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CHAPTER

3

c0115

Biomass feedstocks for advanced biofuels: Sustainability and supply chain management

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s0010

1 Introduction

p0010 The use of agro-waste as fuel wood is an age-old practice. Presently, biomass supplies about 14% of the world's energy demand. Developing countries account for 75% of this energy from biomass where it is primarily used for domestic cooking and heating purposes (Parikka, 2004). In a few countries such as Brazil, the largest producer and export of sugar in the world, where the sugar industry assues a significant part of its economy, the use of bioethanol for transportation and for electricity generation has seen the wide-scale application. Developed countries use 25% of global biomass energy mainly toward domestic heating needs and for power generation purposes. Today, bioethanol is seen as an important way of reducing our dependency on imported fossil fuels in India. The sustainable and environmentally friendly way of utilizing this vast quantity of biomass offers a win-win situation covering both environmental problems as well as quenching ever increasing per capita energy demand. Bioethanol production from these cellulosic agro-waste residues would certainly bring down the cost pf production and availability of bioethanol without competing with food crops for land and/or water resources. Availability of low-cost bioethanol is prerequisite for enhancing the blending ratio for petrol as a national policy. Till 2014 the blending of Q5

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bioethanol in petrol in India was less than 1%, however, today the sector witnessed a sharp rise in recent years and presently the ratio is between 8.5% and 10.0% in India. Interestingly, the Govt. of India has preponed the target of achieving 20% bioethanol blending in petrol from 2030 to 2025 recently, indicating the strong tail wind the sector is experiencing. According to various assessment reports, surplus crop residue availability in India is about 50–60 million per annum which is theoretically equivalent to 10–15 billion liters of 2-G ethanol. The quantity is sufficient to achieve the 20% cent national ethanol blending target of India. As total petrol consumption in India was estimated to reach 381 billion liters by 2020 (before the pandemic), 20% blending by bioethanol would to lead to foreign exchange savings in a range between $8 billion and 10 billion per annum.

s0015 1.1 Biomass energy

p0015 Biomass typically consists of cellulose, hemicellulose, and lignin. Cellulose is the most abundantly available organic polymer on earth though its content may vary from 90% in cotton to about 30% in wood. Being a polysaccharide consisting of a linear chain of several hundred to many thousands of β linked D-glucose units, cellulose is susceptible to enzymatic degradation. Hemi-cellulose, typically constitutes about 15%–40% of the biomass, being more amenable to hydrolysis its content plays important role in determining the biorefining potential of biomass. Lignin which constitutes about 15%–35% of biomass. This randomly cross-linked aromatic polymer of phenylpropane units joined by different linkages (ex. Ether or covalent), resists biochemical conversion (Kaushik and Biswas, 2007). Depolymerization of lignocellulosic material to smaller molecules is critical for biorefining process which converts these smaller molecules into biofuels. Hydrolysis processes aim to liberate sugars from biomass containing predominately cellulose or hemicellulose whereas thermal processes such as pyrolysis and gasification, is more common for biomass containing predominately lignin. Bio-power or heat can be generated by the release of energy stored in biomass. Fluidized bed combustion (FCC) is most efficient biomass combustion process as it generates high temperature, allows a good air-fuel mixing ratio and long residence time. Bed material agglomeration remains a critical technical bottleneck for more wide-scale applications of FCC. Renewable electricity can be generated through combustion or gasification of biomass (dry) and also through controlled anaerobic digestion of biogas. Cofiring of biomass and fossil fuels (usually coal) is a low-cost means of reducing greenhouse gas emissions, improving cost-effectiveness, and reducing air pollutants in existing power plants. Pulverized fuel combustor (PFC) is the preferred technology due to its easy adaptability to minimum requirement for equipment modification. Bed agglomeration remains a critical challenge for co-combustion of biomass, as bed de-fluidization often leads to unplanned shutdown (Shimizu et al., 2006). Thermal energy can also be generated through the gasification process, where auxillary fuel is converted to a gaseous product, termed as producer gas, where major components are carbon oxides, hydrogen and methane, as other hydrocarbon species. Tars in the producer gas pose a significant technical challenge for the gasification process. Generally, higher gasification temperature leads to lower tar production hence, optimized use of auxillary fuel is desired (Holfbauer and Knoef, 2005). Pyrolysis is a process in which biomass gets heated at high temperature in absence of oxygen to generate solid char, vapors, and

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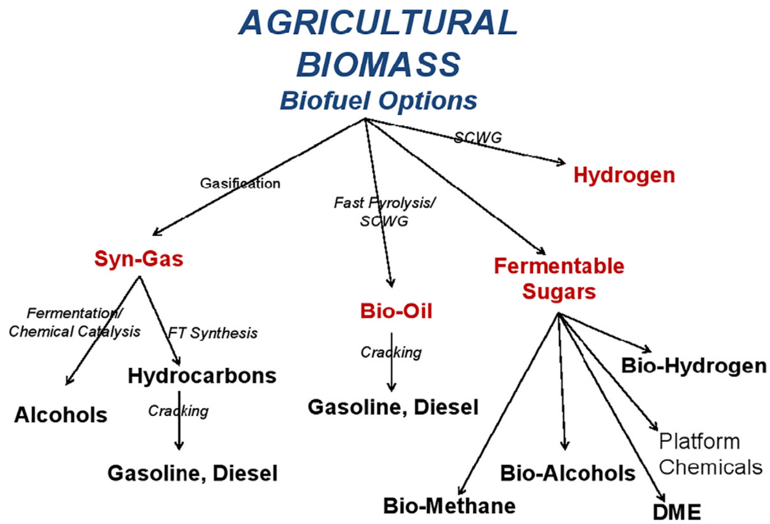

Q1 f0010 **FIG. 1** Biofuel options from biomass.

noncondensable gases, separation, and condensation of gaseous compounds leads to the production of bio-oil. Direct application of this bio-oil in engines or turbines as fuel becomes challenging due to its acidity, high oxygen and moisture content and viscous nature. The usability of bio-oil can be augmented through hydrotreating and hydrocracking which reduces its density and viscosity by hydrotreating or hydrodeoxygenation (Pang, 2016).

p0020 Biomass, like agricultural residues, can be converted to various advanced biofuels and biochemicals by adopting thermo-chemical, catalytic, and biochemical platforms. Various possible products from biomass are shown in Fig. 1.

s0020 1.2 Biofuels

p0025 "Biofuel" is short for "biomass fuel," a term used for liquid fuels produced from biomass (Table 1), such as ethanol, bio-oil, and biodiesel that help to alleviate demand for petroleum products and improve the greenhouse gas emissions profile of the transportation sector. To promote biofuels as an alternative energy source, the Govt. of India in December 2009 announced a comprehensive National Policy on Biofuels which was revised during 2018 calling for blending at least 20% of biofuels with fossil fuels by 2030. In India, against the requirement of 3.3 billion liters of ethanol which is the prime source of biofuel for 10% blending in the country, ethanol supply contracts have been signed for 2.37 billion liters during 2018–19. The government has allowed sugar mills to manufacture ethanol directly from sugarcane juice or an intermediate product called B molasses by amending Sugarcane Control Order, 1966. The production of ethanol directly from sugarcane juice or B-molasses will address the issue of sugar overproduction and stabilize sugar prices. In addition, sweet sorghum has huge untapped potential for ethanol production in India. Large-scale mill crushing tests have successfully demonstrated that existing sugar mills can be used effectively, for sweet sorghum juice extraction. For biodiesel production, the cultivation of *Jatropha curcas* on

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t0010 **TABLE 1** Key feedstocks for biofuel production in different countries.

	Major feedstocks	
Country	**Bioethanol**	**Biodiesel**
United States	Corn	Soybean oil/diverse other oils
European Union	Corn/Wheat/Suagrbeet	Rapeseed oil/waste oils
Brazil	Sugarcane/Sweet sorghum	Soybean oil
China	Corn/Sweet sorghum	Waste oils
India	Sugarcane molasses	Palm oil
Canada	Corn	Waste oils
Indonesia	Molasses	Palm oil
Argentina	Corn/Sugarcane	Soybean oil
Thailand	Molasses/Cassava	Pam oil

Source: Modified from OECD/FAO (2019), OECD-FAO Agricultural Outlook. OECD Agriculture Statistics (Database). https://doi.org/10.1787/agr-outl-data-en.

wastelands is promoted by the government. However, substantial research on developing improved cultivars of Jatropha and Pongamia as well as management practices need to be developed before biodiesel from nonedible plants becomes economically viable. The National Biofuel Policy, 2018 envisages 40% reduction in carbon emissions by 2030. The new biofuel policy shifts the focus from first-generation (1G) biofuels which are made from molasses and vegetable oils to 2G biofuels reality. The Oil Marketing Companies (OMCs) are setting up 12 advanced 2G biofuel refineries in several states. The Indian Oil Corporation is currently operating three 2G biofuel plants and plans to increase its capacity from 100 tons to 1200 tons per day in the next 2 years. Third-generation biofuel from algae also has potential and research is on to grow algae using wastewater through decentralized constructed wetland as a business model in rural areas. In addition, the government has top priority for harnessing wind and solar energy for bioenergy and India is already second after China in renewables production with 208.7 Mtoe in 2016. India has already become the world's single largest renewable energy auctions market and the second biggest attracter of clean energy investments. Biofuels remain the principal source of clean and renewable transportation fuels till renewably produced electricity is used to run a significant number of electric vehicles. The international biofuel sectors are strongly influenced by national policies with three major goals: farmer support reduced greenhouse gas emissions, and/or reduced energy independency.

s0025 1.3 Bioproducts

p0030 It is well established by researchers that compound which can be synthesized from fossil fuels can also be obtained from biomass. Such renewable source would reduce the environmental footprints of products such as antifreeze, plastic materials, glue, artificial sweeteners, and toothpaste. Other bioproducts formed during biomass heating in presence of oxygen such as biosynthesis gas, which is an important precursor for the production of photo films,

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textile and synthetic fibers. Compounds such as phenol an important precursor for woodsticks, plastic molds, insulating foam, etc. can be extracted from bio-oil produced by pyrolysis. “Bioproduct” is short for “biomass products” and can be used to describe a chemical, material, or other (nonenergy) product such as composites, plastics, and adhesives fertilizers, lubricants, industrial chemicals, etc. Bioproducts are widely used in our day-to-day lives today such as various cosmetics such as skin cream, nail polish remover (acetone), shampoo, hair conditioner (palmitic acid), mascara, etc. Renewed demand for biobased cosmetics has resulted in market size of $3 billion in 2019. Microalgal oil producers have the potential to generate 120 barrels (1 barrel equivalent to 159 L) of oil per acre which can be used as a renewable fuel. Valuable bioproducts such as omega-3 fatty acids can be sourced from algal cultivation on a commercial scale. Bio-based surfactants and solvents can be used to produce detergents and other cleansers.

