Grain to gain:
Impact of corn on India's biofuel revolution

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SHAPING VIBRANT INDIA

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Introduction

1.1 Ongoing energy transition and its key challenges in India

India is the world's third-largest energy-consuming country, although its per capita energy consumption is only one-third of the world's average. As India has set an ambitious target of becoming energy independent by 2047 and achieving net zero by 2070, the Government of India is committed to setting up 50% of cumulative power generation from non-fossil fuel-based energy resources by 2030. Furthermore, the country has set up five goals as Panchamrit at COP26.

The five commitments made at the global conference were:

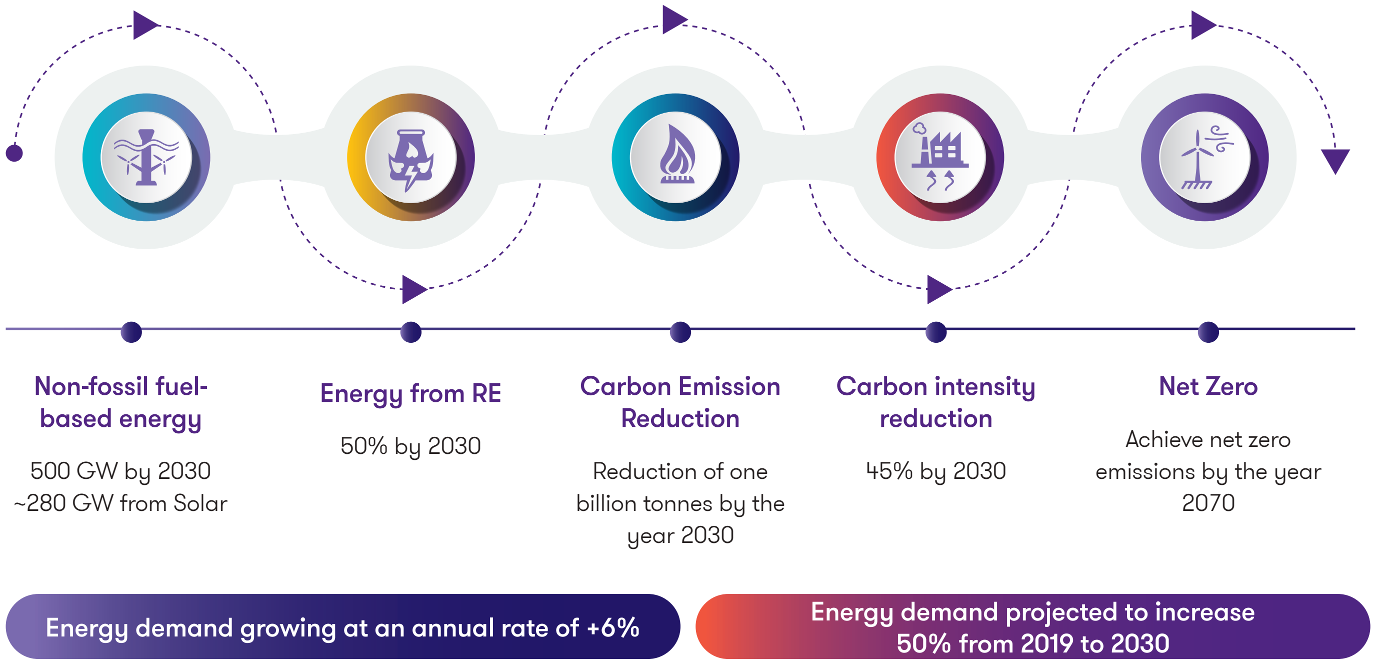

Figure 1: India's climate action

To attain this objective, increasing the utilisation of domestically sourced renewable energy stands as the cornerstone of India's energy transition. Fulfilling these ambitious commitments necessitates extensive decarbonisation efforts on a monumental scale. To meet India's new 2030 goals, the country must install an additional 320 gigawatts (GW) of non-fossil fuel energy capacity within this decade. India has experienced the swiftest renewable energy capacity expansion growth rate among all major economies in the last seven years. It will need to ramp up the addition of renewable capacity substantially, aiming for an average annual increase of around 45 to 46 GW of non-fossil fuel energy capacity to achieve the targets.

However, the push towards an energy transition to achieve net-zero emissions presents numerous challenges, particularly in large and diverse economies such as India. The key challenges can be categorised into economic, technological, and policy and regulatory sectors based on the insights.

Economic challenges

Investment requirements:

India is estimated to require an investment of USD 14 –17 trillion by 2070 to successfully transition to net-zero energy systems. Such a substantial capital outlay represents a significant burden on the national economy.

Capital expenditure:

Upfront costs are substantial, with peak investments expected between 2035-2050. Efficient allocation and management of these funds are critical to simultaneously sustaining India's growth and energy transition.

Operational costs:

Adoption of new technologies such as green hydrogen, CCUS and biofuel are likely to increase operational expenses for end-users due to their higher costs compared to conventional fuels.

Technological challenges

Resource and land requirements:

Large-scale adoption of grid-scale renewable energy and an additional RE capacity for green hydrogen production necessitates significant land and resource availability.

Adoption pace and technological maturity:

Challenges such as slow adoption rates, the need for long-duration storage, and the maturity of new technologies like FCEV, CCUS affect the transition timeline..

Infrastructure transition:

Existing infrastructures, particularly in heavy industries like cement and steel, need to transition to cleaner technologies, requiring substantial technological and infrastructural overhaul.

Policy and regulatory challenges

Lack of clear roadmap:

Absence of a definitive plan for phasing out coal-based power and scaling renewable energy integration

Variable subsidies and policies:

Absence of a carbon tax and sufficient mandates for renewable energy adoption slows down the transition process

Infrastructure and regulatory needs:

Necessity for more focused policy on land allocation, open access, energy banking, and infrastructural development for supporting technologies

1.2 Significance of Biofuels in India's ongoing energy transition

Biofuels are renewable energy sources derived from biological materials such as plants, algae, or animal waste and are increasingly becoming vital in India's strategy to achieve its ambitious 2070 carbon neutrality goal. Their significance in the country's energy portfolio is marked by their renewable nature and the policy support and strategic role they play in reducing dependency on fossil fuels.

Enhancing energy security

Biofuels offer India a strategic advantage in enhancing energy security. The use of domestically produced biofuels, such as ethanol blended with petrol, which reached a 10% blending rate in 2021-22, supports local agriculture and industry, thereby fostering economic resilience.

Reducing environmental impact

Use of Biofuels significantly reduces emissions of GHG gases and pollutants, helping India meet its climate goals. The lifecycle production of biofuels, if managed sustainably, can substantially reduce carbon footprints compared to traditional fuels.

Economic benefits

With government initiatives such as subsidies, tax exemptions, and reduced import tariffs on biofuel-related products, there is a significant incentive for investors and companies to engage in biofuel production. This economic stimulation extends to technological advancements and innovation, spurred by government-funded research and development in the biofuel sector.

1.2.1 Impact of Increased Biofuels Usage on Various Sectors in India

Impact of increased biofuels usage on various sectors in India: The integration of biofuels into India's energy landscape impacts various sectors significantly, including agriculture, the automotive industry, the energy sector, and supply chain and logistics. Here's how increased biofuels usage is influencing these areas:

Impact on the transport industry

- Reduction in crude oil imports: The use of ethanol-blended fuel aims to reduce India's dependency on imported crude oil, lower carbon emissions, and provide a cleaner alternative to fossil fuels.
- Adaptation to flex-fuel vehicles: The automotive industry is adapting to biofuels with initiatives like the introduction of flex-fuel vehicles, which can run on varying blends of gasoline and ethanol.

Impact on the energy sector

- Enhanced energy security: Biofuels provide a renewable alternative to conventional fossil fuels, helping reduce dependency on finite resources and enhancing energy security.
- Economic and environmental benefits: The E20 programme, which targets a 20% ethanol blend by 2025, could save billions in oil imports, reduce carbon emissions, and align with India's net-zero emissions goals.

Impact on industry sector

- **Biomass as a feedstock or fuel:** Replace feedstock or fuel with sustainably produced biomass –
- **In the aluminum sector:** Biomass co-firing for process heat generation in alumina refining
- **In the cement sector:** Thermal substitution rate of 15–20% with biomass, waste
- Impact on agriculture
  - Economic uplift for farmers: The production of biofuels, particularly ethanol from sugarcane and its by-products, has provided an alternative revenue stream for farmers, helping to alleviate the sugar glut and promoting the diversion of surplus crops like rice and maize for ethanol production.

1.2.2 Challenges in transition to biofuels:

- **Infrastructure adjustments:** Biofuels require different handling and storage facilities, leading to infrastructure and fleet management changes within the logistics sector.
- **Crop patterns:** Demand for biofuel crops is changing agricultural practices, potentially shifting land use from food to energy crops, which raises concerns about food security and environmental sustainability.
- **Transport sector:** Engine modifications and distinct chemical properties of biofuels necessitate specialized transportation vehicles.
- **Regulatory compliance and business opportunities:** Compliance with environmental regulations and the potential for new business avenues in biofuel logistics.

1.2.3 India's policy targets for biofuel adoption

India's National Policy on Biofuels (NPB) 2018 and the Global Biofuels Alliance (GBA) are two pivotal initiatives aimed at promoting the use of biofuels:

1. National Policy on Biofuels (NPB) 2018: This policy focuses on reducing crude oil imports, enhancing farmers' incomes, efficiently using drylands, and promoting sustainability. It provides financial and fiscal incentives for producing various generations of biofuels, from first-generation (1G) to third-generation (3G). It supports initiatives like the Sustainable Alternative Towards Affordable Transportation (SATAT) to establish compressed biogas (CBG) production units and market CBG as a green fuel.

- With approximately 500 million tonnes of biomass available annually, the nation has set ambitious targets,
  - Blending targets for ethanol (20% blending by 2030).
  - Blending targets for biodiesel (5% by 2030)
  - Beyond blending targets, India established guaranteed pricing, long-term ethanol contracts, and technical standards and codes.
- Buoyed by its success, the government moved the 20% volume blending target for ethanol forward by 5 years to 2025-26, which was incorporated in an updated National Policy on Biofuels in 2022.

2. Global Biofuels Alliance (GBA): Initiated by India during its G20 Chairmanship and supported by countries including the USA, Brazil, and others, the GBA aims to accelerate global adoption of biofuels. It promotes technological advancements, increases sustainable biofuel usage, and sets high standards and certifications. The GBA also functions as a knowledge hub and expert repository to foster global collaboration and support the substantial increase in biofuel production needed to meet global net-zero emissions targets by 2050.

1.2.4 Biofuel feedstocks available in India

Sugar cane accounts for the majority of ethanol production with the rest coming from food grains such as maize and surplus rice stocks determined by the Food Corporation of India. To diversify feedstocks beyond sugar cane, India provides separate pricing for maize-based ethanol and includes ethanol produced from agricultural residues such as cotton stalks, wheat straw, rice straw, bagasse and bamboo.

India's diverse agricultural landscape provides a variety of feedstocks that are essential for biofuel production. These feedstocks form the backbone of the biofuel industry, supporting both ethanol and biodiesel production:

Sugarcane and its by-products

Sugarcane is one of the primary sources for ethanol production in India. Initially in the Indian ethanol industry, by-product molasses was mainly used as a feedstock and most ethanol plants were set up near the sugarcane plants, similar to how petrochemical plants were set up near the petroleum oil refineries. States such as Uttar Pradesh, Maharashtra, and Karnataka are involved in widespread cultivation of sugarcane in India.

Jatropha

Jatropha oil was considered for biodiesel production in The National Biofuel Policy of 2008 but its limited availability and high costs hindered widespread use. Although promoted as a drought-resistant crop suitable for degraded soil, Jatropha plantations faced ecological and economic challenges, leading to poor performance. Despite government initiatives at national and state levels to promote Jatropha cultivation, these efforts were largely unsuccessful due to various obstacles.

Corn

Corn is increasingly being used as a feedstock for ethanol production, especially with the government's push to diversify beyond traditional sources. The surplus production of corn in states such as Bihar, Karnataka, and Madhya Pradesh provide a significant opportunity for its use in biofuel production.

In the USA, non-edible yellow dent corn is mainly used for ethanol production, animal feed, and industrial purposes like starch and oil. The USDA reports an average yield of 180 bushels per acre, with some hybrids reaching 250 bushels. In India, non-edible yellow corn is grown primarily for animal feed and industrial uses, with Gujarat, Madhya Pradesh, Rajasthan, UP-Bihar, and Maharashtra as major producers. Boosting this corn's production in India could supply the ethanol industry, increasing farmers' income and addressing the food vs. fuel debate.

