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

WOOD RESIDUES

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INTRODUCTION

RELEVANCE

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

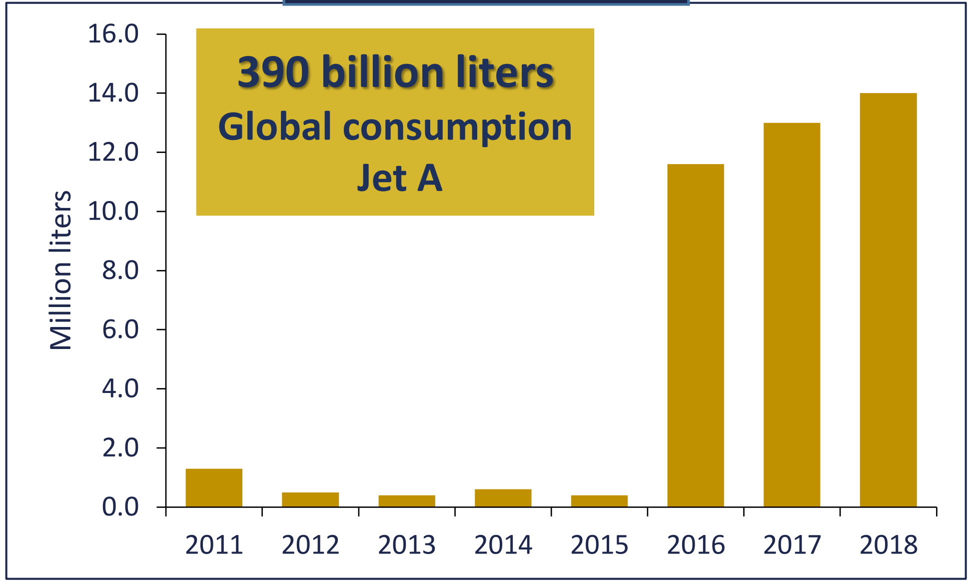
POSSIBLE PATHS

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

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).

ESTIMATE POTENTIAL USE

Provide information about feedstock availability and potential production of SAF.

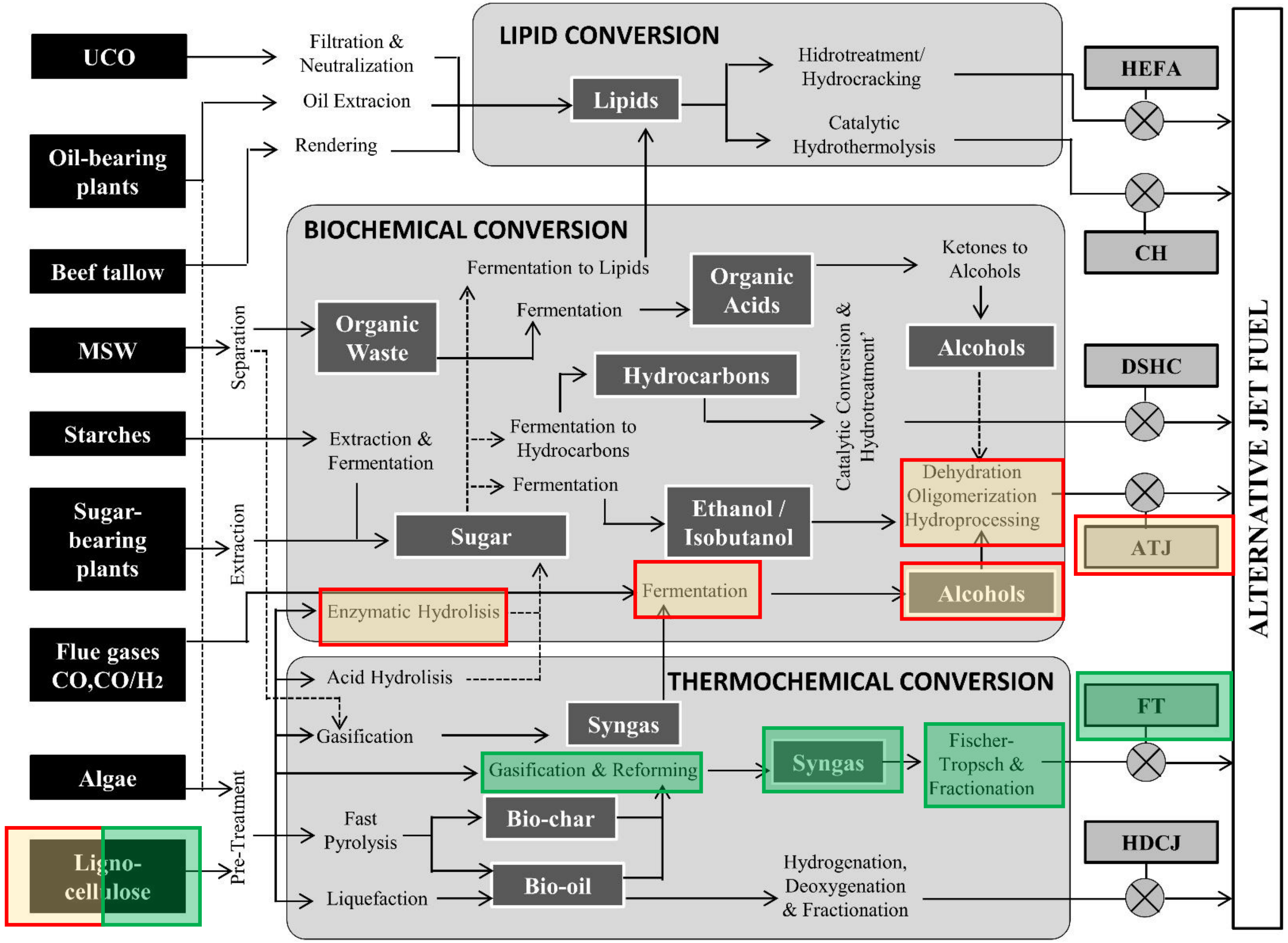
Pathways for SAF production:

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 use with fossil kerosene within blending limits (v/v).

This case study focusses on lignocellulosic ethanol as a feedstock, using ATJ technology, and lignocellulosic material as a feedstock, using FT technology

Pathways for SAF production*

Source: Boeing et al. (2013)



Recently, ASTM 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

General objective

Map eucalyptus residues availability for SAF production with geographical detail, thus enabling future studies on investment opportunities and strategies.

Specific objectives:

- Identify the current production and availability of eucalyptus in Brazil
- List the current applications of this residue
- Identify locations for feedstock collection and their production capacity
- Identify potential locations for processing industries
- Identify the demand (airports)
- Develop maps:
    - Spatializing the availability of eucalyptus residues
    - Matching the availability of residues with potential processing locations
    - Matching potential processing locations with the consumption sites
    - Matching all the above with transport infrastructure (gas pipelines, harbors)

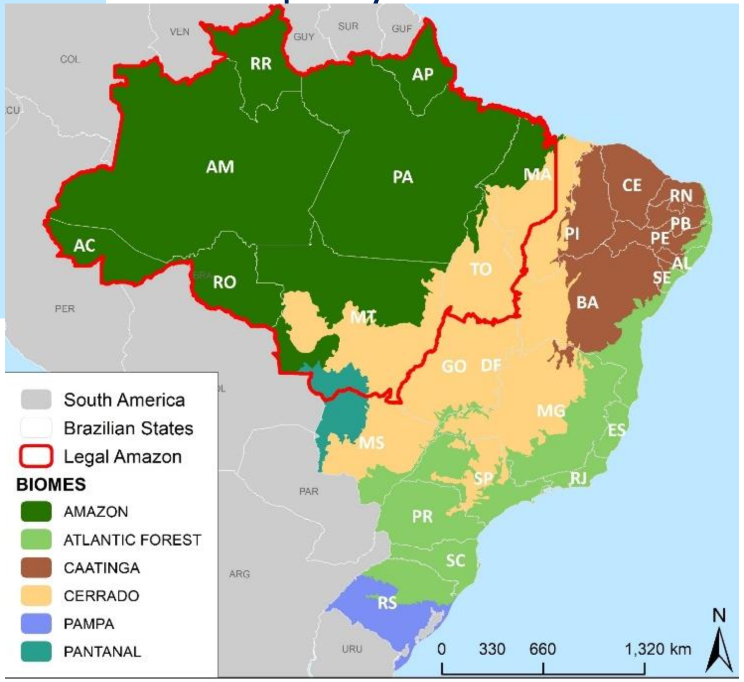

CONTEXT

GEOGRAPHY AND BOUNDARIES OF BRAZIL

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 a 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 feedstock availability, which is spatialized by availability in each municipality.