s0030

2 Biomass feedstocks

p0035 Biomass feedstocks for energy production can result from plants grown directly for energy or from plant parts, residues, processing wastes, and materials from animal and human activities. This makes biomass, a flexible and widespread resource that can be adapted locally to meet local needs and objectives. Every region has its own locally generated biomass feedstocks from agriculture, forest, and urban sources and most feedstocks can be made into liquid fuels, heat, electric power, and/or biobased products. In general, the classification of feedstocks may be based on categories of plants or residues and by the energy products they produce. Major energy crops available to fulfill the feedstock demand are Switchgrass, Miscanthus, high biomass or energy sorghum, as well as crop residues, such as rice straw, wheat straw, corn stover, corn cobs, etc. The second-generation (2G) of biofuels can be generated by using the nonfood parts of plants such cell walls, composed of structural polysaccharides, such as cellulose and hemicelluloses. This is considered to be advantageous over the first generation of biofuels as it has a higher energy production potential, lower cost, sustainable CO_2 balance, lack of competition with the food production and availability of a wide range of plant biomass sources at affordable costs to a biorefinery. In recent years, much emphasis is given to the production of ethanol from agricultural wastes/residues which contain cellulose (most abundant on earth) and hemicelluloses, the carbohydrates that can be converted to ethanol by fermentation. Cellulose has earlier been taken into account for chemical/biological saccharification and subsequent biological conversion of the monomeric sugars to ethanol. Advanced technologies based on cellulosic feedstocks are often seen as relevant technologies for the future as they are supposed to cause less competition with food products and emit safer levels of greenhouse gas emissions.

s0035 2.1 Sugar crops

p0040 These include sugarcane, energy cane, sugarbeet, sweet sorghum, high biomass sorghum, etc.

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s0040 2.1.1 Sugarcane

p0045 Sugarcane (*Saccharum* spp.) is the main feedstock for bioenergy production, especially in the tropical and subtropical regions of the world (Long et al., 2015). In addition, to its adaptability for use in sugar and ethanol production, sugarcane crop residues, such as straw and bagasse, have increasingly been used in electricity cogeneration during burning of residues in boilers and in the second-generation of ethanol production (Dias et al., 2011; Sordi and Manechini, 2013). Ethanol produced from sugarcane, is a renewable fuel derived from sugarcane that grows typically in tropical and subtropical climates. The harvested stalks are roughly 70% moisture and the dry matter is composed basically by sucrose and lignocellulose. Approximately, one-third of the total energy in the above-ground biomass of today's sugarcane cultivars, is captured as the sugars (mostly sucrose) fraction present in the stalk while another third is present in the fibrous sugarcane bagasse and the last third is the trash left in the field after harvesting. Both last fractions are essentially lignocellulosic materials. Compared to other types of ethanol available today, using sugarcane ethanol to power cars and trucks yields greater reductions in greenhouse gases. In 2010, the EPA designated Brazilian sugarcane ethanol as an advanced biofuel due to its 61% reduction of total life cycle greenhouse gas emissions, including direct indirect land use change emissions.

p0050 Countries like Brazil has replaced more than half of its fuel needs with sugarcane ethanol,—making ethanol the standard and gasoline as the alternative fuel.

s0045 2.1.2 Energy cane

p0055 Energy cane (Fig. 2) is an interspecific hybrid arising from backcrossing two species, *S. spontaneum* (high fiber content) and *S. officinarum* (high sugar content), thereby producing a plant with higher fiber and lower sugar content when compared to sugarcane (Matsuoka et al., 2014). Among all the dedicated bioenergy crops so far analyzed, existing sugarcane cultivars are outstanding in terms of annual, renewable productivity per unit area, in terms of either wet or dry matter and energy cane has the potential to produce two to three times more than this (Burner and Legendre, 2000). As productivity is the main driver for the sustainability of any energy biomass source (economic, environmental, social, etc.), energy cane has the potential to effectively contribute to the world demand of bioenergy. From energy cane, ethanol is not the only combustible liquid that can be produced; jet fuel, biobutanol, biodiesel, biogas, methanol, syngas, and others are all forms of fuel that could potentially be obtained from energy cane (Tao and Aden, 2009). The introduction of new advanced low-carbon technologies with the addition of sugars converted from cellulosic materials and the development of high-biomass sugarcane (energy cane) has opened a new agroindustrial path. In energy cane, the carbon partition is more oriented toward fiber production instead of soluble sugars accumulation, resulting in a biomass index greater than 300 ton ha^{-1} Greater growth seen in energy cane might be attributed to a vigorous rate of nocturnal growth with angulation in relation to the time of 11.89°, which is lower in sugarcane, with angulation of 5.47° (de Abreu et al., 2020). The perspective to improve the potential yield of bioethanol to almost 25,000 L per hectare is real (from 6900 today). In Brazil, some energy cane genotypes, such as VX12–1022 and VX12–0646 which have potential for greater dry biomass production than sugarcane in both the plant cane and first ratoon crop cycles have been identified (Boschiero et al., 2019). Considering a projected global consumption of gasoline of 1.7 trillion litters in 2025, energy

f0015 **FIG. 2** Energy cane (Diniz et al., 2019).

cane-based bioethanol would be able to replace 10% of total gasoline consumed in the world using less than 10 million hectares of land. Furthermore, the world would quickly experiment with expressive carbon dioxide CO_2 emissions reduction in the transport sector, responsible for one-quarter of the total CO_2 emissions (Center for strategic studies and management, 2017).

p0060 The joint Louisiana State University (LSU) and the Houma-USDA program succeeded in producing some energy cane cultivars like US79–1002 which recorded fiber percentage as high as 28% with exceptionally high productivity: five harvests from a single planting averaged 211 t ha^{-1} per harvest, with continual yield increase from plant cane to the fourth ratoon (total biomass, wet basis) against 58 t ha^{-1} for a conventional sugarcane cultivar (Giamalva et al., 1985). A steady linear increase in productivity from 182 t ha^{-1} in plant cane to 247 t ha^{-1} in the fifth ratoon of energy cane US79–1002 was observed by Bischoff et al., 2008. Averaged across the three crops and two locations, energy cane had significantly higher biomass yield, lower nonstructural carbohydrate (reducing sugars and sucrose) concentrations, and higher concentrations of cellulose, hemicelluloses, and lignin than sugarcane. Although there were no differences between sugarcane and energy cane in total carbohydrate concentration (839 to 842 g/kg DW), energy cane had 80% higher cellulose, 63% higher hemicelluloses, and 76% higher lignin; 69%, 64%, and 56% lower sucrose, glucose, and fructose concentrations, respectively, than sugarcane, when averaged across the three crops and two locations (Zhao et al., 2020).

s0050 2.1.3 Biomass sorghum

p0065 Sorghum is a short duration crop of about 3–4 months and produces higher biomass yield with less inputs. Energy sorghum, including biomass and sweet type varieties, has recently gained favor as bioethanol feedstock among numerous candidate crops (Rooney et al., 2007; Xie, 2012). Biomass sorghum does not produce grain until very late in the growing season. Instead, the plant puts all its energy in growing tall and can reach 4–5 m at the end of the growing season (Fig. 3). This sorghum type usually has more number of leaves, fibrous roots,

f0020 FIG. 3 Biomass sorghum in India.

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greater potential for vegetative growth, and is suitable for mechanization (Venuto and Kindiger, 2008). This form has long been used as forage, but it has recently attracted attention Q6 as a potential source of domestic, environmentally sustainable, renewable and affordable biofuel. Besides producing second-generation ethanol, biomass sorghum also releases energy during biomass combustion (da Silva et al., 2018). It is a good substitute to corn and sugarcane with additional benefit of less water consumption. It is an annual grass having higher dry matter yield like perennial crops but in less duration, thus facilitating cheaper crop rotation. The convertibility of high biomass lines of sorghum to bioethanol is of special interest as the use of sorghum biomass for biofuel production will not lead to food price increase. In some sorghum genotypes, proportion of cellulose can vary between 27% and 52%, while the range of hemicellulose content is 17%–23% and lignin content is 6.2%–8.1%. Along with the biomass yield, low lignin, high cellulose, and hemicellulose contents are also the desirable selection attributes for energy sorghum genotypes (Mahmood and Honermeier, 2012). The natural attributes like abiotic stress tolerance, diverse genetic base, viable seed industry, and sound breeding system make sorghum a perfect candidate for establishing an efficient and low-cost biofuel industry. The convertibility of high biomass lines of sorghum to bioethanol is of special interest as the use of sorghum biomass for biofuel production will not lead to food price increase. Dry biomass production of several potential bioenergy sorghum crops can be impressive: 18–32 $\mathrm{Mg\,ha^{-1}}$ for sweet sorghum, 16–24 $\mathrm{Mg\,ha^{-1}}$ for forage sorghum, and 32 $\mathrm{Mg\,ha^{-1}}$ for photoperiod-sensitive sorghum (Rooney et al., 2007). The potential exists to further develop sorghum as a bioenergy crop because it possesses an array of traits such as brown midrib, sweet stalks, staygreen, and high biomass that can be combined via plant breeding and genetic manipulation to maximize the conversion of biomass to ethanol (Vermerris et al., 2007). Total dry biomass yields in the energy sorghum hybrids EJ7281 and ES5200 were observed to be fluctuating between 22.2 and 37.5 $\mathrm{t\,ha^{-1}}$ (Bartzialis et al., 2020). In Northern China, the most productive sorghum biomass hybrid GN-4, exhibited biomass and theoretical ethanol yields >42.1 $\mathrm{t\,ha^{-1}}$ and 14,913 $\mathrm{L\,ha^{-1}}$, respectively (Tang et al., 2018). Bioethanol yields were estimated to be in the range of 223–506 L/ton in the sorghum straw dry matter in a study on Bioethanol Production from Biomass of Selected Sorghum Varieties Cultivated as Main and Second Crop is given in Table 2 (Batog et al., 2020).

p0070 In India, under a US-India Joint Clean Energy Research and Development Center project on Development of Sustainable Advanced Lignocellulosic Biofuel Systems, several high

t0015 **TABLE 2** Bioethanol yield from sorghum straw ($\mathrm{L\,Mg^{-1}}$ of straw DM).

	Year I	Year II	Year I	Year II	Year I	Year II
Variety	Crop					
	Main	Second	Main	Second	Main	Second
Rona 1	430	403	456	425	506	474
Santos	243	223	266	240	258	235
Sucrosorgo 506	413	365	484	428	451	397

Source: Batog, J., Frankowski, J., Wawro, A., Łacka, A., 2020. Bioethanol production from biomass of selected sorghum varieties cultivated as main and second crop. Energies 13, 6291. https://doi.org/10.3390/en13236291.

t0020 **TABLE 3** Structural carbohydrate content in high biomass sorghum variety ICSV 25333.

