Chapter 1

Introduction

Abstract

Energy is the most important driver for industrial and socio-economic development of a country. The requirement of fossil fuel based fuels is steeply rising in all countries including India whose rising fossil fuel based energy requirement is met through imports. In order to reduce dependence on fossil fuels and adverse environmental impacts all countries are making efforts to develop various renewable energy sources for energy sustainability. Out of the different renewable energy sources biomass in various forms has global availability in large amounts and has started receiving increasing attention as viable and sustainable alternatives. It is available as virgin and waste biomasses of various types. However, they all comprise primarily cellulose, hemicellulose, lignin and some other small organic and inorganic constituents. Most of these can be converted into cleaner fuels and other value added products through bio-chemical or thermo-chemical routes. This chapter also focused up on possible option of bioenergy from biomass in India. India being an agrarian and a tropical country is endowed with huge volume of virgin and non-virgin biomass that has the potential to provide a steady supply of feedstock for chemicals and energy.

1. Introduction

Energy is inevitable for social and technological development of a country. Energy plays an important role in carrying out manufacturing activities, industrial development, transport, recreation and related activities. Due to changing life-style growth of population and urbanization, the global demand for energy has increased rapidly (Mishra et al., 2018). Currently increasing demand of energy, diminishing supply of oil and their rising price, finite nature of fossil fuel resources and environmental degradation are the important issues facing the world (Disco et al., 2017, Sut et al., 2016).

For a developing country like India with more than 1.30 billion people, the major requirements of energy are for electricity and transportation fuels like petroleum products. The energy requirement is increasing rapidly in the agriculture, industrial, transportation and domestic sectors. As per the published report of the Statistical Review of World Energy (BP Statistics 2011) the consumption of the global primary energy has increased by 4.4% of the total energy in 2010. United States of America was the second devourer of energy (19%) after the China (20.3%). As per Hiloidhari et al (2014) report, in order to fulfill the required energy demand of citizens, it is required to increase the energy generation to 800GW by 2031-2032 from the current generation of 183GW. According to Kumar and Jain (2010), during 1970–71 to 2006–07, coal utilization in India has expanded from 71.2 MT to 462.7 MT, petroleum crude oil utilization has gone up from 18.4 MT to 146.5 MT and the petroleum gas utilization has increased from 0.64 Giga cubic meters (GCM) to 31.36 GCM. Additionally, power utilization has likewise expanded from 43.7 TWh to 443.1 TWh during this period. In year 2018-2019 the total production of petroleum products was 32.474 thousand metric tonnes while the consumption was 213.216 thousand metric tonnes. The details of crude oil and petro-production and petro-fuel consumption during 2014-15 to 2018-19 are presented in Tables 1.1 and 1.2, respectively (Ministry of petroleum). Therefore, the pressure to import the crude oil increased with time as the demand increased. It can be seen from these tables that the production of crude oil has not increased as fast as the consumption, thus India is in the 5th position in crude oil importing countries globally. India imports crude oil from Saudi Arabia (18%), Iran (11%), Africa

(22%) and other middle east countries (34%) and other countries of the western hemisphere (10%).

Table 1.1: Production of crude oil in India (in Thousand Metric Tonnes)

Item	2014-15	2015-16	2016-17	2017-18	2018-19
(a) Onshore					
Andhra Pradesh	254	295	276	322	296
Arunachal Pradesh	76	57	55	50	43
Assam	4466	4185	4203	4342	4275
Gujarat	4653	4459	4605	4591	4626
Rajasthan	8783	8490	8049	7720	7464
Tamil Nadu	240	255	284	345	395
Total (a)	**18472**	**17741**	**17472**	**17369**	**17099**
Organization wise Production					
OIL	3412	3226	3258	3376	3293
ONGC	6069	5817	5934	6010	6074
PSC Regime	8991	8698	8280	7984	7732
(b) Offshore					
ONGC	14758	15264	14921	14785	13484
PSC Regime	2661	2495	2108	1890	1892
Total (b)	**17419**	**17759**	**17029**	**16676**	**15376**
Grand Total (a + b)	**35891**	**35500**	**34501**	**34045**	**32474**

Source: Basic Statistics on Indian Petroleum and Natural Gas, Economic Division, Ministry of Petroleum and Natural Gas, Government of India, New Delhi, 2010-11

Table 1.2: Consumption of petroleum products in India (in Thousand Metric Tonnes)

