POLICY PAPER 105

Sugarcane-based Ethanol Production for Sustainable Fuel Ethanol Blending Programme

NATIONAL ACADEMY OF AGRICULTURAL SCIENCES, NEW DELHI
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CONVENER : Dr Bakshi Ram, Director, ICAR- ICAR-Sugarcane Breeding Institute, Coimbatore

CO-CONVENERS : Dr R. Viswanathan, Head, Crop Protection, ICAR-Sugarcane Breeding Institute, Coimbatore

Dr P. Murali, Senior Scientist, Head, Statistics and Economics Section, ICAR-Sugarcane Breeding Institute, Coimbatore

REVIEWER : Dr S. Solomon, former Director, ICAR-Indian Institute of Sugarcane Research, Lucknow

EDITORS : Dr P.S. Birthal and Dr Malavika Dadlani

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Tel.: 011-25846051-52; Fax: 011-25846054
Email: naas-mail@naas.org.in; Website: www.naas.org.in

Preface

India's current energy strategy endeavours to produce 175 gigawatts of renewable energy by 2022, reduce GHGs energy emission by 33%-35% and attain a share of non-fossil fuel-based energy electricity mix of 40% by 2030. Biofuels assume significant importance in meeting these targets. The primary approach for biofuels is to promote indigenous non-food feedstock production. The National Policy on Biofuels–2018 targets 10 % fuel ethanol blending in petrol by 2022 and 20 % by 2025, and 5% blending in diesel by 2030. It broadens the scope for raw material procurement for ethanol production, including sugarcane juice. The adoption of sugarcane variety Co 0238, developed by the ICAR- SBI, has broken the yield and sugar recovery barriers, resulting in surplus sugar production. The excesses must be diverted to produce fuel ethanol to sustain sugarcane production.

Realising the importance of biofuel feedstocks, the National Academy of Agricultural Sciences (NAAS) organised a brainstorming session on 'Sugarcane-based Ethanol Production for Sustainable Fuel Ethanol Blending Programme' on September 18, 2020. The session was attended by eminent scholars and experts from the sugar and ethanol industries. This policy paper is an outcome of the deliberations of this brainstorming session. I gratefully acknowledge the contribution of Dr Bakshi Ram, Convener of the brainstorming session, distinguished participants and reviewers. My special thanks are to Mr Subodh Kumar Singh, Joint Secretary (Sugar & Administration), Directorate of Sugar, Government of India, for his valuable suggestions. My thanks are also due to Dr Kusumakar Sharma, Dr P. S. Birthal and Dr Malavika Dadlani for their editorial support.

(Trilochan Mohapatra)
President, NAAS

March 2022
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1. INTRODUCTION

The energy strategy of our country aims to chart a pathway to meet the Government's ambitious announcements, such as 175 gigawatts (GW) of renewable energy capacity by 2022, reduction in energy emissions intensity by 33%-35% by 2030 and raising the share of non-fossil fuel-based power in the electricity mix to 40% by 2030 (Niti Aayog). The Paris Agreement is a landmark environmental accord adopted by all in 2015 to address climate change and its impacts (UNFCCC 2015). The deal aims at reducing global greenhouse gas emissions to limit the global temperature rise to 2 degrees Celsius above the pre-industrial levels by the end of this century.

Globally, biofuels assume importance due to growing energy demand and environmental concerns. To encourage the use of biofuels, several countries have put forth different policy options mechanisms, incentives and subsidies suiting to their domestic requirements. Fortunately, India is endowed with abundant renewable energy resources. Therefore, their use needs to be encouraged in every possible way. The Government of India envisages a strategic role for biofuels in the energy basket. It has prepared a roadmap to reduce import dependence on conventional or fossil fuels by adopting a five-pronged strategy that includes increasing domestic production, biofuels and renewables, energy efficiency norms, improvement in refinery processes and demand substitution. The primary approach for biofuels in India is to promote indigenous non-food feedstock production.

Bioethanol can be produced from sugar-containing materials, starch, celluloses and lignocelluloses (NAAS Policy paper 2015). However, the present policy of the Ethanol Blended Petrol (EBP) programme allows bioethanol to be manufactured from sugarcane juice, B-Heavy and C-molasses and non-food feed-stocks like cellulose and lignocellulosic materials. It also includes second-generation (2G) ethanol. However, its production cost is still high due to costly equipment and the exorbitant cost of cellulolytic enzymes used in the pre-treatment of bagasse.

Meanwhile, the wonder sugarcane variety Co 0238 of the ICAR-Sugarcane Breeding Institute has broken sub-tropical India's yield and sugar recovery barriers. The cane yield under field conditions has almost doubled (150 to 250 t/ha), and the average sugar recovery has improved by 2.08 units (22.6%). Its widespread adoption has made the country surplus in sugar. Hence, it can be diverted in a meaningful way for fuel ethanol production to sustain sugarcane production and meet the blending target of EBP. This demands a comprehensive policy to solve the sugar surplus complex, meeting the target of the ethanol blending programme and bringing a balance between food and fuel production. Hence, the brainstorming session explores the availability of the feedstock to produce the required quantity of fuel ethanol production to fulfil the 20 % blending target, stable and long-term pricing policy for fuel ethanol production, demand and supply-side issues in the ethanol value chain in India.

2. STRATEGY FOR BIOFUEL PRODUCTION

The Indian approach to biofuels is based solely on non-food feedstocks raised on degraded or wastelands that are not suited to farming, thus avoiding a possible conflict of fuel vs food security. An estimated 55.3 million hectares of land is considered wasteland, which can be used to cultivate biofuel crops (Maheswari et al., 2007).

In 2014, the Government of India developed a comprehensive roadmap for biofuel production and its use to facilitate optimal development and utilisation of indigenous biomass feedstocks to produce biofuels to satisfy the growing energy demand in an environmentally benign and cost-effective manner. Subsequently, it brought out a ***National Policy on Biofuels-2018*** that broadens the scope for raw material procurement for ethanol production and supports sustainable fuel ethanol production measures to achieve the target of 10 % blending during 2021-22 and 20 % by 2025. The main highlights of the policy are:

- **Funding:** It provides funding support of Rs. 50000 million to second-generation (2G) ethanol bio-refineries over six years, in addition to tax incentives and higher purchase price compared to first-generation (1G) fuels.

- **Forex savings:** It was estimated that 10 million litres of E10 will save Rs. 280 million worth of forex. Accordingly, the supply of about 1500 million litres of ethanol in 2017-18 saved Rs. 42000 million in forex.

