

# Ethanol production:

## A saviour for sugar industry

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*Sugarcane is a widely grown crop that contributes significantly to the global agricultural economy, including India. Sugarcane cultivars primarily fall into two categories: thin and hardy (*S. barberi* and *S. sinense*), and thick and luscious (*S. officinarum*). The aristocratic *S. officinarum* has huge, soft-rinded stalks and its juice is high in sugar, primarily sucrose. India produces between 25 and 32 million tonnes (MT) of sugar each year, accounting for 15–17% of global sugar production. In India, 55 cultivars have been approved for commercial production on 4.9 million hectares (Mha) land, yielding an average of 69.5 tonnes per hectare (t/ha). To avoid surplus sugar production, Indian government implemented a new biofuel policy in 2018 that allowed ethanol manufacturing directly from sugarcane juice. This approval allowed it to be blended with gasoline, saving a significant amount of money on crude oil imports. Crushing sugarcane stalks and obtaining sugar-rich cane juice is the first steps in making ethanol from sugarcane. Sugar distillery industries are robust and self-sustaining because of the use of by-product resources such as molasses and bagasse. This article aims to provide insights into the current changing global scenario of sugarcane production and opportunity of industrial ethanol production directly from sugarcane juice that would be a savior for the sugar industry.*

**Keywords:** Biofuel, Crude oil, Ethanol, Pre-treatment, Sugarcane

**S**UGARCANE (*Saccharum* spp. Hybrid complex) is a crop of industrial importance, grown in 110 countries. It is known for the production of sugar, ethanol, jaggery and khandsari. India is 2<sup>nd</sup> highest sugar producer country after Brazil. As of 2019, India accounts for 24.5% of the world's sugarcane production. Sugarcane crop is grown in the distinct agro-climatic zone, i.e. tropical regions including Maharashtra, Gujarat, Madhya Pradesh, Goa, Puducherry, Tamil Nadu, Andhra Pradesh, Karnataka and Kerala; and sub-tropical regions Uttar Pradesh, Bihar, Haryana and Punjab. The sub-tropics account for about 55% of the country's total cane acreage. The top two sugarcane producing states are Uttar Pradesh and Maharashtra. Uttar Pradesh ranked first in the list of India's top states for sugarcane



Sugarcane crop

output in 2017–18, with 1623.4 lakh tonnes produced. Maharashtra came second in the state rankings, with 726.4 lakh tonnes production. Karnataka came in third place with 299.0 lakh tonnes production, and it quickly developed a reputation for producing India's best sugarcane.

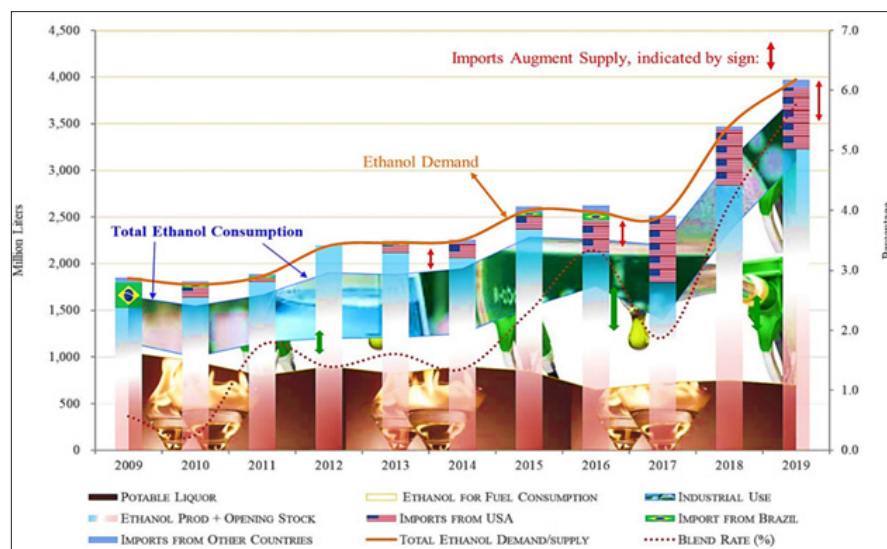
### Ethanol Blending Program (EBP) in India