Products	2014-15	2015-16	2016-17	2017-18	2018-19
Light Distillates	**50944**	**57743**	**61441**	**66053**	**72109**
LPG	18000	19623	21608	23342	24907
Motor Spirit	19075	21847	23765	26174	28284
Naphtha	11082	13271	13241	12889	14131
Others	2787	3002	2827	3648	4787
Middle Distillates	**82933**	**88517**	**89042**	**93551**	**96379**
SKO	7087	6826	5397	3845	3459
ATF	5723	6262	6998	7633	8300
HSDO	69416	74647	76027	81073	83528
LDO	365	407	449	524	598
Others	342	375	172	476	493
Heavy Ends	**31643**	**38414**	**44114**	**46562**	**44728**
Furnace Oil (FO)	5584	6482	7046	6605	6195
LSHS	377	150	104	116	369
Fuel oil (FO+ LSHS)	5961	6632	7150	6721	6564
Lubes/Greases	3310	3571	3470	3884	3668
Bitumen	5073	5938	5936	6086	6708
Petroleum Coke	14557	19297	23964	25657	21346
Waxes	156	173	182	199	286
Others	2586	2802	3411	4015	6157
Total consumption	**165520**	**184674**	**194597**	**206166**	**213216**
Refinery fuel and losses (RBF)	17669	18773	20070	21164	21454
Grand Total	**183189**	**203447**	**214667**	**227330**	**234670**

Notes: Consumption includes sales by all companies & direct private imports. SKO – Kerosene, LDO – Light Diesel Oil, LSHS – Low Sulfur Heavy Stock, HHS – High sulphur heavy stock, ATF – Aviation turbine fuel, **Source:** Petroleum Planning & Analysis cell, New Delhi (2019).

The cost of petroleum products such as diesel, kerosene oil, petrol, and jet fuel has increased rapidly in recent years with a net rise of over 2.12 times from 2010 to 2020. Thus there is an earnest requirement for renewable and sustainable substitutes for liquid transportation fuels for decreasing the pressure on economy of the nation and accomplishing sustainable development (EIA, 2012).

Another issue that has forced to focus attention in this direction is the GHG emission because of the utilization of huge amount of diesel and petrol. India is presently amongst the top 5 contributors of carbon emission (Wikipedia, 2012). Normally, ignition of 1 liter of petroleum causes an emission of 2.31 kg CO_2, while burning of 1 liter of diesel releases 2.68 kg of CO_2. To reduce the emission of CO_2 in the environment it is necessary to replace the petroleum products with renewable energy resources (Wikipedia, 2012). Moreover the use of fossil fuels results in environmental threats such as atmospheric pollution and global warming (Mishra et al., 2018; Ceylan et al., 2014; Dhyani et al., 2017). It is being increasingly felt that in order to accomplish the CO_2 free energy consumption by the human society, the full or partial substitution of fossil fuels by the renewable energy sources as well as proper implementation of the carbon capture and storage (CCS) technologies are the must (Plis et al., 2016).

During the past 2–3 decades, there have been extensive global R&D efforts directed towards developing various renewable energy resources to supplement the energy demand and reduce the environmental concerns (Azizi et al., 2017). For a country like India, renewable energy resource such as biomass, solar, wind and small hydro etc. have been identified as the potential resources. Among all the renewable energy resources, various types of biomass (forest biomass, agro-waste, domestic solid waste and some industrial wastes) are being considered as the most suitable candidates for meeting the world energy demand with little change in the infrastructure and technology currently being used for fossil fuel based systems. Further, it is estimated that the biomass are the fourth largest energy resource available in the world (Chutia et al., 2013). It is a low cost renewable candidate for energy production to substitute fossil fuels (Jayaraman et al., 2017). It is easily available, renewable, and sustainable. It is also a carbon-neutral fuel because it liberates the same amount of CO_2 to the atmosphere through the combustion as was consumed through the photosynthesis for producing the green biomass plant (de Caprariis et al., 2017).

Food crops are the source of first generation bio-fuels like bio-ethanol and biodiesel (Ho et al., 2014). Commercially bioethanol is produced by fermentation from starch/sugar-based crops like sugar cane, sugar beet, sweet sorghum, corn, wheat, barley, potato, yam, and cassava (Guo et al., 2015). Non-food crops such as waste biomass (including organic components of municipal solid waste) and lignocellulosic biomass (such as cereal crops straw, sugar cane bagasse, forest residues, agricultural residues, energy crops, grasses, wood residues, etc.) mainly contain 35–55% cellulose, 20–40% hemicellulose, and 10–25% lignin (Sims et al., 2010) and are considered as suitable feedstock for obtaining the second generation bio-fuels like methane, hydrogen, syngas, etc. through thermal and bio-chemical routes. Microalgae and macroalgae have been considered as the suitable feedstock for producing the third generation bio-fuels like butanol through the biochemical route (Azizi et al., 2017).

