renewable energy [31].

One may cultivate a wide variety of biomass crops for the sole aim of harvesting their energy content. Sugar cane, maize, sugar beets, cereals, elephant grass, kelp (seaweed), and many more are among the various crops that have been utilized for energy. A crop's viability as a source of renewable energy depends on two primary aspects. High dry tonnage per hectare is a criterion for good energy crops. Increased productivity lessens the need for agricultural land and decreases the price of biomass power. In a similar vein, the energy input into a biomass crop's production must be higher than the energy output. Recent developments in conversion technology have opened the door to lignocellulosic biomass as a source for bio-ethanol production [28].

Biomass fuels vary widely in their compositions, particularly with regard to inorganic elements crucial to the pressing issues of fouling and slagging. Several undesired reactions in combustion furnaces and power boilers may be traced back to the presence of alkali and alkaline earth metals, in addition to other fuel ingredients like silica and sulfur, and the facilitation of these processes by chlorine.

The characteristics of biomass fuels are more variable than those of coal. Fuel nitrogen (N) percentage, for instance, may range from w0.2 to more than 1%, whereas ash level can be anywhere from 0% to 16%. (Table 10). Apart from its low bulk density and poor heating value compared to coal, biomass also has a high moisture content (often over 27% and occasionally over 51% when burnt), a potentially high chlorine (Cl) concentration (varying from roughly 0.1 to 1.5%) (Table 10).

The high volatility of biomass fuel and the high reactivity of both fuel and the consequent char make it an attractive combustion feedstock. The biological, inorganic, energetic, and physical characteristics of biomass are significantly different from those of coal. Compared to coal, biomass typically has lower carbon (C), greater oxygen (O2), higher silica (SiO2) and potassium (K) content, lower aluminum (Al) and iron (Fe) content, higher moisture content, lower density, and poorer friability. Certain biofuels, such as straw, may actually have higher concentrations of Cl than coal. Analyses of the final products show the elemental differences between coals and biomass (Table 10).

The inorganic components of coal also vary by rank and location, giving it still another distinguishing feature over biomass. Common fuel ash compositions

Table 1
Moisture, ash and higher heating value (HHV) analysis of biomass fuels

Fuel common/scientific name	Moisture (wt% of fuel)	Ash (wt% of dry fuel)	HHV (MJ/kg, daf)	Refs.
Almond shells/*Pranus dulcis*	7.5	2.9	19.8	[39]
Almond hulls/*Pranus dulcis*	8.0	5.8	20.0	[48]
Beech wood/*Fagus orientalis*	6.5	0.6	19.6	[47]
Hazelnut shell/*Corylus avellena*	7.2	1.4	19.5	[39]
Oak wood/*Quersus predunculata*	6.0	1.7	19.8	[40]
Oak bark/*Quersus predunculata*	5.6	9.1	22.0	[40]
Olive pits/*Olea europaea*	7.0	1.8	22.0	[48]
Olive husk/*Olea europaea*	6.8	2.1	21.8	[39]
Pistachio shells/*Pistocia vera*	8.1	1.3	19.9	[48]
Rice straw/*Oryza sativa*	11.2	19.2	18.7	[48]
Spruce wood/*Picea orientalis*	6.7	0.5	20.5	[47]
Switcgrass/*Panicum virgatum*	13.1	5.9	19.9	[48]
Wheat straw/*Triticum aestivum*	6.4	8.1	19.3	[48]

In Table 11, we see several examples. Coal, as a group, contains higher concentrations of Al, Fe, and Ti than does biomass. Compared to coal, biomass is a better source of silica, potassium, and even calcium (Ca).

Biomass has a low heating value since it has a higher oxygen to carbon ratio but is still far less efficient than solid fossil fuels. Moreover, the chlorine concentration of certain bio-fuels, such as straw, might be higher than that of coal. Ash production is greatly influenced by chlorine. Several inorganic substances, including potassium, are more mobile when exposed to chlorine. Biomass has been burnt directly in combustion applications, either as a secondary fuel or in place of a main fuel. Issues with ignition and combustion might arise due to biomass' high moisture and ash concentrations. Biomass has poor heating properties, which causes issues with flame stability. Flame stability issues should be mitigated, and corrosion impacts lessened, if biomass is blended with high-quality coal.

