Development of Database Management System (DBMS) for Sustainable Aviation Biofuel in Brazil

Case study: ATJ pathway / ethanol from steel off-gases

Authors: Arnaldo Walter, Joaquim E. A. Seabra, Jansle Vieira Rocha, Marjorie Guarenghi, Desirèe Dalmane, Nathália Vieira (Unicamp), João L. Santos (GeoMeridium)

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Executive summary

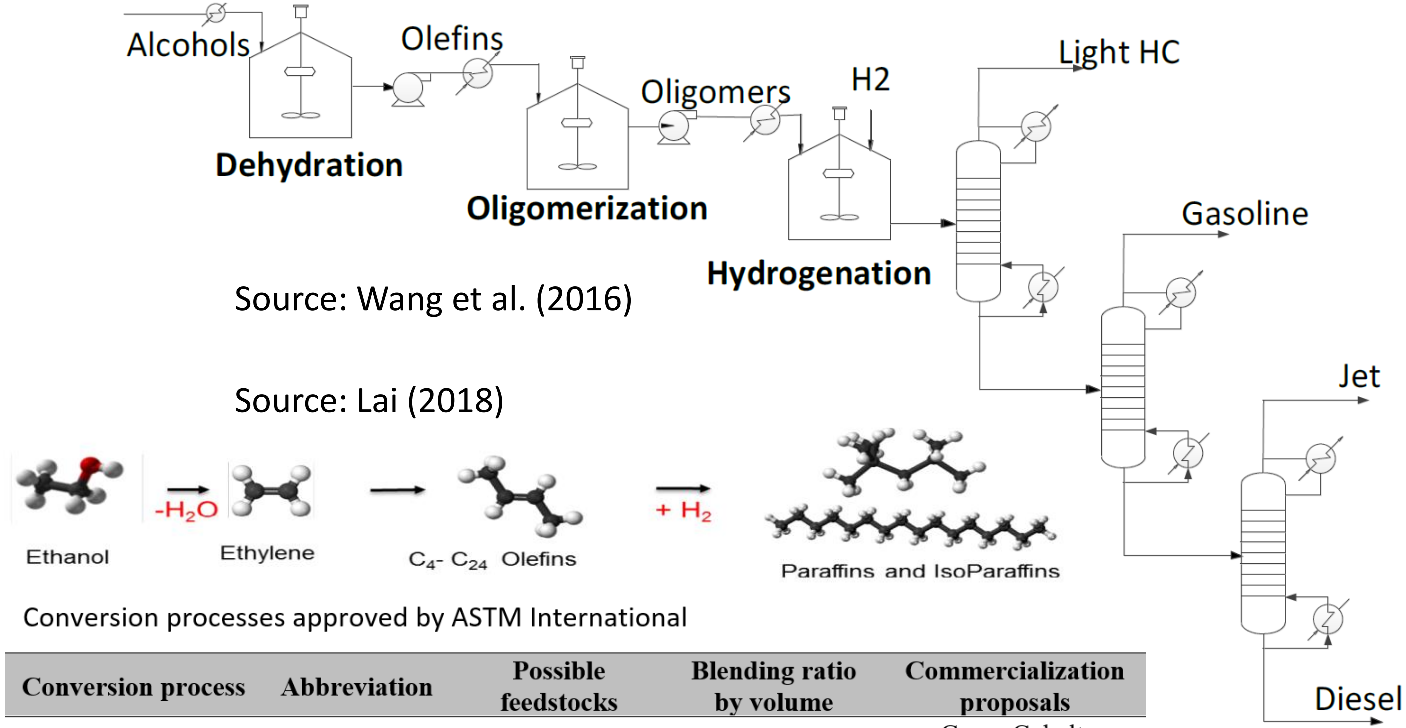
- The case studies developed within the scope of the project aim to illustrate the use of the information available in the platform database to assess the potential for sustainable aviation fuels (SAF) production in Brazil. It is not possible to draw ultimate conclusions based on the results obtained, but an effort was made to make the studies as comprehensive as possible.
- This report is related to the ATJ-SPK route, based on the steel off-gases that are available in some Brazilian steel mills. Only flared gases were considered, as the displacement of off-gases used as fuel would likely result in the additional use of fossil fuels (e.g. natural gas). Once the low availability of flaring gases reduces the potential of producing SAF, what is presented is not a case study like the others available on the platform.
- The premise is that the off-gases flared in four steel plants would be used for the production of ethanol; all these steel mills are located in Southeast, Brazil. Then, the ethanol would be transported by truck to two oil refineries, where the SAF would be produced: REVAP, in São José dos Campos (SP), and REGAP, in Betim (MG).
- However, it is shown that the best economic solution would be the production of ethanol in only two steel plants, those where the availability of BOF gas flared is greater (Cubatão and Tubarão), and the production of SAF at REVAP. The lowest estimated minimum selling price (MSP) would be 1601 $€.t^{-1}$ of SAF (37.4 $€.GJ^{-1}$).
- The low availability of BOF gas flared in Brazil implies low potential for SAF production through this route. The production that has the best economic result corresponds to only 0.81% of the Brazilian consumption of jet-fuel in 2018.

Summary

- About the pathway;
- About steel off-gases and its availability in Brazil;
- Methodology;
- Case studies;
- Results, analysis & comparisons;
- Eligibility under CORSIA;
- Conclusions;
- References;
- Supplementary Material.

About the pathway (1)

- The conversion route assessed here is referred as “Alcohol-to-Jet” (ATJ). ATJ fuels can be produced from alcohols such as methanol, ethanol, butanol and long-chain fatty alcohols (Wang et al, 2016).
- Here it is considered ethanol production from the fermentation of steel off-gases, according to a process developed by LanzaTech (see next slide).
- A scheme of the ATJ process is presented in the figure. The main steps are alcohol dehydration, oligomerization, and hydrogenation.
- The necessity of high-purity ethanol is uncertain, but here it was only considered the use of anhydrous ethanol.
- The route ATJ-SPK (Synthetic Paraffinic Kerosene) was approved by ASTM D7566 in 2011.



Source: Wang et al. (2016)

Source: Lai (2018)

Conversion processes approved by ASTM International

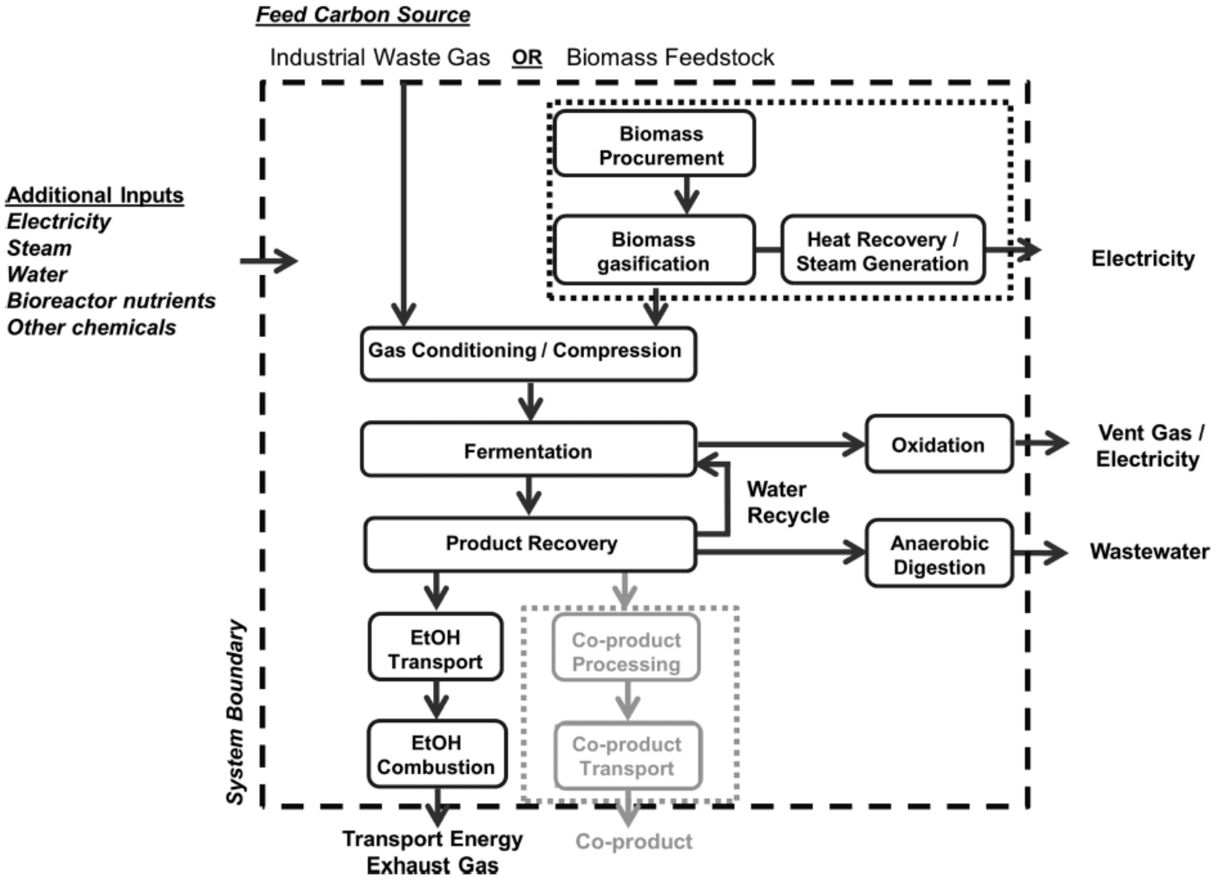
Conversion process	Abbreviation	Possible feedstocks	Blending ratio by volume	Commercialization proposals
Alcohol-to-jet synthetic paraffinic kerosene	ATJ-SPK	Biomass from ethanol or iso-butanol production	50%	Gevo, Cobalt, Honeywell UOP, Lanzatech, Swedish Biofuels, Byogy

Source: adapted from ICAO (2018) and ASTM (2020)

- Prussi et al. (2019) state that fuel produced by the ATJ-SPK route has been supplied for commercial flights.

