AN ASSESSMENT OF INDIA's POTENTIAL TO SUSTAINABLY FULFILL THE MANDATES OF ITS ETHANOL BLENDING PROGRAMME (EBP)

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Abstract

India is the third-largest emitter of CO_2 in the world. A major portion of these emissions comes from the burning of imported fossil-fuels in its road transport sector. To conserve the environment and to secure its energy needs, India has embarked on an ambitious program to blend ethanol with gasoline. However, most of the ethanol produced in India is from food-based feedstock which is being questioned for its sustainability. To overcome the same, India can leverage its huge potential of 2nd generation feedstock to produce bioethanol in large quantity. This paper has therefore used data available from various government and world-body (like FAO) reports to assess the amount of 2nd generation feedstock available in India that can be sustainably utilised for bioethanol production. The results obtained from the use of 'spatial availability' modelling tools have been used, where data gaps exist. These estimates have then been used to evaluate the possible ethanol production using empirical data available for the yields obtainable from biochemical and thermochemical pathways. The results indicate that India can produce between 65-92 billion liters of bioethanol per annum (based on base-year 2020) which can allow it to not only fulfill mandate of E20 blending ration but also of E50 ratio, when required.

Keywords:Bioethanol, Crop-Residue, Energy-Crops, Ligno-Cellulosic Biomass, India

1. Introduction

Under the growing concerns of climate change and also to reduce its imports of fossil-fuels, the Government of India, through its National Policy on Biofuels, has been promoting the use of biofuels (with targets of 5% and 20% blending in diesel and petrol respectively by 2030). As the blending of ethanol in petrol crossed 10% in the year 2021-22, the Government shifted the target of 20% ethanol-blending to year 2025-26 from 2030.[i]India is currently producing 4.2 billion litres of ethanol and intends to increase the production to 14-15 billion litres so that 10 billion litres of ethanol is available to meet the mandates of its Ethanol Blending Programme by 2025.

Though, the government has already approved the use of non-food feedstock like cellulosic and lignocelluloses materials including petrochemical route for the production of ethanol, most of the ethanol (70%) production in the country is from sugarcane molasses while the balance 30% is from grains. Sensing the stiffness of blending-targets, the government also permitted the use of food-feedstocks like B heavy molasses, sugarcane juice, damaged food grains & surplus food grains for supporting enhanced ethanol production in the country.

However, it should be noted both sugarcane and rice are land and water-intensive crops. With 45% of land in India already under cultivation, there is hardly any additional cultivable land available for expansion of cropping area. Further, irrigation of crops is necessary in India as the monsoon season is limited in duration while crop-cultivation is carried out round the year. Thus, India has already stretched itself in terms of land and water resources and the continued utilisation of food-crops for biofuel production will not only result in increase of the food prices but will also add to water-stress. Accordingly, the use of non-food feedstock would be necessary to ensure that the EBP is implemented in a sustainable and effective manner in India.

2. Aim

The aim of this paper is to assess the quantum of feedstock that can be sustainably drawn for ethanol production and to evaluate the level to which the mandates of EBP can be sustainably met by the country indigenously.

3. Materials & Methods

Ethanol production can be classified into various generations, like 1st, 2nd, 3rd and 4th generation, depending upon the feedstock and technology employed for its processing. Since 3G and 4G pathways are still immature and the use of 1G feedstock is debatable from sustainability point of view, this paper will focus on the 2G feedstock only. Accordingly, only non-edible feedstock like agricultural residues, forest residue, fruit and vegetable wastes etc.; energy crops grown without causing land use changes or water stress; waste lipids like Used Cooking Oil, animal fats and tall oil; MSW are being considered. Sugar streams derived from surplus of sugarcane or spoiled grains (rice) have been evaluated to assess their impact on the overall production capacity. To assess the potential of bio-ethanol from above mentioned feedstock, a four-step evaluation will be conducted:

Establish the total annual crop and commodity production.

