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TECHNO-ECONOMIC AND ENVIRONMENTAL ASSESSMENT OF BIOJET FUEL PRODUCTION IN BRAZIL

(Presented by Brazil)

SUMMARY

This Information Paper presents a summary of the study entitled "Techno-economic and Environmental Assessment of Biojet Fuel Production in Brazil". The study assumed the introduction of completely self-sufficient biorefineries, i.e. which only take different types of biomass (sugarcane stalks and straw, forest resources, and vegetable oils) as main inputs and do not rely on external electrical energy, natural gas, or other energy sources for the production of biojet fuel and other biofuels. The analysis prioritized three biojet fuel conversion routes already approved or currently under analysis by ASTM International. Twelve biorefinery scenarios were defined and assessed in terms of economic and environmental impacts.

1. INTRODUCTION

1.1 Brazil is internationally recognized for its long experience in the use of biomass for energy purposes, mainly with sugarcane and oil crops for ethanol and biodiesel production, respectively. Modern bioenergy represents around 30% of the Brazilian energy matrix, and has a long track record reconciling biofuel production, food security, and rural development. Much of what Brazil has done in the bioenergy area was accomplished by long-term policies and investment in research and by building up human capacity (Cortez et al, 2014).

1.2 The development of a new industry will entail the participation of different sectors of the Brazilian economy including not only research institutions and biofuels producers, but also feedstock producers, financial institutions, international relations groups, the aviation industry, and environmental and social advocacy groups. Regarding the potential for the development of sustainable aviation biofuels, Brazil is seen as a key player, having a unique strategic advantage worldwide.

1.3 Committed to foster the biojet fuel value chain in Brazil, Embraer S.A. and The Boeing Company Joint Research Center - Sustainable Aviation Biofuels Research & Development, located at the Technological Park in the city of Sao Jose dos Campos, SP, Brazil, contracted the study "Techno-economic and Environmental Assessment of Biojet Fuel Production in Brazil" under the responsibility of the Brazilian Bioethanol Science and Technology Laboratory (CTBE) of the Brazilian Center for Research in Energy and Materials (CNPEM). This study compared different routes for biojet fuel production integrated to sugarcane biorefineries in Brazil. Twelve scenarios were designed with sugarcane mills annexed to different ASTM-approved Synthetic Paraffinic Kerosene (SPK) biojet fuel technologies: Hydroprocessed Esters and Fatty Acids (HEFA), processing palm oil, macauba oil, or soybean oil; Gasification and Fischer-Tropsch Synthesis (FT), consuming sugarcane bagasse, straw, and eucalyptus; and Alcohol to Jet (ATJ), processing 1G ethanol, 2G ethanol, or isobutanol. H_2 required for biofuel production is produced on-site either through water electrolysis (WE), catalytic ethanol steam reforming (CESR), or separated from synthesis gas (in FT routes).

2. ASSUMPTIONS

2.1 For the biorefinery conception, the base sugarcane mill was considered as an autonomous ethanol distillery processing 4 million tonnes of sugarcane/year and which recovers 50% of sugarcane straw from the field. This is the average size of new sugarcane mills in Brazil (Bonomi et al, 2016), especially in the sugarcane expansion region (Central-Western Brazil). There are currently around 30 sugarcane mills in Brazil with such milling capacity or higher. After process integration, as shown in Figure 1, the product portfolio of a biorefinery can potentially include renewable hydrocarbon fuels along with hydrated ethanol and electrical energy.

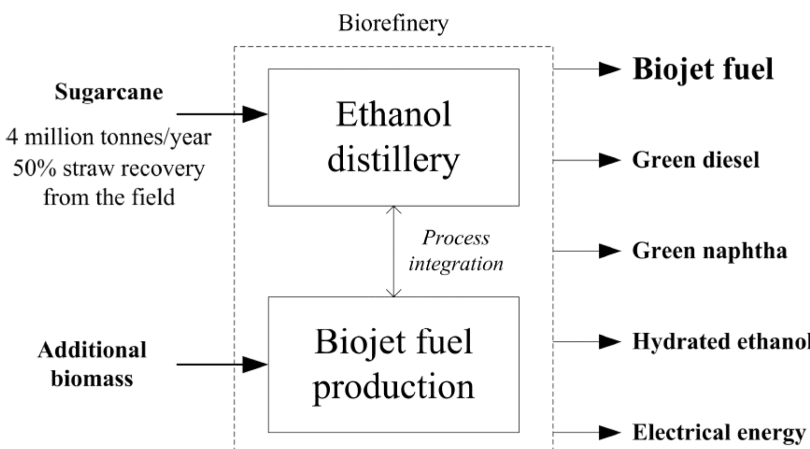

Figure 1. Biorefinery combining an ethanol distillery and a biojet fuel production plant

