Bioethanol Extraction and Its Production from Agricultural Residues for Sustainable Development

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Abstract

Bioethanol is a reasonable alternative option, its generation from readily available in an enormous amount and eco-friendly bio-resources, i.e., agricultural residues, one of the most suitable and renewable alternative options in place of fossils fuels resources, which being to deplete in an upcoming day. According to the recent statistical analysis report of Economic Co-operation and Development (OECD) and the Food and Agriculture Organization (FAO), for the 2017–2026 year, discussed the cereal feedstocks availability like Wheat and Rice across the world for biofuel production. Wheat and rice cereal cops contribute approximately, 742 Mt and 495 Mt million hectares annually, instead of other cereal crop residues such as Pearl millet (*Pennisetum glaucum*), Barley (*Hordeum vulgare*), Gram pea (*Cicer arietinum*), Sugarcane (*Saccharum officinarum*), and Great millet (*Sorghum vulgare*), abundantly available in Asian countries only. Instead of agricultural residues, municipal sewage waste (MSW) can also be utilized as organic biomass for bioethanol production in Mediterranean countries. As per advanced technologies concern, all of these are described in this chapter, they are direct combustion, combustion after physical processing, thermo-chemical and biological processing followed by the simultaneous saccharification and co-fermentation (SSCF) and consolidated bioprocessing (CBP). In addition, other applications of recycled wastes were also discussed. The foremost aim of the chapter was too focused on the latest development with respect to technologies related to the biofuel sector and sustainable development of the agricultural sector as well.

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Agricultural residues · Bioethanol · Biomass · Simultaneous saccharification and co-fermentation · Consolidated bioprocessing

7.1 Introduction

Fossil fuels are known to be a finite source of energy, but now it is slowly depleted, and possibly vanishes in a couple of next few decades. The possible explanation of this current problem is to replace fossil fuels with the eco-friendly biofuels that have become a realistic, focused area of research in the last few decades. Another problem of climatic and global warming issues arises due to the burning of fossil fuels, which warn us to take strict initiative steps to look forward to substituting fossil fuels, that will be, replaced by biofuels in an upcoming day, so as to meet our energy demands. Biofuels produced from biomass (Abdeshahian et al. 2010). The term biomass (Greek bio meaning life + maza meaning mass) refers to non-fossilized and biodegradable organic material originating from plants, animals, and microorganisms. The biomass comprises of by-products, residues, and waste derived from agriculture, forestry, and related industries, as well as, and these are non-fossilized and biodegradable organic fractions of industrial and municipal solid wastes (Williams et al. 1997). Moreover, the biomass originated from the decomposition of non-fossilized and biodegradable organic materials (Demirbas 2009) had gases and liquid fractions. Thus, the biomass considered as bioenergy resources and alternative options, in terms of, sufficient energy value per unit mass, but its energy value is significantly lower than that of fossil fuels. Till date, several researchers focused on biomass consumption as a valuable energy source and acting as a promising research area in a couple of decades. Biomass is a renewable feedstock, accustomed to producing biofuels (in a solid, liquid, and gas forms) for sustainable development in an upcoming year (Stocker 2008). However, a variety of crop residues are being produced (Pedersen and Meyer 2010; Kumar et al. 2019) around the world, and these crop residues were utilized to produce biofuels by adopting a different pre- and post-processing steps of pretreatment and production methods, for, e.g. thermochemical conversion (e.g., combustion, pyrolysis, hydrothermal liquefaction, and gasification), biochemical conversion (e.g., microbial fermentation, enzymatic hydrolysis, and anaerobic digestion), and chemical treatment (e.g., transesterification).

According to the feedstock materials utilized and associated conversion methods adopted, biofuels are further classified into three biofuel generations: First-generation biofuels based on crop plants (Amartey and Jeffries 1994; Shukla and Cheryan 2001; Azeredo et al. 2006; Ganjyal et al. 2004; Kim et al. 2004; Jerez et al. 2005; Aithani and Mohanty 2006; Kılıc and Ozbek 2007; Singh 2008), Second-generation biofuel is sourced from lignocellulosic biomaterials or non-edible feedstocks materials (Brumbley et al. 2007; Nass et al. 2007; Nel 2010), Third

