# Feedstock to Biofuels:

## Opportunities for advanced biofuels - Supply chain analysis and reduction in CAPEX/OPEX

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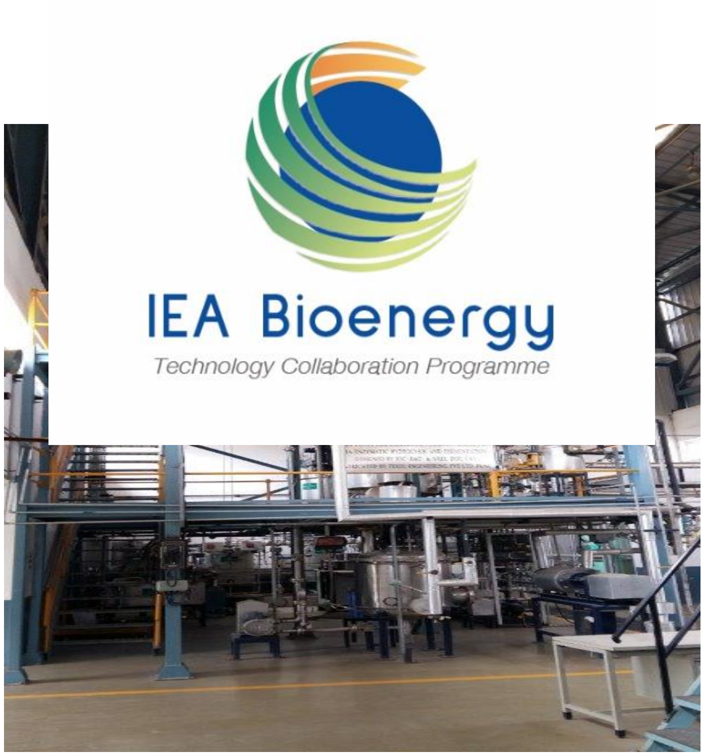


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## Opportunities for advanced biofuels - Supply chain analysis and reduction in CAPEX/OPEX

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## 1.0 Executive Summary

IEA Bioenergy Task 39 had commissioned India to lead a study on "Feedstock-to-biofuels", especially a biomass supply chain assessment for the production of 2nd Generation (2G) ethanol, to help understand the developments in India and other groups/member countries. It was also envisaged that the study may include economically sustainable bio-based technologies for the production of renewable fuel from surplus non-food and non-fodder biomass feedstocks. It was also desired by the Task 39 team that the "Feedstock-to-biofuels" report might comprise advances in 2G ethanol processes in India and other countries such as the USA, Brazil and Germany. The study mainly focussed on biomass availability, prevalent biomass supply chain approaches, and different process schemes, including the type of pretreatment technologies used by 2G ethanol technology developers. Furthermore, the study included life cycle analysis and environmental impact assessment to identify the GHG emissions and energy consumption hotspots during the lignocellulosic bioethanol production process.

Currently, the costs of most advanced biofuels options are much higher than those of conventional biofuels and their fossil fuel competitors; therefore, one of the objectives of this study was an urgent need is to identify the hotspots and opportunities for cost reduction by allowing larger economies of scale, in combination with the significant "learning effect" that occurs in technology development. This study might help identify all the potential opportunities across the feedstock-to-biofuel supply chain to reduce capital and operating costs for advanced biofuels production.

Accordingly, the authors surveyed the prior art and inputs from various references. Inputs covering some of the above aspects were acquired from IEA Bioenergy Task 39 representatives of the USA, Brazil and Germany. All the information were collated into this consolidated report.

**The key findings of the report are as follows:**

- The report mainly focuses on the biomass availability specific to these regions, variation in the chemical composition, biomass supply chain approaches, different process schemes, including the type of pretreatment technologies by 2G ethanol technology developers
- Although 2G ethanol technologies are available in India, Brazil, Germany and the USA, these technologies are not viable at current Capex and Opex.
- Feedstock availability, capital cost, and production cost are the key challenges towards sustainable and commercial production and implementation of 2G ethanol technology.
- In India, most agri-businesses falter in performance in the medium to long term due to the failure to address raw material availability issues. Entrepreneurs/investors looking at establishing 2G ethanol plants consider the continued availability of required quantities of cellulosic raw materials at predictable price ranges as one of their top priorities.
- In India, the time gap between two crops is low. Therefore, farmers burn biomass residues, especially rice straw (generated after harvesting), to clear the fields for the next crop. Since the farmers have limited resources and low exposure to advanced

technologies, it would be prudent for entrepreneurs to invest in the mechanization of the harvesting and baling process.

- Without reducing biomass quality caused by seasonal weather variations, biomass storage is also critical for ensuring the sustainability of 2G bioethanol plant operations year-round. Thus, stakeholders need to conduct a focussed study, explore opportunities, and develop models to find a practical solution to store biomass and make it available year-round. Biomass logistics should be monitored well, since each operation where biomass is handled, increases the dust (i.e. ash content). This will lead to high transport costs and potential problems (in terms of biomass treating) into the biochemical reactors (e.g. rocks can block the stirrers).
- A good strategy would be investing in a supply chain business comprising procurement/collection, aggregation, baling, and storage before investing in the bioethanol plants. This would give them first-hand knowledge of the challenges involved and improve the confidence levels of their bankers and stakeholders as well.
- In India, some established supply chain models such as ITC E-Choupal Model, Amul Model, NDDB Safal model are applied in rural India for Agri-produced Logistics. These models have been designed to tackle the challenges posed by the unique features of Indian agriculture, characterized by fragmented farms, weak infrastructure and the involvement of numerous intermediaries. Such types of models may be applied for biomass supply chain management.
- Production of cellulolytic enzymes and their application for fermentable sugar production is identified as a hotspot to further reduce GHG emissions.
- The utilization of solid waste, generated from the bioethanol plant, to generate power and subsequently replace the fossil-derived energy requirements of the bioethanol plant can play a major role in reducing the GHG emissions of the 2G bioethanol production process.
- To address the Opex cost of production of 2G ethanol, there is an urgent need to develop cost-effective pretreatment technology with low or no chemicals, indigenous 2G enzyme technology with an onsite enzyme production model, and the valorization of lignin-rich residues to produce high-value chemicals. These technologies can make 2G ethanol cost-competitive compared to 1G ethanol cost.

## 2.0 Introduction

GHG emissions by various sectors such as road transport, industries, aviation, and marine sectors are a major area of concern worldwide. The recent Intergovernmental Panel on Climate Change (IPCC) report is **'code red for humanity'** and a warning sign for policymakers worldwide(Pörtner et al., 2022). The report also makes it clear that the global warming experienced to date has made irreversible changes to many of our planetary support systems. The oceans will now continue to warm and become more acidic. Mountain and polar glaciers will continue to melt for decades or centuries. The authors of the IPCC report believe that $1.5^0$C will be reached by 2040 in all scenarios. If emissions aren't slashed in the next few years, this will happen even earlier. One of the pathways to achieve net zero involves reducing greenhouse gas emissions as much as possible by adopting clean technologies.

Global concerns to decarbonize the transport sector and the constant thrust from the various international and national agencies have made bioethanol an attractive alternative liquid fuel to replace gasoline and mitigate GHG emissions. In comparison to conventional ethanol or first-generation (1G) ethanol, which is produced directly from food/feed crops and other products/wastes derived from it (such as corn, wheat, starch, molasses, etc.), second-generation (2G) bioethanol is derived from non-food/fodder lignocellulosic biomass. Therefore, it offers several advantages such as avoiding the food vs fuel debate, low land-use change impacts and high GHG mitigation. 2G bioethanol is considered an advanced biofuel because it can reduce GHG emissions by more than 80% (a fuel is regarded as an advanced biofuel if its lifecycle GHG emissions are at least 50% lower than the fossil-derived fuel)(Schnepf & Yacobucci, 2010). Thus, significant progress has been made in this sector, and more than 20 different commercial plants were set up globally in the last decade, especially in the US, Europe and Brazil.

India is one of the fastest-growing economies in the world. It is the third-largest importer of crude oil after China and the US and continues to rely mainly on imports. In the last five years, annual import volumes of petroleum and petroleum products have risen 25% to 307 billion liters. Additionally, India is the fourth largest consumer of primary energy at 24.9 quadrillion British thermal units (BTUs), following China, the US and Russia. It is also the eighth largest energy producer at 14.18 quadrillion BTUs. As a result, India is increasingly dependent on energy imports despite considerable fossil fuel resources.

The industry and transport sectors are the largest end-users of energy in India and account for half of the total energy consumed. The main fuels supplying this demand are coal (in industry), petroleum (in transport), and electricity (in buildings, industry, and agriculture). Growth in the transport sector will continue to increase petroleum consumption. Transportation consumes close to 70% of the total diesel supply, 66% used by passenger and commercial vehicles. Gasoline is also used for light-duty transportation, 60% for two-wheelers such as motorcycles and scooters. Currently, diesel alone meets an estimated 46% of transportation fuel demand, followed by gasoline at 24%. Gasoline and on-road diesel consumption combined are forecast to rise over the next 5 years from the current estimate of 98 billion liters in 2018 to 126 billion liters by 2023.

India has made important progress towards meeting the United Nation's Sustainable Development Goals, notably Goal 7 on delivering energy access. Both the energy and emission intensities of India's gross domestic product (GDP) have decreased by more than 20% over the past decade. This represents commendable progress even as total energy-related carbon dioxide ($CO_2$) emissions continue to rise. India's per capita emissions today are 1.6 tonnes of $CO_2$, well below the global average of 4.4 tonnes, while its share of global total $CO_2$ emissions is some 6.4%.

India is an active player at international fora in the fight against climate change. The country's Nationally Determined Contribution under the Paris Agreement sets out targets to reduce the emissions intensity of its economy and increase the share of non-fossil fuels in its power generation capacity while also creating an additional carbon sink by increasing forest and tree cover. Although the emissions intensity of India's GDP has decreased in line with targeted levels, progress towards a low-carbon electricity supply remains challenging.

The government of India has emphasized achieving energy security with a target of reducing import dependence, i.e. usage of fossil fuels by 10% from current levels by the year 2022. This target will be achieved by adopting a five-pronged strategy that includes increasing domestic production of biofuels and renewables, improving energy efficiency norms, improving refinery processes, and compelling substitution. This envisages a strategic role for biofuels in the Indian Energy basket. The growing concern about the import dependence on fuel in tandem with environmental pollution issues has driven the need for alternative fuels with superior environmental benefits and are economically competitive with fossil fuels. Renewable energy resources are indigenous, non-polluting, and virtually inexhaustible. India is endowed with abundant renewable energy resources. Therefore, their use should be encouraged in every possible way. An indicative target of 20% blending of ethanol in gasoline is proposed by 2025(Rakesh Sarwal et al., 2021).

The government of India announced *"The National Policy on Biofuels-2018"* on 8$^{th}$ June 2018. The Policy encourages innovation and provides thrust to Research and Development (R&D) and Demonstration in biofuels by utilizing developed/emerging technologies while undertaking RandD activities. The Policy targets developing next-generation biofuel conversion technologies based on new feedstocks and promoting the use of domestically available feedstocks that utilize the Country's biodiversity.

The policy also aims to provide financial and fiscal incentives specific to biofuel type, categorized as first-generation (1G), second-generation (2G) and third-generation (3G) fuels. The first-generation category of biofuels includes bioethanol and biodiesel. The second generation comprises ethanol from lignocellulosic biomass, non-food crops, industrial waste and residue streams and Drop-in Fuels from biomass, MSW, plastics and industrial waste. The third-generation includes compressed Bio-CNG from food waste, biomass, MSW and sewage water, etc. In the new policy, many new additional raw materials for 1G ethanol production have been included which are going to increase availability of 1G ethanol, such as Sugarcane Juice, Sugar-containing materials like Sugar Beet, Starch-containing materials like Corn, Cassava, damaged food grains like wheat, broken rice, and Rotten Potatoes. However, new additional raw materials for 1G ethanol would not substantially improve the demand for bioethanol for even E10 gasoline on a pan-India basis. Therefore, production of ethanol from 2G technologies is essentially required to sustain the demand for ethanol by OMCs. Biomass is abundantly available in India, therefore research into biomass conversion to various valuable green fuels such as ethanol, methanol, Bio-CNG is essential for India's energy security. Moreover, technologies to convert abundantly available MSW, industrial plastic waste, flue gases, etc., into energy would be highly beneficial to India.

This report constitutes the work carried out on the project "**Feedstock to Biofuels: Opportunities for advanced biofuels - supply chain analysis and reduction in CAPEX/OPEX**". The primary objective of this report is to critically evaluate advances in second-generation bioethanol production from lignocellulosic biomass and identify the key challenges and novel opportunities to reduce the process costs. This report shall provide detailed insights into the 2G ethanol process, including supply chain assessment specifically in India, with brief details of Brazil, Germany, and the USA. The authors are experts working in this area of research and actively contributing to the progress of 2G bioethanol technology at national and global levels.

Each chapter firstly described the surplus availability of feedstocks, variation in the chemical composition and the potential of surplus biomass for 2G ethanol production was assessed. The prevalent pretreatment technologies and the selected process schemes were evaluated in the next chapter. The challenges in supply chain management and various plans/strategies to resolve the supply chain issues were explored. Finally, the life cycle analysis and environmental impact assessment pertaining to indigenous feedstocks and specific process schemes were carried out to identify the hotspots for further process intensification.