- **Oil Marketing Companies** (OMC) **Capex:** 100 Kilo litre per day (KLPD) bio-refinery requires an investment of Rs. 8000 million. Currently, OMCs are setting up twelve 2G bio-refineries with a total investment of Rs. 10,0000 million. This should lead to an additional capacity of about 1200 KLPD annually.

- **National Biofuel Coordination Committee** Under the new biofuel policy, a *National Biofuel Coordination Committee* was set up in 2018. It envisages resolving the lack of raw material availability by expanding the base materials to include B-Heavy molasses, sugarcane juice and damaged grains unfit for human consumption. The Ministry of Petroleum and Natural Gas (MoP&NG) is presently undertaking the EBP programme to achieve 10% ethanol blending in petrol by 2021–22.

- **Incentivise ethanol production:** An interest subvention scheme has been introduced to incentivise ethanol production by augmenting and enhancing its production capacity. The scheme is monitored jointly by MoP&NG and the Department of Food and Public Distribution (DFPD) of the Ministry of Consumer Affairs, Food & Public Distribution, Government of India. So far, the DFPD has approved (*in-principle*) 114 proposals for a maximum loan amount of Rs. 61,390 million. These proposals are estimated to add another 2000 million litres to ethanol production capacity.

- **Straighten inter-and intra-state movement**: The amendment of the Industries Development and Regulation Act (IDRA) aims at the smoothening inter-and intra-state movement of ethanol by giving the central government exclusive control over it. The possibility of higher blending in ethanol-surplus states of Uttar Pradesh (UP) and Maharashtra is being explored to avoid the movement of ethanol across the country. For this, the Bureau of Indian Standards has already notified E-20 Standards.

- **Minimum purchase price (MPP):** MPP of bioethanol will be announced with periodic revisions. Major thrust will be given to research, development and demonstration focusing on plantations, processing and production, including second-generation biofuels. Financial incentives including subsidies and grants, will be provided for 2G biofuels (National Policy on Biofuels-2018).

3. TRENDS IN FUEL ETHANOL PRODUCTION

3.1. Global Scenario

Today's most common ethanol production process uses yeast to ferment the starch and sugars in corn, sugarcane, and sugar beet. Corn is the primary feedstock for fuel ethanol in the United States because of its abundance and low price. The starch in corn kernels is hydrolysed into sugar fermented into alcohol. Sugarcane and sugar beet are the most common feedstocks used to make fuel ethanol elsewhere in the world. Brazil, the second-largest fuel ethanol producer after the United States, makes most of its fuel ethanol from sugarcane and derivatives (IFPRI, 2006).

The trend in global ethanol production from 2007 to 2020 is, depicted in Fig.1. The United States has been the most prominent fuel ethanol producer since 2007, followed by Brazil. Together the United States and Brazil account for 84% of the global ethanol production. European Union, China and Canada are the other leading fuel ethanol producers.

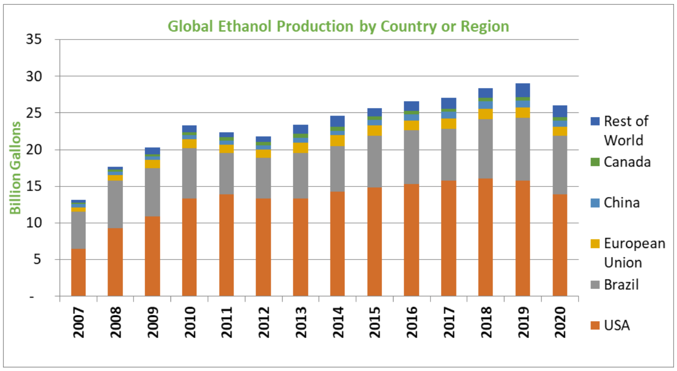

Fig. 1. Trend in global fuel ethanol production

Source: Renewable Fuels Association (RFA)

The fuel ethanol production and its use are increasing, despite fluctuation in crude oil prices. The US leads in fuel ethanol production with 60 billion litres, mainly produced from corn, followed by Brazil with 33 billion litres produced from sugarcane (Fig.2). Although India ranks fifth in fuel ethanol production, its production is minuscule compared to the US and Brazil. India has achieved 5.8 % blending in 2019 and aims to double it by 2021-22.

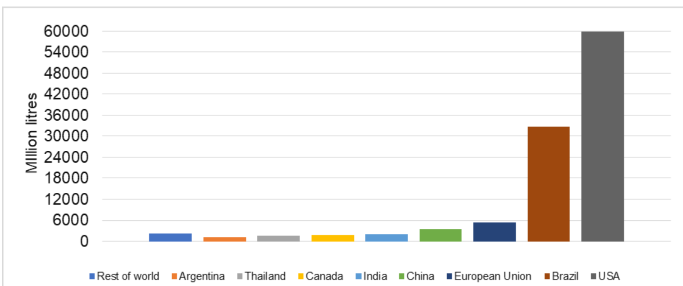

Fig. 2. Fuel ethanol production by major countries in 2019

Source: https://www.statista.com

In this context, it will not be out of place to mention that India can learn from Brazil to make mandatory blending and utilise this blended fuel in vehicles. Currently, the sugarcane products provide 17% of Brazil's energy matrix, reducing nearly 600 million tonnes of carbon dioxide equivalent (CO_2eq) emissions since 1975 (UNICA, 2010a). Brazil also launched Flex Fuel Vehicles (FFV) in 2003, which can run on more than one type of fuel with a provision to store different alternative fuels in the same tank. Currently, a large proportion of its cars run on un-hydrous ethanol. There is a need to adopt some good practices like the lignocellulosic technology and Flexi model to save foreign exchange and eliminate sugar surpluses.

3.2. Indian Scenario

Based on official estimates for the demand for petroleum products, the ethanol requirement for blending with petrol estimated at 5%, 10%, 15%, and 20% levels are given in Table1.

