MAPPING FEEDSTOCK AVAILABILITY FOR THE PRODUCTION OF SUSTAINABLE AVIATION FUELS IN BRAZIL

FLUE GASES

RSB

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TEAM

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INTRODUCTION

RELEVANCE

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AMBITOUS TARGETS

The International Civil Aviation Organization (ICAO) is pursuing the GHG reduction on international flights:

- Improve fleet fuel efficiency by 1.5% per year from 2009 to 2020
- Carbon Neutral Growth from 2020
- Reduction of GHG emissions by 50% in 2050, as compared to 2005

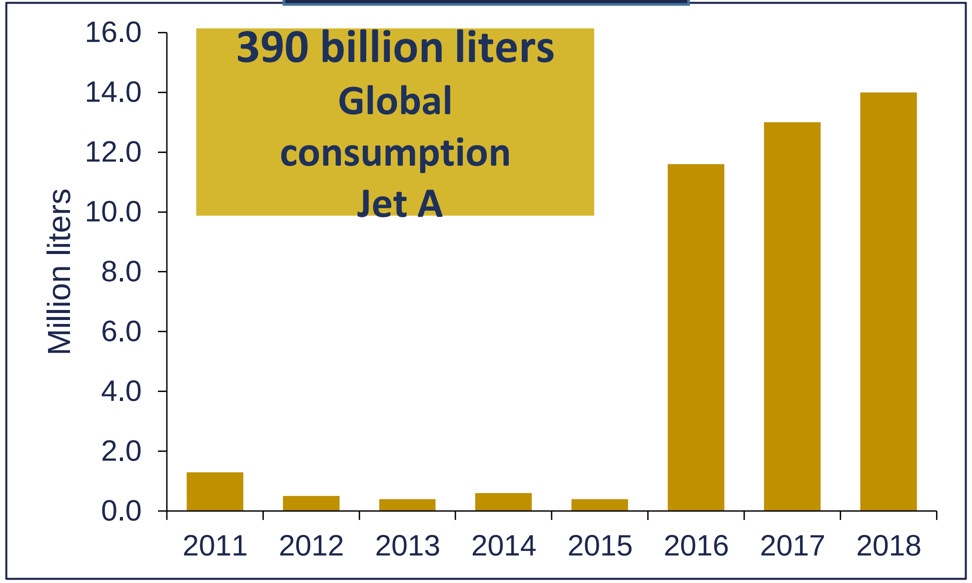
POSSIBLE PATHS

Improvements in the design and engine of aircrafts, or in the operations and infrastructure of aviation could help to achieve these targets. But they are limited.

SAF

Among the options, the substitution of fossil fuels by Sustainable Aviation Fuels (SAF) is considered the only one with the potential to achieve significant GHG reductions in the short-term.

SAF PRODUCTION



Source: ICAO (2020)

SAF must provide a reduction of, at least, 10% in GHG emissions when compared to fossil kerosene (on a life cycle basis), and must not have been obtained from high-carbon areas since 2008 (ICAO, 2019)

Thus, residual feedstocks are strategic options for significant GHG reductions, which will likely lead to low costs for SAF production.

GENERAL OBJECTIVES

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IDENTIFY AND MAP

Identify and map alternative residual feedstocks for SAF production in Brazil, including CO-rich industrial off-gases, beef tallow, used cooking oil, forestry residues, and sugarcane residues (bagasse and straw).

POTENTIAL

Provide information about feedstock availability and potential production of SAF.

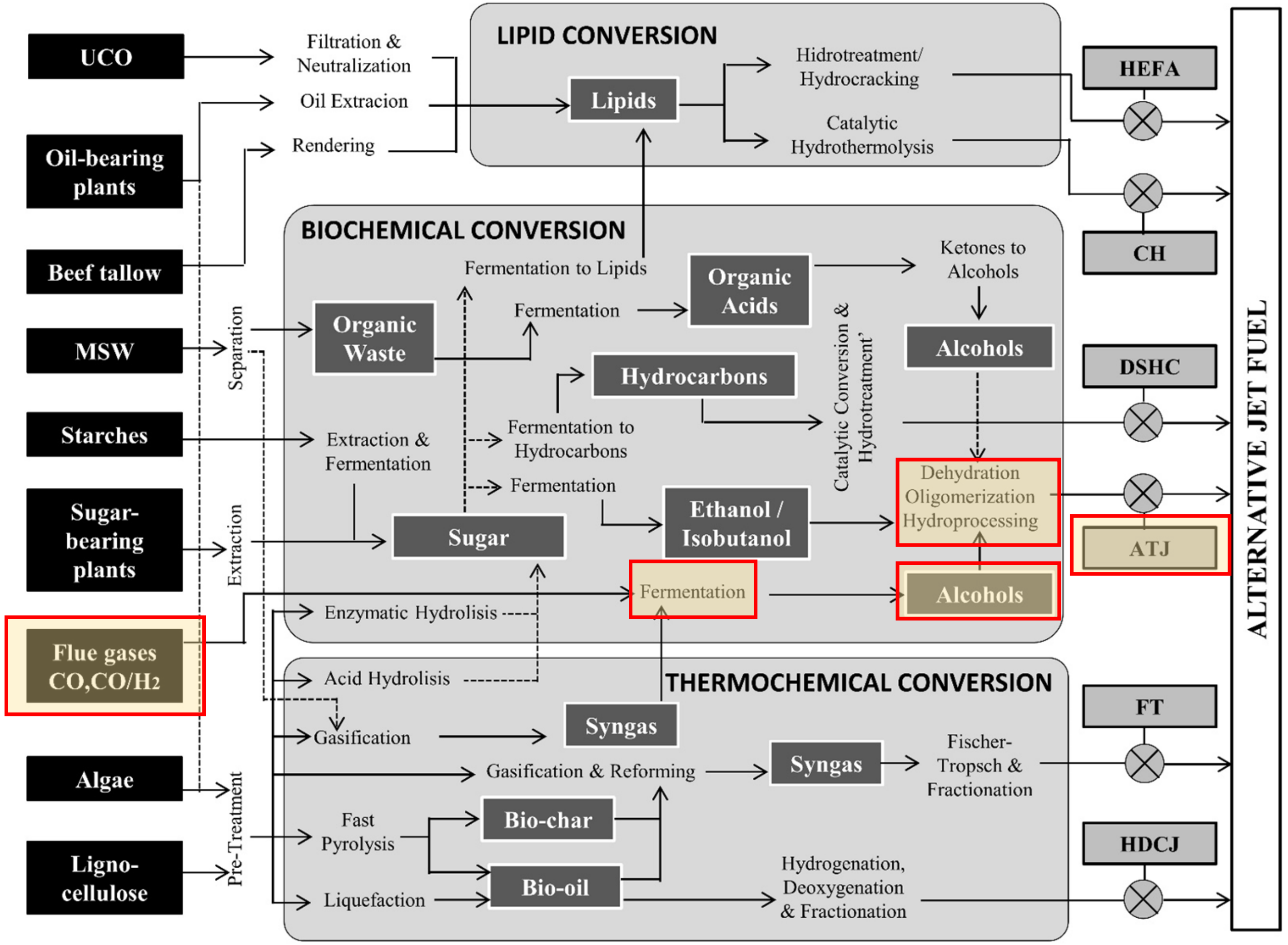
Pathways for SAF production:

Several pathways (feedstock + conversion technology) can be used to produce SAF. Some of them are currently approved or in the pipeline for approval by ASTM. An approved pathway means that the SAF produced is certified as a drop-in fuel and can be used with fossil kerosene within blending limits (v/v).

This case study focuses on ethanol obtained from fermentation of steel-off gases as feedstock, using ATJ technology

Pathways for SAF production*

Source: Boeing (2013)



** ASTM recently approved the co-processing of vegetable oils, greases, and Fisher-Tropsch biocrude with fossil middle distillates in oil refineries (maximum blend 5% v/v). Co-processed fuels is not represented in this figure.*

OBJECTIVE OF THIS REPORT

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General objective

To map the availability of flue gases from steel mills for SAF production, with geographical detail, to enable future studies on investment opportunities and strategies.

Specific objectives:

- Identify and map the locations of the Brazilian steel mills
- Identify the current generation of flue gases from steel refining processes, as well as their use for energy purposes and availability on flares
- Discuss the availability of flue gases to supply a commercial ethanol plant based on gas fermentation
- Identify and map the current demand for kerosene in Brazilian airports
- Match the previous information with transport infrastructure (gas pipelines and harbors)

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CONTEXT

GEOGRAPHY AND BOUNDARIES OF BRAZIL

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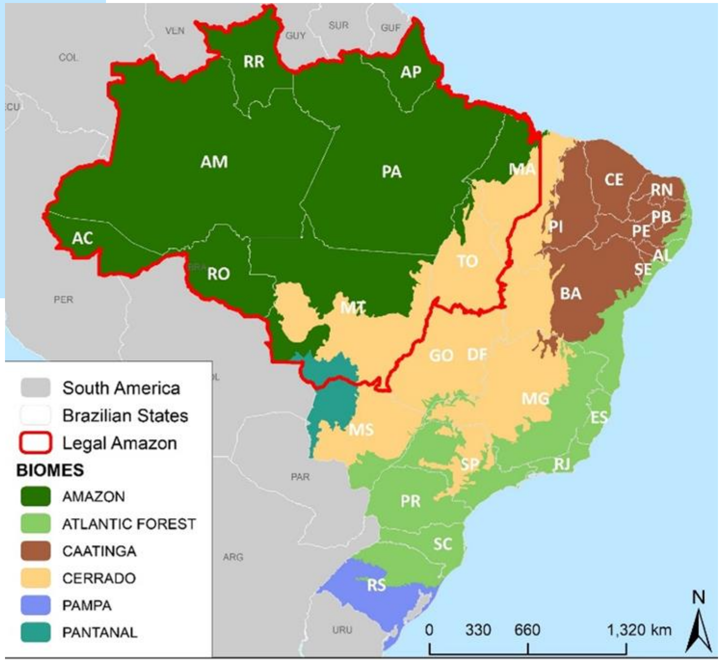
The Federative Republic of **Brazil** is a country of continental dimensions, whose territory **covers around 8.5 million km²**.

Politically, **Brazil is divided into 27 federative units**, composed of 26 states and one federal district (where the national capital is located).

These federative units are subdivided into municipalities. The municipalities in the Northern region (in green) have much larger areas than in the Southeast, for example, due to historical and geographical reasons. This fact needs to be considered in order to understand the availability of feedstock, which is spatialized by availability in each municipality.



The second map displays the boundaries of six Brazilian continental biomes: Amazon, Cerrado (or Brazilian savannah), Caatinga, Atlantic Forest, Pantanal and Pampa.

FLUE GAS

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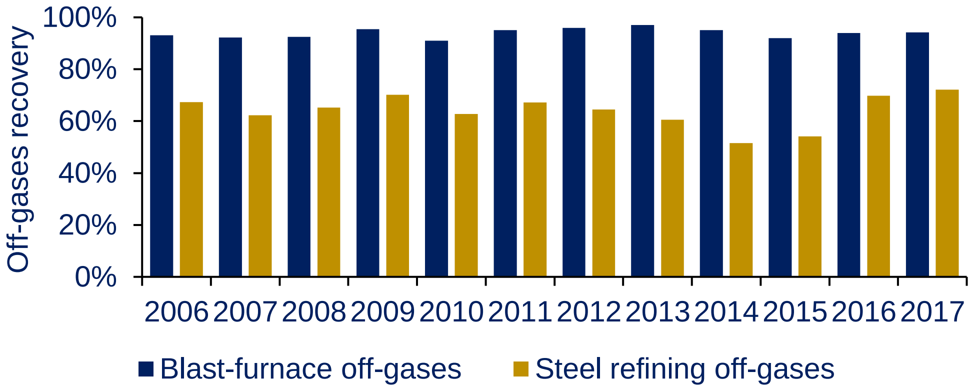
Commercial plant for production of ethanol from steel off-gases in China
https://bityli.com/nw3Go

Recovery of off-gases in Brazilian steel mills to be used as an energy source in internal processes



Source: ABM (2017)

WHAT ARE FLUE GASES?

The flue gases herein considered comprise the off-gases released during the steel refining process.

Steel is an alloy of iron and carbon, which are obtained from iron ore and coal (or charcoal), respectively. After a preparation stage, a load of iron ore and coke or charcoal are reduced to pig-iron in a blast furnace. In turn, the crude steel is obtained at a refining stage by adjusting the carbon content of pig-iron with a consequent emission of carbon.

The main refining technologies are Basic Oxygen Furnace (BOF), also called Linz–Donawitz-steelmaking (LD), and Electric Arc Furnace (EAF), which correspond to roughly 78% and 21% of the global steel production, respectively (*Instituto Aço Brasil, 2018*).