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

WOOD RESIDUES

https://bityli.com/lmkop

https://bityli.com/IOqGV

https://bityli.com/VLcEf

https://bityli.com/LszWO

WHAT ARE WOOD RESIDUES?

Wood residues herein comprise forestry residues from planted forests, such as leaves, branches, barks, and treetops, which are generated during harvesting operations. In this study, only residues from eucalyptus crops, which have represented around 70% of the planted forest areas in Brazil (IBA, 2019), are considered.

CURRENT USE OF WOOD RESIDUES

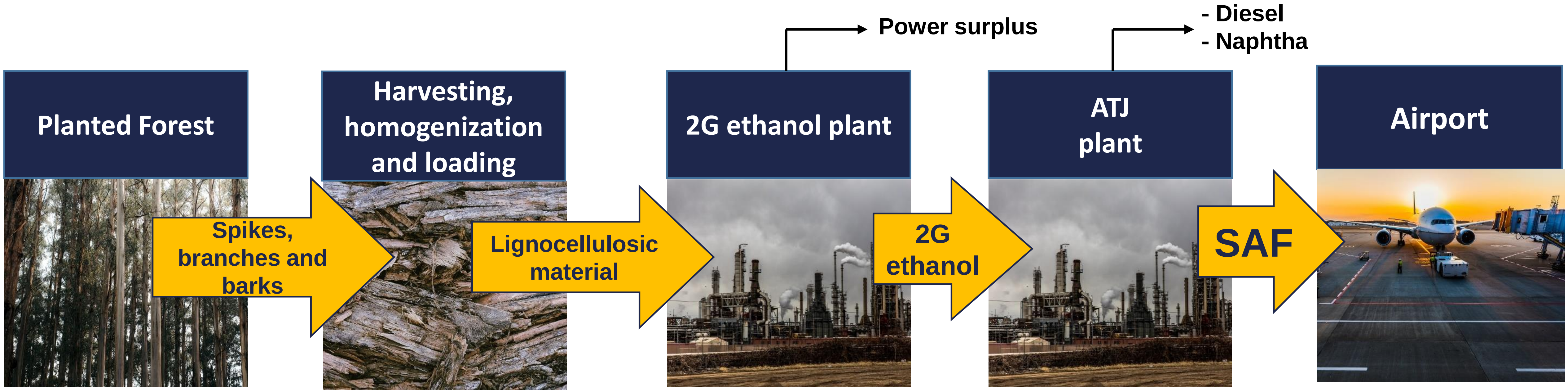
According to recent reports from the Brazilian wood industry (IBÁ, 2019), all residues generated during harvesting operations are kept on the field. However, based on interviews with Brazilian paper and pulp companies, a share of wood residues is commonly recovered , in some cases, as a source of energy for industrial processes. Likewise, some operations related to residue generation, such as debarking, are carried out only at industrial plants – for logistics reasons - and a share of these residues are used as a source of energy.

Based on these interviews, it was possible to infer that the recovery of forestry residues from fields are more related to financial and logistics reasons than to agronomic issues. No losses on agricultural productivity are observed in areas with full recovery. However, the environmental benefits of keeping residues on the fields are commonly found in the literature.

SUPPLY CHAIN FOR ATJ PATHWAY

The wood residues are generated during harvesting operations of eucalyptus crops. The residues would be collected, chopped, and transported to a stand-alone 2G ethanol plant. In this plant, ethanol is obtained through steam explosion, followed by enzymatic hydrolysis in an advanced design. Furthermore, this plant was considered to be self-supplied by processing residues used in a cogeneration system, with power surplus generation.

Subsequentially, the ethanol would be sent to an ATJ plant for SAF production. Within the ATJ technology, alcohol molecules are dehydrated, oligomerizeted, and finally hydrogenated to suitable hydrocarbon chains, to be used as a drop-in fuel, including SAF. 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.



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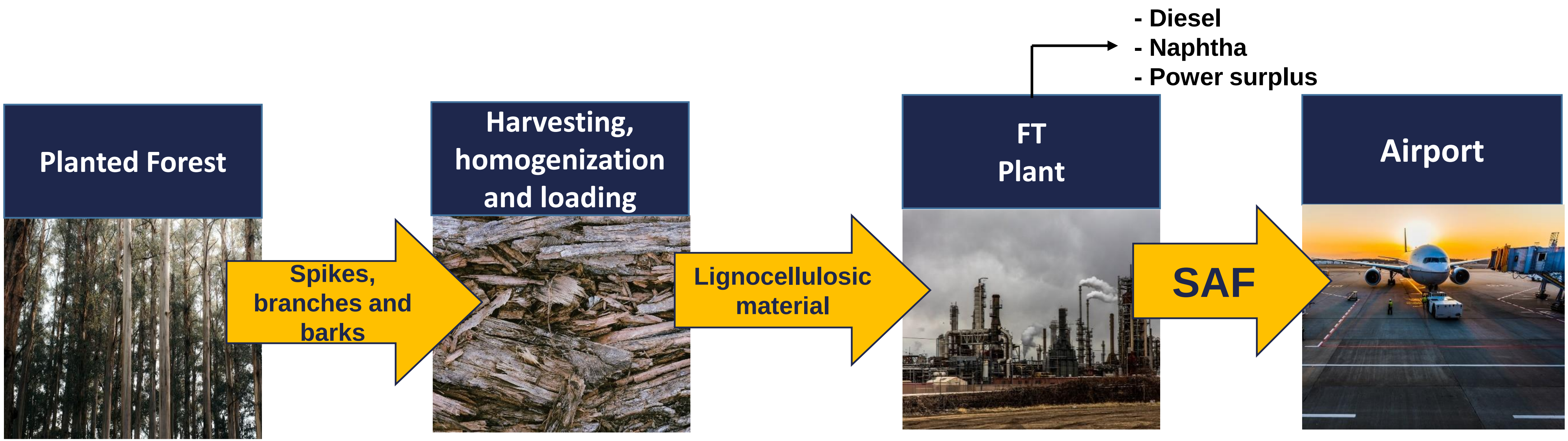
SUPPLY CHAIN FOR FT PATHWAY

Differently from the ATJ pathway the FT method does not require any intermediary conversion. Therefore, the wood residues would be collected after the harvesting of eucalyptus crops, chopped, and transported to a FT plant.

In the FT plant, this material is gasified to syngas. After a clean-up process, syngas goes to a Fischer-Tropsch reactor, where it is catalytically converted into liquid, long-chain hydrocarbons, which are then cracked, isomerized and fractioned into drop-in jet fuel and other products.

Lastly, the SAF would be distributed to consumption sites, considering that the blending of SAF and fossil kerosene (Jet A) would take place at the airport.



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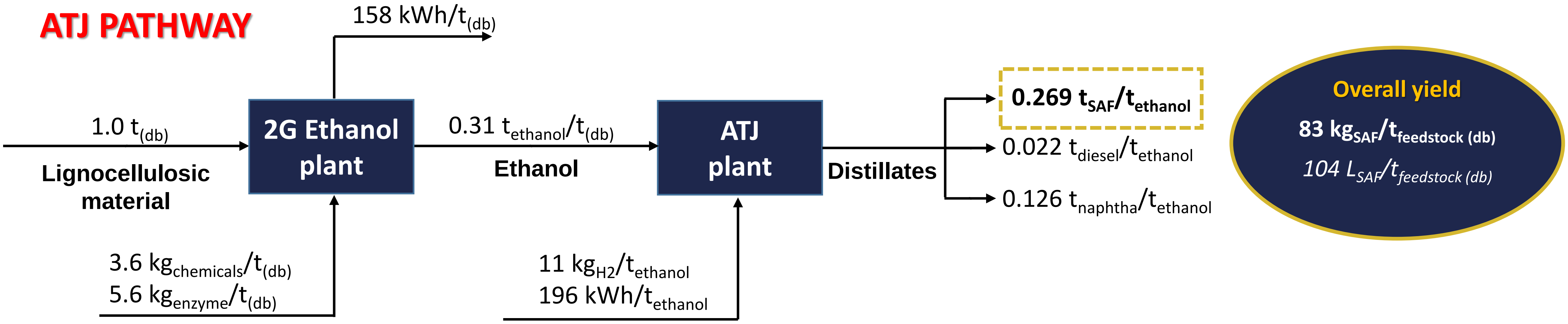
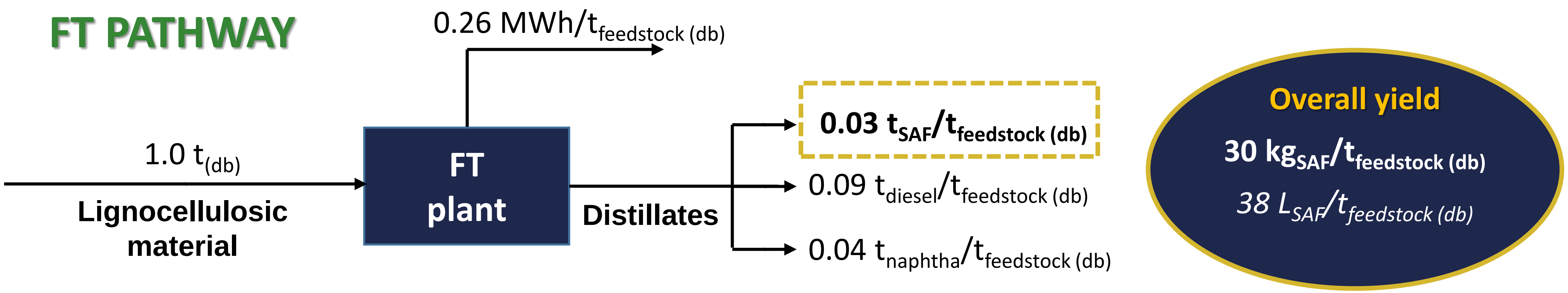
SUPPLY CHAIN: General yields and main inputs

ATJ PATHWAY



FT PATHWAY



Sources: For ATJ pathway, VBS (2019), Bonomi et al. (2016), and Klein et al., (2018). For FT pathway, Jong et al. (2015).