The government of India started the ethanol blending programme to achieve sustainable development goals, energy security, employment, a clean environment, and GHGs reduction. National Policy on Bio-fuels 2009 targeted an ethanol

blending of 20% in petrol by 2017. The GOI authorized 10% obligatory ethanol blending with petrol/gasoline across whole cane-growing states as part of the Ethanol Blending Program (EBP). One reason was that 10 million litres of E10 biofuel/ethanol might save ₹28 crores in foreign exchange and approximately 20,000 tonnes of CO<sub>2</sub>. However, by 2017, the government of India had only reached a countrywide level of blending of 2% ethanol with petrol and 0.1% with diesel. However, in India's new National Biofuel Policy 2018, the national blending objective for gasoline was amended and maintained at 20% ethanol blends. According to the new EBP, ethanol must be manufactured directly from molasses, juice and damaged food grains such as broken rice and wheat. To avoid extra sugar production, the government has permitted ethanol manufacture directly from sugarcane juice. This permission paves the way for blending of ethanol with petrol and saves a lot of foreign exchange on importing crude oil.

#### Ethanol production, supply and consumption in India

According to the GAIN research, India presently has around 330 distilleries, producing over 4.8 billion litres of ethanol per year. Approximately 166 distilleries produced 2.6 billion litres of ethanol used in biofuel and industrial chemicals production. The total quantity given for EBP by the Indian Sugar Mill Association was 1.8 billion litres, of which 1.6 billion litres were blended with gasoline for a 4.1% blend rate in 2018. In 2019, India's total ethanol consumption was 3.1 billion litres. Although domestic production has risen, India remains a net importer of ethanol. The United States is the largest ethanol supplier in India. In 2018, Indian ethanol imports were down 14% to 633 million litres, valued at \$269 million. Generally, industrial and chemical users in India import ethanol to augment their cumulative demand, mainly when the local supply is short. A recent USDA report showed that India's average ethanol blend rate



India ethanol production, supply and consumption

Source: GAIN report, 2020, India: Biofuels Annual, USDA (<https://www.fas.usda.gov/data/india-biofuels-annual-3>)

reached approximately 5.8% in 2019 then 4.1% in 2018. Sugar mills and oil marketing companies (OMCs) plays an essential role in the ethanol blending programme. Some states like Uttar Pradesh, Karnataka, Haryana, Punjab, Uttarakhand and Bihar achieved more than 5.8% ethanol blending levels with petrol.

#### Bioethanol production from sugarcane juice and bagasse

Ethanol generation from molasses and cane juice is a well-known technique that is gaining popularity due to its use and applications in ethanol blending programmes worldwide. However, there are two significant wastes from sugarcane juice processing and ethanol fermentation: bagasse (solid) and vinasse (liquid). Sugarcane bagasse can be used for various purposes, including providing heat, steam and electricity for ethanol production and biodegradable paper goods. On the other hand, following the ethanol recovery process, vinasse, also known as spent wash, is produced as an unwanted waste at the bottom of the distillation unit column. Vinasse is a dark-colored wine with high organic content and an acidic pH (4.0–4.5). Therefore, it can be used to produce methane. Generally it is treated through methanization before disposal. However, currently, treated vinasse disposal is a significant concern for sugarcane industries.

Around 250 kg of bagasse is generated per tonne of sugarcane, which can be used to make ethanol. Fiber, juice, syrup (water), soluble solids, and non-soluble solids make up a detailed mass balance and composition of sugarcane biomass. It comprises 73–76% water, 10–16% soluble solids, and 11–16% dry fiber.