In general, the recovery of off-gases as an energy source – mainly from blast-furnace operations (see the graph) – is a usual practice in steel mills. Off-gases from refining processes have been recovered by 60%.

Considering their different compositions, steel off-gases from BOF technology would be suitable for the novel fermentation technology patented by LanzaTech, which has already reached commercial scale (*Lanzatech, 2018*).

SUPPLY CHAIN

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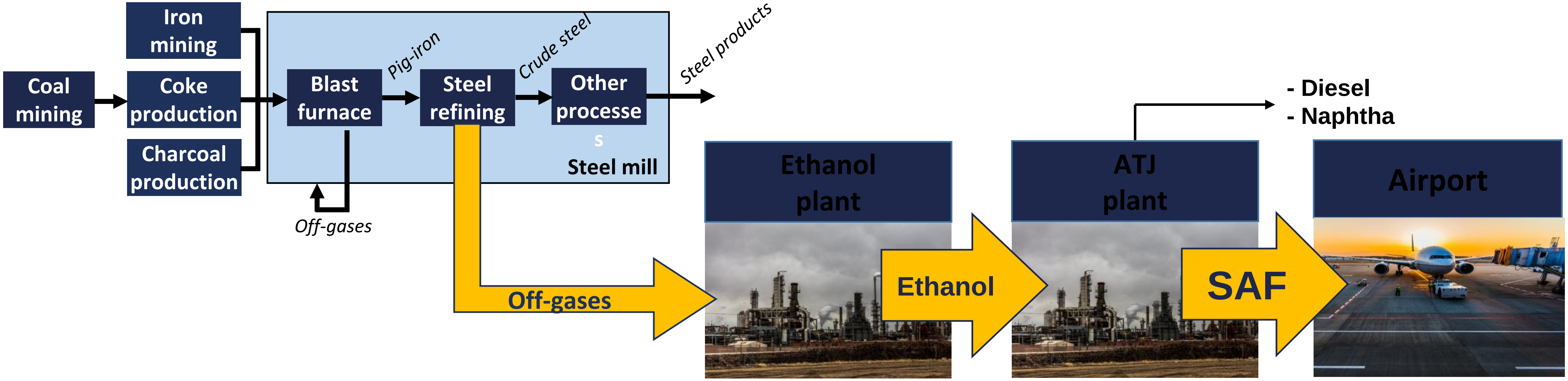
This pathway considers ethanol production through the fermentation of the off-gases released during the steel refining process. This novel technology has already reached commercial scale (Brooks et al., 2016; LanzaTech, 2018) and was described by Handler et al. (2016). The fermentation process was tailored to maximize ethanol production, with minimal co-product generation and no co-product recovery. Likewise, biogas from anaerobic digestion of the biological solids (spent microbial biomass) filtered from the distillation would be mixed with a portion of the reactor vent gas and used for internal energy supply. The remaining vented gas from the fermentation bioreactor would be scrubbed, oxidized, and released into the atmosphere.

In turn, the ethanol would be sent to an ATJ plant, where it is converted into SAF. In the ATJ technology, alcohol molecules are dehydrated, oligomerizeted, and finally hydrogenated into suitable hydrocarbon chains to be used as a drop-in fuel. Lastly, the SAF would be distributed to consumption sites, considering that the blending of SAF and fossil kerosene (Jet-A) would occur at the airport.



Source Picture: Unsplash

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SUPPLY CHAIN: General yields and main inputs

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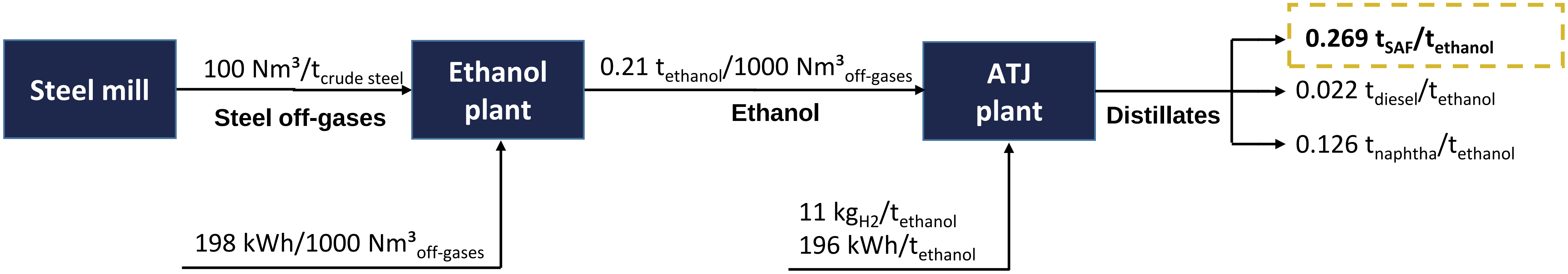

Overall yield

58 $kg_{SAF}/1000\ Nm^3_{off\text{-}gases}$

78 $L_{SAF}/1000\ Nm^3_{off\text{-}gases}$

Sources: Handler et al. (2016), Klein et al., (2018)

FEEDSTOCK AVAILABILITY

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GENERAL ASSUMPTIONS

The potential availability of **steel flue gases** to produce ethanol, which is used as an intermediary feedstock for SAF production, was estimated based on the following data and assumptions:

- Brazilian steel mills based on BOF technology for steel refining and crude steel production (Instituto Aço Brasil, 2018)
- Steel flue gases generation from steel refining process (ABM, 2017). When data was not available, the value of 100 $Nm^3/t_{crude\ steel}$ was assumed.
- The use of steel flue gases along the last years, i.e. recovery as an energy source or flaring (ABM, 2017). When data was not available, it was assumed that all off-gases are recovered and used as an internal energy source.
- For the fermentation of steel flue gases, an overall yield of 0.217 $L_{ethanol}/Nm^3_{flue\ gases}$ was estimated, assuming a theoretical maximum ethanol conversion rate of 80% (LanzaTech, 2019) and a net yield of 0.936 $L_{ethanol}/Nm^3_{flue\ gases}$ (Handler et al., 2016).

SCOPE

The potential availability of steel flue gases was estimated based their generation and current use in Brazilian steel mills. The data were spatialized according to the location of the steel mills. The steel mills with suitability to supply one ethanol plant on commercial scale (58 million liters ethanol per year produced from 214 million Nm^3/year) were selected.