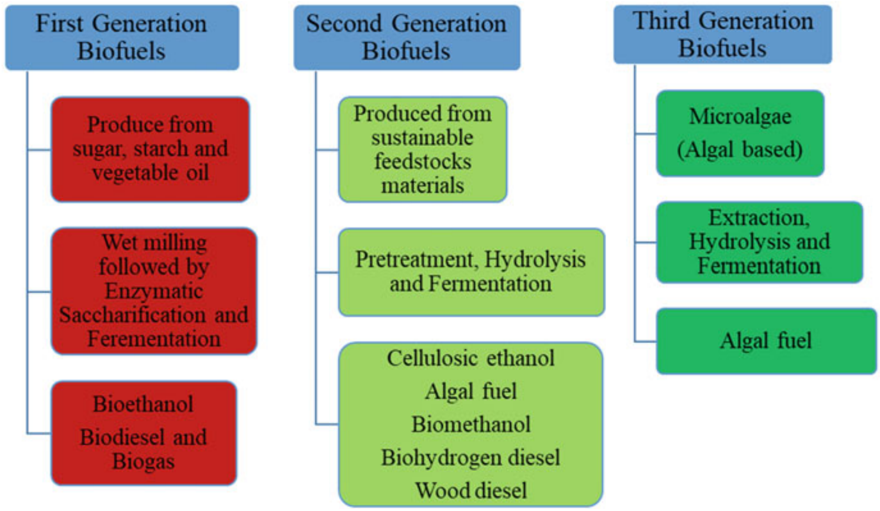

Fig. 7.1 Biofuels classification trends with pretreatment technologies

generation biofuels derived from algal biomass (Lakaniemi et al. 2013) (Fig. 7.1). However, an important concern to environmental forfeits of contending the use of crop residues should be evaluated on short-term and long-term perception basis, considering its impact on agricultural land and biofuel productivity. Several varieties of biofuels are available today, out of them, bioethanol is the most demanding, and thus, it required in a huge amount.

Traditionally, biomass-derived energy is utilized for the generation of liquid fuels: bioethanol and biodiesel. In India, bioethanol is mainly produced by the fermentation of molasses (Sengupta and Poddar 2013), a by-product of the sugar industry, and biodiesel, which is made from non-edible oilseeds. That is why Indian researcher's focused on the research, which is, based on the cellulosic biomass transformation into ethanol. Now, it can be possible to generate ethanol from a cultivated cellulosic biomass of Jatropha plants, for the local and municipal mass production of biodiesel, which is fit for the environment, and it can lead to better incomes generator especially, for a rural people. Meanwhile, with the establishment and continuous improvement of a Jatropha system, definitely, improves the four significant aspects of development and it ensures a sustainable way of life for the farmers, and their supporting land (Kapadia et al. 2019).

As per the report of (NUiCONE) Nirma University International Conference on Engineering Proceedings, India has now changed its strategies, in order to, enhance the biofuel production beyond to 1%. Thus, it has been observed that the 85% increment in biofuel production since 2009.

In the 2015 year, both the USA and Brazil collectively produced 85% of world ethanol. Instead of this, alone the USA becomes the largest ethanol producers in the world, with the 15 billion gallons production capacity as reported at the end of the 2015 year (Srivastava et al. 2019) and according to the current global biofuel demand, reached to 6.5% per annum. This current mandate reported that renewable fuels predominate as transportation fuels in the USA by the end of the 2022 year. Its production is increased to 36 billion gallons per year, contribute at least 21 billion gallons of fuel derived from non-corn, cellulosic, and non-edible biomass resources (Ziolkowska and Simon 2014). Furthermore, the Agro-based industry has 51.3 gallon litre (GL) capacity of producing bioethanol, derived from the 180.73 million tons of available biomass of sugarcane bagasse (Saini et al. 2015). Other than cereal crops, industrially processed wastes, and various fruit wastes such as pineapple peel (8.34%), banana peel (7.45%), apple pomace (8.44%), palm oil empty fruit bunch (14.5%), and a mixture of apple and banana (38%) wastes are also employed to evaluate the quantification of bioethanol potential (Gupta and Verma 2015).

7.1.1 Agricultural Residue

Agricultural sector is one of the central integral parts of an economy, especially demonstrated in developing countries like India, Thailand, Indonesia, and Philippines, etc. Although, the crop itself, contributes a large number of residues, accounting to about 140 billion tons (Sugathapala and Surya 2013) of a generation of crop residues were produced every year. The term agricultural residue describes all the organic materials, which are produced as by-products, actually derived from the agriculture activities (Bertero et al. 2012). These crop residues constitute a significant part of the total annual production of biomass residues and become a leading source of energy (Prasad et al. 2007) at the domestic and industrial level. Agricultural residues can be further categorized into the field-based residues and process-based residues. Such categorization is essential, especially, under the context of energy application, availability and accessibility to these sources critically depend on this attribute. Availability of field-based residues for energy application is usually limited, since its collection for energy utilization is difficult, and therefore, it can be utilized for other alternative purposes, such as fertilizing and animal feed. However, processed based residues are usually available in a relatively bulk amount, and it may be utilized as an energy source for the same industry, holding little transportation with no handling cost.

7.1.2 Agro-Waste Composition

Several developing countries reported that the there is a scarcity of fossil fuels so, they rely on biomass-based bioenergy originated from agricultural residues such as Wheat straw, Rice straw, Stovers, Sugarcane bagasse, Coconut shell, and Cornstalk, etc. (Gaurav et al. 2017). Fig. 7.2 describes the major biomass resources of India. All these residues are lignocellulosic biomass, which consists of structural elemental polymers: cellulose $(C_6H_{10}O_5)x$, hemicellulose $(C_5H_8O_4)y$ (pentose sugar) such as xylan and lignin $(C_9H_{10}O_3(CH_3O)0.9\text{-}1.7)z$ (polyphenolic compounds), where x,y,z represents the composition of biomass materials. A cellulosic fraction consists of sugar molecules with longer chains of carbon, linked together to form a polymer.