Treatment	Cellulose % (w/w)	Xylose	Arabinose	Total Sugars	Lignin	Ash	Total of components
Raw biomass (triplicate)	46.29	27.26	8.22	81.77	14.56	2.42	98.75
	45.19	28.01	7.99	81.19	14.77	2.88	98.84
	46.01	28.11	8.09	82.21	13.90	1.75	97.86
Acid treatment	57.39	17.99	2.21	77.59	8.01	3.17	98.77
Alkali treatment	74.26	20.58	–	94.84	2.15	0.75	97.74

Source: ICRISAT 2016.

biomass sorghum genotypes with a dry biomass of $>25\,t\,ha^{-1}$ were developed at ICAR-Indian Institute of Millets Research (ICAR-IIMR) and International Crops Research Institute for the Semiarid Tropics (ICRISAT). Further, a high biomass sorghum entry ICSV 25333, promising for biomass yields in multilocation trials across India was investigated for its structural carbohydrate content (Table 3) and ethanol production potential which was 288 L/ton when C5 and C6 sugars were fermented together.

s0055 ### 2.1.4 *Brown midrib sorghum*

p0075 The major impediment of converting biomass to biofuels is high pretreatment costs for removal of lignin besides high cost of enzymes used for saccharification. An advantageous feature of sorghum, which has been exploited worldwide for bioenergy, is the presence of brown midrib (*bmr*) mutations that can reduce lignin content. Lowered lignin has been shown to increase the conversion efficiency of biomass into ethanol. In an 11-year long-term Biomass and Potential Ethanol Yields study of Annual and Perennial Biofuel Crops, Roozeboom et al., (2018) reported $15.1\,t\,ha^{-1}$ dry biomass yields and $4.7\,m^3/ha$ estimated total ethanol yields for BMR sorghum. Rivera-Burgos et al. (2019) reported a theoretical ethanol yield of 383 L/ton of dry biomass from brown midrib sorghum for control variety Atlas bmr and 403 L/ton for "brown-sweet" double mutant RIL group. In India, ICAR-IIMR has been in the forefront in development of feedstocks for lignocellulosic biofuel development. During 2019, CSV 43 BMR, which is India's first public sector bred brown midrib-low lignin sorghum variety with $16\,t\,ha^{-1}$ of dry biomass has been released from this institute for commercial cultivation. This line offers promise as a lignocellulosic biofuel feedstock for second-generation biofuel production because of the higher yield of fermentable sugars during pretreatment and enzymatic saccharification owing to its low lignin content.

s0060 ## 2.2 Energy crops

p0080 Dedicated energy crops include herbaceous plant species like miscanthus (*Miscanthus* spec.), switchgrass (*Panicum virgatum*), Johnson grass (*Sorghum halepense*) and other fast-growing woody plant species like willow (*Salix* spec.), poplar (*Populus* spec.), eucalyptus (*Eucalyptus* spec.). A steady supply of uniform and consistent-quality biomass feedstock is necessary for large-scale viability of cellulosic ethanol production. Feedstocks for lignocellulosic biofuels can be divided into two main categories: dedicated energy crops and residues. The potential of dedicated energy crops to increase farm profits and/or decrease the variability of profits will largely dictate the extent to which farmers will plant dedicated energy crops.

s0065 ### 2.2.1 *Switchgrass*

p0085 Switchgrass is currently at the center of considerable attention and research. Switchgrass (*Panicum virgatum* L.) is a perennial plant native to North America that is well adapted to marginally productive croplands. Switchgrass has excellent potential as a bioenergy feedstock for cellulosic ethanol production, for heat and electricity production through direct combustion, gasification, and pyrolysis. It has consistently high yields relative to other species in varied environments and it requires minimal agricultural inputs. It is relatively easy to establish from seed, and a seed industry already exists (McLaughlin and Kszos, 2005; Sanderson et al., 2007). Switchgrass grows 3–10 ft tall, typically as a bunchgrass, but the short rhizomes can form a sod over time. In addition to potential bioenergy production, switchgrass finds it utility in soil and water conservation, carbon sequestration, and wildlife habitat. In the first year after seeding, it is common for fields to produce 75%–100% of potential yield, producing 8–13 Mg ha^{-1} on a dry matter (DM) basis (Mitchell et al., 2010). Switchgrass yields in Saunders County Nebraska ranged from 11.2 to 16.8 DM Mg ha^{-1}, with potential ethanol yields of 3740–5620 L ha^{-1} (Mitchell et al., 2012). In an 11-year long-term Biomass and Potential Ethanol Yields study of Annual and Perennial Biofuel Crops, Roozeboom et al. (2018) reported 11.3 t ha^{-1} dry biomass yields and 3.8 m^3/ha estimated total ethanol yields for Switchgrass. Average greenhouse gas (GHG) emissions from switchgrass-based ethanol were 94% lower than estimated GHG emissions for gasoline (Schmer et al., 2008).

s0070 ### 2.2.2 *Miscanthus*

p0090 Giant miscanthus (*Miscanthus x giganteus Greef* et Deu.) is a perennial, warm-season Asian grass with the C4 photosynthetic pathway. It is a cold-tolerant and capable of high biomass yields at cool temperatures. Further, it tolerates marginal lands and some flooding. It has been extensively studied in the European Union and is now used commercially there for bedding, heat, and electricity generation. Its production currently occurs in Europe apart from the USA. Recently, Japan and China have taken renewed interest in this native species and started multiple research and commercialization projects. In the United States, it is also a leading feedstock for cellulosic ethanol. It is more amenable to thermochemical conversion to biofuel than biochemical conversion, with good potential for the heat and power as well as animal bedding industries. Miscanthus Giganteus is distinguished from other biomass crops by its high yields, particularly at cool temperatures, which can be more than double those typical of switchgrass. Harvestable yields for the standard $M \times g$ range from 10 to 30 Mg DM ha^{-1} depending on location and interannual weather variations during the growing season (Kalinina et al., 2017). Heaton et al., 2008 reported *M.* × *giganteus* peak dry biomass yields of 60.8 Mg ha^{-1} in a single site-year in central Illinois, USA, and a 3-year average of 38.2 Mg ha^{-1} over three locations in the state. The ranges for hemicellulose (295–303 g/kg), cellulose (446–458 g/kg) and lignin (70–80 g/kg) were reported by Battaglia et al., 2019. Fermentation of hydrolyzed Miscanthus using *Saccharomyces cerevisiae* resulted in an ethanol concentration of 59.20 g/L at 20% pretreated biomass loading (Han et al., 2011). In response to biomass production, total ethanol production was greater for miscanthus than for switchgrass—5594 vs 3699 L ha^{-1} (Scagline-Mellor et al., 2018).

s0075 **2.2.3 Hybrid poplar**

p0095 Hybrid poplars (*Populus* spp.) are among the fastest-growing trees in North America and are well suited for a variety of applications such as biofuels production, pulp and paper and other biobased products, such as chemicals and adhesives. Poplars are popular trees for landscape and agriculture use worldwide. They are known as "the trees of the people" (Gordon, 2001) and are considered one of the most important families of woody plants for human use. Poplars are more desirable for biofuels than many other woody crops because of their fast growth, their ability to produce a significant amount of biomass in a short period of time, and their high cellulose and low lignin contents. Yields of first-generation hybrid poplar planted on croplands in the Lake States of the USA have been estimated to be in the range of 7.9–11.8 dry Mg ha^{-1} $year^{-1}$. Poplar species and hybrids have cellulose contents ranging from ~42% to 49%, hemicellulose from 16% to 23%, and total lignin contents from 21% to 29%. The cellulose content of poplar is higher than that of switchgrass and corn stover and comparable to other hardwood feedstock such as eucalyptus, making it a desirable feedstock for the production of ethanol (Sannigrahi et al., 2010).

s0080 **2.2.4 Bamboo**

p0100 Bamboo is distributed in the tropics and subtropics and is the most widely utilized flowering perennials of the Poaceae family, with nearly 1500 species under 87 genera (Ohrnberger, 1999). The strong and flexible woody stem of bamboo is also used as a construction material and is frequently called "timber of the poor." In recent years, modern technology has expanded the use of bamboo beyond the traditional uses and currently, it can be utilized in many ways; in fact, it has more than 1500 applications (Lobovikov et al., 2007). Bamboo stands are dense and productive, with an average above ground net biomass production in the order of 10–20 t ha^{-1}/year (Scurlock, 2000). Due to their high growth rate which has been reported to be the highest on the planet, reaching 120 cm in 24 h, there is a fast turnover of harvest and regrowth from the same stand without damage to the plant (Tripathi and Khawlhring, 2010). The entire plant, of which includes the stem, branch and its rhizome, can be used to produce biofuel in the form of charcoal and briquette. Due to its fuel characteristics, high productivity, and short rotation, bamboo is now being explored as a potential feedstock to generate electricity through power plants and biofuels to substitute fossil fuels (Singh et al., 2017). Compared to other feedstocks, bamboo biomass has a relatively high cellulose and low lignin content which makes it suitable for bioethanol production. The chemical composition of bamboos have been reported to contain approximately 40%–48% cellulose, 24%–28% hemicellulose and 20%–26% lignin (as a percentage of dry matter), suggesting that with the appropriate technology there is an abundant pool of cell wall sugars available for bioethanol production (Yamashita et al., 2010). Sadiku et al., 2016 reported that the chemical composition of *Bamboo vulgaris* was in the range of 4%–7% for extractives, 61%–78% for cellulose, and 39%–46% for the lignin. *Bambusa emiensis* and *Phyllostachyus pubescens* are the two bamboo species that are potentially suitable to be used as a fuel in biomass fired combustion (Engler et al., 2012). As with other bioenergy crops, energy can be recovered from bamboo biomass in three main ways: thermal, thermochemical, and biochemical conversion (Sharma et al., 2018). Direct combustion in power plants is the cheapest and most reliable route to producing power from biomass in standalone applications (IEA Bioenergy, 2009). Solid fuels (charcoals), liquid fuels, and gas (syngas) can be produced from bamboo biomass through pyrolysis. The liquid fuels or pyrolysis fuels can be processed in a biorefinery to produce biofuels. Biomass can be transformed into biogas or biofuels through biochemical conversion (Sharma et al., 2018). India is the second largest producer of bamboo in the world with an annual production of about 32 million tons. About 5.4 million tons of bamboo residues are generated in the country every year by the bamboo processing industries of which about 3.3 million tons remains as surplus. Dilute alkali pretreatment of the biomass resulted in efficient removal of lignin, effectively increasing the concentration of cellulose to 63.1% from 46.7% (Table 4) (Kuttiraja et al., 2013). Enzymatic saccharification and direct fermentation of the enzymatic hydrolysate of pretreated bamboo biomass has the potential to generate 143 L of ethanol per dry ton of bamboo process waste (Kuttiraja et al., 2013). In India, the eight states that lie at the foot of the Himalayas together make up about two-thirds of India's total bamboo production. Apart from keeping up with the country's surging demand for fuel, the Indian government is also trying to fulfill its pledge to meet a 10% reduction in the nation's energy imports by 2022. As a result, the biofuels industry is set to explode into a $15 billion market by 2020 with government backing. Indian oil companies are investing in biofuel refineries to boost ethanol production from nonmolasses sources. A $200 million joint venture between Numaligarh Refinery Ltd. and Finnish technology firm Chempolis Oy will crush bamboo, the longest of the grass family, to produce 60 million liters of ethanol every year in the tea producing state of Assam. This refinery is planning to use 5 lakh MT bamboo as raw material annually to produce 49,000 MT ethanol per annum as the main product. The major bioproducts from this plant will include acetic acid and furfural besides the production of biodegradable plastic out of furfural in collaboration with IIT Guwahati. The plant is scheduled to be commissioned by December 2021. That's enough to meet mandatory requirements for blending with gasoline in the entire northeastern region. This Bio Refinery has selected the National Small Industries Corporation (NSIC) to facilitate the supply of bamboo from farmers to different chipping centers around the Northeast states of Assam, Arunachal Pradesh, Nagaland and Meghalaya. NSIC will be responsible for developing the entrepreneurs that will be at the heart of the supply chain. More than 6000 direct and indirect jobs are expected to be created by 2021 with that increasing to more than 15,000 by 2026.

t0025 **TABLE 4** Biochemical composition of native and pretreated bamboo biomass.

