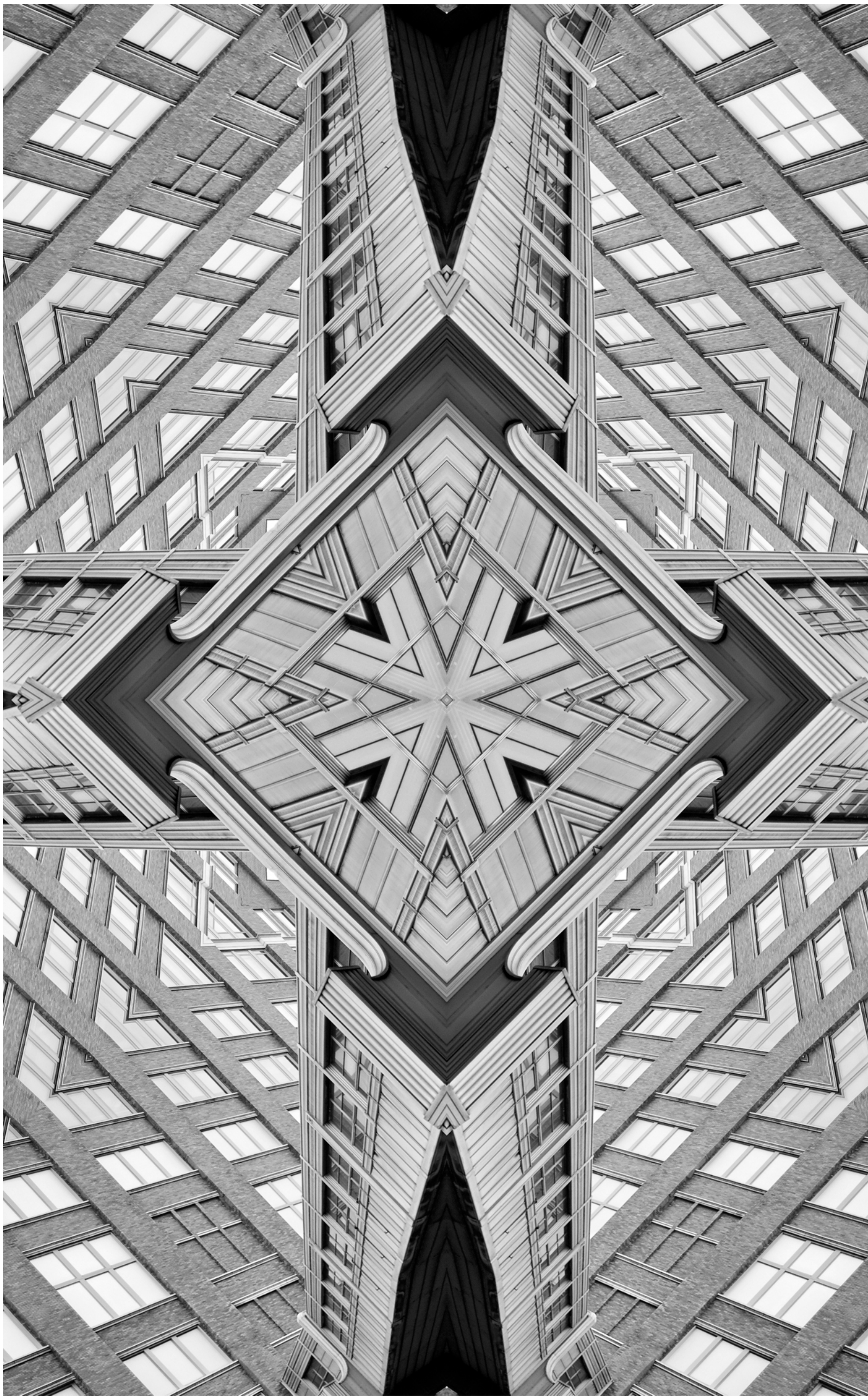
OBSERVER RESEARCH FOUNDATION



Issue Brief

ISSUE NO. 526
MARCH 2022

The Implications of India's Revised Roadmap for Biofuels: A Lifecycle Perspective

Promit Mookherjee

Abstract

Transport activity in India has increased more than sevenfold over the last two decades, its gasoline-fuelled pathway leading to a rapid rise in negative environmental externalities. To decouple the sector's growth from high emissions, policymakers are scaling up efforts to deploy cleaner fuels for the sector; in particular, liquid biofuels have received a significant push. However, while biofuels help lower emissions at the point of use, their lifecycle impacts are heavily dependent on the biomass pathway adopted. Thus, the environmental and social benefits of biofuels are closely linked to the intricacies of the broader agricultural and economic system. This brief assesses India's current biofuel pathway from a lifecycle perspective, identifies the gaps in the present policy, and proposes a long-term sustainable strategy.

