WHITE PAPER

JUNE 2021

TECHNO-ECONOMIC ANALYSIS OF CELLULOSIC ETHANOL IN INDIA USING AGRICULTURAL RESIDUES

Yuanrong Zhou, Stephanie Searle, and Sunitha Anup

www.theicct.org

communications@theicct.org

twitter @theicct

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

BEIJING | BERLIN | SAN FRANCISCO | SÃO PAULO | WASHINGTON

ACKNOWLEDGMENTS

This study was generously supported by the David and Lucile Packard Foundation. Thanks to Anup Bandivadekar, Casey Kelly, and Nikita Pavlenko for helpful reviews.

International Council on Clean Transportation
1500 K Street NW, Suite 650
Washington, DC 20005

communications@theicct.org | www.theicct.org | @TheICCT

EXECUTIVE SUMMARY

The Government of India has made efforts to promote the domestic production and use of ethanol in transport fuel. An ethanol blend target was first established in 2003 and higher targets have been set over time. The government also developed ethanol procurement policies that require Indian oil companies to procure ethanol only from domestic sources at a fixed price set by the government; imported ethanol is not allowed for fuel use. Cellulosic ethanol made from cellulosic biomass such as agricultural residues brings multiple environmental and socio-economic benefits, including less crop burning and enhanced energy independence, but it is a second-generation (2G) biofuel that requires more advanced and expensive technology than first-generation (1G) biofuels made from food crops. Experience from other countries indicates that commercial production of cellulosic ethanol can be challenging even with policy incentives in place.

To accelerate domestic ethanol production, the Indian government is now trying to scale up the cellulosic ethanol industry by providing Viability Gap Funding (VGF), which improves the financial returns of a given project. The Indian government has proposed a cap of INR 1.5 billion (US$20 million) per project for a total of 12 projects at commercial scale. To evaluate the impact of India's proposed VGF on the cost viability of cellulosic ethanol, we develop a discounted cashflow (DCF) model to assess the levelized production cost of cellulosic ethanol in India.

As shown in Table ES1, when no policy support is provided, we estimate a levelized production cost for cellulosic ethanol of approximately INR 93 (US$1.26) per liter for a smaller 36.5 million liter annual production facility and INR 80 (US$1.08) per liter for a larger 70 million liter annual production facility. However, with VGF support in place, we estimate that production costs are reduced by approximately 13% for smaller-scale projects and 8% for larger-scale projects. These estimates are within the range from previous studies. However, our estimated cost is much higher than the current highest ethanol procurement price fixed by the government based on 1G ethanol. If cellulosic ethanol were to be sold at the highest current price of INR 62.65 (US$0.85) per liter, we find that producers would not be able to generate a financial return that is likely to attract private investment, even with the VGF support. In addition to the potential financial challenge, the amount of cellulosic ethanol under the VGF support, as currently proposed, is limited and would only replace around 1% of India's gasoline demand in 2030. This amount is too small to play any substantive role in reaching the ethanol blending target and enhancing the nation's energy independence.

Table ES1. Estimated levelized production cost of cellulosic ethanol in India in this study, for facilities of 36.5 million liters and 70 million liters each year, compared to previous studies

Scenario	36.5M capacity INR per liter (US$ per liter)	70M capacity INR per liter (US$ per liter)	Range from other studies INR per liter (US$ per liter)
No VGF support	92 – 94 (1.26)	79 – 81 (1.08)	INR 40 – 157 per liter (US$0.5 – 2.1 per liter)
With VGF support	80 – 82 (1.1)	73 – 75 (1.0)	(India's highest fixed ethanol price is INR 62.65 per liter or US$0.85 per liter)

This analysis indicates that establishing a cellulosic ethanol industry in India will likely require additional policy support beyond the VGF program, and there are several measures to consider below. Regarding the first three financial support measures, policymakers might choose to employ them individually, or in some combination.

» India already sets different costs for 1G ethanol based on feedstock and could add another, higher pricing category for cellulosic ethanol. In the absence of VGF, our

analysis suggests INR 80 – 95 (US$1.08 – 1.26) per liter would be necessary for cellulosic ethanol producers to attract private investment and at least break even. With VGF as currently proposed, the necessary price is estimated to be INR 70 – 80 (US$1 – 1.08).

» Provide a per liter subsidy for cellulosic ethanol to account for the gap between the production cost and the 1G procurement price. Our analysis suggests a subsidy amount of INR 20 – 35 (US$0.27 – 0.47) per liter would be needed if cellulosic ethanol receives the same highest 1G procurement price at INR 62.65 (US$0.85) and does not receive VGF support.

» Increase the level and scale of the VGF program by increasing the amount of funding per project and funding a larger number of projects. Our results indicate grants of INR 4 billion (US$54 million) per project may be needed with the current 1G procurement price.

» Provide low-interest loans to cellulosic ethanol producers and exempt any import tariffs on equipment and chemicals and enzymes used during production.

» Provide financial and technical support to scale up the collection of agricultural residues through setting higher prices for agricultural residues and building necessary infrastructure.

TABLE OF CONTENTS

INTRODUCTION

India has supported the use of ethanol in transportation fuels through a variety of policy measures for nearly 20 years. In early 2003, the Government of India launched an Ethanol Blended Petrol (EBP) Programme, pursuant to which a certain percentage of ethanol is to be blended with gasoline. The blend target has increased over time and at present, the nationwide ethanol blend target under EBP is set to be 10% (E10) by 2022 and 20% (E20) by 2025 (Sarwal et al., 2021). In response, India's ethanol production (the blue line in Figure 1(a) and its fuel ethanol consumption (orange line in Figure 1a and orange bars in Figure 1b) have risen. The ethanol blend level reached 4.5% in 2019.

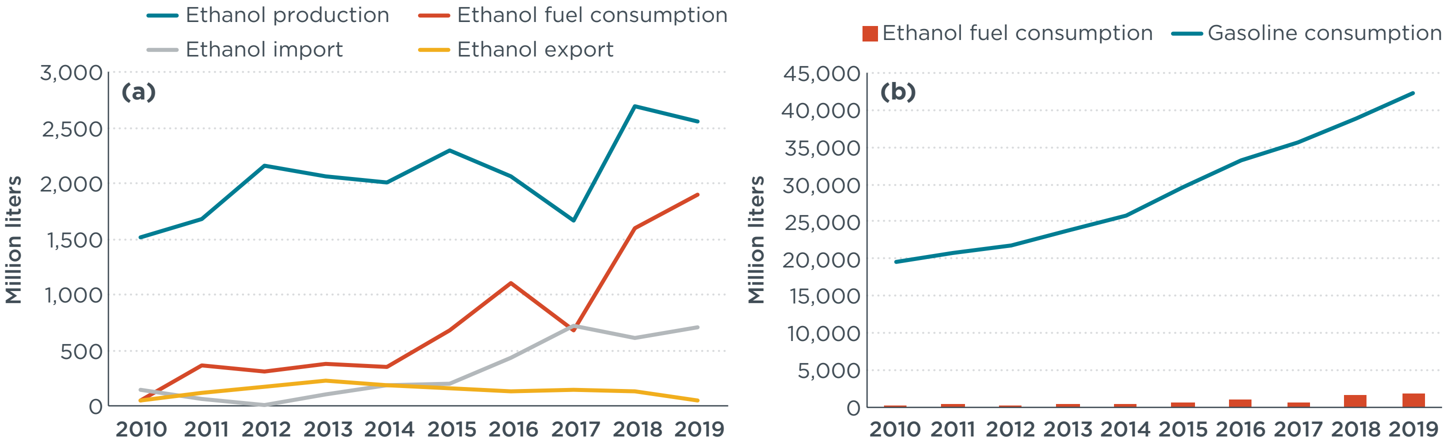

Figure 1. Gasoline and fuel use of ethanol in India between 2010 and 2019. Source: United States Department of Agriculture (2020)

(a) Domestic ethanol production and fuel ethanol consumption and ethanol trades.