## 3.0 Feedstock Availability in India

### 3.1 Biomass availability for 2G ethanol

According to the TIFAC 2018 report on estimation of surplus crop residues in India for Biofuel production, the total dry biomass generated in India was about 683 MT for the major eleven crops. Out of this total dry biomass, only 178 MT (26%) was found to be surplus, and of this surplus, 72% was generated in Kharif season (Kharif crops require good rainfall and these are usually sown at the beginning of the first rains during the advent of the south-west monsoon season, and they are harvested at the end of monsoon season (October–November)), 27% in rabi (Rabi crops are known as winter crops as these are grown in October-November and harvested in spring) and 1% in the summer season. The surplus biomass ranged from 0 to 31.59 MT among the states. The total annual surplus biomass was maximum in Uttar Pradesh (17.68%) followed by Punjab (17.31%), Maharashtra (14.22%), Gujarat (7.6%) and Haryana (5.6%). These five States contributed 62.48% of the total annual surplus crop biomass. Out of the total Kharif crop biomass generated, about 32% was surplus, whereas only 18% was surplus in the rabi season and 0.48% in the summer season. The surplus crop biomass in Kharif season ranged between 0.001 and 24.92 MT and in rabi season between 0.0 to 9.55 MT among different States. The surplus crop biomass was insignificant during summer crop.

For season-based distribution of surplus crop biomass, the State of Uttar Pradesh produced the maximum (19.25%), followed by Maharashtra (16.66 %), Punjab (16.53%), and Gujarat (8.47%) in kharif season. In rabi season, 19.71% surplus biomass was produced in Punjab followed by Uttar Pradesh (13.78%), and Madhya Pradesh (10.63%). The States of Bihar (7.8%), Maharashtra (7.9%) and Rajasthan (7.3%) generated 23% of the surplus biomass in rabi season. Season wise generation of surplus biomass from major crops in different states is given in **Table 1** below:

**Table 1: Surplus biomass from major crops (Reference: TIFAC 2018 report(Niveta Jain et al., 2018))**

| Season | Crop | States |
|---|---|---|
| Kharif | Rice | Punjab, UP |
| | Sugarcane | UP, Maharashtra, TN, AP, Karnataka |
| | Cotton | Maharashtra, Telangana, Gujarat |
| | Soybean | Maharashtra, M.P, Rajasthan |
| Rabi | Wheat | Punjab, UP, MP |
| | Gram | Maharashtra, Karnataka, Rajasthan |
| | Rice | Bihar |
| | Rapeseed and Mustard | Rajasthan, Haryana |

The total annual bioethanol (2G ethanol) production potential of the country is 51.35 billion liters (BL) from 178 MT of surplus crop biomass generated. The ethanol production potential in the country ranged between 0.06 million liters (ML) and 9941 ML across the States (assuming that the cellulose and xylose content in biomass varied between 450 kg to 600 kg per ton of biomass, which could be be converted to ethanol using 2G ethanol technology at the conversion efficiency of 70%). Out of the total annual bioethanol potential, 38.04 BL can be produced in Kharif season and 13.08 BL in rabi season. The maximum potential was found in the State of Uttar Pradesh (9940 ML) followed by Punjab (8459 ML), Maharashtra (7494 ML), Gujarat (3910 ML) MP (3162 ML) and Haryana (2685 ML) states. These six states account for approximately 69 % of the total annual bioethanol potential. During Kharif season UP, Punjab, Maharashtra and Gujarat show higher potential, whereas Punjab, UP, MP and Maharashtra states show higher potential in rabi season.

The potential for 2G ethanol is mentioned in the TIFAC report as 51.35 billion liters, which indicates yields of 22% (w/w) for ethanol conversion in 2G plants. But yields of 2G ethanol depends on the cellulose and hemicellulose content of feed biomass and also vary with the technology used. 2G ethanol Licensors also offer yields as low as 17%. Hence, the potential of 2G is in the range of 39 – 51 billion liters (corresponding to 17% - 22% yield).

**Table 2: Crop wise and season wise area total dry biomass, surplus biomass, and bioethanol production potential of selected crops in India (Reference: TIFAC 2018 report(Niveta Jain et al., 2018))**

| **Crop** | **Season** | **Area (Mha)** | **Dry Biomass (MMT)** | **Surplus biomass (MMT)** | **Bioethanol Potential in Billion Liters (BL)** |
|---|---|---|---|---|---|
| Rice | Kharif | 28.597 | 142.761 | 35.993 | 9.862 |
| | Rabi | 13.334 | 66.997 | 7.267 | 1.991 |
| | Summer | 2.429 | 15.728 | 0.596 | 0.163 |
| | Sub-Total | 44.360 | 225.487 | 43.856 | 12.017 |
| Wheat | Rabi | 30.838 | 145.449 | 25.070 | 6.919 |
| Maize | Kharif | 7.591 | 21.491 | 4.979 | 1.110 |
| | Rabi | 1.190 | 6.389 | 1.057 | 0.236 |
| | Sub-Total | 8.781 | 27.880 | 6.036 | 1.346 |
| Sugarcane | Kharif | 5.037 | 119.169 | 41.559 | 14.629 |
| Gram | Rabi | 8.484 | 26.515 | 8.724 | 2.172 |
| Tur | Kharif | 4.040 | 8.942 | 1.704 | 0.433 |
| | Rabi | 0.073 | 0.225 | 0.051 | 0.013 |
| | Sub Total | 4.113 | 9.167 | 1.755 | 0.446 |
| Soyabean | Kharif | 10.694 | 27.779 | 9.950 | 2.935 |
| Rapeseed and Mustard | Rabi | 5.869 | 17.085 | 5.157 | 1.495 |
| Cotton | Kharif | 12.039 | 66.086 | 29.555 | 7.359 |
| | Rabi | 0.116 | 0.480 | 0.178 | 0.044 |
| | Summer | 0.003 | 0.017 | 0.007 | 0.002 |
| | Sub Total | 12.158 | 66.583 | 29.740 | 7.405 |
| Ground Nut | Kharif | 4.399 | 9.449 | 2.648 | 0.580 |
| | Rabi | 0.593 | 2.145 | 0.961 | 0.211 |
| | Summer | 0.483 | 1.305 | 0.263 | 0.058 |
| | Sub Total | 5.474 | 12.900 | 3.873 | 0.848 |
| Castor | Kharif | 1.176 | 4.589 | 3.013 | 1.133 |
| | Rabi | 0.009 | 0.016 | 0.005 | 0.002 |
| | Sub Total | 1.185 | 4.604 | 3.017 | 1.134 |
| **All Crops across all seasons** | **Grand Total** | **136.994** | **682.618** | **178.738** | **51.348** |

### 3.2 Biomass Feedstock Availability Validation

Oil marketing companies (OMCs) such as IOCL, HPCL, BPCL and MRPL are locating 12 commercial 2G ethanol plants in India at different locations (https://iocl.com/MediaDetails/51352). They have done a survey for the area within the vicinity of the plants (50 miles radius) for biomass availability, and the findings are shown in Table 3:

**Table 3: Survey conducted by oil marketing companies within the vicinity of the proposed plants (50 miles radius) for biomass availability**

| Company | Survey Location | Major Surplus Biomass | Surplus Biomass availability as per TIFAC report in Kilo Tons (1 Kilo Tons =1000 Metric Tons) | Surplus Biomass availability as per an external survey by Oil marketing companies (OMCs) in Kilo Tons (1 Kilo Tons =1000 Metric Tons) |
|---|---|---|---|---|
| IOCL | Panipat, Haryana | Rice Straw | 39.28 | 235.7 |
| | | Bagasse | 20.57 | 212.8 |
| | Bharuch, Gujarat | Cotton Stalk | 149.61 | 229.72 |
| | | Bagasse | 125.1 | 92.79 |
| BPCL | Bargarh, Orissa | Rice Straw | 160.8 | 1122.80 |
| | | Maize Stalks | 0.133 | 173 |
| | Sagar, M.P | Soybean Stalks | 186.1 | 332 |
| | | Wheat Stalk | 107.03 | 65 |
| | Buldhana, Maharashtra | Cotton Stalks | 356.59 | 436 |
| | | Soybean Stalks | 126.69 | 121 |
| | | Maize Stalks | 30.3 | 88 |
| | West Godavari, A.P. | Rice Straw | 220.60 | 1130 |
| | | Bagasse | 587.67 | |
| | Bathinda, | Rice Straw | 858.4 | |

| | | | | |
|---|---|---|---|---|
| HPCL | Punjab | Wheat Straw | 612.9 | 1562 |
| | Badaun, U.P. | Rice Straw | 92.2 | 252 |
| | | Wheat | 36.79 | |
| | | Bagasse | 45.26 | |
| | Muzaffarpur, Bihar | Rice Straw | 74.70 | 130 |
| | | Wheat Straw | 43.83 | |
| MRPL | Devangere, Karnataka | Cotton stalk | 36.24 | 80.7 |
| | | Rice Straw | 49.48 | 56.2 |
| | | Sugarcane trash | 51.66 | 87.7 |

As can be seen from Table 1, the TIFAC data of surplus biomass availability seems to be conservative. The availability of surplus biomass at different locations based on the survey done by OMCs for their 2G ethanol projects is higher in most cases. The TIFAC data of surplus biomass availability covered production statistics from 2010-11 to 2015-16 (based on data availability and accessibility) for selected crops, whereas the data from Oil Marketing Companies (OMCs) is more recent and based on actual survey conducted within that particular region for setting up 2G ethanol plant in that area. Another reason for the differences is figures might be due to increase in cultivation area of crop due to which surplus biomass availability has been increased. Hence the total annual bioethanol production potential of the country shall be more than 51.35 billion liters, and some of the ethanol can be diverted from Bio-jet fuel to meet the blending requirement. Currently, the IRR of 2G ethanol plants is negative with huge CAPEX. The upcoming 2G ethanol plants are meant for EBP (Ethanol Blending Programme) as mandated by NBP-2018.

Further, as per the recently released Roadmap for Ethanol Blending in India 2020-25 (Report by Expert Committee, Niti Aayog and MoPandNG), projected ethanol production is 1350 crore liter (13.50 billion liters) by 2025-26.

**Table 4:** Annual and Sector-wise Ethanol Production Projections

| Ethanol Production Projections | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ESY | For Blending | | | Blending (in %) | For other uses | | | Total | | |
| | Grain | Sugar | Total | | Grain | Sugar | Total | Grain | Sugar | Total |
| 2019-20 | 16 | 157 | 173 | 5 | 150 | 100 | 250 | 166 | 257 | 423 |
| 2020-21 | 42 | 290 | 332 | 8.5 | 150 | 110 | 260 | 192 | 400 | 592 |
| 2021-22 | 107 | 330 | 437 | 10 | 160 | 110 | 270 | 267 | 440 | 707 |
| 2022-23 | 123 | 425 | 542 | 12 | 170 | 110 | 280 | 293 | 535 | 828 |
| 2023-24 | 208 | 490 | 698 | 15 | 180 | 110 | 290 | 388 | 600 | 988 |
| 2024-25 | 438 | 550 | 988 | 20 | 190 | 110 | 300 | 628 | 660 | 1288 |
| 2025-26 | 466 | 550 | 1016 | 20 | 200 | 134 | 334 | 666 | 684 | 1350 |

*Source: Roadmap for Ethanol Blending in India 2020-25*

For 20% ethanol blending in petrol in India by 2025, the requirement shall be about 1016 crore liter (10.16 billion liters). Most of the car fleet are designed for E10, however there are plans to roll out E10 vehicles with E20 compliant materials by 2023.

**Table 5**: Ethanol demand projection

| **Ethanol Supply Year** | **Projected Petrol Sale (MMT)** | **Projected Petrol Sale (Cr. liters)** | **Blending (in %)** | **Requirement of ethanol for blending in Petrol (Cr. liters)*** |
|---|---|---|---|---|
| 2019-20 | 24.1 (Actual) | 3413 (Actual) | 5 | 173 |
| 2020-21 | 27.7 | 3908 | 8.5 | 332 |
| 2021-22 | 31 | 4374 | 10 | 437 |
| 2022-23 | 32 | 4515 | 12 | 542 |
| 2023-24 | 33 | 4656 | 15 | 698 |
| 2024-25* | 35 | 4939 | 20 | 988 |
| 2025-26* | 36 | 5080 | 20 | 1016 |
| * The petrol projections may undergo revision due various factors like penetration of EVs, etc. ** The figures are optimistic, as the E20 fuel will be consumed by new vehicles from April 2023 only. The demand for ethanol will, however, increase due to penetration of E100 two wheelers, which are now being manufactured in the country. | | | | |

*Source: Roadmap for Ethanol Blending in India 2020-25*

### 3.3 Biomass availability in the USA

The biomass availability is determined on the basis of the report published by the US Department of Energy (USDOE)(M. H. Langholtz et al., 2016). It showed that about 1.2 billion tons (or billion metric tons) of combined resources (forest and agriculture residues) could potentially be available at $60 or less per dry ton on a base case basis and 1.5 billion tons in a high-yield scenario by 2040. It showed that, currently, 343 million tons of agricultural residues, wastes, and forest resources are available. However, the highest potential is with energy crops amounting to ~736 million tons by the year 2040.

