

The potential for advanced biofuels in India: Assessing the availability of feedstocks and deployable technologies

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Date: December 2019

Keywords: Biofuels, Low-carbon fuels

Summary

Here we analyze the potential for India to meet the proposed biofuel targets of 20% ethanol blending in gasoline and 5% biodiesel blending in diesel by 2030, as established in the recent National Policy on Biofuels. We estimate that with strong policy support, the maximum supply of ethanol replacements would total 8.1% of projected gasoline demand on a volumetric basis, with 5.6% coming from cellulosic ethanol, and waste-derived diesel replacements would total approximately 3.8% of diesel supply. Thus the overall potential of advanced biofuels to meet India's fuel targets falls short of the 2030 targets, and without strong incentives to support advanced biofuel conversion projects, the delivered volumes could be even lower.

Table 1 provides an overview of the theoretical feedstock potential from each fuel source used in this analysis and the projected blend level in 2030, after taking account of facility deployment rates. The largest potential sources of biofuel feedstocks available in 2030 to supply ethanol and diesel substitutes are crop residues and used cooking oil, respectively.

The primary barrier to advanced biofuel deployment in India by 2030 is the pace of the industry's commercialization. For advanced biorefineries utilizing cellulosic feedstocks such as crop residues or municipal solid waste (MSW), there are substantial uncertainties with respect to the necessary time to design and construct a commercial-scale biorefinery. For that reason, we also incorporate a learning curve-based deployment

rate for advanced biorefineries into the analysis. This assumption causes India's estimated production in 2030 to fall short of its theoretical potential based on biomass availability. While there is enough biomass to meet India's 2030 targets, the industry will likely take longer than a decade to scale up, even under an optimistic outlook for investment.

Nonetheless, we also find that there is sufficient feedstock to meet the target over the longer-term beyond 2030, though there remain substantial cost and supply chain constraints. If meeting the targeted blending levels is desired, India must provide both strong financial incentives for the advanced biofuel industry and a stable policy environment to mitigate investment risks and sustain the industry's long-term

Table 1: Overview of theoretical and projected 2030 advanced biofuel production in India relative to blending targets

	Feedstock	2030 Blending target (%)	Blend level at Theoretical potential (%)	Estimated 2030 blend level at techno-economic potential (%)
Cellulosic ethanol	Crop residues, forest residues, energy crops	20%	100%	5.6%
Conventional ethanol	Molasses		3.0%	3.0%
Diesel-substitutes (Fischer-Tropsch diesel and biodiesel)	MSW, used cooking oil	5%	14.3%	3.8%

Acknowledgments: Anup Bandivadekar, Shikha Rokadiya, and Yuanrong Zhou

growth. Improved incentives for fuels made from wastes and residues could include higher viability gap funding or direct production incentives. These changes would not only improve the financial prospects for advanced biofuels, but also increase policy certainty by making the blending target more achievable.

Introduction

India's 2018 National Policy on Biofuels sets ambitious biofuel blending targets and aims to source biofuels only from sustainable feedstocks. Such feedstocks are primarily defined as non-food feedstocks that do not threaten food security. Specifically, India intends to build upon its previous ethanol mandate by expanding ethanol blending to 20% by 2030; the policy also adds a supplemental biodiesel mandate of 5%.

In the past, India did not meet its biofuel blending mandates. For example, the target set in 2009 of 20% ethanol blending by 2017 was missed almost entirely, as the blend rate reached only 1.9% that year.¹ Similarly, India failed to meet its 2010 target for 20% biodiesel blending, with a blend rate of less than 0.1% in 2017.² The decision to exclude easier-to-convert, first-generation feedstocks from the 2018 policy (molasses excepted) is laudable from an environmental standpoint, but also will likely necessitate the development of a large, domestic advanced biofuels industry within the next decade. If India's new biofuels program follows the same path as the first few attempts, the country could fall even further from meeting

its emissions reduction commitments under the Paris Agreement.

While many countries produce biofuels from first-generation food-based feedstocks such as corn, soybeans, or palm oil, these feedstocks occupy valuable cropland and generate indirect land-use change (ILUC). Additionally, their diversion to fuel may foster food insecurity. India, meanwhile, has identified an abundance of sources for advanced biofuels; these are by-products, wastes, and residues that are available domestically and can be used for energy without disrupting food markets. These sources will also generate steeper emissions reductions than many first-generation biofuels. Still, many by-products, wastes, and residues have existing uses, and diverting them may undermine the benefits of their use for fuel.³ For that reason, it is important to also evaluate the degree to which these materials are "sustainably available"—meaning that they can be diverted for fuel production without adverse effects.⁴

Unlike starchy grains or oilseeds, many by-products, wastes, and residues require additional processing, or a different conversion process entirely, in order to be converted into biofuel. These materials can be produced by technologies such as gasification combined with Fischer-Tropsch synthesis, cellulosic ethanol, and biogas from anaerobic digestion, and they are collectively referred to as "advanced biofuels." In most cases, advanced

biorefineries are more expensive to construct and operate than their first-generation counterparts, and the advanced biofuel industry has struggled to scale up over the last decade. Despite preferential policy support in the United States and the European Union, advanced biofuels still comprise a small fraction of the total biofuel production in those regions. If it is to successfully grow its domestic advanced biofuel industry, India must address the hurdles faced by advanced biofuel manufacturers by implementing a robust set of incentives.

This study assesses the feasibility of achieving India's 2030 biofuel targets by estimating potential advanced biofuel production from a feedstock-availability and infrastructure-deployment perspective. We draw upon activity data for relevant economic sectors to estimate both the total feedstock potential eligible for India's biofuel policy and the share of that feedstock that is sustainably available. We also evaluate the technological potential for converting each feedstock, to estimate the quantity of liquid biofuels that could be produced by 2030; this analysis considers both the conversion yield for each process and the deployment rates for different advanced technologies. Finally, the study evaluates the costs of supporting advanced biofuels and the methods of policy support that would encourage the commercialization of the industry.

Availability of sustainable feedstocks

AGRICULTURAL RESIDUES

Agricultural residues are the leaves and stalks of plants left over after harvesting. They are generally considered to be a sustainable alternative to food crops purpose-grown for biofuels, as they can be collected without expanding cropland. Only the quantity of agricultural residues

1 U.S. Department of Agriculture, "India Biofuels Annual 2018," (2018), https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_New%20Delhi_India_7-10-2018.pdf

2 Planning Commission, Government of India, "Report of the Committee on Development of Bio-fuel," (2003), http://planningcommission.nic.in/reports/genrep/cmtt_bio.pdf

3 Stephanie Searle, Nikita Pavlenko, Sammy El Takriti, Kristine Bithere, *Potential greenhouse gas savings from a 2030 greenhouse gas reduction target with indirect emissions accounting for the European Union*, (ICCT: Washington, DC, 2017), <https://www.theicct.org/publications/potential-greenhouse-gas-savings-2030-greenhouse-gas-reduction-target-indirect>.

4 Pete Harrison, Chris Malins, Stephanie Searle, Anil Baral, David Turley, Lucy Hopwood, *Wasted: Europe's Untapped Resource*, (ICCT: Washington, DC, 2014), <https://www.theicct.org/publications/wasted-europes-untapped-resource>

that is available without compromising soil quality or diverting from other existing uses is generally considered sustainably available.⁵ Figure 1 illustrates our approach to determining the amount of crop residue available for biofuel production. The first step is to estimate total residue production for each crop, and then subtract the amount that needs to remain in the field to protect soil quality. After that, we subtract the amount already collected and used in other industries. If any quantity remains, we consider this to be sustainably available for biofuel production.

