INFIERI 2023 – New Energies

Biofuels as a fast-track for decarbonization in transport sector

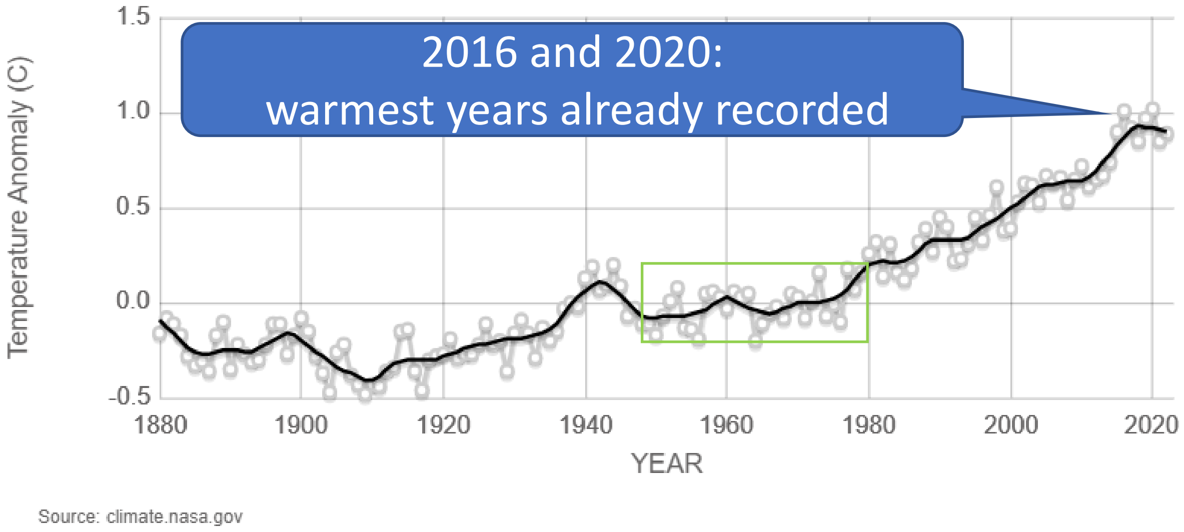
Clayton B. Zabeu
September 2nd 2023

