# “INDIA'S ETHANOL PUSH TO ETHANOL BLENDED PETROL FOR ENERGY SECURITY”

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**Abstract: Ethanol is one of the primary biofuels, naturally produced through the fermentation of sugars by yeasts or through petrochemical processes like ethylene hydration. It is widely used not only as an alternative fuel source but also in various industries as a chemical solvent and in the synthesis of organic compounds. Ethanol also has medical applications as an antiseptic and disinfectant, adding to its versatile uses.**

**In the context of India’s rising energy demand, driven by factors such as a growing economy, an expanding population, increasing urbanization, and evolving lifestyles, ethanol plays a critical role. As of March 2024, around 98% of the fuel used in the road transportation sector comes from fossil fuels, while only 2% is met by biofuels like ethanol. This dependency on fossil fuels presents challenges related to energy security, foreign currency outflow, and environmental impact.**

**Ethanol, as a domestically produced biofuel, offers a strategic opportunity to reduce the country’s dependence on imported fossil fuels. When used responsibly, biofuels like ethanol are more environmentally friendly and sustainable, contributing to a cleaner energy landscape. Additionally, ethanol production and usage align with national goals like generating employment, promoting the "Make in India" initiative, supporting the Swachh Bharat Mission, and contributing to the doubling of farmers' incomes. It also fosters the creation of wealth from waste, further enhancing its importance to India’s economy and energy security.**

**1.Introduction:** India is taking significant steps toward securing its energy future by embracing sustainable practices like ethanol blending. As the world's third-largest energy consumer, the country has traditionally depended on oil imports to meet its growing energy demands. This reliance not only poses challenges to energy security but also leads to a substantial outflow of foreign currency. However, with ethanol blending, India has a promising opportunity to reduce its dependence on imported oil while addressing environmental concerns. Ethanol, a byproduct of sugarcane processing, can be mixed with petrol, cutting down on fossil fuel consumption and reducing harmful carbon emissions that contribute to climate change and public health issues.

The practice of blending ethanol with petrol began in 2001 as a pilot project. Yet, for many years, progress was slow, and ethanol production remained stagnant. Only recently, through a series of comprehensive reforms, has India been able to unlock the full potential of this initiative. These reforms are now driving substantial outcomes, not just by enhancing energy security, but also by revitalizing rural economies. Ethanol production offers a new source of income for farmers, supporting the agricultural sector and fostering economic growth in rural areas. The government's proactive approach to ethanol blending is evident in its decision to advance the target of 20% ethanol blending from 2030 to 2025, demonstrating a strong commitment to sustainable energy practices. During the 7th G-STIC Delhi Conference, Shri Hardeep Singh Puri, Minister of Petroleum and Natural Gas, emphasized India's growing success in ethanol blending and its broader commitment to sustainable energy solutions. He highlighted that, in recognition of the progress made, the government has already begun planning for the future by exploring goals beyond the 20% ethanol blending target. This forward-looking approach indicates that India is not only focused on meeting its immediate energy needs but is also preparing for long-term sustainable energy solutions to address future demands.

**2 Ethanol as versatile biofuels :**

Ethanol is one of the primary biofuels, naturally produced through the fermentation of sugars by yeasts or through petrochemical processes like ethylene hydration. It is widely used not only as an alternative fuel source but also in various industries as a chemical solvent and in the synthesis of organic compounds. Ethanol also has medical applications as an antiseptic and disinfectant, adding to its versatile uses.

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# 3. Literature Review

We conducted a systematic literature pertaining to ethanol blending and its value chain based on the following four themes:

- (a) Ethanol blending in Indian and international contexts (both including and excluding the system dynamics approach);
- (b) Integrated 1G and 2G ethanol production;
- (c) Ethanol production from rice straw and bagasse;
- (d) Policy formulation pertaining to ethanol blending.