Table 1. Projected petrol demand, and ethanol requirements in India

Year	Petrol demand (million litres)	Ethanol blending requirements (million litres)			
		5 %	10 %	15%	20 %
2019-20	37140	1857	3714	5571	7418
2024-25	49482	2227	4453	6680	8907
2029-30	60203	2709	5418	8127	10836

Source: Murali et al. (2016)

Ethanol-blended gasoline's commercial production and marketing started in January 2003. In the first phase of the EBP programme, 5% ethanol blending in gasoline was mandated in nine states and four union territories. In August 2005, the government facilitated an agreement between the sugar industry and petroleum companies to enable the purchase of ethanol. With a strong resurgence in sugarcane/sugar production in 2006-07, the Government of India announced the second phase of the EBP programme in September 2006 that mandated 5% blending of ethanol with petrol (*gasoline*) subject to commercial viability in 20 States and eight union territories. Nonetheless, the target 5% of EBP could not be achieved despite policy support and surplus sugarcane and sugar production. The quantity of ethanol supplied has been significantly lower than the tendered quantity (Table 2), primarily due to the supply-side constraints, including limited distillation capacity and availability of molasses. In 2018-19, India could achieve 5% blending due to new policy directives and fair pricing of fuel ethanol for the EBP programme.

It is established that although the fuel ethanol demand is progressing, the current fuel ethanol production is not sufficient to reach the blending target of 10 % by 2022 and 20 % by 2025.

Table 2: Details of ethanol supplied and blending

Ethanol Supply Year	Quantity tendered by OMC's* (Million l)	Quantity allocated (Million l)	Quantity supplied (Million l)	Blending % PSU OMCs
2012-13	1030	320	154	0.67
2013-14	1150	704	380	1.53
2014-15	1280	865	674	2.33
2015–16	2660	1305	1114	3.51
2016–17	2800	807	665	2.07
2017–18	3130	1610	1505	4.22
2018–19	3320	2390	1886	5.80
2019-20	NA	NA	1730	5.01
2020-21	3250	2850	2430	8.01

*Oil marketing companies (OMCs)

Source: Roadmap for Ethanol Blending In India 2020-25 by NITI Aayog

3.3. Potential of Different Feedstocks for Ethanol Production

Almost any plant-based material can be used as an ethanol feedstock. All plants contain sugars in stalks/grain that can be fermented to make ethanol through biochemical conversion. Plant material can also be converted into ethanol through thermochemical conversion. Selecting a feedstock depends on many factors, including ease of cultivation of a specific crop, geographic advantage, and other uses (e.g., food and feed). Table 3 provides the ethanol production potential of different crops.

Table 3. Potential crops for biofuel production in India

Crop	Ethanol yield (litres/t)	Crop/stalk yield (t/ha)	Ethanol production (litres/ha)
Sugarcane	70	80	5600
Sugar beet	100	50.6	5060
Sweet potato	125	18.8	2350
Potato	110	20.9	2304
Maise	360	5.9	2133
Cassava	180	11.3	2034
Rice	430	4.7	2012
Wheat	340	3.4	1165
Sweet sorghum*	26.3	38.5	1013
Barley	250	3.0	738

Source: FAO production yearbook (1973), *Fresh stalk yield

Sugarcane is the best feedstock for bioethanol production, followed by sugar beet. In India, sugarcane is widely cultivated (except in hills), hence it provides a good alternative as a feedstock for ethanol production. Other crops can also be used for ethanol production, depending on their level of production and availability. The broken grains of cereals can also be a potential source of feedstock for bioethanol production. The share of different kinds of feedstocks in ethanol production worldwide is given in Fig. 3. More than 90 % of ethanol production is derived from maize and sugarcane.

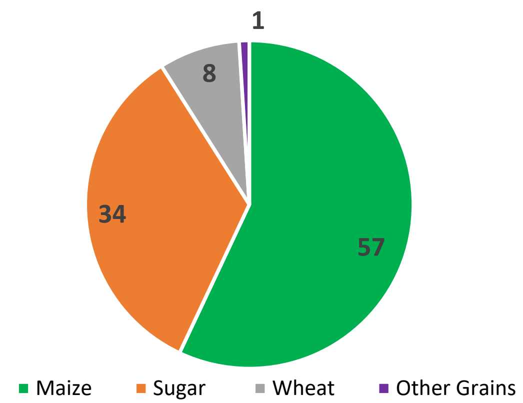

Fig. 3. Global ethanol production by feedstock (2007)

Source: DART-BIO

3.4. Sugarcane and Sugar Scenario in India

The cultivation of sugarcane in India dates back to the pre-Vedic period (2000 BC). Presently, sugarcane yields an annual white sugar production of 30.0-33.2 million tonnes and is the primary source of all major sweeteners. Sugarcane is cultivated between the latitude of 8.5° to 32.1° in both the sub-tropics (North India) and tropics (South India) in an area of about 5 million hectares equalling 3% of gross cropped area and 18.4% of the global area under sugarcane. At the international level, India is the largest consumer and producer of sugar. At present, India is self-sufficient in sugar production, but the demand for sugar has been growing due to the increasing population. At present, about 6 million tons of sugar produced is exported. The estimated sugar demand by 2050 will be 48 million tonnes (SBI-Vision 2050).

Sugarcane and sugar production in the country has fluctuated since the beginning of this century. A vicious cycle of alternate surplus and deficit sugarcane/sugar production and corresponding demand and price is seen till 2016-2017 (Fig. 4).

Nevertheless, India is now producing 30% surplus sugar, which has posed problems to the sugarcane farmers and sugar millers due to a fall in sugar prices (Table 4). It also led to huge cane payment arrears and financial losses to the millers.

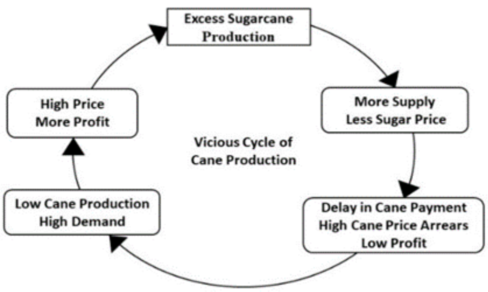

Fig. 4. A vicious cycle of sugarcane production in India

Table 4. Total cane production, sugar demand and surplus cane production in India

Year	Total Sugarcane Production (Mt)	Total sugar produced (Mt)	Total sugar demand (Mt)	Sugarcane required to meet the demand (Mt)	Surplus sugarcane availability for seed, feed and traditional sweeteners and other uses (Mt)
2000-01	296	18.53	16.2	170	126
2003-04	234	13.54	17.5	179	45
2006-07	355	28.36	20.2	205	150
2011-12	361	26.34	22	216	145
2018-19	400	33.16	25.5	233	163
2019-20	377	27.50	24	222	155
2024-25	410	32.0**	30	273#	137
2029-30	425	36.0**	32	291#	134