About the pathway (2)

- Steel off-gases ethanol is based on the gas fermentation technology developed by LanzaTech (www.lanzatech.com). The process utilizes a proprietary microorganism to convert CO-rich gases to ethanol. De Ras et al. (2019) state that the enzymatic conversion uses anaerobic acetogens. The fundamentals of the process are described by Phillips et al. (2017).
- In March 2011 the construction of the first plant, in Shanghai, China, was announced by LanzaTech, Baosteel Group Corporation and the Chinese Academy of Sciences.
- According to a presentation to the US Department of Energy (Simpson, 2017), commercial scale was reached in 2016, and the operation of an additional plant at Jingtang Steel Mill, China, started in 2018. An unit in Gent, Belgium, was predicted to start operation in 2019 (Simpson, 2018).
- In 2018 LanzaTech stated that various demonstration plants, at different scales, have reached more than 70,000 operating hours. The field experience with steel off-gases surpassed 40,000 hours, in four steel mills.
- LanzaTech is producing bio jet-fuel in a demonstration plant at Freedom Pines (GA-US) (almost 39 x 10^6 L.year^{-1}) and another plant is mentioned to operate in China (Bionergy Int, 2019).

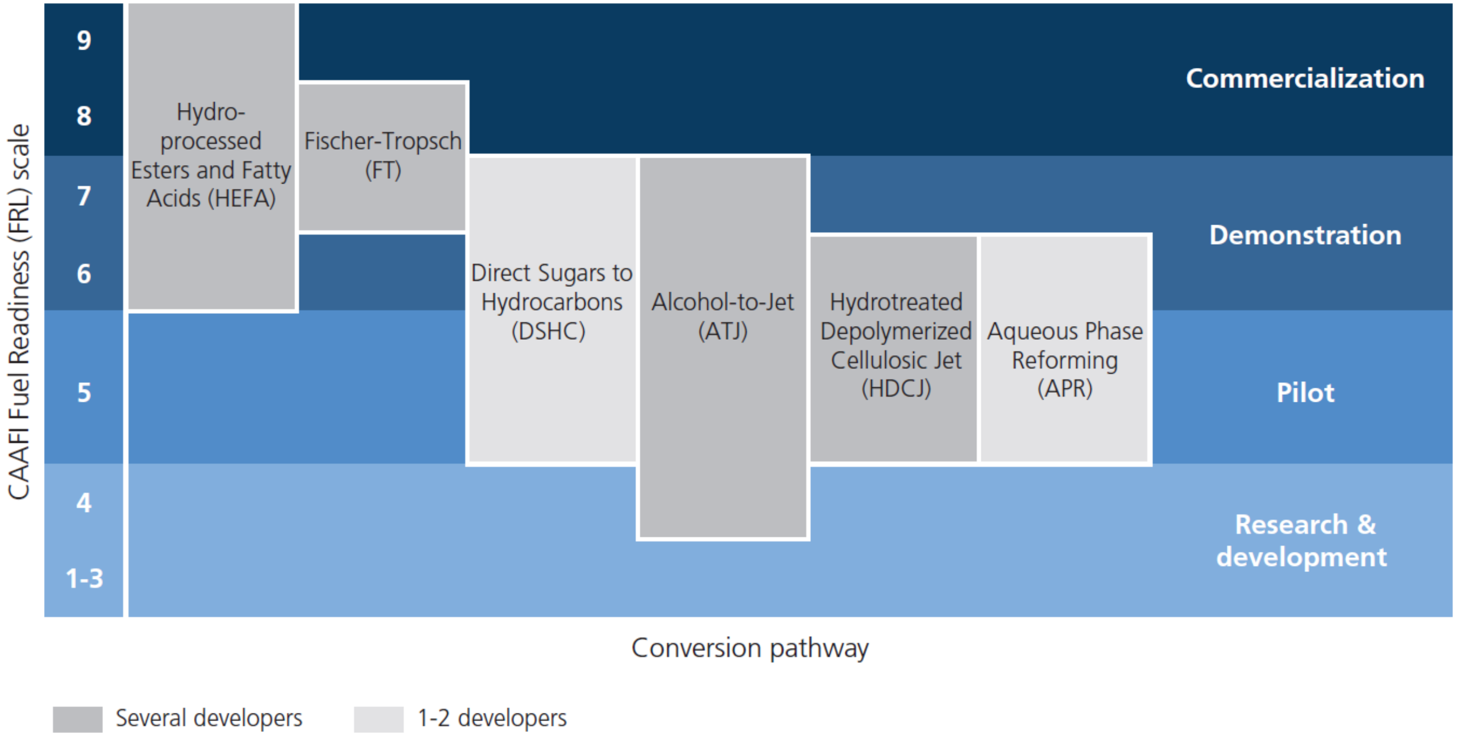


- Figure above presents a block diagram of LanzaTech process, using different sources of carbon.

Source: Handler et al. (2015)

About the pathway (3)

- As for the SAF production, the figure, extracted from de Jong et al. (2017), is a representation of CAAFI's (Commercial Aviation Alternative Fuels Initiative) Fuel Readiness Level Scale (FRL). It is based on NASA's Technology Readiness Level (TRL) scale and is intended to provide a classification to describe the progress of a conversion pathway towards commercialization. Key milestones include proof of concept (FRL 3), scaling from laboratory to pilot (FRL 5), certification by the American Society for Testing and Materials (ASTM) (FRL 7), and full scale plant operational (FRL 9). This figure is not exhaustive, as more pathways have being considered for the production of SAF.



- Similar analysis is provided by Prussi et al. (2019). For the route ATJ-SPK, the authors present the Readiness Technology Level (RTL) at 7-8, as defined by the EU HORIZON Work Programme 2016-2017 (2019), and the FRL at 7, defined as mentioned above.
- As for the production of ethanol from steel off-gas, it is mentioned in the literature (see previous slides) that the process has reached commercial scale.

About steel off-gases

- Gases are produced in the iron and steel production processes; they are the blast furnace gas (BFG), coke oven gas (COG) and the Linz-Donawitz process gas (LDG) (also called BOF gas). In general, they are used as fuel for heating and/or as fuel in combined heat and power (CHP) systems (Hu et al. 2019). In an optimized steel plant, a substantial part of the energy demand is met by these gases.
- Linz-Donawitz is related to the most common process of steel production (basic oxygen furnace). In refining pig-iron the metal charge is melted and crude steel is produced by the adjustment of its carbon content, producing off-gas as a by-product. More than 80% of the Brazilian crude steel is produced by the Basic Oxygen Furnace (BOF) process (Capaz et al., 2020).
- The BOF process is of the batch type, following the refining of pig iron. This explains why the gas is flared or vented in some steel mills (Higashi, 1982).