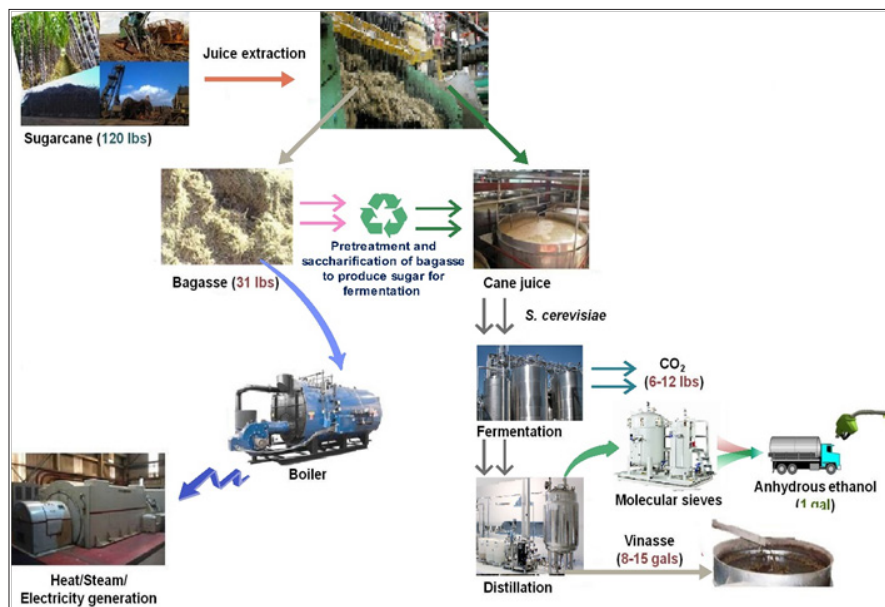
On the other hand, the soluble solids fraction, which is mainly made up of sucrose and other chemical elements, dissolves easily in water. Sugarcane bagasse comprises of cellulose (a polymer of hexose sugar e.g. glucose) and hemicellulose (a pentose sugar e.g. xylose). The hexose and pentose sugar of biomass could be well utilized for producing bioethanol by a different established metabolic mechanistic system of microbial origin. The cellulose and hemicellulose component of pre-treated sugarcane bagasse is subjected to enzymatic hydrolysis to convert the carbohydrate's polymeric structure into glucose and xylose.

The hexose and pentose sugar liberated from biomass pre-treated/hydrolysis and enzymatic saccharification are used to produce ethanol by yeast. Fermentation involves microbial processes, which is a critical factor in achieving higher ethanol yield. The different pretreatment strategies to produce fermentable sugar and ethanol have been tabulated in Table 1.

|                          |                 |                         |                 |
|--------------------------|-----------------|-------------------------|-----------------|
| <b>Agricultural area</b> | <b>1 ha</b>     | <b>Water</b>            | <b>7.000 t</b>  |
| <b>Sugarcane stem</b>    | <b>70.000 t</b> | <b>Juice extraction</b> |                 |
| Water (73%)              | 51.100 t        | <b>Sweet juice</b>      | <b>59.107 t</b> |
| Sugars                   | 9.081 t         | Water (84%)             | 49.616 t        |
| Cellulose                | 3.741 t         | Sugars                  | 8.352 t         |
| Hemicellulose            | 2.229 t         | Others                  | 1.139 t         |
| Lignin                   | 2.238 t         | Total                   | 59.107 t        |
| Others                   | 1.611 t         |                         |                 |
| Total                    | 70.000 t        |                         |                 |
|                          |                 | <b>Bagasse</b>          | <b>17.893 t</b> |
|                          |                 | Water (52%)             | 8.484 t         |
|                          |                 | Sugars                  | 0.729 t         |
|                          |                 | Cellulose               | 3.664 t         |
|                          |                 | Hemicellulose           | 2.183 t         |
|                          |                 | Lignin                  | 2.193 t         |
|                          |                 | Others                  | 0.639 t         |
|                          |                 | Total                   | 17.893 t        |