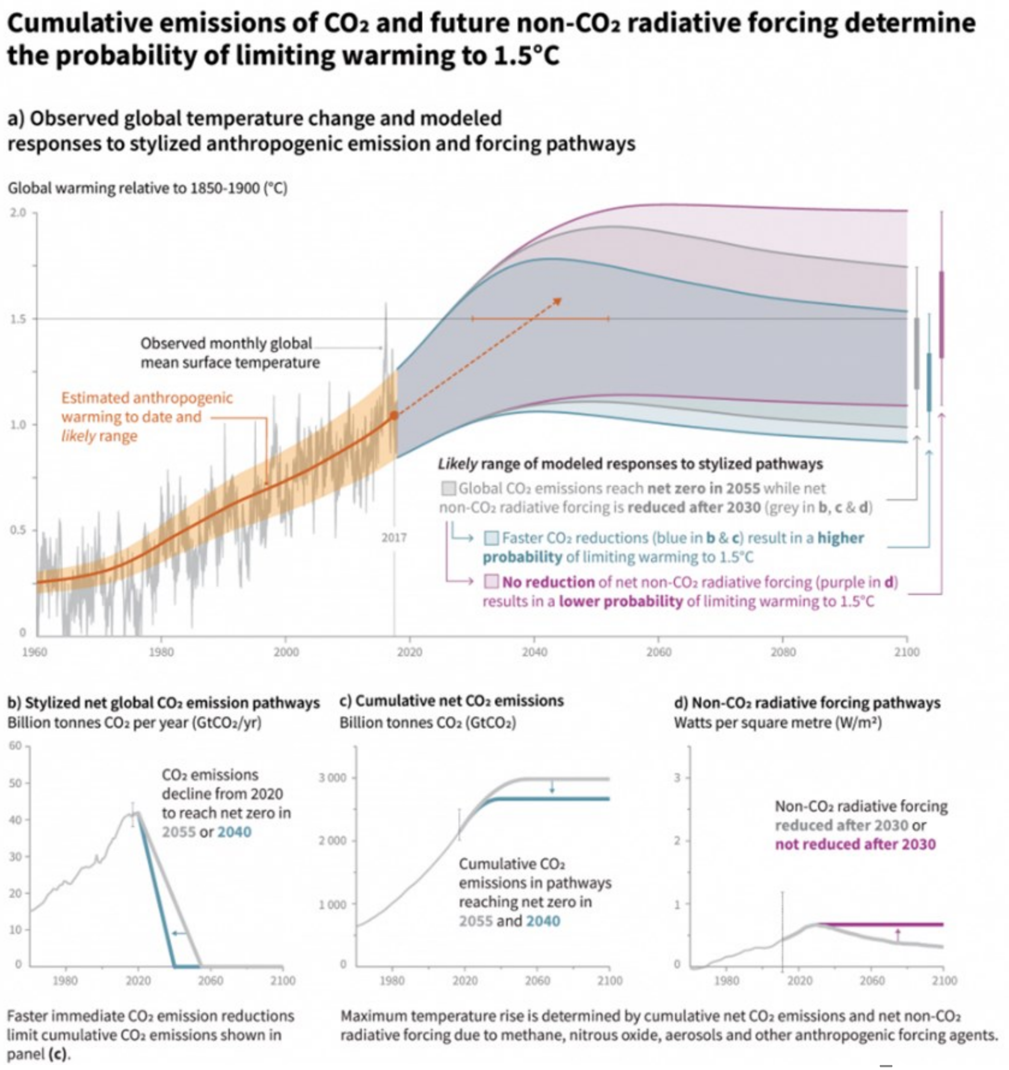
INSTITUTO MAUÁ DE TECNOLOGIA

MAUÁ

Climate changes and GHG

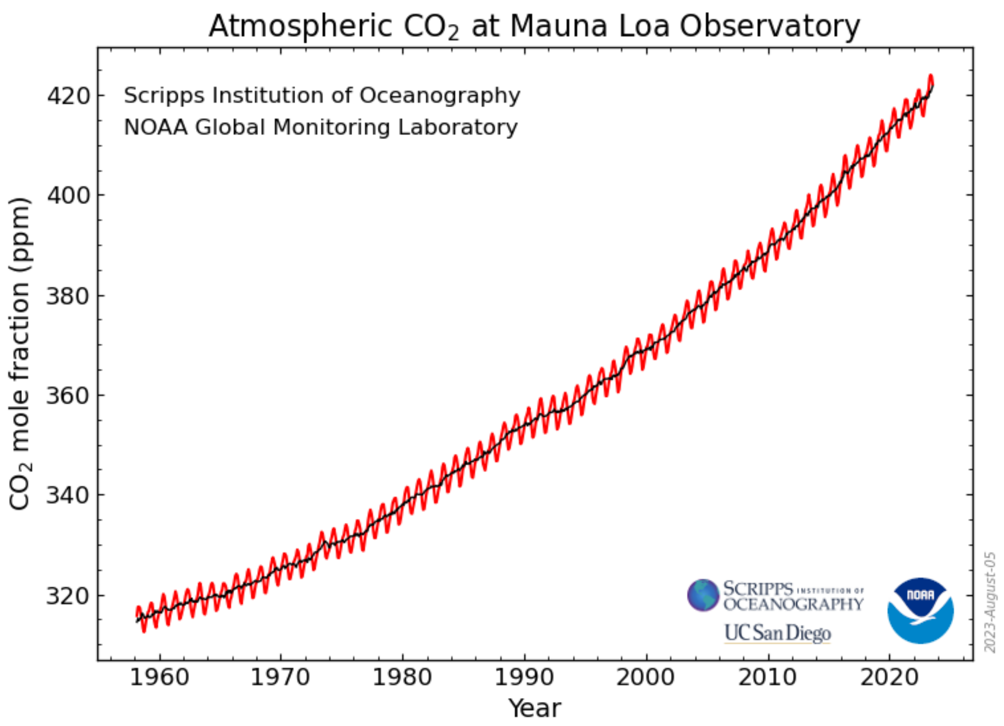
- World temperature increase along the years