Estimate the total crop residues and wastes using established pattern and empirical data.

Identify the current usage of these residues and wastes to estimate the fraction that would be sustainably available for bio-ethanol production. The sustainability aspect is factored by including the existing utilisation of the crop residue for various purposes like local consumption (for which no alternative exists); demands of other sectors; preservation of soil organic carbon, need to minimise soil erosion, conservation of biodiversity, prevent ecological and environmental pollution resulting from on-site burning of residue, and avoidance of land and water stress resulting from increased cropping or land use change (direct or indirect).

Lastly, assess the current and future ethanol production potential from the net available feedstock employing established data on conversion technologies.

To maintain the evaluation contemporary, the baseline year for data-collection has been taken as 2020 as very little updates were posted during the COVID times. Estimates for 2020 have been extrapolated from old data where fresh data on the subject is not available. Most of the data used for establishing the availability of feedstock has been obtained from government sources and renowned global bodies i.e., Ministry of Agriculture, Ministry of New & Renewable Resources, FAO. To assess the spatial availability and suitability of culturable wastelands in India for plantation of energy crops like Jatropha in India, data as obtained from the IIASA (FAO) global agro-ecological zone modelling framework (GAEZ v3.0) is used. This was also reconciled with the results obtained by McKinsey & Company using their Agricultural Commodity Research Engine (ACRE) tool.

The data on process productivity and technological readiness has been obtained from various reports published by McKinsey & Company, WEF, CST and ICCT. Tele-discussions with subject matter experts in India (from IIPM and CSIR) were also conducted to gain insights on India specific issues. Since the inputs provided by these reports have a wide variance, triangulation of data has been done by the authors to find the best fit.

4. Assessment of feedstock availability

4.1 Crop residue:India is one of the largest producers of food grain, oilseeds, sugarcane and fibre in the world. Using, the established crop-production data of 2019-20 and applying Residue Production Ratio (RPR) on them, an estimate of the residues being generated is presented in Table 1. Though a large quantum of this residue (92 Mt)[ii] is being unproductively burnt on the field, most of it is put to use as per its nutritive value, lignin content, density and palatability to livestock. Most common usages are as fodder for cattle, fuel for cooking and as thatch material for housing while some residue is also used for animal-bedding, bio-gas and power generation, compost & manures, mushroom cultivation, soil mulching, making textile composites etc. Thesurplus availability of these crop-residue therefore varies from 10–70%.[iii] Some of the major usage of crop-residue in India are discussed below.

4.1.1 Fodder: Owing to the poor grass productivity in the country, crop residues (specifically cereal crop-residue) form a major source of food for cattle in India. The estimated requirement of dry fodder for feeding the current population of 302 million (only cows & buffalos) at the scale of 6 kg/animal/day works out to 661 Mt/year which implies that around 70-90% of all cereal crop residue will continue to be absorbed for cattle-feeding.

4.1.2 Mulching:Some amount of crop residues should be left in the field to reduce erosion, preserve the soil organic carbon (SOC) and to return NPK (nitrogen-phosphorus-potassium) nutrition to soil. Though there is no conclusive study on the subject, the authors estimate that leaving 10-20% of crop residue on field for mulching would be sufficient.

4.1.3 Power generation:In order to prevent on-site burning, Indian government is also promoting the use of crop-residue for power generation. For example, the SATAT scheme envisages establishment of 5000 plants for producing 15 Mt of CBG by 2023-24 using various kinds of feedstock.[iv] To account for this usage, 20% of the total bagasse availability (amounting to 11.6 Mt) and 13.1 Mt[v] of the total crop-residue is being left aside.

4.1.4 Other uses: The utilisation for other uses like compost, thatches for houses, textiles, mushroom farming is likely to remain constant or reduce over a period of time.

4.1.5 Net Availability: The net residue availability after considering the above discussed utilisations is given in Table 1. Setting aside another 10% for uncollectable quantity and domestic use, the sustainably available crop-residue for energy production is fixed at **175 Mt**.