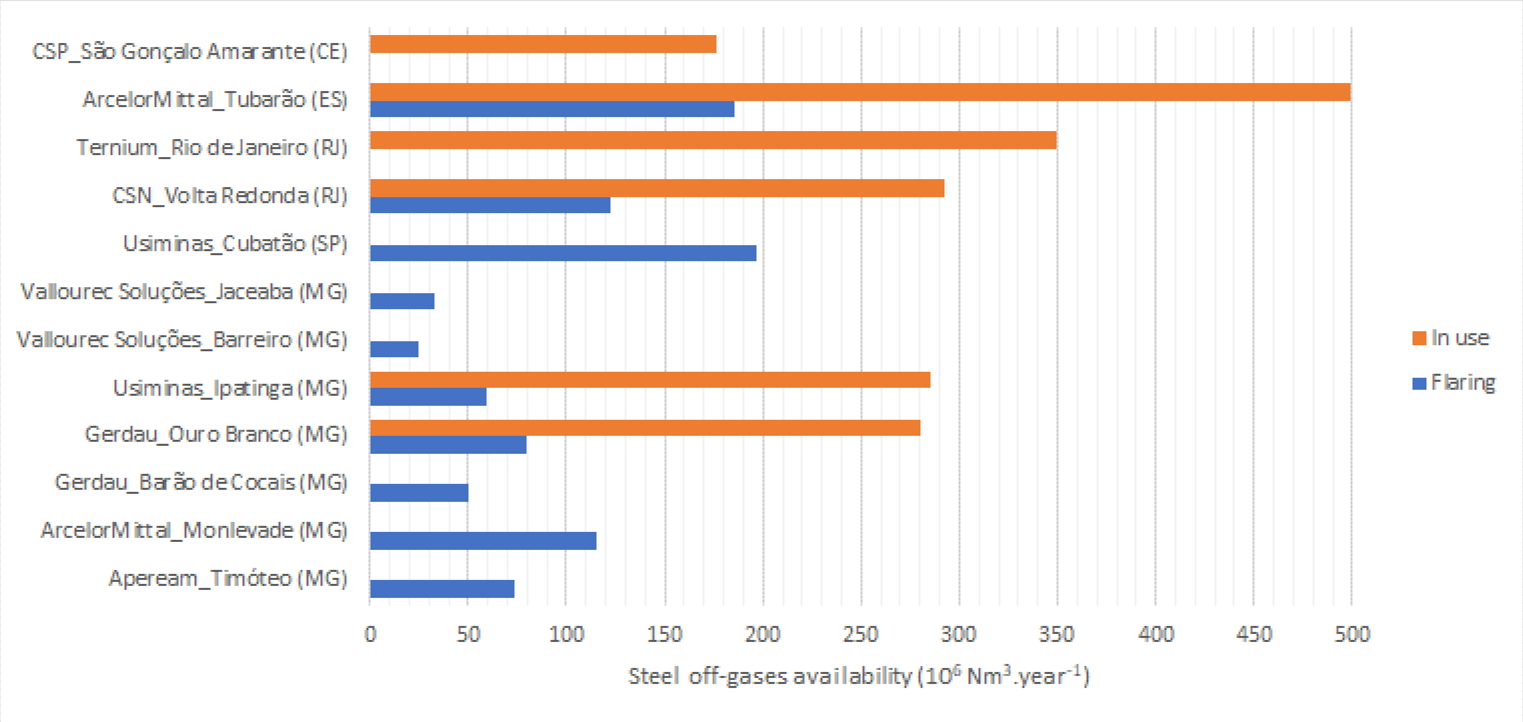
Composition (molar basis)	BFG	COG	BOF
H_2	2.42	60.29	0.96
CO	22.72	5.04	69.15
CO_2	21.18	1.58	14.91
CH_4	0.00	25.31	0.00
C_2H_6	0.18	3.32	0.09
N_2	53.50	4.46	14.89
LHV (kJ/Nm^3)	8,892.1	18,316.7	3,244.5

Source: Lima (2001)

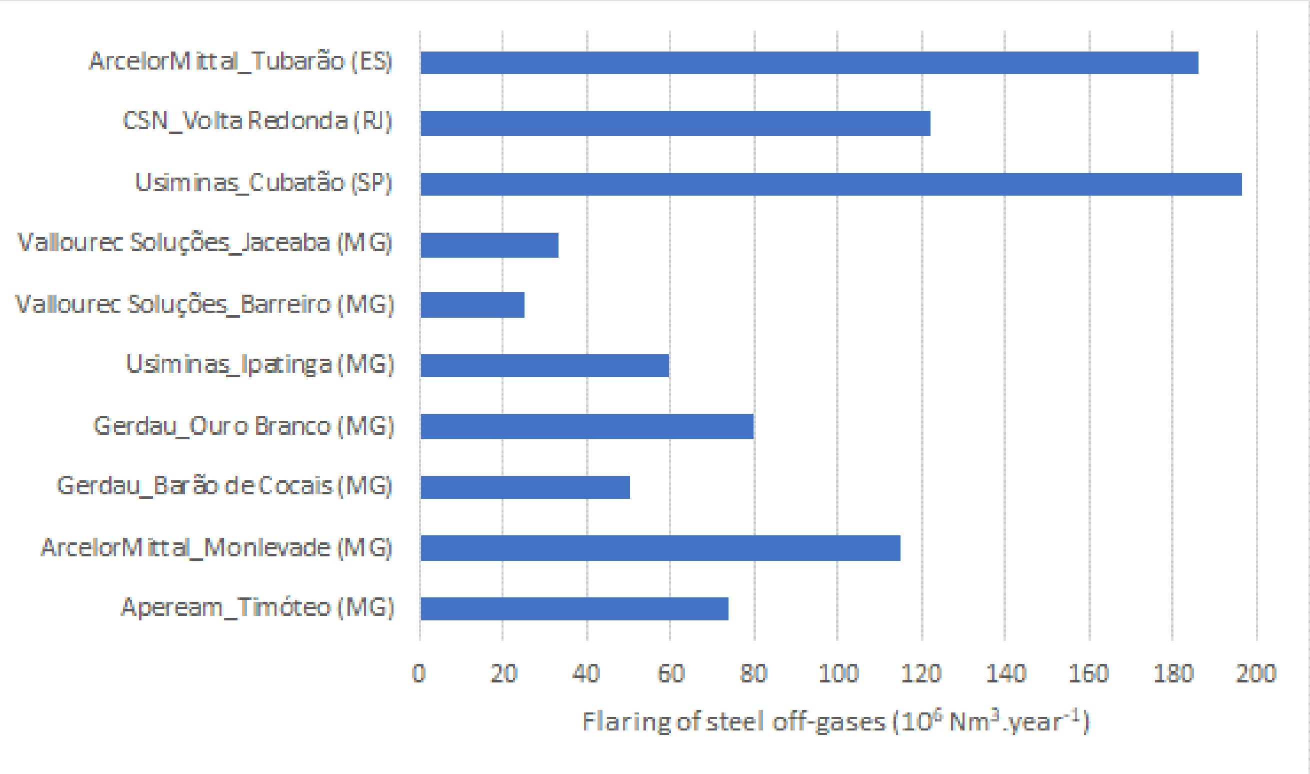
- The table illustrates the typical compositions of the three gases related to iron and steel production, and their energy content. The focus on BOF gas for ethanol production is due to the fact that carbon monoxide is fundamental in the LanzaTech process, but BFG could also be used. Carbon monoxide in BOF is generated in the process of refining hot metal in the furnace.

Steel off-gases in Brazilian steel industry (1)

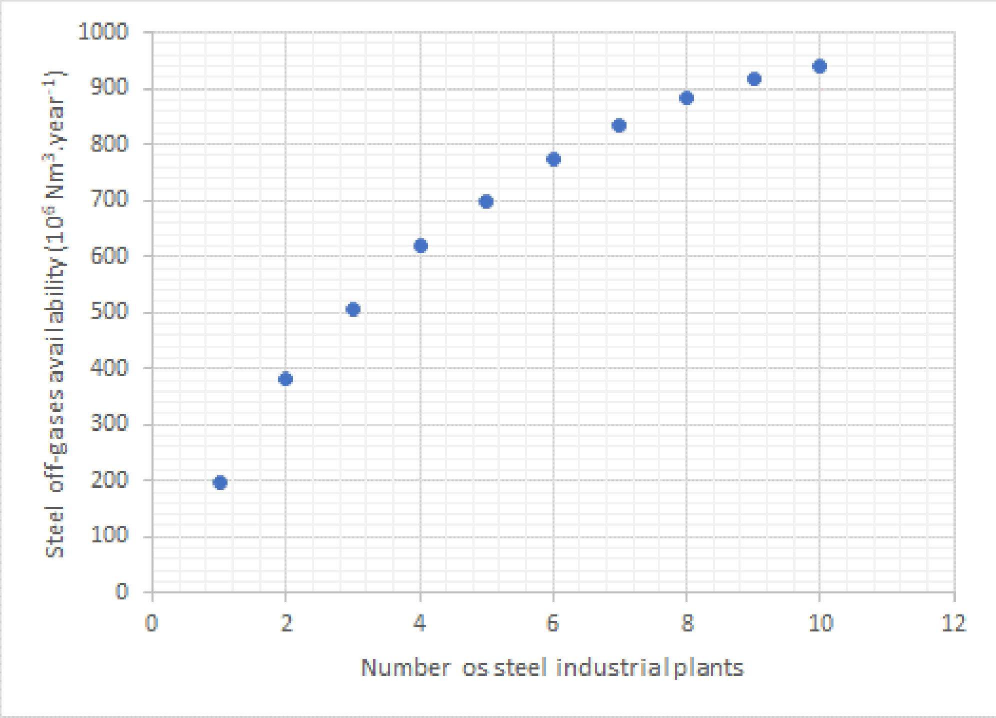
- The availability of BOF gas in Brazilian steel industry was evaluated based on the energy balances of iron and steel industries, which are regularly published by ABM (Associação Brasileira de Metalurgia e Materiais). Data available up to 2017 were compiled in the context of the research by Capaz et al. (2020). The average figures for the past few years have been used for BOF gas.
- The figure illustrates both the volume of steel off-gas in use and flared in 12 Brazilian steelmakers. In half of these plants all BOF gas is completely in use or is used in large quantities.
- It is considered that only the production of SAF from ethanol produced from the flared BOF gas would be considered sustainable and, therefore, here the focus is on these volumes.