To begin, we collected data on India’s historical crop production from the United Nations’ Food and Agricultural Organization (FAO).⁶ We then extrapolated trends in total crop production for the period 2000–2014 out to 2030 for each type of crop; for most crops, total production increased. Next we selected all crops that comprised more than 1% of total food production in India and, finally, applied crop-specific residue production ratios from a previous feed-stock-availability assessment.⁷ Table 2 illustrates the projected growth in crop residue production in India from

Table 2: Projected crop residue production in India, 2010 to 2030

	Crop residue production (million tonnes)
2010	556
2020	708
2030	868

5 Rattan Lal, “Soil Carbon Sequestration: SOLOW Background Thematic Report—T404B,” (Food and Agriculture Organization, n.d.), http://www.fao.org/fileadmin/templates/solaw/files/thematic_reports/TR_04b_web.pdf

6 FAOStat, “Food and Agriculture Data,” accessed April 2019, <http://www.fao.org/faostat/>

7 Stephanie Y. Searle and Christopher J. Malins, “Waste and Residue Availability for Advanced Biofuel Production in EU Member States,” *Biomass and Bioenergy* 89 (June 2016): 2–10. <https://doi.org/10.1016/j.biombioe.2016.01.008>.

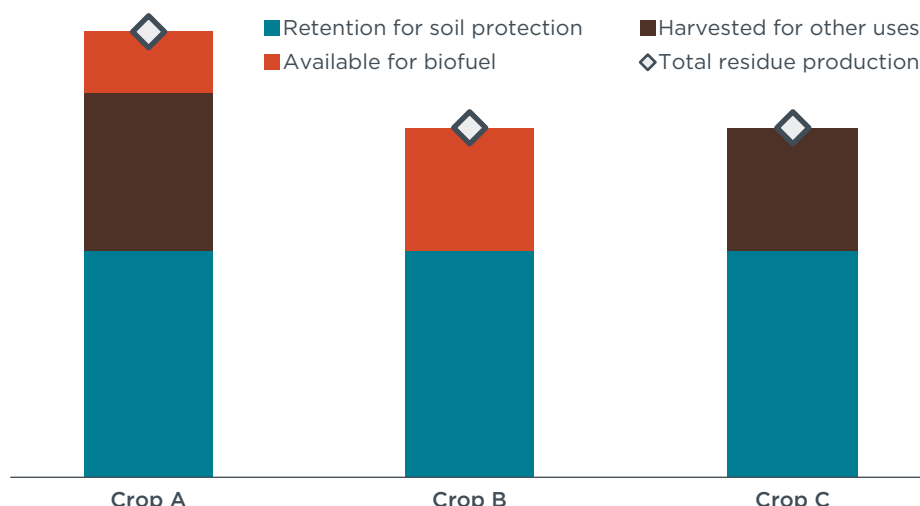


Figure 1: Schematic of our approach to determining the amount of crop residue available for biofuel production.

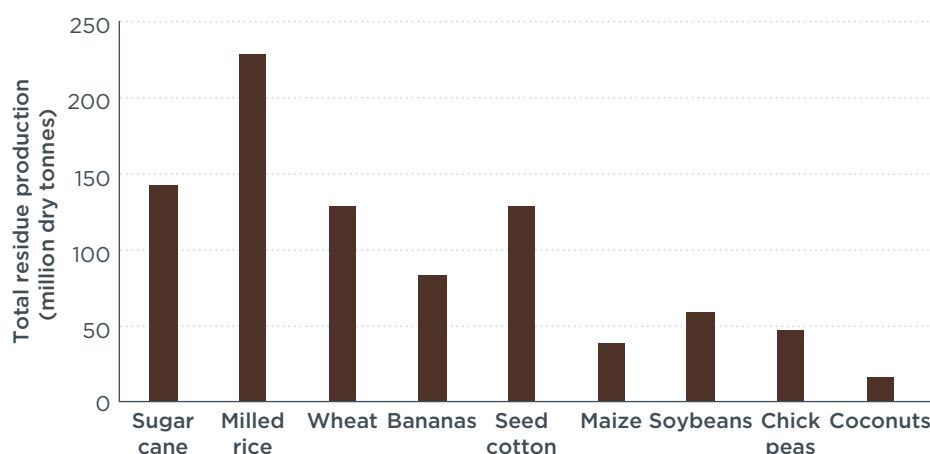


Figure 2: Projected total residue production in million dry tonnes for major crops in India in 2030, in descending order by total crop production in 2014. Note: Potatoes, onions, tomatoes, mangoes, and eggplants were assumed to have zero recoverable residues.

2010 to 2030. Additionally, Figure 2 breaks down total projected 2030 residue production by crop type in million dry tonnes per year. Note that crops are shown in descending order by total fresh-weight crop production in India in 2014.

These projected quantities of crop residue production are comparable to near-term estimates of crop production in India cited within the literature. For example, data assembled from India’s Ministry of Statistics & Program Implementation (MOSPI) indicates that India generated approximately 521 tonnes of crop

residues in 2014.⁸ Additionally, our 2030 projections are similar to those developed by Purohit and Chaturvedi (2018), who estimated crop residue production of 876 million tonnes by 2030 using a similar approach.⁹ Purohit and Dhar (2018) estimated

8 Saroj Devi, Charu Gupta, Shankar Lal Jat, and M.S. Parmar, “Crop Residue Recycling for Economic and Environmental Sustainability: The Case of India,” *Open Agriculture* 2, no. 1, (2017), <https://doi.org/10.1515/opag-2017-0053>.

9 Pallav Purohit and Vaibhav Chaturvedi, “Biomass Pellets for Power Generation in India: A Techno-Economic Evaluation,” *Environmental Science and Pollution Research* 25, no. 29 (2018): 29614–32. <https://doi.org/10.1007/s11356-018-2960-8>.

887 million tonnes of crop residues in 2030, using similar assumptions to Purohit and Chaturvedi but including an additional 9 million tonnes of coconut residues.¹⁰ The gaps between these estimates and the projections in Table 2 are largely attributable to small differences in assumptions about residue production ratios and future agricultural production.

Soil carbon impact of agricultural residue diversion

Note that some amount of crop residues should be left in the field to reduce erosion and support the accumulation of soil organic carbon (SOC).¹¹ Without this practice, soil fertility will gradually decline and long-term crop yields will be reduced. If this happens, the value of a biofuel production policy in promoting long-term energy independence, trade balance, and food security could reasonably be questioned. According to the Harmonized World Soil Database, India's average SOC stocks are 31 tonnes of carbon per hectare (tC/ha), and this is low compared to the global average (75 tC/ha) and compared to other regions such as the United States (59 tC/ha) and the non-Scandinavian European Union (80 tC/ha).¹² Further, India loses approximately 1 mm of topsoil annually.¹³ We estimate that a high level of residue retention in fields is neces-

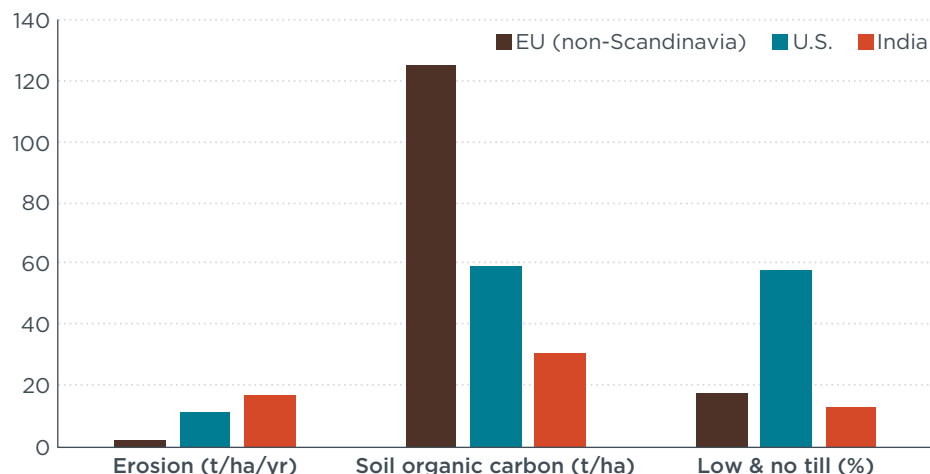


Figure 3: Comparison of erosion rates, soil organic carbon stocks, and rate of zero and reduced tillage in the European Union, United States, and India.

sary to prevent further unsustainable losses of soil carbon and depletion of soil health. The wider adoption of low or no-tillage agricultural practices would also help to maintain soil quality in India, and reduced tillage would help to mitigate soil erosion while improving moisture and nutrient retention. However, as of 2016, only 1.5 million hectares of agricultural land were managed using low- or no-till cropping systems.¹⁴ These systems are very uncommon in India, and apply to only approximately 1% of total cropped land.¹⁵ Figure 3 compares the erosion rates, soil organic carbon stocks, and rates of zero and reduced tillage across the European Union, United States, and India. By all three metrics, India is more vulnerable to soil fertility loss than the other regions.

