A REVIEW ON BIOMASS CONVERSION PATHWAYS, PROPERTIES AND ITS ROLE IN GLOBAL ENERGY SCENARIO

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Abstract. The rises of environmental degradation problems, fossil fuels depletion, and energy security have ensured a surge of interest in biomass as a sustainable power source. Biomass is a form of organic material obtained out of the plants and animals and has huge energy producing connotations of thermochemical and biochemical ways. This review covers in details the most significant ways of converting biomass, which are combustion, pyrolysis, gasification, anaerobic digestion and fermentation. It also points out the physicochemical as well as the fuel characteristics of biomass that acts on its performance and the appropriateness in energy applications. In addition, the review assesses energy situation on the global scene and how to switch to renewable system of energy where biomass can help. This paper offers information on how to optimize the use of biomass to obtain clean and efficient energy through a combination of the relative components proportions and energy attributes of various biomass sources.

Keywords: *biomass energy, thermochemical conversion, biochemical conversion, renewable energy, biofuel properties*

Introduction

The growing energy demands and the necessity to decrease greenhouse gas emissions have shifted the world focus to renewable energy sources. Biomass is one of these and stands out as a solution that is able to provide solutions in energy production as well as in waste management (Demirbas, 2009). Biomass describes biological materials composed of waste agricultural products, forest waste, dung, and specially planted crops used as energy sources that may be transformed into heat, electricity, and fuels by using different technological pathways (Tursi, 2019). Worldwide, biomass offers around 10.15 percent of the primary energy supply except that in the developing nations, the utilization of biomass still plays an important role (International Energy Agency [IEA], 2024). The effective and sustainable utilization of biomass, however, demands scientific knowledge of how to convert this kind of material and what it is made of the aforementioned methods of conversion can be broadly classified as thermochemical (combustion, pyrolysis and gasification) and biochemical (fermentation, and anaerobic digestion) (Bridgwater, 2012). Thermochemical conversion is the use of biomass heating to liberate energy-containing gases or char in controlled conditions, whereas biochemical conversion makes use of the microbial

action to create biofuel like methane and ethanol (McKendry, 2002). These techniques strongly rely on the inherent characteristics of biomass, such as moisture content, volatile matter, fixed carbon, elements proportions (Varghese et al., 2024). Furthermore, the energy situation in the world is changing fast with countries pledging to decarbonisation and using renewable energy (Cantarero, 2020). There is the potential to use biomass fuels to conduct a strategic transformation in the presence of such a necessary strategic role when the carbon benefit is observed; thereby managed sustainably and improved scientifically (Song, 2006). A relative proportion of cellulose, hemicelluloses, lignin, and extractives present in biomass are also very important to optimize the conversion efficiency and the quality of products (Van der Stelt et al., 2011). This review will give a summary opinion on the conversion methods, characteristics of the fuel and the strategic value of biomass with reference to sustainability of the world energy.

Results and Discussion

Thermochemical conversion of biomass

The way to use heat and chemicals is to change biomass or solid fuel into useful energy, fuels or chemical substances. The process is important because it converts agricultural leftovers, forest debris and other organics into energy without polluting the environment. Combustion, pyrolysis, gasification and liquefaction are the four important methods for thermochemical conversion. All three methods have different temperature requirements, depend on the presence of oxygen and can produce heat, electricity, bio-oil or syngas.

Combustion

The use of combustion represents about 90% of the renewable energy obtained from biomass (Lebaka, 2013). At temperatures between 800°C and 1000°C, biomass and oxygen react to make carbon dioxide, water vapor and provide heat in an exothermic reaction.

$$\text{Biomass} + \text{Oxygen} = CO_2 + H_2O + \text{Heat} \qquad \text{Eq. (1)}$$

$$CH_{1.44}O_{0.66} + 1.03\ O_2 \rightarrow CO_2 + 0.72\ H_2O + \text{Heat} \qquad \text{Eq. (2)}$$

A number of details affect how much heat is released, mainly the type and how wet the biomass is. Biomass combustion typically results in 20 MJ/kg of thermal energy (Nussbaumer, 2003). Biomass used in combustion must have less than 50% moisture and an even lower rate is better for burning to achieve greater efficiency. Each combustion system is suited to burn wood, dry leaves, hard plant shells, rice husk and dried animal dung. Engineering progress allows modern biomass plants to supply electricity from 20 to 80 MW and with an efficiency of 25%–40% (McKendry, 2002). Thermal energy is produced from burning biomass which is used to drive mechanical and electrical processes, making combustion a key technology for mass bioenergy production. The most basic method of burning biomass is shown in *Figure 1*.