Steel off-gases in Brazilian steel industry (2)



- About two thirds of the volume of flaring steel off-gases available from 10 industrial plants are concentrated in four plants located in the Southeast, Brazil.
- Based on this fact, the current case study was defined (see following slides).



- The largest volume available in a single steel plant (less than 200 million Nm^3.$year^{-1}$) is not enough to feed the assumed reference plant of ethanol production (that requires 309.5 million Nm^3.$year^{-1}$ of steel off-gases).

Methodology: general procedure

Assessing off-gas availability → Estimating ethanol production and transportation costs → Defining supply curves at the industrial sites (of SAF production) → Estimating SAF production and its costs → Analysis of the results

Scheme indicating the main activities in the process of evaluating the potential and economic viability of SAF, using the platform database.

Methodology: …assessing gas availability and ethanol production

SAFmaps

Assessing steel off-gas availability → Estimating ethanol production costs & transportation costs → Supply curves at the industrial sites → Estimating SAF production and its costs → Analysis of the results

- Identification of the steel plants;
- Quantifying steel off-gases availability;
- Definition of the case study.

→ Gas availability for ethanol production

Ethanol produced from steel off-gases would be transported to pre-defined industrial sites, by truck → Supply curves in each industrial site: ethanol available and its CIF costs

Methodology … assessing costs and analysis of the results

Assessing steel-off gas availability → Estimating ethanol production costs & transportation costs → Supply curves at the industrial sites → Estimating SAF production and its costs → Analysis of the results

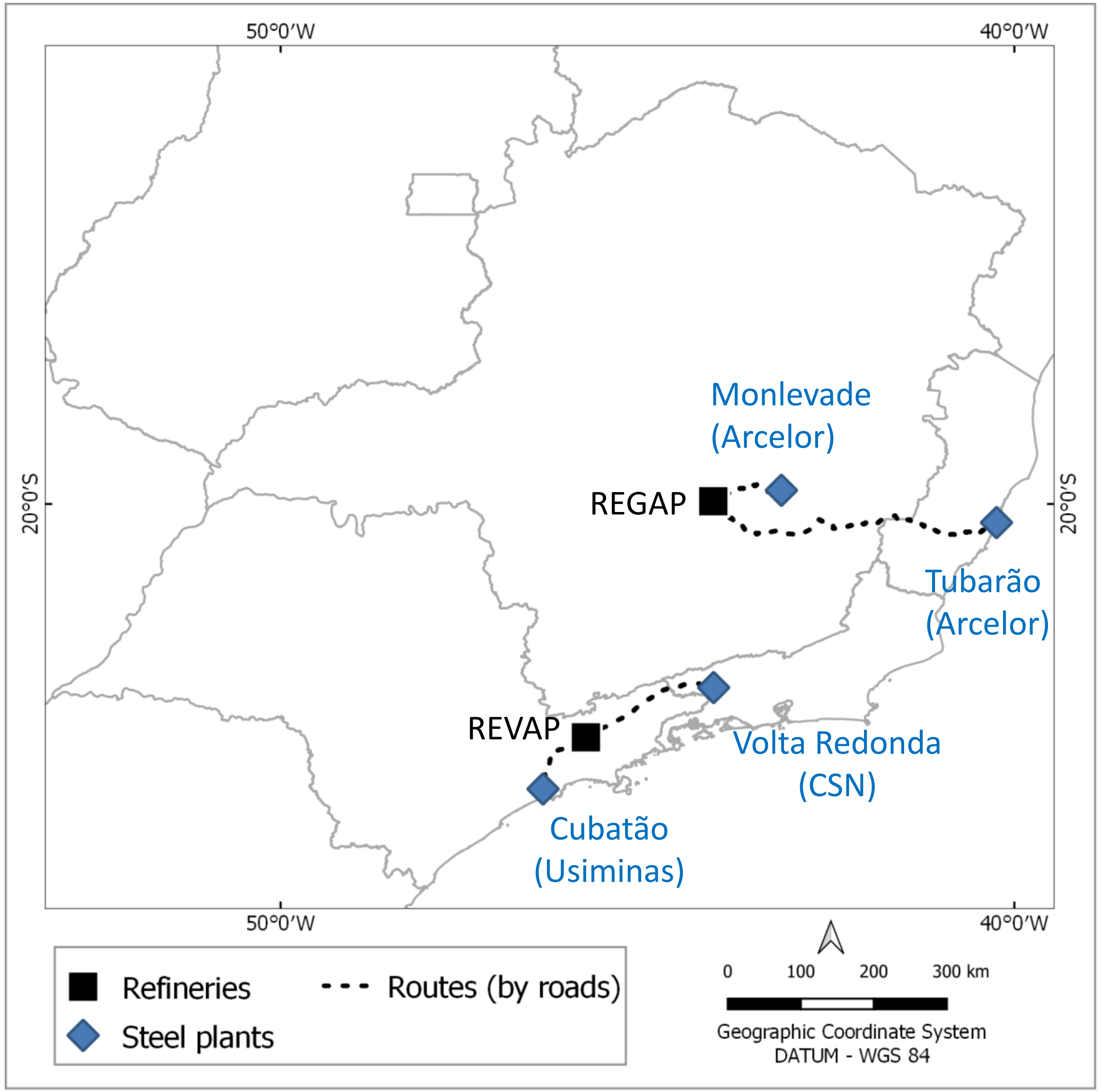
Technical parameters and cost figures have been taken from the literature; costs were adjusted to estimate values in 2018 (even for the n^{th} plant)

→

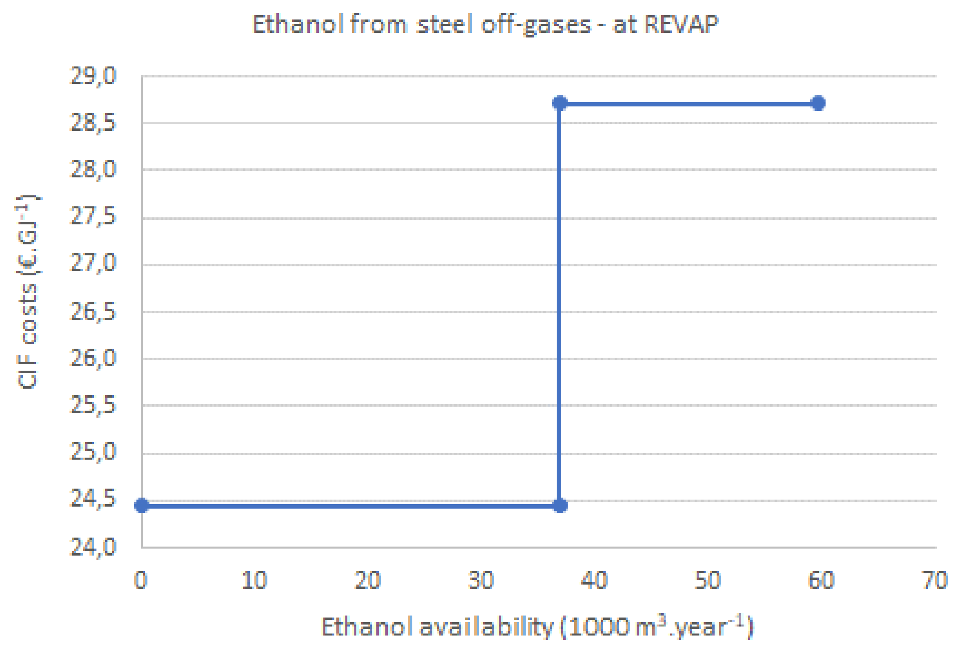
Analysis of the results, comparing with the literature and also with fossil kerosene prices, considering cost reduction opportunities and trends, etc.