India is primarily an agrarian country. Due to availability of high yielding variety of seeds, improved agricultural practices, use of agrochemicals and fertilizers, and better irrigation facilities production of major cereals in India has increased substantially and the country has become food surplus. This has also resulted in the generation of huge volume of various types of agro-wastes, particularly hay and stalks. According to a recent report the annual production (in MT/year) of some typical agro-wastes in India are: arhar stalk - 7.20, banana trunk - 41.9, rice husk - 43.31, rice straw - 154.0, sugar cane bagasse - 110.6, and wheat straw - 131.1 (Hiloidhari et al., 2014). Due to increasing use of farm machinery, lack of awareness, and improper waste management policies this huge volume of biomass is not being gainfully utilized for energy generation and production of value added products. In view of the environmental issues and increasing cost of crude petroleum and petrochemicals it has become necessary to generate scientific data for promoting the use of such wastes as an energy source. Biochemical and thermochemical routes are the two main processes available for converting the low energy content lignocellulosic biomass to value added high energy content liquid, solid and gaseous products (Chutia et al., 2014; Demirbas et al., 2004). Biochemical conversion processes include (anaerobic digestion to methane, ethanol fermentation, hydrogen production for fuel cells, etc.) and thermo-chemical processes include combustion, pyrolysis, gasification, and liquefaction (Lang et al., 2017; Wang et al., 2017). Thus knowledge of the thermal characteristics and thermal degradation behavior of indigenous biomasses will be useful for assessing the energy production potential of locally available biomass as well as to assess their efficacy for use as a feedstock for gasification and pyrolysis.

1.1 What is biomass?

Biomass is a biological material that comes from living or just living organisms and it is also commonly known as the plant derived materials. It is mainly constituted from hemicellulose, cellulose and lignin. Due to its renewable nature and widespread availability in various forms, biomass has started attracting global attention as an environment friendly renewable energy option for the future. In most developing countries about 40‑50% energy requirements are met through biomass derived from large agricultural and forest land mass (Kumar et al., 2019).

1.2 Classification of biomass resources

Out of various renewable energy resources such as hydro, solar, wind, non-fossilized carbonaceous biomasses of various types, etc., the virgin and waste biomasses have the advantage of their abundant availability and net zero carbon foot-print (Saidur et al., 2011). Agricultural wastes (like rice husk, wheat straw, etc.), agro-industrial wastes (bagasse, de-oiled cakes, etc.), forestry wastes (wood chips, sawdust, and bark), virgin biomass like forest waste and perennial wild grasses like *Saccharum munja* (MJ), etc. and domestic solid waste and sludge from wastewater treatment plants have reasonably high energy content (Go et al., 2019). Shi et al (2007) reported that the biomass can be classified in to two categories as productive and unused biomass. Many other researchers classified biomass in to various categories such as agricultural, forestry and aquatic biomass, waste biomass and planted biomass. Figure 1.1 depicts different type of biomasses and Table 1.3 presents the detailed classification of biomass with typical example.