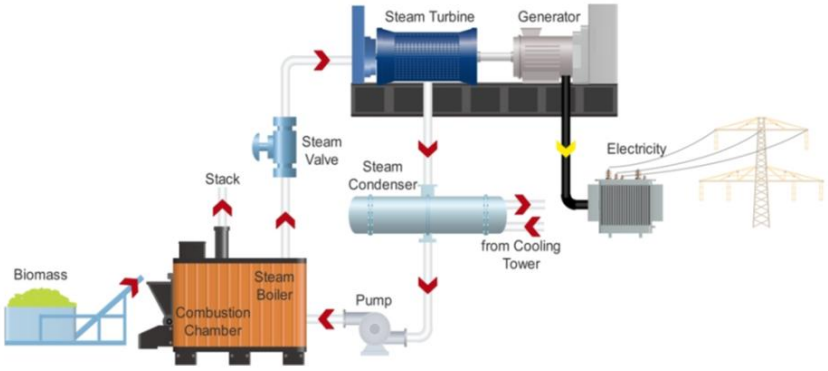

Figure 1. *Biomass combustion scheme.*
Source: Tursi (2019).

Pyrolysis

Burning is the process of subjecting biomass to heat in an oxygen free atmosphere to produce liquid fuel (called bio-oil), charcoal and burning gases (pyrolysis). It usually occurs at the temperature-added chemical generation stage (Kaushika et al., 2016; Lebaka, 2013). Pyrolysis may be classified in three ways by the nature of the process and the criterion of temperature, heating rate and vapor residence time. Conventional Pyrolysis takes comparatively long durations to harness copious amounts of charcoal but at low temperatures. During pyrolysis, biomass components break down within specific temperature intervals. (i) The hemicelluloses can be 470 to 530 K; (ii) Cellulose has a temperature range of 510 to 620 K; (iii) A lignin occurs between 550 to 770 K. The breakdown pattern of each component varies the quantity and quality of the final products. An example is that, at a low temperature and slow heat, more charcoal is formed, whereas at high temperature, and rapid heat, the bio-oil or syngas is produced (Vamvuka, 2011). Pyrolysis is just used with agricultural and forestry residues, such as camelina meal, mustard meal, flax straw, hemp straw and spruce wood only to mention a few. It constructs a method of generating energy out of biomass, reduces the pollution and the amount of fossil fuels being required. Following their manufacture, bio-oil can be shelved and transported to heat plants and power plants, whereas the application of the char and gases is limited to the use of the gases as solid fuels, energy sources or chemical reaction inputs. Since pyrolysis is capable of a lot, it is a key element of the biomass use strategies. The usual flowchart of biomass pyrolysis can be seen in *Figure 2*.

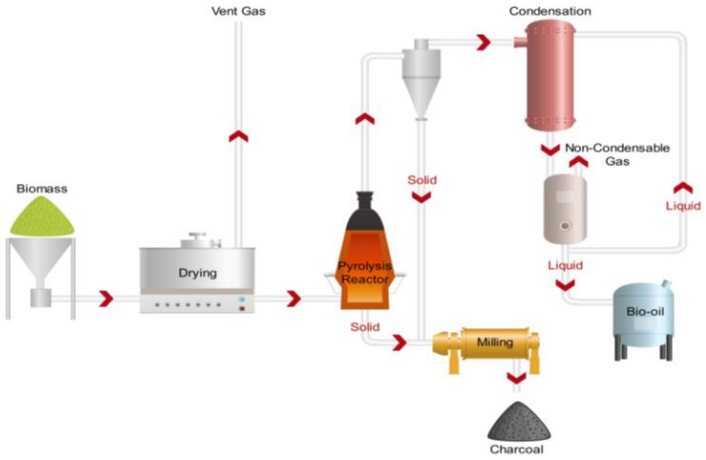

Figure 2. *Biomass pyrolysis scheme.*
Source: Tursi (2019).