Rice husks and other agricultural residues

With India being one of the largest producers of rice, rice husks and other agricultural residues such as wheat straw and cotton stalks serve as important feedstocks for biofuel production. These materials are primarily used to produce biogas and second-generation biofuels, which are crucial for achieving sustainability in energy resources.Despite the higher costs and technological challenges of 2G ethanol production from rice husks and agricultural residues, the Indian government and public sector oil companies are working to establish 2G ethanol plants. Currently, there are no fully commercial-scale plants in India using rice husks, but plans are underway. IOCL has built the first 2G ethanol plant in Panipat, Haryana, costing over INR 900 crore, to produce three crore litres of ethanol annually from two lakh tonnes of rice straw.

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Assessing technical suitability of using corn as feedstock for biofuel production

Around 3,000 petajoules of biofuel are produced globally, diversifying energy sources from conventional to renewable. Corn has abundant starch, which can beconverted to ethanol, and is extensively sused in biofuel manufacture. Its popularity stems from its capacity to mitigate greenhouse gas emissions, its biodegradability, and its clean ignition, thus bolstering energy security. Despite the promising status of corn as a biofuel source, scaling up production necessitates breeding techniques such as varietal crossing and cultivar selection to augment biomass and starch levels.

2.1 Corn as a feedstock for biofuel production

The value of corn as a feedstock for ethanol production is due to the large amount of carbohydrates (~ 84.1%), specifically starch (~ 72%), present in corn. Starch can be readily processed to break it into simple sugars, which can subsequently be sutilised as feed for yeast to generate ethanol. Modern ethanol production can produce approximately 2.7 gallons of fuel ethanol per bushel of corn.

2.1.1 Characteristics of corn suitable for biofuel production

Corn grain is an excellent biofuel source due to its starch richness and the relatively straightforward process of converting it into ethanol. The infrastructure facilitating the large-scale planting, harvesting, and storage of corn significantly contributes to the success of the corn ethanol industry. Figure 1 shows the percentage of ethanol derived from corn over the years. Unlike sugarcane, which can be directly fermented after extracting sugar water, corn starch necessitates cooking with alpha and gluco-amylase enzymes to transform it into simple sugars. Cellulosic feedstocks pose even greater challenges, requiring significant time and energy for conversion into simple sugars. Corn thrives best in highly fertile soils with regular application of supplemental fertiliser, which can be inorganic chemical fertiliser or manure. This fuel derived from corn burns cleaner and elevates the octane level of gasoline. Due to its higher oxygen content than Methyl tert-Butyl Ether (MTBE), ethanol requires only half the volume to achieve the same oxygen level in gasoline.

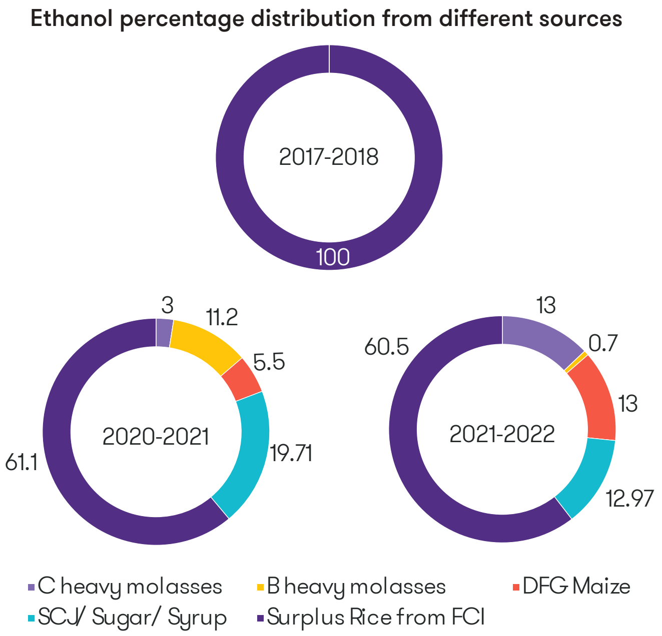


Figure 2: Ethanol percentage distribution from different feedstocks

2.1.2 Conversion processes: Ethanol production from corn

Two major industrial methods for producing fuel ethanol are used — wet milling and dry grind. The majority of ethanol processing in the US is represented by dry grind ethanol production. All newly constructed ethanol plants employ some variation on the basic dry-grind process because such plants can be built on a smaller scale for a smaller investment.

Dry milling

In the dry-grind ethanol process, the whole grain is processed, and the residual components are separated at the end of the process. There are five major steps in the dry-grind method of ethanol production, as depicted in figure 2.

Figure 3: Processes involved in dry grind method of ethanol production

In this process, the entire grain kernel is ground into flour. Starch in the flour is then converted to ethanol during fermentation, producing carbon dioxide and distillers' grain. Dry grinding in the US accounts for approximately 67% of ethanol production. The conversion of corn starch to glucose occurs through primary and secondary liquefaction steps, aided by enzymes. Subsequently, simultaneous saccharification and fermentation (SSF) convert the sugars to ethanol using yeast. After 48–72 hours of fermentation, the mixture contains about 10% ethanol, grain solids, and yeast. After saccharification, the mash is cooled and transferred to a fermenter where yeast is added. Saccharomyces cerevisiae, a common species, efficiently produces alcohol. Protease is also added to break down corn protein into amino acids, serving as an additional nitrogen source for yeast. The fermentation process takes 48-72 hours and yields ethanol concentrations of 10-12%. CO2 produced during fermentation enhances gluco-amylase activity and prevents infections. Distillation then separates ethanol from solids and water. In a multi-column system, heat is applied to separate ethanol based on boiling points. The resulting product contains about 95% ethanol (190-proof). Dehydration removes the remaining 5% water, yielding 100% pure anhydrous ethanol. Denaturant (5% gasoline) is added before storage to make the ethanol unfit for human consumption. Figure 3 captures the dry milling process and the steps explained above.

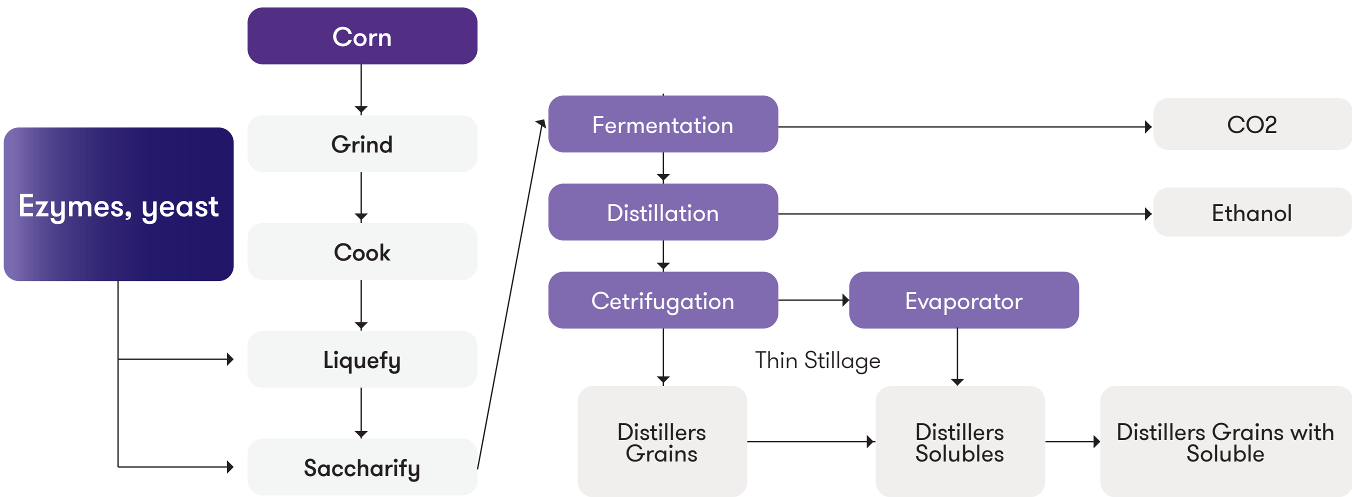


Figure 4: Dry grind- Corn to Ethanol process.

Wet milling

Wet milling is employed to create a range of products beyond fuel ethanol. Large-scale, capital-intensive facilities process corn to produce items such as high fructose corn syrup (HFCS), biodegradable plastics, food additives like citric acid and xanthan gum, corn oil, and livestock feed. This method is termed "wet" because the initial stage involves soaking the grain in water (steeping), which softens the grain and facilitates the separation (fractionation) of the different components of the corn kernel. By dividing the kernel into starch, fibre, and germ, each component can be individually processed to produce various products. The main byproducts of ethanol production in wet mills include two types of animal feed — corn gluten meal (high in protein, 40%) and corn gluten feed (lower in protein, 28%), as well as corn germ, which can be further refined into corn oil.

2.1.3 Technological advancements in corn-based biofuel production

Over the past few years, there have been significant developments in maize-based ethanol production and utilisation in India. In November 2020, the National Biofuel Coordination Committee (NBCC) approved the use of maize for ethanol production. Subsequently, in January and February 2021, grain-based distilleries were included in an interest subvention scheme to encourage capacity expansion. In October 2022, a separate price was established for maize-based ethanol. Additionally, oil marketing companies (OMCs) have increased considerably their ethanol storage capacity, ensuring more than 20 days of storage coverage at their depots. This ongoing process has involved an investment of approximately 750 crores by the OMCs.

Due to rising demand, research and development in corn-based biofuel production processes and technologies have significantly increased. A essential advancement has been the introduction of genetically modified (GM) corn, which is engineered to produce higher ethanol yields by generating greater quantities of sugars or related compounds that can be converted into ethanol. Furthermore, emerging technologies are being developed to improve the efficiency of converting corn sugars into ethanol, focusing on lowering production costs and enhancing overall efficiency.

Key focus areas for development of new technologies include developing hybrids with higher starch content, converting corn kernel fiber to ethanol, and identifying valuable co-products. Various processes, such as quick fiber extraction, enzymatic milling, and dry/wet milling, contribute to ethanol production. Dry grind methods, however, continue to be popular due to their cost-effectiveness and energy efficiency.

2.2 Applicability of corn-based ethanol for alternative fuels

In India, discussions were held to boost ethanol production from maize, involving stakeholders such as the Department of Agriculture and the Department of Food and Public Distribution (DFPD). Efforts are underway to enhance maize cultivation, yield, and quality, including developing high-starch varieties and improving maize DDGS quality by eliminating aflatoxins. Collaboration with seed companies has also begun to train distillers and promote maize cultivation.

The annual production of bio-ethanol in the country is currently 426 crore litres from molasses-based distilleries and 258 crore litres from grain-based distilleries. Plans to boost production to 760 crore litres from molasses-based distilleries and 740 crore litres from grain-based distilleries have been proposed. The Government of India has emphasised on producing bio-ethanol from grains in last few years due to varied uses, which are as discussed below:

Sustainable Aviation Fuel (SAF)

Sustainable Aviation Fuel (SAF) is an alternative to conventional aviation fuel, aiming to reduce greenhouse gas emissions from aviation. One of the most promising new methods is Alcohol-to-Jet (ATJ) production, which utilises bioethanol, a biomass-derived gasoline blendstock already in widespread use, as its main feedstock. ATJ production entails the dehydration of ethanol to ethylene, followed by oligomerisation and subsequent hydrotreating to produce SAF or other drop-in fuel products. Corn-based ethanol can contribute to SAF by converting it into hydroprocessed esters and fatty acids (HEFA), a type of SAF. Benefits includes a reduction in aviation's carbon footprint and supporting sustainability goals. In India, various stakeholders, including MoCA, Niti Aayog, and OMCs, have projected the capacities of upcoming SAF plants and anticipated ATF sales. The indicative blending targets for SAF in ATF are set at 1% by 2027 and 2% by 2028, initially focusing on international flights. With a significant presence in India, Honeywell has developed an innovative ethanol-to-jet fuel processing technology. This technology converts corn-based, cellulosic, or sugar-based ethanol into SAF. It proposes to reduce greenhouse gas emissions by 80% and its modular property can enable rapid installation to speed up the transition process even more.

Liquified Petroleum Gas (LPG)

Corn-based ethanol presents a promising alternative to traditional fuels like LPG, particularly for cooking purposes. It offers several advantages, including its renewable nature, clean combustion with minimal emissions, and safety for indoor use, which helps eliminate Household Air Pollution (HAP). Ethanol provides instant heat upon ignition and serves as a safe alternative to LPG when not pressurised. Additionally, it can be produced sustainably from various feedstocks, making it a cost-effective option. Despite some drawbacks, such as its low heating value when diluted and flammability, ethanol fuels are gaining recognition globally for their potential in clean liquid fuel solutions, particularly in niche applications like marine markets and catering services. This underscores the growing applicability of corn-based ethanol as an alternative fuel to LPG, offering both environmental and societal benefits.