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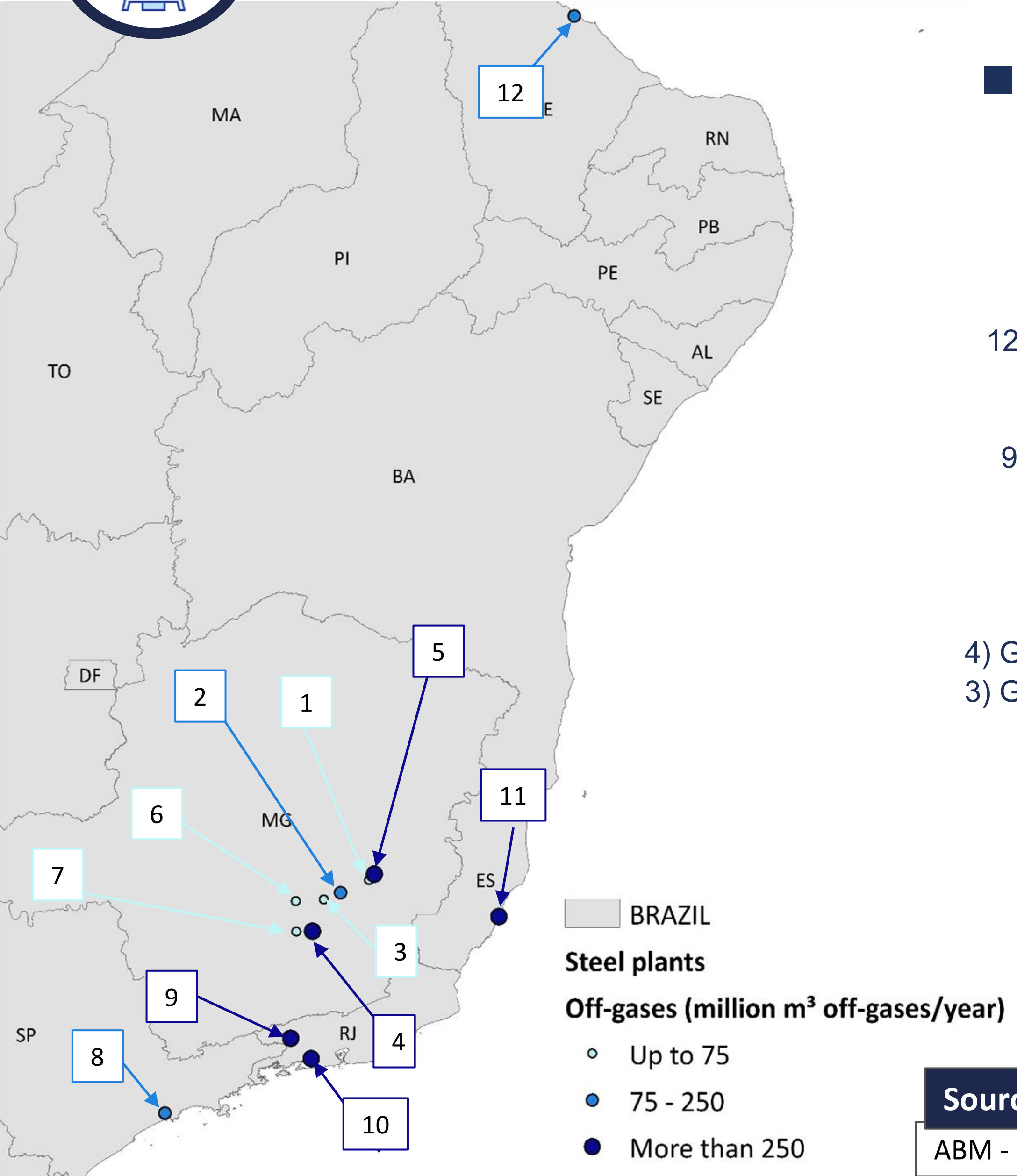
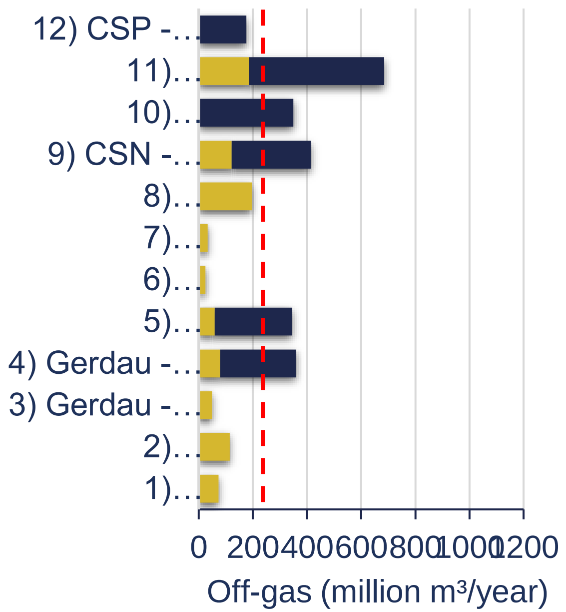
FLUE GAS AVAILABILITY AND INTERMEDIARY ETHANOL PRODUCTION





Scenario	Off-gases (million Nm³)	Ethanol (million m³)*
Brazilian steel mills (Total)	2823 (total)	0.77
	942 (flaring)	0.26
Brazilian steel mills with enough flue gas generation to supply one ethanol plant *(> 214 million $Nm^3_{flue\ gases}$/year)*	2153 (total)	0.58
	448 (flaring)	0.12

**For comparative purposes, the amount of ethanol consumed in Brazil in 2019 was of 35.6 million m³*

Source

ABM - Brazilian Association of Metallurgy, Materials and Mining (2010-2017); Steel Directory Brazil(2018)

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MATCHING FEEDSTOCK AVAILABILITY WITH PROCESSING SITES AND DEMAND

GENERAL ASSUMPTIONS

Regarding the SAF production from flue gases from steel refining process, the spatially explicit data of feedstock availability was combined with possible processing sites and consumers according to the following assumptions:

- Considering possible logistic problems for gas transportation, the ethanol plant was assumed to be close or even integrated to a steel mill.
- ATJ plant, where ethanol is converted into SAF, should be close to an oil refinery due to hydrogen demand for hydrotreating process and process integration possibilities.
- Alternatively, ATJ plants may be located near natural gas pipelines for possible hydrogen production through Steam Methane Reform.
- Before to supply an aircraft, SAF must be blended with Jet A.
- Considering that GHG reduction targets are related to international flights, only the international airports' supply was considered here.