Gasification

The gasification of solid carbonaceous biomass leads to the production of synthesis gas (syngas), which consists of carbon monoxide (CO), hydrogen (H2), methane (CH4) and minor amounts, of carbon dioxide (CO2) and nitrogen (N2). Biomass combustion has high efficiency and direct emissions in the partial oxidation at temperature higher than 750 ℃ (Molino et al., 2016; Rahimpour et al., 2012). Core reactions enable the effective gasification process of creating gaseous fuel using biomass and utilized in a broad range of industries and processes. Syngas could easily be utilized as a convenient intermediate product in many possible ways. Oil energy is invested in electricity by the burn of it on contact with the flames on high-priority machines. The feature is available in diesel engines that consumes up to 60% less diesel compared to the normal diesel engines. Bioenergy may be converted into a synthetic oxidling and synthetic chemicals (synthetic gasoline and ammonia). All gasification systems (be they fixed-bed, fluidized-bed or entrained flow) have an essentially similar basic process, made up of a number of the same stages: (1) Incomplete combustion of biomass in high-heat environment; (2) Syngas obtained that is mainly a combination of CO and H2 (which in most cases contribute over 85 percent of the combustible content of the gas); (3)The gas cleaning and conditioning stage removes impurities like sulfur compounds, tars and particulates to render the syngas in an acceptable form so that it can be used further. Syngas usually has 4.5 to 6 MJ energy per cubic meter that is approximately 10 to 50 per cent compared to what you can get with natural gas (Akia et al., 2014). The choice of the gasifying agent often defaults to air, as it is readily available, however, syngas produced by using pure oxygen or steam has a higher heating value and fewer pollutants. Gasification is important in getting biomass that is not easy to utilize in other forms. This makes its technology unique given that it can handle materials that are heteroatom-enriched materials and extract and recover pollutants, including the ability of converting sulfur to an elemental form, applicable in clean energy production and management of various types of waste. *Figure 3* depicts a diagram of the biomass gastification process common to most applications.

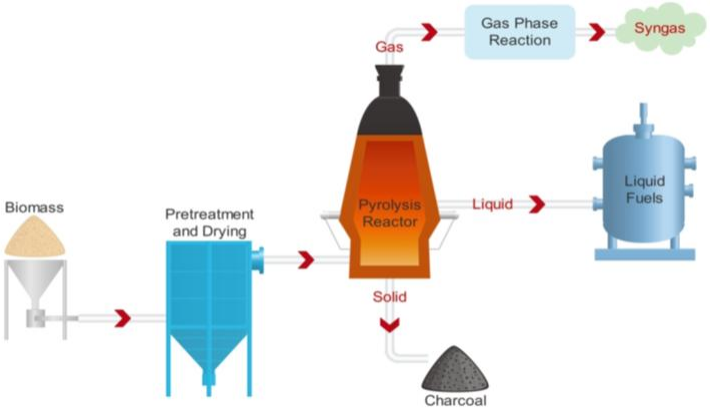

Figure 3. *Biomass gasification process.*
Source: Tursi (2019).

Biomass biochemical conversion

It describes the conversion of biomass organic materials by the use of living organisms, enzymes or bacteria producing usable energy or chemicals. The biochemical procedures may occur at the room temperature and thus, they are well suited in the handling of wet organic matter. Biochemical conversion primarily aims at transforming biomass to biofuels such as biogas and bioethanol, and generates bio-fertilizers and other useful products, through biological changes (Mahish et al., 2024). Such biochemical technologies are quite common among many scientists: (i) No-oxygen digestion; (ii) Utilization of fermentation (i.e., in the production of Bio ethanol); (iii) There is also the digestion alternative referred to as anaerobic digestion. The production of biogas and digestate is carried out by the utilisation of biological process of anaerobic digestion, which treats organic matter in the absence of oxygen. Biogas chief materials are methane (CH4), carbon dioxide (CO2) and some hydrogen sulfide and water vapor. This occurs in four key biochemical constituents: (1) It also decomposes complex organic substances into simpler ones (e.g. decomposition of carbohydrates to sugars); (2) In acidogenesis, monomers turn to volatile fatty acids and alcohols; (3) Causes acetogenesis, further decomposition of acids is carried out to acetic acid, carbon dioxide and hydrogen; (4) The anaerobic digestion then becomes production of methane and carbon dioxide since it is further digested by the methanogenic archaeal. Controlled conditions like anaerobic reactors are used for these stages. The way the process works and how stable it is depend a lot on pH, temperature, hydraulic retention time, the type of substrate and microbial inoculums (Sharma, 2015; Mahalaxmi and Williford, 2014). The usual materials that are used in anaerobic digestion are: (i) They include ashes and other farming residues; (ii) Farm animal manure; (iii) Solid municipal waste (MSW); (iv) Sewage sludge. The uses of the biogas so produced are: (i) Electric generation and heat generation; (ii) Items to be burnt during cooking; (iii) Car fuel (when it is changed to biomethane); (iv) Occupy the gap in pipelines that normally have natural gas. Next, digestate is a useful bio-fertilizer that provides plants and soils with correct nitrogen (N), phosphorus (P), potassium (K) and required trace elements. The use of anaerobic digestion as a digestion treatment has two benefits on the environment, which are, creation of energy and reduction of waste, hence minimized emissions and recycling of usable nutrients. Due to continuous enhancement, it is deployed along the whole United