One of the initiatives by GOI to promote blending and encourage corn-based ethanol in recent times is the Ethanol Blended Petrol (EBP) Programme, initiated in 2003, which aims to boost ethanol-blended petrol usage, targeting 10% blending by 2022 and 20% by 2030. It diversifies feedstocks, addresses procurement challenges, and prioritises environmental sustainability through reduced emissions and improved air quality. Originally, ethanol production heavily relied on sugarcane as the primary feedstock. However, the program has expanded its scope to encompass additional feedstocks such as maize, bajra, fruit and vegetable waste, among others, to bolster ethanol production nationwide. The government has also issued a 'Long Term Ethanol Procurement Policy' under the EBP Programme to ensure stable prices and supply of ethanol. Regulatory stipulations are being made more conducive to provide single-window service for setting up new ethanol distilleries and ease interstate movement of denatured ethanol.

03

Market Perspective

3.1 Status of biofuels market in India

India has recognised the importance and potential of renewable and alternate energy sources. In the last few years, the Indian Government is working on building a robust infrastructure and supporting policies to give a boost to alternate energies. Among other alternate fuels, biofuels and feedstock options (i.e., sugarcane, corn, agriculture waste, bamboo, etc.) have shown some promising results across continents. India, being the third largest global ethanol producer, has enormous capacity to realise full potential of biofuels with the help of technological advances. Due to increased governmental focus, detailed policies and abundance of feedstocks, which can be converted into ethanol and other variants, India could support global demand and accelerate global deployment of ethanol.

Demand for biofuel has reported more than 30% increase in the past five years and is projected to increase by 38 billion litres in the next five years. By 2028, overall biofuel demand is expected to rise to 200 billion litres (around 23%), which will partially come from renewable diesel and biojet and the rest from ethanol and biodiesel. This demand can only be successfully addressed if costs, viability of options, feedstock sustainability and supporting policies are considered while planning. Globally, emerging economies like Brazil, Indonesia, and India are the prime demand generators for ethanol and ethanol-blend fuels in the market. Advanced economies like the EU, the US, Canada, and Japan are also strengthening their transport policies. Factors that limit the usage of biofuels in advanced economies are increased policy and government support on EV adoption, vehicle efficiency improvements, limited feedstock market and high blending costs in some markets.

Beyond blending targets, India established guaranteed pricing, long-term ethanol contracts, and technical standards and codes. Financial support for building new facilities and upgrading existing ones was also provided. Buoyed by its success, the Government moved the 20% volume blending target for ethanol forward by 5 years to 2025-26, which was enshrined in an updated National Policy on Biofuels in 2022.

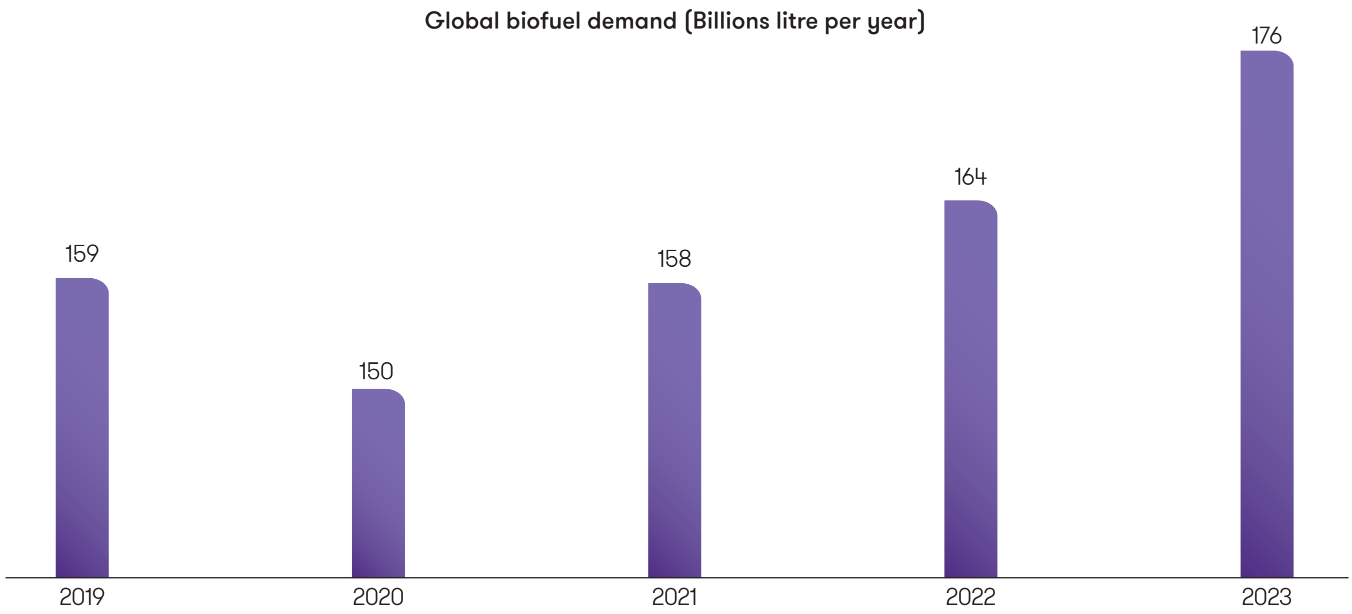


Figure 5 Global biofuel demand (billions litre per year)

The Global Biofuels Alliance can help expand sustainable biofuels.

During COP 28, the world leaders decided key priorities in global renewable space:

- Triple global renewable capacity
- Drive down methane emissions by 2030
- Double progress on energy efficiency
- Transition away from fossil fuels

Biofuels are one of the keys to transitioning away from fossil fuels as a complementary measure to electric vehicles and vehicle efficiency improvements. They are also compatible with existing vehicles and play a significant role in reducing emissions from long-distance road, air and maritime transport over the medium term.

3.2 Potential for corn-based biofuels in India

With new policy embarkment in India during 2018 on permitting production of maize and grain based ethanol under the National policy on biofuels, maize has been identified to be a game changer in this ambitious journey. To meet E20 blending targets which reportedly requires 165 lakhs tons of maize, India needs to speed up its production.

3.2.1 Global demand-supply dynamics of corn

There is a need to produce corn-based biofuel in the world. According to current yield, the top-three countries producing corn are the US, China and Brazil followed by Europe, India, Argentina and Ukraine. They are also catering to more than 80% of market demands

These markets can only supply half of the global transport biofuel demand globally. With the consistent weather changes and unpredictability of natural resources, it is likely that this supply percentage decline to 40% by 2028. Other developing countries need to contribute to sing the demand and supply pattern by investing time and resources to develop corn produce and the process to develop biofuels and meet economies of scale.

Three large economies of the world namely Brazil, India and the US have strengthened their policies and infrastructure to show growth trajectory of around 20% over five years.

The US market is estimated to be the world's largest exporter with a sustainable market share. Countries like the US, Ukraine, Zambia, Argentina, Malawi, Mozambique, and Turkey are unable to sustain corn production resulting in a 1.22 bn metric tonne decline during the last year. Lower area expectations resulted in decline of corn production while higher expanded area shows higher production like in the case of Brazil. On the other hand, both forecast and planning estimates impacts negative yield.

There is an increased demand of corn-based biofuels due to efficient use in transportation. With increased foreign consumption of corn in various industries, the import to such countries will increase as well shooting the demand curve. Asian countries such as China have been increasingly utilising corn for ethanol production by importing corn at a higher price. The imports on the other hand are staggered at 23.0 mn tonne. The prices of import and export fluctuate based on energy feedstocks market prices.

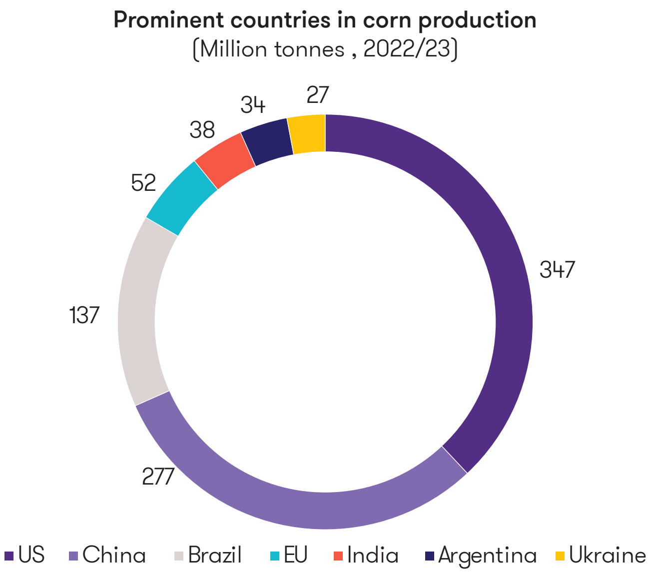


Figure 6 Major countries in the world producing Maize (2022-23)

3.2.2 Demand-supply dynamics of corn in India

After the international market's attention on cultivation and innovation with the use of corn, the Indian Government is also paying attention to its third-most grown cereal in the country. Traditionally, used in poultry feedstock, now this produce has become the key ingredient in producing ethanol and ethanol fuel.

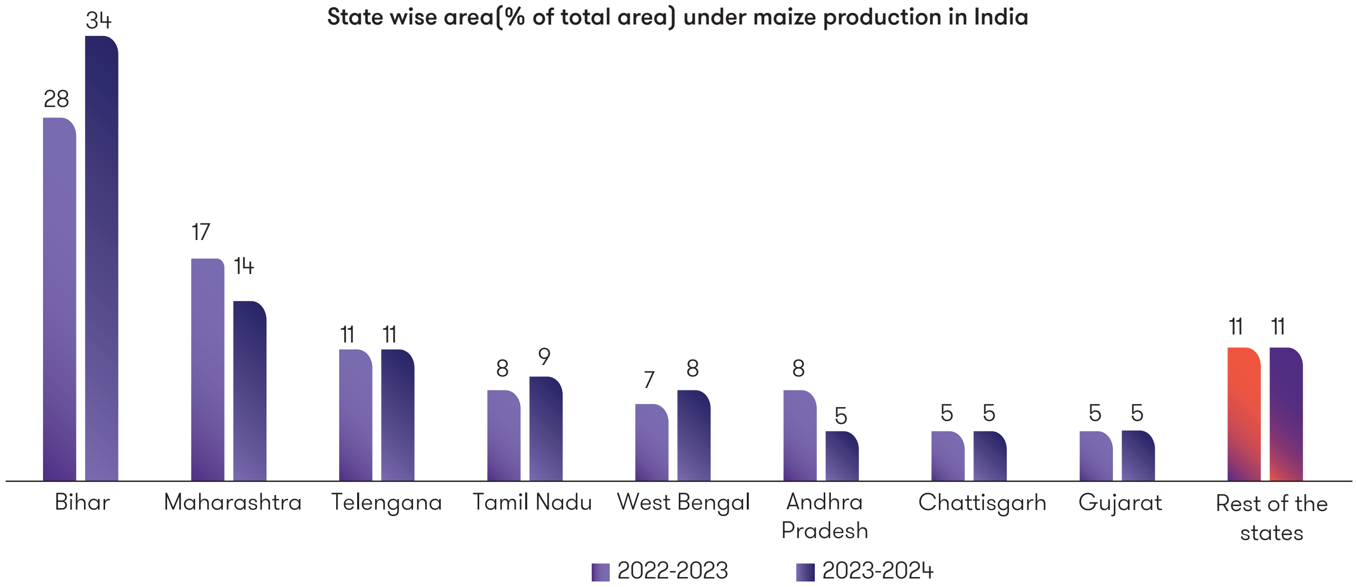


Figure 7 Percentage of area under maize production in different states of India

The Indian government has invested INR 24.51 crore in ICMR for research around corn and ethanol produced by corn. The agri ministry has set a target to cultivate corn by 10 mn tonnes over the next five years to cater to global demands. In 2022-23, the total yield was 34.6 mn tonne and exports to other countries were 3.3 mn tonne. Currently, Bihar is the largest producer of maize production in India, followed by Maharashtra and Telangana.

With robust governance, India can plan for increased corn production to cater to increasing demands in ethanol business. There is a supply and demand gap in the current market, which also impacts the pricing of maize in the export market. Higher demand from both ethanol and poultry industries as well as limited corn production impacts price fluctuation in the market. Compared to late2023, there is a 20% increase in early 2024 in maize prices. This aligns with the government's increased push, which is attracting more players and driving up demand to manage price fluctuations in the market.

3.2.3 Market opportunities and challenges for corn-based biofuels

India achieved its target of 10% ethanol blending in petrol by June 2022. As a result E20 has set a target of achieving 20% ethanol blending by 2025-26. To meet the E20 blending target, India is likely to need 165 lakh tons of maize, which is 48% of the country's current maize production of 346 lakh tons. To achieve this target, India is likely to need to increase maize production to 420-430 lakh tons by 2024-2025 and 640-650 lakh tons by 2029-2030. The agriculture ministry has set a goal to increase corn production by 10 million tons over the next five years.

Opportunities

Reduced dependency on imported fossil fuels: India heavily relies on imported fossil fuels to meet its energy needs. Promoting the production and use of corn-based biofuels like ethanol could help reduce this dependency, enhancing energy security and mitigating risks associated with volatile global oil prices.