Attribution: Promit Mookherjee, "The Implications of India's Revised Roadmap for Biofuels: A Lifecycle Perspective," *ORF Issue Brief No. 526*, March 2022, Observer Research Foundation.

Introduction: The Global Scenario

Biofuels involve the direct conversion of biomass into liquid fuels which can be blended with existing automotive fuels. Ethanol and biodiesel are the two main transport biofuels. These fuels can be produced from a variety of biomass. First-generation (1G) biofuels are usually produced from edible feedstock. Ethanol production primarily involves distilling carbohydrates from sugarcane and beet or distilling starch from food grains such as maize, paddy, wheat, and potatoes through fermentation. First-generation biodiesel is produced from different types of vegetable oils such as canola oil, palm oil, soybean oil, and sunflower oil. Second-generation fuels are produced from lignocellulosic biomass which is obtained from energy crops or waste biomass, such as agricultural and forest residue. Recently, the production of biodiesel from algal biomass has also evolved as an option, sometimes referred to as third-generation biofuel.[1]

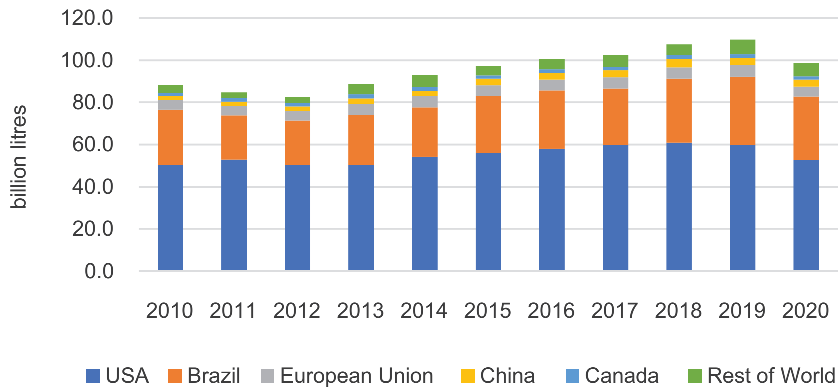
In the global transport-fuel demand, the share of biofuels remains minimal, accounting for only 2.4 percent in 2018.[2] To improve the situation, many countries have implemented dedicated biofuel policies with time-bound blending mandates, incentivising the setting up of distilleries and encouraging the production of energy crops. Brazil's RenovaBio programme is amongst the most ambitious and has resulted in a national ethanol blending rate of 27 percent. Both the EU and China have devised a roadmap to achieve a 10 percent ethanol blending rate. In the US, the Environmental Protection Agency (EPA) is mandated by law to set production mandates for biofuels,[3] which are regularly updated.

Backed by such policy support, ethanol and biodiesel production increased steadily from 2010 to 2019. Ethanol production increased at a compound annual growth rate (CAGR) of 2.4 percent, peaking at approximately 110 billion litres in 2018-19 and accounting for 60 percent of the total liquid biofuel produced. However, reduced demand and supply-chain issues brought on by the COVID-19 pandemic in 2020 led to an 11-percent decline in ethanol production. Biodiesel production stood at around 47.4 billion litres in 2019.

For ethanol, the US is the largest producer (41 percent), followed by Brazil (26 percent), Indonesia (4.5 percent), and China (2.9 percent).[4] Biodiesel production has a wider geographical spread, with the top five countries accounting for only 57 percent of the total production. Indonesia is the largest producer (17 percent), followed by the United States (14 percent) and Brazil (12 percent).

Introduction: The Global Scenario

Figure 1: Global Ethanol Production



Source: Renewable Fuels Association (RFA)[5]

In terms of feedstock, the global transport biofuel market is heavily dependent on 1G production methods, with 2G methods and lignocellulosic feedback producing less than 10 percent of the total share. In Brazil, ethanol is produced almost exclusively from sugarcane, accounting for 95 percent of the total production[6] and biodiesel is produced mainly from soybean oil. In the US, ethanol production is mainly dependent on maize, and 40 percent of the country's total maize production is used for ethanol production. A more diverse mix of feedstock exists for biodiesel, with soybean oil and other waste oils/fats together accounting for 46 percent of the total production.[7]