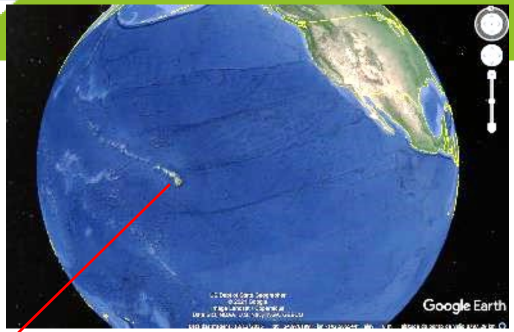


https://www.ipcc.ch/sr15/chapter/spm/
https://climate.nasa.gov/vital-signs/global-temperature/

Climate changes and GHG



July 2023: 422.14 ppm
July 2022: 418.85 ppm
Last updated: Aug 05, 2023



Mauna Loa Observatory

Location

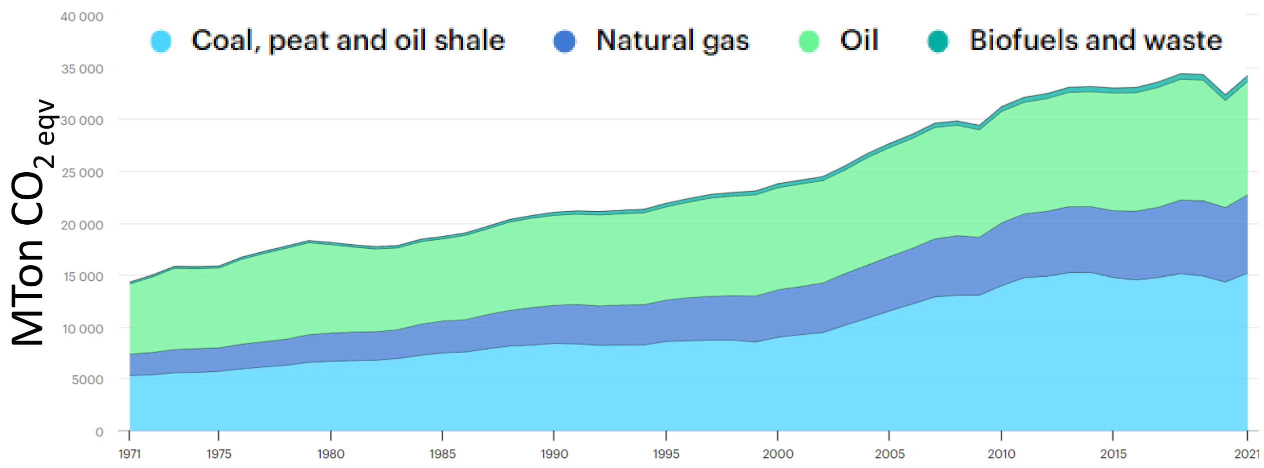
- Country: United States
- Latitude: 19.5362° North
- Longitude: 155.5763° West
- Elevation: 3397.00 masl
- Time Zone: Local Time + 10 hour(s) = UTC