* Estimated as per actual sugar recovery in India

Sugar recovery of 11.0 % was assumed for calculation purposes for the future periods

**Anticipated sugar production

Source: Cooperative sugar 2020 and Murali et al 2016

3.5. Role of ICAR-Sugarcane Breeding Institute, Coimbatore

Fig. 5. Sugarcane Variety Co 0238

Ever since its establishment in 1912, the main objective of the Institute has been to develop improved sugarcane varieties for different agro-climatic regions. ‘Co’ canes, developed at the Institute, have contributed immensely not only in India but also in 28 other countries, either as commercial cultivars or as parents in their hybridisation programmes. So far, the Institute has developed more than 3,200 Co clones, of which about 190 attained commercial status. The cultivation of Co varieties has led to about a three-fold increase in sugarcane area since 1950, resulting in 34.54 times increase in sugar and 7.30 times increase in sugarcane production in 2018-19. The improved varieties respectively contributed to a 2.44 and 1.09 times increase in average cane yield and sugar recovery. The variety Co 0238 developed by ICAR-Sugarcane Breeding Institute, Regional Centre, Karnal, has revolutionised sugar production in subtropical India (Punjab, Haryana, Uttarakhand, UP and Bihar) (Fig. 5). The variety Co 0238 has broken the inverse relationship between yield and sugar recovery and revolutionised sugar production by improving yield and sugar recovery. The yield and recovery levels have improved by 32.67% and 22.58%, respectively, in sub-tropical India, which shares more than half of the cane area in the country (Bakshi Ram and Hemaprabha, 2020).

To overcome the problems emerging due to excess sugarcane production, the Government of India has permitted direct conversion of sugarcane juice and B-Heavy molasses into ethanol in the 2018-19 sugar season. The flexible policy of sugar cum ethanol production is expected to bring sustainability in sugarcane production and help achieve EBP targets.

Recently, ICAR-SBI has developed short duration varieties (8-month maturity) for the year-round availability of feedstock for sugar mills. Promising short duration varieties offer more profit and use less water. It will strengthen the sugar and ethanol industries in the southern states. Recent advancements in converting lignocellulose into ethanol also require additional biomass supply. Based on these requirements, ICAR-SBI has developed exclusive energy canes using *Saccharum spp.* and *Erianthus arundinaceous,* which can be cultivated in the factory's captive energy gardens for the year-round supply of raw materials. Recently, energy cane has emerged as the top candidate for bioethanol production.

Two types of energy canes were contemplated based on the fibre content in cane and brix % in juice. ICAR-SBI has developed clones with mean harvestable biomass yield under limited irrigation conditions of 241.47 t/ha compared to 289.08 t/ha recorded under normal irrigation conditions. The tall and non-lodging nature of the canes makes the clone amenable for mechanical harvesting (Fig.6). These clones can be ratooned at least for seven years, resulting in low input use *(including nutrients)* and a lower cost of production. This type of energy canes can be harvested as whole canes with trash and tops and directly fed into the boilers to produce electricity.

Fig. 6. Energy cane cultivation in Karnataka

3.6. Varietal Requirement for Ethanol Production

The general breeding objective of sugarcane improvement is to develop varieties with high cane yield and sucrose content, resistance to major diseases *(red rot and smut)* and tolerance to major insect pests. High cane yield and high sugar content are essential for ethanol production (Table 5). Varieties with higher sugar content are expected to produce higher ethanol per unit of cane output, but the quantity per unit area will ultimately depend on cane yield. The varieties with moderately high cane yield and sugar content (CoC 671, Co 7704, Co 7717 and Co 1148) produced maximum ethanol per unit area.

Table 5. Estimated ethanol yield from juice of different sugarcane varieties at 12-month crop age

Varieties	Cane yield (t/ha)	% Sucrose	Ethanol yield (litre/ha)
	Tropical		
Co 419	137.6	15.37	9813
Co 62175	175.2	16.19	11638
CoC 671	147.0	18.78	12652
Co 7704	141.9	19.23	12237
	Subtropical		
CoJ 64	49.4	19.49	3257
Co 7314	55.4	19.81	3702
Co 7717	67.8	20.02	4807
Co 1148	71.0	19.02	4717

Source: ICAR-Sugarcane Breeding Institute

Given the limited scope of increasing cane area, varieties (like Co 0238) having higher yield and sugar recovery need to be developed and multiplied for the benefit of both farmers and industries, ultimately meeting the targets of EBP.

At present, sugarcane breeders emphasise sucrose content in the juice while selecting clones at different stages. It is presumed that varieties with very high cane yields and high reducing sugar content or low purity are ideal for improving ethanol yield per unit area. If sugarcane is cultivated for ethanol, the maximum accumulation of reducing sugars (Glucose and Fructose) is considered for harvest. Sugarcane harvesting at eight months of age (3 crops in 2 years) can be explored for ethanol production throughout the year. However, the price policy for such varieties has to be discussed. Research is required to determine the period of maximum reducing sugars accumulation in sugarcane. Sugarcane farmers should be given different prices for ethanol production based on reducing sugar content to facilitating their choices for growing sugarcane for ethanol or sugar. For example, ECO FUEL /Green Future innovation Inc in the Philippines purchases sugarcane only for ethanol production based on the reducing sugar content. The technology (2nd generation) for ethanol production from cellulosic material *(2nd generation)* is still developmental.

3.7. Crushing Scheduling by Sugar Mills

In general, the sugar recovery of sugar mills is low at the start of the crushing season, which improves slowly to a peak and then starts declining towards the end of the crushing season. The mean sugar recovery of 3 years (2012-13 to 2014-15) in Tamil Nadu is depicted in Fig. 7.

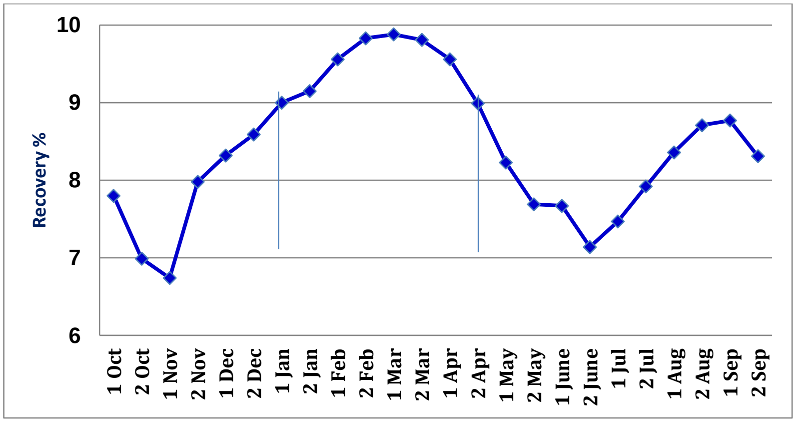

Fig. 7. Mean sugar recovery % in Tami Nadu (2012-13 to 2014-15)

The proportion of reducing sugars is higher at the beginning and end of the crushing season, suitable for producing ethanol. It will be better to divert sugarcane juice or B-Heavy molasses up to 1st fortnight of January and from May onwards. This crushing schedule would improve overall sugar recovery as well as ethanol yield.