Instead of retaining crop residues in place to enhance or maintain soil quality, India already harvests and utilizes unsustainable quantities of them for livestock feed,

bedding, and fuel.¹⁶ Based on data assembled from MOSPI, India generated approximately 521 tonnes of crop residues in 2014, of which 140 tonnes, roughly 26%, were considered “surplus.” This means that 140 tonnes were left on the field in lieu of being harvested for another use.¹⁷ Of the total crop residue not left on the field, the majority, 74%, was used for animal feed, livestock rearing, and domestic heating. Additionally, 92 million tonnes of the surplus crop residues were combusted on-site.¹⁸ Crop residue burning is typically practiced to facilitate faster replanting. Alternative management mechanisms, such as the Happy Seeder, a machine that chops and spreads rice residue while planting wheat seed without tillage, may be either too expensive or labor-intensive.¹⁹ However, crop residue burning not only leads to further soil deterioration, but its combustion also

10 Pallav Purohit and Subash Dhar, “Lignocellulosic Biofuels in India: Current Perspectives, Potential Issues and Future Prospects.” *AIMS Energy* 6, no. 3 (2018): 453–86. <https://doi.org/10.3934/energy.2018.3.453>.

11 Stephanie Searle, Kristine Bitnere, *Review of the impact of crop residue management on soil organic carbon in Europe*, (ICCT: Washington, DC, 2017), <https://theicct.org/publications/impact-of-crop-residue-mgmt-EU>.

12 Harmonized World Soil Database, “Soil Carbon Stocks,” accessed April 2019, <http://web.archive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/>.

13 “India losing 5,334 million tonnes of soil annually due to erosion: Govt,” *The Hindu*, November 26, 2010, <http://www.thehindu.com/sci-tech/agriculture/India-losing-5334-million-tonnes-of-soil-annually-due-to-erosion-Govt/article1571073.ece>.

14 Amir Kassam, Theodor Friedrich, and Rolf Derpsch, “Global Spread of Conservation Agriculture,” *International Journal of Environmental Studies* 76, no. 1 (2019): 29–51. <https://doi.org/10.1080/00207233.2018.1494927>.

15 Government of India, Ministry of Agriculture and Farmers’ Welfare, “Annual Report: 2017–2018,” (2018), <http://agricoop.nic.in/sites/default/files/Krishi%20AR%202017-18-1%20for%20web.pdf>.

16 N.H. Ravindranath, et al., “Assessment of Sustainable Non-Plantation Biomass Resources Potential for Energy in India,” *Biomass and Bioenergy* 29, no. 3 (2005): 178–90. <https://doi.org/10.1016/j.biombioe.2005.03.005>.

17 Devi, Gupta, Lal Jat, and Parmar, “Crop Residue Recycling.” P. 490

18 Ibid.

19 Government of India, Ministry of Agriculture, Natural Resource Management Division, “National Policy for Management of Crop Residues (NPMCR),” (2014), http://agricoop.nic.in/sites/default/files/NPMCR_1.pdf.

emits pollutants such as particulate matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs), all of which contribute to air pollution.²⁰

Using a model developed in Searle and Malins (2016), we estimated the fraction of agricultural residues that need to be left in the field to preserve soil health. By putting India-specific erosion rates, tillage practices, and soil carbon concentration into the linear model, we found that the average necessary amount of residues left in the field is 6.2 t/ha. If India moves to zero-till on half its crop area and low-till on the other half by 2030, this estimate drops to 4.8 t/ha. Using the optimistic 4.8 t/ha estimate, a minimum of 613 million tonnes, 71% of the total amount of crop residues produced, needs to be left in the field to optimally protect soil quality. The remaining 256 million tonnes is lower than the 381 million tonnes of crop residues already harvested for existing uses such as fodder and livestock bedding, according to Devi et al. (2017). Thus, overall, the additional pressure on existing agricultural fields to supply biomass for biofuel production would likely only exacerbate ongoing soil carbon losses. However, as shown in Figure 4, we project that in 2030, there will be 71 million tonnes of agricultural residues available for biofuel production without impacting soil carbon and other existing uses. These mainly come from sugarcane, banana, and coconut production.

FORESTRY RESIDUES

To estimate the amount of sustainably available forestry residues, we utilized data on wood harvests in India from the United Nations' FAO

20 Subramanian Bhuvaneshwari, Hiroshan Hettiarachchi, and Jay Meegoda, "Crop Residue Burning in India: Policy Challenges and Potential Solutions," *International Journal of Environmental Research and Public Health* 16, no. 5 (2019): 832. <https://doi.org/10.3390/ijerph16050832>.

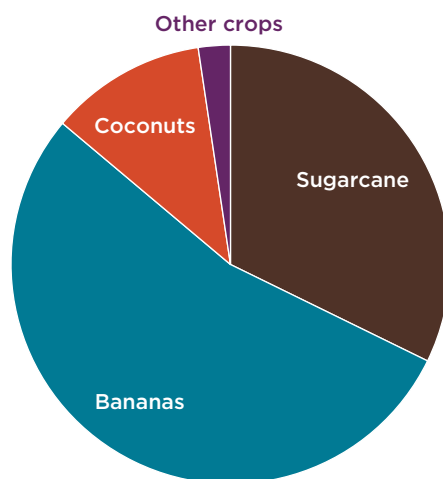


Figure 4: Breakdown of sustainably available crop residues in India in 2030 by crop type.

and assumed forestry harvests remain constant from 2015 to 2030. Based on FAO's estimate of roughly 50 million cubic meters of roundwood production in India and using the residue production ratios from Searle and Malins (2016), we estimate that approximately 10.5 million tonnes of forest residues, including small branches and treetops typically left on-site, would be available. This assumption is notably lower than that used by Purohit and Chaturvedi (2018), which was MOSPI's 2004 estimate of 104 million tonnes of forestry residues. Though the methodology behind MOSPI's 2004 estimate is not available, it is likely that part of the wide divergence between the two estimates is due to the inclusion of other categories of materials in the definition of "forestry residues" in MOSPI (2004).

From the 10.5 million tonnes of forest residue availability, we first assumed that 50% of forestry residues should be left on-site to reduce erosion and return carbon and nutrients to the soil. This is similar to the assumption for agricultural residues. There is less data available on the amount of forestry residues necessary to protect soil quality in various contexts than there is about agricultural residues,

and hence the simplified assumption of 50% retention. From there, we assumed that half of harvestable forestry residues are already utilized as fuel wood and for other purposes and thus are not available for biofuel. Again, this simplified assumption arises from a lack of data on other current uses of forestry residues. Given the general pressure on natural resources in India, this approach likely underestimates existing uses and overestimates sustainable forestry residue availability. Using this approach, we estimate that 2.6 million dry tonnes of forestry residues could be available for biofuel in 2030.