**Table 6:** Biomass availability in the USA

| **Feedstock** | **2017** | **2022** | **2030** | **2040** |
|---|---|---|---|---|
| | **Million Dry Tons** | | | |
| **Currently Used Resources** | | | | |
| Forestry resources | 154 | 154 | 154 | 154 |
| Agricultural resources | 144 | 144 | 144 | 144 |
| Waste resources | 68 | 68 | 68 | 68 |
| **Total Currently used** | **365** | **365** | **365** | **365** |
| **Potential: Bas-case scenario** | | | | |
| Forestry resources (all timberland)[a,b] | 103 | 109 | 97 | 97 |
| Forestry resources (no federal timberland)[a, b] | 84 | 88 | 77 | 80 |
| Agricultural residues | 104 | 123 | 149 | 176 |
| Energy Crops[c] | | 78 | 239 | 411 |
| Waste resources[d] | 137 | 139 | 140 | 142 |
| **Total base-case scenario potential (all timberland)** | **343** | **449** | **625** | **826** |
| **Total base-case scenario (currently used + potential)** | **709** | **814** | **991** | **1192** |
| **Potential: High-yield scenario** | | | | |
| **Forestry resources (all timberland)[b e]** | **95** | **99** | **87** | **76** |
| **Forestry resources (no federal timberland)[b e]** | **78** | **81** | **71** | **66** |
| Agricultural residues | 105 | 135 | 174 | 200 |
| Energy Crops[c] | | 110 | 380 | 736 |
| Waste resources[d] | 137 | 139 | 140 | 142 |
| **Total high-yield scenario potential (all timberland)** | **337** | **483** | **782** | **1154** |
| **Total high-yield scenario (currently used + potential)** | **702** | **848** | **1147** | **1520** |

Note: Numbers may not add because of rounding. Currently used resources are procured under market prices

[a]Forestry baseline scenario.
[b]Forestry resources include whole-tree biomass and residues.
[c]Energy crops are planted starting in 2019. Note: *BT2* assumed a 2014 start for energy crops.
[d]The potential biogas from landfills is estimated at about 230 billion $ft^3$per year
[e]Forestry high-housing, high biomass-demand scenarios.
[f]The high-yield scenario assumes 3% annual increase in yield.

### 4.0 Biomass Chemical Composition

Lignocellulosic biomass composition varied depending upon the type, species, age, area, weather conditions, etc. the chemical composition of wood, agricultural residues and other different types of lignocellulosic biomass is depicted in **Table 7**. The cellulose content is high in softwoods and hardwoods available in Europe compared to the agricultural residues available on the Indian subcontinent. Whereas the ash and extractives content is high in agricultural residues. Rice straw and rice husk are rich in ash containing silica. High extractives were observed in Sugarcane bagasse, Corn stover, Rice straw and Sorghum stalk.

**Table 7. Chemical composition of different lignocellulosic biomass available (% w/w on a dry weight basis)**

| Biomass | Cellulose | Hemicellulose | Lignin | Ash | Extractives |
|---|---|---|---|---|---|
| **Woods** | | | | | |
| Softwood | 40-44 | 30-32 | 25-32 | 1-2 | 4-5 |
| Hardwood | 40-44 | 15-35 | 18-25 | 1-2 | 2-3 |
| **Agricultural residues** | | | | | |
| Rice straw | 34-38 | 17-20 | 12-15 | 10-14 | 16-18 |
| Rice husk | 30-33 | 12-14 | 26-28 | 17-20 | 8-10 |
| Cotton stalk | 38-42 | 18-20 | 22-25 | 3-5 | 7-8 |
| Wheat straw | 35-38 | 18-20 | 20-22 | 5-7 | 12-14 |
| Sugarcane bagasse | 35-38 | 18-20 | 20-24 | 3-5 | 18-20 |
| Corn stover | 28-30 | 16-18 | 24-26 | 10-12 | 17-20 |
| Sorghum stalk | 35-37 | 16-18 | 20-22 | 8-10 | 17-20 |
| Mustard Stalk | 39-42 | 18-20 | 23-25 | 7-9 | 8-10 |
| Corn Cob | 30-32 | 28-30 | 18-20 | 4-6 | 12-15 |
| Jatropha prunings | 38-42 | 15-18 | 25-30 | 4-6 | 10-14 |

Cellulose is the most abundant biopolymer on earth. It is composed of D-glucose units interlinked with each other by β-1,4 glycosidic bonds to form a linear homopolymeric polysaccharide chain having a high molecular weight with about 10,000 monomeric units of D-glucose(Satlewal et al., 2018a). Cellulose is present as a microfibrillar structure due to the presence of strong and highly complex hydrogen-bonding patterns. It offers physical strength for the plant cell wall structure, and it could be several micrometers long. The degree of polymerization is usually high in woody biomass (~5000) structure as compared to the agriculture residues such as bagasse and wheat straw (~1000) and rice straw (~2000)(Satlewal et al., 2018a). Cellulose is highly crystalline in nature due to its highly compact structure.

In contrast, to cellulose, hemicellulose is heterogeneous and amorphous in nature and composed of both C5 (xylose, arabinose) and C6 sugars (glucose, galactose, mannose, and rhamnose) with a high polydispersity index and average molecular weight of <30,000. Hemicellulose is interlinked with both lignin and cellulose through covalent and hydrogen bonding, respectively(Agrawal et al., 2014).

Unlike cellulose and hemicelluloses, lignin is an aromatic polymer having a key role in plant cell walls as a binder or adhesive, which helps in reinforcing and adjoining all fibers together to build up a strong physical structure to sustain the harsh weather conditions(Bhagia et al., 2021; Chauhan et al., 2021). Lignin is chiefly considered responsible for the recalcitrant nature of plants, and its disintegration is a primary step for the extraction the sugars via microbial fermentation(Agrawal et al., 2018a). Lignin is composed of 3 types of monolignols/hydroxycinnamyl alcohols i.e. p- coumaryl, coniferyl, and sinapyl alcohols interlinked with each other by ether and carbon-carbon bonds like β-O-4, 4-O-5, β-β, β-1 and β-5 to make phenylpropanoid units such as p-hydroxyphenyl (H), guaiacyl (G) and syringyl (S). Out of these bondings, the β-O-4 linkage is most majorly present in about 40–60% of concentration. Lignin is linked with the polysaccharides by benzyl esters, benzyl ethers and phenyl glycosides linkages(Satlewal et al., 2018a; Satlewal et al., 2018b).

**5.0 Pretreatment technologies and process schemes**

Pretreatment is the most CAPEX intensive step in the second generation bioethanol production process(Agrawal et al., 2015b; Agrawal et al., 2017b; Agrawal et al., 2018b; Satlewal et al., 2019). Different types of pretreatment processes have been developed, which could be categorized into different groups depending upon the mode of pretreatment and pretreatment conditions such as physical, biological and thermal pretreatments with the potential use of other chemicals, as tabulated in **Table 8**.

The primary objectives of pretreatment are disintegration of the highly ordered structure of biomass in a manner to extract fermentable sugars from it using enzymatic hydrolysis. It involves breaking down the physical structure and strong bonding pattern between the closely interlinked polysaccharide and lignin structure with the help of thermal or mechanical action, sometimes in the presence of a catalyst. As shown by **Table 8**. The thermal and mechanical pretreatments are energy and cost-intensive processes in comparison to biological pretreatment, which is considered as a ‘green’, eco-friendly process but time-consuming. Among the three major types of pretreatments, thermo-chemical pretreatment has received the greatest attention, and most (if not all) of the commercial-scale plants are either based on dilute acid or steam explosion pretreatments with minor modifications. However, the major challenge is to further reduce the capital costs and make the process economical (Agrawal et al., 2015b; Satlewal et al., 2019; Satlewal et al., 2017).

**Table. 8. Salient features of different types of pretreatment approaches**

| Pretreatment | Temperature/ pressure | Chemicals | Inhibitors formation | Costs | Demonstration level/scale | Substrate agnostic | Mode of action | Pros | Cons | References |
|---|---|---|---|---|---|---|---|---|---|---|
| Biological | Mild temperature and pressure conditions | Nil | Nil | Low CAPEX and OPEX | Lab-scale | Yes | Brown and white rot fungi produce enzymes such as lacasses and degrade lignin to improve the enzyme accessibility | Green process, Environment friendly, Low CAPEX and OPEX, less energy intensive | Slow process, Low yields | (Agrawal et al., 2013; Galbe & Wallberg, 2019) |
| Mechanical | Mild temperature and pressure conditions | Nil | Nil | High CAPEX | Pilot-scale | Yes | Particle size reduction improve the substrate surface area, reduce cellulose crystallinity and degree of polymerization | High cellulose digestibility, No inhibitor generation | High energy and power required, High equipment costs | (Barakat et al., 2014; Kapoor et al., 2019) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Dilute acid | 120-180°C, High pressure (3-5 bar) | Mineral acids such as $H_2SO_4$, $HNO_3$, $H_3PO_4$ | High | Low OPEX, High CAPEX | Pilot, Demonstration and Commercial scale | Yes | Xylan hydrolysis develop pores to allow enzyme accessibility, Disruption of lignin-carbohydrate linkages | High cellulose digestibility, Hemicellulose hydrolysis | High inhibitors formation, Corrosive and hazardous conditions, High reactor costs due to specialized MOC | (Agrawal et al., 2015a; Agrawal et al., 2015b; Agrawal et al., 2017a) |
| Dilute alkali | ~100°C, Low pressure | Alkali such as lime and NaOH | Low | High OPEX, Low CAPEX | Pilot and Demonstration scale | Yes | Lignin solubilization and removal, Cellulose swelling, Disruption of lignin-carbohydrate linkages | Lignin removal, High cellulose digestibility, low inhibitor formation, High substrate surface area, No specialized MOC required for reactor | High alkali costs, Long residence time at low temperature reactions | (Satlewal et al., 2019) |
| Hot water | 180-230°C, High pressure (10- | Nil | Low | High CAPEX | Pilot-scale | No | Water acts as mild acid at high | Green process, No | Energy intensive, Large | (Agrawal et al., |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 15 bar) | | | | | | temperature, Acetic acid released from biomass further reduce pH to cause hemicellulose hydrolysis | chemicals added, Improved enzyme accessibility | water requirements, Low efficiency with woody and high lignin biomass | 2018b) |
| Organosolv | >120-180°C, High pressure (> 5 bar) | Organic solvents such as ethanol, methanol, acetone in addition with mineral acids as catalysts | Low | High CAPEX | Pilot and Demonstration scale | Yes | Lignin get solubilized and extracted with organic solvents, Small amount of acids further hydrolyze the hemicelluloses | Chemicals recycling, High purity lignin recovered | Added costs due to solvent recycling, High solvent costs | (Zhang et al., 2016)Win et al., 2016)(Kaur et al., 2021) |
| Steam explosion | 200-280°C, High pressure (15-25 bar) | Nil | Low | High CAPEX | Pilot, Demonstration and Commercial scale | Yes | Sudden pressure release disrupt the biomass structure, | Green process without any chemicals | Low cellulose digestibility, Hemicellulose | (Agrawal et al., 2018b; Semwal et al., 2019) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Water and acetic acid cause hemicellulose hydrolysis | | degradation, | |
| AFEX | 100-200°C, High pressure (> 10 bar) | Ammonia | Low | High CAPEX | Pilot and Demonstration | No | Disruption of biomass structure and lignin-carbohydrates linkages, partial lignin removal | High lignin removal, Ammonia is easy to recycle | Hazardous conditions, Low efficiency with woody and high lignin biomass, High cost of ammonia | (Gao et al., 2014; Mokomele et al., 2018) |
| Ionic liquids | 100-120°C, Low pressure | Imidazolium based ionic liquids such as 1-ethyl-3-methylimidazolium acetate | Low | High OPEX, Low CAPEX | Lab scale | Yes | Disruption of lignin-carbohydrate linkages by dissolving lignin/cellulose | Green nature of ionic liquids, High cellulose digestibility | High solvent costs, Ionic liquids might inhibit enzymatic hydrolysis, Solvent recovery and recycling is major issue | (Satlewal et al., 2018b; Satlewal et al., 2019) |

### 5.1 Pretreatment technologies and process schemes in India

India has taken up a daunting challenge to achieve the target of 20% ethanol blending in gasoline by the year 2030 as per the National Policy on Biofuel (NPB) – 2018. Thus, by working upon the Government guidelines, the Oil Marketing Companies (OMCs) are planning to set up 12 2G-Ethanol bio-refineries across 11 States, including Punjab, Haryana, Uttar Pradesh, Madhya Pradesh, Bihar, Assam, Odisha, Gujarat, Maharashtra, Karnataka and Andhra Pradesh. The estimated investment for the 12 bio-refineries is pegged at about Rs. 14,000 crore or 1.86 billion US $. According to the data available, about 381 billion liters of gasoline is expected to be consumed in the year 2020, and if only 20% of it is successfully replaced by ethanol, it has potential for foreign exchange savings is in the range of $8 - $10 billion USD every year (Abdi, 2019). The following are major 2G ethanol technology developers in India

#### Praj Industries technology

The Praj technology is mainly based upon dilute acid pretreatment, where hemicelluloses are hydrolyzed in the presence of a dilute acid catalyst. The basic process scheme is depicted in **Figure1**.