Agricultural diversification and rural development: Corn cultivation for biofuel production can provide an additional revenue stream for Indian farmers, especially in regions where corn is already grown. This can contribute to agricultural diversification and rural development, generating employment opportunities and boosting rural economies.

Environmental benefits: Corn-based biofuels have the potential to reduce greenhouse gas emissions and improve air quality compared to conventional fossil fuels. This aligns with India's commitments to combat climate change and improve environmental sustainability.

Renewable energy targets: India has set ambitious targets for renewable energy adoption, including biofuels. Government support and incentives to meet these targets could create a favourable market environment for corn-based biofuels.

Technology development and innovation: Investments in research and development of biofuel production technologies, including advanced processing methods and feedstock diversification, could lead to technological innovations that improve the efficiency and sustainability of corn-based biofuels.

Challenges

Competition with food production: Non-edible corn, used for industrial purposes like ethanol production, animal feed, and starch manufacturing, renders the food vs. fuel debate irrelevant in India. Since this type of corn is not directly consumed by humans, it avoids competition with food resources, ensuring that both food availability and energy production can coexist sustainably. This non-competition supports the water-energy-food nexus, addressing key development challenges without compromising human food supplies.

Land use and water resources: Corn cultivation requires arable land and significant amounts of water. In India, where agricultural land is limited and water resources are often stressed, expanding corn cultivation for biofuel production could exacerbate land use conflicts and water scarcity issues.

Infrastructure and distribution challenges: Developing the infrastructure for ethanol production, distribution, and blending into the existing fuel supply chain requires significant investment. Challenges such as inadequate storage facilities, transportation logistics, and blending infrastructure may hinder the widespread adoption of corn-based biofuels.

Policy and regulatory framework: Uncertainty surrounding government policies, including biofuel blending mandates, taxation, and subsidies, can impact investor confidence and hinder the growth of the biofuel industry in India. Clear and consistent policies are essential to provide a conducive regulatory environment for biofuel investment.

Technological and economic viability: While in biofuel technologies offer promise, the economic viability of corn-based biofuels compared to conventional fossil fuels remains a concern. Ensuring cost competitiveness and scalability will be crucial for the sustainable growth of the biofuel industry in India.

Navigating these challenges and capitalising on opportunities will require coordinated efforts from policymakers, industry stakeholders, and research institutions to develop a robust and sustainable biofuel ecosystem in India. This may involve addressing concerns related to food-fuel competition, promoting sustainable agricultural practices, investing in infrastructure development, and fostering innovation in biofuel production technologies.

3.3 Comparison with other biofuel feedstocks: Corn vs. sugarcane, jatropha, etc.

The GOI's increased biofuel ambition demands a shift towards 1G production and edible feedstocks, with serious implications on lifecycle benefits.

	Corn	Sugarcane	Jatorpha
Availability	Corn production is increasing considerably in India.	As India is one of the largest producers of sugarcane, it is primary feedstocks for ethanol production.	It is a non-edible oilseed crop and has limited availablity in India.
Yield	Corn generally has lower ethanol yield per acre compared to sugarcane	Highest ethanol production	Seeds yield oil but in limited yield per acre
Land use	requires arable land and suitable climatic conditions for cultivation	requires suitable tropical or subtropical climates and can be water-intensive.	Can grow in marginal lands non-suitable for agri production
Environmental impact	may require intensive use of fertilisers and pesticides, leading to environmental concerns such as soil degradation and water pollution	less intensive than corn cultivation.	Jatropha cultivation has been promoted for its potential to reclaim degraded lands and mitigate soil erosion. However, there are concerns about its invasive potential and competition with food crops for resources.
Economic viability	The economics of corn-based ethanol production depend on factors such as corn prices, processing costs, and government subsidies or incentives.	Sugarcane-based ethanol production has been economically viable in countries like Brazil and India, supported by government policies, market demand, and efficient production processes.	The economic viability of jatropha-based biodiesel production has been challenged by factors such as low oil yield, uncertain yields in different regions, and the need for significant investment in cultivation and processing infrastructure.
Challenges	Corn has great potential due to steady crop rate; however land availability to increase cultivation could be a challenge.	Due to water intensive crop, extensive cultivation causes severe water stress and drought-like conditions. high fertiliser requirement for sugarcane cultivation also increases the environmental footprint of this pathway. Thus, meeting the ambitious ethanol goal from sugarcane is not necessarily environmentally sustainable from the perspective of the entire agricultural system.	Even though Jatorpha yield is very minimal to cater to the increased biofuel demand, the wasteland used for its production is also utilised by villagers for other activities and thus practically impossible to grow the jatorpha.

Based on these comparisons among sugarcane, jatorpha and corn as major source of biofuels, it is quite practical to invest in increasing production of maize. While Jatorpha cannot be considered for mass corn production to generate ethanol, sugarcane and maize has better outputs. Although sugarcane can produce better yields, to grow considerably it requires many anti-environmental interference. This is not the case with maize. Hence maize stands out among the three based on higher yield and consistent production in favourable climatic conditions with ease. With better economies of scale, rigorous policies and better governance, India can enhance energy security by producing corn-based ethanol thereby, reducing dependency on conventional energy sources.

04

Economic Perspective

The corn market in India stands at USD 1.29 Billion in 2024 and is expected to grow at a CAGR of 7.74% in the forecast period of 2026–30. Key factors of this growth include rising demands for corn-based food products, increasing utilization as livestock feed, and most importantly, demand for corn in biofuel production. This is primarily due to the Government's target of 20% ethanol blending in petrol by 2025. The following figure shows area, production and productivity trend of corn in the last two decades in India:

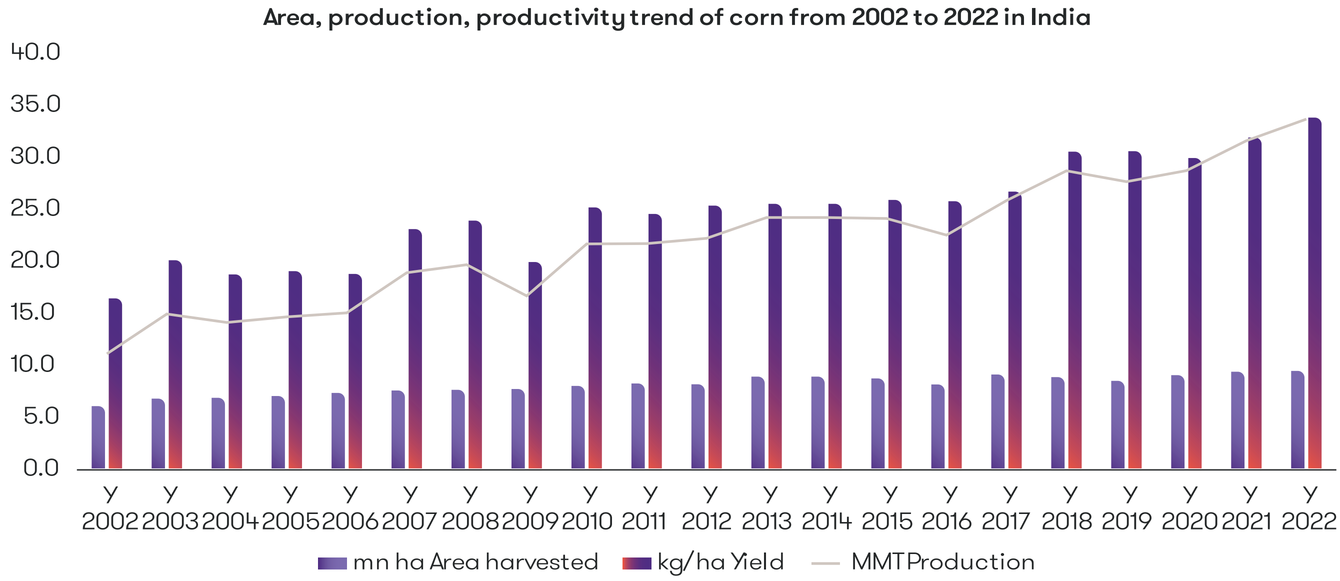


Figure 8: Area, production, productivity trend of corn from 2002 to 2022 in India

International-Planners is planning to construct 20 regional grain-to-ethanol conversion facilities across India. The production centres are expected to generate 6,000,000 gallons of ethanol per month, reducing India's reliance on foreign fuel additives. Additionally, this initiative aims to double the income of average farm workers' families, promoting economic independence. These ethanol centres can be strategically located in the 20 different states that produce corn, sugar cane, and sorghum. Currently, India imports 15 million barrels of ethanol annually. To boost national ethanol production, the Indian Government has offered to underwrite 75% of the development costs for biomass-based ethanol production centres. By producing these 15 million barrels domestically, India stands to save over INR 9,000,000,000 (approximately USD 760,000,000) each year.

4.1 Cost analysis of corn-based biofuel production

4.1.1 Production costs: cultivation, processing, transportation

As of 2023-24, India's corn production is estimated at

32.47%

representing a 14.7% decline from the previous year.

The Government plans to purchase corn at a minimum support price of INR 20,910/mt to facilitate ethanol production. Government agencies will enter into agreements with farmers to ensure a steady supply of feedstock for clean fuel production. Breakdown of cost for maize farming in India along with state-wise variation in cost of production is as shown below:

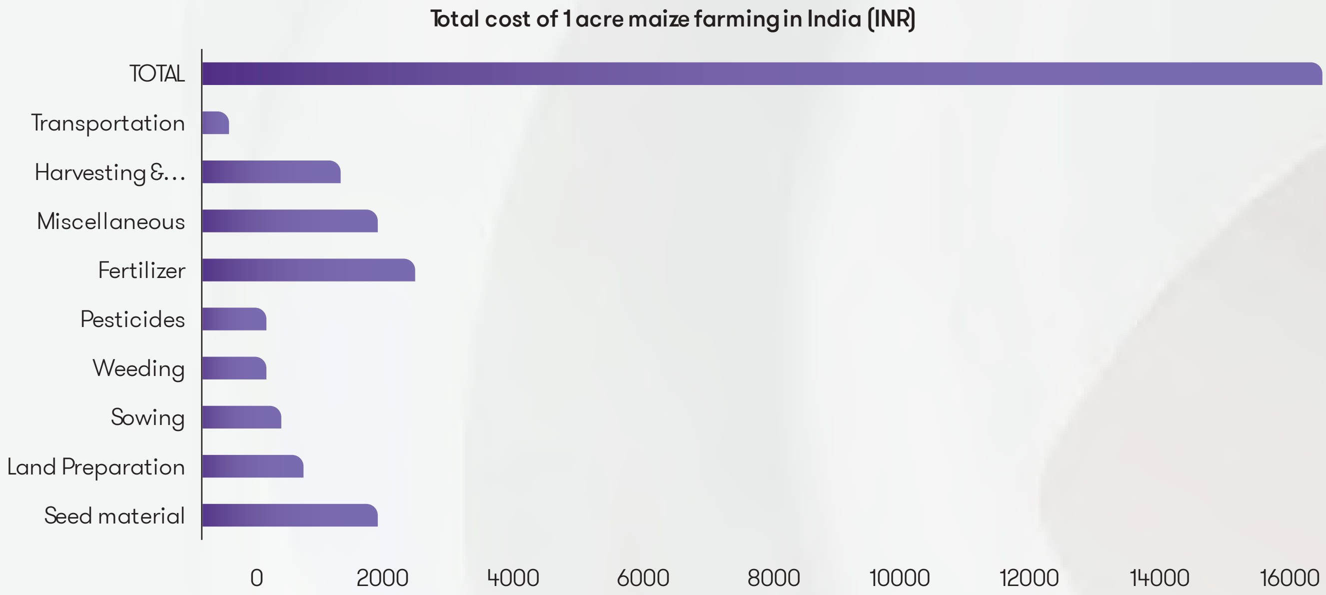


Figure 9 Cost distribution to cultivate 1 acre of land in India (INR)

On average, INR 15,200 sums up as the cost of cultivating 1 acre land for maize production, with the lowest being in Rajasthan, INR 13,500, and highest in Maharashtra, INR 16,000 as seen in figure below:

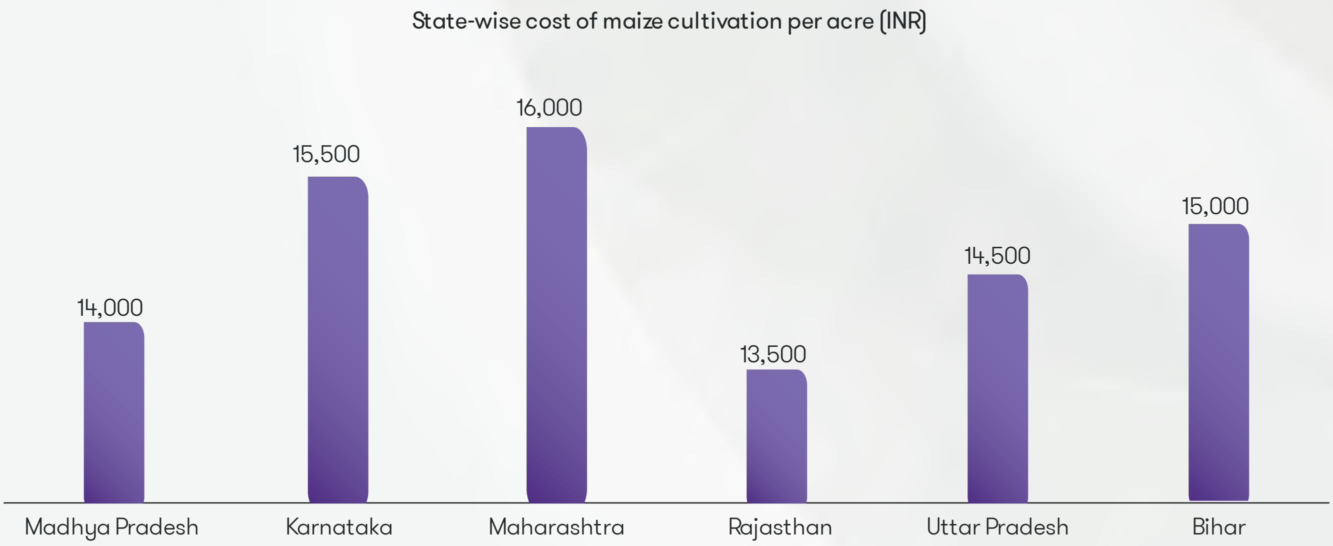


Figure 10 State-wise variation in cost of maize cultivation per acre in India (INR)

Of the corn varieties, yellow dent corn is often bred for high yields and, in regions with suitable growing conditions, can surpass the yields of traditional food corn varieties. A study in the Philippines indicates that yellow dent corn can yield more than double that of traditional corn. For instance, while traditional food corn varieties yield around 2.5-3 metric tons per hectare, yellow dent corn can achieve 6-7 metric tons per hectare under optimal conditions.

In addition to higher yields, yellow dent corn also incurs lower input costs. These varieties are often developed to be more resistant to pests and diseases, reducing the need for costly pesticides. They are also more efficient in nutrient uptake, potentially lowering fertilizer requirements.

If we look at U.S. case, as reported by USDA , corn production rose from 14.2 billion bushels in 2014 to 15.3 in 2023, which is a 7.74% rise. Of this production, approximately 12 of the top 18 growing states reported at least 1% of their corn had dented. Utilizing dented corn for ethanol production offers several economic and environmental benefits. It provides an additional revenue stream for farmers, reduces dependence on fossil fuels, and contributes to the reduction of greenhouse gas emissions.

India's corn production mainly focuses on varieties suitable for human consumption, such as yellow and white maize, used for food, feed, and industrial purposes. Dented corn, primarily used as animal feed and termed non-edible for human consumption, is not yet a major crop for bioethanol production in India. However, evolving energy and agricultural policies, along with global renewable energy trends, could change this. Monitoring biofuel policies, agricultural practices, and technological innovations will be crucial in understanding the future role of dented corn in India's bioenergy sector.

Importing dented corn from the United States and other countries could impact India's agricultural sector, bioenergy industry, and economy in several ways. It would increase feedstock supply for animal feed, bioethanol production, and industrial uses. Access to a reliable source of dented corn could boost ethanol blending programs. However, increased imports might pressure domestic corn prices, affecting Indian farmers' livelihoods, though benefiting industries reliant on affordable feedstock. Additionally, importing dented corn could enhance trade relations, requiring diplomatic efforts and collaboration with exporting countries for smooth trade flows and regulatory compliance.

4.1.2 Price competitiveness with fossil fuels and other biofuel sources

The Indian Government has allocated INR 15.46 crore to the state-run Indian Institute of Maize Research (IIMR) to enhance corn production in ethanol industry catchment areas. IIMR scientists are focusing on climate-resilient high-starch maize hybrids, with INR 5.32 crore earmarked for research by 2025-26. Additionally, INR 3.73 crore has been allocated for scaling up silage production. State-backed agencies like NAFED and NCCF will purchase corn from farmers and offer it to distilleries at the minimum support price (MSP) plus market taxes, with incidental costs covered by the food department. The minimum rate for maize in 2023-24 is INR 2,090 per quintal. Table 1 gives a cost comparison of different fuels.

Table 1 Cost comparison of ethanol and methanol with gasoline

Cost Comparison of Ethanol and Methanol with Gasoline				
S.No.	Parameters	Ethanol	Methanol	Gasoline (petrol)
1	Calorific Value (Kcal/kg)	7100	5500	11,110
2	Density (kg/litre)	0.789	0.791	0.750
3	Price of 1 litre of fuel (INR/litre)	45.6925	19.8	35.9926
4	Energy Equivalent units for 1 litre of Petrol	1.48	1.90	1
5	Price paid by the Government (excluding taxes) for different fuels to replace 1 litre of petrol on energy equivalent basis (INR/litre)	67.62	37.62	35.99
6	Tax on respective fuels (INR/litre)	2.28 (@ 5% GST)	undefined	58.5028
7	Price (including taxes) paid by consumer for different fuels to replace 1 litre of petrol on energy equivalent basis (INR/litre)	69.9 (#3 × #9 + #4)	37.6229 (#3 × #5)	94.49 (#3 + #4)

Corn exports are expected to decrease by 10% during the 2023-24 period due to higher global production, which is estimated to exceed 1,200 million tonnes (MT). If the trend continues, FAS New Delhi's predicts corn MY 2023/2024 exports to reach 1 MMT compared to 3.2 MMT last year. Refer to the table below for further information.

Table 2 India: corn production, supply, distribution

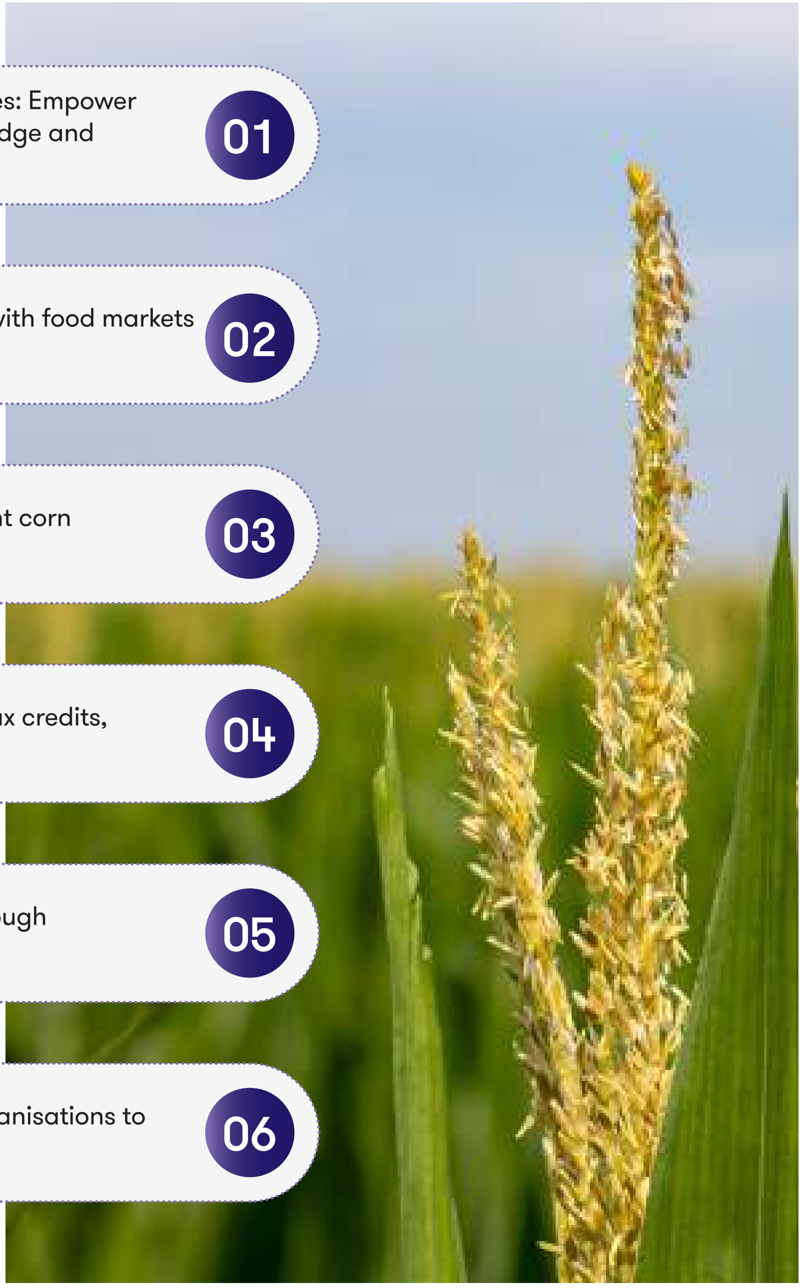
India: Commodity, Corn, Production, Supply, Distribution						
Market Year	**Nov 2021**		**Nov 2022**		**Nov 2023**	
	USDA Official	New Post	USDA Official	New Post	USDA Official	New Post
India (1000 HA)	USDA Official	New Post	USDA Official	New Post	USDA Official	New Post
Area Harvested	9958	9958	10744	10744	10400	10400
Beginning Stock	2028	2028	2395	2395	2658	2658
Production	33730	33730	38085	38085	35500	35500
MY Imports	0	0	0	0	50	50
TY Imports	0	0	0	0	50	50
TY Import from U.S.	0	0	0	0	0	0
Total Supply	35758	35758	40480	40480	38208	38208
MY Exports	3363	3363	3122	3122	2200	1000
TY Exports	3441	3441	3195	3195	2200	1000
Feed and Residual	18100	18100	20600	20600	21000	21000
FSI Consumption	11900	11900	14100	14100	13000	14000
Total Consumption	30000	30000	34700	34700	34000	35000
Ending Stocks	2395	2395	2658	2658	2008	2208
Total Distribution	35758	35758	40480	40480	38208	38208
Yield (MT/HA)	3.3872	3.3872	3.5448	3.5448	3.4135	3.287

4.2 Economic benefits and potential for revenue generation

4.2.1 Employment generation in rural areas

The planned investment of approximately INR 41,000 Crore in capacity addition and new distilleries is expected to generate employment opportunities in rural areas, bolstering the agricultural economy. According to Shri Pandey, this initiative will not only save over INR 30,000 crore in foreign exchange due to reduced crude oil imports but also contribute to the goal of an Atmanirbhar Bharat (self-reliant India) in the petroleum sector.

The Government can support farmers for corn adoption through these steps :



01 Education and skill development programmes: Empower farmers with biofuel crop production knowledge and entrepreneurship skills

02 Market Integration: Align biofuel marketing with food markets to create stable demand

03 Research and Development: Invest in efficient corn varieties and processing methods.

04 Incentives: Offer financial support through tax credits, grants, and subsidies

05 Demonstration Trials: Showcase benefits through hands-on training

06 Collaborations: Partner with agricultural organisations to promote corn-based biofuels.

4.2.2 Contribution to GDP and economic growth

In 2022, India was the ninth largest exporter of corn globally, with exports valued at

USD 1.16 billion
India

The main destinations for Indian corn exports were:

USD 576 million
Bangladesh

USD 129 million
Nepal

USD 243 million
Vietnam

USD 75.9 million
Malaysia

USD 49.7 million
Sri Lanka

During the same year, India imported USD 10.7 million worth of corn, ranking 124th among corn-importing countries. The primary sources of corn imports for India were South Africa (USD 8.29 million), Argentina (USD 1.33 million), the United States (USD 430,000), Tanzania (USD 256,000), and Brazil (USD 248,000). Notably, Tanzania saw significant growth as an import market for Indian corn between 2021 and 2022. (USD 622).

India's corn exports reached USD 816.3 million in the first 10 months of fiscal year 2021–22, surpassing the previous year's total of USD 634.8 million. Corn cultivation is year-round, with the Kharif season covering 85% of the cultivated area. In 2021-22, India produced 32.5 million metric tons of corn, but estimates indicate a decline to 31.5 million metric tons in 2022–23.