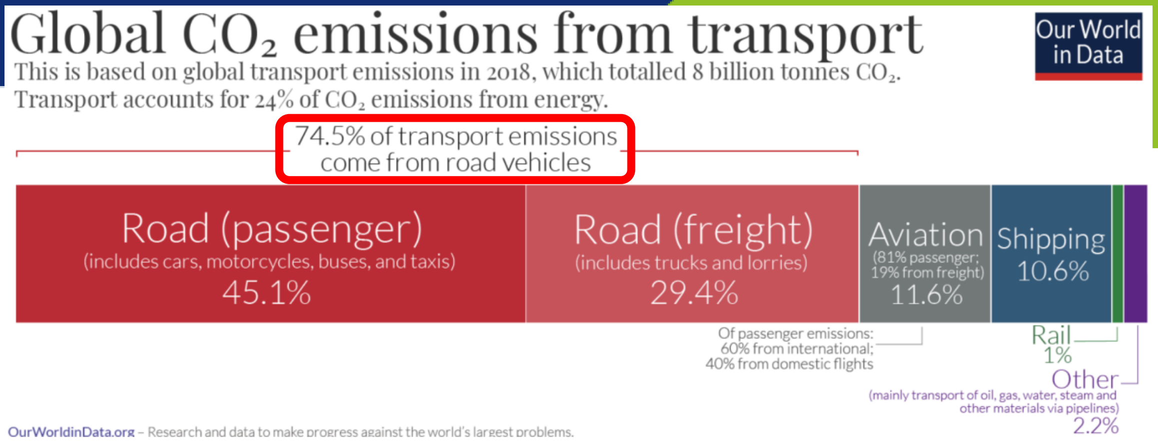
- GHG – *greenhouse gases*: $\mathbf{CO_2}$**,** $\mathbf{CH_4}$**,** $\mathbf{N_2O}$, O_3, H_2O
- CO_2 concentration rise since Industrial Revolution
  - Global concentration increased from ~277 ppm in 1750 to ~418 ppm in 2020 (51% increase)