Crop	Type of residue	Crop yield (Mt)	RPR	Total Residue (Mt)	Residue availability (Mt)	
Rice	Straw & husk	118.87	1.81	216.1	10%	21.6
Wheat	Straw	107.86	1.59	172.6	-	0
Jowar (Sorghum)	Stalk	4.77	2.0	9.54	-	0
Bajra	Straw	10.36	1.99	20.7	-	0

Maize	Stalk & cobs	28.77	2.48	71.9	10%	7.2
Other cereals	Stalk	3.8	2.0	7.6	-	0
Gram	Waste	11.08	1.6	17.7	70%	12.4
Tur/Arhar	Shell & waste	3.89	2.85	11.1	50%	5.55
Masur/Lentil	Shell & waste	1.1	2.79	3.1	50%	1.55
Other pulses	Shell & waste	6.8	2.85	19.4	50%	9.7
Ground nut	Waste	9.95	2.30	22.9	20%	4.58
Rapeseed & mustard	Waste	9.12	2.0	18.2	70%	12.74
Other oilseeds	Waste	22.4	2.01	44.8	70%	41.36
Cotton	Seeds and waste	6.4	3.57	22.8	70%	15.96
Jute & mesta	Waste	1.72	1.6	2.75	80%	2.2
Sugarcane	Bagasse & leaves	370.5	0.4	148.2	40%	59.28
Total		717.39		809.39		194.11

Table 1: Net agri-residue in India for biofuel production
(Source: Compiled by authors based on consultations from experts and data of reports[vi])

4.2 Horticulture Waste:Fruit and vegetable waste (FVW) like peels of pineapple, blueberry, apple, orange, banana, potato, tomato, cabbage, pea provide high yields of 0.3 to 0.38 gram/kg of waste.[vii, viii] In 2010-11, 15.73 Mt of vegetable waste and 15.03 Mt of fruit waste was rendered surplus in India.[ix] Another, 2 Mt of FVW is generated during processing. By extrapolating the available data, estimates of 19 Mt of FVW (at 50% availability for energy purpose) are obtained for 2019-20.

4.3 Forest Residue:As per Indiastat (2015), approx. 95 million cubic meters of round-wood was produced in India in 2010 and the demand for 2020 was estimated at 153 million cubic meters. Taking a RPR of 0.4, an availability of 61 Mt of forest residues is estimated. Leaving aside 20% of forestry residues for soil-quality conservation and another 30% for use by locals as fuel wood and other purposes, a net forest residue of 30 Mt could be sustainably available for biofuel production.

4.4 Energy Crops:Using spatial mapping, the Wasteland Atlas, prepared by Department of land Resources, identifies 19.7 Mha of land with dense scrub, land with open scrub, land affected by salinity/alkalinity, abandoned cultivation area, land under shifting cultivation, degraded pastures/grazing land, mining wastelands and industrial wastelands that can be used for cultivation of energy crops.[x] Considering that this data is of 2008-10 vintage and many wasteland are being increasingly used for additional cropping or development projects, it is estimated that 50% of this land i.e. 10 Mha can be sustainably used for growing energy crops. Assuming that the yields will be lower on marginal lands (@50% of maximum), it can be estimated that this land can provide up to 25 Mt of biomass using miscanthus (@ 5 Mt/ha).

4.5Bamboo: Bamboo is grown over 1,500 acres in Uttar Pradesh, Assam, Tripura, Arunachal Pradesh, Rajasthan, Bihar and other states. A 2G biorefinery established in these States can process 0.5 Mt of bamboo per annum to produce 49 Mt of ethanol, 11 MT of acetic acid, 19

MT of furfural (used in making inks, plastics, antacids, adhesives, fungicides, fertilisers, etc.) and other associated products.