(b) Gasoline consumption and ethanol use in transportation fuel. The percentages indicate the level of ethanol blending.

The government has also set up ethanol procurement policies under EBP. These policies require India's oil selling companies to procure ethanol for transportation from domestic sources (United States Department of Agriculture, 2020). Therefore, although India's ethanol imports have increased (grey line in Figure 1a), these imports are for industrial uses only and are not contributing to the blend target we are discussing. Additionally, through another procurement regulation, the Indian government has administered the ethanol price since 2014. Multiple ethanol prices are set based on feedstock type and the government has revised the prices from time to time. This means that oil companies in India purchase ethanol at the government's fixed price (Press Information Bureau, 2020).

As gasoline demand continues to soar in the country, India must scale up its domestic ethanol production if it is to meet the increasing ethanol blend target. So far, the majority of ethanol produced in India is made from first-generation (1G) feedstocks—food crops—and mostly from molasses. But 1G ethanol made from crops could contribute to food insecurity and production could generate indirect land-use change (ILUC) emissions that undermine the climate benefits (Malins, Searle, & Baral, 2014). Indeed, concerns over food security have prompted interest in second-generation (2G) biofuels sourced from cellulosic biomass, such as agricultural residues and municipal solid wastes. The Indian government seeks to diversify ethanol feedstocks by supporting 2G feedstocks, and this support is important because 2G ethanol, also known as cellulosic ethanol, requires more advanced conversion technology. Unlike 1G feedstocks whose starch and sugar can directly undergo fermentation to produce ethanol, 2G feedstocks such as agricultural residues need to go through a series of additional processes to make their sugars accessible for fermentation. These processes include separating lignin from the cellulose, which then turns into sugar through cellulose hydrolysis.

To support the emerging cellulosic ethanol industry, the Indian government is providing Viability Gap Funding (VGF) under the Pradhan Mantri Ji-Van Yojana program, which was released in 2019 (Ministry of Petroleum & Natural Gas, 2019). As part of this program, the government is giving out a total of INR 19.7 billion (US$270 million) from fiscal year (FY) 2018–19 to 2023–24 to support 12 commercial projects and 10 demonstration projects.[1] The projects fall under two implementation phases, with Phase I running from FY 2018–19 to 2022–23 and Phase II from 2020–21 to 2023–24. In June 2020, the Ministry of Petroleum & Natural Gas released two request for selection (RFS) tender documents that facilitated the roll-out of the VGF program (Centre for High Technology [CHT], 2020). These documents lay out specific selection requirements for cellulosic ethanol project developers to receive VGF. Bidders must meet pre-qualification criteria and submit a comprehensive financial analysis of ethanol production following detailed guidelines in the documents. In addition, the funding that each project can get is limited to INR 1.5 billion (US$20 million) for commercial projects and INR 0.15 billion (US$2 million) for demonstration projects.

Experience from other regions such as the United States and the European Union indicates that producing cellulosic ethanol at a commercial scale can be challenging, from both technical and financial perspectives; therefore, it is crucial for the success of the industry that supporting policy be designed effectively (Peters, Alberici, & Passmore, 2015). The purpose of this study is to evaluate the existing government support in India and its potential to incentivize cellulosic ethanol production. We estimate the India-specific production cost of commercial-scale cellulosic ethanol and evaluate the impact of VGF on the levelized production cost of cellulosic ethanol. From this, we assess whether the VGF provides sufficient incentive under the current administered ethanol price. We also estimate the total aggregate potential production scale under VGF and its contribution to India's overall ethanol blend target. Last, based on the results, we identify policy support that could potentially be effective in scaling up the cellulosic ethanol industry in India.

1 The annual generation capacity of demonstration projects shall be between 0.375 and 1.125 million liters, and there is no capacity specification for commercial projects (CHT, 2020). Additionally, we used a 2020 average conversion rate of 0.0135 USD per INR throughout this study.

METHODOLOGY

To estimate the production cost of cellulosic ethanol, we deploy a discounted cash flow (DCF) model. DCF is a financial model that values an investment by factoring in the expected future value of its cash flows, both outgoing and incoming. Outgoing cash flow includes capital cost (capital expenditure or CAPEX), which is the upfront investment in building the facility, and operational cost (operational expenditure or OPEX), which is the annual expense of running the facility. Incoming cash flow is generated through product sales. Ultimately, DCF estimates the levelized production cost, or the minimum selling price of a product for an investment to be economically viable, i.e., break-even.

Our DCF model is based on the methodology specified in Humbird et al. (2011), which is commonly used in techno-economic analysis on cellulosic ethanol. We follow the RFS guidelines (CHT, 2020) when making model assumptions. If not specified in the RFS, debt and tax related data was collected from other policy regulations (Central Electricity Regulatory Commission [CERC], 2019; PWC, 2020), and project related information, such as construction time, was obtained from existing projects and previous studies (Eisentraut, 2010; Humbird et al., 2011; Kugemann, 2015; Peters et al., 2015; Zhao et al., 2015; Abdi, 2019; Cheng et al., 2019; Mohan, 2019; Parbowo, Ardy, & Susanto, 2019; Biofuels International, 2020; Brown et al., 2020; CDM, 2020).

Table 1, below, lists our assumptions regarding facility design and key economic parameters in the DCF model. Importantly, we develop two scenarios of production capacity. Several existing cellulosic ethanol projects in India have an annual production capacity of 36.5 million liters (Abdi, 2019; Mohan, 2019; Biofuels International, 2020), and we used this number to reflect a typical project size at the current stage. However, given that there are projects in other countries at a much greater scale, it is likely that nameplate production capacity in India will grow over time, especially as the industry develops. Therefore, we analyze a second scenario based on an assumed capacity of 70 million liters annual production per facility.