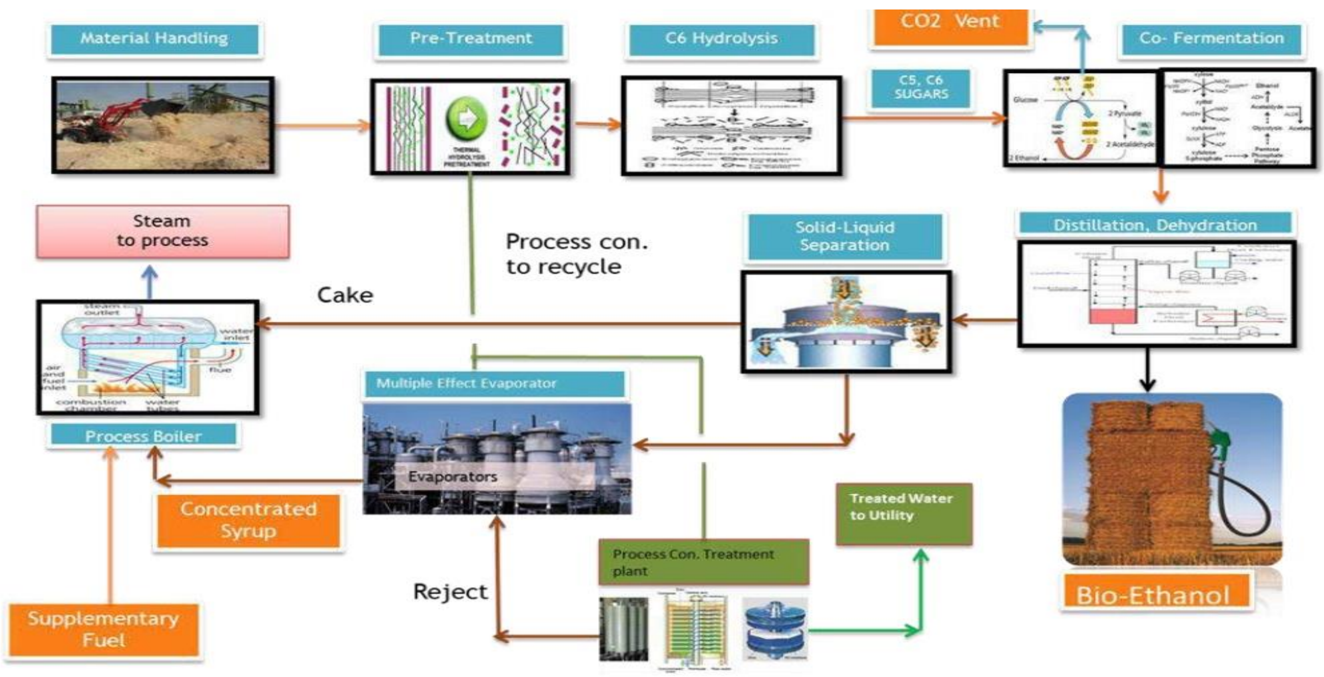


**Figure 1. Praj Industries 2G ethanol technology process scheme**

(http://environmentclearance.nic.in/writereaddata/Online/TOR/29_Jan_2018_162451553QH3SCU21AddDocCom.pdf)

The pretreatment reaction is carried out at about 18%-20% of solid loadings in the presence of a diluted mixed acid solution at about mixture 160 - 190 deg C and 10 - 12 bar pressure. After pretreatment, the reactor is flashed in a flash vessel, and the slurry is transferred to the enzymatic hydrolysis reactor. Finally, the saccharification was carried out at pH5 and 50-55ºC at atmospheric pressure. The process has an integrated system for water recycling and conservation.

**DBT-ICT Technology**

The DBT-ICT Centre, Mumbai, also developed a process for ethanol production from lignocellulosic biomass at demonstration scale (10 tons per day). Now the DBT-ICT Centre is working with industrial partners to design and scale up the technology to 400 ton/day scale with Engineering partners for the commercialization of the technology. This technology claimed to recycle the alkali, enzymes and other chemicals used during the process in order to reduce the operating costs.

The pretreatment is dependent upon the alkali and acid-based biomass fractionation technology where lignocellulosic biomass is fractionated into separate streams of glucose (C6), xylose (C5) and lignin. The C6 and C5 sugars produced as intermediates can be co-fermented to produce ethanol or can be converted to other chemicals, and ash-free lignin can be used directly as boiler fuel or via biogas for steam/power generation.

The salient features of this technology are as follows: a) continuous flow processing from biomass size reduction to fermentation; (b) low chemical, enzyme and water consumption through recycle and reuse; (c) Low overall processing time of 18 h from feed to alcohol; (d) zero liquid discharge; and (e) possibility of using C6 and C5 sugar intermediates for making other products. The process flow diagram is depicted below in **Figure 2.**

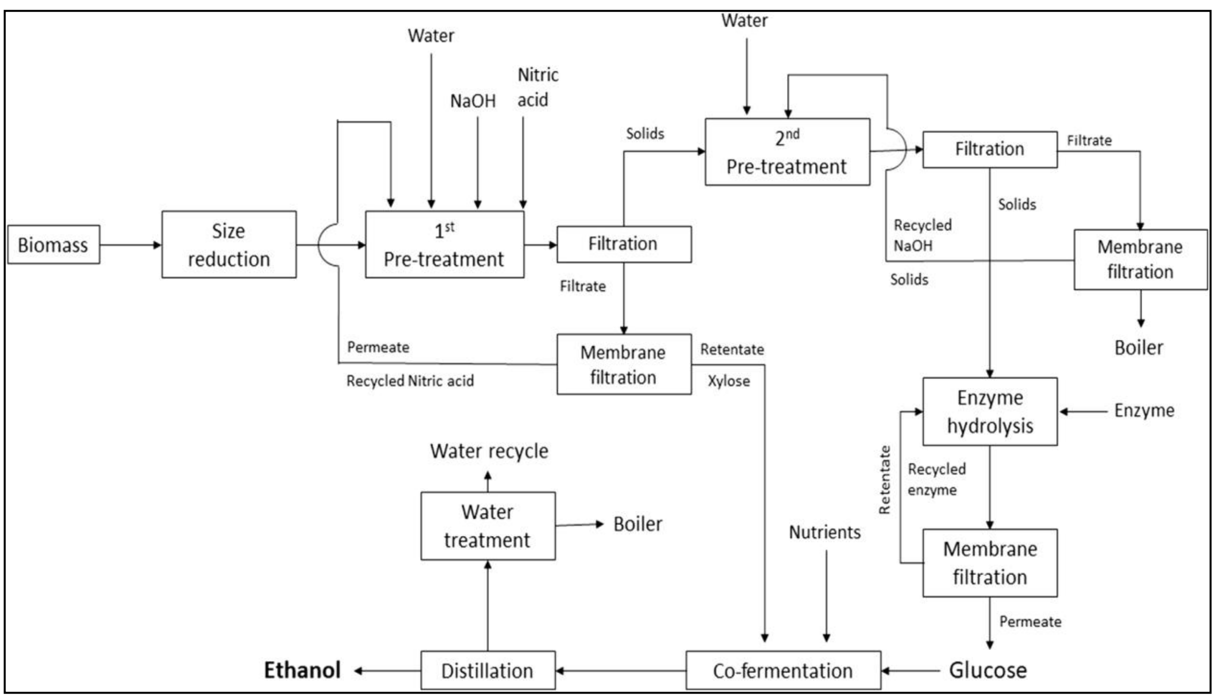


**Figure 2. Process flow diagram scheme of DBT-ICT technology (Reference: Sreekumar et al. (2020))**

The DBT-ICT technology could be divided into seven different steps such as milling, pretreatment, saccharification, fermentation and distillation. The biomass size is reduced from 3 to 5 cm to 200–500 micron in order to enhance the surface area and subsequently the fractionation process efficiency. The first pretreatment is carried out with dilute nitric acid to hydrolyze the hemicelluloses and recover the xylose after membrane filtration, and nitric acid is recycled back to the system while the xylose and other monomeric sugars are sent for co-fermentation. The solid residue recovered after the 1st pretreatment is subjected to 2nd pretreatment with alkali (sodium hydroxide) to extract lignin and generate cellulose for the enzymatic saccharification. After membrane filtration, the excess alkali is recycled back in the system. The lignin recovered after the process is burnt in a boiler to meet the energy demand of the plant. The membrane separation of the enzymatic hydrolysate containing the glucose syrup and enzymes is carried out to recover and recycle the enzymes and glucose syrup is co-fermented to produce bioethanol.

**DBT-IOC Centre technology**

DBT-IOC Centre for Advanced Bio-Energy Research at IndianOil RandD Centre Faridabad has developed Second generation (2G) ethanol technology which has primarily three main features: low chemicals acid pre-treatment technology, indigenously 2G enzyme technology with onsite enzyme production and novel simultaneous hydrolysis and co-fermentation (SSCF) technology, which provide almost half residence time compared to conventional technologies, resulting in lower sizing of fermenters. The key differentiator in DBT IOC Centre 2G ethanol technology is their integrated 2G enzyme technology.

IndianOil RandD is setting up 10 TPD 2G ethanol technology demonstration plants at Panipat to integrate all the processes including onsite enzyme production and optimize the process parameters to generate sufficient data for the commercialization of 2G ethanol technology. This demo plant is expected to be commissioned in Q3 2022.

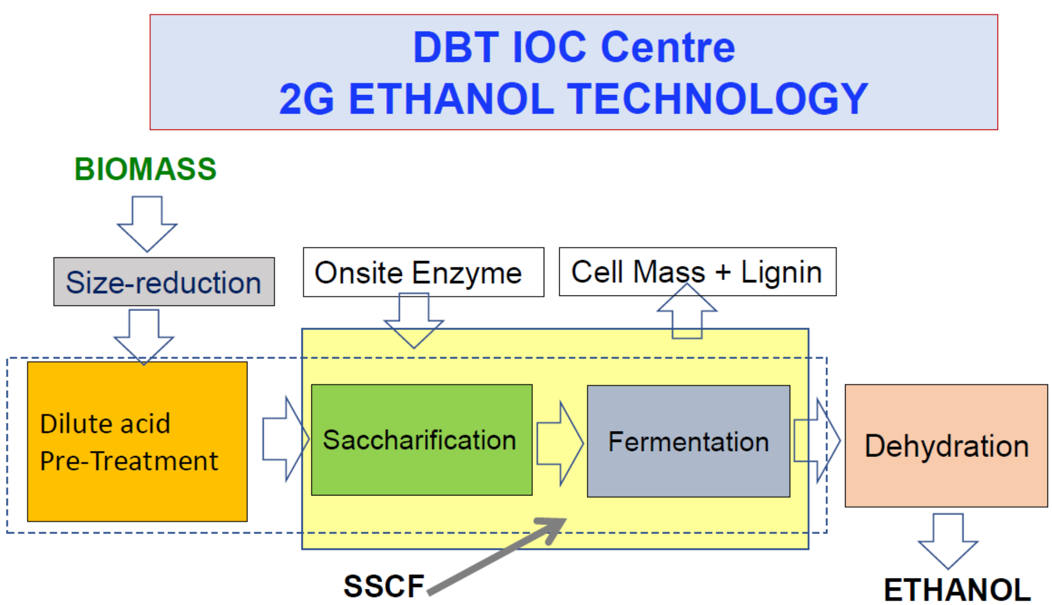


**Fig. 3. The schematic diagram of demonstration-scale DBT-IOC 2G Ethanol technology**

### 5.2 Pretreatment technologies and process schemes in Germany

A new commercial-scale 2G bioethanol production plant is coming up in the southwestern part of Romania at Podari near Craiova on the Clariant Germany technology with an annual capacity of 50,000 tons of cellulosic ethanol. The lignocellulosic biomass such as wheat straw, cereal straw, corn stover, or sugarcane bagasse procured from the local farmers will be used as a feedstock for 2G ethanol production in this plant has a capacity of about 250,000 tons of straw into cellulosic ethanol. Clariant is investing more than EUR 100 million in this plant. The project receives more than EUR 40 million funding from the European Union. The advantages of this technology are integrated process with climate-friendly, state-of-the-art technology, low enzyme costs thanks to integrated, on-site enzyme production, simultaneous one-pot fermentation of C5 and C6 sugars to ethanol, energy and water-efficient process, generation of process energy from by-products, flexible for different lignocellulosic feedstock.

### 5.3. Pretreatment technologies and process schemes in Brazil

The commercial-scale cellulosic ethanol production plants and their capacity are provided in table as below:

**Table 9: Details of leading commercial plants for cellulosic ethanol production in Brazil(Chandel et al., 2019)**

| S. No. | Company | Feedstock | Procedural configuration | Ethanol production (annual capacity) |
|---|---|---|---|---|
| 1 | RaízenEnergia, Costa Pinto São Paulo, Brazil | Sugarcane bagasse | Steam explosion-(logen process), yeast fermentation | 40 million liters<br>million liters |
| **2** | Gran Bio and Beta RenewablesAlagoas, Brazil | Sugarcane straw/bagasse | ProesaTM process, hydrolysis, fermentation | 21.6 MM gal. $year^{-1}$ |
| **3** | Centro de Tecnologia Canaviera (CTC)-Piracicaba, Brazil | Sugarcane bagasse | Continuous steam explosion, hydrolysis and yeast fermentation | 3 million liters per year |

### 5.4 Pretreatment technologies and process schemes in the USA

In 2017, POET-DSM's pioneer cellulosic ethanol production facility in Emmetsburg, Iowa, reported beginning to routinely achieve corn stover conversion yields of 70 gallons ethanol per bone-dry ton of biomass, close to this plant's design target. However, this facility remains in a ramp-up phase for plant throughput. More recently, POET-DSM announced it will add on-site enzyme manufacturing to this facility.