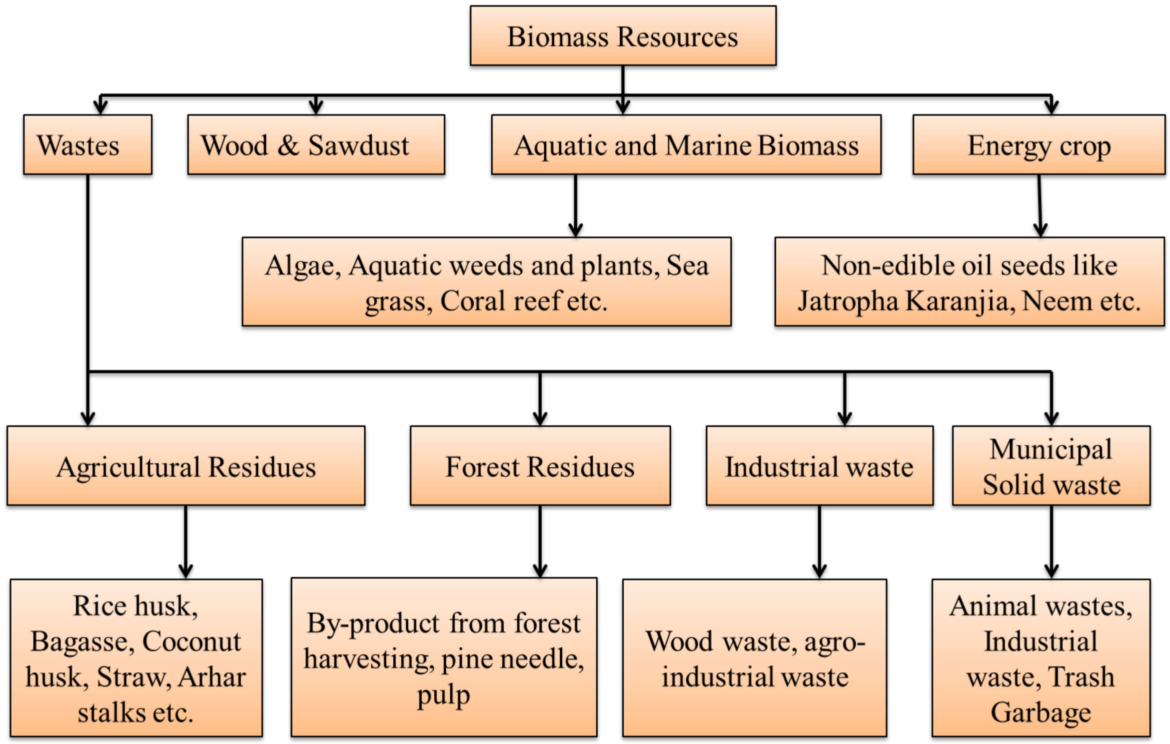

Fig.1.1 Different type of biomasses

Table 1.3 Classifications of biomasses with typical examples

Types of biomass	Main component of biomasses	Typical Example
Terrestrial	Carbohydrate	Sugar cane, corn, sweet sorghum
	Starch	Maize, cassava, sweet potato
	Cellulose	Tropical grasses, poplar, sycamore
	Hydrocarbon	Eucalyptus, green coral
	Grease	Oil palm, rapeseed, sunflower
Aquatic	Fresh water	Water hyacinth
	Ocean	Large kelp
	Microorganism	Green algae, photosynthetic

		bacteria
Residues from Forestry, Fisheries	Agriculture	Wheat bran, straw, vegetable residues, processing residues
	Animal Husbandry	Animal manure, farm residues
	Forestry	Secondary forest
		Woodland remnants
		Crippled material in plants
	Fisheries	Jettisoned and dead fish
Waste	Municipal Waste	Municipal and pulp sludge
	Garbage	Family garbage, feces
Herbaceous biomass		Grasses and flowers (*alfalfa, arundo*, bamboo, bana, brassica, cane, cynara, *miscanthus*, switchgrass, timothy, others); straws (barley, bean, flax, corn, mint, oat, rape, rice, rye, sesame, sunflower, wheat, others); other residues (fruits, shells, husks, hulls, pits, pips, grains, seeds, coir, stalks, cobs, kernels, bagasse, food, fodder, pulps, cakes, etc.).
Wood and woody biomass		Coniferous or deciduous; *Angiospermous* or *gymnospermous*; Stems, branches, foliage, bark, chips, lumps, pellets, briquettes, sawdust, sawmill and others from various wood species

1.3. Constituents of biomasses

Biomass is very complex in nature due to variation in its constituents. The lignocellulosic biomass mainly consists of hemicellulose, cellulose and lignin along with littler measures of low atomic weight superfluous materials and inorganic minerals. Moreover, some biomasses like cattle manure and cereals are rich in proteins and starch respectively. Different constituents of biomasses are shown in Fig. 1.2.

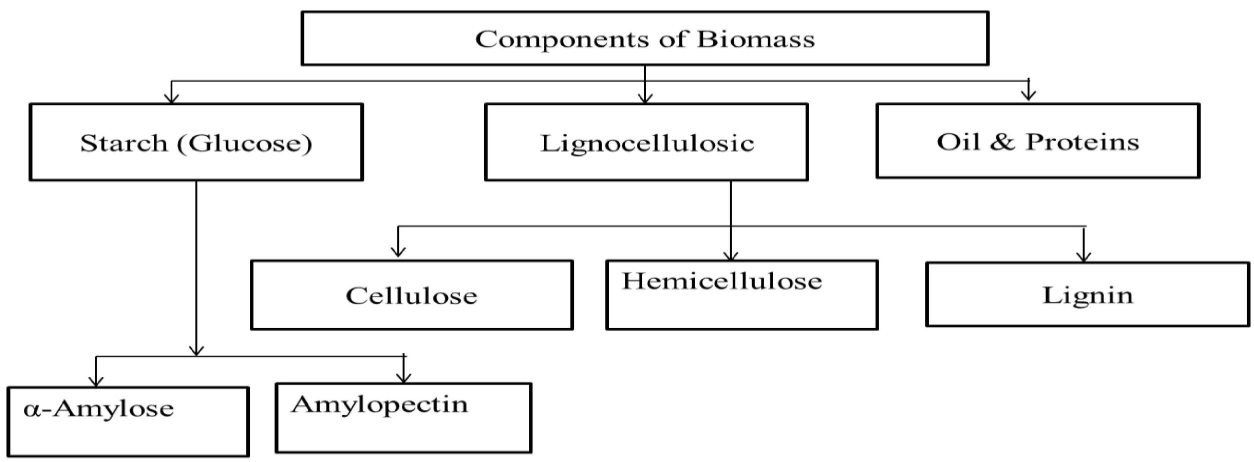

Fig. 1.2 Different components of biomasses

The Fig. 1.3 indicates the how different component of biomass are interrelated to each other. It is seen from Fig. 1.3 that the cellulose polymeric molecules are covered with hemicellulose and lignin polymeric chains.