FEEDSTOCK AVAILABILITY

CONFIDENTIAL

GENERAL ASSUMPTIONS

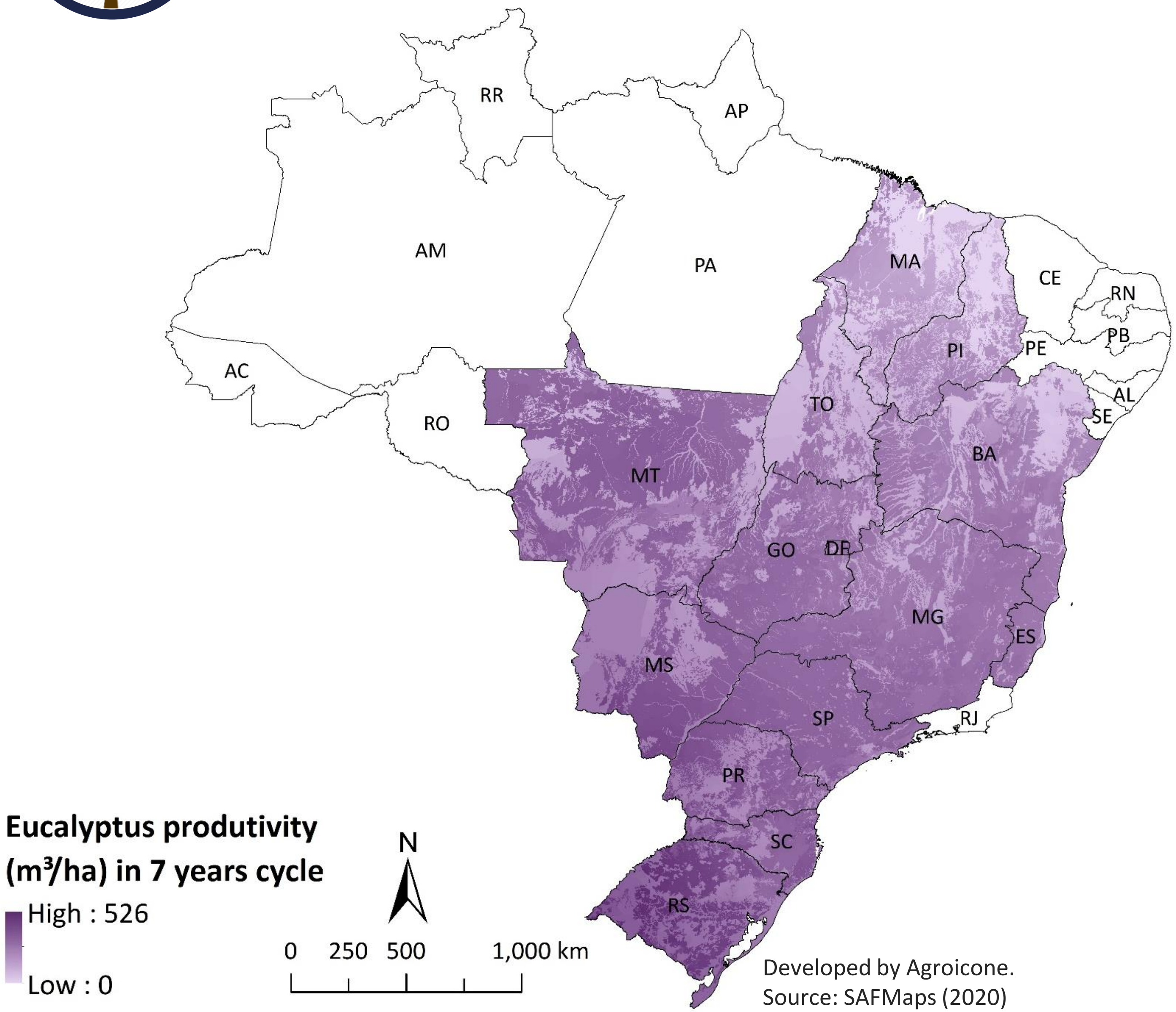
The potential availability of **forestry residues** was estimated based on the following data and assumptions:

- Eucalyptus productivity (m^3/ha.cycle): based on a **raster database,** which reports the productivity of eucalyptus in Brazilian conditions, including soils types and climate parameters.
- Average productivity **per municipality**: calculated based on the productivity of eucalyptus and on recent eucalyptus areas per municipality (SIDRA, 2019). The average productivity per municipality was estimated based on the raster database using ArcGIS® (command "function zonal statistics as table"), according to the shapefile of municipalities' limits (IBGE, 2010).
- Average cycle of eucalyptus: 7 years;
- The rates of residue generation and current use were based on recent reports from the Brazilian Tree industry (IBÁ), which represents the major players of the national wood industry, such as producers of wood floors and panels, paper and pulp, sawn wood, and charcoal.
- Average residue generation during harvesting operations: **0.167 $t_{residues\_(db)}$ per m^3 of wood collected during one cycle**. According to IBÁ (2019), this corresponds to roughly 70% of the total residues estimated for the wood industry. The remaining residues are obtained mostly from industrial operations, and comprise chips, sawdust, black liquor, paper scraps, lime sludge, boiler ash, and chemical compounds.
- Average moisture of wood residues: 11.6%, according to ECN (2017);
- Considering the uncertainties related to logistical feasibility and a suggested recovery rate, it was assumed that **50%** of the total wood residues generated during eucalyptus harvesting operations would be recovered, and the remaining amount would be kept on the field.

SCOPE

The **eucalyptus production** was calculated based on the average productivity of each municipality multiplied by the area of planted eucalyptus in each municipality in 2018. For residues potential, it was assumed a rate of 0.167 $t_{residue}/m^3_{eucalyptus}$ over the potential annual production. Finally, it was considered that 50% of this total amount would be collected from field.