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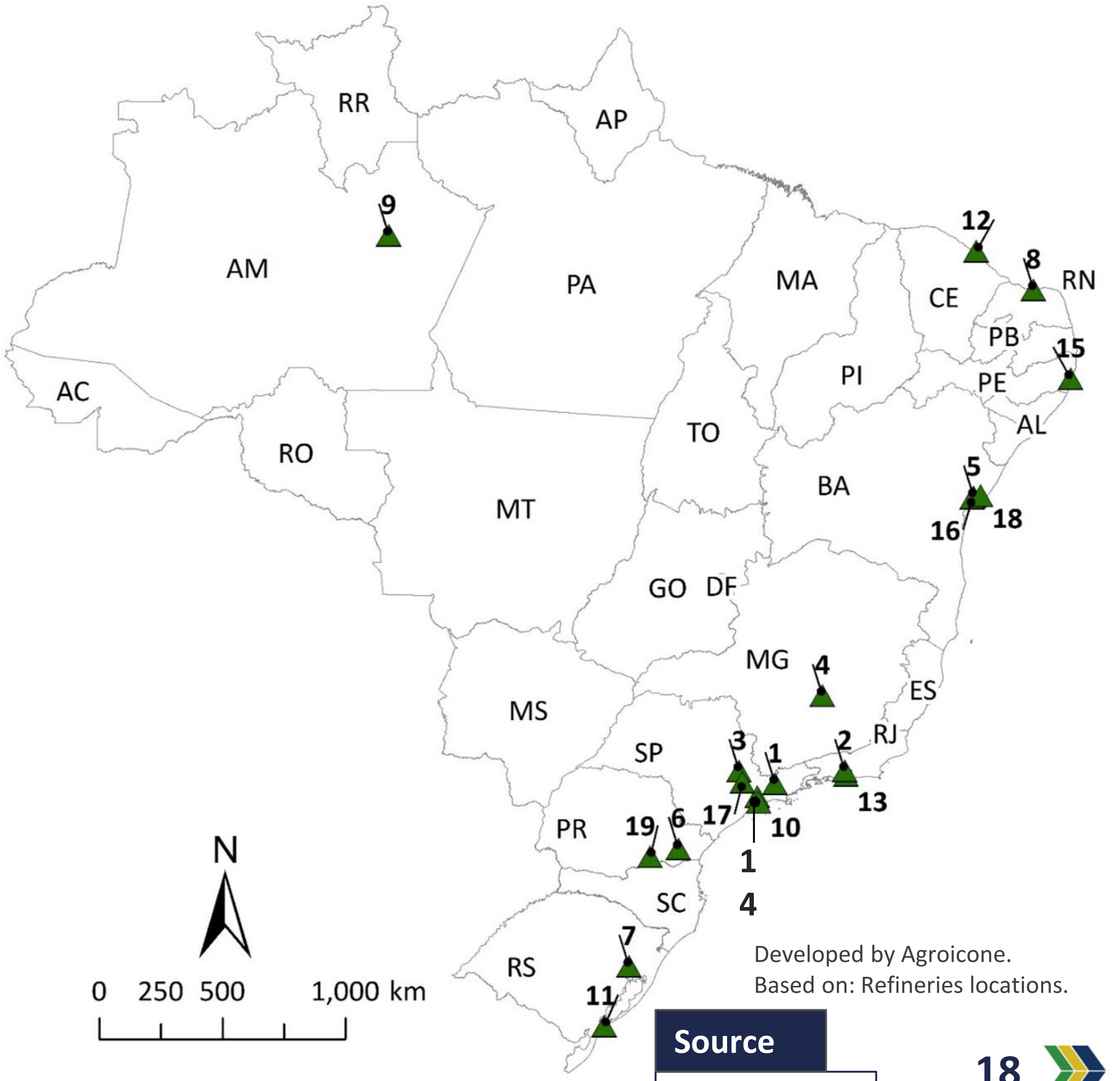
OIL REFINERIES

According to ANP (2019), the map present the of the Brazilian oil refineries.

The refineries that had no production of Jet A were not considered for the following evaluations.

ID	Brazilian Refineries	Jet A Production 2018 (Million m³)
1	Revap (SP)	1.93
2	Reduc (RJ)	1.43
3	Replan (SP)	1.13
4	Regap (MG)	0.71
5	Rlam (BA)	0.36
6	Repar (PR)	0.27
7	Refap (RS)	0.21
8	RPCC (RN)	0.20
9	Reman (AM)	0.13
10	RPBC (SP)	0.02
11	Riograndense (RS)	0
12	Lubnor (CE)	0
13	Manguinhos (RJ)	0
14	Recap (SP)	0
15	Rnest (PE)	0
16	Fasf (BA)	0
17	Univen (SP)	0
18	Dax Oil (BA)	0
19	Six (PR)	0



Developed by Agroicone.
Based on: Refineries locations.