4.6 Municipal Solid Waste: India generates 62 million tons of waste (containing both recyclable and non-recyclable waste) every year (PIB 2016). While about 75% (42.9 million tons) of municipal waste is collected, only 22% (11.9 million tons) of this is treated and the balance (31 million tons) is dumped. Since most of this dumped waste (more than 65%) is organic, it can be employed for biofuel production. MNRE estimates[xi] that total MSW generation will reach 165 Mt by 2031 and 434 Mt by 2050. Interpolating from this trend and assuming that collection rate remains at 75%, the authors assess an availability of **57 Mt** of MSW in 2020 for biofuel production.

4.7Surpluses Crops: Owing to good monsoons and use of higher-yield sugarcane varieties, India has been producing surplus sugar annually in recent times. In 2020-21, after a domestic consumption of 26.5 Mt and exports of 7 Mt, India had a reserve stock of 8.5 Mt.[xii] The excess sugar (approx. 8 Mt) can instead be used to produce ethanol. Since sugarcane is very water intensive, the crop area of this excess sugarcane can be used to alternatively plant low-maintenance crops like sweet sorghum or cassava/tapioca for production of 2 Mt of ethanol.[xiii, xiv]Similarly, excess rice production in the country (India exported more than 20 Mt in 2021-22) can be tapped for providing the 6 Mt of feedstock for grain-based distilleries and further conversion of ethanol to 2 Mt of SAF/ fuels for other hard-to-abate sectors, if required.[xv]

5. Estimated ethanol production capacity

To convert these feedstocks into ethanol, a number of pathways are available, however, as per the technological maturity, availability of technical data and suitability for available feedstock, only the following biochemical (Anaerobic fermentation) or thermo-chemical (gasification followed by Fischer-tropsch synthesis) pathways will be considered in this paper.

Anaerobic fermentation (i.e., hydrolysis followed by fermentation to alcohols) converts substrates such as cellulose into glucose and then to ethanol for use in beverages, fuels, and to other chemicals (e.g., lactic acid used to produce renewable plastics) and products (e.g., enzymes for detergents). While fermentation of starch and sugar-based feedstocks (i.e., corn and sugar cane) into ethanol is common, cellulosic biomass feedstocks are more difficult to process with fermentation. Cellulosic feedstocks, including a large portion of the organic fraction of MSW, need hydrolysis pre-treatment (acid, enzymatic or hydrothermal hydrolysis) to break down some of the recalcitrant hemicellulose and cellulose to simple sugars for fermentation by yeast and bacteria. The lignin portion of biomass, which is approx. 25-30 wt.% of biomass, is also difficult to convert via biochemical processes, and is typically considered for use as boiler fuel or as a feedstock for thermochemical conversion to other fuels and products. Accordingly, the conversion rate from this pathway is lower. Alcohols, like ethanol and butanol, are the primary energy product from hydrolysis and fermentation processes. Current, commercial biofuels include microbially produced alcohols, principally ethanol from Saccharomyces cerevisiae fermentation and n-butanol from Clostridium bacteria or from chemical conversion of ethanol.

Gasification-FT synthesis involve heating of biomass under low-oxygen conditions to produce intermediates like syngas which is further processed using fischer-tropsch process to produce ethanol/gasoline. The gasification-FT process provides better yields and also displays good product selectivity. Depending upon the type of catalysts used (iron or cobalt), greater yields of gasoline or diesel can be obtained through this process.

Both the pathways, even when optimised for a particular product, inevitably produce co-products such as Furfural, Xylitol, L-Arabinose, high fructose syrup etc. which may increase profitability of business, de-risk investment and economise production.[xvi]

The yield of ethanol after selecting the most appropriate pathway for the feedstocks has been worked out in Table 2. The total potential for ethanol production from the assessed feedstock availability can be between 65-92 billion litres. This is much more than the 10 billion litres required for E20 blending and can also permit E50 blending in India.