PRODUCTIVITY OF EUCALYPTUS



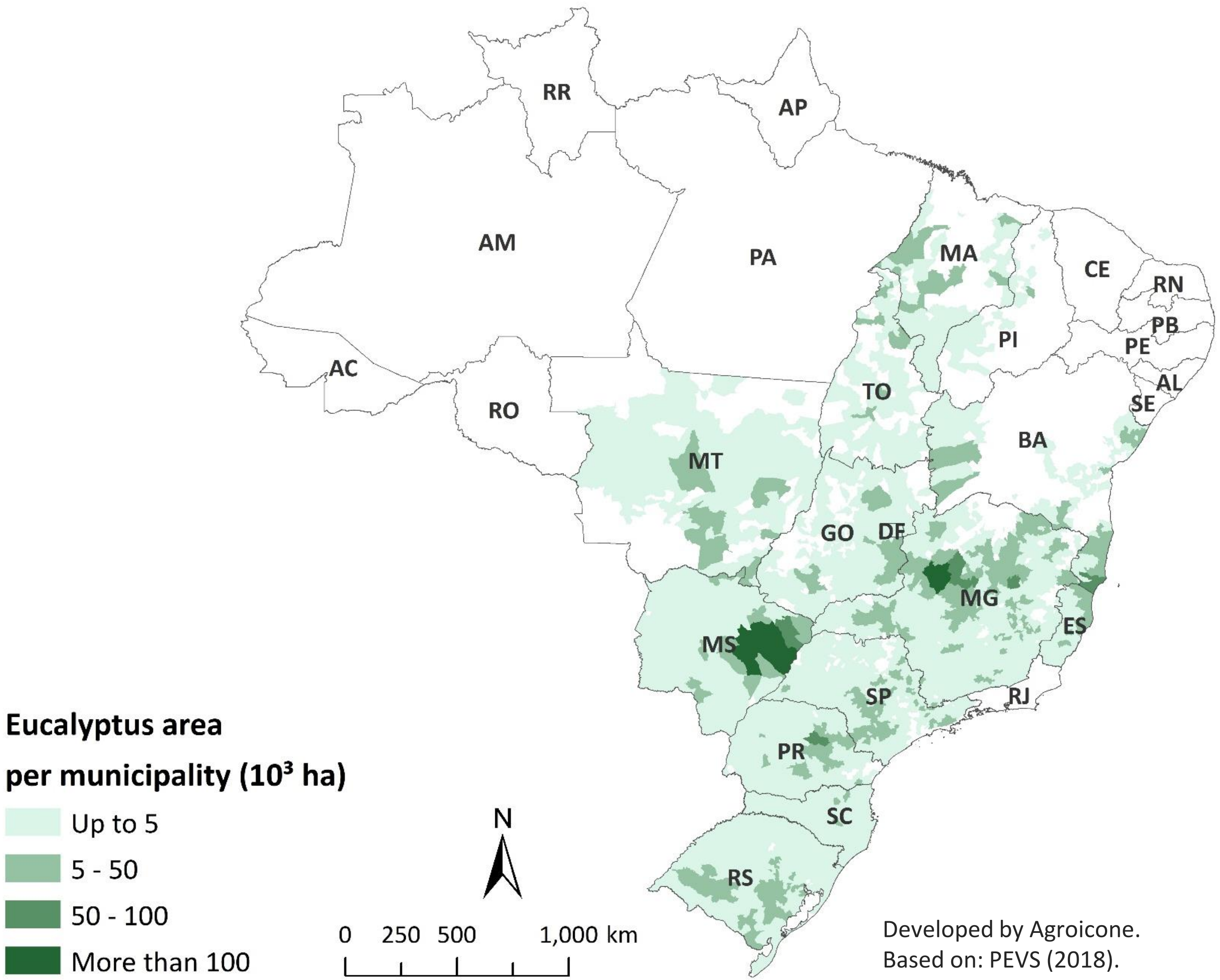
The productivity of eucalyptus was taken from Walter et al. (2020), which is based on a statistic model correlating potential yields with local climatic conditions and soil suitability. The authors also used a study developed by EMBRAPA as reference data, with results of yields based on a procedure for modelling eucalyptus growth.

The statistic model was applied for twelve Brazilian states with eucalyptus production in the last years (IBÁ, 2019). The results were compared **with average and best eucalyptus yields** in Brazil, in recent years.

Furthermore, *No-go areas*, which comprise the Amazon and Pantanal regions, were excluded for this estimation.

The average national productivity of eucalyptus was estimated at 36 m^3/ha per year in 2018.

EUCALYPTUS AREA PER MUNICIPALITY



This study considered a planted eucalyptus area of approximately

7.5 million ha

in Brazil

In 2018, the total area of planted forests in Brazil totaled almost 10 million hectares, out of which 75% were eucalyptus plantations (7.54 million hectares).

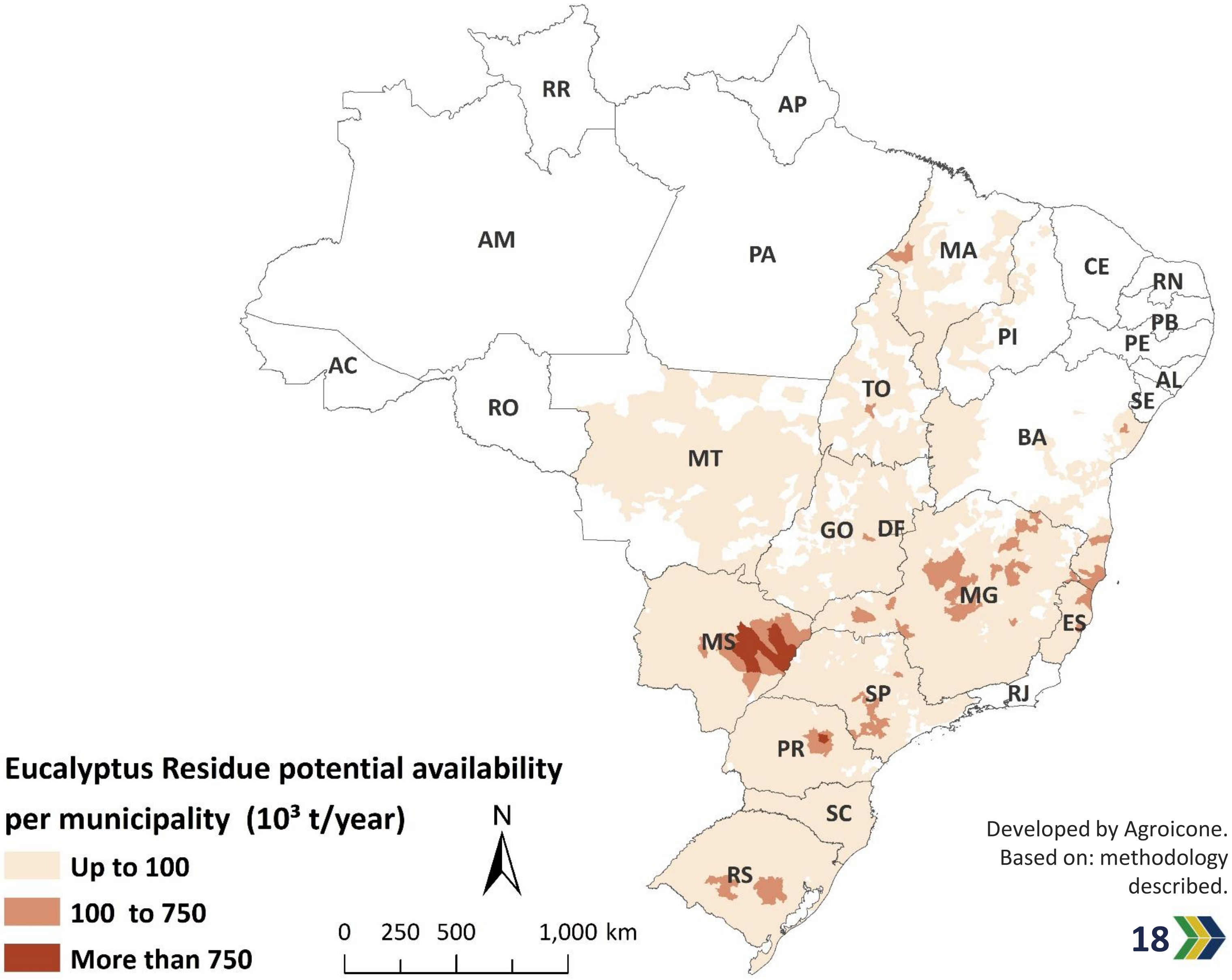
This map shows the planted eucalyptus area per municipality according to IBGE. The eucalyptus production estimates, and consequently the residues potential, were based on this reported area. No new investments or possible expansion of the sector were considered .

EUCALYPTUS RESIDUES

Total potential residues from eucalyptus harvesting operations was estimated at roughly 42 $t_{residues\_(db)}$/year. Considering a 50% recovery rate, the total potential would be of **21 Million $t_{residues\_(db)}$/year**.

The significant potential availability in the East region of the State of MS (7.66 Million $t_{residues}$/year) is worthy of highlight.

Even so, the State of MG presented the highest potential (11.9), with relevant potential in the Center-North areas of this State. SP (6.7) and RS (5.0) occupied the third and fourth position, respectively.



Developed by Agroicone.
Based on: methodology described.