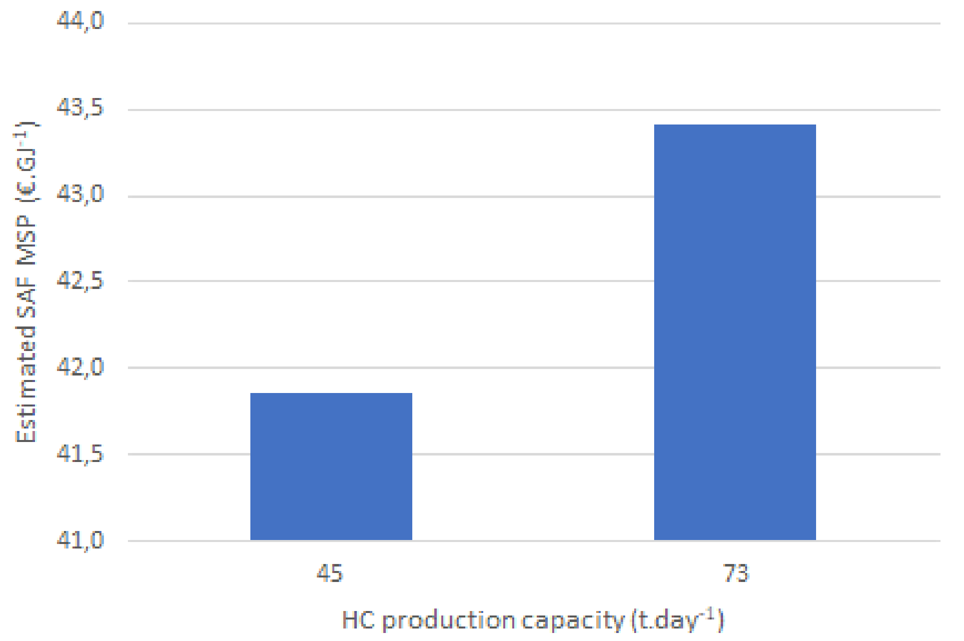
Case studies

- The case studies correspond to the assumption that anhydrous ethanol would be produced from BOF gas in plants annex to the four steel plants that have the highest availability of flared BOF gas.
- In one case, ethanol would be produced in Cubatão (SP) and Volta Redonda (RJ), and transported by truck to REVAP oil refinery, in São José dos Campos (SP). Likewise, ethanol produced in Tubarão (ES) and Monlevade (MG) would be transported to the REGAP oil refinery in Betim (MG).
- Each of these four plants would be smaller than Jingtang Steel's first commercial industrial plant in Caofeidian, China, with a capacity to produce 46,000 tonnes of ethanol per year. Here, the largest plant, the one attached to the Cubatão steel mill, could produce 42,200 $t.year^{-1}$ of ethanol, and the smallest - the one attached to the Monlevade steel plant - could produce 24,700 $t.year^{-1}$ of ethanol.
- The figure shows the location of the four steelmakers here considered, as well as the location of the two oil refineries, where SAF production would take place.

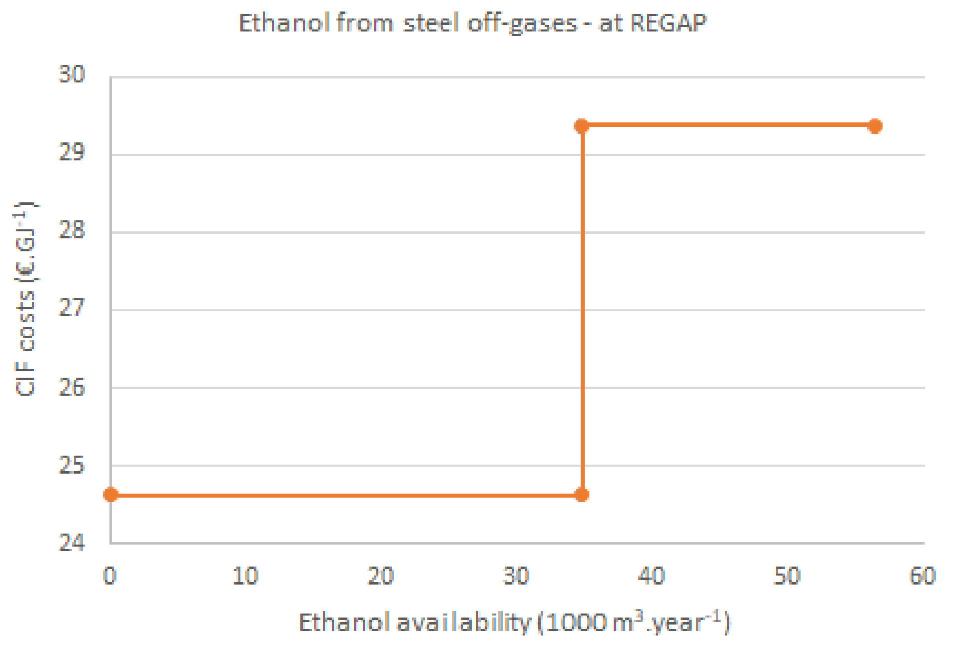


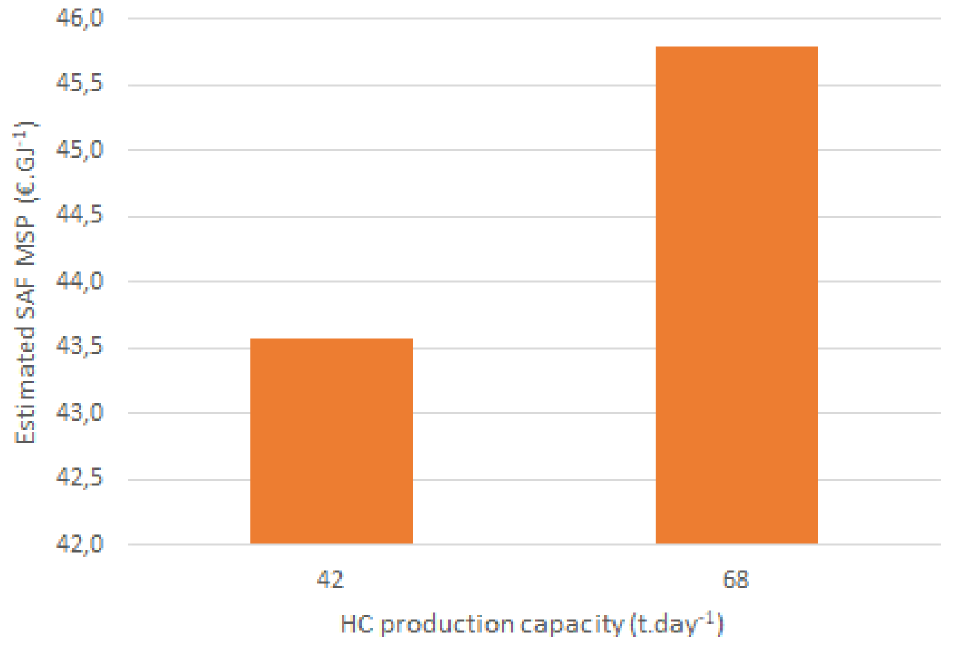
Results: production at REVAP





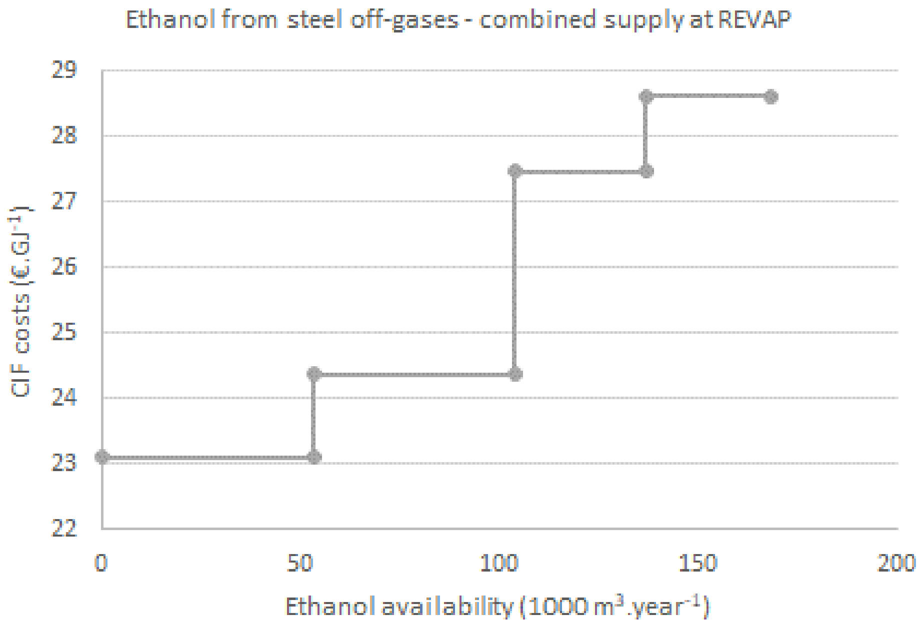
- The upper curve shows the supply curve for ethanol (assuming anhydrous ethanol) at REVAP. The lower cost is for the ethanol production in Cubatão. The cost difference between the output in Cubatão and Volta Redonda is essentially due to the scale of industrial production, as transportation costs represent very little (no more than 0.46 €.GJ^{-1}).
- In fact, the CIF cost is associated to the minimum selling price of ethanol production (see Supplementary Material for details), plus the cost of transport.
- The second figure shows the estimated MSP (minimum selling price) of SAF production, as function of the capacity of hydrocarbon liquids production.
- It is clear that no scale effect is observed. As for the ATJ route, the most significant cost component is the feedstock, and the ethanol produced from steel off-gases in Volta Redonda would be almost 20% more expensive than the production in Cubatão.