MUNICIPAL SOLID WASTE (MSW)

The diversion of MSW to biofuel production could be particularly impactful in India, as biofuel producers can utilize existing MSW collection networks. The majority of MSW in India is disposed of either in the open or in minimally managed landfills without on-site methane capture and recovery systems. Therefore, its diversion for fuel production would also mitigate methane emissions from waste management, a major contributor to India's greenhouse gas emissions.²¹ The EPA's Waste-Reduction Model (WARM) estimates that for a landfill without methane recovery in a wet climate, each tonne of landfill waste generates approximately 1.3 tonnes of CO₂-equivalent emissions, primarily from fugitive methane.²²

Using data from the Indian Ministry of New and Renewable Energy (MNRE),

21 R.K. Kashyap, Parivesh Chugh, and T. Nandakumar, "Opportunities & Challenges in Capturing Landfill Gas from an Active and Un-Scientifically Managed Land Fill Site - A Case Study," *Procedia Environmental Sciences* 35 (2016): 348-67. <https://doi.org/10.1016/j.proenv.2016.07.015>.

22 U.S. Environmental Protection Agency, "Waste-Reduction Model (WARM) Version 14," <https://www.epa.gov/warm/versions-waste-reduction-model-warm#WARM%20Tool%20V14>.

we estimated that India generates approximately 52 million tonnes of MSW annually, of which 43 million tonnes are collected.²³ Within that waste stream, more than 65% of the material is organic, and thus a usable biofuel feedstock for several production pathways.²⁴ India's MSW generation could increase substantially over the next decade, as both its urbanized population and its per-capita waste-generation rate increase. Taking these trends into account, India's per capita waste-generation rate in urban areas is expected to increase from 0.34 kg/day to 0.7 kg/day by 2025, and this will result in a substantial increase in MSW.²⁵ MNRE estimated that total MSW generation will reach 165 million tonnes by 2031, relatively consistent with a World Bank projection of 137 million tonnes in 2025.²⁶

Although MNRE estimated that around 20% of MSW is not collected, improving collection rates would likely be difficult. Holding collection rates constant, we estimate that India would be able to collect 135 million tonnes of the projected 165 million tonnes generated in 2031. Note that an alternative strategy for harvesting bioenergy from MSW is to collect methane from landfills, and this is currently practiced to a great extent in the United States.²⁷ Most landfill gas collected in the United States is combusted on-site for electric-

ity; however, an increasing volume is conditioned, compressed, and then injected into the natural gas grid, where it is used in the transport sector in natural gas vehicles.²⁸ However, the vast majority of landfills in India have not installed landfill gas recovery systems.²⁹

DEDICATED ENERGY CROPS

Energy crops, generally non-food crops grown on marginal lands, are a potentially significant source of low-carbon biofuel in India and they have low ILUC emissions.³⁰ Depending on where and how they are cultivated, energy crops can be grown without creating pressure on the food market. Instead of competing with food crops for limited areas of cropland, these crops are instead able to thrive on lower grade, marginal tracts of land. Previously, India supported the deployment of jatropha, an oilseed crop capable of being grown on degraded lands unsuitable for conventional agriculture.³¹ The Planning Commission of India originally proposed a 20% blending mandate for jatropha-derived biodiesel by 2010.³²

Despite its initial promise, the expansion of jatropha failed to live up to its potential for a variety of reasons, particularly its low yields when cultivated on marginal land relative to success during initial trials.³³

While jatropha has thus far fallen short of expectations, lignocellulosic or herbaceous energy crops are promising. India's Draft National Policy on Biofuels mentions cellulosic energy crops such as switchgrass and arundo donax. These crops may offer better potential as they can often survive under adverse conditions with little labor input and can support biodiversity and soil carbon sequestration.³⁴ With India's growing population, all currently utilized agricultural land will likely need to be maintained or expanded by 2030 to supply sufficient food. India does have some land area that is not currently utilized and that could be appropriate for growing energy crops. Some of this land falls under the broad category of "wastelands" in India, which also includes glaciers, deserts, and bare rock.

To assess the potential land available for energy cropping in India, we utilized spatial mapping data collected by India's Department of Land Resources for its Wasteland Atlas.³⁵ First, we narrowed down the total wasteland availability to focus on land categories capable of supporting energy cropping without significant

23 Government of India, Ministry of New and Renewable Energy, "Power Generation from Municipal Solid Waste," (2016), http://164.100.47.193/Isscommittee/Energy/16_Energy_20.pdf.

24 Ibid.

25 Daniel Hoornweg and Perinaz Bhada-Tata, "What a Waste: A Global Review of Solid Waste Management," (World Bank, March 2012), <http://documents.worldbank.org/curated/en/302341468126264791/pdf/68135REVISED-What-a-Waste-2012-Final-updated.pdf>.

26 Government of India, "Power Generation from Municipal Solid Waste."

27 U.S. Environmental Protection Agency, "Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks: 2nd Edition," (2002).

28 U.S. Environmental Protection Agency, "Proposed Volume Standards for 2018, and the Biomass-Based Diesel Volume for 2019," (2017), <https://www.epa.gov/renewable-fuel-standard-program/proposed-volume-standards-2018-and-biomass-based-diesel-volume-2019>.

29 Chander Kumar Singh, Anand Kumar, Soumendu Shekhar Roy, "Quantitative Analysis of the Methane Gas Emissions from Municipal Solid Waste in India," *Scientific Reports* 8, no: 1 (2018): 2913. <https://doi.org/10.1038/s41598-018-21326-9>.

30 Nikita Pavlenko, Stephanie Searle, A *Comparison of induced land-use change emissions estimates from energy crops*, (ICCT: Washington, DC, 2018), <https://www.theicct.org/publications/comparison-iluc-emissions-estimates-energy-crops>.

31 Kripal Singh, Bajrang Singh, Sanjeet K. Verma, and D.D. Patra, "Jatropha Curcas: A Ten Year Story from Hope to Despair." *Renewable and Sustainable Energy Reviews* 35 (July 2014): 356-60. <https://doi.org/10.1016/j.rser.2014.04.033>.

32 Government of India, Planning Commission, "Report of the Committee on Development of Bio-fuel."

33 Lisa Axelsson, et al., "Performance of Jatropha Biodiesel Production and Its Environmental and Socio-Economic Impacts - A Case Study in Southern India," *World Renewable Energy Congress 2011 - Sweden*, 2470-77. <https://doi.org/10.3384/eqp110572470>.

34 Stephanie Searle, Chelsea Petrenko, Ella Baz, Chris Malins, *Crops of the biofrontier: In search of opportunities for sustainable energy cropping*, (ICCT: Washington, DC, 2016), <https://theicct.org/sites/default/files/publications/Energy%20Crop%20White%20Paper%20vF.pdf>.

35 India Department of Land Resources, "Wastelands Atlas of India 2011," (2011), <https://dolr.gov.in/documents/wasteland-atlas-of-india>.

environmental damage.³⁶ From there, we extrapolated the rate of change in area for three categories over the period from 2005–2008 (the years provided in the dataset) to 2030; this is to estimate land availability in 2030. Using this approach, we estimate that the quantity of available wasteland with open dense scrub will remain fairly constant through 2030, while the available quantity of other land categories, degraded pastures and shifting cultivation areas, will decline. The total defined wasteland area in India declined from 2005 to 2008 and the Department of Land Resources determined that much of it was due to the expansion of cropland onto wasteland. In total, we project that approximately 16 million hectares of the selected land categories could be considered sustainably available in 2030, down from 19.7 million hectares in 2008.

The amount of a given land category that is sustainably available is not necessarily sufficient to justify its use for energy cropping. It is conceivable that much of this area is inaccessible or has other barriers to use. We therefore applied a conservative assumption that 50% of this land area could be cultivated. While many studies highlight the high yields that some types of energy crops can achieve under ideal conditions, under most circumstances, real-world yields are much more modest.³⁷ Given the decline in total wasteland area in India observed from 2005 to 2008, it is likely that the best-quality wasteland has already been converted to cropland, and that this trend will continue to 2030. This is consistent with our understanding that virtually all high-yielding land in

India is already utilized for agriculture and justifies utilizing a lower-end estimate for energy cropping yields on this land.