Several studies pertaining to ethanol blending have been carried out in both Indian and international contexts. Kushal et al. conducted a feasibility analysis for ethanol-blended fuel in India. They concluded that the ethanol value chain needs to be strengthened to achieve ethanol blending targets in the coming years. Sakthivel et al. [4] studied the use of ethanol fuel in the Indian automotive sector and emphasized the importance of alternative feedstocks. However, their study did not touch upon ethanol use in other sectors. Hiloidhari et al. [50] conducted a life cycle assessment of ethanol in different sugarcane seasons for improved sustainability of sugarcane bioproducts in the Indian context. Kumar [3] conducted an economic assessment of ethanol blending and its importance given the growing social cost of carbon. Saikia et al. [1] studied the current status and prospects of ethanol blending in India and recommended using alternative feedstocks for ethanol production and promoting local ethanol production.

As there is a dearth of research applying system dynamics to the study of ethanol blending in the Indian context, we also reviewed studies in the international context. Jin et al. [2] investigated cellulosic ethanol production systems in the U.S. and advocated expanding energy crops on marginal land and developing biorefineries with advanced bioconversion technologies. Guevera et al. [53] evaluated the sustainability of ethanol production in Brazil and discussed important factors in Brazilian ethanol production, its effects on the environment, food production, and water consumption, and future trends. However, their study did not capture 2G ethanol production or the demand side of ethanol in multiple industries. Vimmerstedt et al. [4] explored the conditions needed to sustain an ethanol fuel market and concluded that an economically sustainable ethanol fuel market needs lower pricing than petrol. Bevenutti et al. [5] developed a system dynamics-based life cycle model to compare the use of electric and ethanol options in passenger mobility and concluded that the latter dominate most scenarios. Sagardi et al. [6] studied the feasibility of the ethanol supply chain in Mexico using system dynamics and emphasized the need for local availability of sowing grains and enhanced refining capacity for ethanol production.

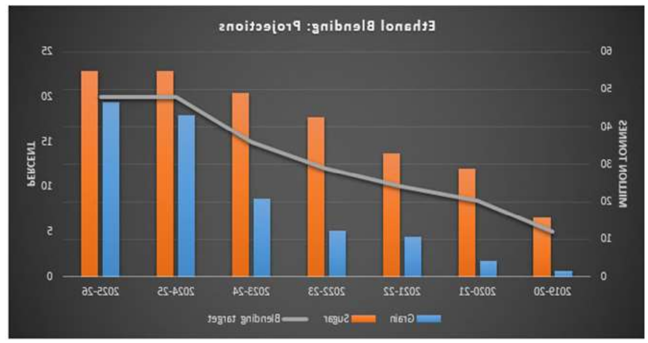
Research studies that consider the production of both 1G and 2G ethanol were also thoroughly examined because the future road map of India's ethanol blending program is based on a combination of 1G and 2G ethanol. Sukumaran et al. [7] studied the availability of feedstock, the potential conversion of yields, and the composition of 1G and 2G ethanol in the Indian context and concluded that developing ethanol from biomass is an appropriate way to achieve a sustainable supply chain of liquid fuels for transportation. Saini et al. [8] evaluated past and present purification and recovery technologies for 1G ethanol to establish a learning trend of 2G ethanol recovery. Watanabe et al. [9], with the help of a hybrid input-output life cycle assessment of 1G and 2G ethanol production technologies in Brazil, showed that integration of 1G and 2G technologies significantly reduces the total greenhouse gas emissions of ethanol production. Carpio et al. [10] studied multiobjective optimization of a 1G-2G biorefinery and concluded that 2G ethanol is not yet consolidated in industries. Stephen et al. [11] showed that 2G ethanol can become competitive if cost reductions occur across all components of the production process. Maga et al. [12], through a comparative life cycle assessment of 1G (sugarcane) and 2G (bagasse and trash) ethanol from sugarcane in Brazil, showed that 2G ethanol allows significant reductions in land use. Buck and Senn [13] studied crop diversity for developing 1G and 2G ethanol in the German context and found that straw substrates are most suitable for ethanol production.