There are several reasons why biomass fuels are good for the environment [32]. Burning biomass fuel does not produce any more carbon dioxide. During photosynthesis, biomass uses up the same amount of atmospheric carbon dioxide (CO2) that a forest uses to produce its own biomass. is burned up and released into the atmosphere. Some of the SO2 and CO2 released during combustion may be absorbed by the alkaline ash left behind after burning biomass [33,34].

3.1. The chemistry of biomass combustion

Biomass combustion is a series of chemical reactions by which carbon is oxidized to carbon dioxide, and hydrogen is oxidized to water. Oxygen deficiency leads to incomplete combustion and the formation of many products of incomplete combustion. Excess air, cools the system. The air requirements depend on the chemical and physical characteristics of the fuel. The combustion of the biomass relates to the fuel burn rate, the combustion products, the required excess air for complete combustion, and the fire temperatures.

In general, combustion properties of biomass can be classified as macroscopic or microscopic. The macroscopic properties of biomass fuels are given with for macroscopic analysis, such as ultimate analysis, heating value, moisture content, particle size, bulk density, and ash fusion

Table 2
Ultimate analyses and ash contents of coal and biomass samples (wt% dry basis)

	C	H	N	O (diff.)	S	Cl	Ash
Coal	81.5	4.0	1.2	3.3	3.0	0.3	7.0
Lignite	65.2	4.5	1.3	17.5	4.1	0.4	7.4
Spruce wood	51.4	6.1	0.3	41.2	0.0	0.1	0.9
Hazelnut shell	50.8	5.6	1.0	41.1	0.0	0.2	1.3
Wheat straw	42.8	5.5	0.7	35.5	0.0	1.5	15.5
Corncob	*49.0*	*5.4*	*0.4*	*44.2*	*0.0*	*0.2*	*1.0*
Corn stover	*49.4*	*5.6*	*0.6*	*42.5*	*0.1*	*0.3*	*3.9*

Tobacco stalk	*49.3*	*5.6*	*0.7*	*42.8*	*0.0*	*0.2*	*2.6*	7
Tobacco leaf	*41.2*	*4.9*	*0.9*	*33.9*	*0.0*	*0.3*	*19.2*	
Almond shell	*47.9*	*6.0*	*1.1*	*41.7*	*0.0*	*0.1*	*3.3*	
Walnut shell	*53.6*	*6.6*	*1.5*	*35.5*	*0.0*	*0.2*	*2.8*	

Source: Refs. [73,74].

temperature. Properties for microscopic analysis include thermal, chemical kinetic and mineral data [11]. Fuel characteristics such as ultimate analysis, heating value, moisture content, particle size, bulk density, and ash fusion temperature of wood fuels have been reviewed [35]. Fuel characteristics include proximate analysis, ultimate anal- ysis, chlorine content, higher heating value, ash elemental analysis, and trace metal content on a selective basis [36]. Fuel properties for the combustion analysis of wood can be conveniently grouped into physical, chemical, thermal, and mineral properties.

Physical property values vary greatly and properties such as density, porosity, and internal surface area are related to wood species whereas bulk density, particle size, and shape distribution are related to fuel preparation methods.

Important chemical properties for combustion are the elemental analysis, proximate analysis, analysis of pyrolysis products, higher heating value, heat of pyrolysis, heating value of the volatiles, and heating value of the char.

Thermal property values such as specific heat, thermal conductivity, and emissivity vary with moisture content, temperature, and degree of thermal degradation by one order of magnitude. Thermal degradation products of wood fuels consist of moisture, volatiles, char and ash.

Some properties vary with species, location within the biomass fuels, and growth conditions. Other properties depend on the combustion environment. Where the proper- ties are highly variable, the likely range of the property is given [11].

Main combustion reactions are:

3.2. Wood combustion analyses

Particle size and specific gravity (a), ash content (b), moisture content (c), extractive content (d), elemental content (C, H, O, and N), and structural component (cellulose, hemicellu- loses, and lignin) content (g) are all factors that affect how well something burns.