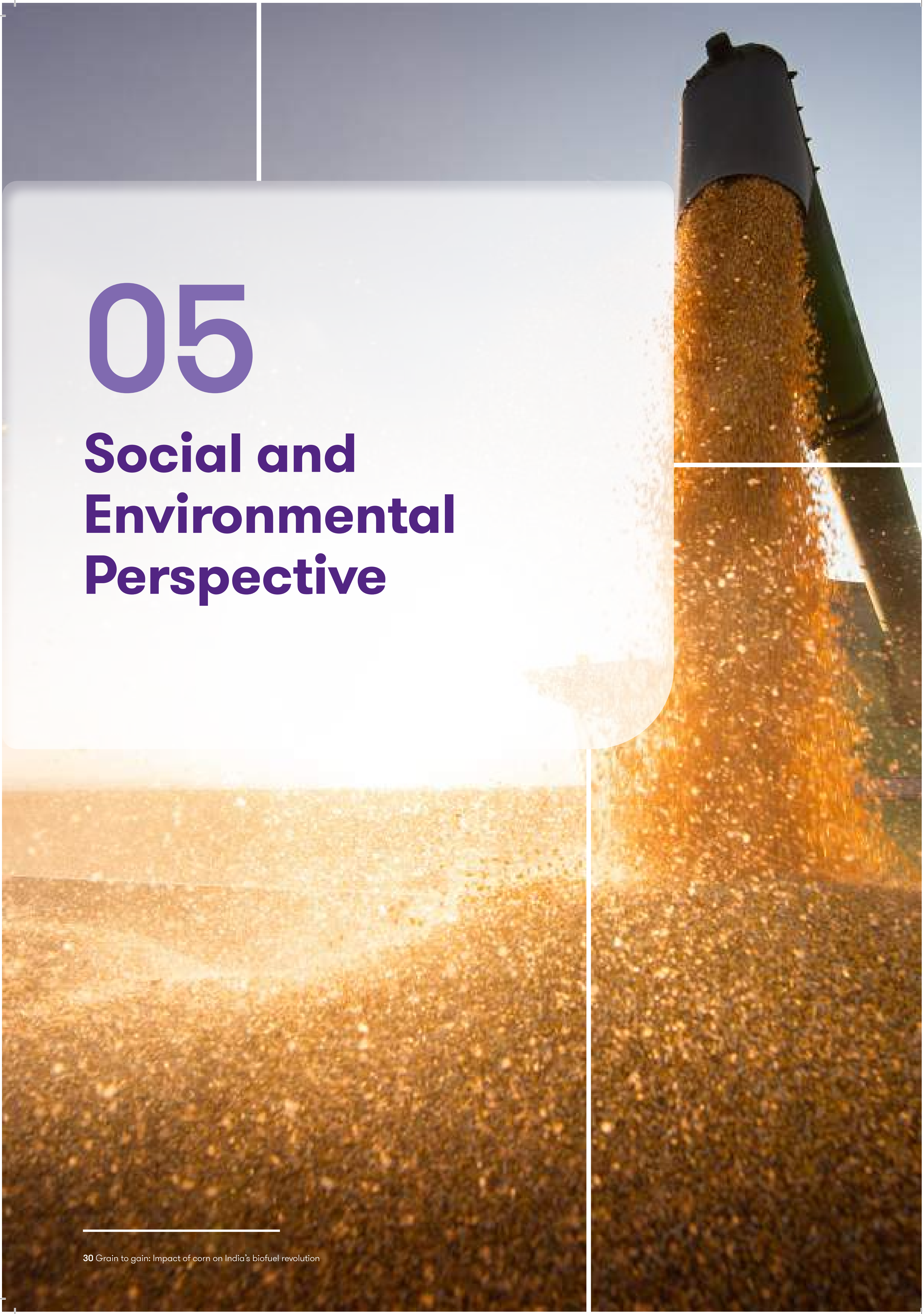
4.3 Economic perspective of importing corn for meeting the demand

Corn-based biofuels have both positive and negative economic impacts. On the positive side, they stimulate agricultural growth, create jobs in farming, processing, transportation, production, and distribution, and enhance energy security by reducing dependence on foreign oil. However, drawbacks include potential food price volatility and higher production costs compared to fossil fuels. The table shows ethanol's share in the total exports to India from the U.S. market.

Table 3 Top US export products to India

Top U.S. Exports: Agricultural and Related Products to India Million USD, Fiscal Year (Oct-Sep)					
Product	**2019**	**2020**	**2021**	**2022**	**2023**
Tree Nuts	776	884	892	1,022	1,005
Cotton	571	155	196	518	237
Ethanol	318	330	199	250	148
Forest Products	55	40	47	80	81
Essential Oils	31	29	33	40	56
Dairy Products	56	47	29	36	39
Other Feeds, Meals & Fodders	12	16	23	28	29
Seafood Products	32	32	51	41	29
Dextrins, Peptones & Proteins	45	25	32	26	27
Soybeans	5	43	5	7	26
Agricultural Products	**2,112**	**1,738**	**1,644**	**2,416**	**1,731**
Agricultural and Related Products	**2,200**	**1,811**	**1,742**	**2,538**	**1,842**

An upcoming news floating in the market is related to the U.S. trade mission proposing that India import ethanol and corn to achieve its 20% ethanol-blended petrol target by 2025. This move follows India's restriction on sugar for ethanol production. U.S. Undersecretary Alexis Taylor sees an opportunity to support India's ethanol industry. However, concerns arise due to potential maize supply shortages as production declines.



05

Social and Environmental Perspective

Expanding biofuel facilities in rural regions creates employment opportunities, elevating the quality of life and stimulating economic development. Enhanced air quality around these plants contributes to the well-being of local residents. This vital social impact highlights the significance of job creation in rural areas, particularly where corn cultivation is prevalent, driving economic progress and enhancing community infrastructure and services.

5.1 Socio-economic impact of corn-based biofuel industry

The corn-based biofuel industry presents a complex socio-economic landscape with both advantages and drawbacks, including reliance on first-generation feedstocks like corn, which raises apprehensions due to competition with food production and potential diversion of agricultural land. This competition risks driving deforestation, water resource depletion, and ecosystem degradation. Although second-generation feedstocks offer some relief, economic viability remains uncertain amidst low oil prices. Third-generation biofuels from microalgae hold promise in mitigating food competition and land use issues but currently face challenges in energy intensity and economic feasibility. Balancing these factors is crucial for effectively navigating the corn-based biofuel industry's socio-economic impacts.

5.1.1 Empowerment of farmers through corn cultivation

The cultivation of corn for ethanol production in India presents a multifaceted opportunity for empowering farmers and fostering agricultural sustainability. Government initiatives, including procuring maize at fixed minimum support prices and expanding cultivation areas, aim to meet the country's biofuels demand while enhancing farmers' economic prospects. Collaborative efforts with organisations such as the Cereal Systems Initiative for South Asia (CSISA) equip farmers with improved practices, machinery, and market access, bolstering incomes and resilience. Successful models in states like Odisha showcase how fallow lands can be revitalised into productive maize cultivation areas, benefiting livelihoods and promoting gender empowerment. Policies permitting diverse feedstocks for ethanol production, including corn, offer avenues for increased production and income streams and align with environmental sustainability goals by reducing greenhouse gas emissions and fossil fuel dependency. This holistic approach underscores the transformative potential of corn cultivation for empowering farmers and driving agricultural advancement in India.

5.1.2 Rural development and poverty alleviation

Bioethanol contributes to poverty alleviation, skill development, and economic empowerment by creating jobs in rural industries. Initiatives encouraging maize cultivation, particularly among women farmers, have led to transformative changes in regions like Odisha, where women have played a vital role in converting fallow lands into productive maize fields. This has boosted agricultural productivity and provided sustainable livelihood opportunities, especially for tribal farmers. Collaborations with government departments and development partners have facilitated market access and value chain development, allowing farmers to secure better prices for their produce and improve their economic standing. Moreover, the adoption of improved maize cultivation practices has led to a considerable increase in productivity across various regions, contributing to enhanced food security and rural development.

5.1.3 Social acceptance and awareness of biofuels in India

Understanding and addressing social perceptions and concerns are essential for successfully implementing biofuel initiatives. The Indian Government has been actively promoting biofuels to achieve sustainability goals faster and reduce dependence on fossil fuels. Biofuels offer economic benefits by reducing government expenditure on fossil fuel imports, increasing farmers' income, supporting new businesses, and achieving energy security and independence. The Government's support for biofuels production has led to significant savings in foreign exchange outflow and benefits to farmers. The Indian Government has implemented various policy interventions and schemes to promote biofuels, such as the policy for co-firing biomass in thermal power plants, the Sustainable Alternative Towards Affordable Transportation (SATAT) scheme, and incentives to boost the biofuels sector. These initiatives aim to accelerate the adoption of biofuels and enhance social acceptance of sustainable energy sources. As India experiences rapid urbanisation and industrialisation, there is a growing need to meet energy demand with cleaner alternatives like biofuels. Promoting the use of biofuels, such as E20, can lead to significant reductions in carbon emissions and contribute to a cleaner environment, aligning with sustainability goals.

5.1.4 Impact on food-energy-water nexus

Implementing the ethanol economy creates jobs, boosts rural incomes and energy access, and has positive health impacts when ethanol is used as a clean cooking fuel, as well as enabling women to spend time on education, work, or leisure instead of gathering wood or other biomass for traditional stoves. The competition between fuel and food is a critical concern raised regarding the potential negative social impacts of increased fuel production. Biofuels have faced criticism for displacing food production from agricultural land, leading to food price hikes that disproportionately affect the most vulnerable populations in developing countries. However, food security is often more about access to food than its availability, and the relationship between biofuels and food security is intricate. Biofuels present both risks and opportunities in this context. By strategically planning with modern technologies and tools and optimising existing agro-industries, biofuels can enhance food production without compromising it. This can be achieved through land use intensification, sing marginal and degraded lands, and transitioning to integrated production systems combining food and fuel production.

5.2 Role of Policy and regulatory framework in aiding the growth

The Government has implemented several schemes for the agricultural sector, which have significantly impacted the production, distribution, and consumption of maize. Table 1 highlights some of these interventions.

Table 1 Government schemes for agricultural sector

Focused efforts on improving farm Productivity & Farmer Income

- ICAR R&D – introduction of high yielding & stress tolerant varieties.
- Pradhan Mantri Krishi Sinchai Yojana for development of irrigation sources in drought prone areas. & Micro

Irrigation Fund Scheme.

- National Mission for Sustainable Agriculture (NMSA) – for improving agricultural productivity in rainfed areas
- Soil Health Card and Fertiliser subsidy
- PM-Kusum: to install the Renewable energy capacity, to power the agriculture pumps.
- Pradhan Mantri Fasal Bima Yojana (PMFBY) for crop insurance & KCC for access to credit
- Pradhan Mantri Fasal Bima Yojana (PMFBY): Putting up a common data infrastructure for farmers in the country.

Building post harvest Infrastructure

- Gramin Bhandaran Yojna for creating adequate post harvest storage facilities
- e-NAM & e-Kisan Mandies for farmer price discovery and access to market
- Atmanirbhar Bharat package for common infrastructure through the Agri Infrastructure Fund
- Promoting Maize dryers at APMCs for improving quality
- MOFPI's Formulation of Micro Enterprises scheme – supports FPOs for development of infrastructure and primary processing.

Promoting Investments in Processing Infrastructure

- MOFPI's Pradhan Mantri Kisan SAMPADA Yojana
- Animal Husbandry Infrastructure Development Fund (AHIDF) incentives investment in animal feed processing facilities
- Pradhan Mantri Matsya Sampada Yojana incentivises investment in fish feed processing units

5.3 Environmental considerations and sustainability of corn-based biofuels

5.3.1 Life cycle assessment of corn ethanol

A life cycle analysis (LCA) of ethanol production from corn grain has shown a net energy ratio between 1.2 and 1.45 (Liska et al., 2009), reflecting a modest positive energy balance of 20% to 45%. However, a USDA study published in 2016 indicates that increased efficiency at ethanol facilities has improved the fossil energy ratios to 2.0 to 1 nationally, with some individual facilities reaching ratios as high as 4.0 to 1. One major criticism of corn ethanol production is the substantial fossil energy consumption it requires. Environmental concerns related to corn production include erosion, pesticide use, and nutrient runoff, which can contaminate surface and groundwater and lead to loss of topsoil and siltation in streams and rivers. Although continuous efforts have been made to address these issues, they persist as significant challenges in crop production. Using maize as a feedstock for biofuel production presents several benefits, such as supporting the agricultural sector, creating jobs, and reducing dependence on foreign oil. Technological advancements such as cellulosic ethanol production have furthered corn's potential in biofuel applications. Despite these advancements, challenges remain, necessitating ongoing innovation and the exploration of alternative feedstocks for the future of corn-based biofuels.

5.3.2 Impact on greenhouse gas emissions and air quality

Research conducted by the US Department of Energy's Argonne National Laboratory indicates that corn ethanol helps reduce the carbon footprint and greenhouse gas emissions. Between 2005 and 2019, the US corn ethanol production more than quadrupled, leading to a 23% decrease in the intensity of greenhouse gas emission (carbon intensity) of corn ethanol. This increase in production volume and lower carbon intensity values resulted in a total reduction of more than 500 million tons of greenhouse gases over the same period. Furthermore emissions have reduced through improvements at ethanol refineries and the adoption of conservation practices on farms, such as reduced tillage, which lowers greenhouse gas emissions associated with corn ethanol.