Feedstock type	Feedstock quantity (Mt)	Ethanol production (billion litres)
Crop-residue	175	37-52
Forestry residue	30	6-9
Energy crops	25	6-8
FVW waste	19	4-6
MSW	57	7-11
Surplus crops	6	2-2.5
Surplus sugar	8	2.5-3
Bamboo	1	0.3-0.4
Total		**65-92**

Table 2: Estimated cellulosic ethanol production capacity in India
Source: Conversion rates evaluated by authors from that available in WWF 2022[xvii], WEF 2020[xviii], ICCT 2019[xix], ICCT 2021[xx], World Bank[xxi]

The biorefineries, apart from producing cellulosic ethanol, will also produce pellets (from surplus lignin); biogas (which can be upgraded to Bio CNG); liquid CO_2/ Dry Ice (for supplies to Poly Houses & cold storages, which would support horticulture activity) & assured quality compost (which will increase farm yields & reduce chemical fertiliser consumption).

6. Technological challenges in 2G ethanol production

The higher cost of 2G ethanol is a constraining factor in enhancing their wider acceptability. The higher cost of majority of the biofuel production technologies are attributed to the poor economies of scale and the availability and price of feedstock. Accordingly, the focus of research is on exploring options for the production of sustainable biomass feedstocks; developing new pre-treatment and conversion technologies for the wide range of feedstock; integrating available conversion techniques to develop efficient processes that deliver a desirable combination of fuels and bio-products; adapting existing conversion systems for new fuel properties and; identifying desirable process combinations that maximise the aspects of affordability, resilience, carbon reductions and deliver wider ecosystem benefits. The key technical challenges relating to the main conversion steps of biofuels pathways and the improvements required are discussed below.

Pre-treatment and Hydrolysis: Pre-treatment and hydrolysis are the most expensive process steps (is energy-intensive and/or use a great deal of chemicals) and the technically most difficult tasks in the fermentation of lignocellulosic biomass to biofuels. The separation of cellulose and lignin is difficult to achieve and reduces the conversion efficiency. The severe pre-treatment conditions forms degraded products (furfurals, acids) which inhibit downstream fermentation. The process is not very flexible as the enzymes used for the hydrolysis process are selective to a feedstock and not suited to mixed feedstocks. Solid loading is often limited, resulting in low product concentrations and large mass flows to be treated downstream. Effective delignification processes, optimisation of pre-treatment conditions and/or development of detoxification methods, reduced energy and materials demand, flexibility in enzyme selectivity and solid loading are some of the improvements required.

Fischer-Tropsch Synthesis:Though this process is commercially available for converting natural gas and coal syngas to liquid fuels, its application for advanced biofuels pathways faces a number of challenges. This is because the typical scale of operation of biomass gasification is several orders of magnitude lesser. At the same time, biomass-derived syngas has a different quality and deactivates the catalyst by sulphur poisoning. Additionally, the selectivity towards required diesel, jet or gasoline fractions are limited to less than 40%. Significant amounts of unwanted olefins, alcohols, acids, ketones, water and CO_2 are also produced. Though these can be upgraded and fractionated to biofuels of choice through hydrogenation, isomerisation, reforming, cracking and distillation; it results in higher capital costs and increased process complexity. Improvements required include refined reactor designs (modular micro-channel reactors) and development of advanced catalyst and catalyst separation systems.

Gasification and Syngas Cleaning:The gasification systems require high quality, homogeneous feedstocks in order to operate reliably and efficiently. Further, most downstream processes require a high-quality syngas, and therefore the raw syngas must be cooled and cleaned to remove dust, alkali metals, halogens, sulphur, tars and CO_2 which increases capital costs and increase energy demand. Some gasifier systems produce high tar levels, which can clog heat transfer equipment and pipes when they condense during cooling processes (fouling). This leads to increased corrosion and erosion, higher maintenance requirements to avoid pipe blockages or reduced performance. Robust gasifier performance including development of plasma gasifiers; integrated processes optimised for energy efficiency and; processes optimised to minimise the environmental and economic impacts of effluents are some steps that can improve the efficiency of this technology.