## 4. Issues

India's ethanol blending policy and its unintended consequences illustrate the complex trade-off between food and fuel security. India, traditionally a major exporter of corn to South and Southeast Asia, is expected to export 84 percent less corn this year and for the first time in two decades, become a net importer of corn. India usually exports 2 MT to 4 MT of corn, but in 2024, exports are expected to drop to 450,000 tonnes, and India is set to import a record 1 MT of corn, mainly from Myanmar and Ukraine, which grow non-GM (genetically modified) corn. India's pursuit of ethanol blending has diminished India's role as a key supplier to the global grains market. Between 2020 and 2024, India's corn exports are estimated to decline by 86 percent. India is also a net importer of ethanol. In 2024, India imported 600 million litres of ethanol, almost 50 percent more than imports in 2023, to meet India's medical, industrial, and beverage demand. The increase in imports of feedstock and fuel contradicts the goal of improving energy self-reliance by reducing imports.

The price of ethanol in India is higher than in countries like the USA (corn-based) and Brazil (sugarcane-based), which are much larger producers of ethanol. This is because India's regulated price of feedstock (sugarcane, corn etc) is maintained at a higher level to support farmers. The minimum support price (MSP) for corn has increased from INR13,650/tonne (t) to INR19,620/t in 2022-23, a 43 percent increase. In the same period, the cost of production of corn increased by about 25 percent. In January 2024, the government raised the procurement price of corn-based ethanol by 29 percent, bringing it to INR71.86 (about US$0.86)/litre. The price of corn-based ethanol in the USA in 2024 was approximately US$0.74/litre. Generous MSP facilitate an increase in corn production and higher income for domestic corn farmers. Import of fuel crops such as corn is likely to continue, as the availability of land for corn cultivation is limited. This will support farmers from other countries. Effectively, taxpayers in India will be providing income support for farmers outside India. India's presence as a large importer of grain in commodity markets will increase globally traded corn prices, to the benefit of corn farmers around the world.

In the nascent stages of the solar industry, subsidies in Germany, Italy, and Spain for solar installations supported the manufacture of solar panels in China. Later, a mature and competitive solar manufacturing industry in China produced affordable solar panels, that facilitated an increase in solar installations in India. Chinese solar panels dominated solar installations in India, which received a wide range of financial subsidies. This meant that Indian taxpayers effectively supported the creation of thousands of solar manufacturing jobs in China. India is now subsidising manufacturers of solar panels within India. As in the case of the solar sector, India may turn to domestic producers of corn to reduce imports and increase "energy security". But, resource constraints - particularly land and water constraints - for domestic production of fuel crops may prove insurmountable in the long run. In the competition for resources between food and fuel, food is likely to win.




# 5. Methodology

Since this study focuses on the dynamic interaction among multiple linkages that reflect important insights into decision-making and policy formulation processes, we analyzed carefully the methodologies available for modeling and simulation to select one that fits our purposes.

Agent-based modeling (ABM) is a computational approach to modeling built on predefined rules in which agents with particular attributes interact with each other and their environment [7]. The approach has been found helpful in research fields pertaining to public health, construction, psychology, and agricultural policies However, with ABMs, it is difficult to initialize, parametrize, and analyze multidimensional output data [4]. Discrete event simulation (DES) and system dynamics (SD) are the other two approaches popular for modeling and simulation [5]. DES models a system whose behavior can be described in terms of events or activities in discrete time, whereas SD models a system as a set of stocks and flows adjusted in pseudocontinuous time [8]. DES has been utilized in research work on health care, virtual reality, and manufacturing systems [6]. The major difference between the two approaches is that feedback is modeled only in the latter approach [9]. While DES is focused on the analytic view, SD takes a more holistic view of the system under analysis [2].