06

Global Perspective

6.1 The US: Leading the biofuel revolution in its agricultural sector

The production and use of bioethanol in the US have gained significant traction over the past few decades due to its potential to reduce greenhouse gas emissions and dependence on fossil fuels. The United States is the world's largest producers and consumers of bioethanol. The US Environmental Protection Agency (EPA) mandates the blending of ethanol into gasoline under the Renewable Fuel Standard (RFS) programme. This programme sets annual targets for the number of renewable fuels, including ethanol, that must be blended into transportation fuel sold in the United States.

The ethanol industry as we know it began in the 1970s when petroleum-based fuels became expensive and environmental concerns involving leaded gasoline created the need for an octane. This saw the emergence of corn as the predominant feedstock for ethanol production due to its abundance and ease of transformation into alcohol. Federal and state subsidies played a key role in the early 1980's when crude prices fell and spawned the "Minnesota Model" for ethanol production, in which farmers began producing ethanol to add value to their corn. Ethanol's use as an oxygenate to control carbon monoxide emissions, encouraged increased production of the fuel through the decade and into the 1990s.

The Renewable Fuels Standard 2005 (RFS) targeted ethanol production of four billion gallons by 2006, increasing to seven and one-half billion gallons by 2012. The Energy Independence and Security Act of 2007 pushed this target to 36 billion gallons annually by 2022 and the new RFS mandates that only 15 billion gallons of production should be produced from corn grain (starch) —the remaining 22 billion should come from other advanced and cellulosic feedstock sources.

6.1.1 The history of corn-based biofuel production in the US

The history of bioethanol production in the US spans several decades and has been influenced by various factors including energy security concerns, agricultural policy, and environmental considerations. Here's a brief overview:

01. Early development in the 1970s

The modern era for bioethanol production in the US began in the 1970s during the global oil crises and the accompanying concerns over energy security. The first commercial-scale bioethanol plant was developed in the US with this in the background

02. Expansion and government support (1980s-1990s)

The 1980s/90s saw a steady increase in bioethanol production under a benign policy support umbrella of the federal and state governments. The federal Government introduced policies to promote the blending of ethanol with gasoline, known as gasohol. This period also saw the implementation of tax incentives and subsidies to support ethanol production. The Energy Policy Act of 1992 laid the base for the Renewable Fuel Standard (RFS), which mandated blending renewable fuels, including ethanol, into transportation fuel sold in the US. The RFS programme provided a long-term policy framework for the bioethanol industry and contributed to its continued growth. Incentives in the form of tax credits and blending mandates also helped create the initial market.

03. MTBE phaseout and ethanol blending (2000s)

The early 2000s saw a significant expansion of corn ethanol production capacity in the US, driven by favourable government policies, abundant corn supplies, and rising demand for ethanol as a gasoline additive. The phase-out of methyl tertiary-butyl ether (MTBE), a gasoline additive, led to an increased demand for ethanol as a blending component in gasoline. As a result, the RFS programme was expanded setting increasingly ambitious targets for renewable fuel use.

04. Expansion of corn ethanol production (2000s-2010s)

The first decade of the 2000s saw a substantial increase in corn ethanol feedstock production and use due to favourable government policies. The Energy Policy Act of 2005 expanded the Renewable Fuel Standard (RFS) programme and introduced the RFS2 programme, which set more ambitious targets for renewable fuel use, including advanced biofuels such as cellulosic ethanol. RFS2 provided incentives for the development and commercialisation of advanced biofuels technologies. Ethanol production capacity grew with new plants constructed across the Midwest of the country, where corn production was concentrated.

05. Cellulosic ethanol and advanced biofuels (2010s-present)

Since 2010, the concerns over environmental sustainability and food-versus-fuel debate have led to intensified efforts to develop cellulosic ethanol and other advanced biofuels to produce bioethanol from non-food biomass sources However, commercial-scale production has been slower to develop than initially anticipated due to technical and economic challenges. Efforts to reduce greenhouse gas emissions, improve energy efficiency, and promote alternative feedstocks are driving innovation and shaping the future of the bioethanol industry in the US.

6.1.2 Evolving policy frameworks for biofuel production in the US

Several evolving policy frameworks have influenced the development and growth of the bioethanol industry in the US. Here are some key ones:

01. Renewable Fuel Standards (RFS)

The RFS programme, established in 2005 and expanded in 2007, mandates the blending of renewable fuels, including bioethanol, into transportation fuel sold in the US. The RFS sets annual targets for renewable fuel volumes, which has been a significant driver of bioethanol production and consumption.

02. Tax incentives and subsidies

Government incentives such as tax credits and subsidies have played a crucial role in promoting bioethanol production in the US These incentives have included the blenders' tax credit, which provided a subsidy for blending ethanol with gasoline, and the ethanol import tariff, which imposed tariffs on imported ethanol to protect domestic producers.

03. Farm Bill and Agricultural Policy

Agricultural policies, including provisions in the Farm Bill, have influenced bioethanol production by supporting corn farmers and providing incentives for biofuel production. Government support for corn production through subsidies, crop insurance, and research funding has indirectly supported the growth of the corn ethanol industry.

04. Environmental Regulations

Environmental regulations and concerns have also influenced bioethanol production in the US. Ethanol is considered to be a renewable fuel with potential environmental benefits, such as reducing greenhouse gas emissions compared to conventional gasoline. Environmental regulations, such as emissions standards and air quality requirements, have driven demand for biofuels as cleaner alternatives to fossil fuels.

05. Infrastructure Development

The availability of infrastructure, such as ethanol blending facilities and fueling stations, has influenced the distribution and consumption of bioethanol in the US. Efforts to expand the infrastructure for distributing and storing ethanol-blended fuels, including E10 (10% ethanol blend) and E85 (85% ethanol blend), have been important for increasing bioethanol use.

06. Research and Development Funding

Government funding for research and development (R&D) has supported advancements in bioethanol production technologies, including the development of cellulosic ethanol and other advanced biofuels. R&D funding has aimed to improve bioethanol production processes' efficiency, sustainability, and cost-effectiveness.

The development of any market requires a sustained policy effort. As can be seen in the case of the US, it was only when the policy framework came together that technology, investment, finance, and supply chains fell into place. Overall, the scale up and development of the bioethanol industry must be based on the bedrock of a facilitating policy framework that allows adoption of new technologies, addresses initial risks through higher returns and keeps everyone focused on the end goal.

6.1.3 Technology evolution: Dented corn for bioethanol

The development of technology for the processing of corn into bioethanol has played a critical role in the US , which is emerging as the foremost producer and user of biofuels like bioethanol.

01. Fermentation technology

Fermentation technology is at the heart of efficient and abundant bioethanol production. Advances in fermentation technology, including genetically engineered yeast strains and optimised fermentation conditions, helped increase ethanol yields and reduced production costs, leading to rapid enhancement of bioethanol use.

02. Enzymatic hydrolysis

Enzymatic hydrolysis involves breaking down the complex carbohydrates in dent corn into simpler sugars using enzymes. This technology has improved the efficiency of ethanol production from corn. It has also enabled alternative feedstocks, such as agricultural residues and dedicated energy crops, for ethanol production.

03. Co-products utilisation

Ethanol production from dent corn generates various co-products, including distillers' grains, corn gluten feed, and corn oil. Technological advancements have been made to improve the utilisation and value of these co-products. For example, distillers' grains can be dried and processed into high-protein animal feed, while corn oil can be extracted and used for biodiesel production or other applications.

04. Process integration and optimisation

Process integration and optimisation involve maximising the efficiency of ethanol production by optimising various unit operations and integrating different process steps. Advanced process control systems, modeling and simulation tools, and data analytics have been employed to optimise the entire ethanol production process, from corn milling to ethanol distillation, and minimise energy consumption and environmental impacts.

05. Cellulosic Ethanol Technologies

While dent corn remains the primary feedstock for bioethanol production in the US, there has been increasing interest in cellulosic ethanol technologies, which enable the conversion of lignocellulosic biomass into ethanol. Key technological developments in cellulosic ethanol include enzymatic hydrolysis of cellulose and hemicellulose, fermentation of pentose sugars by engineered microorganisms, and advanced pretreatment methods to improve biomass digestibility.

Overall, technological developments have been critical for the scale up and development of the bioethanol industry. Continued research and innovation in these areas are essential for further advancing the bioethanol industry and reducing its environmental footprint.

6.2 Brazil: World's second-largest ethanol producer

Brazil, the world's second-largest ethanol producer, has seen a significant rise in the number of ethanol processing plants in its Center-West region. Unlike the US, which is the leading ethanol producer where most ethanol is made from corn, Brazil primarily uses sugarcane for ethanol production. However, new corn ethanol plants are being established across the Brazilian states of Mato Grosso, Mato Grosso do Sul, and Goiás, areas that have witnessed a rapid increase in the second corn crop over the past decade. The growing annual corn harvest and the anticipated rise in ethanol consumption, both domestic and international are the key drivers behind the expansion of these processing plants.

6.2.1 The growth of corn ethanol in Brazil

Corn ethanol plants began appearing in the last decade in Brazil, especially in the Centre-West region. Corn ethanol production increased from 40 million litres in the 2013–14 season to 4.43 billion litres in the 2022–23 season, which runs from April to March in Brazil, according to data from the National Corn Ethanol Union (UNEM) – an institution founded in 2017 to represent the interests of the expanding industry. Meanwhile, sugarcane ethanol has remained relatively stable around 27 billion litres from 2013/2014 to 2022/23, according to the Brazilian Sugarcane Industry Association (UNICA).

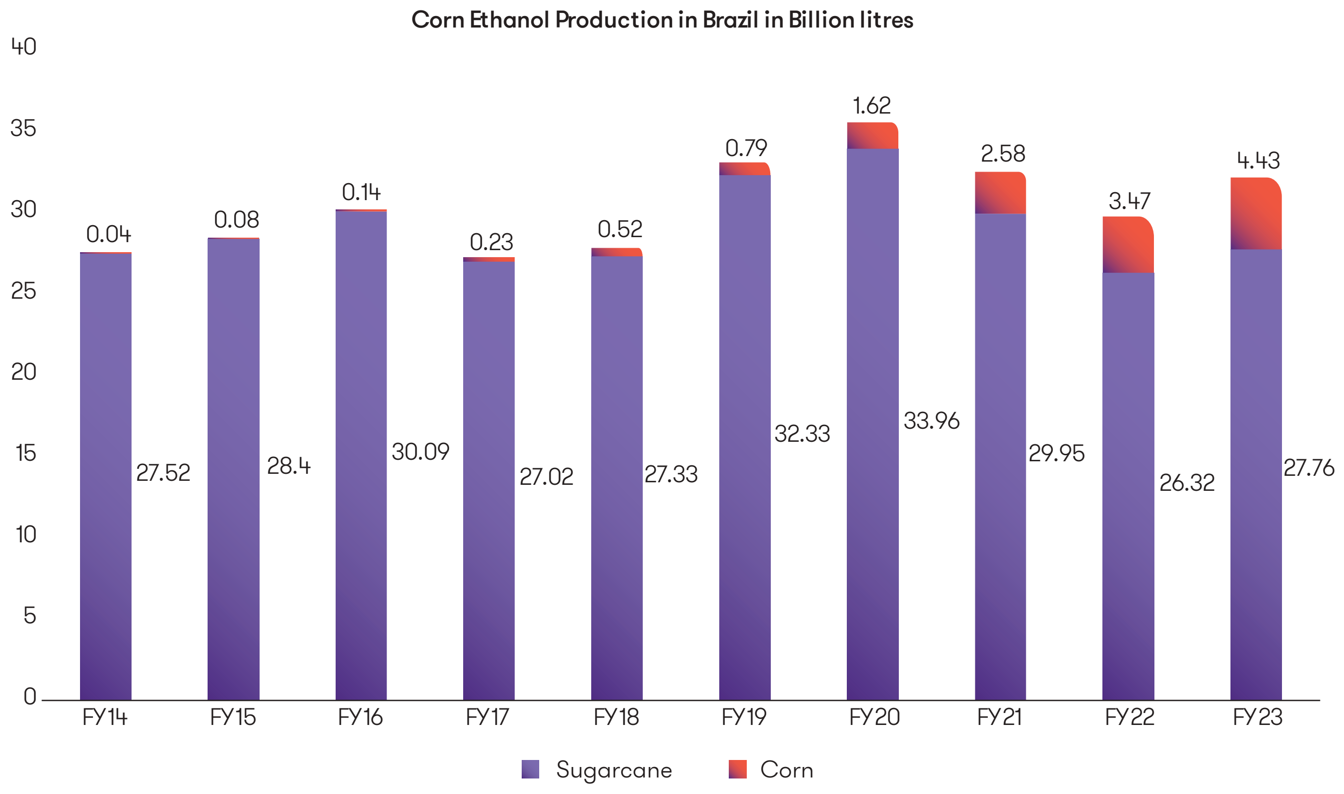


Figure 11: Corn Ethanol Production in Brazil in Billion litres

Sources: Corn Ethanol National Union (UNEM) and Brazilian Sugarcane Industry Association (UNICA)

The National Corn Ethanol Union (UNEM) projects a remarkable increase in Brazil's corn ethanol production, reaching 6 billion litres in the 2023-24 season. This represents a 36% rise from the previous cycle and an extraordinary 800% increase over the past five years. This surge is fueled by the expansion of Brazil's industrial complex, technological advancements, and growing international demand for biofuels, signifying a transformative period for the country's corn ethanol industry.