Source

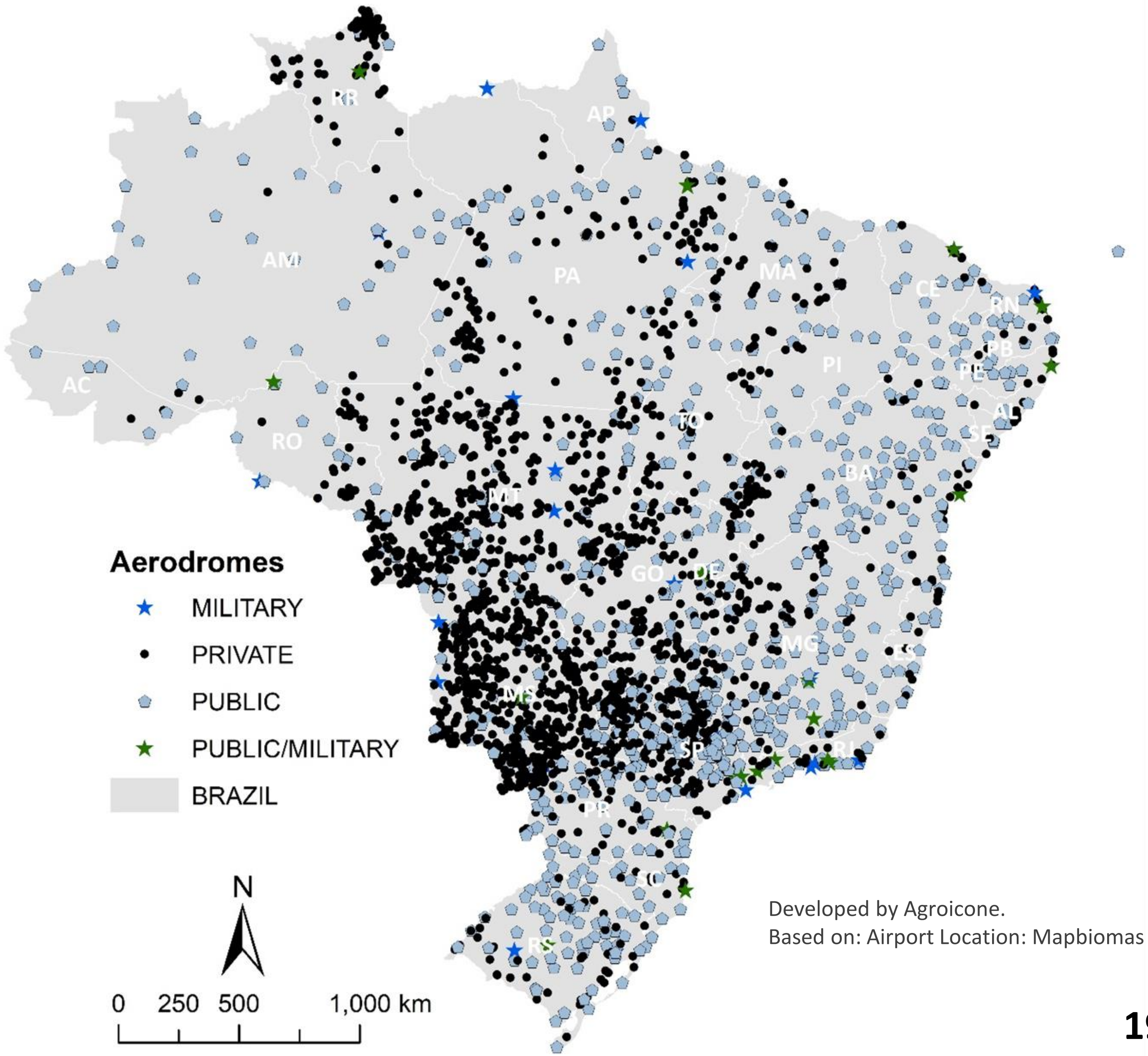
ANP (2019)

AIRPORTS LOCATION

Brazil has more than 2600 registered aerodromes, from those at least 650 are public, 1900 are private and 40 are military.

In 2018 ANAC (National Agency for Civil Aviation) registered the Jet A consumption of 143 airports, from which 34 are international airports.

The ANAC database was used to categorize the International Airports.



Developed by Agroicone.
Based on: Airport Location: Mapbiomas (2018)

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JET A CONSUMPTION AND AIRPORTS

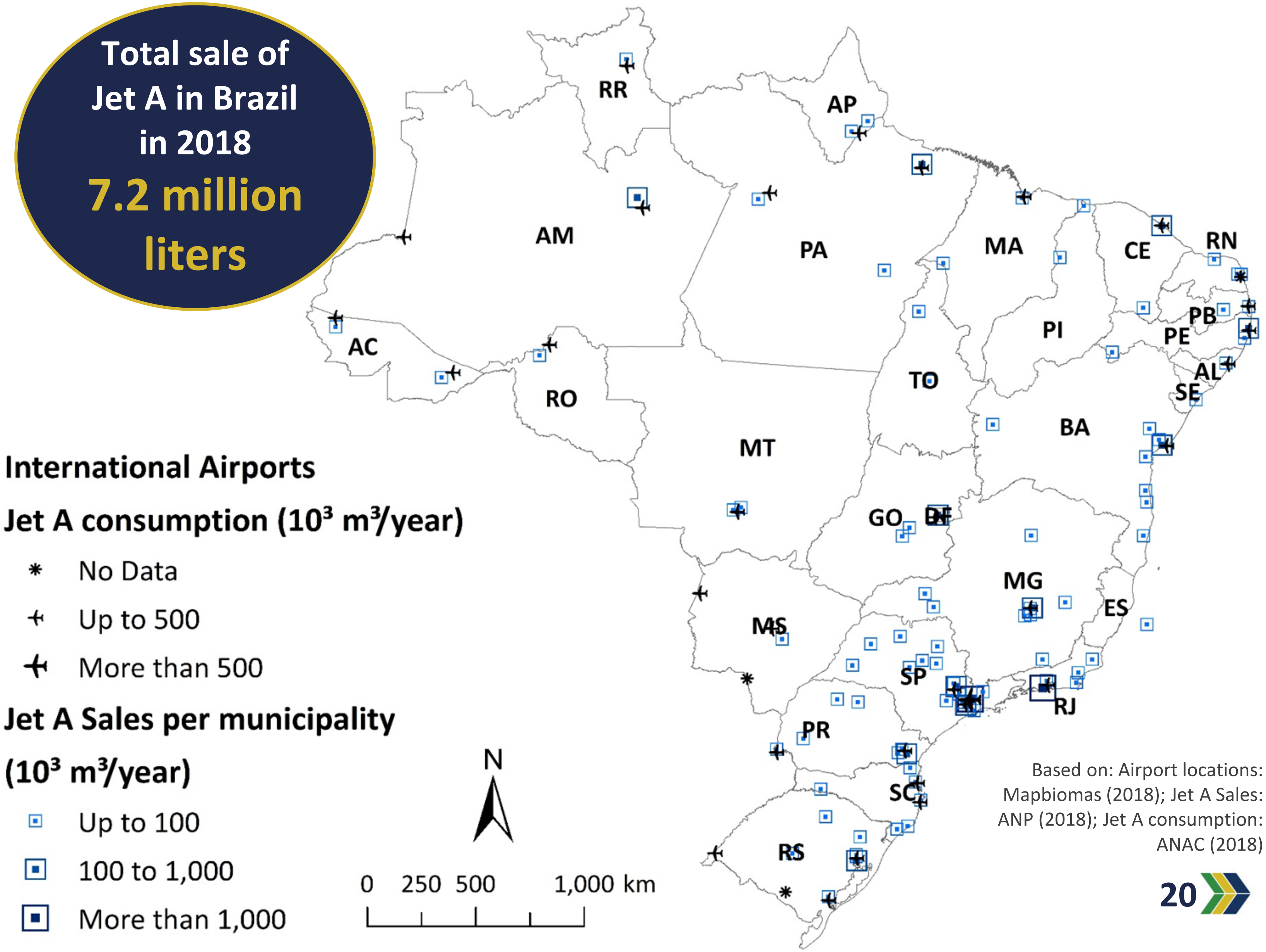
According to The Global Economy (2020), Brazil consumed an average of 123.46 thousand barrels per day of Jet fuel in 2018, whereas the world average, based on 43 countries, is 98.57 thousand barrels per day. Out of the 43 countries analyzed by this research group, Brazil is the 10th highest consumer of Jet fuel.