INSTITUTO MAUÁ DE TECNOLOGIA
MAUÁ

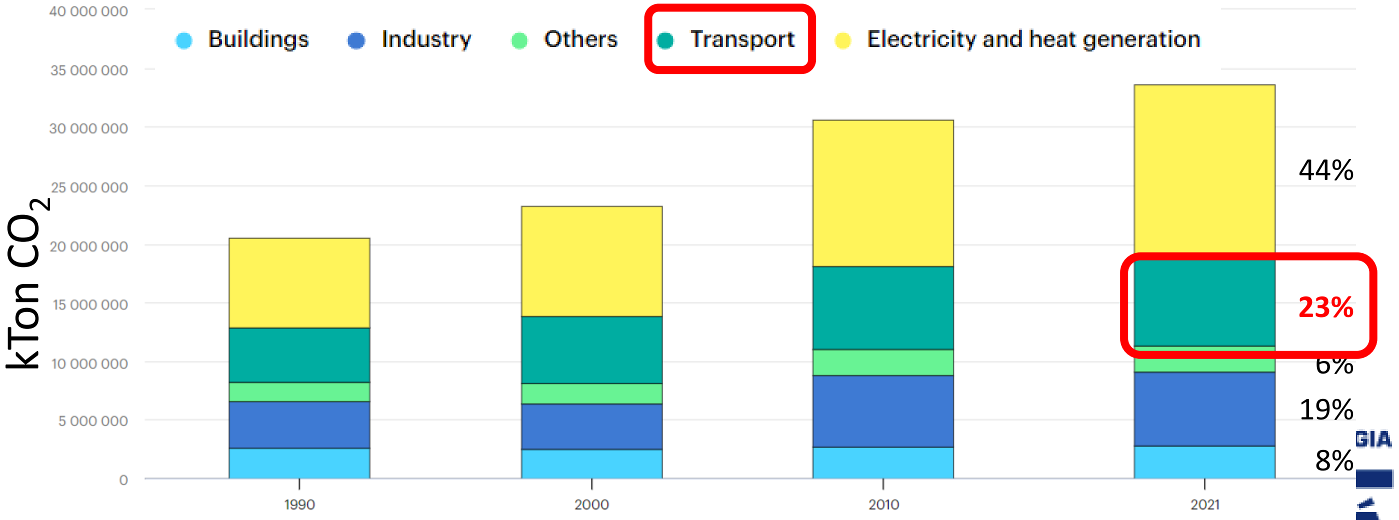
https://gml.noaa.gov/ccgg/trends/

GHG generated by sectors





~17% of world emitted CO_2 comes from road transportation

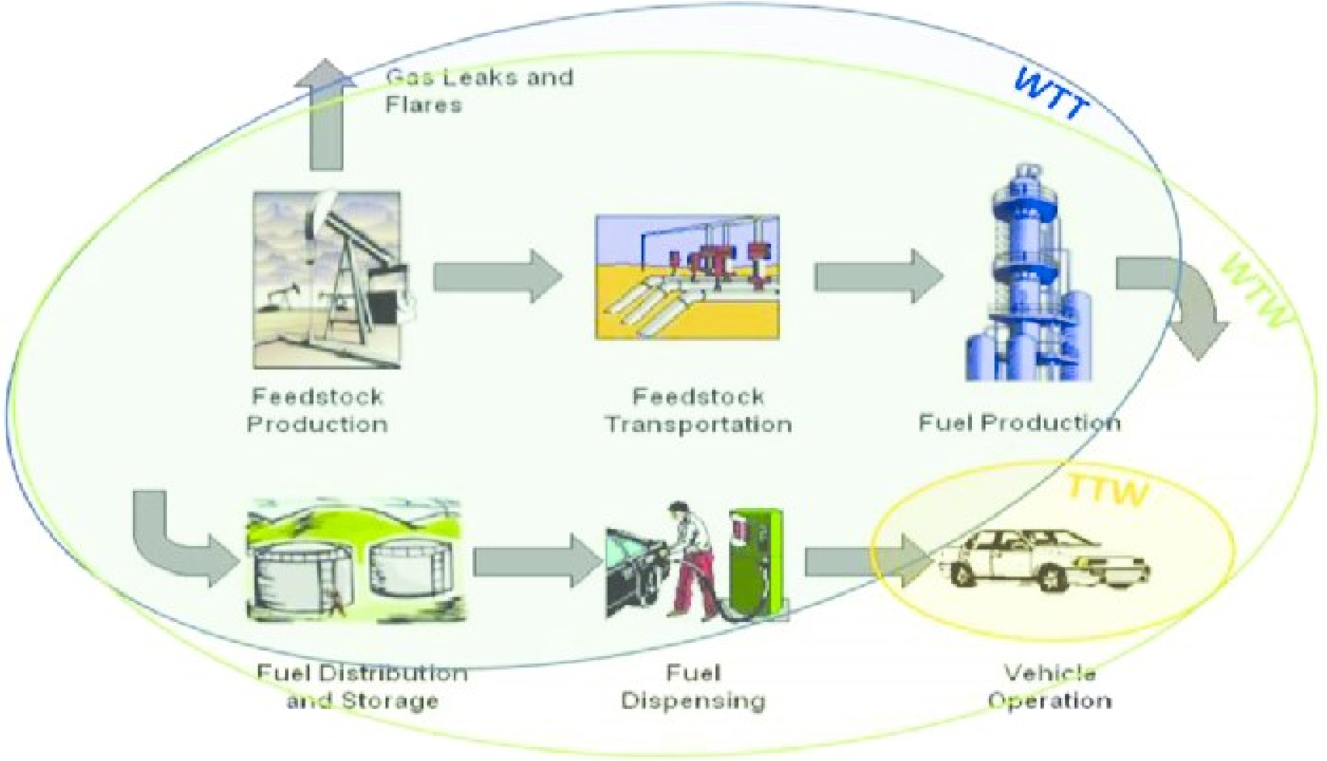


https://www.iea.org/data-and-statistics/data-tools/greenhouse-gas-emissions-from-energy-data-explorer
https://ourworldindata.org/co2-emissions-from-transport