One important model input is the real discount rate. It determines the present values of future cash flows and substantially influences the results. In this study, we use the weighted average cost of capital (WACC) as the discount rate. By definition, this is calculated through the cost of each capital source, and in this case, that is debt financing and equity financing. Debt financing information is obtained from government documents (Table 1). Equity financing costs are related to return on equity (ROE). ROE reflects the profit an investor would need to consider the investment worthwhile. A general rule of thumb is that the riskier the project, the higher the expected return must be to justify investment. However, ROE is usually confidential information and is difficult to obtain. Techno-economic studies on biofuel production use a wide range of ROE assumptions, from 10% to 25%. To come up with a reasonable ROE for India's cellulosic ethanol industry, we referred to the Clean Development Mechanism (CDM) project database (CDM, 2020). CDM provides certified emission reduction credits to carbon-reduction projects. The program will only issue credits when the project is deemed to be additional to a business-as-usual scenario. One of the main criteria for determining this additionality is that the project should not be financially viable without CDM support; in other words, it only becomes financially viable because of the added value of certified emission reduction credits. The CDM Executive Board implicitly limits the ROE that project applicants can assume when calculating financial viability. This is to avoid crediting projects that would have been financially viable under typical industry standards without CDM support (CDM Executive Board, 2012). Approved CDM project applications thus provide us with an indication of reasonable ROEs to assume for different carbon reduction industries, including biofuel. At present, there are no approved cellulosic biofuel projects in the

CDM program. However, there are a number of biomass power projects in the program, and we use these as a proxy. Among these projects, the average ROE without CDM support (which the project applicants deem not viable) is 8%, and the ROE with CDM revenue included (financially viable) can reach over 18%. We use this upper end of 18% because the cellulosic ethanol industry is riskier than the mature biomass power industry. Additionally, this figure falls within the range of assumed ROE for cellulosic ethanol projects from other studies.

Table 1. Assumptions of cellulosic ethanol facility design and key economic parameters

Parameter	Value		Sources
Design and construction time	3 years		Eisentraut, 2010; Humbird et al., 2011; Kugemann, 2015; Peters et al., 2015; Zhao et al., 2015
Facility ramp-up time	2 years		CHT, 2020
Percentage of plant capacity during ramp-up phase	Year 1	Year 2	Humbird et al., 2011; Peters, et al., 2015
	50%	75%	
Plant lifetime (Including ramp-up phase)	20 years		CHT, 2020
Annual ethanol production capacity	Scenario 1: 36.5 million liters	Scenario 2: 70 million liters	Peters et al., 2015; Abdi, 2019; Mohan, 2019; Biofuels International, 2020
Depreciation	5% (straight-line method)		CHT, 2020
Debt:Equity ratio	50:50		
Loan term	13 years		CERC, 2019
Loan interest rate	10.41%		
Corporate income tax	17.16% (Reduced tax rate of 15% + 10% surcharge + health and education cess of 4%)		PWC, 2020
Return on equity (ROE)	18%		CDM, 2020
Discount rate_Weighted average cost of capital (WACC)	12%		From calculation

CAPITAL COST

Equipment purchase is a large portion of total capital cost. We collect equipment cost from industry interviews (Peters et al., 2015) and take the scaling exponent, 0.7, from Humbird et al. (2011) to account for the difference in facility capacity (or equipment size) between the projects and the two scenarios in our model. Since the projects discussed in the interviews were developed several years ago, we also adjust the collected equipment cost using the Plant Cost Index, which updates the equipment cost from a past date to reflect a more up-to-date quote (Chemical Engineering, 2020). The other cost components, such as equipment installation, site development, construction, and working capital, are proportional to equipment purchase cost with a varying ratio for each. We take the ratios from Humbird et al. (2011), except for equipment installation cost; for that, we retrieve the lower ratio, 39%, from Zhao et al. (2015), as it incorporates the regional difference in prices between developed and developing countries. Similarly, we also downscale construction related costs using relative U.S. and Indian construction cost data from Turner and Townsend (2019). We collect land cost from two existing biofuel projects in India (MITCON Consultancy & Engineering Services Ltd., 2014; MITCON Consultancy & Engineering Services Ltd., 2015).

OPERATIONAL COST

Operational cost can be further categorized into fixed operational cost and variable operational cost. Fixed operational cost is the annual expense for labor and overhead, facility maintenance, and other miscellaneous things such as insurance. Again, we use the labor data in Turner and Townsend (2019) to account for cheaper labor in India. We assume labor overheads to be 40% of estimated labor cost, as in Zhao et al. (2015) for developing countries, rather than the 90% in developed countries in Humbird et al. (2011). Maintenance and other miscellaneous costs are assumed to be proportional to capital cost and we take cost ratios from Humbird et al. (2011).

Variable operational cost accounts for the annual expense that is affected by the amount of ethanol production. Costs of feedstock, chemicals, energy, and water all fall under this category. In terms of cellulosic ethanol feedstock, we consider the three types of agricultural residues with the greatest production in India based on the analysis from a previous ICCT study (Pavlenko & Searle, 2019); these are rice straw, wheat straw, and sugarcane bagasse. The RFS requires ethanol producers to use the biomass price in the Renewable Energy Tariff Regulations released by the CERC for economic analysis. While the RFS provides the biomass price for FY 2019–20, we retrieve the most recent biomass and sugarcane bagasse prices for FY 2020–21 from CERC (2020a). Feedstock price varies across states in India, as shown in Table 2. Since we do not propose a specific facility location, we use the average of the feedstock prices to present a middle cost case of cellulosic ethanol in India (Table 2). We then estimate the consumption of each type of feedstock based on the feedstock's specific ethanol yield and moisture content, and collect this information from previous studies.

Table 2. Cost, ethanol yield, and moisture content of three types of feedstock in this study

Feedstock	Price range across states INR/tonne (US$/tonne)	Average price INR/tonne (US$/tonne)	Ethanol yield (g ethanol per g dry biomass)	Moisture content
Rice straw	3,272 – 3,960 (44.2 – 53.5)	3,532 (47.7)	0.38	15%
Wheat straw	3,272 – 3,960 (44.2 – 53.5)	3,532 (47.7)	0.34	14%
Sugarcane bagasse	1,877 – 2,671 (25.3 – 36.1)	2,225 (30)	0.36	40%

Sources: Saini and Saini, 2015; Purohit and Dhar, 2018; Vikash and Shastri, 2018; Adhanom, 2019; Argonne National Laboratory, 2020

To estimate the quantity of chemical, energy, and water inputs, we utilize the process assumptions used in the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model for cellulosic ethanol (Argonne National Laboratory, 2020). We collect the price of chemical materials from previous studies (The Glosten Associates, 2010; Tao et al., 2017) and add the Goods and Services Tax (GST) in India on top of each chemical (Central Board of Indirect Taxes and Customs, 2020). We collect India-specific electricity and water retail prices for industrial users and take the average across states (The Energy and Resources Institute, 2010; Gonsalves, 2018; Power Finance Corporation, 2020).

REVENUE

We assume three revenue streams for cellulosic ethanol producers: sale of ethanol, sale of electricity, and Renewable Energy Certificates (RECs). The ethanol selling price is the levelized production cost that we generate from the DCF model. Electricity is a by-product of the combustion of lignin, a non-carbohydrate material in cellulosic feedstocks that is separated from the feedstock before fermentation because it cannot be converted into ethanol. We use the GREET model to estimate the output quantity of electricity and collect an electricity wholesale price in India (CERC, 2020b).