States enabling urban, rural and off-grid zones to become energy sovereign and enhance their living conditions (Brethauer and Studer, 2015). The anaerobic digestion process has a schematic diagram in *Figure 4.*

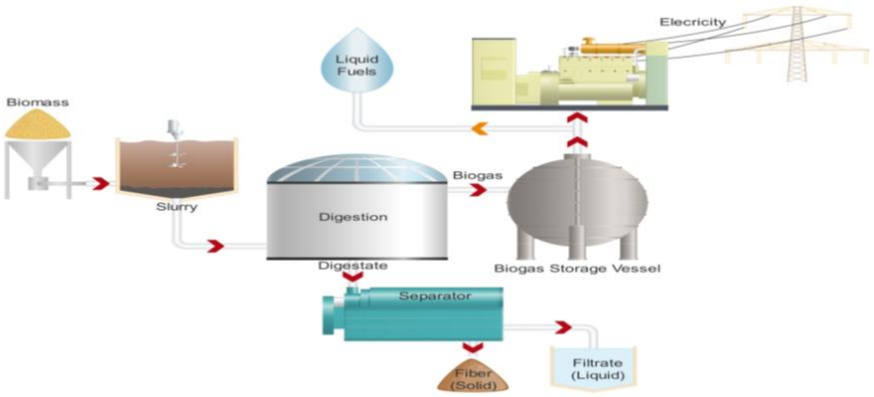

Figure 4. *Biomass anaerobic digestion scheme.*
Source: Tursi (2019).

Fermentation

The chemical process known as fermentation uses yeasts and anaerobic bacteria to produce valuable biofuels and by-products by working on sugars, starches and lignocellulosic biomass in anaerobic conditions (Saggi and Dey, 2019). The process is often used to produce both bioethanol and biohydrogen which have many uses in transportation, heating and electricity generation. Fermentation methods are commonly sorted into two main categories depending on what results are produced.

Bacterial fermentation, also known as ethanol fermentation

Saccharomyces cerevisiae and similar yeasts anaerobically convert both hexoses and pentoses (e.g., glucose and xylose) into ethanol and carbon dioxide during ethanol fermentation (Chandel et al., 2011).

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2 \qquad \text{Eq. (3)}$$

$$3\ C_5H_{10}O_5 \rightarrow 5\ C_2H_5OH + 5\ CO_2 \qquad \text{Eq. (4)}$$

100 g of fermentable sugars produces 51.14 g of ethanol and 48.86 g of CO_2 as a result of the process. Glycolysis (also known as the Embden Meyerhof pathway) is employed for the metabolism of hexoses and the pentose phosphate pathway transforms pentoses (Taherzadeh and Karimi, 2008). Hexose conversion happens more quickly and more efficiently. Feedstocks that support ethanol fermentation are split into groups: (i) Sugar-filled foods and drinks (including molasses, sugarcane juice); (ii) Using cropland and fruit (e.g., corn, cassava). Since the tough structure of lignocelluloses biomass (cellulose, hemicellulose and lignin) does not allow easy access to sugar, it must be broken down with pretreatment first. Some of the common pretreatment methods are: (i) Common techniques: acid and alkaline hydrolysis; (ii) Ionic liquids, steam explosion and supercritical fluid techniques are also involved. The following process takes ethanol

through purification by distilling and dehydrating it and the by-products can be used for fuel or animal feed (Mariod, 2016).

Biohydrogen is produced by fermentation

Fermentation helps make hydrogen which is an efficient and clean source of energy. Two important ways are used: (i) In dark fermentation, anaerobic bacteria change organic materials into hydrogen in the absence of oxygen; (ii) Photofermentation implies fermentation by photosynthetic bacteria when light is present so that the process leads to more hydrogen. The attention on dark fermentation comes from its fast reaction, range of feedstocks it can use and high amount of hydrogen it produces (Urbaniec and Bakker, 2015). Yet, issues like competition between other bacteria and the high price of pure sugar hinder its ability to be efficient and large scale (Jojima et al., 2010). Although mixed cultures can't do the job as efficiently as single-strain cultures, many still use them because their greater range of substances and simpler monitoring help things run smoothly. Both ethanol fermentation and biohydrogen production from lignocellulosic biomass are hindered by the same structural features which means pretreatment is essential. The properties of the process medium such as pH, temperature, holding time and which microorganisms are used, play a key role in deciding how much hydrogen is achieved and what by-products are formed (e.g., acetate, butyrate, lactate, ethanol and CH_4). You can see the processes in biomass fermentation in *Figure 5*.