## 6.0 Biomass Supply Chain Analysis

### 6.1 Cellulosic Ethanol Production Value Chain

The value chain activities can be broadly classified as Biomass/Feedstock Production, Feedstock Handling, Bio-refining and Product Handling, Supply and Distribution. (Figure **4**).

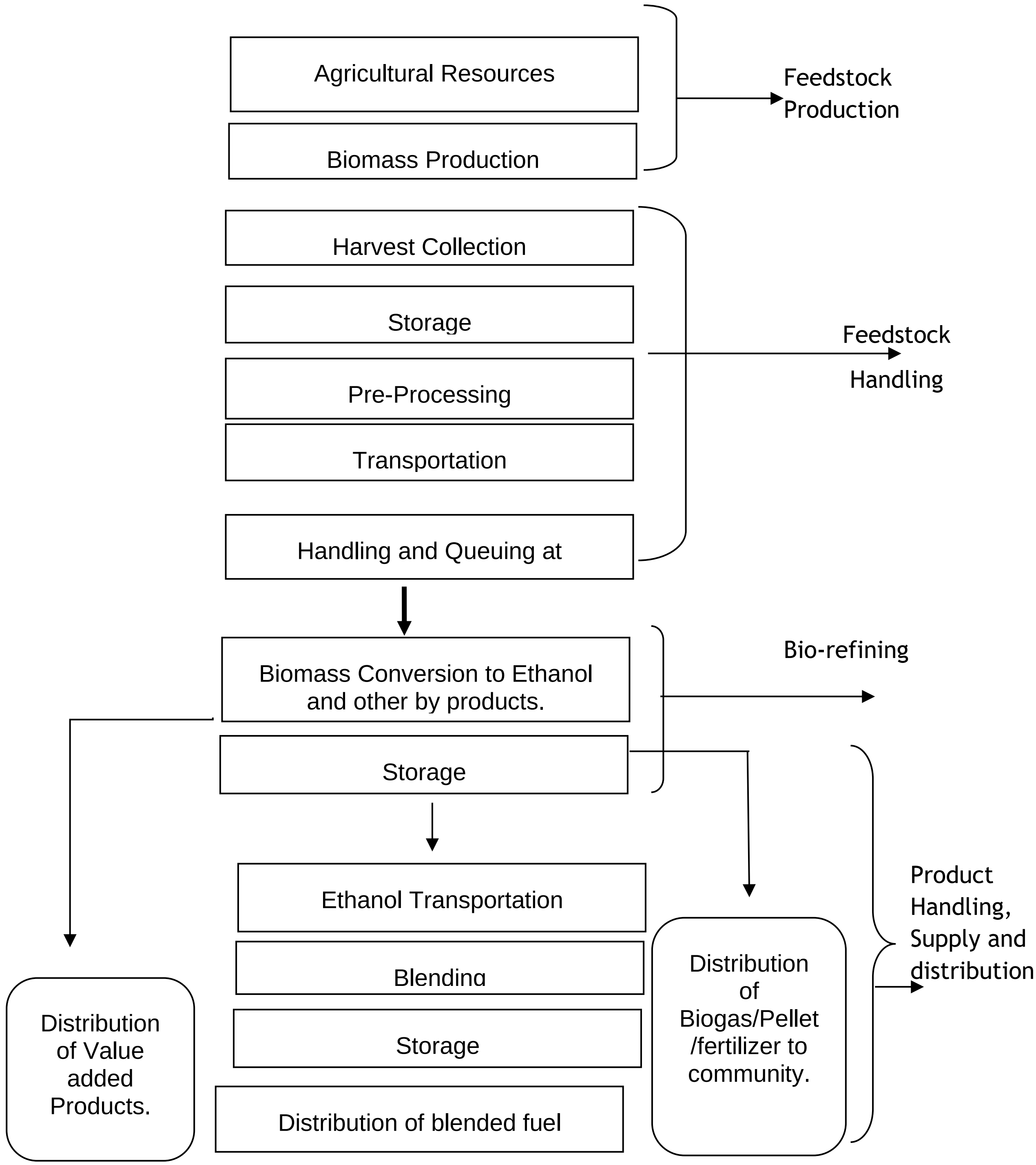


**Figure 4:Typical Lignocellulose Ethanol Production Value Chain**

Though it is assumed that cellulosic biomass is available in abundance, its collection and supply to the production unit involve various steps as mentioned below:

- Biomass feedstock production
- Harvesting and collection, and densification of biomass
- Forwarding it to a primary de-centralized collection point.
- Transportation from the primary de-centralized collection point to the plant.
- Size reduction, where required, so that the biomass is in a form acceptable to the plant.

A pictorial representation of the feedstock supply chain is given below (**Figure 5**):

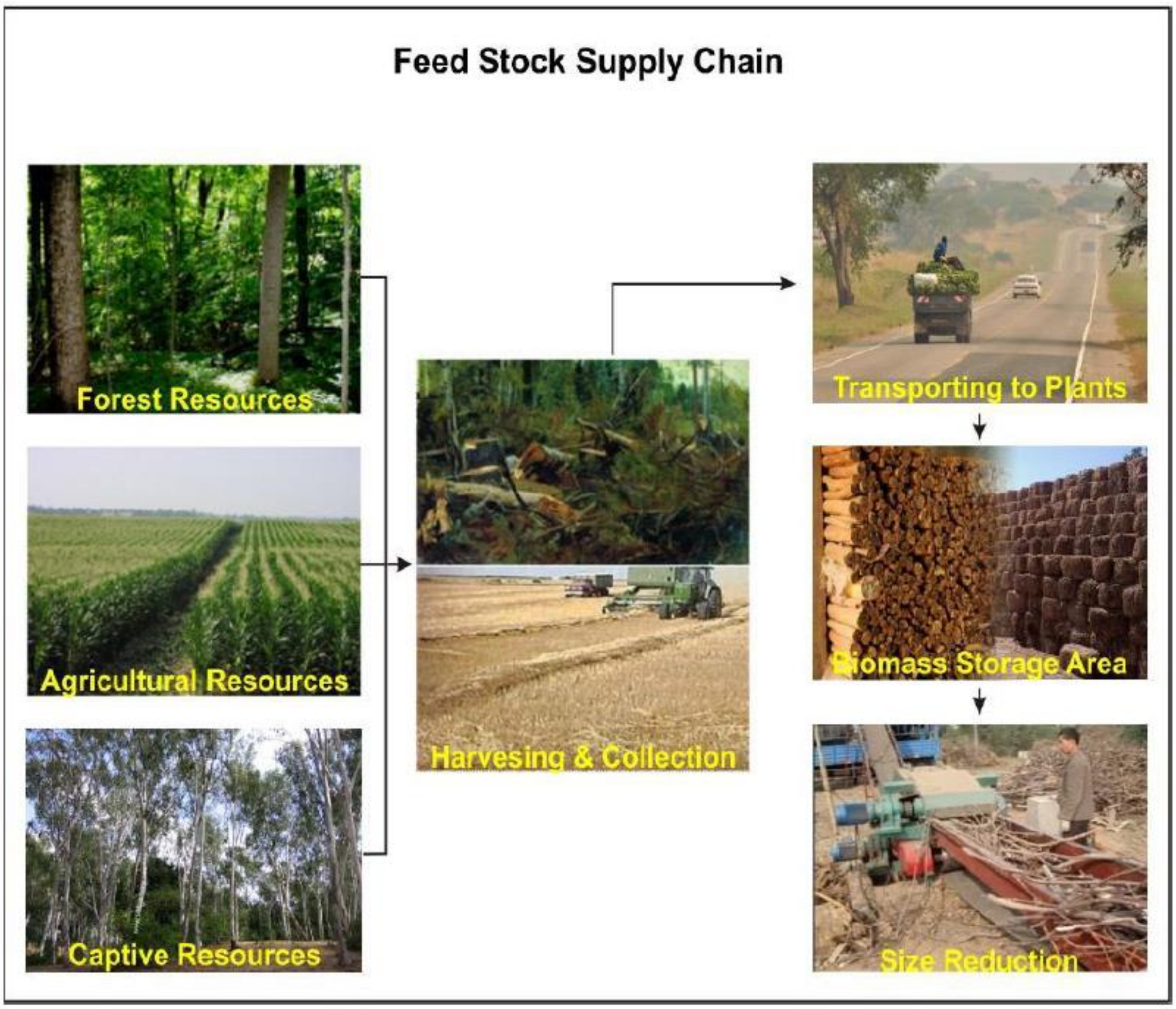


**Figure 5: Typical Components of the Feedstock Supply Chain**

### 6.2 Developing Sustainable Feedstock Value Chain

Worldwide, lignocellulosic based ethanol production projects developed significantly in recent years from pilot to commercial scale, thereby making a number of technologies available to infuse investor confidence. As far as biofuels are concerned, there is no constraint on the demand side. Several times OMCs have indicated their willingness to undertake offtake agreements. However, the major impediment to lignocellulosic ethanol is consistent feedstock supply. In India, most of the farmers have very small land holdings. Since, the farmers have limited resources and low exposure of advanced technologies, hence mechanization of the harvesting and baling process is very low. However, now entrepreneurs are coming up for supply chain business comprising procurement/collection, aggregation, baling and storage due to development of 2G ethanol plants and Compressed Biogas plants in India.

Issues related to feedstock can be categorized as under ( **Figure 6**):

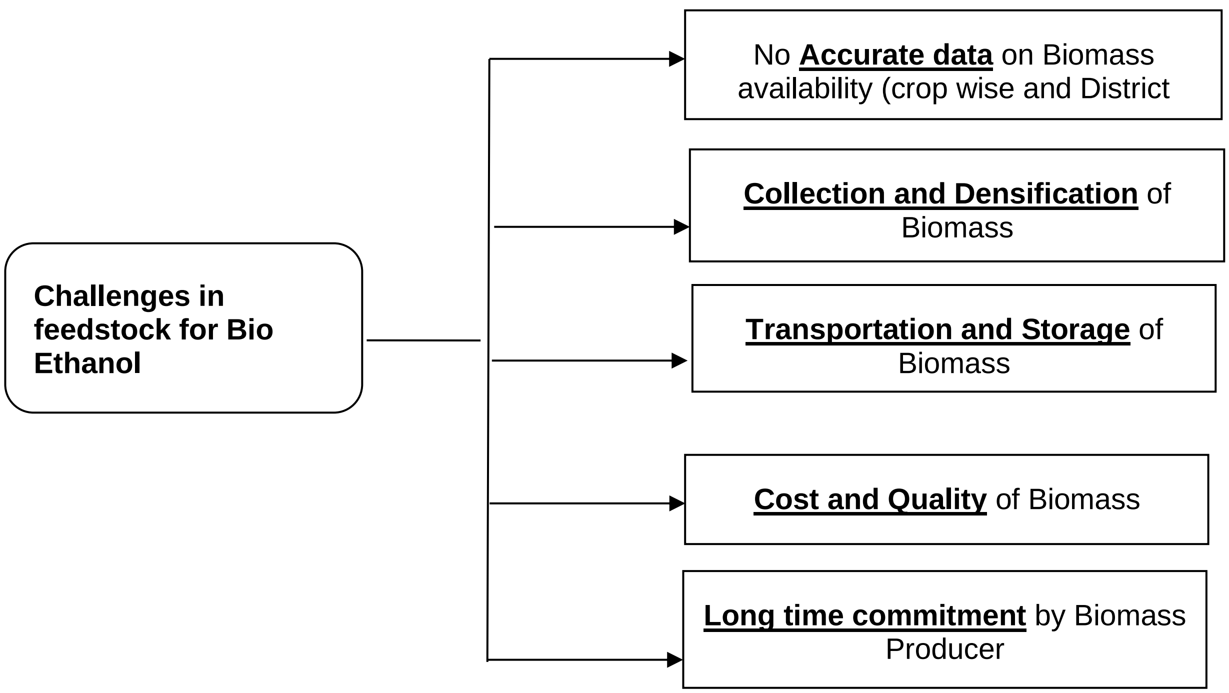


**Figure 6: Typical Challenges in Feed-stock for Bio Ethanol**

It may be clearly noted from the above that Biomass is very critical to lignocellulose-based ethanol projects, which needs to be addressed well before the commencement of any commercial project. For ensuring an uninterrupted supply of biomass over a more extended period at an optimal price, investors should consider various aspects of biomass production and supply chain management.

### 6.3 Models of Feedstock Supply Chain

Based on the various socio-economic and environmental factors, various models for supply chains or a combination of supply chain models may be adopted for ensuring consistent feedstock supply to the plant. Various supply chain models with key features are given below:

**Supply Chain Model**

**Model-I:** Local supply through biomass producers
In this model, the 2G ethanol company can directly procure biomass through the farmers. This way price of biomass can be lowered by having long term supply arrangements directly with large farmers. However any disruption in supply chain may affect the 2G ethanol production.