Mass balance and composition of bagasse of sugarcane

Source: Gnansounou and Dauriat, 2005



Schematic diagram of ethanol production from sugarcane juice and bagasse

Source: Modified and adopted from S Prasad *et al.* 2022 ([https://link.springer.com/chapter/10.1007/978-981-16-5199-1\\_22](https://link.springer.com/chapter/10.1007/978-981-16-5199-1_22))

**Table 1.** Ethanol production from sugarcane bagasse

| Pre-treatment method                                                                                | Microbe                                                       | Initial sugar (g/L)    | Fermentation condition             | Ethanol yield (g/L) |
|-----------------------------------------------------------------------------------------------------|---------------------------------------------------------------|------------------------|------------------------------------|---------------------|
| Steam explosion, temperature: 195°C kept for 7.5 min.                                               | <i>S. cerevisiae</i>                                          | 60.4                   | SSF, at 35°C, 150 rpm, time: 48 hr | 18.3                |
| Alkali-pretreated with NaOH: 15%, temperature: 175°C                                                | <i>S. cerevisiae</i> -LBM-1                                   | 24.0                   | SSF, at 37°C, 180 rpm, time: 10 hr | 8.8                 |
| Pretreated with NH <sub>4</sub> OH-H <sub>2</sub> O <sub>2</sub> temperature: 140°C kept for 60 min | <i>S. cerevisiae</i> SHY07-1 and <i>Pichia stipitis</i>       | 13.9                   | SSF for 120 hr                     | 14.1                |
| Pretreated with dilute HNO <sub>3</sub> temperature: 100°C kept for 30 min                          | <i>Pichia stipitis</i> 3498 and <i>S. cerevisiae</i> VSI 1011 | 79.43                  | 32°C, 120 rpm, time: 36 hr         | 31.01               |
| 0.29 M of NaOH, 0.78% (v/v) of H <sub>2</sub> O <sub>2</sub> , kept for 9.95 min                    | <i>Scheffersomyces stipitis</i> NRRL-Y7124                    | Glucose: 60, xylose 25 | 30°C, 200 rpm, time: 48 h          | 31.50               |

(SSF denotes saccharification and fermentation)

Since fermentation involves microbial processes, the optimization of process conditions is a critical factor in achieving higher ethanol yield. Also, fermentation efficiency is hampered by several inhibitor

molecules produced during the pre-treatment steps, which is still critical to overcoming such challenges in improving overall process economics for ethanol production from sugarcane bagasse. Therefore,

it is essential to develop an efficient synergistic enzymatic cocktail system, where the pre-treatment step can be combined with the saccharification and fermentation step. Such simultaneous saccharification and fermentation (SSF) mode can improve the whole ethanol production process efficiencies.

## SUMMARY

Sugarcane is a widely grown crop used to produce diversified products and by-products, especially raw juice, molasses and fibrous bagasse. The current changing global scenario of sugarcane production and various environmental challenges has given the opportunity of industrial ethanol production directly from sugarcane juice, which would be a savior for the sugar industry. Ethanol production from sugarcane is environmentally friendly and can contribute significantly to the agricultural economy. India, the world's second largest sugar producing nation after Brazil, produced more than 28.2 MT of sugar in 2019–2020. High-yielding sugarcane cultivars contributed a potential role in its commercial production. It is estimated that sugar production may reach up to 31.9 MT in the ongoing 2021–22 marketing year. The scientific community and policymakers are currently focussing on eco-friendly and wise management of its vast amount of bagasse to produce bioenergy. Several pre-treatment technologies are available to achieve high ethanol yield via economically feasible pre-treatment and enzymatic hydrolysis from bagasse. Many challenges exist during the critical step in bioethanol production, such as physico-chemical and biological pre-treatment followed by enzymatic saccharification. However, extensive research is required to develop cost-effective, innovative bioconversion pre-treatment technologies choices and the right selection of efficient methods.

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