Parameter	Native biomass	Alkali pretreated biomass
Cellulose (%)	46.68 ± 0.03	63.11
Hemicellulose (%)	16.43 ± 0.29	14.19
Lignin (%)	17.66 ± 0.39	5.25
Water and ethanol extractives and others (%)	19.17 ± 1.17	16.75

Source: Kuttiraja, M., Sindhu, R., Varghese, P.E., Sandhya, S.V., Binod, P., Vani, S., Ashok Pandey., Rajeev, K.S., 2013. Bioethanol production from bamboo (Dendrocalamus sp.) process waste. Biomass Bioenergy 59, 142–150.

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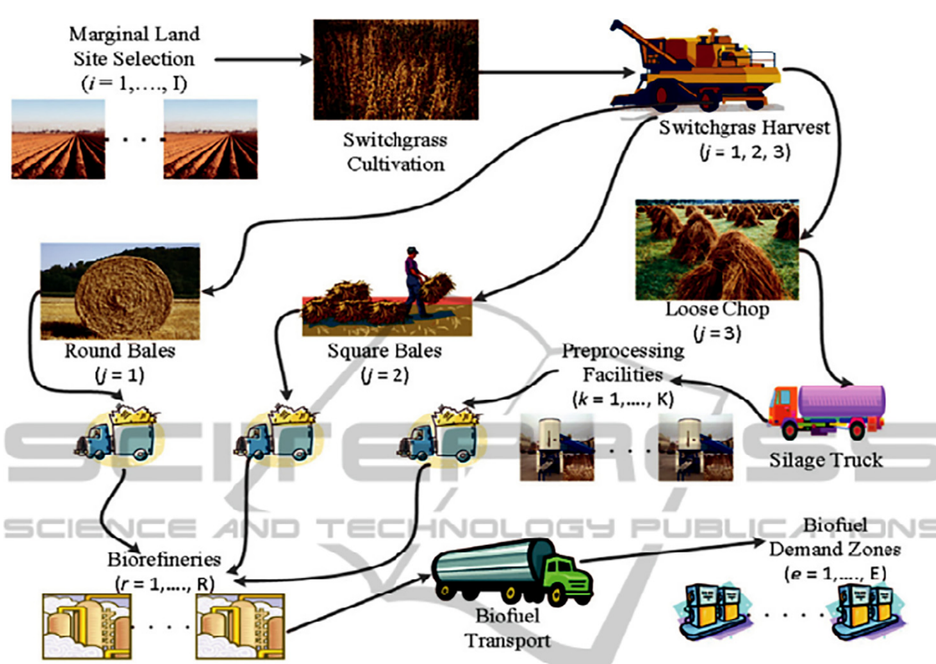
s0085 2.3 Agricultural residues

p0105 Agricultural crop residues are the carbon-based materials that are generated as a byproduct during the harvesting and processing of crops. The residues produced during harvest are field-based or primary residues while the residues produced during processing are secondary residues or agro-industrial residues. The most common residues include rice straw, wheat straw, barley straw, corn stover, corn cobs, cotton stalks, etc. Because of their immediate availability, agricultural residues are expected to play a key role in the development of the cellulosic ethanol or advanced biofuels industry. In general, the residues are utilized in several ways, as a source of fodder, for preventing soil erosion, as a fertilizer, etc. However, almost half of these resources are burnt on the farm itself before the planting of the next season crop. It is estimated that roughly one ton of residue is produced for every ton of grain harvested (Virmond et al., 2013). Cereal straw may represent an ideal resource for biofuel production, as it is a co-product of food production, and thus, its production does not compete with food generation (Townsend et al., 2017). India has enormous potential in the production of biofuels from crop residues (Fig. 4) whose use varies by region and depends on various factors viz., nutritive value, calorific values, lignin content, density etc. While a lot of cereals and pulses have fodder value, the woody nature of rice straw, rice husk, corn stover, corn cobs, cotton stalks etc. makes them a natural choice to be used as feedstock in the production of biofuels. According to a recent study "Availability of Indian Biomass Resources for Exploitation" jointly by Technology Information Forecasting and Assessment Council



Q2 f0025 **FIG. 4** Gross Residue Available from Crop Production in India (Purohit and Dhar, 2015).

(TIFAC) and CSIR – National Institute for Interdisciplinary Science and Technology (NIIST), Sugarcane tops is the most surplus residue in India which is usually burnt in the fields itself. Other crops like cotton, chili, pulses and oilseeds generate surplus as they do not have any other use apart from being used as fuel. The agri. residues are usually burnt in the fields or used to meet household energy needs of the farmers. A potential of 61.1 MMT of fuel crop residue and 241.7 MMT of fodder crop residue are being consumed at farmer level and this can be freed on provision of alternatives to the farmers. The estimated total amount of residues used as fodder was 360 Mt in 2010–11 (Purohit and Fischer, 2014). This accounts for approximately 53% of total residue (Purohit and Dhar, 2015). Agricultural residues available for energy applications were estimated at 150 Mt in 2010–11 (Purohit and Fischer, 2014). The Biomass Atlas of India-BRAI 2015 estimates that an additional 104 Mt of biomass is available in India in forest and wastelands that can be converted into biofuels. Under the assumption that 20% of agricultural residue is lost in collection, transportation and storage and that ethanol yields of 214 L/ton dry matter for cellulosic-ethanol, 130 Mt of residue could be used to produce approximately 28 BL of ethanol annually.

s0090 2.3.1 *Rice straw*

p0110 Rice straw is one of the most potential lignocellulose sources for producing bioethanol because of its surplus availability around the globe. It is a major food crop around world with enormous biomass residues, and it is also a silica-rich C3 crop grown in wetlands. The world's rice area touched 162 million hectares with a record production of 755 million tons (FAOSTAT, 2019) which is distributed in Africa, Asia, Europe, and America. This generates approximately 1132 million tons of rice straw considering the fact that approximately 1.5 tons of rice straw is generated per ton of rice (Satlewal et al., 2018). About 50% of rice straw is burnt in the field while the remaining is utilized as fodder or used in the wood composite industry or left, as such, to decompose in landfills. Kim and Dale (2004) reported that 667.59 million tons rice straw were produced in Asia, and Binod et al. (2010) calculated that this could theoretically be converted into 281.72 billion liters of ethanol. In India, agricultural residues, including wheat and rice straw, are featured as feedstocks for producing biofuels in the National Policy on Biofuels 2018. Rice straw is a particularly attractive biofuel feedstock in northern states including Punjab, Haryana and Western Uttar Pradesh. For farmers, rice straw presence on a harvested field makes it difficult to sow the next crop, wheat. In India, 23% of rice straw residue produced is surplus and is either left in the field as uncollected or to a large extent open-field burnt to quickly get rid of the residues. Due to very small window (15–20 days) between rice harvest and wheat sowing in Punjab and unavailability/costly labor, high costs of renting machinery to mechanically harvest rice straw, farmers resort to burning of the straw. Inefficient burning of rice straw releases large amounts of harmful gases including carbon monoxide, polycyclic aromatic hydrocarbons, volatile organic compounds and nitrous oxides, along with suspended particulate matter. The solution to these problems is developing high-volume, value-added conversion technologies to harness the energy potential of surplus rice straw and also providing remunerative prices to the straw so that farmers can collect the straw and pay a higher wage to attract the needed labor during the short rice harvest time window. By doing so, tremendous waste of lignocellulosic biomass resource can be arrested.

s0095 **Structural constituents**

p0115 Rice straw predominantly contains cellulose 32%–47%, hemicelluloses 19%–27%, lignin 5%–24% and ashes 18.8% (Belal, 2013). Rice straw mainly composes of hexoses (i.e., glucose, galactose, mannose), hemicelluloses (i.e., xylose, arabinose), lignin (both acid soluble and insoluble), ash, silica and extractives (Table 5) (Satlewal et al., 2018). Extractives (nonstructural components) are mainly composed of proteins (about 3%) and pectins (about 2.8%) along with minor amounts of free sugars, chlorophyll, fats, oils and waxes. The presence of silica in general had a positive correlation with the amount of cellulose, hemicellulose and lignin in the cell walls of rice plants and increases the biomass formation of rice. The ash content has a proportion of up to 20% of the total biomass in rice straw (Zhang et al., 2015). In one recent study (Narra et al., 2015), ethanol produced from rice and wheat straw has been compared under same pretreatment and simultaneous saccharification and fermentation conditions and It showed that relatively high ethanol concentration was produced with rice straw (55.49 g/L) in comparison of wheat straw (38.19 g/L). These studies suggested that rice straw produced high bioethanol yield in comparison of wheat straw. For rice straw, pretreating at severities of between 3.65 and 4.25 would give a glucose yield of between 37.5 and 40% (w/DW, dry weight of the substrate) close to the theoretical yield of 44.1% w/DW, and an insignificant yield of total inhibitors. At a pretreatment severity of 3.65, twice as much ethanol was produced from rice straw (14.22% dry weight of substrate) compared with the yield from rice husk (7.55% dry weight of substrate) (Wu et al., 2018).

s0100 2.3.2 *Wheat straw*

p0120 Wheat straw is also a potential feedstock for ethanol production. European Union, China, India, USA, and Canada are the leading wheat cultivating countries in the world. Considering a ratio of 1.3 residue and crop, about 850 million metric tons wheat straw produced annually worldwide can be considered as a huge agricultural reside. As per the report from Otero et al. (2007) surplus wheat straw is able to produce 120 billion liters bioethanol annually, which can replace 93 billion liters gasoline. For wheat straw, about 400 million tons may be globally

t0030 **TABLE 5** Chemical composition of rice straw.