A Lifecycle Perspective

Global experience shows that biofuel production dependent on 1G feedstocks does not guarantee lifecycle benefits. The most significant factor affecting lifecycle emissions is land-use change during the production of the feedstock. For new land to be brought under cultivation for biofuel production, the existing natural vegetation must be cleared, which leads to the release of the stocked carbon and, therefore, a net carbon debt. Furthermore, the use of chemical fertilisers releases nitrous oxide, whose global-warming potential is 300 times higher than that of carbon dioxide. Energy used in transporting the feedstock and blending also contributes to the overall carbon emissions. Thus, uncertainty exists at each stage of the fuel supply chain, and emissions can differ significantly based on land availability and the efficiency of the agricultural system in a particular country.

A 2021 study by the ICCT[8] found that the food-grain-based biofuel approach in Europe led to an average lifecycle carbon intensity of 73 g CO2 eq./MJ, which was only 22-percent lower than fossil gasoline. This translates into a small two-percent reduction in GHG emissions, with a five-percent blending rate. Indeed, for food-based biodiesel, the lifecycle emissions were estimated to exceed gasoline diesel by up to three times. The highest emissions were from palm oil (267 g CO2 eq./MJ), followed by soybean (208 g CO2 eq./MJ) and rapeseed (116 g CO2 eq./MJ). The primary reason behind such high emissions is the release of carbon from direct and indirect land-use change.

Indian Approach to Biofuel Production

In India, the Ethanol Blending Programme in 2003 was the first significant policy step related to liquid biofuels. It mandated a five-percent blending rate for ethanol in petrol for nine states and four union territories, which was extended to the whole country in 2006. The Biofuel Policy, implemented in 2009, was more ambitious, mandating a 20-percent blending rate for both ethanol and biodiesel by 2017. The 2009 policy also moved beyond molasses-based ethanol production to the direct use of sugarcane juice.

Despite these measures, ethanol production remained low in the ensuing years. Issues in the sugarcane supply chain prevented production, and oil-marketing companies were unable to get bids for most of the amount offered for purchase. This prompted a slew of measures in the next few years, including the reintroduction of administered minimum support price and the opening up of alternate routes for ethanol production. By 2018, blending rates reached around four percent, followed by a faster uptake in the subsequent years. As of 2021, the Government of India claims a blending rate of 8.1 percent.[9]

Table 1: Ethanol Production and Blending Rates in India

Supply Year	Quantity Supplied (Crore Litres)	Blending Percentage for PSUs (%)
2012-13	15.4	0.67
2013-14	38	1.53
2014-15	67.4	2.33
2015-16	111.4	3.51
2016-17	66.5	2.07
2017-18	150.5	4.22
2020-21	304	8.1

Source: Compiled from Ministry of Petroleum and Natural Gas (MoPNG) Statistics

The 2009 Policy also outlined a clear pathway for biodiesel production, utilising non-edible oils—specifically, Jatropha Curcus. A large-scale plantation programme was envisaged, focused exclusively on government/community wasteland and degraded/fallow land in forest and non-forest areas. This approach is distinct from other countries, and the Policy provided incentives for non-edible oilseed production as well as guaranteed purchase prices and incentives for setting up expeller units and biodiesel plants. However, the pathway ran into several issues. The oil yield from the Jatropha plant, as well as the required levels of fertilisers and pesticides, fell significantly short of the projections. Indeed, by 2018, a substantial portion of biodiesel production was using multiple feedstocks, not just Jatropha. At present, the biodiesel blending rate in India continues to be as low as 0.1 percent.

The latest update to the Biofuel Policy was made in 2018 and aims at achieving 20-percent blending rate for ethanol and five percent for diesel by 2030. In line with the previous approach, the Policy reiterated the need for a biofuel production pathway dependent on 2G technologies using waste biomass. Thus, the 2018 Policy also focuses on improving research in 2G technologies and developing sustainable solutions in the long run.

However, in 2021-22, there has been a pivot from the policy articulated in 2018. The GoI has announced a scaling up of its ethanol blending ambitions—most notably, the deadline for achieving a 20 percent blending rate for ethanol has been set at 2025. To enable faster transition, the Union government has doubled down on 1G biofuels. In addition to sugar-based production, the use of food grains has been allowed, which includes maize as well as surplus rice from Food Corporation of India (FCI) stocks. The loan interest subvention scheme has also been expanded, to include grain-based distilleries apart from sugar or molasses-based distilleries. The recently constituted "Expert Committee on Roadmap for Ethanol Blending in India by 2025," has outlined a reconfigured approach to meeting the new targets[10] that requires 13.5 billion litres of ethanol to be produced by 2025—a sixfold increase from the 2.7 billion litres produced in 2021.[11] The plan is to obtain 6.8 billion litres from sugarcane and 6.6 billion litres from food grains, which will have a significant impact on the agriculture sector.