A recent meta-analysis of energy crop cultivation suggested that the expected yields on marginal lands may be much lower than those achieved on test plots. The reported yields for switchgrass and eucalyptus, for example, range from 8 to 13 and 14 to 51 dry tonnes, respectively, per hectare on agricultural land, but only 3 to 9 and 0 to 17 dry tonnes per hectare on marginal land.³⁸ We estimated that the average yields on wasteland will be similar to those observed at the low-range for energy crops on marginal lands in warmer climates—roughly 5 dry tonnes per hectare. From this, we estimate a maximum of 39 million tonnes of biomass could be produced from cellulosic energy crops grown on wastelands in India in 2030. However, this estimate is uncertain, due to the wide variation in potential costs and supply chain difficulties associated with agriculture in various wasteland areas.

USED COOKING OIL (UCO)

Both UCO and inedible animal fats can be converted into biofuel through a variety of processes that have already been demonstrated at commercial scales, including conversion into drop-in renewable diesel. Generally, as long as these waste products are not diverted from existing uses, they can be utilized by the biofuel industry with good climate performance.³⁹ However, it is estimated that India generates vast quantities of UCO that are improperly reused in the restaurant industry and thus pose

health risks to consumers.⁴⁰ For that reason, in 2018, the Food Safety and Standards Authority (FSSAI) of India introduced a new requirement that food business operators monitor their oil quality and also set up a program to facilitate the collection and fuel conversion of UCO.⁴¹ Of the 23 million tonnes of cooking oil consumed annually in India, FSSAI estimates that 30%, 6.9 million tonnes, is improperly disposed of and thus available. Of that total, the agency projects that 2.79 million tonnes would be available for biofuel production.⁴² Notably, the potential for household UCO collection (15%) is estimated to be substantially lower than that from centralized sources such as food processors. That is because it is much more difficult to collect.

As of 2018, India's biodiesel industry utilizes a combination of 168,000 tonnes of inedible industrial vegetable oils, UCO, and animal fats to generate 83 million liters of biodiesel.⁴³ Assuming that continued population growth causes proportional growth in cooking oil consumption, and that FSSAI's assumptions of availability and collection rates stay constant through 2030, we estimate that roughly 3.1 million tonnes of UCO would be available in 2030.

BIOMETHANE FROM LIVESTOCK MANURE

Depending on management practices, the disposal of livestock manure at farms can generate methane emissions and contaminate air and water locally. Alternatively, that methane may be cleaned up for use as bio-compressed natural gas (CNG) in vehicles or combusted on-site for

36 The categories we include are: land with dense scrub, land with open scrub, land affected by salinity/alkalinity-moderate, shifting cultivation area-abandoned, degraded pastures/grazing land, mining wastelands, and industrial wastelands.

37 Stephanie Y. Searle and Christopher J. Malins, "Will Energy Crop Yields Meet Expectations?" *Biomass and Bioenergy* 65 (June 2014): 3–12. <https://doi.org/10.1016/j.biombioe.2014.01.001>.

38 Ibid.

39 Chris Malins, *Waste Not, Want Not*, (ICCT: Washington, DC, 2017). https://www.theicct.org/sites/default/files/publications/Waste-not-want-not_Cerulogy-Consultant-Report_August2017_vF.pdf.

40 Food Safety and Standards Authority of India (FSSAI), "Background Note on Used Cooking Oil," (2018), <https://fssai.gov.in/ruco/background-note.php>.

41 FSSAI, "About Repurpose Used Cooking Oil (RUCO)," (n.d.), <https://fssai.gov.in/ruco/>.

42 FSSAI, "Background Note."

43 Ibid.

electricity. While CNG does not displace gasoline or diesel, as it must be used in a CNG-compatible vehicle, we evaluate its potential in this study due to its GHG-reduction potential. Moreover, India's Ministry of Petroleum and Natural Gas recently proposed to build 10,000 additional CNG fueling stations nationwide over the next decade, and aims to further expand the domestic CNG vehicle fleet up from 3 million cars.⁴⁴

India produces very large amounts of livestock manure from its high cattle and buffalo populations—there are roughly 300 million bovine as of its most recent livestock census.⁴⁵ Generally, bovine manure has some of the highest potential methane emissions and is therefore most suitable for alternative treatment. Ravindranath et al. (2005) estimated that 730 million tonnes of manure would be produced per year in 2010.⁴⁶ Using the most recent livestock census data and Intergovernmental Panel on Climate Change (IPCC) factors for manure production in conjunction with the methodology used by Ravindranath et al. (2005), we estimated that cattle in India generated approximately 745 million tonnes of manure (wet weight) in 2012.⁴⁷ As the bovine population of India has been relatively stable since 1997, it is difficult to project the change, if any, to 2030; therefore, we utilized the

2012 bovine population data here to estimate livestock manure potential.⁴⁸

It is somewhat uncertain what proportion of this bovine manure is collectable and could be available for biofuel. Livestock dung produced in sheds or in intensive cattle lots may be easily collectable, but collecting dung from pastures would be far more labor intensive. Some dung is collected and utilized as fuel for cooking and other energy needs, while some, likely a smaller portion, is utilized for ritual purposes. Ravindranath et al. (2005) estimated that 60% of cattle dung and 80% of buffalo dung can be collected, and that 40% of the collectable amount is already utilized as fuel. Another source estimated that 70% of cow dung is currently used for fuel.⁴⁹ However, neither of these sources provided any justification or references for these estimates. The IPCC uses a more conservative set of estimates which suggests that between 51% and 55% of manure is burned for energy, depending on the animal category.⁵⁰ In the absence of any reliable data on dung collection and usage, we provide only an indicative estimate of sustainable availability for biofuel. Using IPCC assumptions for the share of manure burning by cattle category in conjunction with population data from India's livestock census, we estimated that 398 million tonnes of manure are currently being combusted, and then assumed that this quantity is sustainably available for bioenergy production. Using IPCC emission factors and estimates of manure burning for energy, we estimate that if the entire 398 million tonnes of bovine manure is used for anaerobic digestion, it

would yield approximately 7.7 billion m³ of methane (311 PJ).

While manure gasification at large, centralized facilities is theoretically feasible and has been proposed by some, it is much more economical and practical to process manure on-site at an anaerobic digester.⁵¹ Anaerobic digestion utilizes existing technologies and can operate at smaller, less-centralized scales than gasification. It is thus cheaper and more viable in the short-term. To generate biogas via anaerobic digestion at a farm, manure is collected and stored in a lagoon or enclosure and allowed to decompose in a low-oxygen environment over time. Instead of transporting the manure to a centralized facility, the manure can be processed on-site and the solids remaining after digestion is complete can be applied to soils. The methane-rich biogas produced from the digester is collected and can be combusted on-site for heat and energy, or conditioned and compressed for injection into the natural gas grid. An important barrier to the use of manure-derived biogas in the transportation sector is the spatial distribution of farms, which can vary in scale and be distant not only from each other, but also from the natural gas grid. Though anaerobic digestion can be viable at smaller scales than gasification, it still benefits from economies of scale, and the cost of grid interconnection to distribute manure-derived biomethane to the natural gas grid can be prohibitive.⁵²

For these reasons, biogas produced at farms—even those with sufficient scale to support an on-site

44 "10,000 CNG stations to be set up in 10 years: Pradhan," *India Times*, September 7, 2018, <https://economictimes.indiatimes.com/Industry/energy/oil-gas/10000-cng-stations-to-be-set-up-in-10-years-pradhan/articleshow/65713474.cms?from=mdr>

45 Ministry of Agriculture, Department of Animal Husbandry, Dairying and Fisheries, "19th Livestock Census – 2012 All India Report," (2012), http://dadf.gov.in/sites/default/files/Livestock%20%205_0.pdf

46 N.H. Ravindranath, et al., "Assessment of Sustainable Non-Plantation Biomass Resources."

47 Intergovernmental Panel on Climate Change, "Emissions from Livestock and Manure Management," In *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, (IPCC, Geneva, 2006), https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