7. Measures to facilitate greater 2G ethanol production

7.1 Collection of feedstocks: To maximise the productivity, an efficient feedstock collection system needs to be organised. Incorporation of a digital platform in the collection mechanism, education and training of all stakeholders, boosting of public-private partnership and development of greater synergy between waste sellers and buyers will be necessary to facilitate collection in commercial quantities.[xxii] The supply chain will need to cater for transportation costs, seasonality of crop production and the coordination between farmers, transporters and plant owners. Establishment of a biomass depots systems for stocking of biomass and its operation by entrepreneurs (utilizing NABARD & MNREGA schemes) will ensure smooth and continuous flow of feedstock.

For the collection of MSW, an integrated waste-processing system should be established with the help of local municipal bodies that should include the stages of collection, segregation, sorting and transportation of MSW. Creation of a reliable vendor/contractor base for ethanol production plants and sale of co-products will reduce the risk associated with plant operations. Institution of a revenue-sharing mechanism with private municipal contractors will ensure establishment of a smooth and efficient supply chain.

7.2 Other measures: The following measures will helpin providing initial thrust for promoting greater 2G ethanol production in India.

Continuous investment in R&D to identify newer, productive and sustainable feedstock.

To stay ahead of the technology curve, India should move early in to cellulosic ethanol production and accelerate the deployment of new technologies. Similarly, continuous research to find cost-effective catalysts, enzymes and microbes and processes will be crucial to making 2G ethanol production process cost competitive.

A boost to biochemical engineering & service support systems (customized for Indian feedstock) for co-products of ethanol production will be important for ensuring better return on investment and de-risking of plant assets.

The cost of producing biofuels will reduce with maturity of production technologies and economies of scale. Some form of viability gap funding would be necessary, till such time economies of scale kick-in and production technologies mature, to make 2G ethanol cost-competitive with fossil jet-fuel. Short-term schemes that incentivise the production and use of cellulosic ethanol, like a different tax slab or waive-off of some fee, will help in attracting investments. Continuation of administered price mechanism; setting of a differential ethanol price based on raw material utilized for ethanol production. Interest Subvention Scheme can help in rapid of the ethanol production capacity.[xxiii]

Promulgation of a long-term road map will bring transparency and provide confidence to plant operators in venturing into 2G ethanol production in India.

8. Conclusion

The establishment of ethanol production base in India offers a number of advantages like improved climate impact through reduced CO_2 emissions, better air quality (due to reduced stubble-burning), better waste management, infusion of better practices, technology and tools in agriculture, promotion of economic growth and energy self-reliance through creation of new jobs; generation of 10-15% additional incomes to farmers[xxiv]; increased revenue generation for cities by efficient MSW disposal; and exports. Therefore, efforts should be made to maximise these economic and social benefits.

The paper has estimated feedstock availability, also outlined the technological pathways for efficient ethanol production and has identified the levers that can incentivize and support greater ethanol production in India. However, it is an analysis at foundational level and more research is required for studying the sustainability aspect of various feedstock on a lifecycle basis and for optimally allocating available feedstock between demands from competing sectors. Similarly, more research should be conducted to develop cost-effective processes including the identification of resilient microbes/ enzymes/ catalysts that can help 2G production pathways commercialise at the earliest.

References

[1] [i] GoI, MNRE: Ethanol blending program. PIB, New Delhi, Release ID: 1885828, 22 Dec 2022

[2] [ii] GoI Press information: Niti Aayog in an article in The Economic Times in Feb 2019