Additionally, as the electricity is sourced from biomass, cellulosic ethanol producers could theoretically obtain and trade RECs; here these are valued according to the FY 2019–20 average non-solar REC price from CERC (2020b).

RESULTS

Total and per liter ethanol capital cost, fixed operational cost, variable operational cost, and their comparisons with previous studies are presented in Table 3. We estimate the total CAPEX needed for building a 36.5 million liters cellulosic ethanol facility in India is INR 8.8 billion (US$118 million) and for a 70 million liters capacity facility, it is INR 13.8 billion (US$187 million). Annual CAPEX per liter of ethanol gets smaller as the facility capacity increases due to economies of scale. Our estimated CAPEX for both capacity scenarios is within the global range reported in other studies in the literature. India could take advantage of cheaper construction and land cost compared to other developed countries and achieve relatively low CAPEX.

Table 3. Total and per liter ethanol capital cost, fixed operational cost, variable operational cost estimated in this study, compared to range of estimates from previous studies.

		36.5M capacity	70M capacity	Range from other studies
CAPEX	Total capital investment million INR (million US$)	8,768 (118)	13,800 (187)	—
	INR (US$) per liter capacity	240 (3.24)	198 (2.67)	110 – 430 (1.5 – 5.8)
Fixed OPEX	Total annual cost million INR (million US$)	194.4 (2.6)	306.3 (4.1)	—
	INR (US$) per liter ethanol	5.3 (0.07)	4.4 (0.06)	2.1 – 27.4 (0.03 – 0.37)
Variable OPEX	Total annual cost million INR (million US$)	839 – 855 (11.3 – 11.5)	1,601 – 1,691 (21.6 – 22.8)	1
	INR (US$) per liter ethanol	23 – 24.3 (0.31 – 0.33)		1.7 – 70.5 (0.02 – 0.95)

Sources: Gnansounou and Dauriat, 2010; Humbird et al., 2011; Webb, 2013; Peters, Alberici, and Passmore, 2015; Zhao et al., 2015; Gandhan, 2018; Ganguli et al., 2018; Purohit and Dhar, 2018; Adhanom, 2019; Cheng et al., 2019; Brown et al., 2020; Zhou et al., 2020b

We find that total annual fixed OPEX, which mainly represents labor, is about INR 195 million (US$2.6 million) for a 36.5 million liters capacity project and INR 306 million (US$4.1 million) for a 70 million liters capacity project. Our estimate of the per liter ethanol fixed OPEX is toward the lower end of cost range from previous studies, mainly due to cheap labor in India. As stated in the methodology section above, variable OPEX is dependent on feedstock type. We find that the total annual variable OPEX ranges from INR 839 million (US$11.3 million) using sugarcane bagasse to INR 855 million (US$11.5 million) using wheat straw for a 36.5 million liters capacity. Although sugarcane bagasse has much lower ethanol yield on wet biomass basis (Table 2), its significantly lower price enables savings on OPEX. While rice straw and wheat straw have the same biomass price, the slightly lower ethanol yield from wheat straw makes it the most expensive among the three. We find that feedstock and enzymes account for most of the variable OPEX and that variable OPEX represents most of the total OPEX. Compared to other studies, our per liter ethanol variable OPEX estimate is relatively low. This is because of the lower biomass price in India; most of the other studies found that feedstock cost can reach 50% to 80% of total annual operational expense, especially for projects in the United States and the European Union (Humbird et al., 2011; Cheng et al., 2019; Padella et al., 2019; Brown et al., 2020).

Table 4 compares the estimated per liter levelized production cost of cellulosic ethanol in India from our DCF model with costs from previous studies. The difference between our estimates for the 36.5 million liter facility and for the 70 million liter facility suggests that doubling the capacity size could lower the production cost by approximately 10%, due to economies of scale. Feedstock type, meanwhile, only has a minor effect on the production cost, and we find only a 1% variation depending on the feedstock. We also present two scenarios of with or without VGF financial support. The INR 1.5 billion (US$20 million) VGF support has a large impact on the overall financial viability of cellulosic ethanol: It reduces the minimum selling price of cellulosic ethanol by 7.5% for large-scale projects and 13% for small-scale projects. We note, though, that production price will vary by state due to different prices in material inputs, such as feedstock and water. The results of this study represent middle cost scenarios.

Table 4. Estimated levelized production cost of cellulosic ethanol in India from this study compared to previous studies.

Scenario and feedstock		36.5M capacity INR per liter (US$ per liter)	70M capacity INR per liter (US$ per liter)	Range from other studies INR per liter (US$ per liter)
No funding	Rice straw	93.1 (1.26)	80.3 (1.08)	40 – 157 (0.5 – 2.1) (India's fixed ethanol price is INR 62.65/liter or US$0.85/liter)
	Wheat straw	93.6 (1.26)	80.8 (1.09)	
	Sugarcane bagasse	92.4 (1.25)	79.6 (1.08)	
With VGF support	Rice straw	81 (1.09)	73.9 (1.0)	
	Wheat straw	81.5 (1.1)	74.4 (1.0)	
	Sugarcane bagasse	80.3 (1.1)	73.3 (0.99)	

Sources: Gnansounou and Dauriat, 2010; Humbird et al., 2011; Webb, 2013; Peters, Alberici, and Passmore, 2015; Zhao et al., 2015; Gandhan, 2018; Ganguli et al., 2018; Purohit and Dhar, 2018; Adhanom, 2019; Cheng et al., 2019; Brown et al., 2020; Zhou et al., 2020b

In all cases, the production cost of India's cellulosic ethanol is within the range from previous studies. Particularly, a previous ICCT study evaluating the techno-economics of 70 million liter cellulosic ethanol facility in Indonesia that adopted a similar modeling methodology estimated per liter production cost ranging from INR 57.8 to INR 95.6 (US$0.78 to US$1.29), depending on feedstock type (Zhou et al., 2020b). However, even with the VGF support, the production cost of cellulosic ethanol is still much higher than the current highest administered ethanol price, INR 62.65 (US$0.85) per liter.

Table 4 provides an overview of the levelized costs for cellulosic ethanol across the project configurations and feedstock choices in this study. Assuming that the companies involved in these projects need a return typical for the industry in order to attract private investment, the production costs exceed the administratively set ethanol price even with VGF support, by a factor of 1.2. To examine this in a different way, we also estimate the return that cellulosic ethanol producers could get if selling at the highest regulated price for 1G ethanol of INR 62.65 (US$0.85) per liter. Figure 2 illustrates the results of that analysis, and shows the ROE for projects selling cellulosic ethanol without VGF in blue, and with VGF in orange. We estimate that without VGF support, the ROE would be about 4% for large-scale projects and negative for small-scale projects. But even with VGF, the rate of return for large-scale projects remains lower than the industry standard and is less than 9%. While these results show that cellulosic ethanol facilities could generate a return for investors, the 5%–9% range is likely too low to attract many investors given the risk of failure.