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

Sugarcane: Sugar-based ethanol production currently uses (almost exclusively) molasses, a by-product of the sugar-making process. Studies estimating the lifecycle impact of the molasses pathway in India are limited, and largely incomparable with each other, due to different system boundaries. Estimates for this pathway vary based on how energy use is apportioned to the multiple co-products such as trash, bagasse, filter mud, and biogas.[12] A 2015 study by Soam et. al.[13] found that without allocation among co-products, lifecycle emissions for molasses-based ethanol were 8,736 kg CO2 eq./tonne of ethanol, compared to 512 kg CO2 eq./tonne of ethanol when energy-use was apportioned. Moreover, lifecycle emissions were 11 percent lower in the western region compared to the north, due to the greater resource intensity of sugarcane farming, molasses transport, and ethanol production in the northern regions. In particular, transport contributes a much larger share of the total emissions in the northern regions, since the distilleries are located far away from the farms. Currently, there are no estimates on the carbon emissions that will result from the land-use change required for increased sugarcane production. According to Ju Young Lee et al.,[14] meeting the 20 percent blending target from molasses alone will require 19 million hectares of additional land under sugarcane. Thus, the NITI Aayog goal of producing 6.78 billion litres from sugarcane will require an additional 6.26 million hectares under sugarcane by 2025, which will have a significant negative impact on the lifecycle emissions from this feedstock.

The other sugarcane pathway involves the use of sugarcane juice directly, possibly reducing the need for land-use change. This pathway has gained significant traction as a way to increase the price of sugar by better utilising the sugar surplus. However, sugarcane cultivation is water-intensive and depends heavily on consistent rainfall patterns. Indeed, the cultivation of sugarcane has led to severe water stress and drought-like conditions in some districts, affecting all forms of livelihood.[15,16] Moreover, increased sugarcane cultivation will divert irrigation water away from critical food-grain crops.[a] Furthermore,

---

a India ranks 13th amongst countries with the highest water stress. A recent NITI Aayog report suggests that nearly 600 million Indians are facing high to extreme water stress.

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.

Rice: To meet the 2025 ethanol production target of the new roadmap, an estimated 17 million tonnes of food-grains will be needed—a staggering increase from the 78,000 tonnes of Food Corporation of India (FCI) rice allocated in 2020-21. The FCI stock of rice is presently at its highest, at 21.3 million tonnes during December 2021. The current food-stocking norms require the FCI to maintain a buffer stock of around 13 million tonnes to meet the PDS supply as well as the shortfall in procurement. Thus, there is a surplus of around eight million tonnes, which has been proposed for utilisation in ethanol production. However, due to excess procurement during the pandemic, the current rice stocks are much higher than the average stocks in the last few years.[17] The stock also varies seasonally, with significant inflation following the Rabi cropping season. Thus, a steady supply of surplus rice may not be sustainable in the long run.

Moreover, the process of using FCI-procured rice for ethanol is essentially uneconomical, since the economic cost of the stored paddy is usually much higher than the minimum support price at which it is procured, and includes incidental expenses such as transport, labour, taxes, freight, and handling. Some estimates suggest the economic cost per quintal of rice is INR 4,294, almost four times the MSP.[18] For the FCI, selling rice for ethanol is a major loss, since the rates are subsidised at INR 2,000 per quintal. Finally, FCI rice procurement is biased towards Haryana and Punjab, where the MSP-based procurement is stronger. Since these are semi-arid areas, they are not suited for paddy production, leading to a much higher environmental footprint compared to traditional rice-producing areas in Eastern India.

Maize: Since the use of rice for ethanol poses significant risks to food security, the GoI has declared this to be a temporary measure.[19] Thus, in the long run, food-grain-based ethanol production will depend on maize. Globally, the lifecycle emissions from maize have been a contentious issue. Earlier studies in the US suggested that the lifecycle emissions from maize ethanol were higher than gasoline due to large-scale land-use changes.[20,21] Searchinger et al.[21] estimated that maize-based ethanol could nearly double GHG emissions over

30 years, compared to gasoline. However, recent studies by the Environmental Protection Agency[22] show that the impact of land-use changes had been overestimated in previous studies and that the emissions from maize ethanol would be 21 percent lower than gasoline by 2022. A subsequent study by Rosenfeld et al.[23] has shown more promising results, with lifetime emissions estimated to be 39-percent lower compared to gasoline. The key difference in the later studies is their projection of a rapid increase in US maize yields, which will reduce the need for land-use change.