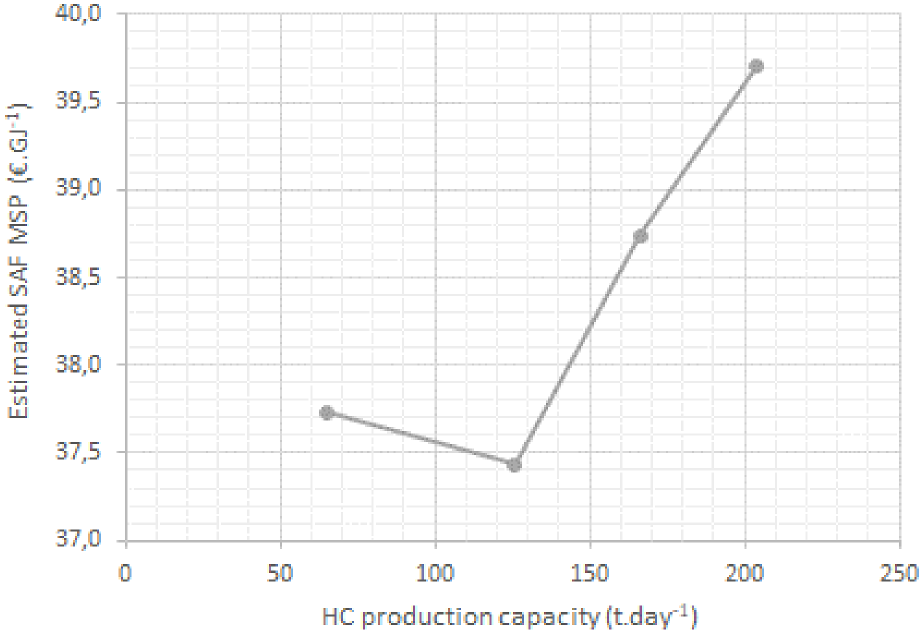




Results: production at REGAP

- Similar results are presented for the SAF production at REGAP.
- The upper figure shows the supply curve. Ethanol would be produced in Tubarão, at a lower cost, and in Monlevade.
- In the case of Tubarão the transport represents less than 4% of the CIF cost at REGAP, despite the larger distance (550 km).
- The second figure shows the estimated MSP (minimum selling price) of SAF production, as function of the capacity of hydrocarbon liquids production.
- Mainly because of the cost of ethanol, production at REVAP is slightly cheaper than production at REGAP, with a difference of around 3% to 4% in the MSP, depending on the industrial capacity.
- As the impact of the transport cost is not significant, a variant was explored next with the aim of combining the lowest cost supplies. Thus, the production at REVAP was re-evaluated, supposing that all ethanol - from steel off-gases – would be available to this unique SAF production plant.





Results: combining supplies at REVAP

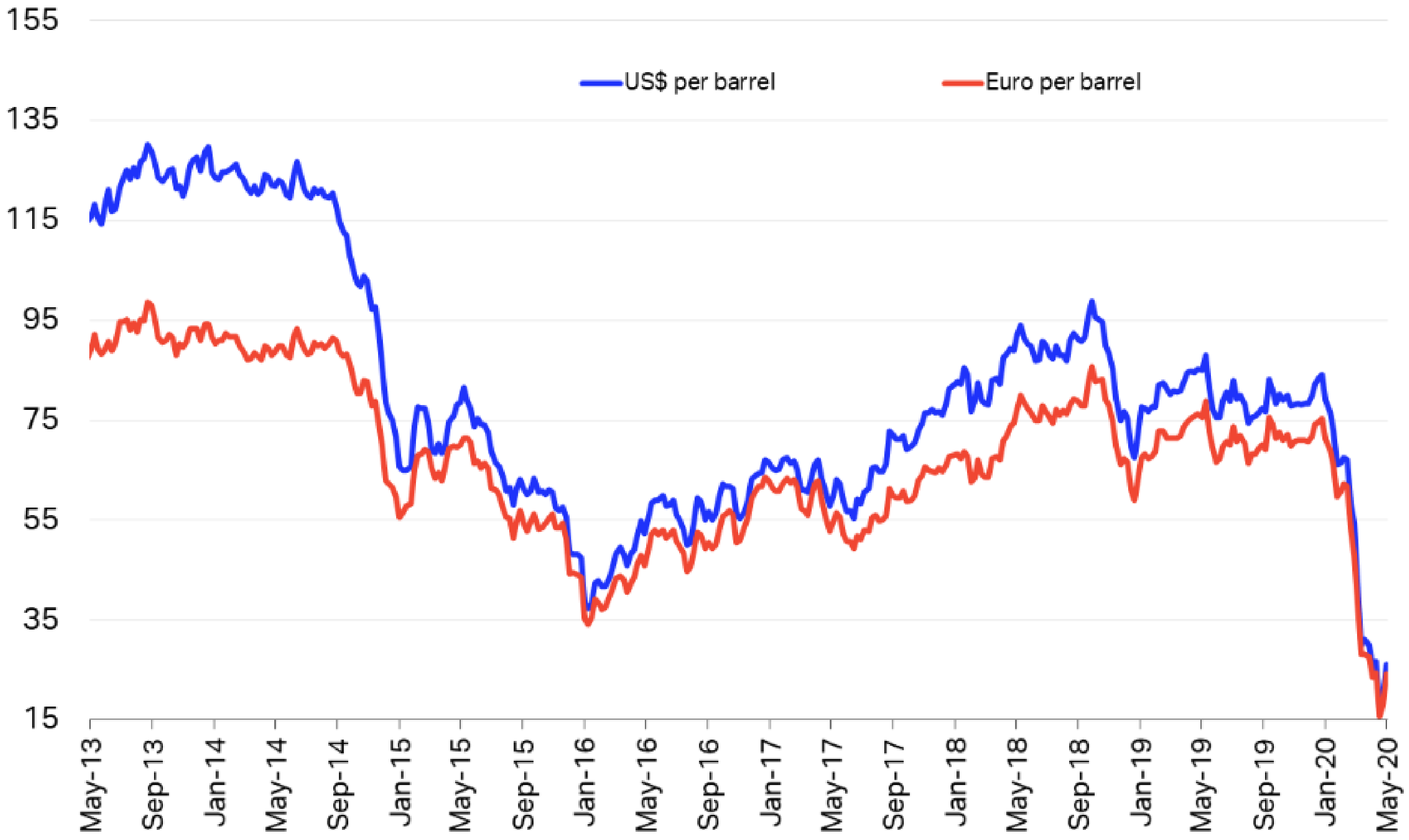
- The upper figure shows the combined supply curve (at REVAP) of ethanol produced from BOF gas in four steel mills.
- The figure at the bottom shows the estimated MSP (minimum selling price) of SAF production, assuming the combined supply and four industrial capacities.
- It is clear the effect of the economy of scale only at the beginning of the range of capacities, and this advantage is quickly lost. This is due to the higher costs of ethanol production in small scale (at Volta Redonda and Monlevade).
- The MSP results presented here are better than those presented previously, for REVAP (for smaller SAF production capacity) and REGAP.
- In summary, the best solution would be the production of 125.9 $t.day^{-1}$ of liquid hydrocarbons (i.e. 94.6 $t.day^{-1}$ of SAF), based on the supply of ethanol from two steel mills (located in Cubatão (SP) and Tubarão (ES)).

Analysis of the results (1)

- The lowest estimated MSP would be 1601 €.t^{-1} of SAF (37.4 €.GJ^{-1}), and values could be as high as 1676-1700 €.t^{-1} (39.2-39.7 €.GJ^{-1}). The lowest MSP corresponds to the production of 41.4 thousand t.year^{-1} of SAF, which is equivalent to only 0.81% of the Brazilian consumption of jet-fuels in 2018.
- Due to the proprietary nature of the ethanol production process from steel gases, there are few estimates of costs or minimum selling prices in the literature. Using similar, but not exactly the same hypotheses (e.g. different discount rate and location factor), Capaz et al. (2020) estimated the SAF MSP at 41.5 US$(2019).GJ^{-1} for the pathway.
- For the MSP of SAF in the range 1600-1700 €.t^{-1}, the break-even price of jet-fuel would be between 245 and 257 $.barrel^{-1}, values that are about three times higher than the highest international market price reached since mid 2013.

Analysis of the results (2)

Jet Fuel Price Currency Comparison



Source: Platts, Datastream https://www.iata.org/en/publications/economics/fuel-monitor

- The figure shows the evolution of the international jet-fuel prices along seven years (from May 2013 to May 2020).
- Jet fuel market prices are extremely correlated with international oil prices (see Supplementary Material).
- The Platts Global Index indicates that the jet fuel index price in Latin America is about 12% higher than the global figure. In Europe it is about 6% lower, and in North America about 8% higher.