The sugar recovery pattern of Saraswati Sugar Mills (SSM), Yamunanagar, Haryana is depicted in Fig. 8. The average sugar recovery during 2019-20 was 11.79%. The expected mean sugar recovery from November to January is 11.20%. By diverting the sugarcane juice to produce ethanol, the industry would have gotten better ethanol yield and sugar recovery of 12.16% (February to May). Such types of crushing schedules will help improve profits for mills.

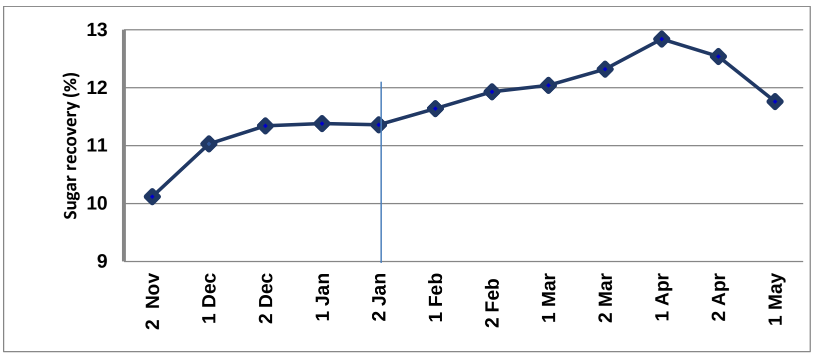

Fig. 8. Sugar recovery pattern of SSM, Yamunanagar, Haryana

Diversion of sugarcane juice to sugar or ethanol production has to be evaluated commercially during the beginning and end of the crushing season. The sugar plant configuration needs to be designed for flexible operations to achieve this. The existing regulatory framework for controlling the input and output needs to be simplified.

Further, some states (e.g., Tamil Nadu, southern Karnataka, Andhra Pradesh, Odisha, West Bengal) traditionally record lower sugar recovery. Except during the peak recovery period, the remaining sugarcane needs to be diverted for ethanol production in such states to maximize profitability to farmers and mills.

3.8. Sweet Sorghum

The National Policy on Biofuels-2018 has identified sweet sorghum as one of the candidate crops for augmenting biofuel production. Sugar industries are exploring possibilities of complementing their existing molasses-based ethanol production with alternative raw material to fill in the lean period of sugarcane crushing for year-round operations. Sweet sorghum is a new generation bioenergy crop that yields grain on par with grain sorghum within a short growing period of four months. Further, it has a low water requirement. It produces high biomass (50-80 t/ha) and alcohol (1500-2000 l/ha), besides broader adaptation and tolerance to various abiotic stresses like drought and salinity. In all the big mill tests, it has been proven that sweet sorghum could be crushed with the available sugarcane crushing machinery. In addition, sweet sorghum is an ideal feedstock for second-generation bioethanol production. The major impediment of converting biomass to biofuels is high pre-treatment costs for lignin removal and the high price of enzymes used for saccharification. An advantageous feature of sorghum is the presence of brown midrib mutations that can reduce lignin content and increase forage digestibility in animals. Lowered lignin also has been shown to increase the conversion efficiency of biomass into ethanol. Given the current remunerative price for ethanol, sweet sorghum as a biofuel feedstock in existing sugar mills will be a win-win situation for industry and resource-poor dryland farmers. As a promising alternative feedstock for sustainable ethanol production, sweet sorghum can also provide a wide range of environmental, economic, and employment benefits under rainfed conditions.

4. SECOND-GENERATION BIOFUELS – CHALLENGES

4.1. Cellulosic Ethanol Feedstocks

Cellulosic feedstocks are non-food based and include crop residues, wood residues, dedicated energy crops and industrial and other wastes. For example, rice and wheat straw and cornhusks are the potential second-generation feedstocks. These feedstocks are composed of cellulose, hemicellulose and lignin. Lignin is usually separated and converted to heat and electricity in the distillery processes. It is more challenging to release sugars from these lingo-cellulosic feedstocks to convert into ethanol. However, there are inherent advantages to using the inevitable by-products of the agricultural industry for biofuel production without additional fertiliser, water, or land to grow these feedstocks. The industry uses some of these non-edible by-products to produce animal feed; however, a considerable quantity could be used for biofuel production.

4.2. Lignin and Saccharification

Biomass is an abundant source of carbon that can be used to produce biofuels. This carbon is a fundamental element of different plant components, including the cell walls, mainly composed of the structural polysaccharide cellulose, hemicellulose polysaccharides and the aromatic polymer lignin. The conversion of biomass into biofuel depends on the enzymatic saccharification of structural polysaccharides into their monosaccharide building blocks that can be subsequently fermented into bioethanol.

Lignin is one of the critical components limiting the conversion of biomass into biofuel. It cross-links to hemicellulosic polysaccharides to form a highly impermeable matrix that imparts strength to the plant cell wall and shields cellulose (Carpita, 1996). Cellulose is the primary source of fermentable sugars from chemical and enzymatic hydrolysis. In addition, it impedes the efficiency of enzymatic saccharification by irreversibly adsorbing hydrolytic enzymes, which renders them ineffective. Simultaneous saccharification and fermentation (SSF) is one process option for ethanol production from lignocellulose. The main benefits of performing the enzymatic hydrolysis and the fermentation, instead of in a separate step after the hydrolysis, are the reduced end-product inhibition of the enzymatic hydrolysis and the reduced investment costs. In this regard, an expensive hydrolysing process to convert feedstock for fermentation and massive industrial waste discharge are to be addressed. The costly processes detail scopes of biofuel production from second-generation feedstocks. Regardless, second-generation biofuel research and policy has the potential to develop this biofuel pathway into an abundant source of biofuel.