3. SCENARIOS

3.1 The work was executed using literature data and with CTBE's know-how of the Brazilian sugar-energy industry. The existing framework of the Virtual Sugarcane Biorefinery (VSB) was adapted to include the routes required for the study. The agricultural phase of the biorefineries (cultivation, harvest, and transport of sugarcane stalks and straw, eucalyptus, macauba, palm, and soybean) were simulated for biomass production cost estimation. Process simulation was also employed to establish mass and energy balances of the biorefineries and to outline process integration strategies. Both capital expenditures (CAPEX) and operational expenses (OPEX) were determined for each scenario and a 25-year discounted cash flow rate was used to determine the Internal Rate of Return (IRR) and minimum jet fuel selling price (MJSP). For MJSP calculation, the selling price of every biorefinery product except for biojet fuel is fixed and the selling price of biojet fuel is varied for the IRR of the biorefinery to attain 12%. The application of this methodology results in applying all price advantages or disadvantages on the selling price of biojet fuel, since this product must account alone for the economic performance of the biorefinery. All product prices and input costs were adjusted to December/2015. Exchange rates of 1 US$ = R$ 3.86 and 1 € = R$ 4.23 were employed mainly for CAPEX estimation. The biorefineries were assessed and ranked in terms of biojet fuel production capacity and capability of substituting 5% of the fossil jet fuel consumption in Brazil in 2014 (equivalent to 375 million L/year). Full techno-economic and environmental impacts assessment were also carried out. The ethanol distillery is considered to be located in Central-Western Brazil (Goiás state), with palm oil production in the North (Pará state), macauba oil production in the Southeast (Minas Gerais state), and soybean oil also in Goiás. Eucalyptus is obtained from regions nearby sugarcane crops. Biomass logistics were taken into account throughout the assessment.

4. RESULTS

4.1 Obtained results show (see APPENDIX 7.1) that the product portfolio of the biorefinery, as well as their economic and environmental performances, are highly dependent on the feedstock, on the SPK biojet fuel production route, and on the plant location. A single biorefinery producing biojet fuel with HEFA/palm oil/WE is able to supply 267 million L/year (71% of the 5% substitution target). Two of such biorefineries with individual CAPEX of R$ 2.2 billion would be sufficient to reach (and easily surpass) the 5% substitution target, thus requiring 348,000 hectares of agricultural land for the cultivation of sugarcane and palm in total. Table E1 summarizes this same analysis for each scenario.

4.2 FT routes presented higher IRR than the minimum acceptable rate of 12%: 16.5% for exclusive sugarcane processing and 13.5% for combined sugarcane and eucalyptus processing. Among HEFA biorefineries, employing macauba oil/WE yielded the best IRR (9.2%) due to the lower production and transport cost of macauba oil in comparison to palm oil and soybean oil (R$ 1,280/tonne, R$ 1,570/tonne, and R$ 1,660/tonne, respectively). ATJ processing of isobutanol produced an IRR of 5.7%. Employing CESR is not an economically-feasible technique for H2 production in comparison to WE, since biorefineries using the technique yield non-calculable IRR (expenses higher than revenues). Results for MJSP are also highly dependent on the biorefinery configuration. The best values are of R$ -0.84/L for FT/sugarcane (meaning that other products from the biorefinery portfolio alone could provide an IRR of 12%), R$ 1.38/L for FT/sugarcane+eucalyptus, R$ 2.29/L for HEFA/macauba oil/WE, and R$ 2.62/L for ATJ/isobutanol. The average of historic prices for fossil jet fuel in Brazil is of R$ 1.91/L. The competitiveness of biojet fuel routes can also be conditioned to the international jet fuel price and, consequently, to crude oil price. With the oil barrel at US$ 40, only the FT/sugarcane scenario is competitive. When oil prices rise to US$ 100/barrel, the following scenarios are able to produce biojet fuel at competitive prices: FT/sugarcane, FT/sugarcane+eucalyptus; HEFA/WE with macauba oil, palm oil, and soybean oil; and ATJ/isobutanol.