The consumption of Jet A was spatialized according to the fuel sales reported by ANP (2018).

In general, international airports are related to high regional consumption rates.

The **highest consumption** occurs in the **Southeast region**, which also holds the largest numbers of national and international flights. Around **58% of Jet A** sales are destined to SP State and RJ State.

Total sale of Jet A in Brazil in 2018
7.2 million liters

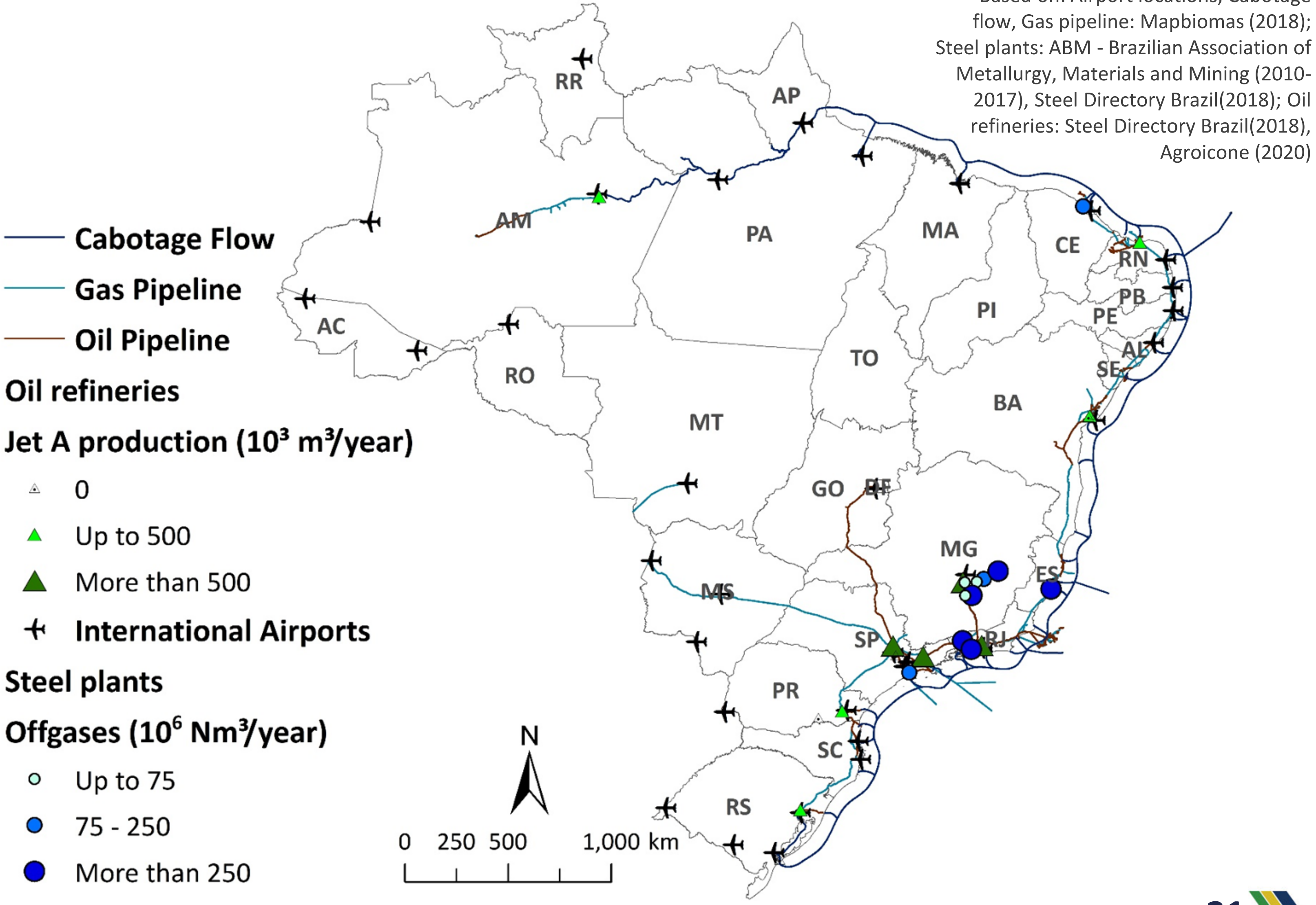


Based on: Airport locations: Mapbiomas (2018); Jet A Sales: ANP (2018); Jet A consumption: ANAC (2018)

MATCHING AVAILABILITY, PROCESSING AND DEMAND

The steel mills with suitable scale for ethanol production are concentrated in the Southeast region, mainly in MG, RJ and ES States, which also have oil refineries and international airports with high Jet A consumption.

The Cabotage Flow could be considered for SAF supply of other airports and export.



Based on: Airport locations, Cabotage flow, Gas pipeline: Mapbiomas (2018); Steel plants: ABM - Brazilian Association of Metallurgy, Materials and Mining (2010-2017), Steel Directory Brazil(2018); Oil refineries: Steel Directory Brazil(2018), Agroicone (2020)