Component	Quantity (weight %)
Glucose	34.0–43.7
Xylose	19.0–22.0
Arabinose	2.0–3.6
Mannose	1.8–2.0
Galactose	0.4
Acid soluble lignin	2.2–6.0
Acid insoluble lignin	13.0–22.7
Ash and silica	7.8–20.3

Source: Satlewal, A., Agrawal, R., Bhagia, S., Das, P., Ragauskas, A.J., 2018. Rice straw as a feedstock for biofuels: availability, recalcitrance, and chemical properties. Biofuels Bioprod. Biorefin. 12 (1), 83–107.

available for biofuel production (Tishler et al., 2015). In some studies, cellulose contents of wheat straw were found to reach almost 50% (Brandenburg et al., 2018). Wheat straw is also composed of cellulose, hemicellulose, and lignin in the range of 33%–40%, 20%–25%, and 15%–20% (w/w), respectively. Ash content in the wheat straw is almost three to four times lower than rice straw, which makes this substrate most suitable for the bioethanol production compared to rice straw (Prasad et al., 2007).

s0105 ### 2.3.3 Corn stover

p0125 Corn stover, i.e., leaves, stalks and bare cobs from maize plants, is the most abundant straw generated in the USA (Panoutsou et al., 2017). Stover yields are generally closely related to grain yields. Since the ratio of grain to total plant biomass (harvest index) is usually near 0.50, the mass ratio of grain to stover in corn is close to 1:1 (Graham et al., 2007) and thus potential stover ethanol yield on a land area basis would be expected to have a direct correlation with grain yield. The upper part of the corn plant is generally less lignified and more digestible than the lower portion of the plant. As such, it is a more desirable fraction for cellulosic ethanol. In a comparative study of ethanol production using dilute acid (DA), ionic liquid (il) and AFEX™ pretreated corn stover, the ethanol yields calculated for DA, IL and AFEX pretreated residual solids were 14, 21.2 and 20.5 kg of ethanol per 100 kg of corn stover, respectively (Uppugundla et al., 2014). Corn cobs are currently being used for heat in some parts of Europe, while in the United States, this feedstock is rapidly being developed as a feedstock for cellulosic ethanol, co-firing, and gasification projects.

s0110 ### 2.3.4 Cotton stalks

p0130 Cotton stalks are the residues left in the field following harvest which are usually buried or burnt to prevent pest build up. It is a potential raw material for conversion to ethanol because it is rich in cellulose (32%–46%) and hemicellulose (20%–28%) (Wang et al., 2016). Bioethanol from cotton stalk was produced utilizing two-stage dilute acid hydrolysis and fermentation of detoxified hydrolysate (Keshav et al., 2016). Highest ethanol concentration of 22.93 ± 1.74 g/L with 0.36 g/g ethanol yield was achieved after 48 h of incubation (Shahzad et al., 2019). To effectively utilize cotton stalk as a feedstock for ethanol production, alkaline pretreatment would be more effective (Silverstein et al., 2007).

s0115 ### 2.3.5 Sugarcane bagasse

p0135 Using sugarcane bagasse as a feedstock for second-generation biofuels would lead to doubling the current output of biofuel production. To maximize the conversion efficiency of sugarcane biomass to biofuels, it is imperative to have sugarcane genotypes with improved total biomass: more cellulose and less lignin, resulting in less enzymatic recalcitrance and better saccharification yield. Dual purpose energy canes with more than 20% fiber and 15% brix can be used for both energy and alcohol production. Considerable technical progress has been made in the production of 2G ethanol and scaling up to commercial scales is underway but no industrial plant has operated yet at full capacity. Energy balance and overall costs need to be improved. Integration of second-generation (2G) with 1G ethanol production provides an option for fully renewable production of energy without the use of fossil fuels for thermal processes and electricity in the conversion process (Center for strategic studies and management, 2017).

s0120

3 Biomass availability

p0140 Biomass availability depends on several factors such as location, availability of land vis a vis competing land uses, competing uses of agricultural residues, market demand, sustainability requirements and policy interventions. These factors have made few states leading in terms of biomass power projects viz. Maharashtra, Uttar Pradesh and Karnataka, each having more than 1 GW of grid interacted biomass power. Other states with favorable policy and opportunities in Biomass are Punjab and Bihar.

s0125

4 Biomass supply chain structure and characteristics

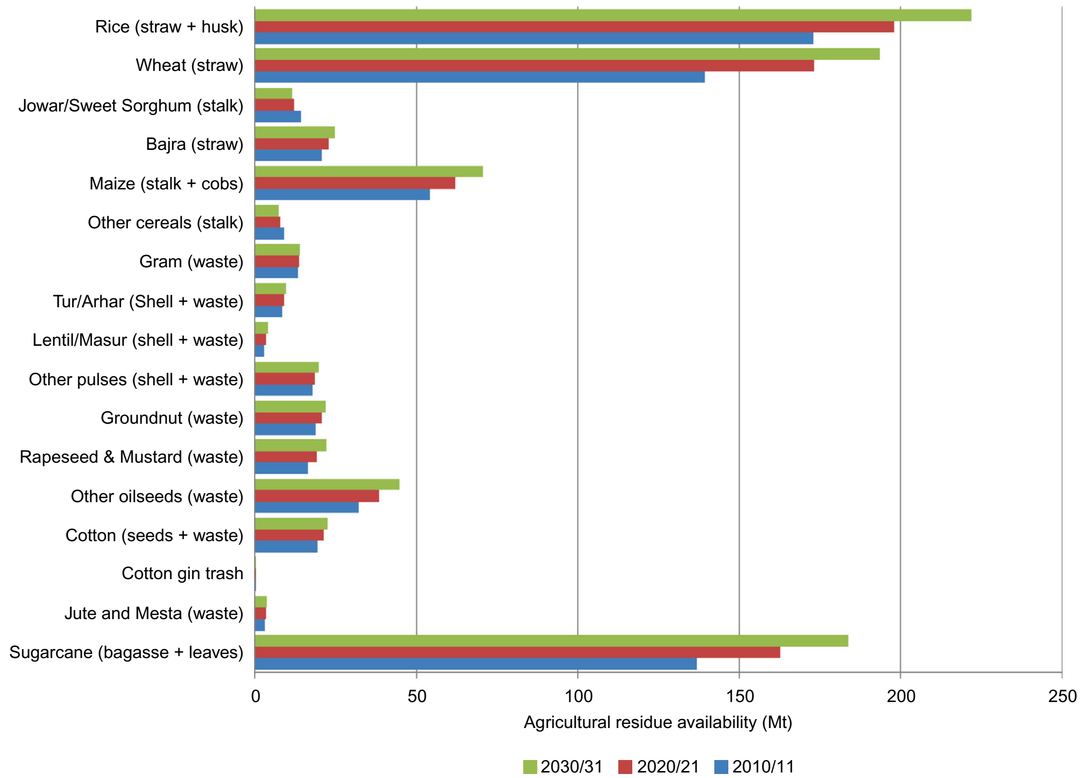
p0145 The biomass supply chain incorporates several components of bioenergy production, which in turn consist of several activities. To obtain the critical mass of biomass residues needed for sufficient energy production, multiple suppliers are often involved in the biomass residues supply chain. This supply chain, also known as the Biomass supply chain, is composed of four main components, including (i) Biomass harvesting/collection (from single or several locations) and Preprocessing/pretreatment; (ii) storage (in one or more intermediate locations), (iii) transport (using a single or multiple levels) and (iv) final conversion in the biorefineries, as shown in Fig. 5 (Zhang et al., 2013). The biomass-to-energy supply chain can be classified into three parts: upstream, midstream and downstream (An et al., 2011), which is similar to the division made by Sandersson (1999) who identifies upstream supply, conversion and downstream provision. Upstream, is viewed as the part that supplies biomass to energy production. Midstream refers to energy conversion in power plants and downstream refers to energy distribution to consumers of energy. The single largest limiting factor for the production of bioenergy is the unavailability of biomass. The structure of the global market for biomass and the associated supply chains is evolving quite dynamically. Traditionally, biomass has been used for energy (mainly thermal) production in areas close to its production sites. However, an emerging practice for energy producers is to procure biomass from several suppliers in order to develop the critical mass necessary for the justification of an energy production facility.

s0130 4.1 Feedstock supply and logistics

p0150 This is one of the key components of a supply chain which provides the biorefineries with diverse feedstocks which are infrastructure-compatible and stable. For biomass feedstocks, emphasis would be on development of supply chain for economical and time-sensitive collection, pretreatment, storage, and transport.

s0135 *4.1.1 Seasonal availability*

p0155 Agricultural biomass types are usually characterized by seasonal availability, thus becoming a critical challenge in the operation of biofuel supply chain and dictating the need of storing large amounts of biomass for lengthy time periods increasing the operational costs of the biorefinery. In India, rainy season rice and maize are harvested during Sep-Oct, while wheat which is grown during the winter season is harvested during April where the residues would be available. The corn stover in the U.S. Corn Belt is mainly harvested from September



f0030 **FIG. 5** Example of supply chain to produce bioethanol from switchgrass (Zhang et al., 2013).

through November. The analysis of a database of switchgrass biomass productivity studies showed that single harvest systems were the most practical and economically feasible for bioenergy systems and it should be harvested once in the fall, after killing frost, for biofuel production (Wullschleger et al., 2010). Wood residues are less seasonal unlike crop residues. Meticulous planning of the harvesting and scheduling of the biomass is needed for ensuring an uninterrupted supply to the industry. Perishability of the biomass products increases the complexity of biomass supply chains affecting the transportation and length of storage time. The greatest operational challenge is to manage the biomass storage to ensure an uninterrupted supply to the biorefineries. Biomass Supply Chains need to be robust with inbuilt flexibility to adapt to unforeseen market volatility, as the demand of the produced energy depends on the price of competitive fuel substitutes.

s0140

5 Exploring nuisances of sustainable biomass supply

p0160 The establishment of sustainable bioenergy supply chains would have to be remuneratively attractive to a wide range of stakeholders in the long term. Equitable and sensitive distribution of economical gains in different strata of the value chain would increase its social acceptance among communities. Lastly, the supply chain must be sensitive to specific