4.3 Green diesel produced in the industrial plant is used to substitute all (in HEFA and FT biorefineries) or part (in ATJ biorefineries) of the fossil diesel employed in sugarcane agricultural operations (13 thousand tonnes/year). This practice greatly improves the environmental impacts of the venture as a whole, as well as reduces the production cost of sugarcane stalks and straw used in ethanol distilleries. All biojet fuel types produced in the biorefineries presented reductions in greenhouse gas (GHG) emissions greater than 50% when compared with fossil jet fuel (83.6 g CO_2 eq/MJ jet fuel), thus being characterized as advanced biofuels. FT-derived biojet fuel yielded emissions of 9.3-9.4 g CO_2

eq/MJ, with 16.9-22.3 g CO_2 eq/MJ jet fuel for HEFA/WE and 17.7 g CO_2 eq/MJ jet fuel for ATJ/isobutanol.

5. CONCLUSIONS

5.1 The present study assessed the potential of producing biojet fuel in integrated biorefineries with ethanol distilleries in Brazil. Among biorefineries using HEFA technology, those employing WE for H_2 production can process more vegetable oil than their counterparts employing CESR – consequently, biojet fuel production is higher in the first case. The former plants are able to reach between 61% and 71% of the jet fuel substitution target, while the latter ones attain from 33% to 37% of the same target. FT biorefineries show interesting global results when integrated to ethanol distilleries. Although with relatively low biojet fuel production (reaching between 11% and 27% of the 5% substitution target), both assessed biorefineries are able to produce hydrated ethanol, electrical energy, and proportionally high quantities of naphtha to be sold to the market. Finally, ATJ biorefineries present mixed techno-economic results. Estimates for the MJSP showed competitive numbers in comparison to fossil jet fuel at various oil barrel prices. Finally, all biorefineries are capable of producing biojet fuel with reduced GHG emissions: below 50% in comparison to fossil jet fuel. The detailed methodology and main results are presented by Klein et al. (2017).

5.2 The best option for supplying the target of 5% conventional jet fuel substitution by biojet fuel in Brazil passes through the optimization of certain parameters and assumptions. This includes the refinement of process simulations for the most promising scenarios with data on biojet fuel production provided by the industry. Other developments comprise the determination of the best possible biorefinery locations depending on the biojet fuel production technology and locally available feedstocks.

6. REFERENCES

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APPENDIX

Table 1 - Comprehensive table with the main outcomes of the assessed biorefineries

Biojet fuel route	Biojet fuel feedstock	H_2 production	5% jet fuel substitution target *	# plants to at least 5% target	CAPEX for at least 5% target (R$ billion)	Total agricultural land to at least 5% target (thousand ha)	IRR of the biorefinery **	Production: Diesel (million L/yr)	Production: Ethanol (million L/yr)	Production: Electrical energy (GWh/yr)	GHG emissions *** (g CO_2 eq/MJ jet fuel)
HEFA	Palm	WE	71%	2	4.3	348	3.7%	122	360	0	22.3
HEFA	Macauba	WE	69%	2	4.2	250	9.2%	118	360	0	17.3
HEFA	Soybean	WE	61%	2	4.0	1,332	3.6%	105	360	0	16.9
ATJ	Isobutanol	WE	43%	3	3.5	158	5.7%	4	0	631	17.7
HEFA	Palm	CESR	38%	3	4.7	351	NC	65	0	630	34.5
ATJ	1G2G Ethanol	WE	37%	3	4.7	158	NC	11	0	0	24.8
HEFA	Macauba	CESR	37%	3	4.7	273	NC	63	0	637	28.7
HEFA	Soybean	CESR	33%	3	4.6	1,170	NC	57	0	649	29.2
ATJ	1G Ethanol	WE	28%	4	4.2	211	0.6%	8	0	525	20.7
FT	Sugarcane+Eucalyptus	Gasification	27%	4	8.0	341	13.5%	81	360	45	9.3
ATJ	1G Ethanol	CESR	20%	5	5.0	263	NC	6	0	657	24.5
FT	Sugarcane	Gasification	11%	9	12.0	474	16.5%	33	360	156	9.4

* Substitution of 5% of the Brazilian fossil jet fuel consumption in 2014, equivalent to 375 million L/yr

** Values shown as NC indicate non-calculated IRR (revenues lower than expenses)

*** For comparison, GHG emissions of conventional, fossil jet fuel: 83.6 g CO_2 eq/MJ jet fuel)

Abbreviations

ATJ: Alcohol to Jet
FT: Gasification and Fischer-Tropsch Synthesis
HEFA: Hydroprocessed Esters and Fatty Acids
CESR: catalytic ethanol steam reforming
WE: water electrolysis
CAPEX: capital expenditures
GHG: greenhouse gas
IRR: Internal Rate of Return

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