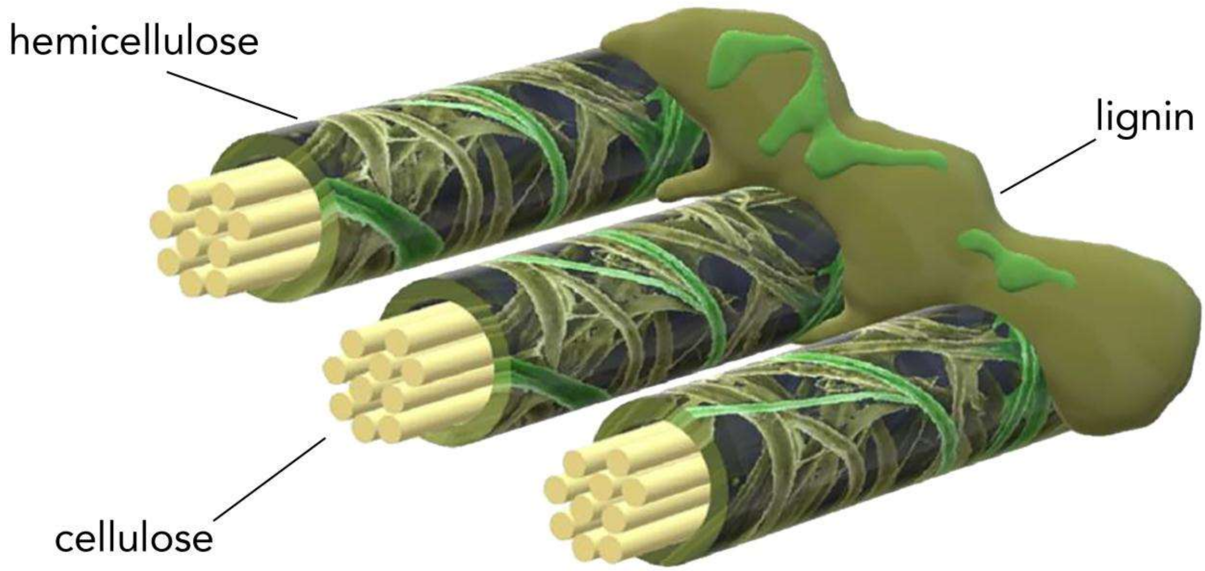

Fig. 1.3 Different layers of chemical composition of a plant cell (Tursi et al., 2019)

A brief account of the basic characteristics of each constituent is given below.

1.3.1 Cellulose

Cellulose, a straight polymer, is a complex carbohydrate (or polysaccharide) with a high molecular weight and a limit of 10,000 monomeric units of D-glucose, connected by β-1, 4-glycosidic bonds (Giudicianni et al., 2013). Cellulose can be represented by the chemical formula of $(C_6H_{12}O_6)_n$, (where n indicates the degree of polymerization) and its structural base is cellobiose (i.e., 4-o-β-D-glucopyranosyl-D-glucopyranose) as depicted in Fig. 1.4. It is one of the most plentiful organic compounds present in the biomass. In general, on an average it varies is the range of 40-50 wt% of the dry biomass. The reactivity and morphology of cellulose chains are generously impacted by the intermolecular hydrogen bonds between the hydroxyl group on C-3 carbon and the oxygen of the close by glycoside ring. The development of these bonds makes the particles more steady and rigid.

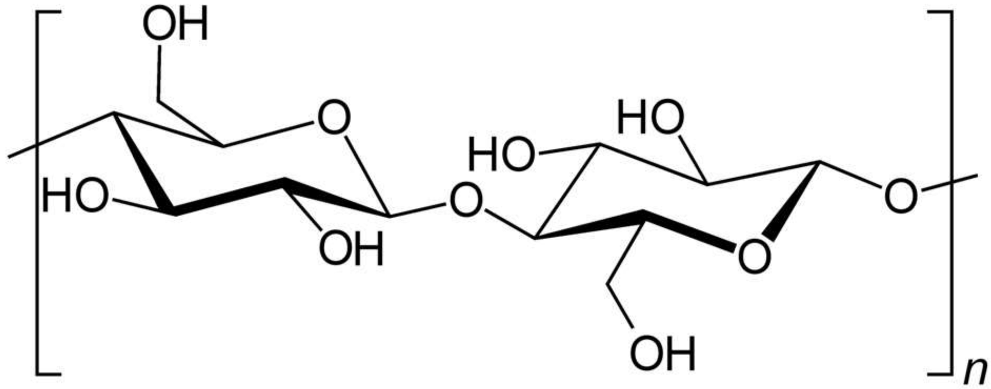

Fig. 1.4 General chemical structure of cellulose

At times, the presence of numerous intermolecular connections can create a systematic crystalline region due to the significant vicinity between the various monomers as shown in Fig. 1.5.