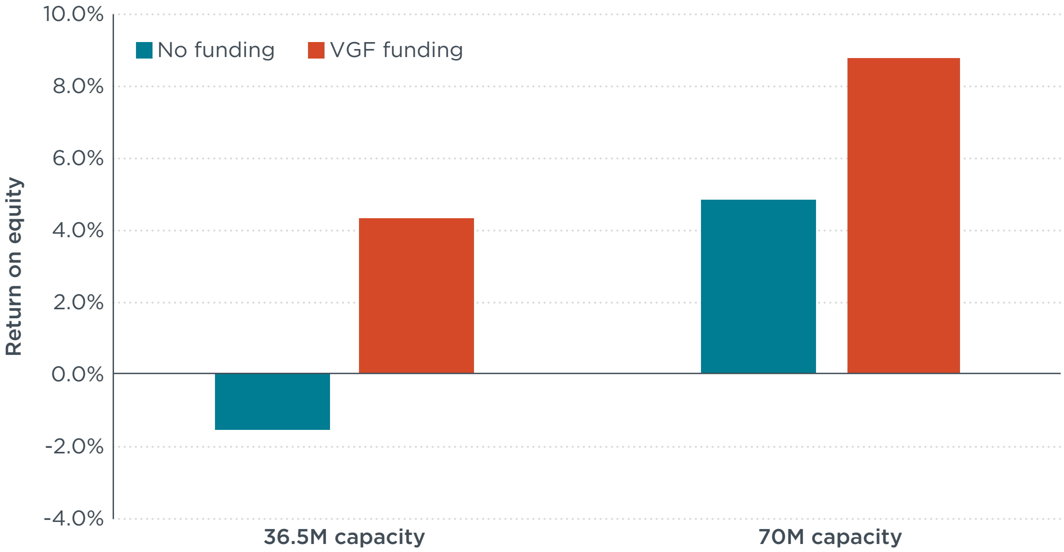

Figure 2. Return on equity (ROE) that cellulosic ethanol producers can generate if selling ethanol at the regulated price of INR 62.65 (US$0.85) per liter.

Next, we consider the potential scale of a cellulosic ethanol industry that could be supported with the VGF program. The VGF program, as currently proposed, will support a maximum of 12 commercial projects and 10 demonstration projects, and we project the amount of cellulosic ethanol production this could support in Figure 3. (This calculation does not take into account the market constraints, such as higher production cost, that would need to be overcome for cellulosic ethanol facilities to sell ethanol competitively.) We follow the two implementation phases specified in Pradhan Mantri Ji-Van Yojana. We assume a total of 10 million liters from the 10 demonstration projects in our projection. We assume the 6 commercial projects in the first phase have the capacity of 36.5 million liters each, while the 6 projects in the second phase are of 70 million liters each, as the industry grows. We assume that by 2030, all 22 projects will be running at their full capacity and estimate that the total annual cellulosic ethanol production could reach 650 million liters. This amount would meet about 1.1% of gasoline demand in 2030, based on ICCT's projection for a business-as-usual scenario.

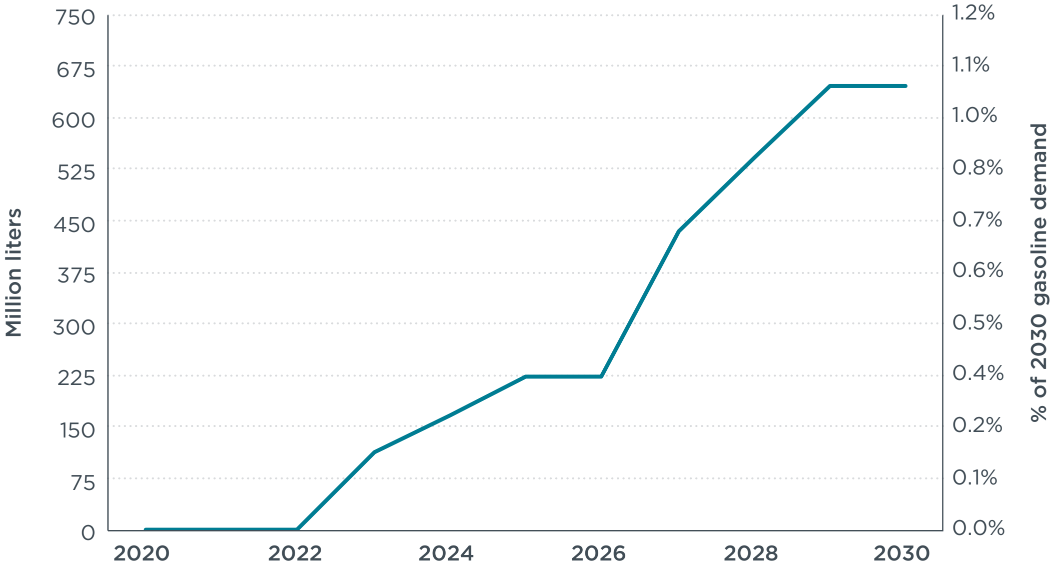

Figure 3. Potential cellulosic ethanol production amount under the Viability Gap Funding (VGF) support

BENEFITS OF CELLULOSIC ETHANOL

Developing a cellulosic ethanol industry in India would bring multiple environmental and socio-economic benefits. First, it could help address the longstanding crop burning issue. Currently, approximately 48 million dry tonnes (Food and Agriculture Organization, 2020) of agricultural residues are burned on the farm field each year to enable faster replanting; this significantly affects local air quality and leads to adverse health effects. Converting agricultural residues into ethanol is an alternative to burning and is in line with the government's stated goal of reducing crop burning.

Second, producing significant volumes of cellulosic ethanol domestically would reduce fuel import demand, contribute to the ethanol blend target, and enhance energy security in India. Fuel is one of the top three import products in India (World Bank, 2020) and about 80% of fuel demand is met by imports (The Economic Times, 2019). India imported 260 million tonnes of crude oil and petroleum products per year on average over the past 5 years, and this cost INR 7.34 trillion (US$99 million) each year (Ministry of Petroleum & Natural Gas, 2020). Domestic production of cellulosic ethanol also aligns with the increasing national ethanol blend target. To reach the E20 target by 2025, India probably needs at least 7.2 – 9.2 billion liters of ethanol each year (Sarwal et al., 2021). Should all currently burned agricultural residues be converted into cellulosic ethanol, 22 billion liters of cellulosic ethanol could be produced annually.

Third, developing this new industry can accelerate local economic development. According to the Government of India's Press Information Bureau (2018), operating a cellulosic ethanol facility at 36.5 million liters annual production capacity has the potential to create about 1,200 jobs. In addition, this investment can also bring additional income to farmers who sell agricultural residues to ethanol producers.