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ecosystem services pertaining to the area. Centre for Economic and Social Studies (CESS), Hyderabad, India conducted an empirical analysis of High Biomass Varieties (HBV) promoted by ICRISAT and ICAR-IIMR in the farmers' fields at different locations of Indore and Gwalior region of Madhya Pradesh, India with the assistance of scientists of Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya (RVSKVV), Gwalior, India to elucidate these aspects. These HBV varieties were meant for use as feed stocks for biofuel production. Surveys undertaken by CESS tried to address the suitability of HBVs of sorghum and pearl millet feedstocks with regard to crop economics, socioeconomic dynamics, potential upscaling, issues with regard to use of wasteland, and finally the carbon neutrality. Farmers of Gwalior, Khargone, Dewas and Morena districts, who had taken up the varieties for high biomass production developed by ICRISAT and ICAR-IIMR in their lands (part of MLT) were surveyed during 2014–15 *kharif*. Focused group discussions (FGD) have also been conducted by CESS team in Gwalior and Indore region with MLT farmers during the years 2015 and 2016. Major finding of the 2014 *kharif* trials was that the average income collectively from both grain and fodder yield was relatively lower for the new variety than compared to the ones being cultivated in the previous year. The HBV sorghum grain yield (2015–16 *kharif*) in Nagzari was less due to less rains and some of it was eaten by birds and the fodder yield too was less. The reason for high HBV sorghum yield (*kharif* 2015–16) in Nagdha are fertile soils and one supplemental irrigation in September month (in the event of no rains). As grain yield was high, there was a reduction in fodder yield. The reason for less HBV sorghum yields in Palnagar is due to excess rains and failure of seed to germinate and the farmers had to go for second sowing which led to delay in sowing period and eventual low yields. In Nahardonki HBV crop height was very good but no grains were harvested due to multiple cuttings for fodder purpose. In Bijoli (Gwalior region) during 2015–16 *kharif*, there was very less rain and it was almost like a drought and hence low yields in HBV sorghum. However Hybrids and Traditional sorghum varieties did reasonably well (Table 6). In Palnagar and Bijoli, HBV sorghum yielded a fodder

t0035 **TABLE 6** Sorghum and pearl millet crops and their year-wise grain and fodder yeilds.

Region	Year	Village	Crop	Variety	Avg. grain yeild in Q/acre	Avg.grain value in Rs./Q	Dry fodder yeild in kgs/acre	Value of fodder in Rs./kg
Indore	2015–16	Nagzari	Sorghum	Existing varieties (Hybrids)	10–12	1300–1500	1600–2000	2
	2015–16		Pearl millet	Existing varieties	4	1300–1400	700–800	2–2.5
	2014–15		Sorghum	HBV	4.5 to 5	Consumed	400	–
	2015–16		Sorghum	HBV	1	Consumed	350	–
	2015–16	Nagdha	Sorghum	Existing varieties (hybrids)	14	1200–1300	1000–1250	2
			Sorghum	HBV	14	Consumed	1000	2
	2015–16	Palnagar	Sorghum	HBV	1–1.4	Consumed	2800	2

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TABLE 6 Sorghum and pearl millet crops and their year-wise grain and fodder yeilds—cont'd

Region	Year	Village	Crop	Variety	Avg. grain yeild in Q/acre	Avg.grain value in Rs./Q	Dry fodder yield in kgs/acre	Value of fodder in Rs./kg
Gwalior	2015–16	Nahardonki	Pearl millet	HBV	Nil	–	6000	Own use
			Pearl millet	Existing varieties (mostly hybrids)	12	1200	2000	5
	2014–15		Pearl millet	Existing varieties	12	900–1000	1000	3
	2013–14		Pearl millet	Existing varieties	12	1100	1000	2
	2015–16	Bijoli	Sorghum	Hybrids	12	1000–1200	1600–2000	1
				Peeli sorghum	8	2000–2500	3200	1.5–2
				Desi safed sorghum	8	4500	3200	1.5–2
				HBV	4	Consumed	3200–4000	1.8–2
			Pearl millet	Existing varieties	8–10	–	1600–2000	1
Baseline Survey	2013–14	Average of all villages	Sorghum	Traditional sorghum	12.06	–	950	1.5–2
				Hybrid sorghum	11.41	–	890	1–1.5
		Average of all villages	Pearl millet	Traditional pearl millet	10.50	–	1000	1.5–2.0
				Hybrid	22		925	1–1.25

Source: FGD with sampled farmers of Indore and Gwalior region during 2014–15 and 2015–16 and Baseline survey of 2013–14.

quantity of around 3000 kgs. In Nahardonki village of Morena District (Gwalior region), despite zero grain yield in HBV Pearl millet crop, the fodder yield was highest with 6000 kgs/acre. The value of sorghum dry fodder changed from village to village. However, it generally ranged between 1 and 2 rupees/kg. In the case of pearl millet crop fodder, there was wide range during 2015–16 *kharif* as it varied between Rs. 1 per kg in Bijoli to Rs. 5/kg in Nahardonki of Gwalior region. The cost of fodder has implications for biofuel production as it is this material that is used a raw material. The lower the fodder price the more economical will be the biofuel production from these crops. From last 2 years, there is huge increase in market price of *safed* sorghum (traditional variety of the region) due to its utility for some industrial purpose. Hence, farmers are increasing the area under this crop in Gwalior region and there is a growing demand for the seed of this crop. In the case of both pearl millet and sorghum crops, with regards to overall per acre income, existing varieties were doing slightly better than ICMV 05777 and ICSSH-28 respectively and far better than other HBV varieties used in MLTs in farmers field during *kharif* 2015–16 (Tables 7 and 8). When it comes to biomass yield, 2015-ICFPM-1 of pearl millet crop and ICSSH-28 and ICSV 93046 were performing much better than existing varieties in 2015–16 *kharif*. In a base line survey done by CESS, Hyderabad in 2012–13 on impact of promoting food crops for biofuel cultivation, it was found that 38.44% of the households agreed that it will result in shortage of food grains while 61.56% did not perceive a reduction in the food supply. Majority of the respondents felt that there would not be any impact on food security, citing the reason that they would supplement sorghum/pearl millet either by procuring from fair price shops or from retail markets. Out of the 128 households which felt that there will be a reduction in food grains, 66.40% felt that such reduction in grains will impact the household food security, while 33.60% did not agree. The development of biofuels to meet the requirements of the transport sector can bring about changes in the land use pattern of the country and could threaten food security and other agrarian supplies. The potential diversion or displacement of food crops is also considered to be a serious problem for livestock sector. Though the analysis of CESS study shows that the impact might not be much regarding food grain security, there is a considerable amount of apprehension on its potential impact on fodder security. It is evident that even before the cultivation of these crops for biofuels production, a majority of the households

t0040 **TABLE 7** Details of grain and fodder yields of high biomass varieties vis-à-vis existing varieties during the year 2015–16 Kharif.

	Pearl millet						**Sorghum**		
Particulars	**2015-ICFPM-7**	**2015-ICFPM-1**	**ICMV 05222**	**ICMV 05777**	**IP 6107**	**Existing varieties**	**ICSSH 28**	**ICSV 93046**	**Existing varieties**
Grain yield in Qtls	4.00	–	4.66	6.66	4.00	12	7.82	–	10
Fodder yield in kgs	1260	3000	1740	1460	1410	2000	2924	2550	2000
Fodder income in Rs.	3150	7500	4350	3650	3525	6000	5263	4590	3000
Grain value in Rs.	4800	–	5592	7992	4800	14,440	9384	–	12,000
Cost of cultivation in Rs.	1180	1610	2095	1816	1498	10,000	6046	1986	6000
Gross income in Rs.	7950	7500	9942	11,642	8325	20,400	14,647	4590	15,000
Net income in Rs.	6770	5890	7847	9826	6827	10,400	8601	2604	9000

Source: Field survey 2016.

t0045 **TABLE 8** Village-wise response of farmers regarding the impact of use of sorghum/pearl millet for biofuel production on fodder security in Madhya Pradesh.

Village name	Yes	No	Total
Nagada	47.06 (8)	52.94(9)	100.0(17)
Chinvani	55.6(10)	44.4(8)	100.0(18)
Nagaziri	61.1(33)	38.9(21)	100.0(54)
Rupkheda	46.7(7)	53.3(8)	100.0(15)
Baraha	37.03(20)	62.96(34)	100.0(54)
Bijoli	31.8(7)	68.2(15)	100.0(22)
Dahel	52.9(9)	47.1(8)	100.0(17)
Jakara	19.2(10)	80.8(42)	100.0(52)
Nahar Donki	100.0(22)	0.0(0)	100.0(22)
Ummed Garh	75.8(47)	24.2(15)	100.0(62)
Total	51.96(173)	48.04(160)	100.0(333)

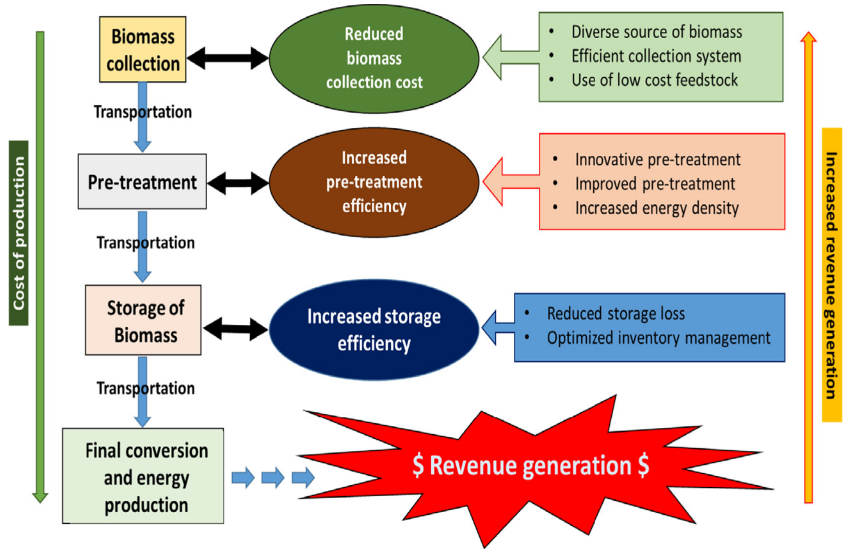
Source: Field survey.