MATCHING FEEDSTOCK AVAILABILITY WITH PROCESSING SITES AND DEMAND

GENERAL ASSUMPTIONS

Regarding the SAF production from wood residues, the spatially explicit data of feedstock availability was combined with possible processing sites and consumers according to the following assumptions:

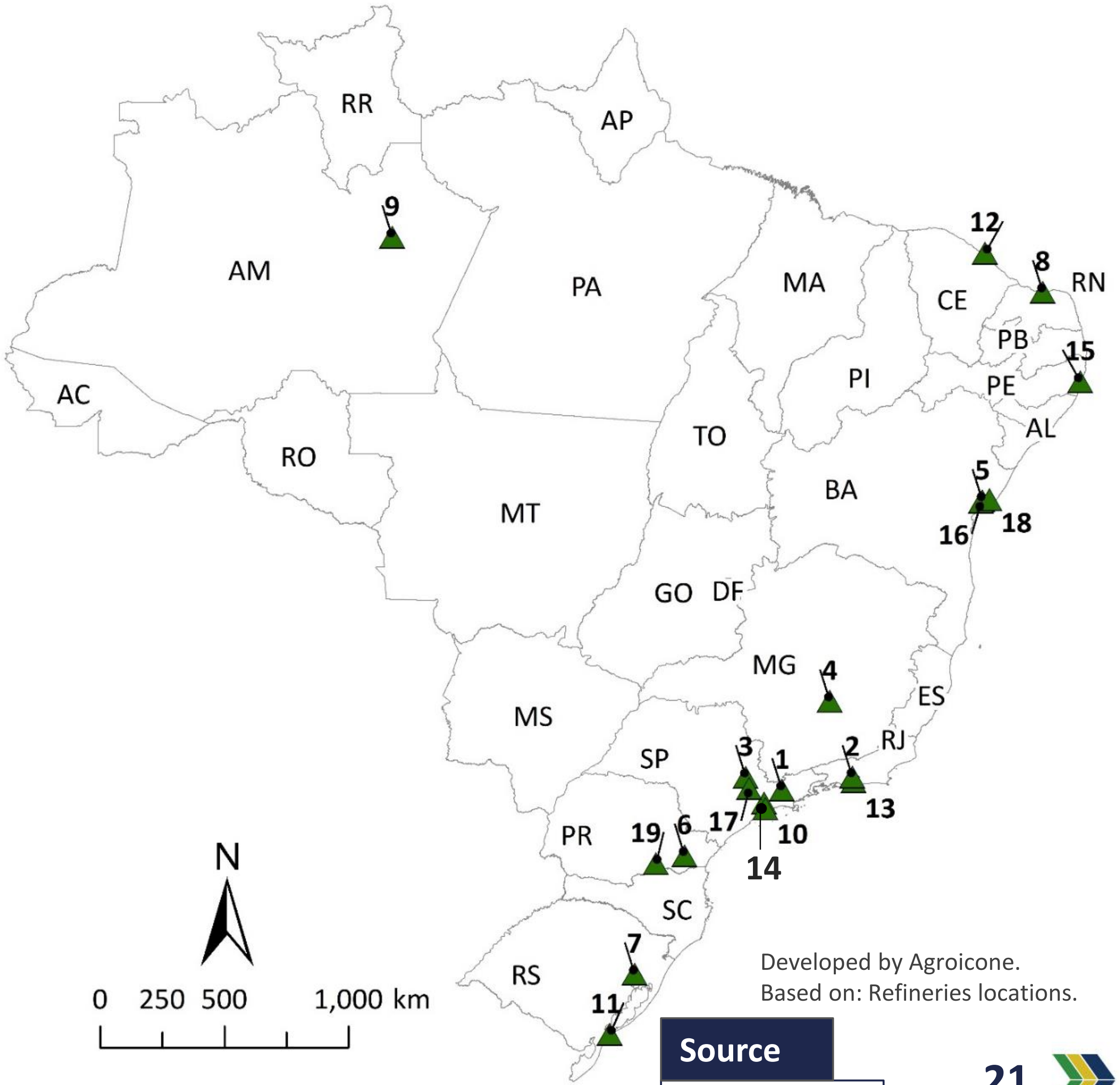
- The wood residues would be collected from the field;
- The 2G ethanol plants, which are an intermediary stage in the ATJ pathway, could be placed close to paper and pulp plants (or even integrated to them) due to the possible advantages of logistic costs or process integration. The pulp and paper sector is the main consumer of planted wood in Brazil, consuming roughly 48% of the total eucalyptus produced in Brazil (IBÁ, 2019).
- The FT plants should be close to the feedstock collection, reducing the relative capital expenses for building the industrial plants and the transportation costs.
- ATJ plant, where ethanol is converted into SAF, should be close to an oil refinery due to hydrogen demand 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.

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



Source

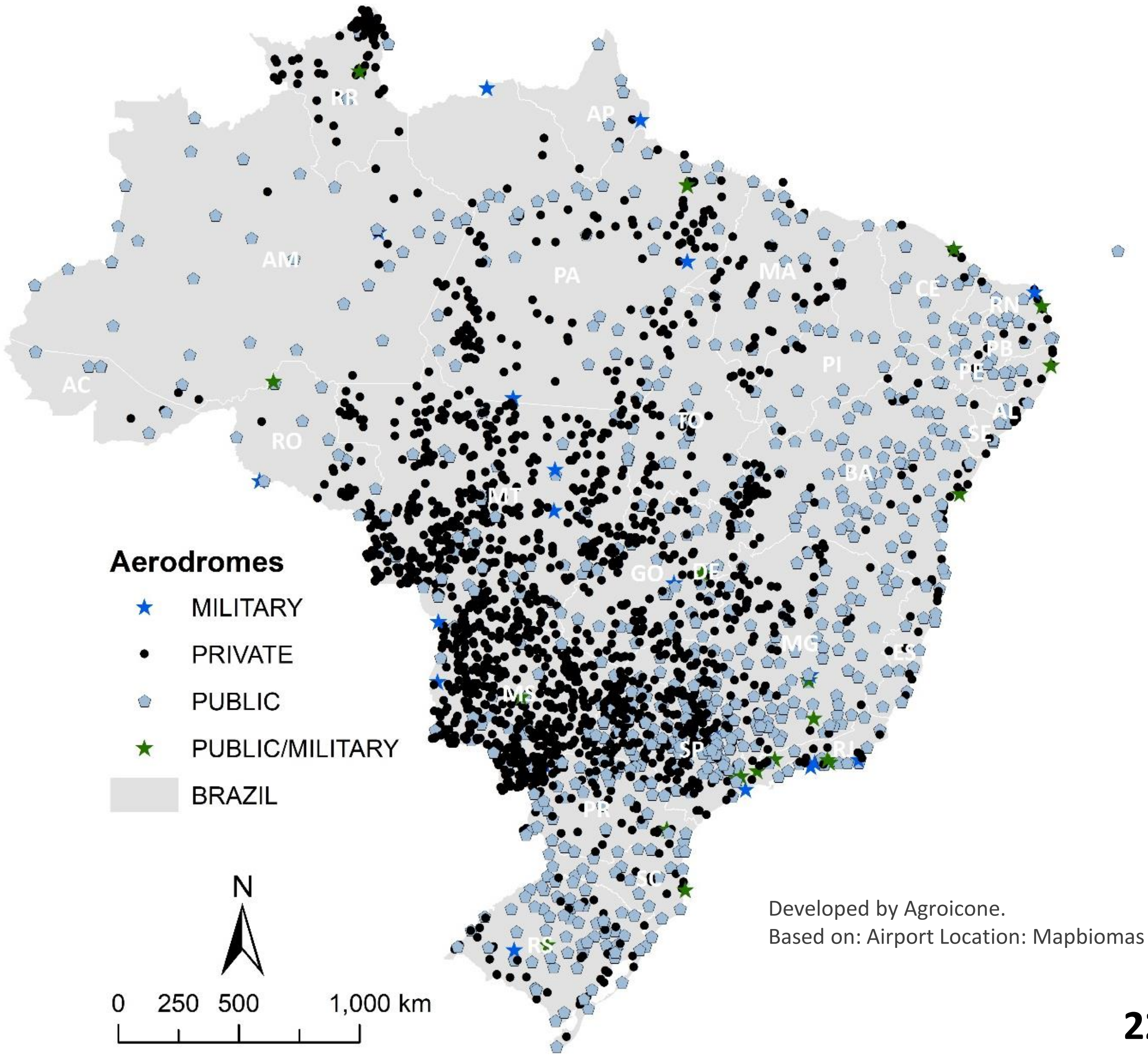
ANP (2019)

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)