[3] iii M Hiloidhari, Dhiman Das, and D.C. Baruah 2014. 'Bioenergy potential from crop residue biomass in India', Renewable and sustainable energy reviews, 32 : 504-512
[4] iv Indian Oil, Petroleum Minister Launches SATAT Initiative to Promote Compressed Bio-Gas as an Alternative, Green Transport Fuel, https://iocl.com/Satat.aspx (link as of 22/2/21).
[5] vAssessed from data of 2012-13 published on MNRE website and using empirical figures of 1.6 kg of bagasse consumption/KWh of power generated (at load factor of 50%) and 1.21 kg of biomass consumption/kWh of power generated (at load factor of 80%).
[6] vi Ravindranath, N.H., Lakshmi, C.S., Manuvie, R., Balachandra, P. 2011. Biofuel production and implica- tions for land use, food production and environment in India. Energy Policy, 39 (10), pp. 5737-5745
[7] viiH Huang, N Quereshi, MH Chen, W Liu, Vijay Singh. Ethanol production from food waste at high solid content with VRT. Journal of Agriculture and Food Chemistry. 2015, 63,10,2760-66.
[8] viiiKnowledge consortium of Gujarat, Dept of higher education, Govt of Gujarat. Bioethanol production from fruit and vegetable waste using yeast. Journal of Science, 16, Jun-Aug 2018
[9] ix S Bhattacharjya, A Sahu, MC Manna and AK Patra, ICAR-IISS. Potential of surplus crop residues, horticultural waste and animal excreta as a nutrient source in central and western regions in India. Current Science, vol 116, No 8, 25 Apr 2019
[10] x India Department of Land Resources, "Wastelands Atlas of India 2011," (2011), https://dolr.gov.in/documents/wasteland- atlas-of-india
[11] xi GoI, Ministry of New and Renewable Energy, "Power Generation from Municipal Solid Waste," (2016), http://164.100.47.193/lsscommittee/ Energy/16_Energy_20.pdf.
[12] xiiMinistry of Consumer Affairs, Food & Public Distribution. PIB Delhi, 04 May 2022. Release ID: 1822713.
[13] xiii ISSASS. 2007. Feasibility Study for an Integrated Anhydrous Alcohol Production Plant Using Sweet
[14] Sorghum as Feedstock. Final Report. International Society for Southeast Asian Agricultural Sciences (ISSASS), Inc. Rm. 411a, Vega Center, Los Baños, Lagun
[15] xivhttps://krishijagran.com/agripedia/are-tuber-crops-the-next-generation-bio-fuels/ accessed on 29 Jun 2022
[16] xv Cabinet Committee on Economic Affairs (2020), Cabinet Approves Modified Scheme to Enhance Ethanol Distillation Capacity in the Country, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1684626 (link as of 22/2/21).
[17] xvi GoI, MoPNG Notification, 2019. Pradhan Mantri JI-VAN Yojana.
[18] xvii WEF (CST & McKinsey), May 2022. Insight Report: Delivering on the Global Power-to-Liquid Ambition
[19] xviii WEF (CST & McKinsey), 2020. Insight Report: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation.
[20] xix ICCT 2019 (N Pavlenko and S Searle). Working Paper 2019-22, The potential for advanced biofuels
[21] in India: Assessing the availability of feedstocks and deployable technologies. Dec 2019
[22] xx ICCT 2021 (J O'Malley, N Pavlenko, S Searle). Working paper 2021-13: Estimating sustainable aviation fuel availability to meet growing EU demand
[23] xxiCheng, Jay & Timilsina, Govinda (2010). Advanced biofuel technologies: status and barriers. The World Bank, policy Research Working Paper Series
[24] xxii The Economic Times (2019), Government Launches Programme for Converting Used Cooking Oil into Biodiesel in 100 Cities, https://economictimes.indiatimes.com/industry/energy/oil-gas/government-launches-programme-for- converting-used-cooking-oil-into-biodiesel-in-100

cities/articleshow/70617703.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst (accessed on 25/2/22).
[25] [xxiii]https://mopng.gov.in/en/refining/ethanol-blended-petrol accessed on 03 Feb 2023
[26] [xxiv] WEF, CST (2021). Insight Report: Deploying Sustainable Aviation Fuels at Scale in India