WTT/TTW/WTW

GHG generated at each stage – extraction/production/Transportation & final usage

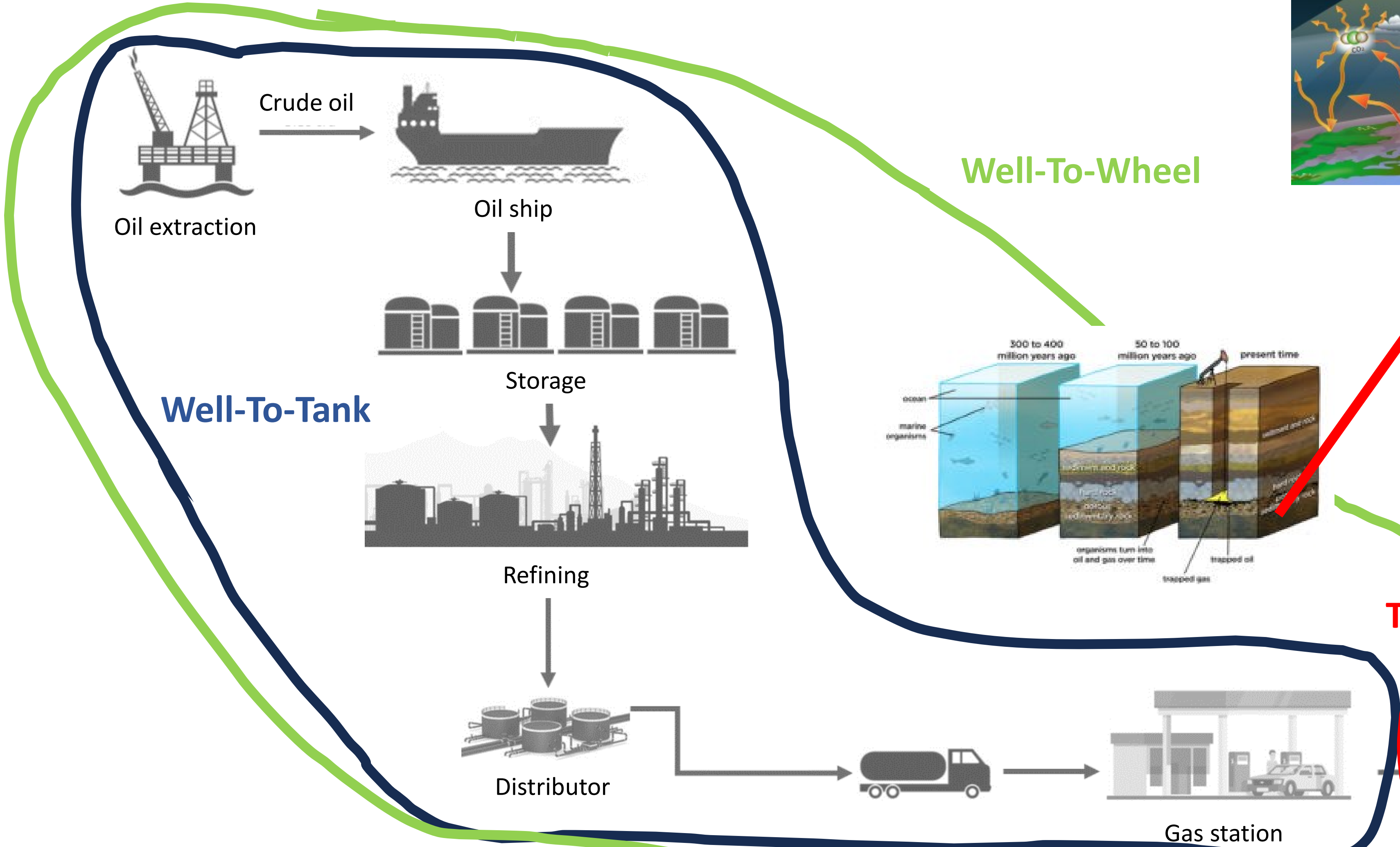
- WTW – *well-to-wheel* – full chain
- WTT – *well-to-tank* – production phase
- TTW – *tank-to-wheel* – utilization phase