In India, maize production in 2020-21 stood at 24.51 tonnes. Production has remained largely stable in the last five years. However, the domestic consumption of maize has consistently exceeded production in the same period, prompting 458,100 tonnes worth of maize imports during 2019-20. Presently, most of the maize is utilised for poultry feed (47 percent); the rest is used for livestock feed (13 percent), starch (14 percent), and exports (six percent). As per estimates from the Indian Institute of Maize Research (IIMR), the average yield for maize in India is 2.8 tonnes/ha. and 4.4 tonnes/ha. for the Kharif and Rabi seasons, respectively. This is less than half the US average yield (10.4 tonnes/ha.)[24] and lower than that of most other maize-producing countries.

Considering an ethanol yield of 380 litres/ tonne as suggested by the NITI Aayog, meeting the food-grain requirement for ethanol production from maize will require an additional 4.82 million ha. of land under maize cultivation—more than half of the present 9.42 ha. under maize cultivation. Thus, a maize-dependent pathway will require major land-use changes. The US experience has already shown that a low-yield maize pathway combined with land-use changes not only leads to minimal carbon emission benefits but can also increase maize prices, severely impacting the poultry and livestock industry.

Biodiesel: The use of Jatropha for biodiesel production has largely been unsuccessful due to low yields. The expected yield was 2-5 mg/ha. per year, whereas the actual yield was closer to 0.5-1.5mg/ha. per year.[25] Thus, the actual land required to produce a five percent blending rate is much higher than expected and farmers' profits much lower. The situation is exacerbated by the unavailability of oilseeds. Consequently, by 2018, only around 0.5 million ha. were estimated to be under Jatropha cultivation. Further, Jatropha was found to increase weeding in many areas, ruining local habitats and leading to the loss of other ecosystem services.

The focus on Jatropha was partly aimed at reviving areas classified as "wasteland." However, there has been much contention regarding the classification of wastelands. Baka[26] argues that wasteland classification in India is a political construct that ignores social, political, and ecological relations on the ground. The "Wasteland Atlas of India-2019" classifies 5.5 lakh sq. km of land as *wasteland*, around 16.96 percent of the total geographic area. Since an area is classified as a wasteland if its economic productivity is low, the areas that are not under productive agriculture or forests are often labelled as wastelands. However, large tracts of these lands are often already occupied and utilised by villagers,[27] who are unwilling to give them up. Further, ecologists have pointed out that certain ecologically productive habitats such as grasslands, too, are sometimes ad-hoc classified as wastelands,[28] despite the fact that they provide crucial ecosystem services and are essential for maintaining biodiversity. In some cases, existing biomass on land classified as "wasteland" provides more energy and environmental services than what it would post conversion.

Thus, India's present approach to biofuel production presents the following key challenges from a lifecycle perspective:

1. The low yield for sugarcane and maize in India will require land-use change, significantly affecting embodied emissions.

2. The agricultural sector receives subsidies for inputs and power, in addition to MSP, leading to unsustainable use of water and fertilisers.

3. Land revival programmes are inhibited by the lack of a robust mechanism for the classification of wastelands and complicated land ownership patterns.

4. The use of competing agricultural feedstocks can create conflict between different agricultural lobbies. Just recently, sugarcane farmers wrote a letter to the prime minister, alleging that OMCs were increasingly favouring ethanol from maize, affecting their livelihoods.[29]

5. Promoting 1G biofuels will lead to technology lock-ins, delaying the switch to 2G feedstocks. Incentives for sugarcane- and maize-based production will be difficult to repeal once implemented, given the strength of agricultural lobbies in most states.

Policy Recommendations

For a sustainable transition, the long-term biofuel pathway should be based on waste (2G) and algal biomass (3G). Such approaches will ensure reductions not only in oil imports but also in carbon emissions. Estimates by the IEA suggest that halving carbon emissions by 2050 will require 90 percent of all biofuels to be produced from wastes. Furthermore, a waste-based pathway will ensure higher levels of biofuel production, since a larger part of the biomass can be apportioned for fuel production, without posing a threat to food security and land. In the long run, waste-based biofuels will also be cheaper for consumers, since the raw materials are cheaper than edible feedstock. In India, the cost of ethanol is significantly higher than in other countries, due to government-regulated pricing of agricultural commodities. It can also be an effective solution to the problem of air pollution arising from the burning of agricultural wastes.