Dimensions and Density of Particles 3.2.1

Successful combustion requires biomass particles to be at least 0.6 cm in size, and ideally considerably larger. Biomass, as comparison to coal, is far less dense and has much greater aspect ratios. Size reduction is likewise far more challenging.

3.2.2 Ash content

The percentage of ash or inorganic elements a plant contains is affected by both the kind of plant and the level of pollution in the soil in which it is grown. Ash makes up around 0.5% of wood's typical composition [1]. The ash percentage of hardwoods is around 0.5%, whereas that of softwoods is just 0.4%. Soluble ionic compounds may have a catalytic influence on the pyrolysis and combustion of the fuel, but insoluble compounds operate as a heat sink similar to water, reducing combustion efficiency. Char is more likely to occur when inorganic chemicals are present [37]. The heating value is closely related to the ash content. A less attractive fuel source is a plant component with a high ash concentration [38].

Mineral content might vary between and even within different biomass samples. Although calcium, potassium, silica, and magnesium salts make up the bulk of the mineral content in fruit shells, salts of many other elements may also be found there in trace levels [39].

Dryness/Wetness (3.2.3)

In general, the heating value of biomass is reduced by its moisture content [38]. Biomass contains water in the interstices of dead cells and in the cell walls themselves. When drying, the fuel's internal moisture content equalizes with the surrounding air's relative humidity. With air-dried gasoline, equilibrium is typically about 20%. The species of wood tested showed a wide range of moisture content, from 41.27 to 70.20 percent [40]. Wood fuel loses its heating value as its moisture content rises. Different tree parts have different moisture levels. It typically starts at the base of the plant and grows toward the roots and the top of the plant [41].

The physical properties and quality of the pyrolysis liquid are affected by the amount of water present in the biomass before and throughout the process. The obtained findings demonstrate that the highest liquid output on a dry feed basis takes place at lower pyrolysis temperatures between 691 and 702 K [42], which is the case for greater beginning moisture concentrations.

3.2.4 Content Extraction

Once again, the heat content is modified, which is a crucial component in determining whether or not a given substance may be used as a fuel.

how much of its organic components (sometimes referred to as "extractives") can be burned [43]. There seems to be a positive contribution of extractives towards the growth of HHV, since the HHVs of the extractive-free plant sections were found to be lower than those of the unextracted portions. The heating value is directly proportional to the extractive content. A plant component with a high extractive content is attractive for use as a fuel source. Likewise, the quantity of extractives present affects the heat content, which is an extremely significant component in determining the usefulness of any substance as a fuel. Higher heating values of wood fuels were achieved by the use of extractives [38].

Element Content, 3.2.5

The features of combustion are strongly affected by the fuel's chemical and physical makeup. Proximate analysis (also known as elemental analysis) and chemical analysis are both viable methods for studying biomass (called as ultimate analysis).

Carbon atoms tend to predominate and overshadow slight differences in hydrogen abundance, which is why oxidation status is connected to heat content in natural fuels. Tillman [44] also discovered a linear link between HHV and carbon content, using published figures for several wood species.

3.2.6 Composition of structural elements

The biopolymers in biomass fuels come from many different kinds of cells, and their cell walls are made of cellulose, hemicelluloses, and lignin. Higher lignin levels in biomass fuels result in higher heating value (HHV) values [45,46]. Increases in FC content are often seen in wood fuels of higher calorific value [47].

3.3 Biomass's Potential Energy Sources

In Table 12 [39,40,47,48], you may find the HHV, ash, and moisture content analysis of the biomass fuels. The heating value, often known as the calorific value or heat of combustion, is the conventional metric for the energy content of a fuel. Enthalpy shift during combustion with water condensation is quantified by the increased heating value at constant pressure.