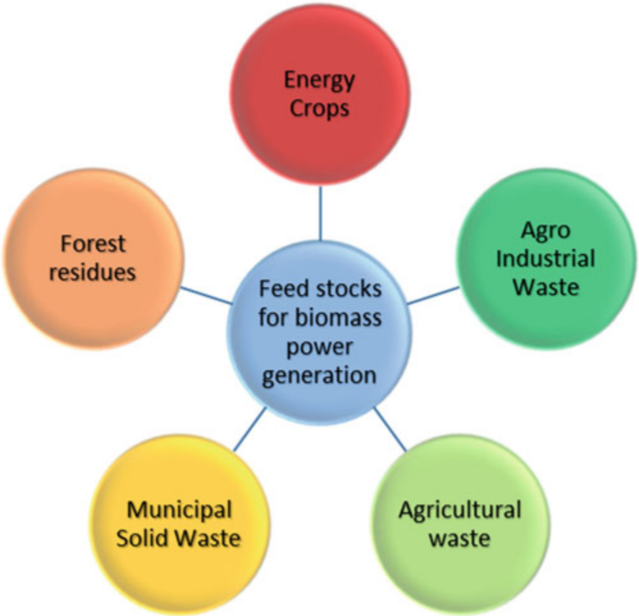

Fig. 7.2 Biomass resources available in India

The lignin fraction consists of non-sugar type moieties that act as a glue, holding together the cellulosic fibres, and contributes to structural rigidity to plant tissues. Lignin contains a very high energy structure, but due to its hardness, it is difficult to decompose, it means they are not easily breakable. For example, Woody plants have typically slow growth characterized, and composed of tightly bound fibres, giving a hard-external surface, while herbaceous plants are usually perennial, with more loosely bound fibres, indicating a lower proportion of lignin content, which binds together with cellulosic fibres tightly. Both the polysaccharides elementary materials are good examples of natural long-chain polymers. The relative proportions of cellulose and lignin content in biomass are one of the critical determining factors while demonstrating the choosing the plant species for subsequent processing or suitability as energy crops.

Biomass chemistry makes up the three essential elements: Carbon, Oxygen, and Hydrogen. In addition, Nitrogen, Sulphur, Chlorine, Potassium, and Silica can also be found in a sufficient quantity, usually, less than 1% of dry matter but well above this quantity is occasionally found. Because of the presence of carbohydrate structure in biomass, actually determines the highly oxygenated energy resources compared to conventional fossil fuels, includes the Hydrocarbons (HC) liquids and coals. Therefore, the bio-refineries industries should be developed, in order to, enhance the production of biofuels, that is, dependent on the efficient bioconversion technologies, the biochemical composition of biomass, incentives and government policies. Some agricultural residues are listed below in Table. 7.1

Table 7.1 Different agricultural residues with biochemical composition extracted from crops and plants mass type

Agro-residues	Hemicellulose (%)	Cellulose (%)	Lignin (%)	References
Rice straw	20.47–31.42	28.1–43.77	4.84–23.3	Mancini et al. (2018a), Shen et al. (2019), Xin et al. (2018), Negi et al. (2018)
Wheat straw	10.5–43	28.8–51.5	5.4–30	Tsegayea et al. (2019), Mancini et al. (2018b), Tian et al. (2018), Geng et al. (2019)
Almond shell	28.0–38.0	29.0–31.1	27.7–35	Queiros et al. (2020)
Cashew nut shell	18.6	41.3	40.1	Popa (2018)
Coir pith	0.15–0.25	36–43	41–45	Panamgama and Peramune (2018)
Corn straw	14.8–21.3	27.9–42.6	8.2–19	Liu et al. (2018)
Eucalyptus	11–18	45–51	29	Carrillo et al. (2018)
Groundnut shell	18.7	35.7	30.2	Ganguly et al. (2020)
Horticultural Waste	28.6	34.5	36	Li et al. (2018)
Jute fibres	18–21	45–53	21–26	Ahuja et al. (2018)
Millet husk	33.3	29.6	14	Packiam et al. (2018)
Nut shells	25–30	25–30	30–40	Shah et al. (2018)
Oat straw	27-38	31–39.4	16–19	Rattanaporn et al. (2018)
Palm fibre	19.9	35.4	27.3	Rattanaporn et al. (2018)
Mustard straw	21.5–30	30.9–35	16–25.3	Robak et al. (2019)
Sorghum straw	24.0–27.0	2.0–35.0	15.0–21.0	Almeida et al. (2019)
Wheat shell	30	10–15	4–8	Laca et al. (2019)
Wheat husk	22.3–50	29–49	5–21	Alonso (2018), Kumari and Singh (2018), Hysek et al. (2018), Lin et al. (2019), Bhatia et al. (2018)

7.1.3 Agricultural Residues Available for Energy Plantation

Usually, agricultural biomass is available in a considerable amount for a cattle feed, utilized for fuel generation and power production, especially fruitful in a rural area of India, and makes the rural people livelihood easier and more comfortable. Some crops like such as corn, sugarcane, grains, pulses, rubber, etc. are available today in a vast amount for a biomass power generation (Davis et al. 2014). In India, the requirement of enormous power demand is likely to be fulfilled by adopting the variety of readily available energy bio-resources in Indian villages. Some prominent biomasses such as burflower-tree (*Neolamarckia cadamba*), Gum arabic tree (*Vachellia nilotica*), Bamboo (*Bambusa vulgaris*), Julie flora, and *Melia dubia* are also acted as energy plantation resources (MNES. In: Ministry of non-conventional