The following are some policy suggestions for ensuring long-term and sustainable increase in biofuel production:

1. **Expanding 1G biofuel, rooted in sustainable land use:** Instead of a top-down target-based approach, the proliferation of sugarcane and maize for ethanol should be part of a broader, sustainable land-use strategy. The GoI must develop a criterion for identifying land with potential for conversion to energy crops; such criteria must not be restricted to the simplistic classification of wetlands prevalent today. Global standards, such as the ones developed by the Roundtable on Sustainable Bio-material (RSB), can provide a guide but will have to be adapted to the Indian context. Overall, the standards must account for crucial factors such as net GHG emissions, local pollution, food security, land laws, and resource availability. Newer institutional arrangements must be made, to monitor compliance to the standards, before implementing specific projects.

2. **Developing sustainable supply chains for 2G feedstock:** There is currently little data on the suitability of different 2G feedstock. Each potential lignocellulosic feedstock has its advantages and disadvantages (See Table 2). It is imperative to formulate a roadmap for 2G feedstock, with a focus on those that minimise land-use change and promote a circular economy. Since most of these feedstocks have a low density, transport costs are usually high. An integrated 2G biofuel roadmap must address this, taking into account

A Shared Developmental Agenda

spatial and temporal constraints. This will require an understanding of the availability of feedstock as well as the technological requirements for conversion to biofuels. Already, a significant amount of research has been done on models for optimising supply chains for 2G fuels.[30,31] Going forward, the GoI must collaborate with research institutes to develop a viable model for India.

3. **Financing research and development for 2G biofuels:** Most of the 2G biofuels, such as cellulosic ethanol and biomass to biodiesel, are in the early phases of commercialisation. Faster uptake of these fuels is hindered by the high costs of production and high risks, which throttle innovation. To tackle this issue, public enterprises should scale up investment in pilot projects for 2G biofuels. The Pradhan Mantri JI-VAN Yojana already aims to provide INR 1,969 crores to develop 22 projects focused on 2G technologies. The scope and budgetary outlay for such schemes should be expanded. Further, international grants and loans should be redirected towards 2G fuels, and existing frameworks (e.g., the Clean Development Mechanism) can be leveraged to direct funding to this sector. To this end, it will be crucial to establish the value proposition for 2G fuels, starting with a comprehensive lifecycle emissions inventory of 1G and 2G. Government policy and mandates can help accelerate the demand for these products and enable the creation of viable markets for these fuels. Innovation will also need to be encouraged through fiscal incentives, such as tax credits for the production of cellulosic biofuel and loan guarantees for pilot projects. Some of the measures have already been successfully applied in other countries.

Table 2:
Snapshot of Lignocellulosic Biomass Options for Second-Generation Biofuels

	Feedstock	Advantages	Constraints	Availability
Dedicated Energy Crops				
Short-rotation crops	Poplar, willow eucalyptus, Locust.	Fast-growing, prevention of soil erosion, increased soil fertility in some cases.	Invasive species leading, potential for land-use changes, low energy density	Year-round
Perennial crops	Miscanthus switchgrass, reed canary grass, and other grasses	Useful for reviving degraded land, prevention of soil erosion, increased soil fertility in some cases.	Invasive species, potential for land use changes, low energy density	Summer and Autumn
Primary Residues				
Agriculture	Straw, stover	Cheap, promotes a circular economy, no land-use change, additional value creation for farmers, reduced pollution from waste burning	Low energy density, reduced nutrient cycling	Only during crop harvesting season

	Feedstock	Advantages	Constraints	Availability
Forestry residues	Treetops, branches, stumps	Cheap, no land-use change, prevents forest fires	Competing uses for fuel and fodder, low energy density, loss of organic matter, and biodiversity habitat	Year-round
Secondary Residues				
Crop processing	Coffee, rice, corn, cacao	No land-use change, concentrated at processing site, reduces disposal costs,	Competition with heat and electricity generation	Year-round
Sugar ethanol production	Sweet sorghum, bagasse, pulp		Animal feed	Only harvesting season
Forestry processing	Sawdust, bark		Competition with heat and electricity generation	Year-round
Tertiary Residues				
Municipal solid waste	Palettes, furniture, timber	Concentrated at landfill sites, reduces disposal costs, no additional land	Competition with heat and electricity generation	Year-round