Many efforts have been made to establish a relationship between heating value and composition. Since cellulose is more easily oxidized, it has a lower heating value than lignin. The heating value of biomass is often increased by the presence of other chemicals, such as HC in the fuel at lower degrees of oxidation [49].
Prior research [5] established equations for approximating the HHVs of different lignocellulosic materials, based on their final analytical results. An analysis was performed to see whether there was a correlation between the measured HHV and the C, H, and O contents of the samples (wt%). In this way, the HHV (MJ/kg) of lignocellulosic materials, such as C, H, and O, may be determined using Eq. (1):

HHV Z 0:335C C1:423H K 0:154O (1)

3.2.1. Pyrolysis
The term "pyrolysis" refers to the process of destroying organic compounds using heat in the absence of oxygen. Thermochemical pyrolysis is the primary route for upgrading biomass into a usable fuel. When biomass is cooked without oxygen, or with a restricted supply of oxygen, a gas mixture rich in hydrocarbons, a liquid similar to oil, and a carbon-rich solid residue are produced.
More than 95% of the energy content of biomass is recovered by thermochemical transformation (pyrolysis and/or gasification). At moderate temperatures (825 K), pyrolysis typically produces a pyrolysis gas made up of H2 and CO [49,50]. The process of pyrolysis is the quickest, easiest, and, most likely, the oldest way to improve the quality of a fuel by breaking it down into its component parts. It is also possible to perform pyrolysis with the addition of a tiny amount of oxygen (known as "gasification"), water (known as "steam gasification"), or hydrogen (known as "hydrogenation"). Methane is one of the most valuable byproducts because it can be used in high efficiency gas turbines to produce power.
When cellulose and hemicelluloses are heated, the sugar units cleave off, releasing mostly volatile byproducts. Because lignin can not easily break down into smaller molecular weight pieces, most of it burns to char. As the pyrolysis temperature of the wood was raised gradually, the volatiles were driven out, and a solid was formed.

Table 13
Ash compositions of typical fuel samples (wt% of ash)

Fuel sample	Si_2O	Al_2O_2	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Cl
Coal type 1	42.0	20.0	1.2	17.0	5.5	2.1	1.4	5.8	5.0	–
Coal type 2	59.7	19.8	2.1	8.3	2.1	1.8	0.8	2.1	2.0	–
Coal type 3	51.5	22.6	2.0	14.9	3.3	0.9	1.0	2.0	3.5	–
Lignite	35.3	17.3	1.2	5.4	18.1	3.3	1.1	4.6	12.1	–
Spruce wood	49.3	9.4	–	8.3	17.2	1.1	0.5	9.6	2.6	0.8
Wheat straw	48.0	3.5	–	0.5	3.7	1.8	14.5	20.0	1.9	3.6
Hazelnut shell	33.7	3.1	0.1	3.8	15.4	7.9	1.3	30.4	1.1	0.1

Source: Ref. [73].

residue that is different chemically from the original startingmaterial.

Pyrolysis of wood has been studied as a zonal process [17]. Thermal degradation properties of hemicelluloses, celluloses and lignin can be summarized as follows [18]:

Thermal degradation of hemicellulosesOof celluloseO of lignin

It is possible to use torrefaction to enhance the fuel qualities of wood. It entails gradually heating wood in an inert environment to a temperature of 575 K [16]. After processing, the wood becomes a uniformly dense and dry solid with increased energy content.

Higher torrefaction temperatures and longer residence times improve the calorific value of torrified wood by raising the carbon content of the solid product while decreasing the concentration of hydrogen and oxygen. When the temperature rises, more CH4, H2, CxHy, and CO are produced in the byproduct gases, while less CO2 is produced. Although the torrefied samples do absorb some moisture, it is far less than the moisture content of the original material [16].

At first, cellulose and hemicellulose disintegrate into simpler compounds. This results in a "activated cellulose," which breaks down by two competing processes, one producing volatiles (anhydrosugars), and the other producing char and fumes. Depending on the reaction temperature, thermal breakdown of activated cellulose and hemicelluloses into volatiles and char may be broken down into several classes. All these processes occur simultaneously and in order inside a fire.

Pyrolitic cracking of the fuel is the main source of the gaseous emissions. When flames are present, the temperature of the fire rises, and more oxygen is made accessible by thermally-induced convection.