4.3. Production and Advancement in Second Generation Bio-Ethanol

The development of low-cost enzyme cocktails is one of the main challenges in producing 2G ethanol. Researchers at the Brazilian Center for Research in Energy and Materials (CNPEM) have genetically engineered a fungus to create a cocktail of enzymes that break down the carbohydrates in biomass, such as sugarcane trash (tops and leaves) and bagasse, into fermentable sugar for industrially efficient conversion into biofuel. The fungus was rationally modified to maximise the production of these enzymes using the CRISPR/Cas9 gene-editing technique (Santos et al., 2020). The fungus produces many enzymes on agro-industrial waste, a cheap and abundant feedstock. The bioprocess developed by the CNPEM researchers produced 80 grams of enzymes per litre; this is more than double the concentration previously reported in the scientific literature for the fungus (37 grams per litre). In addition, gene-editing technology like TALEN has improved saccharification by reducing lignin in sugarcane. Although the platform was customised for cellulosic ethanol production from sugarcane residues, it can break down other kinds of biomass. Advanced sugars can produce other bio renewables such as plastics and intermediate chemicals.

Algae can be used as a 2G biofuel producer. It has been shown that algae are the highest producer of biofuels (Murali and Hari, 2011). Soybean can produce between 378 and 473 litres of biofuel per ha, rapeseed between 1,065 and 1,088 litres per ha, mustard 1,325 litres per ha, palm oil 6,150 litres per ha and algae 94,625 litres per ha. However, the barriers must be overcome before one begins to roll down the highways based on sustainable, carbon-neutral gasoline, starting with finding ways to break lignocelluloses biomass down into fermentable sugars. It appears that the 2G biofuel at the research level and commercial production may not be possible in the near future. Therefore, at present, the bioethanol program will continue to depend entirely on first-generation fuels.

5. DEMAND-SIDE INITIATIVES FOR FUEL ETHANOL BLENDING PROGRAM

5.1. Fuel Ethanol Filling Stations

Ethanol blending has become mandatory in India, with 20% blending by 2025. It encourages commuters to buy Flexi vehicles in the coming years. In addition, there are demands to run eco vehicles, farm implements and vehicles with ethanol to reduce pollution. It will accelerate the ethanol demand and ensure the value chain for fuel ethanol. However, the facility of ethanol filling bunks needs to be created in the existing fuel station in a phased manner.

5.2. Flexi Fuel Vehicles (FFV)

A flexible-fuel vehicle (FFV) or dual-fuel vehicle (colloquially called a flex-fuel vehicle) is an alternative fuel vehicle with an internal combustion engine designed to run on more than one fuel; usually, gasoline blended with either ethanol or methanol fuel and both fuels are stored in a common tank. Modern flex-fuel engines can burn any proportion of the resulting blend in the combustion chamber as fuel injection, and spark timing is adjusted automatically according to the actual mix detected by a fuel composition sensor. Flex-fuel vehicles are distinguished from bi-fuel vehicles, where two fuels are stored in separate tanks. The engine runs on one fuel at a time, for example, compressed natural gas (CNG) and liquefied petroleum gas (LPG), or hydrogen.

By March 2018, about 60 million ethanol-based FFVs, including automobiles, motorcycles and light-duty trucks, were manufactured and sold across the world, with their market being concentrated in Brazil *(30.5 million light-duty vehicles and over 6 million motorcycles),* the United States *(21 million)*, Canada *(1.6 million)* and Europe *(243,100)*. In addition to FFV running with ethanol, in Europe and the US, there have been successful test programs with methanol FFV, known as M85 flex-fuel vehicles.

5.3. Long Term Price and Procurement Policy for Ethanol

The sugar industry has been demanding a long-term pricing formula for ethanol to encourage setting up or capacity enhancement of fuel ethanol production. It is recommended that the Ministry of Petroleum and Natural Gas holistically examine the suggestion, keeping in view the need to provide some indication for the pricing formula for ethanol to reduce uncertainties of the returns on the investments in bioethanol production. Similarly, the production and purchase support measures for a minimum of ten years are expected to sustain the fuel ethanol demand for averting the risks and uncertainty in the upcoming ethanol market.

6. CONSTRAINTS IN THE EBP PROGRAMME

The future viability of the Indian sugar industry will depend on value-addition and diversification through ethanol and cogeneration. Diversification will improve economic efficiency and profitability in the industry. Support of the Government of India for ethanol production and conversion of bagasse into electrical power has made significant progress. However, these industries face various constraints from State Governments. They still have controls on the sale of molasses, such as levy or allocation of fixed quota/price for potable industry, inter-state movement restrictions, etc. To tap its full potential, molasses need to be freed entirely from such controls. These issues need to be addressed on priority to tap the full potential of feedstocks to produce the required volume of fuel ethanol for EBP. The industry needs to be assured of investment protection in pricing, procurement and payment for sustaining ethanol production.

During the Brain Storming Session, many sugar industry representatives participated, and some of the issues raised by the industry are discussed here. As per the Notification of the MOEF dated January 16, 2020, the 'No Increase in Pollution Load' certificate from the concerned State Pollution Control Board or Union Territory Pollution Control Committee' has been made mandatory. Sugar mills shall undertake the production of ethanol from B-heavy Molasses or Sugarcane Juice Sugar Syrup or Sugar. Because of the better yield of the ethanol, there will be an increase in ethanol production beyond the environmental clearance granted capacity, even without any expansion of existing plant and machinery or technology. The industry is experiencing a problem getting approvals for months together after the submission of documents and presentation with the regulatory authorities.

As per the Notification of the Ministry of Consumer Affairs, Food & Public Distribution dated August 22, 2020, the Government has allowed the production of ethanol from B-Heavy Molasses, sugarcane juice, sugar syrup and sugar; and has also fixed the remunerative ex-mill price of ethanol derived from these feed-stocks. The state-wise targets for ethanol manufacture have also been fixed. Sugar mills/distilleries have been advised to utilise at least 85 % of their existing capacity to produce ethanol. Further, to make the entire approval process more efficient, the following issues need to be addressed by Regulatory authorities to increase the availability of Ethanol for Blending:

- As per the government regulations, under given Environment Clearance (EC) conditions, distilleries are to be allowed to increase their 50% capacity by a change in raw material (B-heavy/cane juice usage), provided there is no increase in Pollution load. But some state pollution control board recommends using an Incinerator to enhance the capacity to achieve ZLD.
- With the usage of B Heavy /cane juice for production of Ethanol, there is an overall reduction in pollution load as mentioned below: (Basis 120 KLPD capacity C-Molasses vs B-Heavy/Cane juice usage)

S. No.	Items	C-Molasses	B-Heavy Molasses	Cane juice (syrup)
1.	Spent wash generation (KL/KL of alcohol)	8.00	4.22	4.05
Spent wash generation reduction:		47.25%	49.37 %	
2.	COD Load (Tons COD/day)	107.73	48.07	34.10
COD load reduction:		55.34 %	68.34 %	
3.	SLOP generation (60% concentrated, T/Hr)	9.03	3.56	2.53
SLOP generation reduction :		60.57 %	71.98 %	

Hence, using the Incinerator Boiler Scheme as a secondary treatment scheme for Zero Liquid Discharge (ZLD) is not viable. Further, the industry faces constraints in getting such a low capacity Incinerator Boilers.