(51.96%) believe that the use of these crops will affect the fodder security of their animals. On the other hand, 48.04% of the sample households perceived that there won't be any impact on fodder security. It was very interesting to see that across all study villages of the five districts, there were a few households that did perceive that there would be fodder insecurity in the event of cultivation of these crops for biofuels production. A further investigation was conducted to understand whether the diversion of fodder/biomass for biofuel production will affect the milk economy of the region. Nearly 33.9% of the samples households perceived that it will affect the milk economy, whereas 66.1% responded negatively.

s0145

6 Sustainable supply chain management

p0165 Sustainable supply chain management concept would necessarily consider the interdependence between the economic, the environmental, and the social performances of a biomass to energy plant (Chaabane et al., 2012). Economic sustainability would aim to optimization and scheduling of processes to maximize the net profits through maximizing revenue generation with minimal raw materials, inventory and production costs. Similarly, social sustainability, would ensure that the process meets the expectation of employees and local stakeholders. Environmental sustainability is generally linked to reduction in carbon footprint as well as environmental pollution. It also includes a reduced dependency on nonrenewable resources, increased energy efficiency, absence or decrease in the consumption of hazardous materials and lastly the frequency of environmental accidents (Gimenez et al., 2012). The complexity of logistics is the main challenge for large-scale biomass to energy production. The main components of the whole process is given in Fig. 6. For the sake of



f0035 FIG. 6 Sustainable supply chain management.

understanding let's consider biomass collection, pretreatment, storage and conversion of biomass to energy are the four basic building blocks of the overall supply chain. Each of these four steps is linked via means of transportation. Major tradeoff comes between transportation cost and capitol cost for establishing the production facilities. Let's consider each block an attempt their optimization in an attempt to understand the macropicture (Meixell and Gargeya, 2005).

s0150 6.1 Biomass collection

p0170 Steady supply of biomass is prerequisite of biomass energy production. For any given location for the establishment of a biomass energy unit, understanding the existing biomass generation and their usage needs to be critically analyzed. The assessment must attempt to visualize futuristic scenarios. For example, an area predominantly producing huge volume of cotton stock, the viability of cotton cultivation in terms of agro-climatic factors should be assessed. A diverse plethora of biomass stream invariably reduces the vulnerability of such a plant from unforeseeable situations such as advent of new pest or disease for a particular feedstock or competition with other usage of the same feedstock, cost of collection and segregation of a more widely distributed biomass for example kitchen waste from a cluster of villages etc. As highlighted in the previous section escalation of grain price may adversely effect agro-waste generation. Overall, diverse source of biomass which are sustainable for the foreseeable future and minimal transportation as well as collection cost leads to optimized biomass supply in the long-term. Financial attractiveness of the whole process is key as often over optimization with an aim to maximize profit for the top of the pyramid of value chain may be detrimental for the long-term viability of the plant.

s0155
6.2 Biomass pretreatment

p0175 Typically biomass contains a lot of moisture and are low in energy density. Lignocellulosic biomass comprising of structural carbohydrates such as cellulose and hemicellulose can be subjected to mechanical pretreatment, steam and steam explosion pretreatment, hot water pretreatment, ammonia fiber explosion and chemical pretreatments viz., acid, alkali, organosolv, CO2 explosion etc. Pretreatment (say drying of rice straw) of the harvested biomass close to the source leads to reduced transportation cost and storage space requirement and increases and conversion efficiencies. Challenge here would be that if price is fixed at weight basis tendancy of keeping moisture or dust may look remuneratively attractive to the members of the value chain at the bottom of the pyramid. Hence, selection of pricing criteria guided by scientific unambiguous methods increases transparency and pretreatment efficiency. A comparable analogy would be the quality check for milk in terms of fat and protein content at the grass root level procurement process. Often 'what gets measured gets done' is the mode of operation which leads to efficient pretreatment process. For example, not harvesting a biomass that gets procured for biological valorization processes such as biogas generation immediately after spraying pesticide or herbicide would increase the safety in handling as well as augment the efficiency of biodegradation. Thus proper awareness built-up about what improves the process and technical back-stopping is of immense value in the long-term. Often such new practices need to be sincerely followed for multiple seasons to allow stakeholders to assimilate and adapt to the newer processes.

s0160
6.3 Storage

p0180 Often agro-waste gets generated seasonally with bulk volume of biomass generated over a handful few weeks of a season. Hence, the planning must be realistic and adopted through a consultative process with all the different stakeholders. A farmer hiring a tractor would surely harvest as much as possible in a single day in order to minimize the cost of harvesting. As such storage capacity is needed to ensure year-long availability of biomass. However, a good blend of short-duration crop residue, long-duration crop residue and perennial biomass waste stream leads to optimized storage space utilization over the temporal scale (Sharma et al., 2013). Please note here diversification of in-coming waste stream needs to be optimized and not the optimization of the storage of a single biomass stream. Scientific inventory management leads to minimal loss of biomass during storage. Adherence to safety guidelines is always beneficial in the long term.

s0165
6.4 Transport

p0185 Both biomass collection and delivery require extensive efforts in equipment selection, shift arrangement, vehicle routing, and fleet scheduling (DOE/EERE, 2013). Road transport is often preferred, due to the limited accessibility of some production sites. However, other modes of transport like rail can be used. In many cases, the fleet of vehicles is limited and the number of travels per period is restricted by various constraints like vehicle range or driving time regulations.

s0170 6.5 Conversion of biomass to energy

p0190 The conversion process for biomass to energy must be efficient, however, several factors need to be considered before the selection of any process. The most important criteria would be the per unit production cost of the process. Robustness of the process in a given location considering access to skill sets, quality of electricity and chemicals if any should be analyzed in detail. For example, a highly efficient and sophisticated process which need uninterrupted three-phase electricity may not be viable for certain locations in a rural area. However, shifting the unit closer to the urban clusters for the want of improved facilities and infrastructure may increase the transportation and/or storage cost. Different shortlisted suitable technologies must be evaluated based on their operational costs, biofuel productivity, and biomass requirement to make an optimal selection. Flexible variables can be used for the selection of biomass to energy conversion pathways at the supply chain level and the selection of catalysts, equipment, operation protocol, scheduling, and processing methods at the process level. Evaluation of the economic objectives viz. net present value, annualized total cost, etc. apart from conventional costs for construction, materials and labors, we should also take into account the government subsidies and revenue generation potential form selling the byproducts such as bio-oil (DOE/EERE, 2013). Policy support in terms of subsidized electricity, low-cost land availability, tax holidays and accommodative flexible labor laws all play important role in establishing such a unit. Policy support can also lead to improved infrastructure and planning. For example, often biomass fuel lead to the generation of low-quality steam in terms of power generation. Setting up of fossil fueled based power plant which can buy this steam as input for power generation or an energy-intensive industry like cement factory may lead to a win-win situation for both. Here establishing the industrial ecosystem and infrastructure would lead to increased efficiency.

s0175 6.6 Focus on innovation and flexibility to changing local scenarios

p0195 Irrespective of meticulous planning at the time of the establishment of the plant, continuous adaptation, technology upgradation and improvement of the whole value chain with changing local scenario would ensure long-term viability of the plant. Hence, the optimized configuration of a sustainable biofuel supply chain may not be static and would rather evolve over time. In particular, application of multiperiod planning models proposed for generic supply chains to biofuel supply chains may be the preferred approach. Equitable distribution of the revenue generated across the pyramid of value chain would make the system sustainable in the long-term. Providing local farmers who supply a given biomass input say, pigeon pea stock with modern know-how to modern pigeon pea cultivation would be wise use of some fraction of the revenue in the long-term. Improving water use efficiency of the local farmers by irrigation scheduling or reuse of treated wastewater would similarly augment the long-term viability of biomass based energy plants.

s0180 6.7 Awareness generation and stakeholder meetings

p0200 The importance of awareness generation cannot be overrated. Yet, many a times the focus on establishing the perfect processing unit undermines the time and effort required to

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establishment rapport among different stakeholders. The biomass collection team, the supplier of various biomass, the pretreament units, the storage personnel and the people involved in biomass to energy generation process must discuss each other's requirement through numerous stakeholders' meetings. Setting-up of a dispute resolution committee with representation from each stakeholders would help to resolve potential conflicts. The processes involved must look for innovative methods to improve efficiency as a continual process. Overall, sustainable supply chain management should focus on both human and machine aspect of it as ignoring either would lead to failure.

s0185

7 Policy support for advanced biofuels

p0205 The eleventh five-year plan (2007–2012) highlighted the severe shortages of energy, the dominance of coal and the need to expand resources through exploration, energy efficiency, renewables, and research and development (Planning Commission, 2007). Subsequent, policy Q7 initiatives led to the development of National Action Plan on Climate Change, launched in June 2008. Though India does not have any binding emissions targets, the policies reflect a response to global concerns to address climate change. The National Mission for a 'Green India' aims to achieve afforestation of 6 million hectares of degraded forest lands and to expand forest cover from 23% to 33% of India's territory by 2022. The term 'biofuels' means liquid fuels that are derived from biomass, such as biodegradable agricultural, forestry or fishery products, wastes or residues, or biodegradable industrial or municipal waste. Biofuels are derived from biomass and use photo-synthetically fixed C, thus, facilitating recycling of atmospheric CO2. Based on feedstock type, conversion process, technical specification of the fuel and its application, biofuels are categorized as first generation (1G), second generation (2G) and third generation (3G). Out of 83 billion liters biofuels which contribute about 1.5% of the global transport fuel consumption, 40% of global production of biofuel is in Brazil, China and Thailand outside the OECD region. Biofuel is expected to provide about 9% of the total transport fuel demand by 2030 with the production expected to rise to 159 billion liters in 5 years' time globally (IEA Renewables information, 2018). In India, ethanol is primarily pro- Q8 duced from sugarcane molasses and used as a biofuel for blending with petrol. In January 2003, Government of India (GOI) mandated 5% blending of ethanol with gasoline through its ambitious Ethanol Blended Petrol Programme (EBPP) which faced shortage of ethanol. Since then, petroleum with an ethanol blend has been developed and used in nine states and four union territories: Andhra Pradesh, Daman, Diu, Goa, Dadra, Nagar Haveli, Gujarat, Chandigarh, Haryana, Pondicherry, Karnataka, Maharashtra, Punjab, Tamil Nadu and Uttar Pradesh (Ethanol Producer Magazine). In 2005, the country became the world's fourth largest producer of ethanol at 1.6 billion liters and at the same time the world's largest consumer of sugar. To promote biofuels as an alternative energy source, the GOI in December 2009 announced a comprehensive National Policy on Biofuels formulated by the Ministry of New and Renewable Energy (MNRE), calling for blending at least 20% of biofuels with diesel (biodiesel) and petrol (bioethanol) by 2030. However, greater push for biofuels is received through the National Biofuel Policy, 2018 that envisages 40% reduction in carbon emissions