By analyzing the processes of pyrolysis, ignition, and combustion, we may learn the following about coal and biomass particles:

(1) Pyrolysis starts earlier for biomass compared with coal.
(2) The VM content of biomass is higher compared with that of coal.
(3) The fractional heat contribution by VM in biomass is onthe order of 70 compared with 36% for coal.
(4) Biomass char has more O_2 compared with coal. The fractional heat contribution by biomass is on the order of 30 compared with 70% for coal.
(5) The heating value of volatiles is lower for biomass compared with that of coal.
(6) Pyrolysis of biomass chars mostly releases CO, CO_2, and H_2O.
(7) Biomass has ash that is more alkaline in nature, which may aggravate fouling problems.

The organic compounds from biomass pyrolysis are the following groups:

(1) A gas fraction containing: CO, CO_2, some hydrocarbons and H_2.
(2) A condensable fraction containing: H_2O and low molecular weight organic compounds (aldehydes, acids, ketones and alcohols).
(3) A tar fraction containing: higher molecular weight sugar residues, furan derivatives, phenolic compounds and airborne particles of tar and charred material whichform the smoke.

3.2.2. Char combustion

The char that forms is extremely reactive because to the trapped free radicals and has a porous structure. Graphite and other pure carbon compounds have nothing in common with char. In other words, a lot of absorbent surface area. Char's characteristics are linked to the fuel's physical and chemical make-up and the circumstances under which it was pyrolyzed.

Glowing combustion is the burning of the active carbon (the char) to create CO2 in the presence of adequate oxygen and high enough temperatures. When temperature and residence time are increased, fewer solid products are produced but more gas, tar, and water are produced. Under these settings, the inert gas flow was not observed to significantly affect the product distribution. Smoldering happens at low temperatures or in low-oxygen environments (characterized by smoking or emission of unoxidized pyrolysis products). Flaming combustion describes how the VMs are being burned. At higher temperatures, flaming predominates whereas at lower temperatures, smoldering is the norm.

3.2.3. Gasification

Traditionally, biomass gasification methods have relied on partial oxidation or partial combustion principles, yielding a hot, filthy, low Btu gas that must be immediately ducted into boilers or dryers. These technologies are an inefficient source of useable energy [1] that has a number of drawbacks, including a narrow range of potential uses and the exacerbation of existing environmental issues.

As a high-temperature pyrolysis process, gasification is performed with the goal of maximizing the release of gas. The resultant gas is a combination of carbon monoxide, hydrogen, methane, carbon dioxide, and nitrogen; it is referred to as producer gas. The gas may be burned to generate process heat and steam, or sent through gas turbines to generate electricity, making it much more adaptable than the initial solid biomass (often wood or charcoal).

In order to achieve these aims of increasing biomass utilization, biomass gasification technologies will likely play a significant role. Technology advancements in gasification have made it possible to transform sustainable biomass feedstocks into clean fuel gases and synthesis gases. Gasification of biomass represents the cutting edge of the renewable energy sector.

methods, and it is being used to increase the effectiveness and decrease the initial investment in gas turbine technology for biomass energy generation. Combined-cycle gas turbine systems, in which waste gases from the gas turbine are recovered to create steam for use in a steam turbine, may achieve high efficiency (up to roughly 50%). Studies have shown that biomass suffocation plants may be just as cost-effective as their coal-fired counterparts [1].

Commercial gasifiers come in many shapes and sizes and may be fueled by many different materials, such as wood, charcoal, coconut shells, and rice husks. The economic availability of biomass sets a cap on power generation that, in most areas, is 80 MW.

3.3. Combustion properties and combustion considerations

Every device's combustion process must be modified to account for the volatile fuel used in biomass burning. Unlike coal, whose primary combustion process is char formation and gas-solids oxidation, biomass, when added to a coal-fired PC boiler, provides a fuel whose primary reaction sequence is volatilization and gas-phase combustion [52].

As an alternative fuel, biomass may be used in coal-fired boilers.

Documentation provided by Ref. [11].

All of the physical and chemical characteristics of biomass and coal fuels are listed in Table 13. As compared to most types of coal, biomass has a far lower heating value. This is due in part to the high O2 level and the normally high moisture content. There is a false impression created by the decreased heating values that the flame temperatures are also reduced.