JET A CONSUMPTION AND AIRPORTS

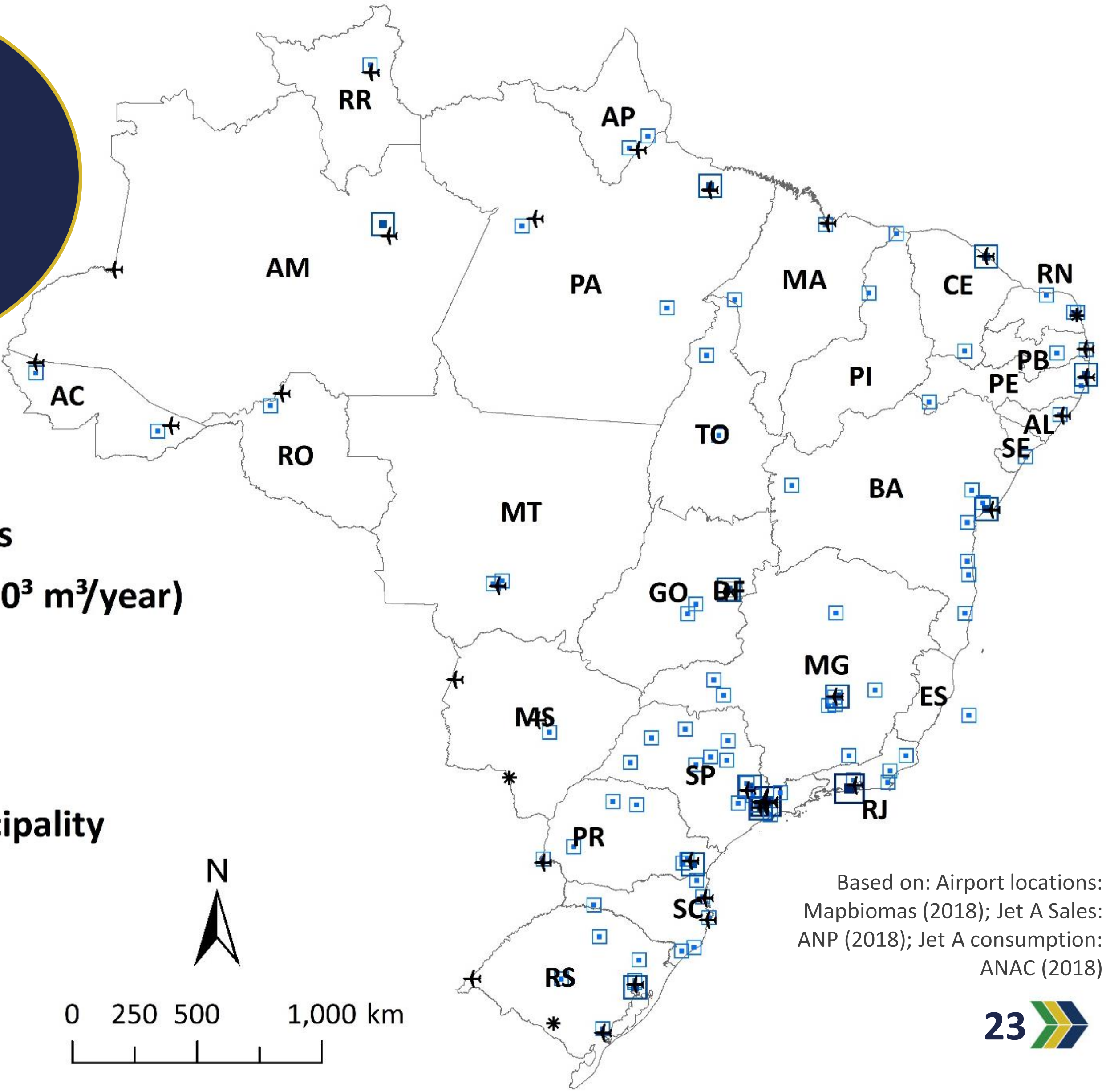
According to The Global Economy (2020), Brazil consumed an average of 123.46 thousand barrels per day of Jet fuel in 2018, whereas the world average, based on 43 countries, is 98.57 thousand barrels per day. Out of the 43 countries analyzed by this research group, Brazil is the 10th highest consumer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



International Airports

Jet A consumption (10³ m³/year)

- No Data
- Up to 500
- More than 500

Jet A Sales per municipality (10³ m³/year)

- Up to 100
- 100 to 1,000
- More than 1,000

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

MATCHING FEEDSTOCK, PROCESSING SITES, AND AIRPORTS – ATJ PATHWAY

International Airports

Jet Sales per municipality (10^3 m³/year)

- Up to 100
- 100 to 1,000
- More than 1,000

Oil Refinery

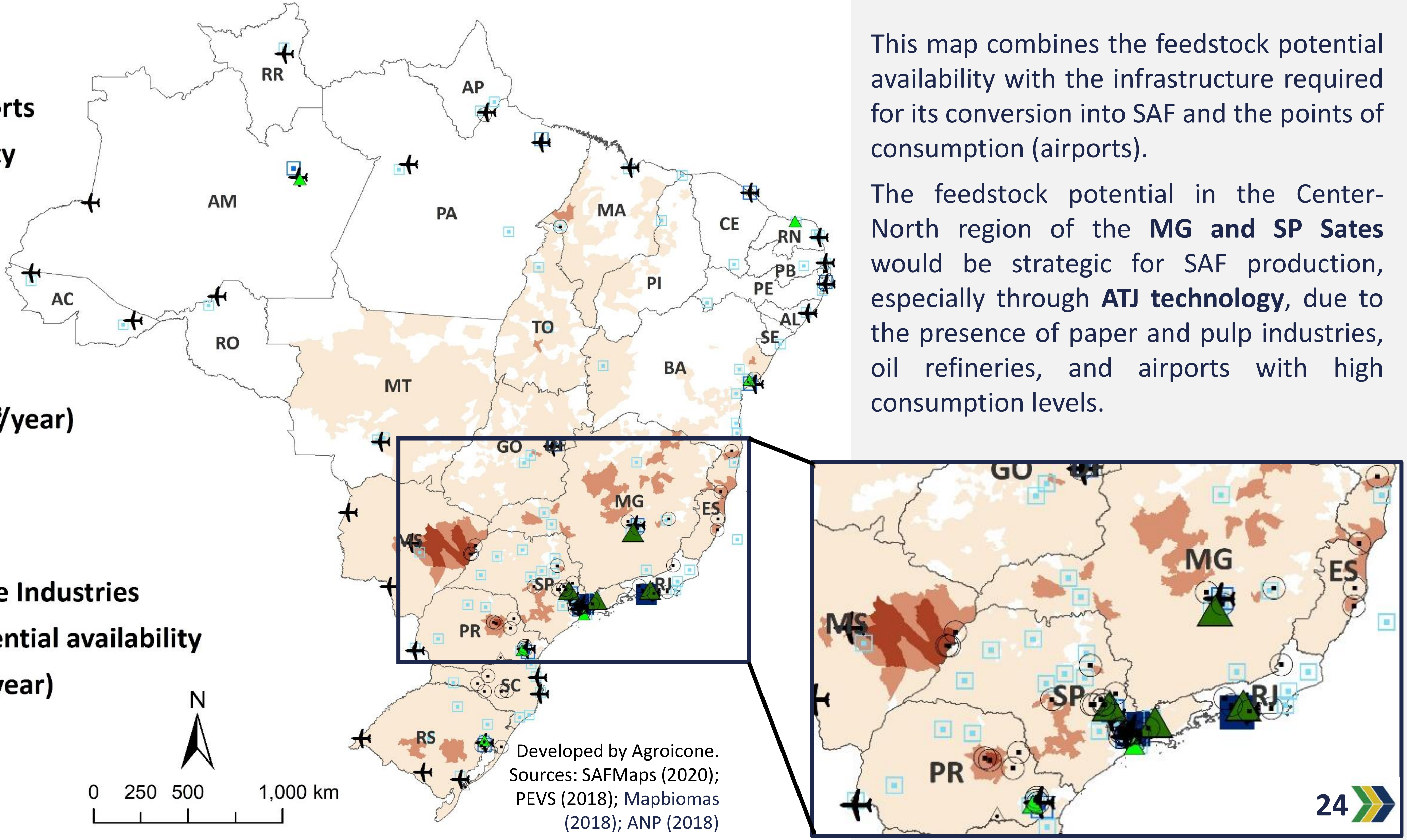
Jet A production (10^3 m³/year)

- 0
- Up to 500
- More than 500

Paper and Cellulose Industries

Eucalyptus Residue potential availability per municipality (10^3 t/year)