48 Ministry of Agriculture, "19th Livestock Census."

49 Ministry of Animal Husbandry and Dairying, "Bi Products of Cattle—Organic Manure and Cow Urine – Medicines – Draught – Gas – Electricity" (n.d.), <http://dahd.nic.in/related-links/chapter-v-part-1>

50 Intergovernmental Panel on Climate Change, "Emissions from Livestock and Manure Management."

51 Prokash C. Roy, Amitava Datta, and Niladri Chakraborty, "Assessment of Cow Dung as a Supplementary Fuel in a Downdraft Biomass Gasifier," *Renewable Energy* 35, no. 2 (2010): 379–86, <https://doi.org/10.1016/j.renene.2009.03.022>

52 Chelsea Baldino, Nikita Pavlenko, Stephanie Searle, Adam Christensen, *The potential for low-carbon renewable methane as a transport fuel in France, Italy, and Spain*, (ICCT: Washington, DC, 2018), https://www.theicct.org/sites/default/files/publications/Biogas_potential_FR_IT_ES_2018109.pdf

Table 3: Sustainable biofuel feedstock potential in India in 2030

Feedstock	Crop residues	Forestry residues	Used cooking oil	Municipal solid waste	Energy crops	Livestock manure
Estimated total production in 2030 (million tonnes per year)	868	10.5	6.9	165	39	745
Sustainable availability in 2030 (million tonnes per year)	71	2.6	3.1	135	39	N/A ^a
Potential conversion pathways and yields (tonnes fuel per tonne feedstock)	Cellulosic ethanol (0.3) ^b	Cellulosic ethanol (0.3) ^b	Biodiesel (0.96) ^c	Gasification and Fischer-Tropsch to drop-in diesel (0.12) ^d	Cellulosic ethanol (0.3) ^e	Biogas (0.24 m ³ methane/kg volatile solids) ^f
Potential biofuel volumes in 2030 (million tonnes per year)	21.2	0.79	3.0	10.7	11.8	N/A
Potential biofuel volumes in 2030 (billion liters per year)	26.7	1.0	3.3	13.4	14.8	N/A

^a While theoretical biogas potential from livestock manure is estimated to be 7.7 billion m³ in 2030, the spatial distribution and cost constraints associated with supplying this to the natural gas grid for use in the transport sector likely significantly reduces its actual availability.

^b Nikita Pavlenko, N., Sammy El Takriti, Chris Malins, Stephanie Searle, *Beyond the biofrontier: Balancing competing uses of the biomass resource*, (ICCT: Washington, DC, 2016), <https://www.theicct.org/publications/beyond-biofrontier-balancing-competing-uses-biomass-resource>.

^c UK Department for Transport, Renewable Fuels Agency, "Default Input Values for the Renewable Fuel Transportation Obligation," (2010).

^d Nikita Pavlenko, et al., *Beyond the biofrontier*.

^e Daan Peters, Sacha Alberici, Jeff Passmore, Chris Malins, *How to advance cellulosic biofuels*, (Ecofys, 2015), <https://theicct.org/publications/how-advance-cellulosic-biofuels>

^f Intergovernmental Panel on Climate Change, "Emissions from Livestock and Manure Management."

digester—is more likely to be combusted into heat and electricity for those farms than exported for use in CNG vehicles. It is possible to condition and compress gas at each farm and then transport the bio-CNG to natural gas fueling stations or pipeline injection points, and this is being demonstrated in the United States.⁵³ However, this is generally only feasible if gas injection points are located near large, industrial-scale farms with economies of scale. As India has few CNG fueling stations, it is unlikely that many farms are located within viable trucking distance to an injection point. Building the long-distance pipelines necessary to collect CNG from farms in India would likely be highly expensive, and the added cost of pipeline connections for small-scale farms greatly impacts the cost of producing biogas from livestock

manure.⁵⁴ It is therefore unlikely that bio-CNG from cattle manure could be a significant source of transport fuels in India by 2030.

TOTAL SUSTAINABLE FEEDSTOCK POTENTIAL

Table 3 illustrates both the total production potential and the sustainably available portion for each of the feedstock categories assessed. Across categories, the quantity of sustainably available residues is much smaller than the production potential from each resource. Notably, only about one tenth of India's crop residue potential may be realized. This is due to high rates of soil erosion and existing demands for other uses. Together, the sustainably available quantity of crop residues, energy crops, and MSW could theoretically contribute approximately 55 billion liters of liquid fuels in 2030. Smaller quantities of forest residues and UCO would supply the remaining portion of low-impact feedstocks.

⁵⁴ Baldino et al., *The potential for low-carbon renewable methane*.

We compare these values to a business-as-usual scenario of energy consumption in India for 2030, assuming continued increases in transportation energy demand. The on-road sector is expected to consume approximately 117 million liters and 42 million liters of diesel and gasoline, respectively. Without taking into account the time lag for deploying new technologies, supply chains, and conversion facilities, the theoretical potential of 42.5 million liters of ethanol would be sufficient to displace approximately 100% of India's projected 2030 gasoline consumption, and the 16.7 million liters of diesel-replacements would displace 14% of its diesel consumption on a volumetric basis. On an energy-equivalent basis, these displace 62% and 14%, respectively.

India's potential for future biofuel production

Though India has proposed a favorable policy framework and financial support for advanced biofuels, developing a brand-new industry can still take substantial time. Advanced bio-refineries in both the United States

⁵³ Steven Verburg, "Dane County Leads Switch to Selling Gas Made by Manure and Garbage," *Wisconsin State Journal*, November 14, 2017, http://host.madison.com/wsj/news/local/govt-and-politics/dane-county-leads-switch-to-selling-gas-made-by-manure/article_f235b17c-1477-5269-9446-ffa173df4d80.html

and European Union have struggled to expand and achieve commercial scales of production, despite nearly a decade of policy support.⁵⁵ To date, the cellulosic biorefineries in operation are dwarfed by the scale of the first-generation biofuel industry. Many of the initial second-generation biorefineries are struggling due to a combination of delays and cost overruns, which are often attributed to pre-treatment difficulties.⁵⁶ Other delays are attributable to issues with siting, permitting, and construction.

In the United States, three commercial-scale facilities with a nameplate capacity of more than 40 million liters have begun operating within the last three years. However, two of the three have already been sold due to high production costs and technology difficulties.⁵⁷ Thus far, all have struggled to reach their nameplate capacities and required a lengthy “start-up” period in order to troubleshoot the production process.⁵⁸ During this time several ventures, including KiOR’s 13-million-gallon facility producing drop-in fuels from wood, failed. This was due to difficulties in reaching production targets and happened in spite of substantial policy incentives.⁵⁹ All of this and the numerous projects that failed prior

to commercialization suggest that in order to reach appreciable production volumes in India in 2030, long-term investments and the policies to support them should begin by 2020.

For those reasons, this analysis uses a conservative scenario for biofuel deployment that factors in the time delay associated with new refinery construction as well as a learning curve wherein the number of facilities expands over time linearly. This reflects a realistic scaling up of the industry, where new entrants begin constructing facilities in response to the proven success of the initial projects.

Previous analysis suggested that successfully supporting the advanced biofuel industry would require substantial government expenditure in the form of some combination of capital grants, production subsidies, and long-term procurement contracts.⁶⁰ This is due to the aforementioned factors and the extra cost of feedstock conversion compared to first-generation biofuels.⁶¹ Here we optimistically assume that the Indian government supports the construction of 10 new cellulosic ethanol plants starting in 2019, each with a nameplate capacity of 45,000 tonnes per year (approximately 56 million liters). This is similar in production capacity to fairly large commercial cellulosic ethanol plants in the United States and Brazil.⁶² The assumed facility is roughly comparable with the Numaligarh Refinery, a cellulosic ethanol facility recently proposed in Assam, with a scale of roughly 61.5 million liters annually (49,800 tonnes

of ethanol).⁶³ However, it is nearly twice the size of the pilot biorefinery project approved by the Indian government in 2018 to be constructed in Panipat, Haryana, with a capacity of 36.5 million liters per year.⁶⁴ Starting in 2020, we assume the Indian government supports, or private investment is obtained, for 10 new pyrolysis diesel or gasification plants each year, each with a capacity of 27,000 tonnes per year (roughly 33 million liters). The rate of facility deployment modeled here is far greater than that of the United States or European Union.⁶⁵ We thus consider this to be an optimistic, upper-end estimate for potential advanced biofuel deployment in India, and achieving this rate of facility deployment would require stronger and more stable policy support than in the United States and European Union.