Table 7.2 Indian zone wise available agro-feedstock materials and cost/t. (Kumar et al. 2015)

Indian regions	States	Available agro-waste	Approximate cost range of feedstock (Rs/t)
North-west	Rajasthan, Gujarat	Stalks of Mustard, Juliflora, Maize, Coriander, Soybean, Cotton, Pigeon pea, and Sesame	1300–2500
Central and South-west	Madhya Pradesh, Maharashtra	Cotton stalk, Soy husks, Mustards, Maize stalks, Chilly, Rice husk, Juliflora, and Bamboo	1500–2800
South	Andhra Pradesh, Karnataka, Tamil Nadu, Kerala	Rice husk, Juliflora, Groundnut, Coconut shell, Bengal gram, Chilly stalk, Cane trash, Maize, and Chickpea	1200–2500
North-East	Jharkhand, West Bengal	Wood chips, Rice husk, and Sugar cane	1100–2600
North	Punjab, Haryana, Himachal Pradesh, Uttaranchal, Uttar Pradesh	Rice husk & straw, Mustard stalk, Straw and Wheat husk, Juliflora, and Cane trash	1550–3000
Central and South-east	Orissa, Chhattisgarh	Rice husk, Cotton stalk, Sawdust, and Juliflora	1100–2600

energy sources. Government of India 1996), and their extensive usage for energy purposes, is because of having a drier matter content, high calorific value, and high carbon proportion, with low moisture and ash content, *etc*.

According to Ministry of New and Renewable Energy (MNRE), approx., 200million tonnes of agro-processing and domestic wastes are generated annually in India and disposed of in a regular manner, and these disposed of sites, are actually managed by local farmers and the unorganized sector, rural worker and the low income-based small agro-industries (Singh 2008). Since these processes entangled no or little production costs, therefore, they are totally ignored, and that is why, they are not utilized properly because the majority of wastes are amounts of leafy wastes, which are burnt out in these disposed of sites, and causes air pollution and even harm the soil fertility. A list of zone wise available agro-feedstock materials listed below in Table 7.2.

7.2 Global Scenario of Agro-Lignocellulosic Residues

Wheat and Rice are the main cereal crops of India, and its farming productivity is approx. 379 million hectares (Mha) per annum, but it has been contributed, in terms of, production per capita in the irrigated lands. During the harvesting of wheat and rice crops, their waste residues such as wheat straw and rice straw are leftover on agriculture land. These left residues/it may be a hinge material, which is generally utilized for animal feed, house construction, and fuel generation. In a recent decade, mechanized harvesting machinery released an enormous straw residue in a considerable amount, but farmers prefer to burn in situ else the residues would interfere with tillage and seeding of next session crops (Chauhan et al. 2012). Incineration of crop residues should also be avoided because it leads to a severe environmental issue mainly concerning with accelerated decomposition of soil organic matter (SOM), resulting into reduced soil fertility by vanishing the soil microbial activity (Biederbeck et al. 1980), and other health hazards issues are also associated with it, which leads to a severe respiratory and eye irritation problems.

As per the OECD-FAO's recent statistical reports, for 2017–2026 year, recorded the world cereal production to be 2563 metric ton (Mt) annually, it was noticed that the annual wheat and rice production is 742 Mt and 495 Mt subsequently (Nilsson et al. 2015), that is, described in this report in a comprehensive manner. At the same time, the 301Mt annual production of other Coarse Cereals is also recorded in the same year.

Rice and wheat production rate considerably increased and reached an average level of production, indicated at an industrial scale. It indicates the residues to product ratio, which decides the exact agricultural practices, that would be lie 0.416–1.875 in the range that was recorded mostly in the Southeastern Asian countries (Bhattacharya et al. 1993). Thus, these residues can be utilized for the purpose of biofuel production. The statistical report of the OCED-FAO agricultural outlook for the 2017–2026 year depicts the annual wheat, and rice crop residues production (Carrillo et al. 2019) is approximately 1336 Mt and 891 Mt subsequently, produced throughout the world.

The Wheat and Rice residues majorly constitute the total biomass residues, which are produced yearly through the agricultural practices; therefore, these residues are widely available and a vital source of energy in a domestic and industrial scale. In 2017–2018 the report stated that the annual production of Wheat and Barley in Turkey, that is, approximately 19.5Mt and 7.0Mt, respectively. In the 2017–18, it was reported that the annual production of wheat and rapeseed in Australia is 23.5Mt and 3.2 Mt respectively. The annual productions of corn in Vietnam and Argentina, was approx. 5.6–42.0 Mt respectively, as per the reports of 2017–18.

An organization like Foreign Agricultural Services (FAS) and World Agricultural Supply and Demand Estimates (WASDE) recorded globally, the whole crop production in every year and announced the list of selected food crop residues such as Great millet (*Sorghum vulgare*), Pearl millet (*Pennisetum glaucum*), Maize (*Zea mays*), Finger millet (*Eleusine coracana*), Barley (*Hordeum vulgare*), Gram (*Cicer arietinum*), and Sugarcane (*Saccharum officinarum*), and acquire a unique position in Asian countries, just because of likely to be utilized as bio-resources for biofuel production. Indian Ministry of Agriculture, published a research article in the 2005 year, discussing the post-harvesting of sunflower seeds, and oilseed crops cultivated at a large scale in India. India occupies a unique position in oilseed crop production in the world, especially in case of sunflower seed. It accounts for 1250 thousand MT (4.77%) of total world production of sunflower in the 2004 year. This studied article reports the Silver leaf sunflower, which has a unique property of drought-resistant rather than its wild species, which undoubtedly, produces a more extensive, and more solid stem, which grows up to 4.5 m tall (Picot et al. 1984). Because of these reasons, the post-harvesting practices were not concentrating much on the residue collection. At present, several researchers were planned to collect the Sunflower seeds, acting as a potential source for biofuel production.