POTENTIAL SAF PRODUCTION FROM FLUE GASES

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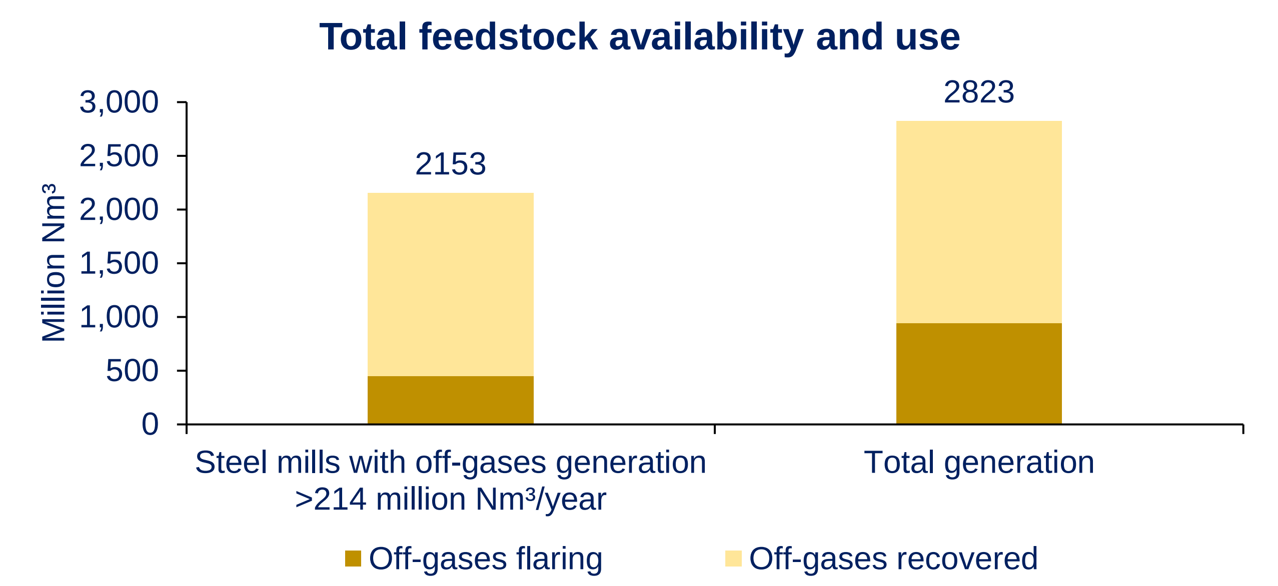
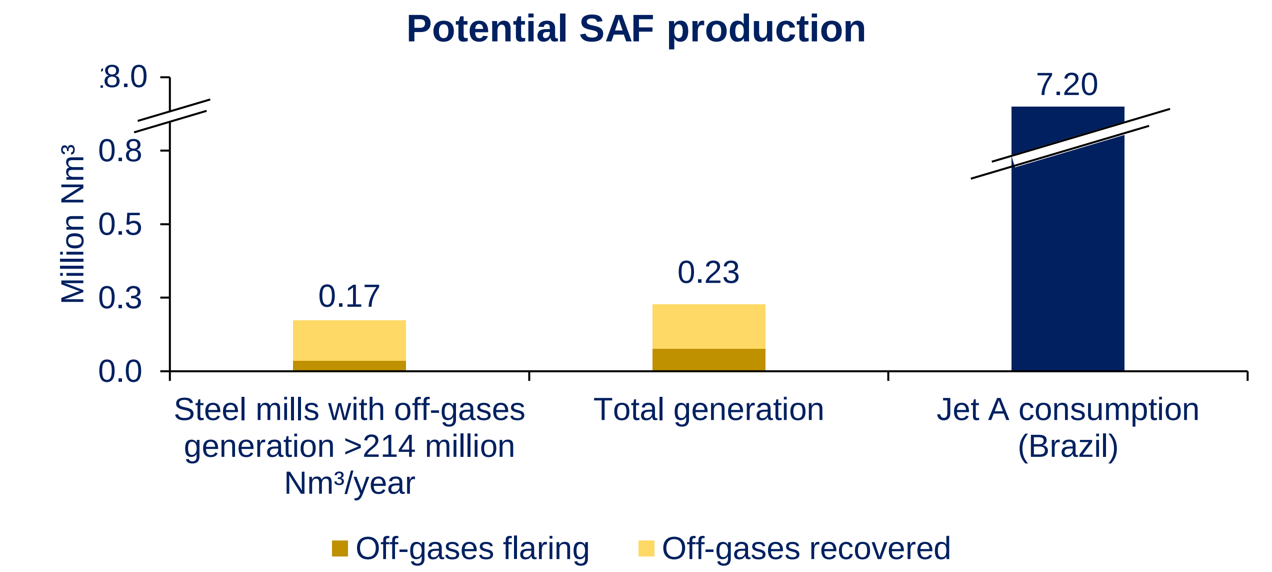
Following the global trends of steel making processes, more than a half of the off-gases released during the BOF refining process have been recovered to be used as an internal energy source. Therefore, it is reasonable to suppose probable consequences in changing the current use of flue gases for ethanol production.

In this context, the additional use of natural gas is considered an immediate effect, as confirmed in interviews with steel mills staff. This can lead to relevant impacts on the economic and environmental feasibility of products obtained from steel flue gases.

The total flue gases generated from the Brazilian steel mills could supply **3.2% of the current demand for kerosene**. The SAF production considering the only five steel mills that would be able to supply one ethanol plant would correspond to **2.3% of the current demand for kerosene**.





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FINAL REMARKS

KEY-MESSAGES

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- This project has made significant effort in building a **spatially explicit database** comprising the availability of flue gases from the steel refining process for SAF production, through ATJ technology.
- This mapping considers a novel technology of **CO-rich gas fermentation** to produce ethanol, which has already reached commercial scale.
- During the steel-making process, the flue gases obtained from the pig-iron production and the steel refining process are commonly recovered to be used as an internal energy source, mainly in the former case. Regarding the different compositions of both flue gases, only those generated in steel refining processes through **BOF technology** would be suitable for the novel fermentation process.
- In Brazil, around 85% of the crude steel is produced by 12 steel mills that employ BOF technology. The total use of flue gases for SAF production would supply roughly **3% of the total demand for kerosene in Brazil**. Considering the only five steel mills that would be able to supply one ethanol plant on commercial scale, the potential SAF production would correspond to 2.3% of the demand for kerosene.
- It is worth highlighting that around 60% of the flue gases from the steel refining process are **currently being used** in Brazil. Therefore, switching its use for ethanol production could lead to **possible impacts on the economic and environmental feasibility of SAF**. Even so, it could be a strategic option for the steel industry.
- Considering the availability of flue gases, Minas Gerais, Rio de Janeiro, and Espírito Santo States would be responsible for 30.1%, 24.3%, and 18.4% of the potential SAF production. The steel mills located in these States are close to oil refineries and important airports, which highlight the strategic importance of this pathway, even with a low potential production.

NEXT STEPS

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- The project has not performed analysis on issues that deserve to be further investigated, such as:
  - Cost evaluation
  - Life Cycle evaluation
  - Optimization of logistics
  - Integration with other feedstock and with other fuels.

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