More volatile matter (VM) yields may be obtained from biomass fuels as compared to coals. Typically, biomass will have a VM content of 70-80%, whereas coal would have a VM content of 10%-50%. Take note of the difference in volatility between the two fuels; the VM/FC ratio of biomass is normally O4.0. When discussing coal, the VM/FC ratio is almost usually 1.0. Volatile yields tested by the American Society for Testing and Materials (ASTM) regularly underestimate the actual yields after burning, although in both situations, bio-fuel yields much exceed those of coal. Yet, there is a possible issue with carbon consumption when co-firing bio-waste with coal.

Concerns for the environment that are directly tied to energy production and use

The presence of one or more toxins in the air at concentrations and for durations that are harmful, or have the potential to be harmful, to human health and welfare, animal welfare, and plant life. Air pollution occurs when dangerous compounds are released into the atmosphere and contaminate the air. Damage to the environment and to people's possessions are only two of the many negative outcomes of air pollution. It has led to climate change by decreasing the atmosphere's protective ozone layer.

The term "air quality standard" (AQS) refers to the maximum allowable concentration of a pollutant in the air outside a building at any given moment. When harmful gases and particles in the air reach concentrations above the AQSs, this is known as air pollution.

4. Conclusion

Biomass energy generation has numerous distinctive features that result in positive ecological impacts. As a result of improved management, it may help minimize acid rain, soil erosion, water pollution, and the burden on landfills; it can also offer habitat for animals; and it helps moderate climate change. Most contemporary boilers generate either heat, steam, or electricity. There is a wide range of direct combustion system architectures. The combustion system's layout and efficiency are both affected by the fuel used. The method utilized for burning biomass directly is similar to that of burning coal.

With the high furnace temperatures and efficient air-fuel mixing that characterize pulverized coal combustion, air hazardous emissions from biomass combustion were often extremely low, and frequently close or below detection limits.

Conservation of fossil fuel resources, reduced dependence on fuel imports, utilization of agricultural and forest residues, reduction of emission of harmful species from fossil fuel combustion, recultivation of underutilized farming land, and waste minimization are just some of the ecological and, in many cases, economic benefits that accrue from the use of such fuels in industry.

There are several technical issues with the biomass burning technique. The fouling and corrosion of combustor components by the alkaline biomass ash must be addressed first. Combustor surface fouling has been a crucial factor in the development and implementation of combustion equipment. Increasing temperatures cause issues with corrosion and fouling.

liquid by-products of burning biomass. Reduced heat transmission from combustor surfaces due to slagging and fouling, together with corrosion and erosion, shortens the lifespan of the equipment [84].

Biomass may either vastly outperform coal in terms of ash deposition or significantly underperform. Blends of biomass and coal produce deposition rates that are intermediate between those of the neat fuels but, on average, less than one would predict from extrapolating between the behaviors of the neat fuels. Second, further research is needed to determine the largest biomass particle size that may be successfully fed into and burnt by a particular boiler using a particular feeding mechanism.
Finally, pulverizer performance in real-world settings must be investigated. Attaining high mix ratios and optimal combustion performance with biomass may need the use of dedicated pulverizers.
The use of numerical research is also covered. Being a renewable resource, biomass is a desirable option for use in industrial and municipal boilers. Biomass fuels may have a wide range of biomass constituents. The composition of ash produced by biomass is quite different from that of coal. Particularly inorganic components lead to severe issues with poisonous emissions, fouling, and slagging. Ash contains metals that, when combined with chlorine and other fuel ingredients like silica and sulfur, may cause a number of undesired reactions in the combustion furnace or power boiler. Ash fouling and slagging in biomass combustors are caused by reactions involving elements including Si, K, Na, S, Cl, P, Ca, Mg, and Fe. Corrosion caused by chlorine in biomass might disrupt operations. Heat transport is impeded by ash deposits, and serious corrosion may occur at high temperatures. Combustion rates and pollutant emissions also seem to be affected by biomass content. Systems that burn biomass produce no harmful emissions and hence greatly reduce environmental damage. Using biomass energy has several benefits, the most notable being a decrease in pollution caused by greenhouse gases.

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