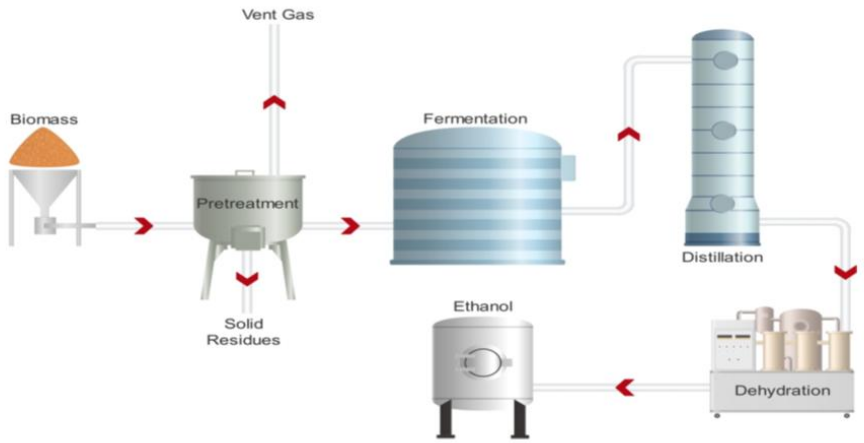

Figure 5. *Biomass fermentation scheme.*
Source: Tursi (2019).

Properties of biomass as an energy source

The conversion procedure for biomass energy production strongly depends on the physical and chemical properties of biomass materials. The conversion process efficiency together with selected technological methods depends on biomass properties while these properties affect both technology cost and operational feasibility (Adams et al., 2018). The essential properties for evaluating biomass for energy purposes involve determination of moisture content along with heating value (HV) and fixed carbon (FC) and volatile matter (VM) and ash/residue content and alkali metal. Detailed explanations about these aspects follow in the subsequent subsections.

Moisture content

Blood content simultaneously drives both the conversion system performance and the heating value output of biomass materials (Adams et al., 2018). The presence of moisture exists throughout biomass cell walls while also being found in between dead cell pockets (Akin, 2008). The drying operation makes biomass moisture content converges to match ambient air humidity levels. The moisture levels in aquatic weeds surpass 90% as reported by Little (1967) while wood species show water content between 41.27% and 70.20% according to Demirbas (2004). Biochemical anaerobic digestion necessitates biomass with high moisture however thermochemical combustion and gasification need low moisture content to operate efficiently (Inayat et al., 2025). Although water in biomass does not release energy during combustion it hinders the energy balance yet it helps produce hydrogen during gasification. The efficiency improvement from reducing biomass moisture below 30% remains minimal according to Juneja et al. (2013). Biomass moisture exists within two types of categories which are: intrinsic and extrinsic moisture: (i) Natural biomass water content that does not respond to outside weather conditions; (ii) Biomass moisture content that depends on external environmental conditions is referred to as extrinsic moisture. The heating value of raw materials decreases proportionally to their moisture content while simultaneous changes occur to both physical attributes and quality of the pyrolysis products.

Fixed carbon and volatile matter

Solid fuels contain their chemical energy in two main forms which are called fixed carbon (FC) and volatile matter (VM): (i) Fixed carbon consists of all remaining solid material which exits moisture and ash after volatilized compounds release: (ii) Biomass components turn into vapor during heat application (at 950°C for 7 minutes) including all moisture contents.

Heating value

When biomass is consumed in air its released energy manifests as the heating value that operates under units of energy per unit mass or volume. There are two forms: (i) The Heating Value at Higher Temperature (HHV) accounts for the vaporous water heat and indicates the highest possible quantity of recoverable energy; (ii) The practical usable energy is expressed by Lower Heating Value (LHV) since this measure does not include latent heat (*Table 1* and *Table 2*).

Table 1. *Correlations for HHV based on proximate analysis.*

S/N	Correlation	Reference
1	HHV (MJ/kg) = 0.196 (FC) + 14.119	Demirbas (1997)
2	HHV (kJ/kg) = 354.3FC + 170.8VM	Cordero et al. (2001)
3	HHV (MJkg) = 0.3536FC + 0.1559VM-0.0078Ash	Parikh et al. (2005)
4	HHV (MJ/kg) = 0.1905VM + 0.2521FC	Yin (2011)