7.2.1 Other Lignocellulosic Residues

The cellulosic fraction of the municipal solid waste (MSW) can be a potential source for the bioethanol production due to their easy availability, but difficulties are associated with processing and handling of MSW which represented an as challenging problem for researchers. Municipal solid waste (MSW) is an inexpensive source of organic biomass, and its categories include domestic and industrial waste as well. Hadar 2013 reported that the 30 metric tons of annual ethanol production could be achieved from 50% of the 180 million tons of MSW, which is, only produced in the Mediterranean countries.

Oil palm industries occupy a significant place in Island like Indonesia. The waste obtained from oil palm industries, that is, the waste of oil palm empty fruit bunches or frond, mesocarp fibre, and oil palm trunk, obtained after the milling and refining activities. In palm oil processing plants, only 10% of the total dry matter was converted to oil, remaining 90% being oil palm biomass that can be utilized to produce the biofuels and their by-products. Sukiran et al. 2017 reported that palm oil products obtained from palm oil industry waste reached up to a sum of 25.64MT/annum.

7.3 New Directions to Overcome the Problems of Agro-Industrial Waste Contamination

Most of the agro-industrial residues are recycled as animal's feedstock, but its bulk mass is burnt in an open field. In 2008 year, global biofuel production was reached to about 83 billion litres, contributing about 1.5% of the global transport fuel consumption. In 2016 year, transport biofuels consumption has been increased to 4% of the world demand. In this respect, the USA and Brazil are the two largest producers. While in 2018 year, Brazil, China, and Thailand are three largest producers outside the OECD region, with a share of about 40% of the total production. Biofuel production is expected to rise to 159 billion litres in the last 5 years' decades as reported by IEA agency Renewable information, 2018. Now, it is expected that biofuels contribution provides roughly 9% of the total transport fuel demand by the end of the 2030 year, and its extended analysis demonstrates that the biofuels could provide 26% of total estimated transportation fuel by the 2050 year, while the second-generation biofuels accounting for roughly make up 90% of all biofuels (Hafiz et al. 2019). Bioethanol is a renewable and sustainable biofuel, a second-generation biofuel, with a promising future to compensate for the global energy crisis with the improvement in environmental quality (Aditiya et al. 2016). Second-generation bioethanol has excellent potential if implemented nationally. More than half of the second-generation biofuels production are still in the Blue-Map Scenario (oriented to reduce to a half of the CO_2 emissions, that is, related to the global energy by 2050 compared to 2005, already outlined in the World Energy Outlook, 2009 as announced by International Energy Agency 2010 which projected to occur in non-OECD countries, like China and India, accounting for 19% of the total production (Hafiz et al. 2019) globally. India position 13th place itself in world production of agricultural crops, alone Mexico generates large amounts of agro-industrial waste (AIW), which are usually raw unprocessed and discarded materials (Carrillo et al. 2019). Now Mexico could increase its ethanol production, in order, to reduce and replace the extensive current consumption of fossil fuels, and reduces the adverse impact of harmful environmental. Moreover, the presence of the wide variety of soils, climates, and ecosystems, Mexico has an ideal condition for growing the varieties of lignocellulosic biomass to produce a value-added commercial product. These agricultural residues generations are directly linked to the farming practices, and the technologies employed for cultivating, harvesting, transportation, storage, and processing. According to Thompson's Web of Science (web of knowledge.com), there have been 85 articles published in Mexico on the subject of biomass for ethanol production between 2010 and present. During the period of 2000–2009, for comparison, only 16 articles were published on the subject. This reflects the extensive research inputs in order to explore the high potential of second-generation bioethanol in Mexico. However, Second-generation bioethanol faces specific technical barriers in the sense of, economically non-competitiveness, pinpointed on a commercial scale. Therefore, an efficient process must be determined in order to define the heterogeneity of the lignocellulosic substrates without affecting the yield and productivity (Parisutham et al. 2014) of fuels.

India is the fifth largest consumer of energy after the USA, China, Russia, and Japan, accounting for 4% of the global energy consumption (as per the report of Federation of Indian Chambers of Commerce and Industry Price water house Cooperation 2013). With annual energy demand growing steadily at a rate of 4.8%, India is projected to become the world's third-biggest energy consumer by the end of 2030year. Now, India focused on the sustainable and renewable energy alternative options to fulfil their huge energy demands in order to save the petroleum and associated resources, the only reason of this hike in energy demand is because of a sharp increase in human population along with urbanization. The bioethanol market in India is expected to increase drastically, with steady growth in the transportation sector and stop the continuous consumption of petroleum products. The bioethanol is a cleaner and greener fuel because it reduces the carbon emission and makes our environment pollution-free. The market value of potable alcohol industry is reached to expected fuel price value of Rs 300 billion and has been growing at a fast rate of 7–10% per year, as discussed by (ICRIER) Indian Council for Research on International Economic Relations Policy Report, 2011.