Last, cellulosic ethanol can bring substantial climate benefits. Although there are uncertainties regarding the carbon intensity of cellulosic ethanol, especially regarding indirect emissions from land use change and ILUC, regulations in the European Union and the United States estimate the life-cycle carbon intensity of cellulosic ethanol from agricultural residue in the range of -31 gCO_2e/MJ to 32 gCO_2e/MJ, with the consideration of both direct and indirect emissions (Environmental Protection Agency, 2010; Valin et al., 2015; Official Journal of the European Union, 2018; California Air Resources Board, n.d.). This means that cellulosic ethanol is likely to generate 66% to 130% life-cycle GHG emissions savings relative to gasoline, which is 93–100 gCO_2e/MJ. Cellulosic ethanol not only provides significant GHG emissions reductions compared to fossil fuels, but it also has better climate performance than 1G ethanol.

POLICY RECOMMENDATIONS

The results show that the initial development of India's cellulosic ethanol industry will likely require policy support beyond the VGF program, as that funding alone does not make cellulosic ethanol cost-competitive with even the highest priced 1G ethanol. We therefore have several recommendations for financial incentives for cellulosic ethanol that could be implemented by the Indian government if it desires to increase support to improve the chances of the industry maturing. Such financial incentives would be a clear signal of the government's determination to support the industry, and that could, in turn, help attract financiers for project development (Zhou et al., 2020a).

The Indian government could support the cellulosic ethanol industry through multiple approaches, each of which is discussed in more detail below:

» Add a separate pricing category for cellulosic 2G ethanol and set the regulated price higher than 1G ethanol

» Provide a per liter subsidy to account for the price gap between the highest fixed price for 1G ethanol and the production cost of cellulosic ethanol

» Increase the level and scale of the VGF program through both increased funding per project and a larger number of projects

» Provide additional financial incentives, such as giving low-interest loans to cellulosic ethanol producers and exempting import tariffs of equipment and chemicals and enzymes used during production

» Provide financial and technical support to scale up the collection of agricultural residues

Regarding setting the ethanol price, the government currently fixes different 1G ethanol price levels based on different types of feedstocks and the highest price is for ethanol made from pure sugarcane juice, INR 62.65 (US$0.85) per liter. While the Indian government has not specified any ethanol prices for 2G feedstocks, the results of this study suggest that INR 80 – 95 (US$1.08 – 1.26) per liter is the minimum selling price at which cellulosic ethanol facilities could deliver a return on investment typically expected for the industry without VGF or other policy support. With VGF as currently proposed, the minimum selling price is estimated to be INR 70 – 80 (US$1 – 1.08).

Alternatively, policymakers could maintain the 1G ethanol price for 2G but provide a per liter subsidy to account for the price gap between the ethanol price and the levelized production cost of cellulosic ethanol. The necessary subsidy thus would be INR 20 – 35 (US$0.27 – 0.47) per liter without VGF support.

Another approach that policymakers could take is increasing the level and scale of the VGF. Currently, the VGF is capped at INR 1.5 billion (US$20 million) or 20% of project cost, whichever is less, for each of the 12 commercial projects under this program. We estimate that for the projects to be commercially viable under the current highest fixed 1G ethanol price, the necessary grant upfront would need be at least INR 4 billion (US$54 million), approximately 40% of project cost. Policymakers could also expand the VGF program to support a larger number of commercial projects. The likely ethanol production under the current VGF is around 650 million liters each year, much lower than the 7.2 – 9.2 billion liters that would be needed for the 2025 E20 target.

Of course, policymakers could also employ a combination of these approaches. For example, they could set a separate, slightly higher price for 2G feedstocks that does not fully bridge the gap with 1G ethanol and simultaneously provide a per liter subsidy and/or a higher upfront grant. We also note that, in practice, cellulosic ethanol production costs would vary by state and the results in this study represent middle cost scenarios. Production costs in some states are likely to be lower or higher than the study results due to different prices for feedstock, energy, and water.

In addition to building on existing policies, the Indian government could also provide other forms of financial support. For example, policymakers could exempt any import tariffs relevant to cellulosic ethanol production. The two components that cellulosic ethanol producers in India are most likely to import from other countries are equipment and enzyme. The government could also provide low-interest loans to cellulosic ethanol producers as a way to reduce their financial burden and attract private investors.

Last but not least, the Indian government could provide support to other relevant sectors. Particularly, scaling up the collection of agricultural residues is one of the keys to the development of a cellulosic ethanol industry in India. Previous studies noted that in India, technical and economic difficulties make it challenging to get farmers to collect crop residues instead of burning (Alexaki, van den Hof, & Jol, 2019; Bhuvaneshwari, Hettiarachchi, & Meegoda, 2019). The government administered agricultural residue price in India is much lower than other countries. If the price were raised by 50% to INR 5,300/tonne from the current average of INR 3,500/tonne, the levelized cost of production for cellulosic ethanol would only increase by less than 6%. At the same time, setting higher prices for agricultural residues could provide significant financial incentive to farmers in crop collection. Increased crop collection activities could also help the cellulosic ethanol industry by building a sustainable feedstock supply chain. In addition to any financial incentives, local governments could also develop training and facilitation programs to address difficulties along the crop residue collection process. Ultimately, action by local governments will be necessary to develop necessary infrastructure, such as building farm roads to facilitate transporting agricultural residues from farm field to cellulosic ethanol plants (Zhou et al., 2020b).

CONCLUSIONS

Cellulosic ethanol is an emerging technology that could bring many benefits to India. In large volumes, it would help enhance energy independence through reduced fuel imports. It could also contribute to meeting the increasing ethanol blend target, alleviate a longstanding crop burning issue and thus reduce air pollution and improve health outcomes, create job opportunities, and bring additional revenues to farmers. Cellulosic ethanol has significantly lower carbon intensity than fossil fuels and offers better climate performance than 1G ethanol. All of these benefits are in line with Indian government's long-term development goals.

This study developed a techno-economic analysis of the cellulosic ethanol industry in India. We estimate an India-specific cellulosic ethanol production cost (middle cost) to be about INR 80 – 95 (US$1.08 – 1.26) per liter without VGF or INR 70 – 80 (US$1 – 1.08) per liter ethanol with the funding. We find that this would be a globally competitive price, less expensive than we expect cellulosic ethanol to be when produced in other countries and regions such as the United States and Europe; this is largely due to India's competitive labor costs and abundant biomass resources. However, even with VGF, results show that cellulosic ethanol cannot be produced cheaply enough to be sold at the highest fixed ethanol price for 1G of INR 62.65 (US$0.85) per liter and also generate a return on investment that is likely to attract private investors. Even if these cost challenges were to be resolved, the amount of cellulosic ethanol that would be supported by the VGF program as currently proposed would only be sufficient to replace around 1% of gasoline demand in 2030. This would not do much to help to reach the increasing ethanol blending target or reduce fuel import demand.