Eligibility under CORSIA

- Eligible fuels in the context of CORSIA include Sustainable Aviation Fuels (SAF) (produced from biomass or residues) and Lower Carbon Aviation Fuels (LCAF) (from fossil energy sources). Both must be certified from the point of view of sustainability. For SAF, in the CORSIA pilot phase (2021-2023), only two principles must be accomplished (see Supplementary Material): 1) they should generate lower carbon emissions on a life cycle basis, and 2) should not be made from biomass obtained from land with high carbon stocks.
- Here, compliance with Principle 2 is not a matter of concern due to the use of residual gases as feedstock. In addition, it was only considered the use of BOF that is flared.
- To comply with Principle 1, the SAF could not emit more than 90% of 89 $gCO_2eq.MJ^{-1}$ (the assumed footprint of fossil fuel for aviation) (i.e. 80.1 $gCO_2eq.MJ^{-1}$) over its life cycle. The producer can either use the Default Life Cycle Emissions Values, published by ICAO or, alternatively, assess the carbon footprint of its own production. The study of the route ATJ-SPK from steel off-gases is not yet finished and, consequently, its Default Value is not available.
- Capaz et al. (2020) estimated that GHG emissions would be 24.8 $gCO_2eq.MJ^{-1}$ of SAF, which would result in a reduction in emissions of approximately 72% vis-à-vis the conventional jet-fuel. This value is low compared to the results presented by Handler et al. (2016), which estimated the GHG emissions at 31.4 $gCO_2eq.MJ^{-1}$ only for ethanol produced from BOF gas. On the other hand, Simpson (2017) states that based on a demonstration plant, GHG emissions were estimated at 32.6 $gCO_2eq.MJ^{-1}$ of SAF, being 19.6 $gCO_2eq.MJ^{-1}$ of ethanol. In addition, Wolf (2019) states that the GHG emissions in the LanzaTech process could be in the range 25-45 $gCO_2eq.MJ^{-1}$ of ethanol.
- Despite the uncertainties, it seems that the production of SAF by this route would be considered sustainable, but with the risk of high costs of carbon abatement due to the high production costs.

Conclusions

- The reported case study addresses the production of SAF through the ATJ-SPK route, from ethanol produced from steel off-gas. Only the volume of BOF gas flared was considered. It was assumed the possible production of ethanol in four steel mills (all them located in Southeast, Brazil), and the production of SAF in two oil refineries (REVAP (SP) and REGAP (MG)).
- The volume of BOF gas flared in Brazil is relatively low, and this imposes a constraint due to scale effects. The lowest estimated MSP would be 1601 €.t^{-1} of SAF (37.4 €.GJ^{-1}), and the highest values could be 1676-1700 €.t^{-1} (39.2-39.7 €.GJ^{-1}). The best solution would be the production of ethanol in the two steel plants where the availability of BOF gas flared is greater (Cubatão and Tubarão), and the production of SAF at REVAP.
- We found few references for GHG emissions of SAF produced through the route ATJ-SPK, from flared steel off-gas, varying from 24.8 to 32.6 $gCO_2eq.MJ^{-1}$ of SAF. However, both figures seem to be low compared to the results presented by Handler et al. (2017) only for ethanol produced from BOF gas (31.4 $gCO_2eq.MJ^{-1}$). A second reference is the estimate presented by LanzaTech (varying from 20 to 45 $gCO_2eq.MJ^{-1}$), but these values are presented with no further details. Thus, there are doubts related to avoided emissions, but it seems that the threshold for SAF being considered sustainable could be easily reached.
- The low availability of BOF gas flared in Brazil implies low potential for SAF production through this route. The production that presents the best economic result corresponds to only 0.81% of the Brazilian consumption of jet-fuel in 2018.

References (1)

- ABM - Associação Brasileira de Metalurgia e Materiais. Balanços Energéticos Globais e Utilidades. Balances for diferente years.
- ASTM. 2020. Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons. ASTM International. https://doi.org/10.1520/D7566-19B
- Bioenergy International. 2019. LanzaTech advances on alcohol-to-jet scale-ups in the United States and Japan.
- Brasil - Ministério do Meio Ambiente. Dados geoestatísticos das Unidades de conservação aprovadas até março de 2020. Brasília. Scale 1:5.000 to 1:100.000. Available at: http://mapas.mma.gov.br/i3geo/datadownload.htm. Accessed: mar 2020.
- Capaz, RS, Guida, E, Seabra, JEA, Osseweijer, P, Posada, JA. 2020. Mitigating carbon emissions through sustainable aviation fuels: costs and potential. Biofuels, Bioproducts & Biorefining.
- Chemical Engineering. 2019. Chemical Engineering Price Cost Index. Information available at https://www.chemengonline.com/2019-cepci-updates-january-prelim-and-december-2018-final/
- de Jong, S, Hoefnagels, R, Faaij, A, Slade, R, Mawhood, R, Junginger, M. 2015. The feasibility of short-term production strategies for renewable jet fuels - a comprehensive techno-economic comparison: The Feasibility of Short-term Production Strategies for Renewable Jet Fuels - A Comprehensive Techno-economic Comparison. Biofuels, Bioprod. Bioref. 9, 778–800. https://doi.org/10.1002/bbb.1613
- de Jong, S, Hoefnagels, R, van Stralen, J, Londo, M, Slade R, Faaij, A, Junginger, M. 2017. Renewable Jet Fuel in the European Union – Scenarios and Preconditions for Renewable Jet Fuel Deployment towards 2030. Utrecht University.
- De Ras, K, Van de Vijver, R, Galvita, VV, Marin, GB, Van Geem, KM. 2019. Carbon capture and utilization in the steel industry: challenges and opportunities for chemical engineering. Current Opinion in Chemical Engineering, 26, pp. 81–87.

References (2)

- EU HORIZON Work Programme 2016-2017. 2019. General Annex. Available at: ec.europa.eu/research/participants/data/ref/h2020/other/wp/2016-2017/annexes/h2020-wp1617-annex-ga_en.pdf.
- Handler, RM, Shonnard, DR, Griffing, EM, Lai, A, Palou-Rivera, I. 2016. Life Cycle Assessments of Ethanol Production via Gas Fermentation: Anticipated Greenhouse Gas Emissions for Cellulosic and Waste Gas Feedstocks. Industrial & Engineering Chemical Research.
- Higashi, I. 1982. Energy Balance of Steel Mills and the Utilization of By-product Gases. Transactions ISIJ, Vol. 22.
- Hu, Z, He, D, Kai Feng, Liu, KFP, Jia, Y. 2019. Optimal Design Model of the Energy Systems in Iron and Steel Enterprises. Applied Sciences, 9, 4778.
- IBGE – Instituto Brasileiro de Geografia e Estatística. 2019. Information available at https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9105-producao-da-extracao-vegetal-e-da-silvicultura.html?=&t=resultados
- ICAO – International Civil Aviation Organization. 2018. Sustainable aviation fuels guide, Version 2. ed, Transforming Global Aviation Collection. ICAO, UNDP, GEF.
- ICAO – International Civil Aviation Organization. 2019. Information about CORSIA. Available at (https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-FAQs.aspx)
- LanzaTech. 2020. Information available at www.lanzatech.com
- Lai. K. 2018. Lanzatech technology and progress in commercialization. Presentation in an IEA Bioenergy Task 39 Conference.

References (3)

- Lima, RNO. 2001. Avaliação de Arranjos Cogeradores em Siderúrgicas Brasileiras Com Auxílio de Simulação Computacional. PhD. Thesis. University of Campinas (Unicamp).
- Medeiros, EM, Noorman, H, Maciel Filho, R, Posada, JA. 2020. Production of ethanol fuel via syngas fermentation: Optimization of economic performance and energy efficiency. Chemical Engineering Science
- Phillips, JR, Huhnke, RL, Atiyeh, HK. 2017. Syngas Fermentation: A Microbial Conversion Process of Gaseous Substrates to Various Products. Fermentation, 3 (28).
- Prussi, M, O'Connell, A., Lonza, L. 2019. Analysis of current aviation biofuel technical production potential in EU28. Biomass and Bioenergy, 130.
- Simpson, S. 2017. Presentation to the US Department of Energy. Available at https://www.energy.gov/sites/prod/files/2017/07/f35/BETO_2017WTE-Workshop_SeanSimpson-LanzaTech.pdf
- Simpson, S. 2018. Presentation to the European Commission. Available at https://ec.europa.eu/energy/sites/ener/files/documents/25_sean_simpson-lanzatech.pdf
- Wang, W.-C., Tao, L., 2016. Bio-jet fuel conversion technologies. Renewable and Sustainable Energy Reviews 53, 801–822. https://doi.org/10.1016/j.rser.2015.09.016
- Wang, W.-C., Tao, L., Markham, J., Zhang, Y., Tan, E., Batan, L., Warner, E., Biddy, M., 2016. Review of biojet fuel conversion technnologies (Technical Report No. NREL/TP-5100-66291). National Renewable Energy Laboratory, Golden, CO, USA.
- Wolf, C. 2019. Presentation available at www.ubrabio.com.br.

Development of Database Management System (DBMS) for Sustainable Aviation Biofuel in Brazil

Case study: ATJ pathway / ethanol from steel off-gases
Supplementary Material

List of Contents

- Industrial parameters – ethanol plant and SAF plant;
- Jet-fuel prices;
- About CORSIA and eligible fuels.