**Key Features**

- Direct contract with biomass growers
- Additional layers in the supply chain can be avoided.
- Additional costs of decentralized infrastructure can be saved.
- Sowing of the crop may be regularized by the ethanol-producing company, such as in the case of sugarcane.
- Dedicated harvesting teams may be created by the ethanol-producing company to ensure a controlled and continuous supply of biomass to the plant, as in the case of sugarcane.
- The entire downstream related risk is to be borne by the investors.

**Model II** - Supply through the Aggregator/ Organizer
In this model, the 2G ethanol company shall procure the biomass through long term supply arrangements with entrepreneurs who are in business of biomass supply chain. This arrangement will be helpful in consistent supply of biomass to the company. However, the biomass cost shall be higher.

**Key Features**

- Creating mediators like cooperatives/NGO'S etc., for aggregation and possible densification or processing of biomass.
- A decentralized Primary biomass collection centre may be created by the company.
- Investors in the upstream value chain may participate in ensuring consistent biomass supply.
- Project Risk may be distributed.
- Risk related to the upstream of the value chain can be distributed to Supply Chain Management Company (SCMC).
- Extensive community participation in biomass collection and densification.

**Model-III -**Producer Organisation

In this model, 2G ethanol company shall procure biomass from biomass producer organisation, who may also be shareholders in the company, This model is similar to cooperative model.

**Key Features**

- Producer organizations/co-operatives is formed by a group of producers for either farm or non-farm activities.
- It is a registered body and a legal entity.
- Producers are shareholders in the organization.
- It deals with business activities related to the primary produce/product.
- It works for the benefit of the member producers.
- The producers share the profit, and the balance goes to the share capital or reserves.
- Producer's organizations or collectives are considered institutions that can protect small farmers from adverse effects.
- Producer organizations help farmers buy or sell better due to scale benefits and lower transaction costs for sellers and buyers, besides providing technical help in production and creating social capital.

**6.4 Models Applied in Rural India for Agri-produced Logistics**

India is a diverse country divided into various agro-climatic zones. Each zone has the typical Agriculture practices that have evolved over time. Rural communities of different regions have different cropping patterns and cultures, which defines the socio-economic culture of the region. Keeping the socio-economic aspirations of the rural community in the centre of the project, various agri input companies are successfully running their projects in rural India. Key features of a few rural supply chain models of a few organizations are depicted below:

**ITC E-Choupal Model**

The ITC e-Choupal is an innovative model embedded with social goals which empowers farmers and hopes to trigger higher productivity and income through a host of services related to know-how, best practices, timely and relevant weather information, a transparent discovery of prices, access to quality agri-inputs at competitive prices and so on. This model makes use of the physical transmission capabilities of current intermediaries - aggregation, logistics, counter-party risk and bridge financing -while disintermediating them from the chain of information flow and market signals.

The ITC e-Choupal model has been specifically designed to tackle the challenges posed by the unique features of Indian agriculture, characterised by fragmented farms, weak infrastructure and the involvement of numerous intermediaries, among others. e-Choupal' also unshackles the potential of the Indian farmer who has been trapped in a vicious cycle of low risk-taking ability > low investment > low productivity > weak market orientation > low-value addition > low margin > low risk-taking ability. This made the farmer and the Indian agribusiness sector globally uncompetitive, despite rich and abundant natural resources.

Such a market-led business model can enhance the competitiveness of Indian agriculture and trigger a virtuous cycle of higher productivity, higher incomes, enlarged capacity for farmer risk management, larger investments and higher quality and productivity.

Further, a growth in rural incomes will also unleash the latent demand for industrial goods so necessary for the continued growth of the Indian economy. This will create another virtuous cycle propelling the economy into a higher growth trajectory. Appreciating the imperative of intermediaries in the Indian context, 'e-Choupal' leverages Information Technology to virtually cluster all the value chain participants, delivering the same benefits as vertical integration in mature agricultural economies like the USA.

'e-Choupal' makes use of the physical transmission capabilities of current intermediaries - aggregation, logistics, counter-party risk and bridge financing -while disintermediating them from the chain of information flow and market signals.

With a judicious blend of click and mortar capabilities, village internet kiosks managed by farmers - called sanchalaks, enable the agricultural community to access information in their local language on the weather and market prices, disseminate knowledge on scientific farm practices and risk management, facilitate the sale of farm inputs (now with embedded knowledge) and purchase farm produce from the farmers' doorsteps (decision making is now information-based).

Real-time information and customised knowledge provided by 'e-Choupal' enhance the ability of farmers to take decisions and align their farm output with market demand and secure quality and productivity. The aggregation of the demand for farm inputs from individual farmers gives them access to high-quality inputs from established and reputed manufacturers at fair prices. As a direct marketing channel, virtually linked to the 'mandi' system for price discovery, 'e-Choupal' eliminates wasteful intermediation and multiple handling. Thereby it significantly reduces transaction costs.

'e-Choupal' ensures world-class quality in delivering all these goods and services through several product/service-specific partnerships with the leaders in the respective fields, in addition to ITC's own expertise.

While the farmers benefit through enhanced farm productivity and higher farm gate prices, ITC benefits from the lower net cost of procurement (despite offering better prices to the farmer), having eliminated costs in the supply chain that do not add value.

Launched in June 2000, 'e-Choupal', has already become the largest initiative among all Internet-based interventions in rural India. 'e-Choupal' services today reach out to over 4 million farmers growing a range of crops - soybean, coffee, wheat, rice, pulses, shrimp - in over 35000 villages through 6100 kiosks across 10 states (Madhya Pradesh, Haryana, Uttarakhand, Uttar Pradesh, Rajasthan, Karnataka, Kerala, Maharashtra, Andhra Pradesh and Tamil Nadu).

The problems encountered while setting up and managing these 'e-Choupals' are primarily of infrastructural inadequacies, including power supply, telecom connectivity and bandwidth, apart from the challenge of imparting skills to the first-time internet users in remote inaccessible areas of rural India.

Going forward, the roadmap includes plans to integrate bulk storage, handling and transportation facilities to improve logistics efficiencies.

**Key Elements of Supply Chain Model**

- ✓ ***Sanchalak***: A village-level ITC kiosk with internet access is placed in the house of a lead farmer.
- ✓ ***Samayojak* Hub**: A brick-and-mortar infrastructure – the procurement centre – located within a tractorable distance (25-30km), a similar distance to other procurement channels used by target farmers in the area managed by a Consignment Agent – now called the samayojak
- ✓ **An ITC *Choupal Saagar* procurement-cum-Retail Hub:** Bringing appropriate farm and non-farm services close to farmer's doorstep

**Salient Features of Model**

- Decentralized model for Agri-produce procurement.
- Created a larger rural ecosystem, which together has ensured that fortune was created 'FOR' the bottom of the pyramid, rather than merely seeking a fortune 'AT' the bottom of the pyramid.
- Model Agriculture Produce Marketing Committee (APMC) Act to enable a direct interface between farmers agri-businesses and to expand the scope for value creations.
- Creating a congenial eco system where each stakeholder aspiration was protected.
- Accurate prediction and supply chain management of agri-produce

**Amul Model**

The Amul model is based on the supply chain practices of the Gujarat Co-operative Milk Marketing Federation (GCMMF). GCMMF is owned by a chain of farmers who formed a network of cooperative societies. Milk was collected from more than 2.4 million farmers in 11,615 villages twice a day and tested, graded, and transported to the processing centres. GCMMF's products were marketed through 50 sales offices located across India to 4,000 stockists. These stockists supplied the products to more than 500,000 retail outlets.

**Key elements of Supply Chain Model**

- ✓ Village Cooperative societies are owned by producers.
- ✓ Milk processing units and ware house.
  - Whole seller and CandS
  - Retailers
- ✓ Home delivery contractors

**Salient Features of Model**

- The entire value chain –from procurement to processing and marketing – is controlled by the farmer's cooperative, directly linked to the final customer.
- The Cooperative collects the milk directly at the producers' doorsteps.
- Active participation of farmers in decision-making, as well as transparency and democratic management.
- Fair pricing mechanism of produce.
- Large reach- even a producer producing only 2 litres a day can benefit from the programme. Farmers receive 80% of the retail price through up-front payments when the milk is sold and subsequent distribution of profits as a corporate member.
- Effective governance-in the Amul model, farmers own the company that controls the post-production stages of procurement, processing, and marketing of milk and milk products.
- Coordinated delivery of services- These include technical support, collection, market access and brand name development and distribution.
- Value-added/Vertical integration- Amul is vertically integrated from production to retail.
- Information flow- Procurement prices are announced in advance and are variable according to fat content.
- Trust-Trust has been established through farmers´ participation in the ownership of the enterprise and through transparency with regard to business transactions and elections.
- Capacity building-There is considerable focus on capacity building

**PRESPL (Punjab Renewable Energy Systems Private Limited) model**

PRESPL is one of the largest organized players in the Bio-Energy Supply Chain Management (SCM); successfully catering to Biomass requirements of IPPs (Independent Power Plants), Captive and Co-Generation Power Plants and processing plants covering aggregation, processing, storage and transportation; dealing with farmers, through VLEs till industry, with adequate earnings and profits for all stakeholders.

**Key Elements of Supply Chain Model**

- ✓ **Collection Centre Model**
  - Biomass is collected during the season and stored at different collection centers (CC) identified in the catchment area of the plant (about 15-20 km radius).
  - About 25 kg rectangular bales are formed, which are stacked at a height of about 4-5 meters with space between them for a fork lifter as well as air movement. Necessary precautions are kept for fire
  - At different CC about 8000-10000 tons of biomass is stored in open areas. The area required is about 10 acres at each CC.
  - The stored biomass is processed and transported to the plant as per requirement

- ✓ **Direct to plant supply model ( during harvest season)**
  - Biomass is directly transported to the plant from the field. Biomass is collected, processed and transported to the plant for ready use.
  - Storage of biomass at the plant area

**Salient Features of Model**

❖ **Biomass collection strategy**

- Reducing the frequency of collection ( i.e. to collect when it is available most)
- Implementing post-harvest collection of crop residue and recyclables
- Automating collection practices like cutter, Recker and Baler (Automated and semi-automated collection vehicles to improve efficiency and reduce cost. Both vehicle types reduce manual labor)
- Introduction of Village Level Entrepreneur (VLE), who are assigned to achieve the targets of biomass supply set by PRESPL

❖ **Pre-Operation Activities**

- Starts four-five months before the harvest season
- Survey and Feedback recording and in-depth analysis
- Identification and setting up of Collection centers (CC) according to the available data

- Advertisement and awareness programs in catchment areas via mass media, social societies, community and religious centers.
- Seeking help from local administrative bodies to prevent burning of biomass by farmers.
- Identifying and contracting with labor and biomass contractors.

❖ **Post-Harvest/Operational Activities**

- Biomass Processing in fields – Cutting, Baling etc.
- Logistics planning and Transportation of biomass from fields to CC and/or to Plant.
- Smooth functioning (Operation and maintenance) of CCs, weighing, storing, processing (if required) and security.
- Contractor/VLE Management, advertisements and awareness programs.
- Continuous and multi-level training and skill honing of Field Officers, Technicians, Collection centers, Contractors (Balers, laborers).
- Ensuring Biomass Safety

**Food Security Army, Kerala**

Food Security Army (FSA) is an initiative in the state of Kerala in India wherein they provide agro machinery at the door step of the farmer to receive instructions for execution of works on his farm. The FSA has the technical knowledge of farming operations and is trained to carry those out with modern agro machinery. They are attired in FSA uniform and are ready to render services round the clock. Their services can be sought through mobile phones and are the service providers for farming activities (source: https://rkvy.nic.in/static/download/RKVY_Sucess_Story/Kerala/Food_Security_Army.pdf).

**Key Elements of Supply Chain Model**

- A dedicated team of service providers in agri-services.

**Salient Features of Model**

- A dedicated group of enthusiastic professionals trained to provide comprehensive solutions to agro-social problems faced by farmers in their day to day farming or any other financial activities.
- Solutions at door steps.
- After-sales services in Agri industries.
- Active participation of the community in decision making.
- Dissemination of advanced Agri mechanizations practices.
- For Mobile Agro Machinery Training Unit, Mobile Agro Machinery Repair and Service Unit, Farm Machinery Facilitation Centre and Agro Machinery Operation Service Centre.

**Producer Organization- SAFAL(NDDB)**

India is the world largest producer of many vegetables but there still exists huge gap between per capita demand and supply due to enormous waste during post-harvest handling & marketing. These losses are a missed opportunity to recover value for the benefit of farmers. The deploying of appropriate strategic and operating models, will allow the efficient closure of gaps between demand and supply so as to contribute to doubling farmers' income. The gap between demand and supply is due to ineffective market links, poor handling and lack of consolidation on both the demand-side and supply-side. On the supply side, the government has agenda to promote modern cultivation practices and collaborative farming. On the demand side, the government has example of NDDB's vegetable marketing initiative, ie. Mother Dairy Fruit & Vegetable Pvt Ltd (SAFAL) (source: https://nccd.gov.in/PDF/Analysis_NDDB_veg_model.pdf). The NDDB (National Dairy Development Board) model can be understood in its 2 main product formats – for Milk and the case of SAFAL for fruits and vegetables.