There are several approaches that the Indian government could pursue to help scale up the cellulosic ethanol industry. First, within the existing policy framework, policymakers could entertain some combination of three measures: set a separate price for cellulosic ethanol (2G) that differs from 1G ethanol, at INR 80 – 95 (US$1.08 – 1.26) per liter if there is no VGF and INR 70 – 80 (US$1 – 1.08) per liter with the funding; provide a per liter subsidy for 2G ethanol to address the price gap; or increase the level of VGF. Second, policymakers could expand financial support by exempting import tariffs relevant to cellulosic ethanol production and/or providing low-interest government loans to cellulosic ethanol producers. Last, the national and local governments could work to establish and maintain a robust feedstock supply chain by providing necessary financial and technical support to farmers for collecting agricultural residues and by building necessary infrastructure, such as farm roads. Given all the benefits from cellulosic ethanol, the strong ambition behind increased ethanol blending, and the existing efforts from the government, India has a great opportunity to commercialize cellulosic ethanol in the near future.

REFERENCES

Abdi, B. (2019, June 20). Indian oil to invest Rs 700 crore in setting up 2G ethanol plant at Panipat refinery. *ETEnergyWorld*. Retrieved from https://energy.economictimes.indiatimes.com/news/oil-and-gas/indian-oil-to-invest-rs-700-crore-in-setting-up-2g-ethanol-plant-at-panipat-refinery/69872795

Adhanom, B.T. (2019). *Sugarcane bagasse-based bioethanol producing biorefinery plant simulation and techno-economic analysis* (master's thesis). Addis Ababa University, http://etd.aau.edu.et/handle/123456789/19345

Alexaki, N., van den Hof, M., & Jol, K. (2019). *From burning to buying: Creating a circular production chain out of left-over crop residue from Indian farm land*. Retrieved from https://www.rvo.nl/sites/default/files/2019/12/MVO-Nederland-rapport-India.pdf

Argonne National Laboratory (2020). *GREET model*. Retrieved from https://greet.es.anl.gov/

Bhuvaneshwari, S., Hettiarachchi, H., & Meegoda, J.N. (2019). Crop residue burning in India: Policy challenges and potential solutions. *International Journal of Environmental Research and Public Health, 16*(5), 832. doi: 10.3390/ijerph16050832

Biofuels International. (2020, February 7). TATA project win order for bioethanol plant in India. Retrieved from https://biofuels-news.com/news/tata-projects-wins-order-for-bioethanol-plant-in-india/

Brown, A., Waldhelm, L., Landalv, I., Saddler, J., Edadian, M., McMillan, J.D. ... Klein, B. (2020). *Advanced biofuels – Potential for cost reduction*. Retrieved from IEA Bioenergy, https://www.ieabioenergy.com/publications/new-publication-advanced-biofuels-potential-for-cost-reduction/

California Air Resources Board. (n.d.). *LCFS pathway certified carbon intensities*. Retrieved from https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

Centre for High Technology. (2020). *RFS no. CHT/PM JI-VAN/RFS/Commercial/2020/02*. Retrieved from https://cht.gov.in/en/pages/eoitenders

Central Board of Indirect Taxes and Customs. (2020). *GST rates*. Retrieved from https://cbic-gst.gov.in/gst-goods-services-rates.html

Central Electricity Regulatory Commission. (2019). *CERC RE Tariff Order 2019-20*. Retrieved from http://www.cercind.gov.in/2019/orders/Draft%20RE%20Tariff%20Order%20for%20FY%202019-20.pdf

Central Electricity Regulatory Commission. (2020a). *No. RA-14026(11)/4/2020-CERC*. Retrieved from http://www.cercind.gov.in/2020/regulation/159_reg.pdf

Central Electricity Regulatory Commission. (2020b). *Report on short-term power market in India: 2019–20*. Retrieved from http://www.cercind.gov.in/2020/market_monitoring/Annual%20Report%202019-20.pdf

Chemical Engineering. (2020). *The chemical engineering plant cost index*. Retrieved from https://www.chemengonline.com/pci-home

Cheng, M.H., Wang, Z., Dien, B.S., Slininger, P.J.W., & Singh, V. (2019). Economic analysis of cellulosic ethanol production from sugarcane bagasse using a sequential deacetylation, hot water and disk-refining pretreatment. *Processes*, *7*(10), 642. doi: 10.3390/pr7100642

CDM Executive Board. (2012). *Methodological tool: Tool for the demonstration and assessment of additionality (Version 07.0.0)*. Retrieved from https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-01-v7.0.0.pdf

Clean Development Mechanism. (2020). *Project search*. Retrieved from https://cdm.unfccc.int/Projects/projsearch.html

European Union, *Directive (EU) 2018/2001 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast), L 328/82*. (2018). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

Food and Agriculture Organization. (2020). *FAOSTAT burning – crop residues*. Retrieved from http://www.fao.org/faostat/en/#data/GB

Gandham, S. (2018). *A technical perspective on 2G biofuels and the way forward*. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/14_sriganesh_gandham-hpcl.pdf

Ganguli, S., Somani, A., Motkuri R.K., & Bloyd, C. (2018). *India alternative fuel infrastructure: The potential for second-generation biofuel technology*. Retrieved from the U.S. Department of Energy's Office of Scientific and Technical Information, https://www.osti.gov/servlets/purl/1530891/

Gnansounou, E., & Dauriat, A. (2010). Techno-economic analysis of lignocellulosic ethanol: A review. *Bioresource Technology, 101*(13), 4980–91. doi: 10.1016/j.biortech.2010.02.009

Gonsalves, O. (2018, April 5). India's industrial water rates and supply. *India Briefing*. Retrieved from https://www.india-briefing.com/news/industrial-water-rates-india-supply-16547.html/

Humbird, D., Davis, R., Tao, L., Kinchin, C., Hsu, D., Aden, A., … Dudgeon, D. (2011). *Process design and economics for biochemical conversion of lignocellulosic biomass to ethanol*. Retrieved from the U.S. National Renewable Energy Laboratory, https://www.nrel.gov/docs/fy11osti/47764.pdf

Kugemann, M. (2015). *Financial analysis of a biochemical cellulosic ethanol plant and the impact of potential regulatory measures* [Working Paper No. 2015-057]. Retrieved from https://www.merit.unu.edu/publications/working-papers/abstract/?id=5907

Malins, C., Searle, S., & Baral, A. (2014). *A guide for the perplexed to the indirect effects of biofuels production*. Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/ICCT_A-Guide-for-the-Perplexed_Sept2014.pdf

Ministry of Petroleum & Natural Gas. (2019). *Pradhan Mantri Ji-Van Yojana*. Retrieved from https://mopng.gov.in/files/uploads/PM_JI-VAN_YOJANA.pdf

Ministry of Petroleum & Natural Gas. (2020). *Petroleum*. Retrieved from Petroleum Planning & Analysis Cell https://www.ppac.gov.in/content/3_1_Petroleum.aspx

Ministry of Petroleum & Natural Gas. (2021). *Roadmap for ethanol blending in India 2020-25*. Retrieved from https://niti.gov.in/sites/default/files/2021-06/EthanolBlendingInIndia_compressed.pdf

MITCON. (2014). *Detailed project report (DPR) on integrated sugar (5000 TCD), cogen power (30 MW) & ethanol plant (60 KLPD)*. Retrieved from http://environmentclearance.nic.in/writereaddata/Online/TOR/0_0_05_Dec_2014_1806251771draft_DPR_-Lokmanya_Nov_2014.pdf