Source: Adapted from Eisentraut (2010).[32]

4. **Support for alternative feedstock for biodiesel production:** While using Jatropha for biodiesel production eschews the food-security issue, it accounts for limited production. Thus, the Biofuel Policy must expand the list of feedstocks that can be sustainably used. This will require a twofold approach. First, alternative non-edible vegetable oils should be considered for plantations and biodiesel production. India has 11 tree species that have high oil content in their seeds and can be used for producing biodiesel.[33] The GoI must focus on a comprehensive mapping of these and formulate a

roadmap for utilising them. Further, government support should be provided to projects aimed at developing more efficient methods of extracting oil from oilseeds. Second, the use of waste or recycled oil for biodiesel must be enhanced. While India has approximately 33 biodiesel units that can utilise repurposed cooking oil, most suffer from a lack of feedstock availability. According to the Food Safety and Standards Authority of India (FSSAI),[34] India produces around three million tonnes of used cooking oil (UCO), 60 percent of which goes back to the food chain, leading to adverse health impacts. Currently, the FSSAI does not have the resources required to enforce the established standards for the disposal of used cooking oil. Thus, larger agencies such as State Pollution Control Boards must be deployed, and the procurement of UCO for conversion to biodiesel strengthened. OMCs have already issued an EOI seeking biodiesel made from UCOs, and the government has announced a scheme for greater procurement of UCO. Going forward, such efforts need to be sustained and amplified.

Conclusion

The key tenets of India's Biofuel Policy are unique and forward-looking, with a clear focus on 2G feedstocks and land regeneration. However, in its desire to accelerate biofuel blending targets, the present administration has strayed from the Policy and redoubled its focus on food-grain based feedstock. Such a pivot has significant negative implications in terms of lifecycle emissions, water stress, ethanol pricing, and distortions to the agricultural supply chain—exacerbating unsustainable land-use practices without guaranteeing emissions reduction.

The GoI must return to the country's original vision and divert the available resources towards 2G production methods, based on a clear roadmap and backed by policy and financial support. While this can delay biofuel blending targets by some years, it will not only ensure a sustainable reduction in emissions but also provide multiple economic and environmental co-benefits. A long-term, sustainable approach to biofuel production can help India become a champion for sustainable transport biofuels.

Promit Mookherjee *is an Associate Fellow with ORF's Centre for Economy and Growth.*

Endnotes

1 Takeuchi, Kazuhiko, Hideaki Shiroyama, Osamu Saito, and Masahiro Matsuura. Introduction to *Biofuels and Sustainability: Holistic Perspectives for Policy-making*. Springer Nature, 2018.

2 International Energy Agency, *Renewables,* 2019

3 Environmental Protection Agency, *Final Renewable Fuel Standards for 2019, and the Biomass-Based Diesel Volume for 2020,* 2020.

4 Renewable Energy Policy Network for the 21st Century, *Renewables 2021: Global Status Report,* 2021.

5 Renewable Fuels Association, *Annual Ethanol Production: U.S. and World Ethanol Production, 2020.*

6 Statista, *Fuel ethanol production in Brazil from crop year 2018/19 to 2020/21, by feedstock*, 2021.

7 Ron Kortba, "Where Will All the Feedstock Come From," *Biodiesel Magazine,* April 02, 2019.

8 Georg Bieker, "A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger car," International Council of Clean Transportation (ICCT), 2021.

9 Sanjeeb Mukherjee, "India achieves highest-ever ethanol blend of 8.1% with petrol in 2020-21," *Business Standard,* December 08, 2021.

10 NITI Aayog and MoPNG, *Roadmap for Ethanol Blending in India 2020-2025: Report of the Expert Committee*. 2021.

11 Mohanty Singh and Nandy, "India's ethanol blending target faces feedstock challenges on its path," *S&P Global Platts,* September 02, 2021.

12 Ioannis Tsiropoulos, André PC Faaij, Joaquim EA Seabra, Lars Lundquist, Urs Schenker, Jean-François Briois, and Martin K. Patel, "Life cycle assessment of sugarcane ethanol production in India in comparison to Brazil," *The International Journal of Life Cycle Assessment* 19, no. 5 (2014): 1049-1067.

13 Shveta Soam, Ravindra Kumar, Ravi P. Gupta, Pankaj K. Sharma, Deepak K. Tuli, and Biswapriya Das, "Life cycle assessment of fuel ethanol from sugarcane molasses in northern and western India and its impact on Indian biofuel programme," *Energy 83* (2015): 307-315.