**Key Elements of Supply Chain Model**

- Crop-specific producers organizations are formed/linked by SAFAL (NDDB)
- It has a relationship with various input companies like Monsanto, Pioneer, Morarka, etc. which can further link to producers organizations for various agri-input services.
- SAFAL also launched in 2010 a market development programme for rural producers called Ode to Earth, under which products from 65 groups are being marketed and sold. It has been able to garner support from funding agencies like Sir Ratan Tata Trust (SRTT), Rabo Bank and government programmes like Rashtriya Krishi Vikas Yojana ( RKVY), Rashtriya Swasthya Bima Yojana (RSBY) and SFAC (Small Farmers Agri-Business Consortium)

**Salient Features of Model**

- Fruit and Vegetable (SAFAL) Shops are opened for the ESM and their dependent sons since 1989. The Scheme is available in NCR viz Gurgaon, Ghaziabad, Noida/Greater Noida, and Faridabad.
- The selected concessionaire undergoes free training for two weeks with Mother Dairy prior to the allotment of booths/shops.
- Remunerations up to 9% for the sales of fruits and vegetables (Safal shops) and 3% for Dals(Pulses)
- Felling of ownership inculcated amongst the farmers /producers communities
- Upwards and downwards linking established for betters profit realizations

**6.5 Suggested Action Plan for Supply Chain Management for Assured Bio Mass Supply**

| What | How |
|---|---|
| Collection of reliable data on surplus biomass available in Targeted area | ▪ Synthesize knowledge about season-wise crop yielding patterns, crop residue production, availability, utilization pattern, surplus availability, collection efficiency, quality, and environmental social and economic impact.<br>▪ Apply latest tools and techniques to the existing data on yield, quality and environmental impact and analyze it in a process-based model as well as create more data (say via remote sensing)<br>▪ The application of the latest measurements like crop eco-physiology analysis to ascertain the overall sustainability.<br>▪ A secondary data source may be referred to for collecting information on surplus biomass data available in the targeted region.<br>▪ Carry out a detailed survey in the area to collect accurate information about the availability of surplus biomass.<br>▪ Proper checks and balances and monitoring of data collection activities should be ensured<br>▪ Proper analysis of collected data must be done to draw a meaningful conclusion/input for the project. |
| Creating awareness amongst biomass producers | ▪ Engage local people and local languages in awareness programmes.<br>▪ Educate farmers through various audio visual aids regarding financial, social, and environmental benefits of disposing surplus biomass to the bio mass supplier company<br>▪ Creating the right eco system for farmers participating in bio mass supply chain activities. |
| Interventions of Mechanized farming practices | ▪ Analysis of current harvesting technology at various parameters like crop quality, cost, time taken, fuel efficiency, biomass qualities and attributes and areas of improvement shall be marked<br>▪ Analysis of Innovative harvesting technology in terms of feasible and financial affordability such as combine harvester and baler machines or rice straw cotton stalk etc.<br>▪ Engage Agri farm machinery Suppliers for providing customized solutions for various agricultural activities like harvesting, baling etc.<br>▪ Local entrepreneurs should be engaged and trained to develop |

| | |
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| | customized farm equipment.<br>▪ Optimization of harvesting operations to determine biomass quality, cost and sustainability and reducing storage capacities<br>▪ Optimization of bulk densification process –both from equipment and operation point of view.<br>▪ Optimization of baling, chopping and briquetting technologies by calculating its energy balance and cost effectiveness with respect to radius of collection. |
| Transportation, handling and storage | ▪ Total area of operations (radius of 30-50 Km.) will be optimized.<br>▪ Decentralized information cum procurement centre located within a tractorable distance (10-15 km), a similar distance to other procurement channels shall be created and preferably managed by a local agent.<br>▪ Procurement hub may be supported by the kiosk with internet access from that farmer can assess information with respect to price, latest agronomy or any other latest information related to agriculture |
| Effective bio mass logistic chain | ▪ Preparation of detailed crop harvesting window of the crop residue from the field.<br>▪ Logistics calendar of biomass supply to collect information on biomass available in harvesting window and increase its bulk density to improve transport and storage facilities<br>▪ Optimizations of supply chain model through planning and logistics design to assess the economic potential and sustainability in the supply chain given various scenarios viz. different type of feedstocks, primary and secondary ware house distance, different end uses of products, and different technologies. etc.<br>▪ Assessment of Socio-economic and environmental suitability and sustainability of entire biomass supply chain<br>▪ Provision of a dedicated fund for development of supply chain management infrastructure in project cost |

| | |
|---|---|
| Assured bio mass availability to the plant | ▪ Clustering of ethanol plants in specific areas of operation may lead to competition for biomass and may result in underutilization of capacity as experienced in the case of rice mills in various states of India<br>▪ Command area concepts like sugarcane should be enforced |
| Mechanization of biomass collection | ▪ In India, the time gap between crops are very short. Therefore, cutting of crops, collection of biomass and bailing is required to be mechanized. In view of this, biomass supply chain entrepreneurs are required to invest in the mechanization of crop cutting, collection and bailing to complete the process in the minimum possible time. Most of the farmers in India cannot afford to invest in a mechanized process and, therefore, burn their biomass residues (stubble) after harvesting to clear the fields for tthe next crop.<br>▪ Therefore, it is very important that biomass supply chain entrepreneurs should invest in machines and collect the biomass from fields in the minimum possible time. |
| Biomass Storage | ▪ Appropriate storage of biomass is required for running a commercial 2G bioethanol plant year-round without degrading the biomass quality despite the seasonal variations of weather. For example, rice straw is a seasonal crop and is available for a few months only. Therefore, it needs to be stored for plant operation for the next 8-9 months, duly protected from moisture, microbial degradation, and catching fire. Unfortunately, this area was ignored in the past, and very limited data is available in the public domain.<br>▪ Thus, stakeholders need to conduct a focussed study, explore opportunities, and develop models to find a practical solution to store biomass and make it available year-round for 2G ethanol production. |

## 7.0 Challenges in Supply Chain management in India

Bio-ethanol business in India is attracting wider attention from various stakeholders ranging from the Union government, State governments, Project investors, other investors in the value chain, farmers etc. to name a few. Feedstock supply is one of the most critical components of any biomass-based project, primarily due to its scattered production (i.e. production by masses). The success of this sector largely depends on the sustainability of biomass supply chains. This calls for an urgent need to pursue a multi-pronged strategy to make the supply chain selfsustainable. In the Indian context, six critical sustainable and robust biomass supply chain development and management issues and possible redressal mechanisms are discussed below:

### 7.1 Ex-situ Management of Biomass / Crop Residues

Currently, there is no dedicated policy for ex-situ management of crop residues. Therefore, entrepreneurs, including business organizations, may not find it attractive to enter into the activity of aggregation of crop residues. It may be prudent to have an attractive central or centrally sponsored scheme to promote ex-situ management of crop residues.

### 7.2 Role of Government in Resource Mapping

There is a requirement of block-wise mapping of biomass production (with its type), its availability (crop-wise), Plants/utilities based on biomass, the extent of their utilization, a net surplus of biomass, availability of revenue/panchayat land etc. This will help in defining and earmarking a cluster dedicated for each of these Plants and utilities. A realistic assessment of the aforementioned items is required. In the past, there has been a wide difference between the reported data and actual site conditions. In the presence of these inputs, all players in the biofuels' supply chain would be able to correctly assess their business potential and accordingly plan their investment. Clustering of the area and mapping it to a specific Plant may help in the availability of biomass at a reasonable price.

### 7.3 Pricing of Feedstock

Price of most of the biofuels viz. Biodiesel, Bio-ethanol, Compressed BioGas, etc., has already been fixed by the government for a medium to long term basis. These prices are not linked to feedstock prices. In fact, the feedstock pricing has been left to market forces. It means that there is pricing regulation in the downstream side of the biofuels' value chain (i.e. demand side) but no such mechanism is available for upstream (feedstock supply) side. This disconnect between the two sides of the business is likely to strain the linkages between the two ends, thereby making the venture non-sustainable, more so as this sector is in the evolution stage only. *To make this business sustainable, there is a requirement to link pricing of biofuels with the pricing of feedstock*. A certain portion of this feedstock cost could be compensated by the government in various forms. One of the ways to do so could be in the form of a price subsidy.

### 7.4 Incentives by Government during Initial Period (next 3-5 years)

Government may have to provide incentives/subsidies on land required for setting up biomass aggregation and storage and working capital to fund this process. Financial institutions (FIs) may be asked to create a dedicated fund for this purpose. As this funding (cost reimbursement of biomass aggregation) would be for a relatively volatile sector (due to price variation and inconsistent availability of biomass), there is a need to provide an adequate comfort to these FIs in case of any financial issues.

### 7.5 Similarity in Approach for All Bio-Energy Projects

Biomass is used in multiple bio-energy projects. Power projects are one such example. The Central Electricity Regulatory Commission (CERC), a statutory body under the Ministry of Power, fixes electricity tariffs for the power generated from biomass utilization. In this tariff calculation, the cost of biomass is also taken into consideration and declared annually. By doing so, a base price, which is higher (>Rs 3400/Ton for some states), already gets fixed for such biomass in the applicable area /region. If there are other bio-energy projects such as CBG, Bio-ethanol etc., also in such areas or nearby areas, it becomes very difficult for these plants to operate profitably at this higher price of feedstock. Therefore, there is a need to remove this anomaly by either linking biofuel prices to biomass prices, as done in the case of biomass-based power projects, or making the upstream side (biomass supply) similar for all projects by following a consistent approach.

### 7.6 Awareness Generation and Extension Activities

It is perceived that there is more awareness among farmers and entrepreneurs of certain states such as Punjab and Haryana with respect to opportunities available in biomass aggregation and supply than in other states. However, more efforts are needed by the Agriculture department and renewable energy authorities of the respective states to enhance this awareness about the economic value of the biomass, its utilization through existing government schemes, aggregation equipment used in the management of biomass/crop residues, demonstration of this equipment etc. Some of these aforementioned factors, if appropriately implemented, may help in developing a sustainable biomass supply chain.

## 8. Life cycle analysis and environmental impact assessment

### 8.1. Environment impact of commercial bioethanol plants in India

Enhanced global concerns about climate change and the highly volatile costs of fossil fuels are the primary rationales behind the research and development in the area of renewable and alternative sources of energy. The production of second-generation (2G) bio-ethanol from lignocellulosic biomass has attracted wide interest because of its potential to partially replace the liquid transportation fuels, which contribute about almost 18% of the global GHG. Over 20% of energy-related $CO_2$ emissions are produced by the transportation sector (Liu et al., 2020). Another advantage of 2G bioethanol is the absence of competition with food crops and land use issues. 2G ethanol is more suited for developing nations like India, where substantial amounts of agro-based residues (such as rice straw stubble) are generated and left on the field as waste or burnt on fields as a waste management practice. This practice leads to severe air pollution and disturbs the natural soil micro-flora and fauna. Hence, it is critical to carry out environmental impact assessment studies and find out the hotspots of GHG emissions for bioethanol production from agro residues in a sustainable manner. Life cycle analysis is considered as an approach to critically evaluate the process of utilizing the lignocellulosic biomass for 2G bioethanol production, screening of new technologies, and to identify the main drivers of the environmental profile of bioethanol, thereby indicating priority areas for potential improvements.

Unlike the US, Brazil and Europe, where second-generation (2G) bioethanol production is based upon corn, sugarcane and wood as feedstocks, Indian 2G bioethanol production is mainly dependent upon non-food and non-fodder agricultural residues such as rice straw, cotton stalk and mustard stalk. In this section, life cycle analysis with a focus on Indian subcontinent in particular with Indian specific feedstocks (such as rice straw, wheat straw, cotton stalk, mustard stalk, sugarcane baggase) and pretreatment technologies (dilute acid pretreatment, alkali pretreatment, steam explosion and ammonia pretreatment) were evaluated.

Rice is amongst the top 3 primary staple cereal crops in the world and feeds more than half of the world population. In the year 2017, 687 million tons of rice were produced in Asia, with India as the top exporter to the world. At cultivation and during harvesting of rice grains, several byproducts are generated, which include panicle rachis, leaf blades, leaf sheaths, and stems which are collectively known as rice straw. Typically, about 1.5 tons of rice straw is generated per ton of rice. This will produce about 250 million tons of rice straw in India, corresponding to 165 million tons in the year 2017 (Satlewal et al., 2018a).

Soam et al. (2016) conducted an environmental impact assessment study on the production of second-generation bioethanol in India using rice straw as the feedstock. Actual experimental inventory data was collected in a pilot-scale facility commissioned at IndianOil RandD Centre, Faridabad, India (https://www.dbtiocberc.org/facilities/). Two different pretreatment approaches (dilute acid (DA) and steam explosion (SE)) were evaluated for the Greenhouse gas (GHG) emissions, net energy ratio (NER) and net energy balance (NEB). One MJ transportation fuel is the functional unit in this study, and the results were compared with gasoline.

This study showed that total ethanol production yields from rice straw through different pretreatment approaches such as dilute acid (DA) and steam explosion (SE) were only marginally different from each other. By dilute acid approach, 239 liters of ethanol is produced from each ton of rice straw as compared to 253 liters of ethanol from steam explosion.