The comparative results on the Bio-composting process as a secondary treatment for achieving ZLD are given below:

S. No.	Items	C-Molasses	B-Heavy molasses	Cane juice (syrup)
1.	Concentrated spent wash generation (30 % solids for Bio composting) KL/ day	434	171	121.50
Concentrated Spent wash generation reduction:		60.10 %	72.00 %	
2.	Covered area for Bio composting (acres)	28.72	11.31	8.04
Covered area requirement reduction:		60.62%	72.00%	

(For 90 days of Bio-composting operation covered area have been considered)

The results indicated the reduction in land requirement by 61-72 % while using the B-Heavy molasses/cane juice syrup, making the scheme attractive and viable for achieving ZLD norms. It is worthwhile to mention the following facts:

- An expense of 40 % of the total CAPEX of the Ethanol Project is required only for Incinerator Boilers.
- Existing boilers and turbines shall be utilised for steam/power requirements throughout the season.
- To achieve a 20% blending target by 2025, the industry needs an investment of Rs. 300,000 million. With the Bio-composting process to achieve Zero Level Discharge (ZLD) norms, Government spending shall reduce to 60 %.

7. IMPACT OF BIOFUEL FEEDSTOCK ON FOOD/PRICE/ LIVELIHOOD

A genuine concern arises from diverting arable land from food production to bioenergy crops that may hurt food production and food security. It is also argued that bioenergy crops need only be grown on degraded or wasteland, not fertile land. As ethanol production for fuel is basically from sugar molasses, it will not significantly impact the production, prices, and trade of sugar for food and industrial use (Murali et al., 2016). Despite a decline in production of sugarcane/sugar and consequently sugar molasses, higher prices of alcohol vis-a-vis fixed ethanol prices had limited fuel ethanol production. Suppose ethanol prices are linked to sugar molasses prices, then it may impact the availability of sugar molasses for use in cattle feed and alcohol for industrial and potable liquor. When 20% of the EBP programme is implemented, it will impact the availability of sugarcane juice and sugar molasses for alternative uses when the biofuel production is less than the demand. But it may not show an adverse impact on other crop production and livelihood of the farmers. Nevertheless, the international sugar and molasses markets have had surplus productions during the past decades. Therefore, the impact on the availability and prices of sugar will be minimum, and it would be helpful to ease out the present glut in the international sugar markets/trade.

India does not produce any ethanol from cereal grains. Fortunately, India's sugar demand has been increasing, necessitating 30 million tonnes of sugar production by 2025. Therefore, sugarcane cultivation is inevitable and must be increased substantially to satisfy domestic demand. However, there is no scope for increasing the sugarcane area. We have to improve productivity by developing elite varieties like Co 0238 and production/protection technologies to increase cane productivity to 100 t/ha as envisaged in ICAR-SBI Vision 2050. The only hitch is sugarcane pricing. Price should be increased substantially to sustain the sugarcane farmers in sugarcane cultivation. Then, the sugar industry will not be lacking in meeting the requirement of fuel ethanol in the country. Potentially India became a sugar surplus country for the past five seasons, which led to huge cane price arrears to the farmers and liquidity crisis in the industry. Nearly 14 million tonnes of accumulated sugar stocks will lead to further losses in the current season. Hence, diversion of juice/sugar to ethanol will substantially reduce the glut in sugar, increase sugar price and probably a viable sugar complex. The new biofuel policy helped divert about three million tonnes of sugar equivalent for bioethanol production during 2021-22. This scenario supports using excess sugar for bioethanol, avoiding glut in sugar in the market, regular cane payment, etc. Further, India can quickly achieve the growing demand for sugar and alcohol in the coming years with the improved sugarcane varieties and production technologies.

8. THE WAY FORWARD

The Government of India, since 2016, has been putting in place policies to achieve the EBP targets within a stipulated time frame. It has addressed issues like a better price for ethanol, the Oil Company, small case may be used blend, supply issues and restrictions imposed by the State Governments. For successful implementation of India's ethanol blending programme, three critical policy factors, namely, consistency, stability in price and flexibility, are essential. It may be made clear that ethanol blending with petrol will continue irrespective of oil prices, and such an unequivocal statement will prepare the stakeholders to make necessary investments. To sustain this industry, a policy needs to be in place to ensure a regular feedstock supply.

By 2040, it is estimated that India will become the largest consumer of crude oil (IEA). Importing the bulk of that requirement will leave us vulnerable economically and strategically. Ethanol blending is a possible way to avoid the grim situation.

The recommendations of the brainstorming session are given below:

i. Ethanol has competing users, and to get their share for blending, the OMCs should pay remunerative price. The GoI has been ensuring remunerative price from 2017-18 onwards. For ensuring price stability, ethanol pricing should be delinked from the crude prices. The GoI should also handhold the programme till it stabilises.

ii. Flexibility must be allowed to produce ethanol directly from cane juice or convert B heavy molasses earlier in the process, instead of manufacturing sugar when there is a glut in products. This will end the sugar cycle (non-climate triggered) and the debilitating cane arrears.

iii. Prices of ethanol from sugar beet, sweet sorghum and cellulosic agricultural wastes are not available; determining their prices would ensure the year-round feedstocks and ethanol supply.

iv. Among various lignocellulose feedstocks for cellulosic ethanol production, cornhusk residue shows advantages due to its high cellulose content and no pre-treatment requirement. This potential needs to be explored for the Indian condition.

v. A mission mode programme involving relevant ministries and departments is needed to develop indigenous 2G biofuels technologies, including cocktail enzymes. The patented and protected imported technologies are costly and may not suit Indian conditions.