Table 2. *Correlations for HHV based on ultimate analysis.*

S/N	Correlation	Reference
1	HHV (MJ/kg) = 0.4373C-1.6701 or HHV = 0.2949C + 0.8250H	Yin (2011)
2	HHV(MJ/kg) = 0.3491C + 1.1783H +0.1005S-0.1034O-0.0151N-0.0211-Ash	Channiwala and Parikh (2002)
3	HHV(kJ/kg) = 3.55C2-232C-2230H + 51.2C×H + 131 N + 20600	Friedl et al. (2005)

Ash/Residue content

The solid end product from biomass chemical reactions or any combustion process constitutes ash. Similar to water content ash functions as a heat absorber which diminishes the efficiency of heating processes (Vassilev et al., 2014). Soluble ionic compounds found in biomass generate performance effects on pyrolysis as well as combustion processes due to their chemical nature (Liu et al., 2017). The mineral content found in ash differs between different types of biomass according to Demirbas (1997). An amount of ash in biomass reduces how easily it can be handled and processed as well as driving up total energy conversion expenses. The residual solid material from biochemical processes contains more material than ash because it includes non-biodegradable carbon (recalcitrant carbon) that can be thermally combusted afterward (Prismantoko et al., 2024). High ash concentrations in thermochemical conversion systems result in two main negative effects: (i) The availability of fuel energy decreases due to this factor; (ii) Plant efficiency decreases through the reduction of operational effectiveness because excessive ash creates sticky residues at high temperatures while also raising maintenance expenses.

World energy scenario

The world's energy requirements have increased substantially because of quick population expansion and speeded up industrial expansion. During a single generation the worldwide population grew around 2 billion people mainly from developing nations. Major energy problems together with environmental complications exist as fundamental issues during the 21st century (Kannan and Vakeesan, 2016). Alternative energy sources including biomass and wind power together with solar and geothermal and hydroelectric power demand greater importance for solving these challenges (Tekin et al., 2014). Emerging economies lead the substantial rise in energy demand through rapid development among China and India who jointly drive more than fifty percent of this increase. The Organization for Economic Cooperation and Development member states maintain a constant energy consumption level. The data in *Figure 6* reveals that China holds the number one position in terms of energy market expansion at present. The data indicates India will pass China in energy consumption levels during the prediction period. Global energy consumption will steadily increase during the next thirty years and the highest growth will happen in Asian non-OECD territories. Over the next three decades non-OECD Asia (including China and India) will experience a whopping 40 quadrillion British thermal unit (Btu) increase in their energy consumption above OECD nations. The distribution of worldwide fuel supplies has undergone transformation. Renewable power solutions and nuclear and hydroelectric technologies together will contribute to half of the predicted energy supply expansion during the upcoming twenty years as displayed in *Figure 7*. According to current energy statistics renewable energy demonstrates the highest growth rate annually at 7.1%. The international primary energy structure shows an anticipated increase of renewable energy from its present 3% status during 2015 to 10% by 2035.

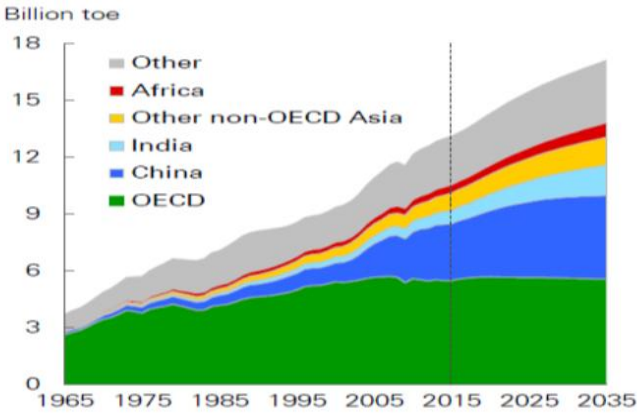

Figure 6. *World energy consumption by region.*

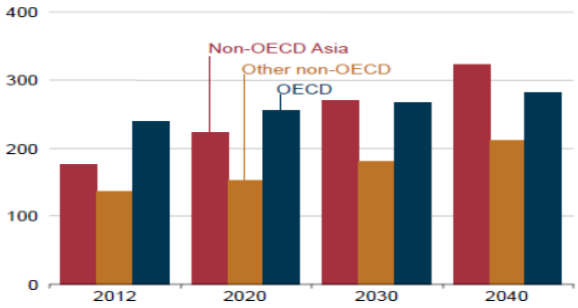

Figure 7. *World energy consumption by country grouping, 2012–40 (quadrillion Btu).*

Future predictions (*Figure 8* and *Figure 9*) show renewable energies including biomass and biofuels with wind power and solar, geothermal as well as hydroelectric energy maintaining their position as the world's quickest growing resource. Experts anticipate renewable and biomass energy consumption to grow by 2.6% each year from 2012 to 2040. The growth rate for nuclear power reaches 2.3% yearly while maintaining a similar pace.