As expected, the GHG emissions were minimum with steam explosion (288 kg CO2 eq./ton straw) compared to dilute acid (292 kg CO2 eq./ton straw). Thus, steam explosion offered dual advantages over dilute acid pretreatment, i.e. high ethanol yields with a lower carbon footprint. It was observed that “enzyme production” is the hotspot with the highest GHG emissions in both the DA and SE based technologies for ethanol production.

The net energy input with dilute acid based pretreatment process was 1736 MJ/ton straw and 1377 MJ/ton straw with steam explosion pretreatment. The utilization of waste containing lignin as a solid fuel to meet the energy demand of the ethanol production plant by partially replacing the coal-derived electricity is the chief contributor to the reduction in GHG emissions during bioethanol production.

However, if coal-based electricity is replaced with another alternative, such as renewable clean sources of electricity (hydro, solar or wind-based) then these benefits would get nullified as in the case of developed nations in the US and Europe, where the contribution from clean renewable sources in electricity generation is high. The comparative evaluations with gasoline showed a reduction of GHG emissions by 89% and 77% with NER of 2.7 and 2.3 for the steam explosion and dilute acid pretreatment, respectively.

In another interesting research study carried out by Indian Oil RandD, Faridabad, India, the impact of extractives removal by different concentrations of alkali prior to dilute acid pretreatment was evaluated for ethanol yields, enzyme requirements and life cycle assessment

(Soam et al., 2018). It was observed that ethanol yields increased from 218 to 267 L by extractives removal pre-procedure using alkali.

The enzyme requirements were reduced by ~20-40%, depending upon the concentration of alkali used in the modified dilute acid pretreatment approach. It is due to the fact that alkali-based pre-processing step removed most of the extractive and small amount of the lignin, and it reduced the undesired solids to be treated during enzymatic hydrolysis and simultaneously improved the enzyme efficiency with better substrate accessibility.

The life cycle analysis of the process showed that although alkali-based extractives removal improved the total ethanol recovery and reduced the enzyme requirements, the GHG emissions were also increased substantially. The production process of chemicals and enzymes used during the rice straw pretreatment is the 'hotspots' of GHG emissions during the bioethanol production process with a maximum of 34% and 66% contributions, respectively. A systematic comparison of all different scenarios is depicted in **Table 10 and 11.**

The global warming potential, which is a combined function of GHG emissions (such as $CO_2$, $CH_4$ and $N_2O$), was lowest with MP1 where only warm water was used for extractives removal in comparison to dilute acid pretreatment without any extractives removal pre-procedure. This is primarily due to the reduction in enzyme and other chemicals used during enzymatic hydrolysis because of removal of undesired lignin and extractives by 8-13% and 60-70%, respectively. Thus, it helped in reducing GHG emissions during enzyme production and other chemicals. Moreover, the ethanol yields were also improved by the extractive removal procedure by 10-20%. But, it was also observed that the addition of alkali over the critical limit (0.4%) did not give any advantage in terms of GHG emissions, although it improved the ethanol yields. Thus, the dosage of alkali utilization should be critically decided for extractives removal followed by dilute acid pretreatment.

**Table 10. LCA assessment of steam explosion and dilute acid pretreatments for the production of bioethanol from rice straw on 1 Metric Ton basis (Reference: Soam et al. (2016))**

| S.No. | Salient features | Steam explosion pretreatment | Dilute acid pretreatment |
|---|---|---|---|
| 1 | GHG emissions (kg CO2 eq.) | 292 | 288 |
| 2 | Avoided GHG emissions (kg CO2 eq.) | -246 | -208 |
| 3 | GHG emission reductions of 100% ethanol with respect to gasoline process (%) | ~90 | ~80 |
| 4 | Energy consumption (MJ) | 1378 | 1736 |
| 5 | Net energy balance (MJ/L) | 16.3 | 14.9 |
| 6 | Net energy ratio | 2.7 | 2.3 |

**Table 11. LCA of extractives removal pre-procedure for dilute acid pretreatment of rice straw (Reference: Soam et al. (2018))**

| S. No. | Salient features | Dilute acid pretreatment | Extractive removal by biomass soaking in water (60°C, 1 h) followed by dilute acid pretreatment | | | |
|---|---|---|---|---|---|---|
| | | CP | MP1 | MP2 | MP3 | MP4 |
| 1 | Alkali addition (in %) | Nil | Nil | 0.2 | 0.4 | 0.5 |
| 2 | Acid addition (in %) | 1 | 1 | 1 | 1.1 | 1.1 |
| 3 | Ethanol yields (L/ton) | 218 | 242 | 256 | 262 | 267 |
| 4 | Global Warming Potential ($kgCO_2eq./L$) | -0.42 | -0.58 | -0.47 | -0.32 | -0.26 |
| 5 | Eutrophication Potential ($kgPO_4eq./L$) | $0.2*10^{-3}$ | $0.7*10^{-4}$ | $0.3*10^{-3}$ | $0.3*10^{-3}$ | $0.4*10^{-3}$ |
| 6 | Acidification potential ($kgSO_2eq./L$) | $-5.9*10^{-3}$ | $-6.8*10^{-3}$ | $5.6*10^{-3}$ | $-4.9*10^{-3}$ | $-4.5*10^{-3}$ |
| 7 | Photochemical oxidant creation potential | -0.1 | -0.1 | 0.1 | 0.4 | 0.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | ($kgC_2H_4$eq./L | | | | | |

## 8.2. Life cycle analysis and environmental impact assessment from Brazil

Elias et al. (2021) carried out a life cycle assessment of 1G-2G bioethanol and bioelectricity facilities using a cradle-to-gate approach. The 1G-2G-anhydrous-ethanol-plus-electricity from sugarcane process conditions will help identify the hotspots of environmental concerns in simultaneous operation. The functional unit was defined as 1 MJ of anhydrous ethanol for carrying out this study using the SimaPro 8.4 software and Ecoinvent database 3.0. The biorefinery produces ethanol and surplus electricity; energetic allocation dealt with the multifunctionality. Other outputs such as boiler ashes, sugarcane trash, vinasse, and filter cake are assumed to be consumed within the system boundaries. Additional water leaving the system boundaries is not considered(Elias et al., 2021). The environmental impact assessment was conducted for different parameters such as abiotic depletion (AD), global warming potential(GWP100), ozone layer depletion (ODP), human toxicity (HT), freshwater aquatic ecotoxicity (FWAET), marine aquatic ecotoxicity (MAET), terrestrial ecotoxicity (TET), photochemical oxidation (PO), acidification (AC) and eutrophication (EU).

This study showed that, in comparison to 1G-2G process, the 1G process is more detrimental to the environment amongst all the parameters examined here, except for the photochemical oxidation (PO). The major factor responsible for the high PO in the case of the 1G-2G process is the use of cellulolytic enzymes.

## 8.3. Life Cycle Analysis and environmental impact assessment from USA

According to the United States Environmental Protection Agency, the transportation sector contributes the highest GHG emissions (~30% in the year 2017) among all other sectors.

Argonne National Laboratory has conducted thorough research studies on GHG emissions using the GREET model (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation). It was observed that enzymes and yeast together contribute 1.4 and 27 % of farm-to-pump GHG emissions for corn and cellulosic ethanol, respectively. Over the course of the entire corn ethanol life cycle, yeast and enzymes contribute a negligible amount of GHG emissions but increase GHG emissions from the cellulosic ethanol life cycle by 5.6 g $CO_2$e/MJ(Dunn et al., 2012).

In another study, the life-cycle energy consumption and GHG emissions from using ethanol produced from five feedstocks: corn, sugarcane, corn stover, switchgrass and miscanthus was examined(Wang et al., 2012). It showed that switching from corn to sugarcane and then to cellulosic biomass could significantly cause the reduction in energy use and GHG emissions from using bioethanol. Relative to petroleum gasoline, ethanol from corn, sugarcane, corn stover, switchgrass and miscanthus could reduce the life-cycle GHG emissions by 19–48%, 40–62%, 90–103%, 77–97% and 101–115%, respectively.

Different ethanol production pathways using sorghum as raw material showed diverse well-to-wheels (WTW) energy use and GHG emissions due to differences in energy use and fertilizer use intensity associated with sorghum growth and differences in the ethanol conversion processes(Cai et al., 2013). All sorghum-based ethanol processes could reduce the WTW GHG emissions by 35% in contrast to conventional gasoline by using wet or dried distillers grains with solubles (DGS) as the co-product, and fossil natural gas (FNG) is consumed as the process fuel. The reduction increased to 56% for wet or dried DGS co-production when renewable natural gas (RNG) from anaerobic digestion of animal waste is used as the process fuel. The sweet sorghum-based ethanol can reduce GHG emissions by 71% or 72% without or with the use of co-produced vinasse as farm fertilizer, respectively, in ethanol plants using only sugar juice to produce ethanol. If both sugar and cellulosic bagasse were used in the future for ethanol production, an ethanol plant with a combined heat and power (CHP) system that supplies all process energy could achieve a GHG emission reduction of 70% or 72%, respectively, without or with vinasse.

A study carried out by Pereira et al. (2019) compared the main differences and commonalities in methodological structures, calculation procedures, and assumptions for the major commercial biofuel, ethanol, across three public LCA tools, BioGrace (EU), GHGenius (Canada), and GREET (U.S.), and a research-oriented fourth, the Virtual Sugarcane Biorefinery (VSB), a Brazilian platform for sugarcane ethanol assessments. The calculated emissions across models ranged from 16-45 for sugarcane, 43-62 for corn, and 45-68 g $CO_2$eq $MJ^{-1}$ for wheat ethanol. The agricultural production (e.g., N2O emissions from fertilizers; energy and fuel use; straw field-burning; and limestone application) and ethanol shipping were found to be the major causes for variations for differences calculated for sugarcane ethanol. The percent contribution from these factors are beyond the scope of this study and cited reference might be referred for further information.

## 9.0 Conclusions

As per the recently released Roadmap for Ethanol Blending in India 2020-25 in June 2021, projected ethanol production is 1350 crore liters by 2025-26. For 20% ethanol blending in petrol in India by 2025-26, the requirement shall be about 1016 crore liters. The current report focused on biomass availability (mainly agricultural residues), prevalent and newly emerging supply chain models, pretreatment approaches, the current status of process scale-up and technology demonstration and life cycle assessment studies focused in India with inputs from other countries i.e. the USA, Brazil and Germany. It was observed that apart from sugarcane bagasse, rice straw and cotton stalk residues are predominantly available surplus feedstock for 2G bioethanol production with a total of more than 50 billion liters of 2G bioethanol production potential in India each year. In the USA, over 1 billion tons of combined resources (forest and agriculture residues) are available for 2G bioethanol production, which could be potentially available at $60 or less per dry ton on a base case basis, and it might increase to 1.5 billion tons by the end of 2040. The chemical composition of surplus biomass, salient features of different pretreatment approaches and different process schemes by 2G bioethanol technology providers/licensors were evaluated. It showed that, currently, the high Capex and Opex of the 2G bioethanol production technologies do not allow it to compete with the 1G bioethanol production process. Feedstock availability, capital costs, and production costs have been identified as the key challenges towards sustainable and commercial production and implementation of 2G ethanol technology.

Developing a robust and sustainable supply-chain model that allows the year-round availability of high-quality seasonal feedstocks such as rice straw or cotton is another area of concern. Most agri-businesses falter in performance in the medium to long term due to failure to address raw material availability issues. Entrepreneurs/investors looking at establishing 2nd Gen bioethanol plants could consider continued availability of required quantities of cellulosic raw materials at predictable price ranges as one of their *top priorities*.

In India, the time gap between two crops is very short. Therefore, farmers burn biomass residues (generated after harvesting) in order to clear the fields for the next crop. Since the farmers have limited resources and limited knowledge of advanced technologies, it is prudent for the entrepreneurs to invest in mechanization of the harvesting and baling process. Moreover, it would be a good strategy if they invest in a supply chain business comprising procurement/collection, aggregation, baling and storage prior to their investment in the bioethanol plants. This would give them first-hand knowledge of the challenges involved and improve the confidence levels of their bankers and stakeholders as well. The investment is also required for the mechanization of biomass harvesting.

Appropriate storage of biomass is required for running a commercial 2G bioethanol plant year-round without degrading the biomass quality despite the seasonal variations of weather. Thus, stakeholders need to conduct a focussed study, explore opportunities, and develop models to find a practical solution to store biomass and make it available year-round for 2G ethanol production.

Thus, a significant impetus is needed to attract entrepreneurs/investors and stakeholders for establishing the farm-to-gate feedstock supply-chain model. The pros and cons of some of the established supply chain models such as ITC E-Choupal Model, Amul Model, and NDDB Safal model applied in Rural India for Agri-produced Logistics are discussed in brief to provide a path forward for its application in biomass supply chain management.

Life cycle assessment showed that the pretreatment approach played a critical role in the GHG emissions of the 2G bioethanol production process. The production and application of cellulase enzymes to produce fermentable sugars are identified as a hotspot to reduce the GHG emissions of the process. Further, the significant reduction in GHG emission of the 2G bioethanol process is obtained through utilization of solid waste generated from the bioethanol plant to generate power and subsequently replace the fossil-derived energy requirements of the bioethanol plant.

Finally, it was concluded that a cost-effective pretreatment technology with low or no chemicals, indigenous 2G enzyme technology with onsite enzyme production model, and Valorization of Lignin-rich Residue to produce high-value chemicals has potential to make the 2G ethanol cost-competitive compared to 1G ethanol cost.

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