Hence, we chose SD as the methodology for this study, as it focuses on strategic policy analysis and addresses the challenges associated with the complex process of decision-making. Researchers, practitioners, and academicians have utilized SD tools to model and simulate various scenarios that clarify the impacts and interdependent relationships among different processes, players, and systems]. SD is considered an important and effective way to articulate and analyze relationships between system components and to simulate their behavior with respect to time

SD has been applied in a range of contexts to study the impact of various important variables on renewable energy systems and decision-making. It has been helpful in evaluating sustainable business models, energy and climate change constraints on global growth, the use of biowaste to produce ethanol, and policies on energy dependency and ethanol production The SD approach is also ideally suited to uncertainties and nonlinearities. SD can model highly dynamic markets and make it possible to understand medium- and long-term policies and their effects on socioecological systems where sustainability cannot be ignored [7].

### *6.* Conversion of Juice to Sugar and ethanol

To form a syrup, the juice is heated and treated (to remove unwanted inorganics and to avoid sugar inversion). The sugar is then separated from the syrup through a process of crystallization or drying, leaving behind filter cake, liquid effluents (combined in the model as *Waste Yield from CSC* and amounting to 55.2% of the crushed sugarcane), and molasses (4.5% of the crushed sugarcane) [13]. Molasses obtained as a by-product are fermented to produce ethanol (*M ethanol*). It is assumed that, initially, the molasses obtained are used for ethanol production and that nothing goes to waste or is otherwise diverted. The ethanol yield can be increased if less sugar is produced from the sugarcane juice, leaving behind more concentrated molasses for fermentation. The sugar produced is either sold in the markets for local consumption or, in the case of surplus production, exported. The remaining inventory is stored for future use.

### 6.1.2. Direct Conversion of Juice to Ethanol

The juice can be treated directly through the fermentation process to produce ethanol (*J ethanol*), with a yield 6.3 times greater than that obtained from molasses, but the process is seldom used as a standalone treatment, as it poses a threat to food security [2, 6]. In the model, *Proportion of Sugar Cane Juice Used to Make Direct ethanol* is initially set to zero and subsequently increased to 12% during sensitivity analysis.

## 6.2. Ethanol Production from Bagasse

Of the total bagasse produced from the milling of crushed sugar cane, about 80% is used as a primary fuel source for the sugar mills [10]. Thus, about 20% of the bagasse produced is available for making 2G or cellulosic ethanol [10]. Using the excess bagasse to produce ethanol removes the need for its disposal, which would have led to pollution in some form. The ethanol yield from bagasse is estimated to be 0.25 $m^3$ per tonne of bagasse used [3]. The sector map of ethanol production from bagasse (*B ethanol*) is shown in Figure 3.

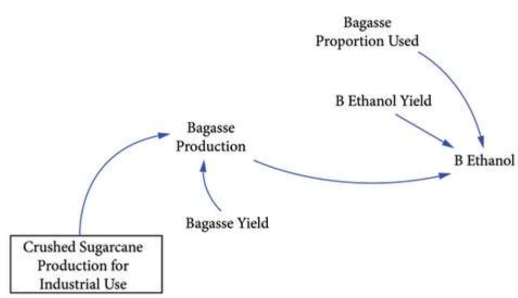



Figure 3Part of the SD model representing

ethanol production from bagasse.

**7.Result and conclusion :**

Ethanol has the scope and ability to provide environmental benefits and support the agricultural economy. This study has used SD to model ethanol production and consumption in India. Through the model developed, we have explored traditional production and consumption of ethanol and addressed emerging trends in the industry, which include the use of alternative sources of ethanol on the production side and the increased use of ethanol as an eco-friendly energy source.