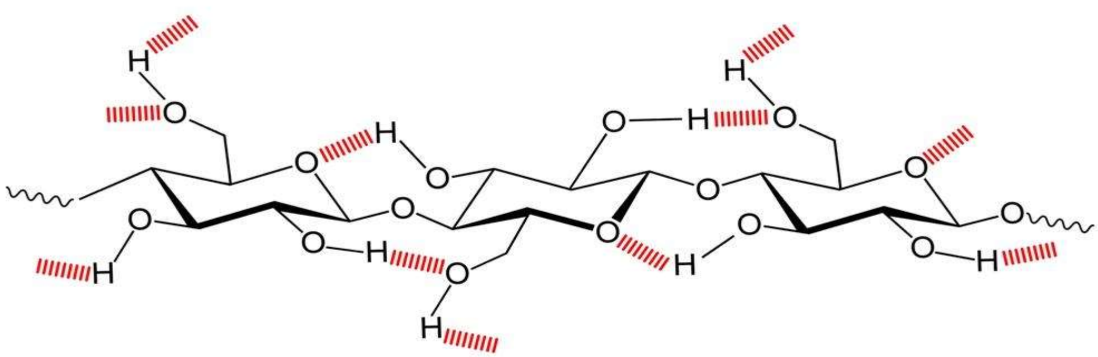

Fig. 1.5 Hydrogen bonding in cellulose

1.3.2 Hemicellulose

Hemicellulose is the second largest constituent of biomass after cellulose and it varies in the range of 25-30wt% of dry biomass. It is a complex, branched and heterogeneous polymeric network, based on pentose sugars (xylose and arabinose), hexose sugar (glucose, mannose, and galactose) and sugar acids (methylglucuronic and galacturonic acids). It is firmly connected to the outside of cellulose micro fibrils surface. The substance and structure of hemicellulose are distinctive depending upon the type of biomass. In nature it is found in the amorphous form. The components of hemicellulose are depicted in Fig. 1.6.

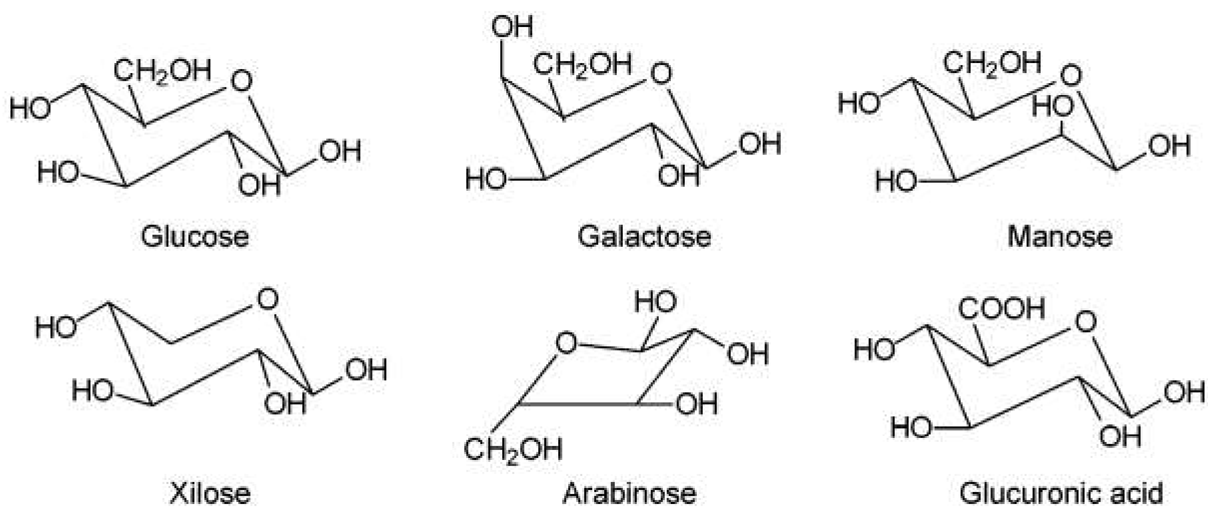

Fig. 1.6 Different component of hemicellulose unit

1.3.3 Lignin

Lignin is a complex amorphous aromatic polymer with a three-dimensional network, made out of phenyl propane units connected together. The monomeric units are held together by various ways: through oxygen bridge between two propyl and phenyl groups, between a phenyl and a propyl gathering, or through carbon-carbon connections between similar groups. Specifically, this macromolecule is framed through the radical oxidative polymerization of three hydroxycinnamyl alcohols speaking to the essential auxiliary monomers: p-phenyl monomer (type H), guaiacyl monomer (type G) and siringyl monomer (type S), derived from coumarinic, coniferyl and synapyl alcohol, separately. The basic chemical structure of lignin is shown in Fig. 1.7. The elemental composition varies as- around 61-65% carbon, 5-6% hydrogen, and the remaining is oxygen (Fromm et al., 2003). It has high atomic weight and is amorphous in nature. Typically lignin in the biomass is varies around 20 wt. % - 35 wt. %.