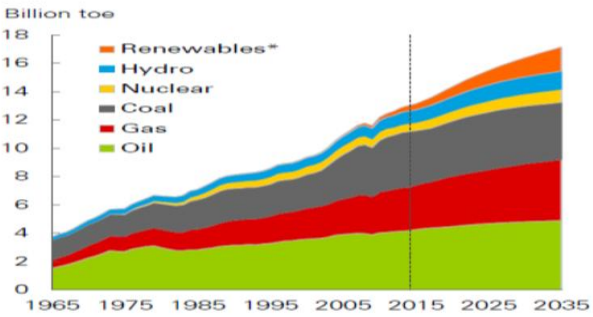

Figure 8. *Primary energy consumption by fuel.*

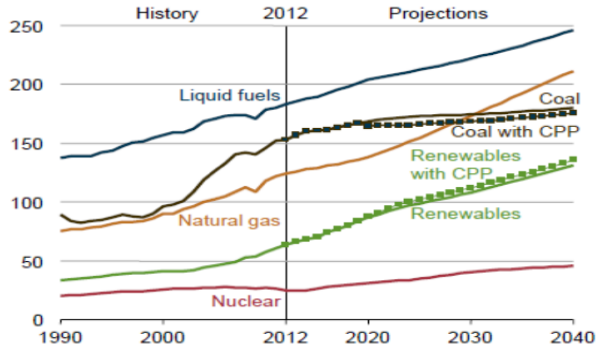

Figure 9. *World energy consumption by types of source, 2012–40 (quadrillion Btu).*

Biomass has served as a major traditional energy source because it supplies between 10–14% of global energy requirements. The analysis shows that the world will exhaust its oil reserves by the year 2050. According to McKendry (2002) and Saxena et al. (2009) biomass has the potential to supply roughly 50% of global energy requirements following energy depletion.

Characteristics and properties of biomass fuels

Organic substances in biomass materials consist mostly of cellulose along with hemicellulose and lignin combined with minor components from extractives (Zhu et al., 2022). The three fundamental cell wall substances cellulose hemicellulose together with lignin build the primary structure of plant tissue (Sun, 2010). According to the approximate calculation of their empirical formulas these major components follow the below pattern: (i) Cellulose: $CH_{1.67}O_{0.83}$; (ii) Hemicellulose: $CH_{1.64}O_{0.78}$; (iii) Lignin: $C_{10}H_{11}O_{3.5}$.

Cellulose

Cellulose exists as a chain of glucose units where each element contains β-(1, 4)-D-glucopyranose arrangements. The β-configuration between units leads to lengthy chains that typically measure 100,000 in molecular weight (Demirbas, 2009). The depiction of this structure appears in *Figure 10*.

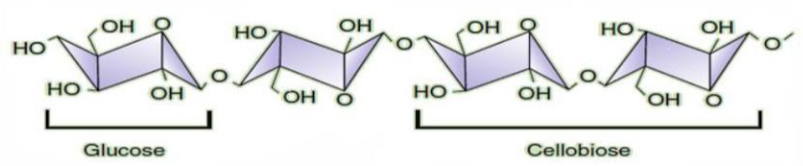

Figure 10. *Molecular chain structure of cellulose.*

Hemicellulose

The branched polysaccharide group known as hemicellulose consists primarily of five-carbon sugars (xylose and arabinose) and six-carbon sugars (glucose and mannose) with uronic acids that include methyl glucuronic and galacturonic acids (Popa and

Spiridon, 1998). The structural properties of hemicellulose differ from cellulose because its molecular weight stays below 30,000 Daltons and the substance exhibits reduced crystallinity and increased amorphous characteristics (McKendry, 2002). Pertaining to plant cell wall structure, hemicellulose exists as a non-covalent bond with cellulose microfibrils. The main sugar compound found in hemicellulose consists of xylonic acid units. Hardwood xylan contains a xylose backbone formed through β-(1, 4)-glycosidic bonds which is further extended through α-(1, 2)-glycosidic bonds with 4-O-methylglucuronic acid groups. The attachment of O-acetyl groups happens to fill the hydroxyl positions at C2 and C3 positions (Martins et al., 2022). Softwood xylan contains less acetylation but its structure includes arabinofuranose branched units that form α-(1, 3)-glycosidic bonds with the main chain (Martínez-Abad et al., 2020). The illustration of this concept appears in *Figure 11*.