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by 2030 (MNRE, 2018). In an attempt to curb the carbon footprint of biofuel new policy shifts the focus from first generation (1G) biofuels which are made from molasses and vegetable oils to 2G biofuels made from cellulosic and lingo-cellulosic biomass/woody crops, agricultural residues and municipal waste feed stocks. Such policies necessarily is an attempt to move toward a circular economy through encouraging "Waste to Wealth" initiatives. Also utilization of these wastes for ethanol generation will eliminate the problem of stress to arable land and water resources and other issues related to food security associated with 1G biofuels. In fact, in Union Budget for the year 2018–19, central govt. has also focused on Waste to Wealth conversion projects e.g. Gobar Dhan Scheme to produce bio CNG. New National Biofuel Policy 2018 will ensure cost-effective and pollution free import substitute of polluting fossil fuels. Moreover, govt. will authorize OMCs to sell EBP with ethanol percentage up to 10% under Ethanol Policy India. Furthermore, govt. will implement this National Biofuel Policy 2018 in a mission mode to make our environment pollution free. First generation biofuels such as bioethanol are produced mainly from starch derived from food or fodder crops like sugarcane, sugar beet, sweet sorghum stalks, corn, wheat etc. Biodiesel is produced by transesterification, whereby lipids (oils and fats) in edible/nonedible oil, such as palm, soybean, rapeseed, Jatropha, Pongamia, etc. are reacted with alcohols (ethanol or methanol) (Ortiz et al. 2006). Bioethanol from molasses have competing uses and unfavorable policy acceptable by producers and GoI has led to only 1.7% blending, contrary to the national aspiration and commitment of reaching 5% blending by 2020. However, as indicated above the current level of ethanol blending is 4.7% in 2017–18 and new Biofuel Policy released by the Government of India has enabled the sugar factories to produce ethanol from molasses or sugar directly and signed the contracts for purchasing 2.37 billion liters of ethanol for blending (MNRE, 2018). The first-generation ethanol is the largest source of biofuel at present and search for alternative crops to food crops such as sugarcane for ethanol production is relevant in a country like India explore issues of water scarcity and food security. Central government of India in its 2018 New Biofuel Policy has indicated provision of incentives to all state-run oil marketing companies. These OMCs has made an agreement of long-term offtake of 2G ethanol under Biofuel Policy India. For this reason, OMCs are assuring suppliers for 15-year offtake contracts. Indian Oil Corporation (IOC) has recently signed an agreement with Punjab government. Under this agreement, IOC will establish various CNG plants in Punjab in upcoming 5 years. In addition to this, OMCs are going to set up 12 advanced biofuel refineries in several states. IOC is currently operating three biofuel plants and plans to increase its capacity from 100 to 1200 t per day in next 2 years. The most prominent driving forces for advanced biofuels on a global scale are political instruments, agreements, and regulations to reduce reliance on nonrenewable, imported fuels and to meet GHG reduction targets. The demand for biofuels, heat and electricity is increasing steadily around the globe. Major policy-related interventions for adoption and promotion of bioenergy have also been realized by several countries over the past few decades. Policy drivers such as blending targets, renewable portfolio standards have been more critical in influencing bioenergy expansion at local to global scales than market factors. Government commitment and support and financial incentives therefore continue to be important for significant, large-scale mobilization of the bioenergy supply chains.

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s0190
8 Reduction of water foot-print of biofuel production

s0195
8.1 Wastewater and algal biofuel

p0210 Use of wastewater such as urban wastewater for algal cultivation could offer potential benefits serving a dual purpose of treating the wastewater as well as producing lipids-rich biomass, which could be used for biodiesel production (Chisti, 2013; Úbeda et al., 2017; Datta et al., 2019). Wastewater provides macro and micronutrients essential for algae growth. Algae assimilate nutrients by bio-sorption and utilize it for its metabolic activities and store excess energy in the form of lipids, carbohydrates and proteins. Among the various strategies possible for economical large-scale production of microalgal biomass, a coupling of wastewater treatment with algal farming is possibly the most sensible due to the similar scale and production facilities that both industries rely on (Delrue et al., 2016). The additional benefit from such coupling is the promotion of on-site local industries and more importantly, the elimination of a large negative environmental footprint that would otherwise arise from the pollution associated with nutrient manufacturing, transportation and change in land use. Despite these two opportunities, many research and development challenges have still to be overcome in order to benefit from the full potential of the combination of microalgae production and wastewater treatment.

s0200
8.2 Indian scenario on wastewater treatment and reuse in agriculture

p0215 At present of the 62,000 MLD (million liter per day) the total wastewater generated in major Indian cities only 23,277 MLD gets treated (CPCB, 2000). About 70% of people in India live in Q11 villages and rural wastewater management remains a challenge in India. The link between health and hygiene of the villagers and good wastewater management practice needs no further elaboration. Energy and chemical-intensive conventional wastewater treatment technologies such as activated sludge process, sequential batch reactors are neither feasible nor sustainable in rural setting with limited resources (Datta et al., 2016). Often in water scarce semiarid villages the raw wastewater from these sumps are utilized for salad crop or vegetable cultivation. The fitness of such agro-produce for human consumption is suspect, moreover, raw wastewater irrigation causes excessive weed growth, nutrient-rich run-off and eutrophication of freshwater sources nearby. The suspended solid particles get accumulated in the soil and over a long period can significantly deteriorate the physical property of the soil.

s0205
8.3 Potential of constructed wetlands

p0220 Despite their apparent simplicity constructed wetland (CW), a proven age-old wastewater treatment system, are complex ecosystems involving biogeochemical processes such as filtration, sedimentation, plant uptake or phytoremediation and microbial degradation. The recently concluded Indo-EU project titled “Water4Crops” funded by Department of Biotechnology (Govt. of India) and the European Commission under the seventh framework has established the potential of constructed wetland. The joint India-EU project review held in New Delhi (15th–16th June 2016) identified the decentralized wastewater treatment using

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constructed/engineered wetlands using filtration, phytoremediation and microbial transformations as a suitable and ready technology for scaling-up in India, as a business model (Datta et al., 2016; Tilak et al., 2016). The technology can be integrated in rural development Q3 schemes and could become part of the Swatch Bharat initiative of the Government of India. The various types of constructed wetlands used over the last four decades can be grouped into two broad categories viz. free water surface (FWS) wetlands or subsurface flow (SSF) wetlands. In short, the former involves a pond whereas the latter involves a dry surface (as their names suggest). One major advantage of SSF CWs (though being slightly expensive than FWS CWs owing to the filtering media cost) is the better control of mosquito menace. The CWs may also be used for growing algae for biofuel production and provide additional income source for the villagers during the construction, operation as well as maintenance activities.

s0210

9 Challenges

p0225 Producing advanced biofuels from biomass feedstocks is even more challenging than producing first generation biofuels. The major challenges are discussed hereunder.

s0215 9.1 Seasonal availability of biomass

p0230 Most of the biomass materials are seasonal and are required to be available in huge quantities to be qualified as feedstocks for biofuel production in biorefineries. Supply of biomass is critical to the reliable and efficient operation of any biomass-based biorefinery. The cost of feedstocks will significantly influence the cost of biofuel production. About one-third of biofuel production cost is associated with biomass cost and the cost of biomass ($ per ton) is directly proportional to the yield (ton per ha) (Duffy and Nanhou, 2002), which is influenced by soil fertility, location, and genetics. Another challenge would be to influence food grain growing farmers to cultivate biomass feedstocks assuring them of a guaranteed buy-back. The willingness of stakeholders to invest in infrastructure and technology is challenged by uncertainties surrounding long-term feedstock supply of both crops and value chain residues.

s0220 9.2 Biomass harvesting

p0235 Harvesting of different types of biomass requires different types of machinery which would influence the cost of harvesting making it an energy intensive process.

s0225 9.3 Moisture content in biomass

p0240 The presence of high moisture content in biomass causes biological degradation, mold formation and losses in the organic contents during storage (Johansson et al., 2006), that could reduce the yield of the fuel produced from these materials. Storing biomass at <10% can extend the conservation time of the materials and reduce major losses (sugars) in the biomass during the storage period (Balan, 2014). High oxygen contents of biomass materials can also negatively affect their conversion to various products such as fuels.

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s0230 9.4 Density of biomass and transportation cost

p0245 Biomass has a relatively low energy density and hence requires more quantities of biomass to supply the same amount of energy as a traditional hydrocarbon fuel. The low density of biomass is reported to influence the transportation cost. Transportation cost is also influenced by the moisture content, distance from the field to biorefinery, available infrastructure, available on-site technology, and the mode of transportation (rail or road) (Balan, 2014; Kumar et al., 2006). Biomass material should be used in densified forms to overcome moisture, storage and handling problems.

s0235 9.5 Biomass supply chain and logistics

p0250 The supply chain steps pertaining to biomass production, harvesting, pretreating, storage and transporting biomass to centralized biorefineries will directly impact the cost of feedstock delivery. Apart from the above, the other constraints are nonavailability of standards for biomass classification, grading and quality. Besides this, there is a lack of established market pricing mechanism. In addition to these logistic challenges, efficient and commercially viable conversion technologies are also lacking for a number of supply chains and regions; and the valuation of by-products and co-products such as CO_2, ash, lignin is often lacking.

s0240 10 Conclusions

p0255 Rapid depletion of limited fossil fuels coupled with detrimental effects on environment has occurred due to human reliance. Production of bioenergy through utilization of dedicated, rapidly growing high-biomass feedstocks on nonarable lands and exploitation of agro-industrial waste materials can offer a solution to this issue. Utilization of Biomass feedstocks for advanced biofuel production depends on factors like availability, characteristics as fuel, and most importantly opportunity cost. The emerging concept of advanced biofuels would require a careful and judicious design of the biomass supply chain which holistically integrates different components of the supply chain to enhance the quantum of energy return, improves the greenhouse gas balance, reduces the water footprint of the bioenergy production facility and achieves environmental sustainability. At the global level, success in the commercial development and deployment of advanced biofuel technologies would require a significant amount of technological interventions through increased amounts of Research and Development to overcome the current cost barriers.

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Non-Print Items

Abstract

Circular economy is increasingly being seen as a sustainable route to development. The utilization of traditional waste streams for wealth generation is experiencing increased focus from policymakers. Agricultural activities globally generate billions of metric tons of waste biomass annually, which includes solid, liquid, and gaseous residues. Valorization of such agro-waste as feedstock for bioethanol production seems to be the only feasible route toward the achievement of the national blending target of 20% ethanol-blending with petrol. The cellulosic agro-wastes offers a more sustainable option compared to 1st generation biofuels which were dependant on food crops such as sugarcane, corn, and oil seeds. Particularly, in geographies with limited land and water resources, the dilemma to choose between food crop and energy crop has led to food vs fuel and sustainability issues. Major energy sources of feedstock may be switchgrass, miscanthus, high biomass, or energy sorghum, as well as crop residues, such as rice straw, wheat straw, corn stover, and corn cobs. Governmental policies that regulate agriculture, industry, and trade significantly influence the profitability of biofuels and play an important role in the development of a country's energy sector. However, there needs to be an increased awareness about these policies at the grass root level. While doing site selection for any advanced biofuel plant, one of the key criteria is sustainable availability of feedstock with an efficient and robust biomass supply chain management system. Biomass is a sustainable low carbon source that can replace fossil carbon via multiple thermo-chemical and biochemical technologies to produce almost all advanced biofuels for road/aviation transport. This chapter reviews the various feedstocks available for advanced biofuel production, supply and process chain analysis, sustainability, and industrial optimization. Though examples for bioethanol are given, but the discussed biomass can also provide fungible fuels, methanol, and Hydrogen by various technology platforms.

Keywords: Biomass, Biofuels, Feedstock, Agricultural residue, Supply chain, Management