India's bioethanol programme exclusively depends upon non-edible feedstock materials like sugarcane molasses, sugarcane bagasse. Although, India being the second largest sugarcane producer accounts for only 1% of the global biofuel production (Shinoj et al. 2011).

In India, most of the bioethanol production and its blending with gasoline has been largely driven by the National Biofuel Policies (http://mnre.gov.in/file-manager/UserFiles/biofuel_policy.pdf). In the 2003 year, India has started the Ethanol blended petrol programmes to promote bioethanol production and allows the 5% blending with gasoline, but this programme was failed due to the shortage of sugarcane molasses supply. In 2010 year, Government of India had made the National Biofuel Policy which changed the bioethanol blending target to 20% by 2017 and searches out the other alternative biomass and renewed their development program for innovative bioprocess technologies. Alone India produces of 686 million tones of crop biomass per year, out of them, only 34% surplus of biomass can be used for bioenergy generation (Hiloidhari et al. 2014). An alternative raw material i.e. cane juice, Miscanthus, Sweet Sorghum and other readily available lignocellulosic biomass, which are also renewable available need to be promoted for contented the blending targets. Now in India, it should also improvise new technologies, intended for better biomass conversion into biofuels, for the sustainable development of the bioenergy sector of the country.

7.4 Methods of Extracting Energy from Biomass

Methods explored are directly concerning with primary fuels generation or its biomass processing form depends on the size reduction, drying compaction (densification), and carbonization, *etc*.

Categories are as follows:

1. Direct combustion (simplest method).
2. Combustion after following physical processing such as sorting of raw biomass, chipping, compressing or air drying.
3. Thermo-chemical processing to upgrade the biofuel: further divided into pyrolysis, gasification or liquefication (Katyal 2007).
4. Biological processing: example: anaerobic digestion and fermentation.

7.4.1 Conversion of Agro-Residues into Bioethanol: Processes Involved for Bioethanol Production

One of the comfortable availabilities of Lignocellulosic biomass (LCB) in nature fascinates the possibilities of exploring and enhanced the production of second-generation fuels throughout the year. Conversion of biomass into biofuels can be made by the biomass processing unit, that is, applicable to the bulk mass of biomasses as well as for the range of biomasses such as hardwood to straw residues. This LCB conversion to bioethanol generation is accomplished in three stages:

(i) Pretreatment, (ii) Saccharification, and (iii) Fermentation of sugar to ethanol recovery.

7.4.2 Pretreatment of Lignocellulosic Biomass

Recovery of sugar from lignocellulosic biomass is far more difficult due to its recalcitrant nature, structural characteristics of biomass including the, *i.e.,* heterogeneity of lignin polymers, toxic inhibitors generation, and high energy requirement to yield a low energy product. In this pretreatment stage, these highlighted factors are overcome by choosing a suitable pretreatment technology to circumvent the problems faced during lignocellulosic ethanol production. Pretreatment is a necessary step to alter some structural characteristics of lignocellulose (Garcia et al. 2009), without losing glucan and xylan content (Vandenbossche et al. 2014). The extent of lignin deformation and cellulose recovery depends upon the choice of pretreatment technologies utilized (Kumar and Wyman 2009). In a recent decade, there are many techniques that have been developed to encounter the problems faced during the pretreatment processing, but still, they are in demonstration level owing to lack of process intensification.

7.4.3 Saccharification

Cellulose hydrolysis, also known as saccharification, is the process in which the cellulose is converted into glucose. A variety of raw materials are utilized for bioethanol production. Mainly three types of materials are used for this purpose: sugars, starches, and cellulosic materials. A complex sugar like starches must be hydrolyzed to simpler sugar by the action of enzymes from malt or mould. This is an indirect method. Cellulose (from wood, agricultural residues, waste sulfite liquor from the pulp, and paper mills) must likewise be converted into sugars, generally by the action of acids or cellulolytic enzymes (Franks et al. 2006). An enzymatic saccharification is the quite cost-effective, less corrosive, and mild method as compared acid or alkaline methods in terms of ethanol production. Factors affecting enzymatic saccharification process involve substrate concentration, enzyme loading, temperature, and time of saccharification (Tucker et al. 2003).

7.4.4 Fermentation of Sugar to Ethanol Recovery

Sugars extracted from Cane or Sweet Sorghum juice (Kılıc and Ozbek 2007), molasses can be used directly for ethanol production via fermentation. This can be possible by incorporating the most common and robust fermenting microorganism such as *S. cerevisiae* and *Z. mobilis* are employed to produce ethanol. Actually,

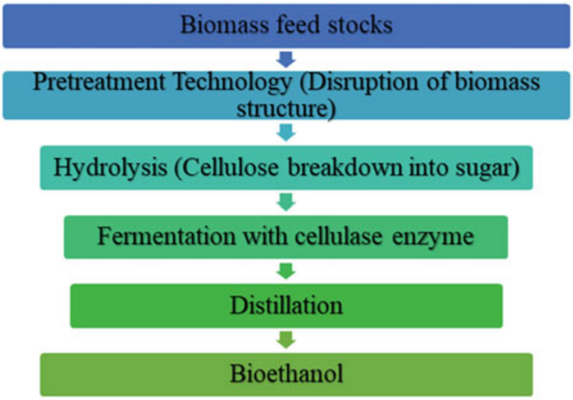

Fig. 7.3 Process flow diagram of biomass conversion process into bioethanol (Joshi et al. 2014)

produced ethanol is drawn out from sugars derived from starch and sucrose, which has been commercially utilized by yeast (Diaz et al. 2015). However, *S. cerevisiae* is capable of converting only hexose sugars to ethanol. In addition, other most promising yeast *Pichia stipitis*, *Candida shehatae,* and *Pachysolen tannophilus,* that have the capability to use both the pentoses and hexoses sugars simultaneously.