MITCON. (2015). *Detailed project report (DPR) on 80 KLPD ethanol plant from cane molasses*. Retrieved from http://environmentclearance.nic.in/writereaddata/Online/TOR/0_0_07_Dec_2015_1834272031DraftDPR_Distillery-_Pingale_Sugar.pdf

Mohan, N. (2019, December 30). IOCL's ethanol plant the answer to stubble trouble. *Hindustan Times*. Retrieved from https://www.hindustantimes.com/cities/iocl-s-ethanol-plant-the-answer-to-stubble-trouble/story-bPTg9LkPBvJdhDrwVuUqQN.html

Padella, M., O'Connell, A., & Prussi, M. (2019). What is still limiting the deployment of cellulosic ethanol? Analysis of the current status of the sector. *Applied Sciences, 9*(21), 4523. doi:10.3390/app9214523

Parbowo, H.S., Ardy, A., & Susanto, H. (2019). Techno-economic analysis of dimethyl ether production using oil palm empty fruit bunches as feedstock – a case study for Riau. *IOP Conference Series: Materials Science and Engineering*, 534, 012060. doi: 10.1088/1757-899X/543/1/012060

Pavlenko, N., & Searle, S. (2019). *The potential for advanced biofuels in India: Assessing the availability of feedstocks and deployable technologies*. Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/Potential_for_advanced_biofuels_in_India_20191213_0.pdf

Peters, D., Alberici, S., & Passmore, J. (2015). *How to advance cellulosic biofuels: Assessment of costs, investment options and required policy support*. Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/Ecofys-Passmore%20Group_How-to-advance-cellulosic-biofuels_rev201602.pdf

Power Finance Corporation. (2020). *Report on performance of state power utilities*. Retrieved from https://www.pfcindia.com/DocumentRepository/ckfinder/files/Operations/Performance_Reports_of_State_Power_Utilities/Report%20on%20Performance%20of%20State%20Power%20Utilities%202018-19.pdf

Press Information Bureau. (2018, May 16). *Cabinet approves National Policy on Biofuels – 2018* [Press release]. Retrieved from https://pib.gov.in/PressReleseDetail.aspx?PRID=1532265

Press Information Bureau. (2020, October 29). *Cabinet approves Mechanism for procurement of ethanol by Public Sector Oil Marketing Companies under Ethanol Blended Petrol Programme - Revision of ethanol price for supply to Public Sector OMCs for Ethanol Supply Year 2020-21* [Press release]. Retrieved from https://pib.gov.in/PressReleasePage.aspx?PRID=1668400

Purohit, P., & Dhar, S. (2018). Lignocellulosic biofuels in India: current perspectives, potential issues and future prospects. *AIMS Energy, 6*(3), 453–486. doi: 10.3934/energy.2018.3.453

PWC. (2020). *India corporate – taxes on corporate income*. Retrieved from https://taxsummaries.pwc.com/india/corporate/taxes-on-corporate-income

Saini, J.K., & Saini, R. (2015). Lignocellulosic agriculture wastes as biomass feedstocks for second-generation bioethanol production: concepts and recent developments. *3 Biotech*, *5*, 337–353. doi: 10.1007/s13205-014-0246-5

Sarwal, R., Kumar, S., Mehta, A., Varadan, A., Singh, S.K., Ramakumar, S.S.V., & Mathai, R. (2021). *Roadmap for ethanol blending in India 2020–25*. NITI Aayog and Ministry of Petroleum and Natural Gas. Retrieved from https://niti.gov.in/sites/default/files/2021-06/EthanolBlendingInIndia_compressed.pdf

Takriti, S.E., Searle, S., & Pavlenko, N. (2017). *Indirect greenhouse gas emissions of molasses ethanol in the European Union*. Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/EU-molasses-ethanol-emissions_ICCT-working-paper_27092017_%20vF.pdf

The Energy and Resources Institute. (2010). *Review of current practices in determining user charges and incorporation of economic principles of pricing of urban water supply* [Project Report No. 2009IA02]. Retrieved from http://mohua.gov.in/upload/uploadfiles/files/TERI_UC_Report26.pdf

The Economic Times. (2019, May 5). India's oil import dependence jumps to 84 per cent. Retrieved from https://economictimes.indiatimes.com/industry/energy/oil-gas/indias-oil-import-dependence-jumps-to-84-pc/articleshow/69183923.cms

Turner & Townsend. (2019). *International construction market survey 2019*. Retrieved from http://www.infrastructure-intelligence.com/sites/default/files/article_uploads/Turner%20Townsend%20International%20Construction%20Market%20Survey%202019.pdf

United States Environmental Protection Agency, *40 CFR Part 80, Regulation of fuels and fuel additives: Changes to Renewable Fuel Standard Program*. (2010). Retrieved from https://www.govinfo.gov/content/pkg/FR-2010-03-26/pdf/2010-3851.pdf

United States Department of Agriculture. (2020). *India biofuels annual*. Retrieved from https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_New%20Delhi_India_07-06-2020

Valin, H., Peters, D., van den Berg, M., Frank, S., Havlik, P., Forsell, N., & Hamelinck, C. (2015). *The land use change impact of biofuels consumed in the EU: Quantification of area and greenhouse gas impacts*. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/Final%20Report_GLOBIOM_publication.pdf

Vikash, P.V., & Shastri, Y. (2018). Conceptual design of a ligno-cellulosic biorefinery and its supply chain for ethanol production in India. *Computers and Chemical Engineering,* 121, 696–721. doi: https://doi.org/10.1016/j.compchemeng.2018.11.021

Vikaspedia. (2020). *National policy on biofuels 2018*. Retrieved from https://vikaspedia.in/energy/policy-support/renewable-energy-1/biofuels/national-policy-on-biofuels-2018

Webb, A. (2013, August 7). *What does it take to build an advanced biofuels plant*? *BioFuelNet Canada*. Retrieved from https://www.scribd.com/document/454718148/What-Does-It-Take-to-Build-an-Advanced-Biofuels-Plant-Biofueled-Blog

World Bank. (2020). *World Integrated Trade Solution*. Retrieved from https://wits.worldbank.org/about_wits.html

Zhao, L., Zhang, X., Xu, J., Ou, X., Chang, S., & Wu, M. (2015). Techno-economic analysis of bioethanol production from lignocellulosic biomass in China: Dilute-acid pretreatment and enzymatic hydrolysis of corn stover. *Energies*, *8*, 4096–4117. doi:10.3390/en8054096

Zhou, Y., Evans, M., Yu, S., Sun X., & Wang, J. (2020a). Linkages between policy and business innovation in the development of China's energy performance contracting market. *Energy Policy*, *140*, 111208. doi: 10.1016/j.enpol.2019.111208

Zhou, Y., Searle, S., Pavlenko, N., Kristiana, T., Sudaryadi, & Amukti, R.H. (2020b). *Techno-economic analysis of cellulosic ethanol in Indonesia using palm residues*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/techno-economic-cellulosic-ethanol-2020