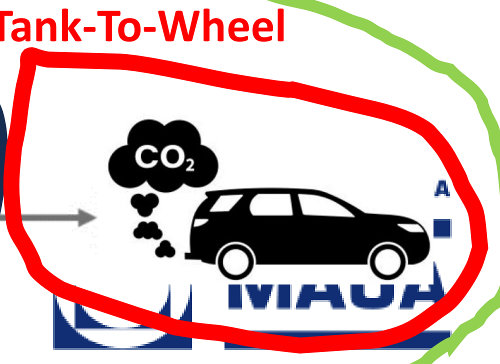


Domanovszky, H. (2014) “Gas propulsion or e-mobility is the solution on the way of clean and carbon free road transportation?”, Periodica Polytechnica Transportation Engineering, 42(1), pp. 63-72. https://doi.org/10.3311/PPtr.7254

WTT/TTW/WTW

Fossil fuel scenario



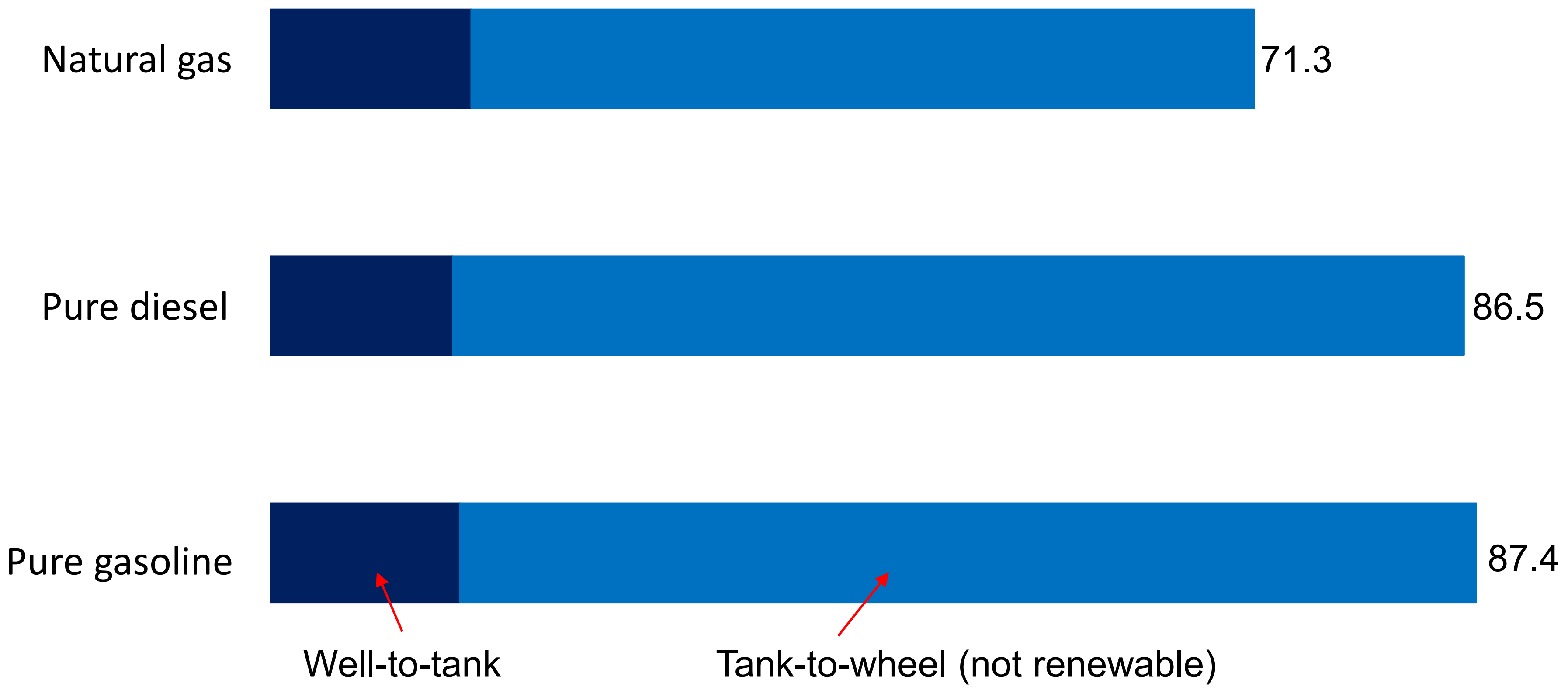


In all phases there is CO_2 emissions to the atmosphere