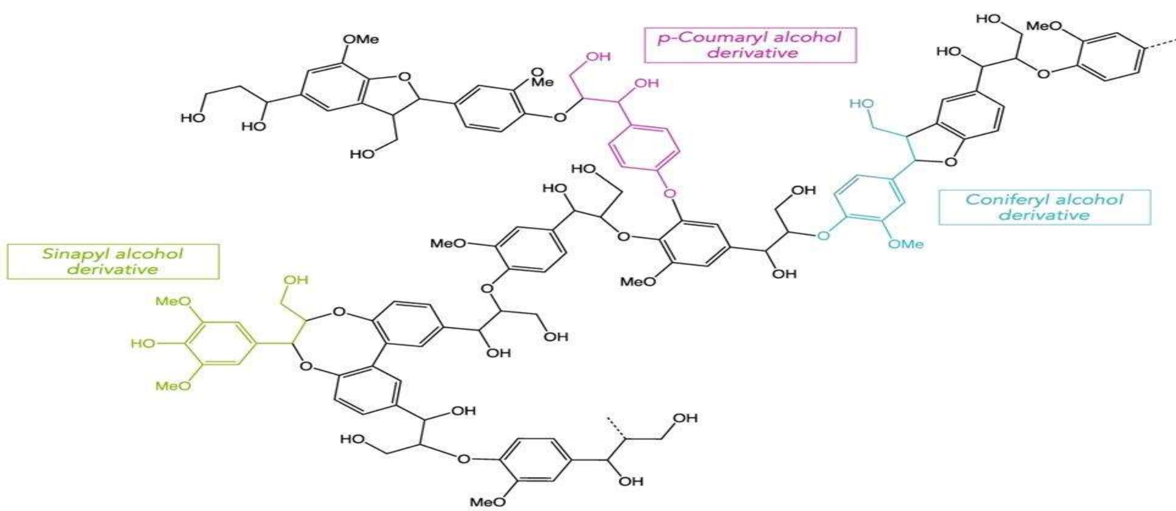

Fig. 1.7 Chemical structure of lignin

1.3.4 Organic extractives

Biomass also comprises modest quantity of natural extractives, which are relatively lower molecular weight mixes and soluble dissolved in neutral solvents. The extractives comprises fats, proteins, simple sugars, phenolic, waxes, pectin, alkaloids, resins, gums, starches, trepans, saponins, glycosides, and essential oils. Extractives function as intermediates in digestion, give assurance against bug attack and microbial destruction (Mohan et al., 2006). They additionally add to the characteristics properties, for example, Colour, smell, and taste of the biomass.

1.3.5 Inorganic elements

As a rule, biomass additionally contains inorganic substances in trace, whose amount varies as it depends upon the type of the biomass and the characteristics of the soil on which it grows (Alaswada et al., 2015). Among these, the basic components are salts of metals, for example, calcium, sodium, potassium, magnesium, phosphorus, silicon, aluminum, and iron (Werkelin et al., 2005). Inherent inorganic elements greatly contribute to enhance product compositional variability issues due to their catalytic effects. Especially oxides and mixed oxides of alkali and alkaline earth metals (AAEMs)) play important roles. Several technical problems also arise due to their presence. Various pre-treatment methods are used to reduce their effects.

1.4 Biomass as energy option for India

India is primarily an agrarian country. Due to availability of high yielding variety of seeds, improved agricultural practices, use of agrochemicals and fertilizers, and better irrigation facilities, agricultural produce in India has increased substantially. This has also resulted in the generation of huge volume of various types of agro-wastes. Estimations are made regularly by the National Productivity Council for the calculation of crop to residue of various crops and data are updated regularly by the Ministry of Agriculture of Government of India. Apart from agricultural residues forestry wastes are also the major contributor of major amount. A study directed by Indian Institute of Science (IISc) Bangalore under the project of biomass chart book of India supported by Ministry of New and Renewable Energy, Government of India, puts the estimate of surplus agro-residues (for the year 2008-09) accessible for bio-fuels at around 125 MMTPA and the estimated energy potential for this biomass is 16.25 GW of electricity production. The amounts of agricultural residues available during 2014-2019 are given in Table 1.4.

Table 1.4: Production of major crops (in Million Tonnes) and estimated amount of agro-residues for bio-fuels

Crops	2014-15	2015-16	2016-17	2017-18	2018-19	Types of Agro-residues	Net availability of agro-residues for biofuels* (2020/2021)
Food grains	**262.03**	**251.54**	**275.11**	**285.01**	**284.95**		
Rice	106.48	104.41	109.7	112.76	116.42	Straw and husk	15.8
Wheat	86.53	92.29	98.51	99.87	102.19	Straw	0.0
Maize	24.17	22.57	25.90	28.75	27.23	Stalk and cobs	8.5
Nutria Cereals	42.86	38.52	43.77	46.97	42.95	Stalk	0.0
Pulses	**17.15**	**16.32**	**23.13**	**25.42**	**23.40**		
Gram	7.33	7.06	9.38	11.38	10.13	Waste	9.7
Tur (Arhar)	2.81	2.56	4.87	4.29	3.59	Shell and waste	3.1
Lentil (Masur)	1.04	0.98	1.22	1.62	1.56	Shell and waste	1.3
Oilseeds	**27.51**	**25.25**	**31.28**	**31.46**	**32.26**		
Groundnut	7.40	6.73	7.46	9.25	6.69		1.9
Rapeseed and Mustard	6.28	6.80	7.92	8.43	9.34	Straw and husk	13.9
Soybean	10.37	8.57	13.16	10.93	13.79		-
Sunflower	0.43	0.30	0.25	0.22	0.22		-
Cotton#	34.80	30.01	32.58	32.81	28.71	Seeds and waste Gin	15.3 0.3