This growth is fueled by improved industrial capabilities, evidenced by the increase in ethanol plants and the adoption of advanced technologies to enhance industrial yield. Key benefits include abundant raw materials, especially second-crop corn in Brazil, which conserves land, facilitates nutrient recycling, and adds organic carbon to the soil. The corn ethanol sector not only meets the rising demand for biofuels but also plays a significant role in the essential process of decarbonisation.

High concentration in Center-West region

There are 20 ethanol plants in Brazil utilising corn as the feedstock. These are located in the states of Mato Grosso (11 units), Goiás (6 units), Mato Grosso do Sul (1 unit), Paraná (1 unit), and São Paulo (1 unit). Nine plants are corn-only, while the rest are flex plants producing ethanol from sugarcane and corn In addition, 10 other businesses have received construction authorisation, which would bring Brazil´s production capacity to 9.6 billion liters of corn ethanol by the 2030/2031 season, according to the UNEM forecast.

While flex plants usually process sugarcane at the height of that crop's harvest season and switch to corn for about three months during the "inter-harvest" period, full plants are committed to processing corn only, year-round. Although the cost of building a flex facility can be 30 to 40% higher than building a corn-only plant, flex plants generate more money than sugarcane-only plants, which typically sit idle for several months (USDA, 2020).

Brazilian corn-based ethanol producer FS has received certification that its corn-based ethanol complies with international requirements to produce sustainable aviation fuel (SAF)

The Lucas do Rio Verde unit of FS has been certified under the International Sustainability Carbon Certification (ISCC) Corsia programme in the Mato Grosso state of Brazil. ISCC stands out as a leading international certification scheme for biomass and bioenergy, sustainability in land use, traceability, and verification of greenhouse gas (GHG) emissions.

In addition to the overarching ISCC Corsia certification, FS has also obtained an add-on certification for low use change (LUC) risk, attributed to its collaboration with the second-crop corn supplier, GF group. This certification confirms that the biofuel produced does not result in GHG emissions associated with indirect land use change (ILUC), which occurs when land previously used for pasture or agriculture for food and feed markets is redirected to biofuel production. FS becomes Brazil's first corn biofuel producer to achieve this recognition, positioning itself within the sustainable aviation fuel (SAF) supply chain across all member states of the International Civil Aviation Organization (ICAO). This certification enables the company to ensure the traceability of renewable fuel, a crucial aspect in the aviation industry's pursuit of achieving net zero emissions by 2050.

The certification underscores that Brazilian ethanol derived from second-crop corn, similar to its sugarcane counterpart, can serve as a low-carbon feedstock for producing biofuel in sectors that pose challenges in decarbonisation, such as aviation, as stated by FS' CEO, Rafael Abud.

Some key biofuel policies are as discussed below:

- Since the 1970s, Brazil has mandated ethanol blending in gasoline, reaching 27% in 2015 and maintaining this level until 2021. The National Alcohol Programme (Proálcool), launched in 1975 in response to the 1973 oil crisis, aimed to reduce Brazil's dependency on oil imports and lessen the economy's vulnerability to external shocks. Proálcool is considered a pioneering biofuel initiative, producing hydrous ethanol as an alternative fuel for dedicated vehicles.
- The Brazilian Biodiesel Production and Use Programme (PNPB), initiated in 2005, is a Federal Government initiative focused on the sustainable production and use of biodiesel. It emphasises social inclusion and regional development through job and income generation. According to Law No. 11.097/2005, diesel sold at retail must contain a biodiesel blend (Bxx), defined broadly as any fuel derived from renewable biomass for use in Diesel cycle engines.
- The National Agency of Petroleum, Natural Gas, and Biofuels (ANP) specified green diesel and quality control requirements in Resolution No. 842/2021. This regulation incorporates current technological advancements and permits the use of various biofuels in Diesel cycle engines, beyond just FAME biodiesel.
- In 2017, Brazil enacted the Brazilian Policy for Biofuels, known as RENOVABIO, through Law No. 13,576/2017. This policy establishes a regulatory framework to revitalise the biofuels sector, promoting energy efficiency in biofuel production and use. Its goals include reducing the carbon intensity of the transport fuel matrix by 10% and avoiding 620 million tons of CO2 equivalent emissions from 2018 to 2030.
- In 2020, Brazil began trading Decarbonisation Credits (CBIOs), each representing 1 ton of CO2 equivalent avoided, on the Brazilian stock exchange (B3). Despite the effects of the COVID-19 pandemic, fuel distributors met 97.6% of the established target, achieving 14.9 million CBIOs. The average price of CBIOs was BRL 43 (USD 8), generating BRL 650 million (USD 125 million) in revenue for producers.

6.2.3 Corn-based biofuel: Pros and cons in Brazilian context

Corn has certain advantages over sugarcane, but it also presents some challenges. In Brazil, ethanol plants are powered by burning biomass, as natural gas is often prohibitively expensive. Most ethanol production facilities use bagasse, the fibrous byproduct of sugarcane, as their primary fuel source. In contrast, corn ethanol plants mainly rely on eucalyptus biomass, although some companies are experimenting with other biomass sources (USDA, 2020). While sugarcane provides its own biomass fuel, its limited growing season and rapid fermentation post-harvest pose challenges. On the other hand, corn ethanol plants can operate year-round and produce various coproducts, such as corn oil, Distillers Dried Grains (DDG), and Distillers Dried Grains with Solubles (DDGS).

The production efficiency of ethanol plants varies depending on the crop being processed. According to UNICA, ethanol yield from sugarcane is 80-85 litres per ton, whereas corn is 410-430 liters per ton. However, sugarcane yields 6,500-7,500 litres of ethanol per hectare, while corn ethanol yields 2,000-3,500 litres. Another distinction is that the corn ethanol industry lacks dedicated planted areas, whereas the sugarcane ethanol industry, benefiting from more vertical integration, has its own plantations and maintains stronger direct relationships with sugarcane suppliers.

07

Conclusion

Maize offers unparalleled flexibility in cultivation, product diversification, processing, marketing, distribution, and value creation for all participants in the supply chain. By leveraging this flexibility along with the increasing demand, we can accelerate farmer income and enhance natural resource conservation, provided we address the key challenges faced by stakeholders throughout the value chain.

7.1 Recommendations for policymakers, industry stakeholders, and researchers

To fully unlock the potential of 2G ethanol and realise its socio-economic and environmental benefits, concerted efforts are required across multiple fronts. The following policy recommendations are proposed:

Create an Economic Framework for Ethanol from Corn

The promotion of ethanol from corn has to be based firmly in the overall long-term social, economic and environmental benefits t. An Economic Benefit Framework needs to be created for corn to ethanol based on a very comprehensive economic model which not only evaluates the whole corn to ethanol value chain, areas where investments are required, but also the impact of these investments on the key stakeholders, the social impact of these investments like employment generation, investment in new production facilities etc., as well the environmental impact of replacing gasoline with ethanol. The country needs to create an economic value for ethanol investments and transition plan, which needs to be executed over a three-year period.

The Economic Benefit Framework

The intention of the Economic Benefit Framework is to address not only the realisation of the direct tangible benefits accruing from these projects in the short term, but also the potential for larger, longer-term economic benefits (externalities). The Economic Benefit Framework would also provide a platform for bringing on board a diverse set of decision makers and stakeholders on a single platform to discuss and debate the economic rationale behind these investments and to look at corn to ethanol development in the short-, medium- and long-term horizon.

Need to evolve new economic valuation methodologies for Corn to Ethanol Projects

Current valuation methodologies do not consider social and environmental benefits when valuing new innovative investment decisions. These benefits are merely acknowledged as positive externalities with no bearing on the actual market price for ethanol, which in turn results in lower pricing of ethanol-based fuels. The project evaluation, valuation of investments and the pricing of ethanol needs to create a more rounded methodology.

Subsidies and Financial Incentives will be critical for kick starting the industry:

The policy makers need to use the global and Indian experience of promoting (from scratch) new clean energy technologies such as solar, wind, EVs and batteries. The focus of scale up and commercialisation of these technologies has to be on scaling production (through enhanced feedstock availability and production plants) to ease in accessing financing which allows investments in these facilities to finally creating the mandate required for pushing up the demand for ethanol as it has been happening in the Renewable Energy Sector (through Renewable Purchase Obligations) over the past few years.

- Incentivising mega-biorefineries and ensuring duty-free import of dented corn will be instrumental in catalysing the 2G ethanol revolution. Moreover, empowering Indian farmers through lucrative incentives and technological support is paramount, fostering a conductive ecosystem for sustainable 2G ethanol production.
- Production of adequate feedstock will require allowing cheap imports initially so that the production facilities can be developed. Initial policy support must be provided for import of corn feedstock for initial ethanol production.
- A very strict roadmap needs to be developed to taper down these imports with increase in domestic production. The roadmap needs to estimate the time for various corn crops to come to maturity stage, post which imports would be met with very high import tariff barriers, making ethanol using imported corn unviable.
- Production plants should be encouraged to work with farmers and farmer collectives to create corn-based farms, which can then act as captive feedstock production sites for farmers.

- The Government should provide financial incentives and subsidies to promote 2G ethanol production, including tax breaks, grants for infrastructure development, and price support mechanisms for 2G ethanol producers.
- Gradually increase crease the mandatory blending percentage of 2G ethanol in petrol to incentivise demand for 2G ethanol and stimulate investment in 2G ethanol production capacity.

Identify specific areas for high intensity corn cultivation:

Land use mapping/ land allocation study and necessary legal institutional and other provisions to allow land transition to corn cultivation.

A dedicated Research and Development Programme

There is a need for both private and public sector investment in research and development initiatives to transition from 1G to 2G ethanol production technologies, enhance crop yields, and develop sustainable feedstock supply chains. Focused programmes like DARPA in the US need to be studied and suitable institutional/ incentive mechanisms need to be created to promote research across the corn to ethanol value chain. There is also a need to focus research efforts on second-generation (2G) ethanol.

Streamline market and finance access

There is a need to train regulators, policymakers, financers and insurers on the nuances of investing in corn to ethanol technologies. Moreover, market access should be provided to 2G ethanol producers by streamlining regulatory processes, reducing bureaucratic hurdles, and promoting public-private partnerships for 2G ethanol distribution and marketing.

Separate Policy for Ethanol and Biodiesel:

Biofuel policy in India should be separate for ethanol and biodiesel. The policy framework should provide policy signals based on changing development, financing and production costs for all suppliers and stakeholders across the corn to ethanol value chain. Periodic revision of corn and ethanol is critical to maintaining the sector's initial commercial viability.

Promote development of flex fuel vehicles as in the case of Brazil

Automakers should be made responsible for ensuring production and sale of a percentage of flex fuel vehicles.

Focused technical assistance for 2G Corn to Ethanol Toll out

There is a need to work with multi-lateral and bi-lateral donors to provide technical assistance, training, and financial support to farmers, farmers collectives to take up corn cultivation, create institutional structures and mechanisms for greater engagement between ethanol producers and these collectives and put in place provisions which ensures a fair and remunerative price for produce even in times of glut.

Create a national level nodal agency to manage the development of the sector

The establishment of a national agency with branches in relevant states to design and implement the above stated public support programme, oversee and monitor the industry, periodically review the cost of production and price, design and recommend subsidy and taxes based on the changes in oil prices. Seek assistance of donor agencies to provide technical assistance for the design and establishment of this agency, institutional capacity building, project development and finance in the sector.

Development of International Level Standards

Instruct BIS to develop and implement certification standards for sustainable 1.5G/ 2G ethanol production to ensure environmental integrity and social responsibility across the ethanol value chain.

Incentivise the Public Sector to create enabling infrastructure for Corn to Ethanol

Create programmes a

nd support programmes for PSU's to invest in infrastructure development, including 2G ethanol biorefineries, storage facilities, and transportation networks, to support the expansion of 2G ethanol production and distribution capacity.

Leverage access to global technology packages:

The global precedence set by leading 2G ethanol producers such as the US and Brazil serves as a reference point for India. By leveraging advanced technologies and fostering conductive policy environments, India can emulate their success, ushering in a new era of energy self-sufficiency and sustainability.

Establish synergy between rural livelihood programmes and the biofuel mission:

Further studies to examine potential synergy between India's rural development programmes and the corn to ethanol sector.

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