To examine avenues for increasing ethanol production, the model includes traditional sources of ethanol, such as bagasse and molasses, which are linked to sugar production. The model also considers sources, such as rice straw and sugarcane juice (direct ethanol), that supplement traditional production. By varying the proportion of rice straw burnt (Scenario 1), the model highlights the potential of rice straw as a revenue-making source of ethanol that also reduces detrimental impacts on the environment. Surplus rice straw is readily available in India, and its utilization in ethanol production has two benefits: environmental protection in the form of curbing the burning of rice straw, and avoidance of fuel emissions by replacing conventional petrol with ethanol. However, to implement such a solution, suitable procurement and pricing mechanisms must be developed to divert unutilized rice straw from farmers and towards the production of ethanol and other useful by-products. Similarly, a significant quantity of bagasse that is left over as waste from sugar mills could be utilized in ethanol production. These potential sources require faster progress in setting up 2G ethanol refineries.

Our exploration of the direct conversion of sugar cane juice to ethanol (Scenario 2) shows that extracting direct ethanol may not pose an enormous threat to food security through significant sugar production losses and in fact may generate high revenues. This finding supports the decision by the Indian government to permit ethanol production directly from sugar cane juice. In the case of exceptional circumstances like drought and famine, adjustments can be made to the quantum of juice conversion to ethanol so that food demands are met as a priority.

On the demand side, the model includes various markets for ethanol, such as the petroleum, paint, chemical, and liquor industries, and simulates changes in the blending ratios of ethanol in petrol (Scenario 3). The results support the conclusion that higher blending ratios provide better environmental benefits, while revenue generation varies across medium- to short-term scenarios. Although higher blending ratios provide greater revenue and environmental benefits in the medium term, the long-term benefits of lower blending ratios may outweigh these advantages.

Since these scenarios were analyzed independently, we also explored combinations of production and consumption strategies to check for interactions that can help develop better strategies. Thus, we saw that encouraging 2G ethanol production from rice straw and increasing blending ratios lead to reductions in CO2 emissions. India has an Intended Nationally Determined Contributions target of a 33–35% reduction from the CO2 intensity levels in 2005. CO2 emissions from energy contribute to about 68% of India's total CO2 emissions and are expected to touch 3.8 giga tonnes by 2030 [123]. Calculating the emissions' scenarios for 2030 (the target year of the National Policy on Biofuels, 2018), it is observed that this initiative would contribute to a 1% reduction in the quantum of the total CO2 emissions. Similarly, revenue generation is highest when high blending ratios are combined with high levels of direct ethanol production. The combination of the three scenarios indicates that the best option, in terms of both emissions and revenue generated, involves high blending ratios combined with higher levels of 2G ethanol produced from rice straw.

In the combined scenarios, the impact of direct ethanol is not very pronounced in terms of changing the emissions or the revenue generated compared with the impact of different blending ratios or production of 2G ethanol. In India, oil marketing companies from the public sector had committed to assured offtake for 15 years and have entered into a purchase agreement with suppliers of 2G ethanol. Hence, from the perspective of ensuring food security and encouraging capacity development in 2G ethanol, it may be beneficial to maintain low levels of direct ethanol or to consider its production only as a short-term measure for boosting revenues and reducing dependence on imports of crude and ethanol.

For the 2030 scenario, taking into consideration the expected growth rate of the chemical liquor and petroleum industries, the model indicates that the total amount of ethanol available would be sufficient to meet the blending targets. However, if the chemical and liquor industries take their due share, remaining ethanol quantities may be adequate to meet only 8% blending. If even a maximum level (i.e., 12% direct sugarcane juice to ethanol production) is put into practice, an ethanol fuel blending ratio of 9.4% will be achieved, below the current 10% target and far below the aspirational 20% target. An unforeseen calamity like poor rainfall and drought could further reduce the ethanol yield and, in turn, the blending ratio. Thus, to improve the fuel ethanol blending ratio, measures must be taken to diversify feedstocks for producing 2G ethanol, enhance the infrastructure to scale up the ethanol production capacity, and promote alternative energy sources so that the growth in demand for petrol can be arrested.

Although there is great interest in electric vehicles, the current infrastructure and unavailability of clean power remain barriers to their success in the short to medium term, while the available natural gas resources are not enough to meet the internal demand for petrol. Hence, ethanol is the most viable, sustainable, and eco-friendly alternative fuel option.

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