Jute and Mesta##	11.13	10.52	10.96	10.03	9.77	Waste	2.6
Sugarcane	362.33	348.45	306.07	379.90	400.16	Bagasse and leaves	42.6

Source: (Agriculture Statistics at a Glance 2019)

The estimation of agro-waste generation in India is based on the production of crop. The major crop residue such as wheat straw, paddy stalk, sugar cane bagasse and their leaves, peanut straw, arhar stalk etc. An estimated record of the generation of agro-residue on the basis of crop to residue ratio that could probability is utilized for the estimation of the bio-energy generation potential is given in Table 1.5. The increases in cereals production (crop area, yield and production) during 1961 to 2017 are shown in Fig 1.8.

Table 1.5: Estimation of agro-residues from production of major crops in India (2010-11)

Crop	Main Crop Production (MMTPA)	Type of Residue	Crop to Residue Ratio	Residue Quantity (MMTPA)
Rice	95.32	Straw	1.3	123.92
		Husk	0.3	28.6
Wheat	85.93	Straw	1.5	128.9
Coarse cereals	42.32	Straw and husk	1.8	76.176
Sugarcane	339.17	Bagasse	0.3	101.75
		Top	0.05	16.96
		Trash	0.07	23.74
Cotton	33.43	Stalks	3.0	100.29
		Gin Waste	0.1	3.34
Oilseeds	31.1	Straw and husk	1.1	34.21
Pulses	18.09	Straws	1.3	23.52
Jute	10.58	Stalks	2.0	21.16

GRAND TOTAL	**682.57**

Source: * Agricultural production data is for the year 2010-11 (Agriculture Statistics at a Glance 2011). The residue ratio and conventional uses from reports of Taluka level studies by MNRE

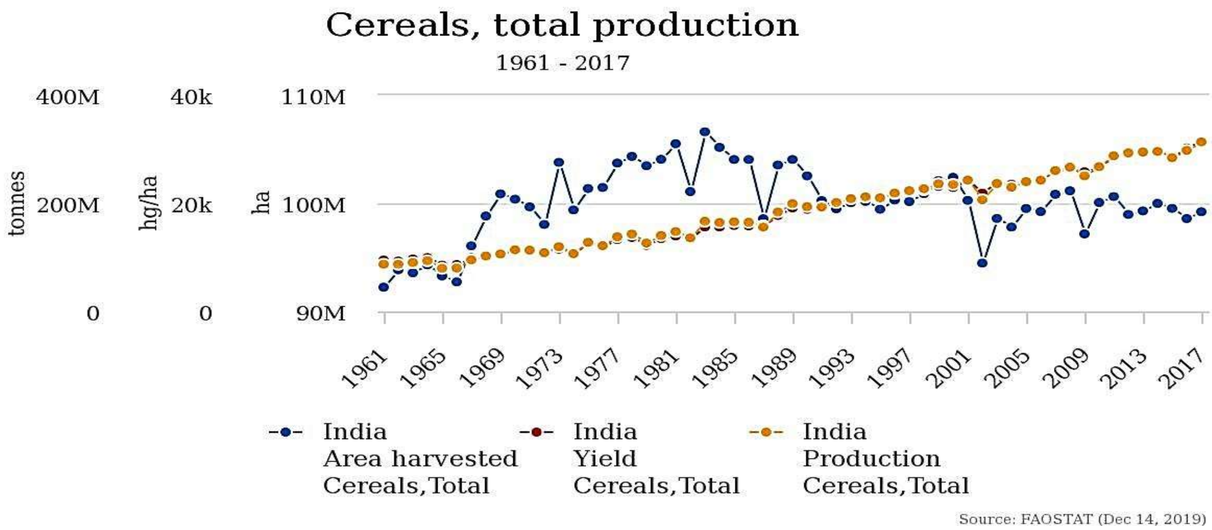

Fig. 1.8 Variation in cereals production from 1961 to 2017 (Faostat, 2019)

From the above it is apparent that India has enormous availability of agro-residues that are currently not being efficiently used. Further, due to ignorance, carelessness, unavailability of appropriate technology, the absence of a clear-cut policy for agro-waste management and poor implementation of existing regulations a major portion of agro-residue is burnt by the farmers in the fields itself causing air pollution and soil degradation. Thus there is need to generate scientific data for modifying the existing technology or develop new technology for utilizing this huge amount of the available biomass as a renewable energy source. The results presented in this thesis are obtained to fulfill this requirement.