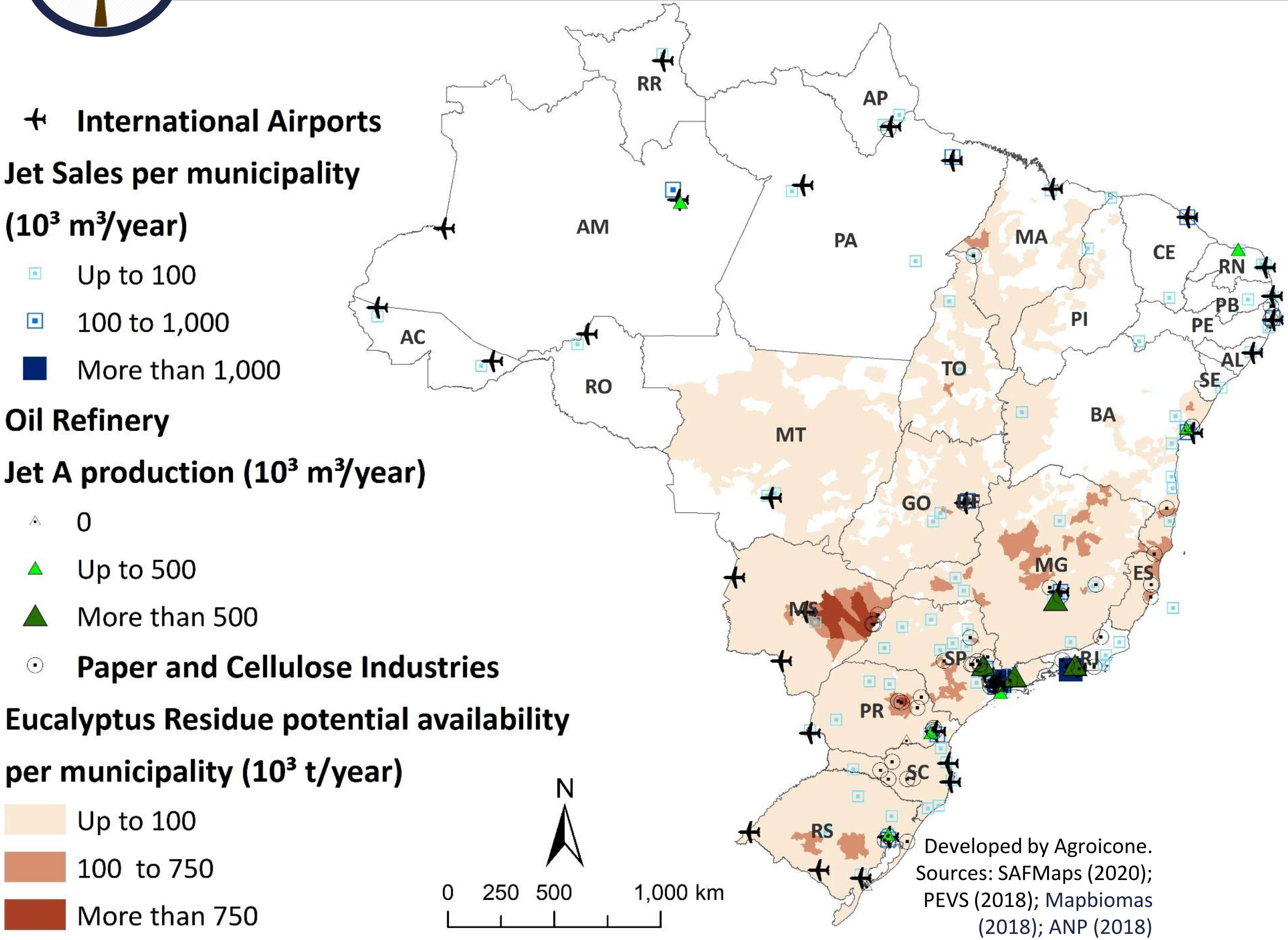
- Up to 100
- 100 to 750
- More than 750



This map combines the feedstock potential availability with the infrastructure required for its conversion into SAF and the points of consumption (airports).

The feedstock potential in the Center-North region of the **MG and SP Sates** would be strategic for SAF production, especially through **ATJ technology**, due to the presence of paper and pulp industries, oil refineries, and airports with high consumption levels.

MATCHING FEEDSTOCK, PROCESSING SITES, AND AIRPORTS – FT PATHWAY



FT plants are, in general, self-sufficient in terms of utilities and hydrogen. Therefore, they could be installed close to feedstock collection sites, decreasing the logistics costs.

On the other hand, the feasibility of FT technology is highly influenced by capital expenses, implying that the **production scale is a strategic issue** to be considered.

In literature, one commercial FT plant was suggested with an annual processing capacity of 0.66 Million $t_{feedstock\_(db)}$ or 0.75 Million t/year) (de Jong et al., 2015).

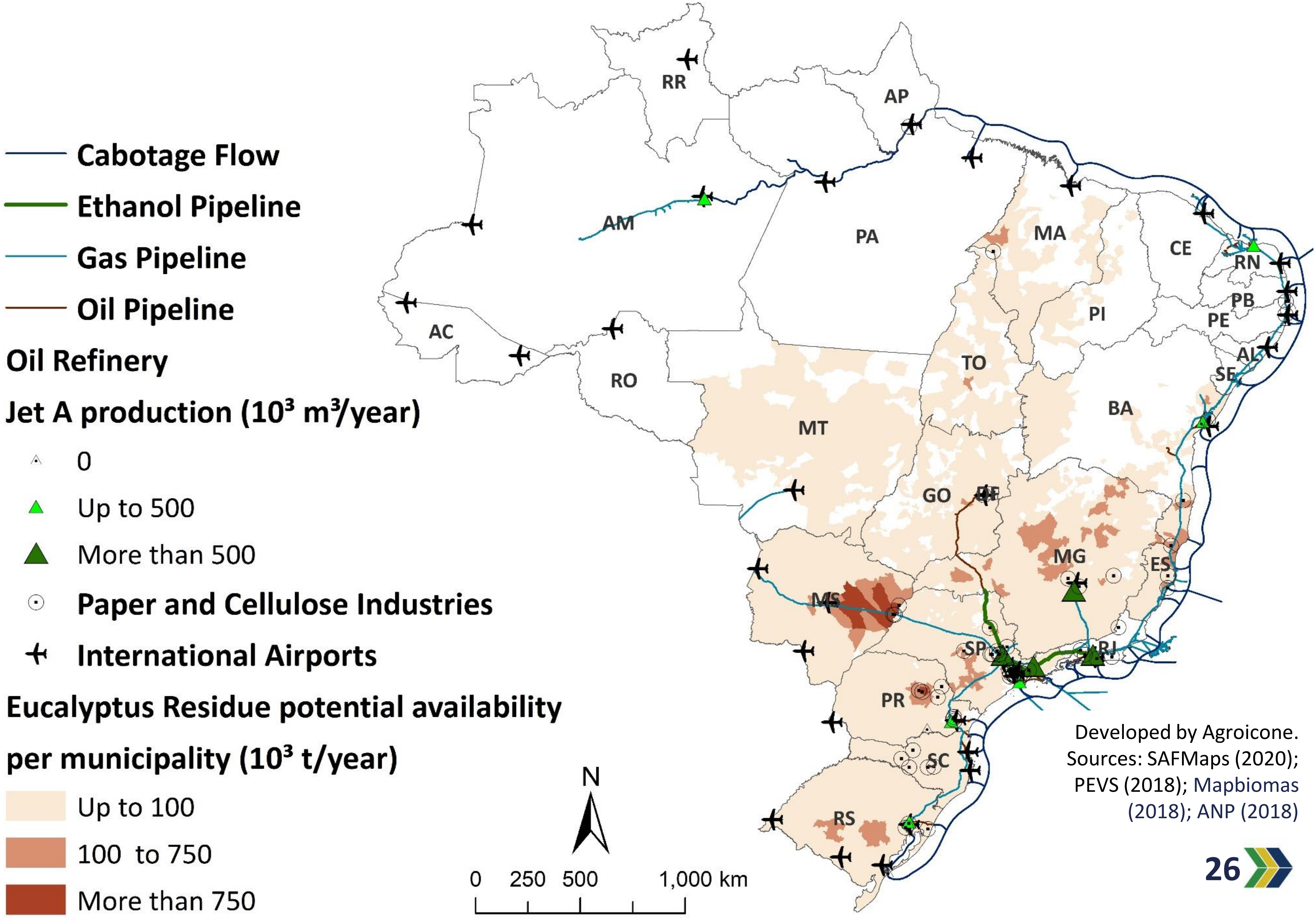
The relevant potential of the **East region of the MS State**, as well as that of the RS and SC States, could be explored through FT technology due to the high availability of wood residues.

MATCHING FEEDSTOCK, PROCESSING SITES, AND AIRPORTS - LOGISTIC

It was suggested that, for SAF production, ATJ plants be placed close to oil refineries, for the reasons mentioned earlier.

The location of gas pipelines are worthy of highlight, since they could supply industrial plants for hydrogen production from Steam Methane Reform. This fact could support the possibility of establishing ATJ plants in MS State.

The airports are the final consumption sites, and the Cabotage Flow and pipelines are the infrastructure for SAF exportation.