One of the Thermo-tolerant yeasts could be more suitable for ethanol production at an industrial level, because of the ability to ferment sugar even at higher temperatures. One of the significant limitations of using thermo-tolerant bacteria is lower tolerance to ethanol ($>$30 g/l) as studied by Talebnia et al. 2010. Furthermore, rest of the solid residue obtained during this process can be further utilized to feed cattle, while bagasse which is obtained from sugar cane can be further utilized for next gasification step or it can be used as a fuel for boilers (Das and Ghatnekar 1979). An above strategy can be represented in a simplified manner, as depicted in Fig. 7.3 highlighting the process flow diagram of biomass feedstock's conversion into bioethanol.

Another supportive strategy for ethanol production via fermentation is simultaneous saccharification and co-fermentation (SSCF) method, which outlined the simultaneous co-fermentation of hexoses and pentoses is carried out by microbial organisms. In SSCF, the co-fermenting microorganisms have to be compatible with operating pH and temperature (Neves et al. 2007) environmental conditions. However, the ability to ferment pentoses along with hexoses is not widespread among the microorganisms and lack of ideal co-fermenting microorganism, that is, one of the most significant obstacles in industrial production of second-generation ethanol (Talebnia et al. 2010). Sometimes co-culture technique proves to be a useful technology, thereby, a combination of hexose and pentose fermenting microorganisms is utilized for complete utilization of biomass sugars. Neves et al. (2007) studied report suggested that the co-culture of *Candida shehatae* and *Saccharomyces cerevisiae* are the two best organisms to conduct the SSCF process.

One of the most recent and advanced technologies for ethanol production via fermentation is consolidated bioprocessing (CBP), where ethanol and all necessary enzymes are produced by a single microbial organism. Bacteria such as *Clostridium thermocellum* and some fungi like *Neurospora crassa*, *Fusarium oxysporum,* and *Paecilomyces* sp. had shown the kind of dual activity. However, bigger drawbacks of CBP technology are because of the less-efficient process with poor ethanol yields and longer fermentation time of more than 3–4 days. Significant cost reductions are also encountered while progressing from improved SSF *via* SSCF to CBP. Other beneficial factors such as broad range of multiple substrate utilization by the microorganism, actually represent the high yield (>90% of theoretical yield), the high titre value of ethanol and should have a high tolerance to ethanol (>40% bioethanol tolerance) to extreme pH and temperature (acidic pH or higher temperature) conditions, an actual inhibitors present in a hydrolysate while pre-processing. All of these above-highlighted factors are responsible for maximizing the recovery of the product like ethanol.

7.5 Agro-Industrial Wastes as Potential Substrates in India for Alternative Fuel Production

Today's scenario, organic wastes generated from agro-industries are considered as the primary sources of environmental pollution.

In general, organic waste mainly exists in two forms:

(i) Agricultural and forestry.

(ii) Industrial waste.

Wastes derived from agricultural and forestry activities include the livestock slurry, manure, crop remains, and some other wastes which are derived from pruning and the maintenance of woodlands (Yusuf 2017). Industries also generate the organic wastes, which includes the by-products of the agri-food industry such as coffee dregs, bagasse, degummed fruits and legumes, milk serum, sludge from wool, cellulose, etc. (Bhat 2019). The present scenario is changed, because of urbanization replacing the rural areas, just for economic development, usually, seen in developing Asian countries like India, Bangladesh, Nepal, Bhutan, Sri Lanka, etc.

Moreover, the quantity of the agricultural and industrial waste has increased to alarming state, leading to a serious concern associated with our environment and therefore, in this respect, several countries have made the legislation, in order to, prevent the serious issues concerning with our environment. However, several norms are made by the Indian government to follow the rules and regulation, in respect to the proper waste management, emphasizing on waste assessment and their removal from urban areas must be followed without disturbing the natural flora and fauna, and recycled the organic waste as fertilizer, in agricultural fields. Furthermore, it strictly imposes norms to control the industrial pollution, just because of the presence of organic and inorganic waste or Municipal solid waste (MSW) (Matsakas et al. 2017) in an environment in a huge amount, the only way to eradicate this arising problem recycle the wastes (Shafya and Mansour 2018), into the cleaner technology, i.e., biofuel production. Another prominent application of recycled wastes was also included in this report are enzyme production, organic acid isolation, pigment extraction, food flavouring and preservative extraction, bioactive compound production, biodegradable Polyhydroxy-acetate (PHA) production, agricultural composting, *etc*. (Samarasinghe et al. 2008). Thus, it has to adopt the regulatory approval on capital investments, in order to, bring these value-added products in the commercial market with comfort.