We assume 3 years required for design and construction of new facilities and 5 years for ramping up to full production. While the industry is still too small in the United States and European Union to have standardized values for construction and start-up time, these values reflect the experiences of several pilot facilities.⁶⁶ We assume that once the first generation of facilities has fully ramped up, lessons learned can be applied to subsequent facilities, which would then fully ramp up production in 3 years. Table 4 summarizes our projected volumes of advanced biofuel

55 Nikita Pavlenko, “Failure to Launch: Why Advanced Biorefineries Are So Slow to Ramp Up Production,” The International Council on Clean Transportation staff blog, November 13, 2018, <https://www.theicct.org/blog/staff/failure-to-launch-biorefineries-slow-ramp-up>.

56 Ibid.

57 See <http://www.governorsbiofuelscoalition.org/duPont-to-sell-cellulosic-ethanol-plant-in-blow-to-biofuel/> and <http://www.biofuelsdigest.com/bdigest/2017/11/02/breaking-news-dupont-to-exit-cellulosic-ethanol-business/>.

58 See <http://www.biofuelsdigest.com/bdigest/2014/09/11/editors-sketchbook-dupont-cellulosic-ethanol-project-nevada-ia/> and <https://www.forbes.com/sites/rrapier/2016/04/26/a-cellulosic-ethanol-milestone/#4e711ebc1072>.

59 Jim Lane, “KiOR: The inside true story of a company gone wrong,” *BiofuelsDigest*, May 17, 2016, <http://www.biofuelsdigest.com/bdigest/2016/05/17/kior-the-inside-true-story-of-a-company-gone-wrong/>.

60 Peters *et al.*, *How to advance cellulosic biofuels*.

61 Ibid.

62 Renewable Fuel Standard Program: Standards for 2018 and Biomass-Based Diesel Volume for 2019, Proposed Rules, Fed. Reg. Vol. 82, No. 139 (July 21, 2017). <https://www.gpo.gov/fdsys/pkg/FR-2017-07-21/pdf/2017-14632.pdf>

63 Government of India, Ministry of Environment, Forest and Climate Change, “Environmental Clearance—Executive Summary,” (2015), http://environmentclearance.nic.in/writereaddata/Online/TOR/O_0_17_Dec_2015_1518377931E_xecutiveSummary-Bio-Refinery.pdf.

64 “Praj wins another 2nd gen biorefinery project,” Praj Industries, August 11, 2019, <https://www.praj.net/wp-content/uploads/2018/05/FY-2017-18-Q4-and-FY18-Results-Release.pdf>.

65 Kristine Bitner, Stephanie Searle, *Effective policy design for promoting investment in advanced alternative fuels*, (ICCT: Washington, DC, 2017), http://www.theicct.org/sites/default/files/publications/Advanced-alternative-fuels_ICCT-white-paper_21092017_vF.pdf.

66 Nikita Pavlenko, “Failure to launch.”

that could be produced over time in this scenario. The potential production of biodiesel from UCO would be additional to these volumes, because the conversion process has a comparatively more streamlined feedstock treatment process and it has already been demonstrated at commercial scale at numerous facilities worldwide.

We project that with aggressive investments and public support, cellulosic ethanol in India could scale up to nearly 2 million tonnes of production by 2030, exceeding a 5% volumetric blend rate. This falls far short of the 20% target, but would still require approximately 50 commercial-scale facilities—each producing 50 Mtonnes of ethanol, to begin operation within the next decade. We project that synthetic diesel production would ramp up more slowly, as the facilities are smaller. MSW-derived synthetic diesel deployment would increase to 1% of diesel demand on a volumetric basis by 2030.

The difference between the results presented here and the high estimates for second-generation biofuel deployment in studies such as Purohit and Dhar (2018) is primarily due to assumptions about the rate of facility deployment, as those studies use similar estimates of the quantity of available biomass.⁶⁷ Purohit and Dhar (2018) do not assume any lag time between the implementation of the policy and the construction and scaling up of the lignocellulosic biofuel industry. This is despite assuming the availability of a larger number of 500-million liter sized bio-refineries, which would be much larger than any existing facility worldwide. Further, Purohit and Dhar (2018) utilized an economy-wide carbon price. They modeled a \$13.9 USD per tonne of CO₂e carbon price that increases to \$200/tonne by 2045. This approach likely overstates the responsiveness of the transport

67 Purohit and Dhar, “Lignocellulosic Biofuels in India.”

Table 4: An optimistic scenario for advanced biofuel deployment in India. Volumes are in thousand tonnes of biofuel per year.

	2022	2025	2028	2030
Cellulosic ethanol	90	540	1,275	1,875
Cellulosic ethanol (blend %)	0.3%	1.7%	3.8%	5.6%
Gasification-FT diesel	0	216	594	891
Gasification-FT diesel (blend %)	0%	0.2%	0.6%	1.0 %

Table 5: Overview of projected 2030 biofuel production

	Feedstock	Theoretical potential based on feedstock availability (billion liters)	Projected 2030 volume (billion liters)
Cellulosic ethanol	Crop residues, forest residues, energy crops	42.5	2.2
Biodiesel	Used cooking oil	3.3	3.3
Fischer-Tropsch synthetic diesel	Municipal solid waste	13.4	1.1
Conventional ethanol	Molasses	—	1.3

sector to carbon pricing, particularly relative to the costs of GHG reductions in other sectors. Not only might this approach fail to take into account the pathway- and feedstock-specific levelized costs for certain pathways, it also only provides sufficient incentives to make lignocellulosic pathways cost-viable after 2030.⁶⁸

Results

After taking into account both feedstock availability and the deployment rate of advanced biorefineries for cellulosic feedstocks, we compare the total volume of advanced biofuels to India’s projected 2030 gasoline and diesel consumption. We find that in 2030, biofuels produced from sustainable feedstocks in India could displace up to 5.6% of gasoline and up to 3.8% of diesel on a volumetric basis. Additional quantities of ethanol

68 Nikita Pavlenko, Stephanie Searle, Chris Malins, Sammy El Takriti, *Development and analysis of a durable low-carbon fuel investment policy for California*, (ICCT, Washington, DC, 2016), https://theicct.org/sites/default/files/publications/California%20Contracts%20for%20Difference_white-paper_ICCT_102016.pdf.

are expected from existing, first-generation molasses production (3% of gasoline consumption) and flexible quantities of food waste, in years where the Ministry of Agriculture and Farmers’ Welfare determines that there is an oversupply.⁶⁹ We do not project that molasses availability will expand, and cap molasses ethanol production at 2018 levels. Due to the unpredictability of surplus grain production and concerns over the sustainability of food-derived biofuel feedstocks, we do not factor grain-derived ethanol into these projections. Further, the use of surplus grain may contribute to longer-term food insecurity by drawing down stocks and reducing the global supply of grains. Also, if this source of feedstock is implemented poorly, it may still contribute to ILUC.

Table 5 illustrates the theoretical fuel production potential for each category of fuel after factoring in the constraints to sustainable

69 Government of India, “Cabinet Approves National Policy on Biofuels–2018,” May 16, 2018, <http://pib.nic.in/newsite/PrintRelease.aspx?relid=179313>.

availability. The table also details the quantity of fuels that would be available in 2030 after accounting for facility deployment. It is critical to note here that the high technical potential for cellulosic ethanol, particularly from agricultural residues and energy crops, and MSW-based synthetic diesel is offset by steep constraints on the pace of deployment for these conversion pathways. In contrast, biodiesel production is a mature technology limited only by the supply of the feedstock.