14 Ju Young Lee, Rosamond L. Naylor, Anjuli Jain Figueroa, and Steven M. Gorelick. "Water-Food-Energy challenges in India: Political economy of the sugar industry," *Environmental Research Letters* 15, no. 8 (2020): 084020.

Endnotes

15 Varsha Torgalkar, "Sugarcane emerges as likely culprit in drought-hit Marathwada; growing cultivation of cash crop depleted groundwater," *Firstpost,* November 18, 2018.

16 Press Information Bureau, "NITI Aayog Report on Water Crisis."

17 Vivek Kaul, "FCI has highest rice, wheat stock since 2005. Modi govt continuing legacy of bad economics," *The Print*, July 8, 2020.

18 Tina Edwin, "India's foodgrain mountain is rising and it is proving to be expensive," *Moneycontrol,* July 02, 2021.

19 Sanjeeb Mukherjee, "Use of FCI rice for ethanol making only an interim measure: Centre," *The Business Standard,* June 16, 2021.

20 Joseph Fargione, Jason Hill, David Tilman, Stephen Polasky, and Peter Hawthorne, "Land clearing and the biofuel carbon debt," *Science* 319, no. 5867 (2008): 1235-1238.

21 Timothy Searchinger, Ralph Heimlich, Richard A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu, "Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change," *Science* 319, no. 5867 (2008): 1238-1240.

22 Jan Lewandrowski, Jeffrey Rosenfeld, Diana Pape, Tommy Hendrickson, Kirsten Jaglo, and Katrin Moffroid, "The greenhouse gas benefits of corn ethanol–assessing recent evidence," *Biofuels,* 2019.

23 J. Rosenfeld, J. Lewandrowski, T. Hendrickson, K. Jaglo, K. Moffroid, and D. Pape. "A Life-Cycle Analysis of the Greenhouse Gas Emissions from Corn-Based Ethanol," Report prepared by ICF under USDA Contract No. AG-3142-D-17-0161, 2018.

24 Global Yield Gap Atlas, "Description of cropping systems, climate, and soils: United States."

25 M. Moniruzzaman, Zahira Yaakob, M. Shahinuzzaman, Rahima Khatun, and A.K.M. Aminul Islam, "Jatropha biofuel industry: The challenges," *Frontiers in Bioenergy and Biofuels* 1, no. 12 (2017): 23-256.

26 Jennifer Baka, "What wastelands? A critique of biofuel policy discourse in South India," *Geoforum* 54 (2014): 315-323.

27 M. Glueck and D. Kashyap, "Liquid biofuels for transportation: India country study on potential and implications for sustainable agriculture and energy," The Energy and Resources Institute (TERI), 2005.

28 Sunil Kumar, Alok Chaube, and Shashi Kumar Jain, "Sustainability issues for promotion of Jatropha biodiesel in Indian scenario: a review," *Renewable and Sustainable Energy Reviews* 16, no. 2 (2012): 1089-1098.

29 Parthasarathi Biswas, "Sugar industry protests OMC 'injustice' to them," *The Indian Express*, December 10, 2021.

30 Reza Babazadeh, Jafar Razmi, Mir Saman Pishvaee, and Masoud Rabbani, "A sustainable second-generation biodiesel supply chain network design problem under risk," *Omega* 66 (2017): 258-277.

31 George G. Zaimes, Nemi Vora, Shauhrat S. Chopra, Amy E. Landis, and Vikas Khanna, "Design of sustainable biofuel processes and supply chains: challenges and opportunities," *Processes* 3, no. 3 (2015): 634-663.

32 A. Eisentraut, "Sustainable Production of Second-Generation Biofuels: Potential and Perspectives in Major Economies and Developing Countries", IEA Energy Papers, No. 2010/01, OECD Publishing, Paris. 2010

33 A. Karmakar, S. Karmakar, and S. Mukherjee, "Properties of various plants and animals feedstocks for biodiesel production," *Bioresource technology* 101, no. 19 (2010): 7201-7210.

34 Food Safety and Standards Authority of India (FSSAI), "Repurposed Used Cooking Oil (RUCO) Booklet."

Endnotes

Images used in this paper are from Getty Images/Busà Photography.

OBSERVER RESEARCH FOUNDATION

Ideas . Forums . Leadership . Impact

20, Rouse Avenue Institutional Area,
New Delhi - 110 002, INDIA
Ph. : +91-11-35332000. **Fax :** +91-11-35332005
E-mail: contactus@orfonline.org
Website: www.orfonline.org