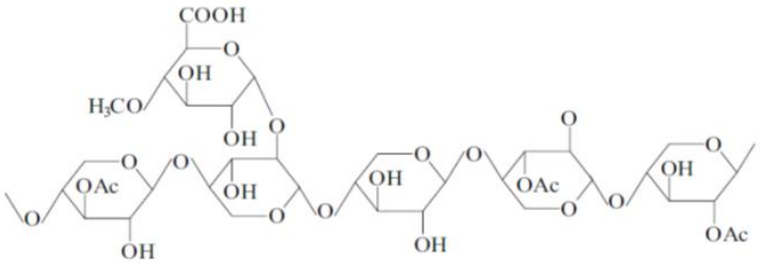

Figure 11. *Schematic illustration of xylans.*

Lignin

The phenylpropanoid chain units assemble into the complicated amorphous polymeric substance known as lignin which has a large molecular weight (Yao et al., 2021). The phenylpropane building blocks combine a three-carbon chain structure with aromatic ring configuration (Kaufman, 2015). The number of methoxyl groups on aromatic rings determines how lignin units are classified into three family types: (i) Structure I: Found predominantly in grasses; (ii) Structure II: Present in softwood (conifers); (iii) Structure III: Found in hardwood (deciduous trees). The resistance to microbial degradation and structural firmness of plants depend significantly on the presence of lignin (Atiwesh et al., 2022). The structural models of lignin appear in *Figure 12*, *Figure 13* and *Figure 14* to display its basic unit alongside its building blocks and complete structural representation.

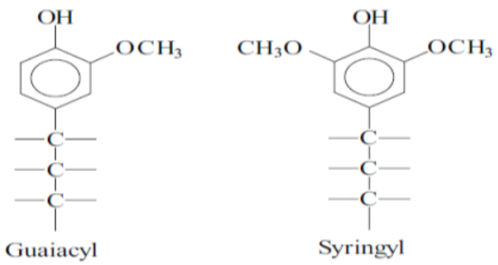

Figure 12. *Basic structural unit of lignin.*

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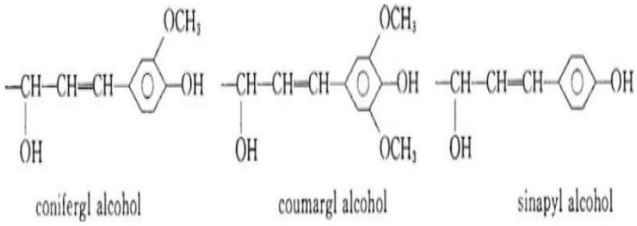

Figure 13. *Schematic illustration of building units.*

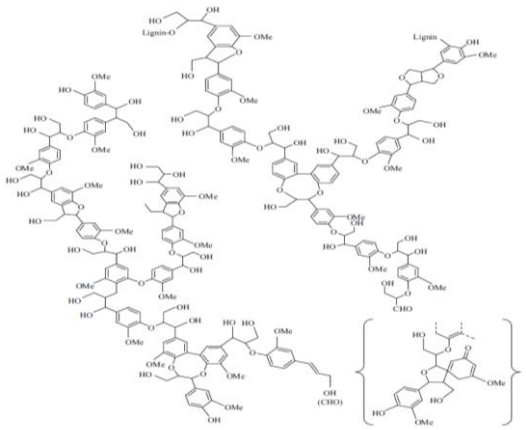

Figure 14. *Structural model of lignin.*

Relative proportions in biomass

Biomass contains three major components which show different weight percentages between 40 to 50% for cellulose and 20 to 40% for hemicelluloses while the lignin content varies widely from 10 to 25 percent (McKendry, 2002): (i) Cellulose: 40–50% by weight; (ii) Hemicellulose: 20–40% by weight; (iii) Biomass contains lignin with distribution varying from 10 to 25% (McKendry, 2002). The conversion behavior along with energy potential of biomass gets primarily established by its structural and compositional characteristics.

Conclusion

Biomass has been a crucial source of renewable energy that can hardly be underestimated and also aid in the transformation of the global economy to cleaner and sustainable energy systems. It also has a wide conversion pathway that includes thermochemical and biochemical conversion with various uses that can provide different energy needs. The performance of biomass as energy source closely relates to its physicochemical properties that would determine how it performs under conversion processes. Trying to address the twin concerns of energy access and climate change the world is facing, developing technology based on biomass by improving characterization of feedstocks, optimizing systems, and improving policies is bound to be an important development in the future. Next steps in the research aspect would concentrate on wider

use of biomass systems, co-processing of biomass with other renew facilities, and lifecycle analysis to obtain the maximum energy level and environmental paybacks.

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Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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