vi. Manufacturing FFVs in India should be encouraged, which could run parallel to promoting electric vehicles considering the potential market available for automobile companies. Additionally, instead of fixing a mandatory blending rate for ethanol, a flexible system should exist wherein the blending rate can change as per the sugar stock (excess) in a year. In this way, the volatility in sugar prices can be kept in control.

vii. Regulatory authorities may review the ZLD scheme's standardisation based on B-Heavy molasses/cane juice usage for ethanol production. For all such sugar mills connected with distilleries, the concentrating spent is to be utilised in a bio composting system.

viii. To increase more availability of ethanol, the GoI may consider issuing provisional orders within a month to start production against undertaking submitted by the industry on submission of application with requisite documents. Final approval may be given within a time-bound manner (say six months) on validation by the competent agencies like National Sugar Institute (NSI), Vasantdada Sugar Institute (VSI) and The Indian Institutes of Technologies (IITs) within two months of production on enhanced capacity.

ix. Finally, green, clean and eco-friendly fuel use among the general public is to be encouraged by various central schemes, tax incentives, and mass media approaches to create awareness for usage of biofuels in the coming years in the country.

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List of participants

1. Dr T. Mohapatra, President, NAAS and Secretary, DARE & DG, ICAR, New Delhi
2. Dr Mangala Rai, Former President, NAAS and Secretary, DARE & DG, ICAR, New Delhi
3. Shri. Subodh Kumar Singh, Joint Secretary (Sugar & Admn.) Directorate of Sugar, GOI New Delhi
4. Dr R. K. Singh, ADG (Commercial Crops) ICAR, Krishi Bhavan, New Delhi
5. Dr Anil K. Singh, Secretary, NAAS, New Delhi
6. Dr P.K. Joshi, Secretary, NAAS, New Delhi
7. Dr Bakshi Ram, Director & Convener, ICAR-Sugarcane Breeding Institute, Coimbatore, Tamil Nadu
8. Dr A. D. Pathak, Director, ICAR-Indian Institute of Sugarcane Research, Lucknow, Uttar Pradesh
9. Dr Narendra Mohan, Director, National Sugar Institute, Kalyanpur, Kanpur, Uttar Pradesh
10. Dr Anjan Ray, Director, Indian Institute of Petroleum, Mohkampur, Dehradun, Uttarakhand
11. Dr Rintu Banerjee, Professor, Agricultural & Food Engineering, IIT, Kharagpur, West Bengal
12. Shri Shivajirao C. Deshmukh, Director General Vasantdada Sugar Institute, Manjari, Budruk, Tal.: Haveli, Dist.: Pune, Maharashtra
13. Dr S.V. Patil, Head & Technical Advisor, Department of alcohol technology, Vasantdada Sugar Institute, Manjari, Budruk, Tal.: Haveli, Dist.: Pune Maharashtra
14. Shri Prakash Naiknavare, Managing Director, National Federation of Cooperative Sugar Factories Limited.2nd Floor, Ansal Plaza, August Kranti Marg, Hudco Place, Block C, Andrews Ganj, New Delhi, Delhi
15. Shri Vivek M. Pittie, President, Indian Sugar Mills Association (ISMA), Ansal Plaza, ‘C’ Block, 2nd Floor, August Kranti Marg, Andrews Ganj, New Delhi
16. Dr Ram Murti Singh, President, North Indian Sugarcane & Sugar Technologists Association (NISSTA), AB Block, Dalippur Tower,6- Sapru Marg, Lucknow, Uttar Pradesh
17. Dr M. Manickam, Chairman and Managing Director, Sakthi sugars Ltd, Coimbatore, Tamil Nadu.
18. Dr Palani G. Periasamy, President, SISMA, South Indian Sugar Mills Association-Tamil Nadu (SISMA-TN), Chennai, Tamil Nadu
19. Shri Rana Inder Pratap Singh, Managing Director, Rana Sugars Ltd, SCO 49-0, Sector 8 C, Madhya Marg, Chandigarh
20. Shri R. Varadarajan, 338, The Uffizi, 8, Avinashi Rd, Peelamedu, Coimbatore , Tamil Nadu

21. Shri Bhosale GM (Distillery) M/s. Jamkhandi Sugars Limited., Post: Naganur, Tq: Jamkhandi, Dsirtrict Bagalkot, Karnataka
22. Dr G.S.C. Rao, Global Cane Sugar Services Pvt. Ltd, 4th Floor, TDI Center, Jasola Vihar, New Delhi
23. Shri S.K. Sachdeva Chief Operating Officer, Saraswati Sugar Mills Ltd, Radaur Road, Yamuna Nagar- 135 001, Haryana
24. Shri N. Prabhahar, Vice President Nava Bharat Ventures Ltd – Sugar Division, Samalkot , East Godavari Dt., Andhra Pradesh
25. Shri Abhishek Agarwal, General Manager, Distillery Division, Bajaj Hindustan Sugar Ltd, Khambarkhera, Uttar Pradesh
26. Dr M S Sundaram, JP Mukherji & Associates Pvt Ltd, Jyothi House, 172, Dahanukar Colony, Kothrud, Pune , Maharashtra
27. Shri Roshan Lal Tamak, Executive Director- Sugar,3rd Floor, World Mark 2, Aerocity New Delhi
28. Shri Praveen Gupta, Executive President, Mankapur Chini Mills PO. Datauli, Tehsil – Mankapur Distt, Uttar Pradesh
29. Shri Atul Mulay, President (Bioenergy Business). Praj Industries, Pune, Maharashtra
30. Dr S.S. Raju, Principal scientist, Central Marine fisheries Research Institute (CMFRI), Cochin, Kerala
31. Dr G. Hemaprabha, Principal Scientist & Head, Division of Crop Improvement, ICAR-Sugarcane Breeding Institute, Coimbatore, Tamil Nadu
32. Dr R. Viswanathan, Principal Scientist & Acting Head, Division of Crop Protection, ICAR-Sugarcane Breeding Institute, Coimbatore, Tamil Nadu
33. Dr C. Palaniswami, Principal Scientist & Acting Head, Division of Crop Production, ICAR-Sugarcane Breeding Institute, Coimbatore, Tamil Nadu
34. Dr K. Hari, Principal Scientist (Microbiology), ICAR-Sugarcane Breeding Institute, Coimbatore, Tamil Nadu
35. Dr P. Murali, Senior Scientist (Agricultural Economics), ICAR-Sugarcane Breeding Institute, Coimbatore, Tamil Nadu

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