Policy design to support advanced biofuels

Our projections rest on an assumption of substantial policy support. This is because the cost of alternative feedstocks and the high upfront expenses of advanced biorefineries make advanced biofuels more expensive than first-generation fuels made from food crops. The necessary pre-treatment to facilitate cellulosic feedstock conversion is an emerging technology that requires significant upfront expense. It also has an uncertain production timeline, at least in the short-to-medium term. Consequently, investors are often hesitant to invest in this technology, even with high nominal incentive values for advanced biofuels in some jurisdictions.⁷⁰

The most effective way to encourage advanced biofuels is direct financial support for early, commercial-scale projects in conjunction with long-term policy stability and incentives for production.⁷¹ The incentives can include direct grant funding or preferential loans to offset the high upfront capital costs for new facilities, which often dissuade investors.

Table 6: Overview of capital and production expenses for commercial-scale advanced biofuel production

	Facility size	Capital expenses per liter of capacity	Levelized cost
Cellulosic ethanol	40–114 million liters/year ^a	\$2.6–\$4.7 USD/liter ^a (186–336 INR/liter)	\$0.6–\$0.7 USD/liter ^b ; (41–49 INR/liter)
Gasification Fischer-Tropsch	120 million liters/year ^c	\$3.1–\$5.2 USD/liter ^d (221–371 INR/liter)	\$1.0– \$1.3 USD/liter ^b (69–96 INR/liter)
Renewable electricity power-to-liquids	9–868 million liters/year ^e	\$3.1–\$7.6 ^e USD/liter (225–540 INR/liter)	\$4.0 USD/liter ^e (279 INR/liter)

* The levelized cost of renewable power-to-liquids in India may differ substantially, depending on the regional costs of producing electricity in India relative to the European Union.

^a Lee R. Lynd, *et al.*, “Cellulosic Ethanol: Status and Innovation.” *Current Opinion in Biotechnology* 45 (June 2017): 202–11. <https://doi.org/10.1016/j.copbio.2017.03.008>.

^b Kyriakos Maniatis, Ingvar Landalv, Lars Waldheim, Eric van den Heuvel, and Stamatis Kalligeros, “Building up the Future: Sub Group on Advanced Biofuels,” (Final Report, Sustainable Transport Forum, European Commission, 2017), <http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetailDoc&id=33288&no=1>.

^c Peters *et al.*, *How to advance cellulosic biofuels*.

^d International Renewable Energy Agency, “Innovation Outlook: Advanced Liquid Biofuels,” (2016), https://www.irena.org/DocumentDownloads/Publications/IRENA_Innovation_Outlook_Advanced_Liquid_Biofuels_2016.pdf.

^e Adam Christensen, Chelsea Petrenko, CO₂-based synthetic fuel: Assessment of potential European capacity & environmental performance, (ICCT: Washington, DC, 2017), https://www.theicct.org/sites/default/files/publications/CO2-based-synthetic-fuel-EU-assessment_ICCT-consultant-report_14112017_vF_2.pdf.

Ensuring the success for these early projects not only builds the technical expertise for building larger facilities later on and creating economies of scale, but also takes the first step in the gradual process of building out supply chains for collecting new feedstocks. India has thus far committed to viability gap funding of up to 40% of an advanced biorefinery’s costs, but the total amount committed is only Rs. 5,000 Crore, approximately \$700 million USD.⁷² Given the high capital costs for cellulosic facilities illustrated in Table 6, it is likely that this level of funding is too small to support anything beyond a handful of projects. At a range of Rs. 186 to 336 per liter of capacity, a single 63-million liter cellulosic ethanol project as used in this analysis would cost between 23% and 42% of the total available viability gap funding.

Direct grant funding for new projects could also attract more investors and bring new technologies onto the market.⁷³ We note that the costs estimated in this paper are for nth-of-a-kind plants, i.e., projects that have benefited from learning from the efforts of pilot projects. As discussed previously, first-of-a-kind plants and pilot projects typically require considerable ramp-up time and troubleshooting, and this increases costs. Alternative mechanisms and financing schemes may be necessary to support advanced biofuel production. For example, contracts-for-difference, an approach currently being developed to support dairy manure-derived biogas in California, would allow the government to provide a price floor for prospective biofuel

70 Pavlenko *et al.*, *Development and analysis of a durable low-carbon fuel investment policy*.

71 *Ibid.*

72 Government of India, “Cabinet Approves National Policy on Biofuels-2018.”

<https://pib.gov.in/Pressreleaseshare.aspx?PRID=1532265>

73 Nikita Pavlenko, Stephanie Searle, Brett Nelson, *A comparison of contracts for difference versus traditional financing schemes to support ultralow-carbon fuel production in California*, (ICCT: Washington, DC, 2017), <https://www.theicct.org/publications/comparison-contracts-difference-versus-traditional-financing-schemes-support-ultralow> and Peters *et al.*, *How to Advance Cellulosic Biofuels*.

producers and thus mitigate substantial investor risk.⁷⁴

Conclusions

Based on this analysis, India cannot achieve the 2030 blend level targets in its 2018 National Policy on Biofuels using only sustainable feedstocks. Through a combination of an assessment of feedstock availability and deployment rate projections for advanced biorefineries, we estimate that even with substantial policy support, India would, at a maximum, be able to displace 5.6% of gasoline and 3.8% of diesel in 2030 on a volumetric basis using advanced biofuels. An additional 3% of gasoline could be displaced through the continued production of molasses-derived ethanol at 2018 levels. At these blending rates, India would come close to reaching its 5% blending target for diesel-replacements, but fall far short of its 20% target for ethanol.

The most salient barrier for the 2030 timeline is the pace of deployment of large, commercial-scale advanced bio-refineries. The most abundant feedstocks in this analysis all required an advanced conversion pathway, including crop residues, MSW, and

energy crops. The theoretical potential from these feedstocks exceeds India's blend targets substantially. However, with only a decade to develop entirely new supply chains for cellulosic feedstocks, deploy pilot conversion facilities, and scale up to commercial biorefineries, we find that even with favorable policy support, the construction time and ramp-up in production for each facility will constrain total production. Given that this deployment projection is much more aggressive than the expansion of the cellulosic ethanol industry in the United States and European Union over the last decade, which happened with policy support, there is reason to believe that the ultimate deployment in India will fall short of this projection. We find that only around one-tenth of the theoretical production potential could be realized by the 2030 target date, even with strong policy support.

In the near term, India's prospects for biofuel production are primarily limited by feedstock availability and technical constraints. If used cooking oil collection rates are improved, this feedstock could provide more than 3 billion liters of biodiesel using existing, commercialized conversion pathways and could

provide immediate carbon reductions. Likewise, molasses ethanol is constrained by sugar supply but can generate moderate GHG reductions relative to gasoline. Due to the unpredictability of surplus food production and concerns over its sustainability, surplus food is not a reliable source of long-term GHG reductions and may still contribute to ILUC.

While it is likely that India's 2030 biofuel blending target is out of reach due to the deployment rate for biorefineries, we find that with the right mix of policies and incentives, there is sufficient availability of sustainable feedstocks to deploy advanced biofuels in the longer term. By establishing a long-term target and strong policy incentives for advanced biofuels, and coupling that with strong sustainability criteria, it is possible for India to leapfrog investment in first-generation biofuels and focus on developing its advanced biofuel industry. Expanding support for programs such as viability gap funding and grants funding can help mitigate investment risks for capital-intensive, first-of-a-kind facilities and early commercial ventures and support the growth of the industry during the crucial early stages.

74 California Air Resources Board, "SB 1383 Pilot Financial Mechanism Concept Paper," (May 2018), <https://ww3.arb.ca.gov/cc/dairy/documents/05-23-18/pilot-financial-mechanism-white-paper.pdf>