Industrial parameters: ethanol plant

- A comprehensive description of the LanzaTech process is presented by Handler et al. (2016). Ethanol would be produced in a plant annex to a steel mill where BOF (basic oxygen furnace) gas would be available. The steam demand would be supplied by a share of the reactor vent gas combined with the biogas obtained from the anaerobic digestion of the biological solids filtered out of the distillation (Capaz, 2020).
- To characterize the efficiency, it was assumed 0.271 litres of ethanol per Nm^3 of BOF (Capaz, 2020). This value corresponds to a slight improvement compared to 0.26 $L.Nm^{-3}$, which corresponds to the yield of the previous industrial units (Lai, 2018).
- In estimating the BOF gas availability, besides the information presented by the energy balances published by ABM, it was considered the specific production of 100 $Nm^3.t^{-1}$ (m^3 off-gases per tonne of crude steel).
- The capacity of the reference plant is 58 million litres of ethanol produced per year. The CAPEX would be 79.6 million US$ (2019) and the specific OPEX would be 329 US$.$m^{-3}$ of ethanol (CAPEX) (Capaz et al. 2020). In an optimization procedure Medeiros et al. (2020) present other cost estimates, but the values cannot be directly compared. Here, the costs were converted to Euro(2018) in order to make possible the comparison with the results of other case studies. It was assumed no market value for flared BOF gas.
- Here, both the CAPEX and OPEX were scaled down assuming a 0.6 scale factor as all four units considered would be lower than the reference plant. The largest one, in Cubatão, would produce 53.3 million litres of ethanol per year.
- It was calculated the minimum selling price of ethanol assuming the same hypotheses used for SAF (see following slide). It was assumed no co-products in case of ethanol production.
- In this case study, the estimated ethanol MSP vary from 0.649 to 0.757 US$(2018).$L^{-1}$.

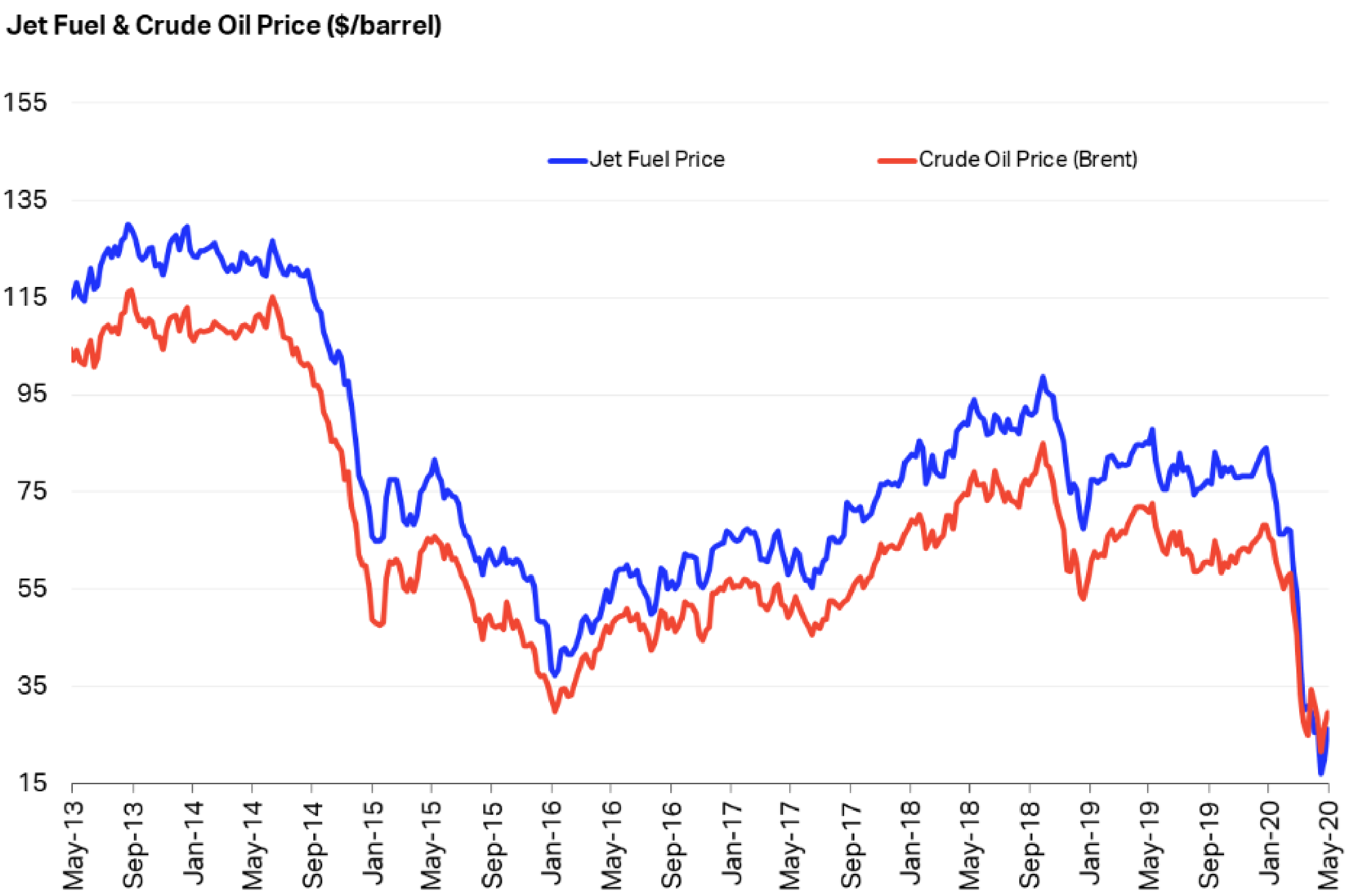
Industrial parameters: SAF plant

- Here, the main reference is de Jong et al. (2015), since it is based on a comprehensive review of performance factors and costs for different pathways.
- It is assumed that SAF is one of the hydrocarbons that can be produced; the production shares are presented in the tables below. The revenue for each co-product was considered in estimating the MSP of SAF.
- In the base case 0.5042 tonne of hydrocarbons could be produced from one tonne of ethanol. This parameter was taken from de Jong et al. (2017).
- In the reference case (de Jong et al., 2015), the production of bio-jet fuels would be equal to 182.6 tonnes of bio-jet per day, operating all over the year with a 90% capacity factor.
- Also based on the reference, the estimated (adjusted) total cost investment would be 51.03 million € (2018). For the capacities considered here (smaller than the reference case), a 0.6 scale factor was used.
- For estimating the MSP in each case, a spreadsheet was developed and the procedure was validated against the results presented by de Jong et al. (2015).

Parameter	Value	Unit
Annual capacity factor	90	%
Number of days in the year	365	days
Output/Input (mass basis)	0.5042	$t.t^{-1}$ (HC liquid/anhydrous)
Bio-jet fuel/FT liquids (mass basis)	0.751	$t.t^{-1}$ (SAF/HC liquids)
Bio-jet fuel density	0.804	$t.m^{-3}$
Bio-jet fuel LHV	42.8	$MJ.kg^{-1}$

Co-product	Factor	Unit
Diesel oil	0.088	$t.t^{-1}$ (diesel/HC liquids)
Naphtha	0.161	$t.t^{-1}$ (naphtha/HC liquids)

Jet fuel prices: historical data and worldwide variations



Source: Platts, Datastream

https://www.iata.org/en/publications/economics/fuel-monitor/

- The figure reinforces the common understanding that aviation fuel prices are strongly correlated to international oil prices.
- Table below shows, as an illustration, the jet fuel average prices in different regions, in May 15, 2020 (the smallest value in many years).

Region	US$.barrel^{-1}	US$.t^{-1}
Global average	30.38	239.84
Asia & Oceania	29.47	232.84
Europe & CIS	28.49	224.50
Middle East	25.72	202.93
Africa	25.72	202.93
North America	32.75	258.73
Latin America	34.13	269.63

CORSIA and eligible fuels

- CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) is a global market-based measure scheme adopted by ICAO Assembly, in 2016, aiming to address the increase of GHG emissions from international aviation.
- An aeroplane operator can reduce its offsetting requirements by the use of CORSIA Eligible Fuels (CEFs), which shall come from fuel producers that are certified according sustainability.
- In the pilot phase of CORSIA (2021-2023), the two principles (and their criteria) that must be met are shown in the table.

Theme	Principle	Criteria
1. Greenhouse Gases (GHG)	Principle: CORSIA eligible fuel should generate lower carbon emissions on a life cycle basis.	Criterion 1: CORSIA eligible fuel shall achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.
2. Carbon stock	Principle: CORSIA eligible fuel should not be made from biomass obtained from land with high carbon stock.	Criterion 1: CORSIA eligible fuel shall not be made from biomass obtained from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks.
		Criterion 2: In the event of land use conversion after 1 January 2008, as defined based on IPCC land categories, direct land use change (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value shall replace the default ILUC value.

Source: ICAO (2019)