Developed by Agroicone.
Sources: SAFMaps (2020); PEVS (2018); Mapbiomas (2018); ANP (2018)

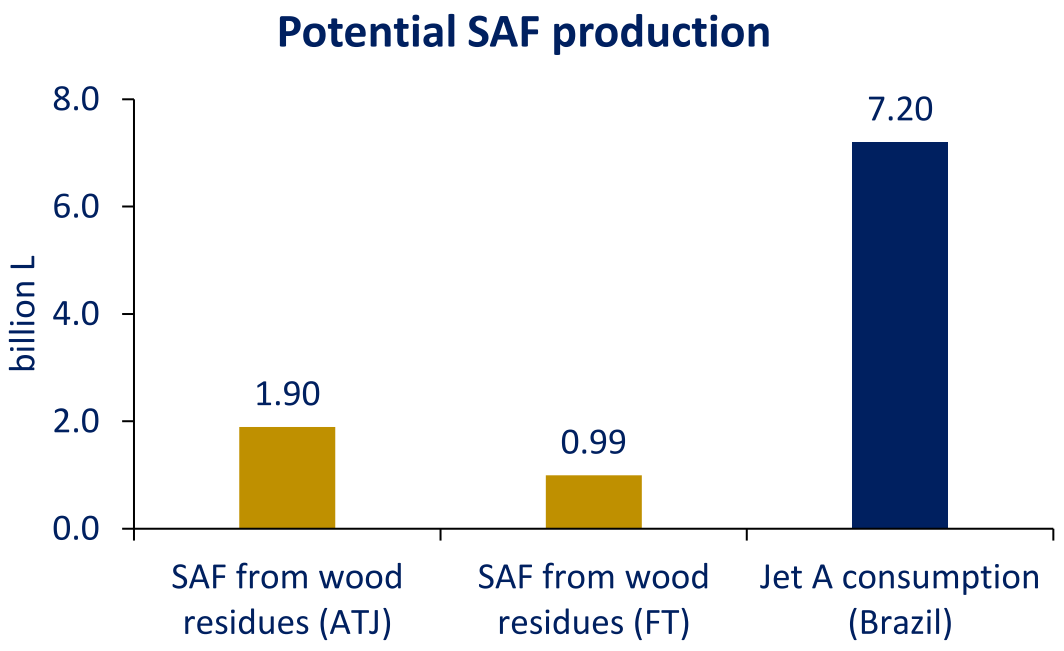
POTENTIAL SAF PRODUCTION FROM WOOD RESIDUES

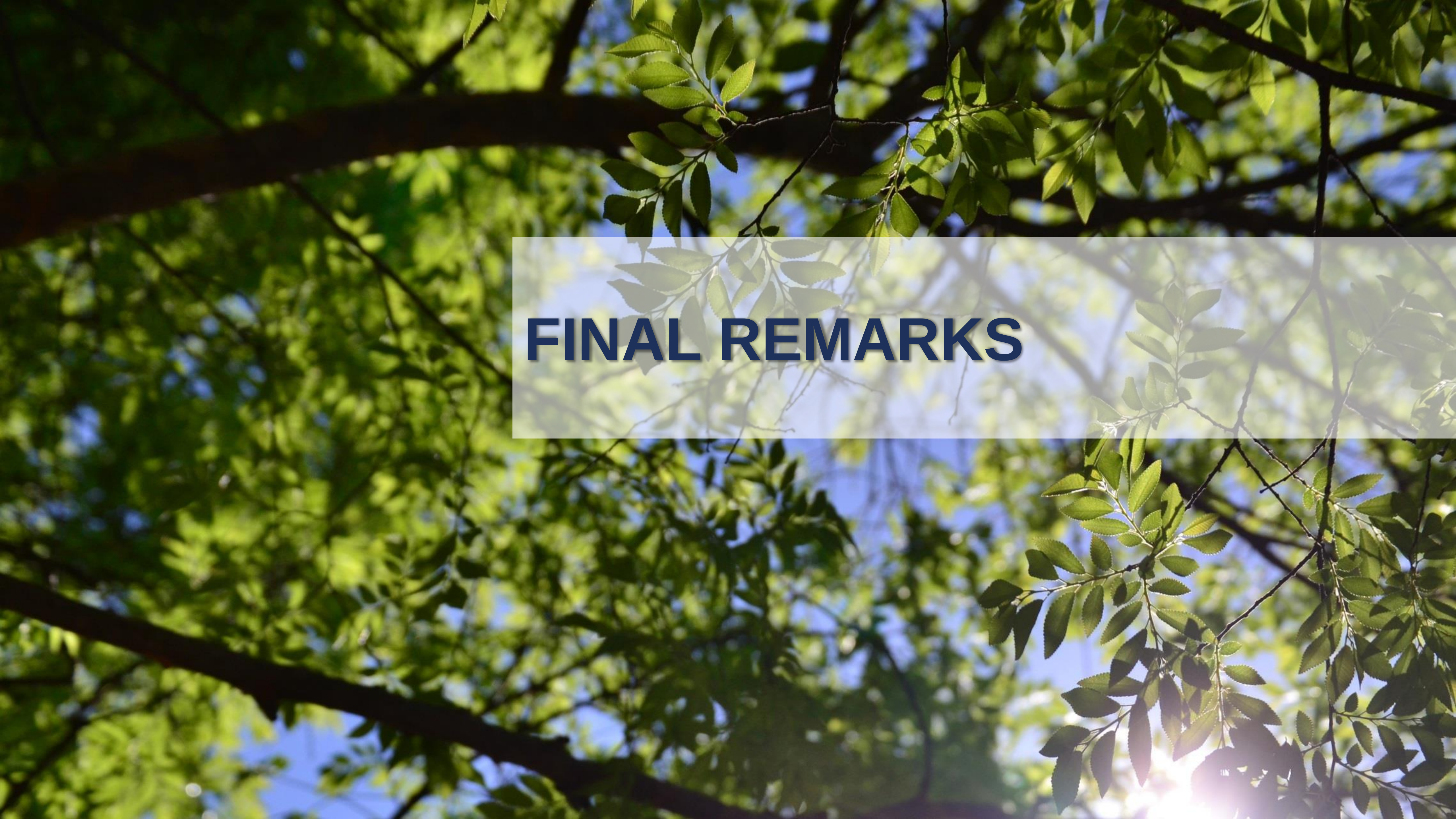
Based on the previous assumptions, the potential amount of forestry residues from harvesting operations would reach roughly 21 million $t_{residues\_(db)}$/year. Through ATJ and FT pathways, this amount could generate 1.0 or 1.9 billion liters of SAF, i.e., **14% and 26% of the total Jet A consumed in Brazil** in the recent years, respectively. Assuming a full recovery of forestry residues, these technologies could supply **28%** and **53%** of the national demand.

Despite the optimistic assumptions for the ATJ pathway - which is based on 2G ethanol production through an optimized process - or those related to the FT design - which favors diesel production instead of SAF - it is worth highlighting the relevant potential of this feedstock, when considering regional contexts.

The SAF from wood residues through the ATJ pathway could **by far surpass** the fossil kerosene consumption in the states of MG (in **1.5-fold**) and MS (in **9.6-fold**), or even provide similar fuel volumes to those consumed in the states of RS and SC, both in the South region. For the state of SP, the largest national consumer, this feedstock could provide up to 8.5% of the Jet A consumption.

Eucalyptus residues could supply between **14 - 26%** of the total demand for Jet A consumption, using **ATJ** and **FT** technologies, respectively





FINAL REMARKS

KEY MESSAGES

- This project has made significant effort in building a **database** on the availability of **wood residue** production, with significant geographical detail on a municipal level for Brazil. The data is **available in an online platform** with functionalities to download information for research and within the interest of investors.
- Wood residues herein comprise forestry residues from planted forests, such as leaves, branches, barks, and treetops, which are generated during harvesting operations. In this study, only residues from eucalyptus crops, which have represented around 70% of the planted forest areas in Brazil (IBA, 2019), are considered.
- The potential availability of wood residues was estimated based on the productivity of eucalyptus and on areas used for eucalyptus production, generating around 0.167 $t_{residues}/m^3_{wood\_harvested}$ per cycle.
- Through ATJ and FT technologies, the total potential wood residues available could supply, respectively, **26% and 14% of the total Jet A consumed in Brazil** in the recent years. In a regional context, wood residues could easily supply the fossil kerosene consumption from the states of MG (in **1.5-fold**) and MS (in **9.6-fold**), or even provide similar fuel volumes as those consumed in the states of RS and SC.
- Considering logistics aspects, in ATJ pathways, ethanol plants could be conveniently placed close to paper and pulp plants. In terms of the placement of ATJ plants, the suggestion is that they be placed close to oil refineries or gas pipeline, if it is feasible produce hydrogen from steam methane reform.
- Regarding the placement of FT plants, which are self-supplied, the suggestion would be to place them close to feedstock collection points, since the scale of SAF production is a relevant issue for economic feasibility of the capital-intensive technology.
- Therefore, the potential in the **Center-North region of MG and SP States** could be strategical for SAF production, especially through **ATJ technology**, due to the presence of paper and pulp industries, oil refineries, and airports with high consumption levels. On the other hand, the relevant potential of the **East region of the MS State** and the South of the RS State could be strategic for supplying regional consumption, especially through **FT technology**.

NEXT STEPS

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

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