7.6 Latest Research Studies on Bioethanol

Recent reported studies, on catalytic conversion of lignocellulosic biomass, to bioethanol G2 production, although, they are not yet mature to be utilized for an industrial purpose. This catalytic process has high selectivity, in terms of, product specificity, and it maintains the balance between the overall cost and effective use, whenever used in a bulk scale or industrial scale (Sudiyani et al. 2014). Looking towards the factors like efficient process design, and optimization of environmental conditions for bioethanol production, some significant obstacles are encountered during the pre-post processing steps, *e.g.,* pretreatment, enzymatic hydrolysis, and post-processing steps, *e.g.,* fermentation, and distillation, these observed methods can be chosen on the basis of efficiency of production in lesser time. For this purpose, the production of fermentable sugars, *e.g.,* pentose and hexose sugars, was done either in the presence of engineered microbial strains or it can be enhanced by adopting the hydrolytic process, which is yet to be achieved as biomass preprocessing step, that is, a major challenging task (Mariano et al. 2013) of any bio-refineries. One of the efficient processes observed during the bioethanol production is distillation, where too much energy is consumed, that is why an alternative green process such as per evaporation/Hybrid integrated membrane system should be commercialized widely on the industrial scale. Thus, in the near future, different types of biomass can be effectively utilized and optimized to produce bioethanol, along with the improvement of technologies (Kumar et al. 2019). However, extensive research work is still required to make the process cost-effective (energy return on investment) and efficient (high energy yields) for better ethanol production.

7.7 Research Gaps while Producing Bioethanol

Bioethanol production from edible bioresources like Sugarcane bagasse (Lisboa et al. 2011) was become a matter of discussion, as an alternative energy resource to reduce the dependencies of regional economies on fossil fuels. Even though the bioethanol generation from sugarcane is considered to be a beneficial and cost-effective strategy, so as to reduce greenhouse gaseous (GHG) emissions, but it is still a matter of controversy just because of insufficient knowledge of maintenance of total GHG emissions balance. Aside from these necessity to the account, another logical impact arises because of land-use change (LUC) causes large amounts of greenhouse gas emissions as well as soil N_2O emissions occurred during the processing of sugarcane. In contrast, GHG emissions are reported (Smith et al.

2019), during the pre-harvest and burning of left residues in an open area, which may adversely impact on the maintenance of total GHG balance. This research study represents the huge research gaps is created owing to the lack of knowledge and awareness of GHG emitting resources relevant to agricultural management while processing of sugarcane production (Smith et al. 2019). In addition to this, it also depends on the Biomass types, biomass cultivation practices, local irrigation practices, vinasse, and filter cake applications. Therefore, a still more strategic research should be planned before executing it, as taking an, *e.g.,* of bioethanol production from sugarcane bagasse, that is, an only viable option to mitigate the problem of energy-related GHG emissions (Bahl et al. 2011). Contrary to findings on GHG emissions, which ultimately affects an environment eco-toxicity and human health, it has also been reported with favourable topics relevant to acidification and eutrophication potential with the use of ethanol as biofuel while others not in favour of conventional gasoline usage (Borrionet al. 2012). Therefore, research is needed to obtain more accurate data to support modelling, analysis, and policies development across a wide range of biofuel areas.

7.8 Conclusion and Future Outlook

Waste to energy option is thus, considered to be the most satisfactory way of disposing of the unwanted waste. The feasible option of waste to energy conversion in any developing country that is greatly influenced by the waste collection, scavenging, and proper waste disposal practices adopted in a particular city/town/village. However, agro-wastes selection and utilization for biofuels generation depend on biomass composition, processing, and conversion technologies. More elaborately, biofuels yield can be enhanced by utilizing the co-substrate mixture, which depend on the agro-waste composition and the route of processing step following, that is, either through biochemically or thermochemically, instead of adopting the excess energy consumption process like distillation. In addition, during the bioethanol generation process, more advanced technologies are also included, they are direct combustion, combustion after physical processing, thermo-chemical and biological processing (*e.g.,* Fermentation of sugar to ethanol recovery) followed by simultaneous saccharification and co-fermentation (SSCF) and consolidated bioprocessing (CBP) methodology. The unwanted waste can be further recycled to generate the various kinds of value-added products such as organic acid production, pigment extraction, biodegradable plastic production, agricultural composting, *etc*. these recycled products, not only provide new ideas to researcher's, but it also reduces the current environmental health hazards, thus, make it eco-friendly in nature. However, still much research work is needed to explore out, in order to, accomplish the work extensively on the up-gradation of bioethanol generation by utilizing an engineered microbial strain to scale up productivity from pilot an industrial scale, instead of this, several researcher's focused on a critical purification step to recover ethanol by replacing the conventional distillation processing step, in order to develop, a new hybrid integrated system of antifouling membranes by injection of the air jet while fermentation.

The significant advantage of this hybrid integrated system is to overcome the fouling problem found during the purification and ethanol recovery stages. Currently, intensive research is being conducted to improve the every processing steps of pretreatment to distillation, so as, to make processes eco-friendly and economical. This agro-industrial residues conversion to economically important substances may not only provide future dimension to researchers but also reduce the current environmental hazards.

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