Adapted from Marcelo Gauto; [Diesel do poço ao posto – entenda a cadeia de preços (linkedin.com)]
Pedrozo, Vinicus – Curso biocombustíveis SAE IMT 2022

WTT/TTW/WTW

Carbon intensity of main fossil fuels [gCO2eqv/MJ]



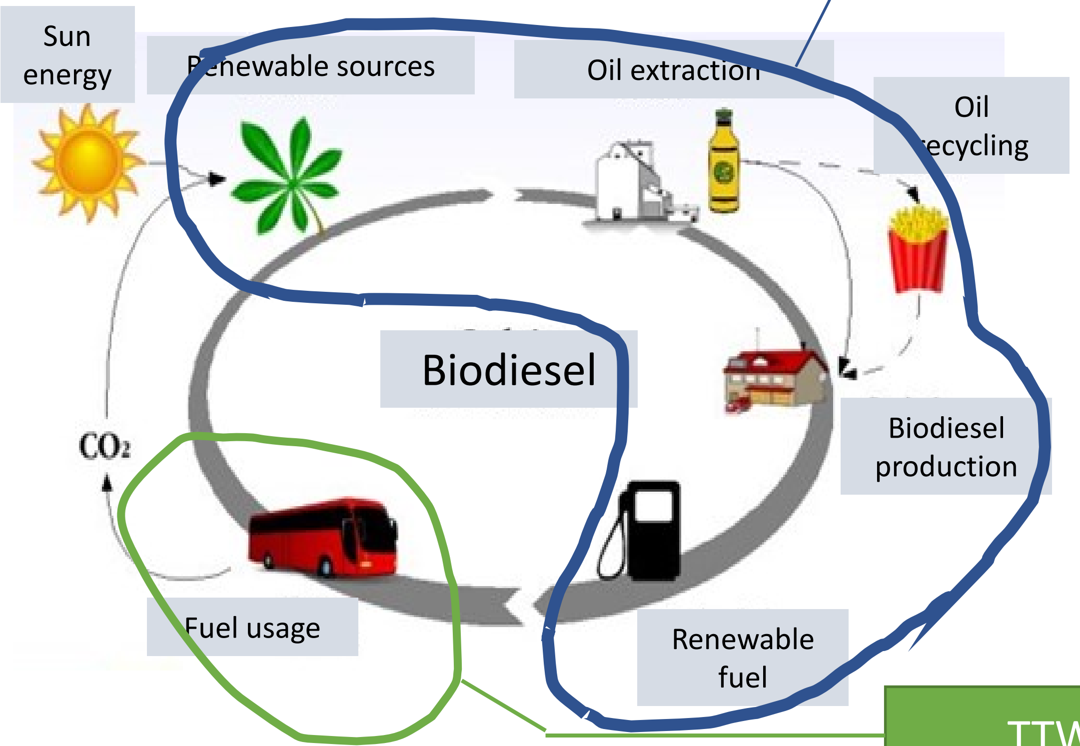
Resolução ANP n.º 758, de 23 de novembro de 2018, que regulamenta a certificação da produção ou importação eficiente de biocombustíveis (ANP).

INSTITUTO MAUÁ DE TECNOLOGIA

WTT/TTW/WTW

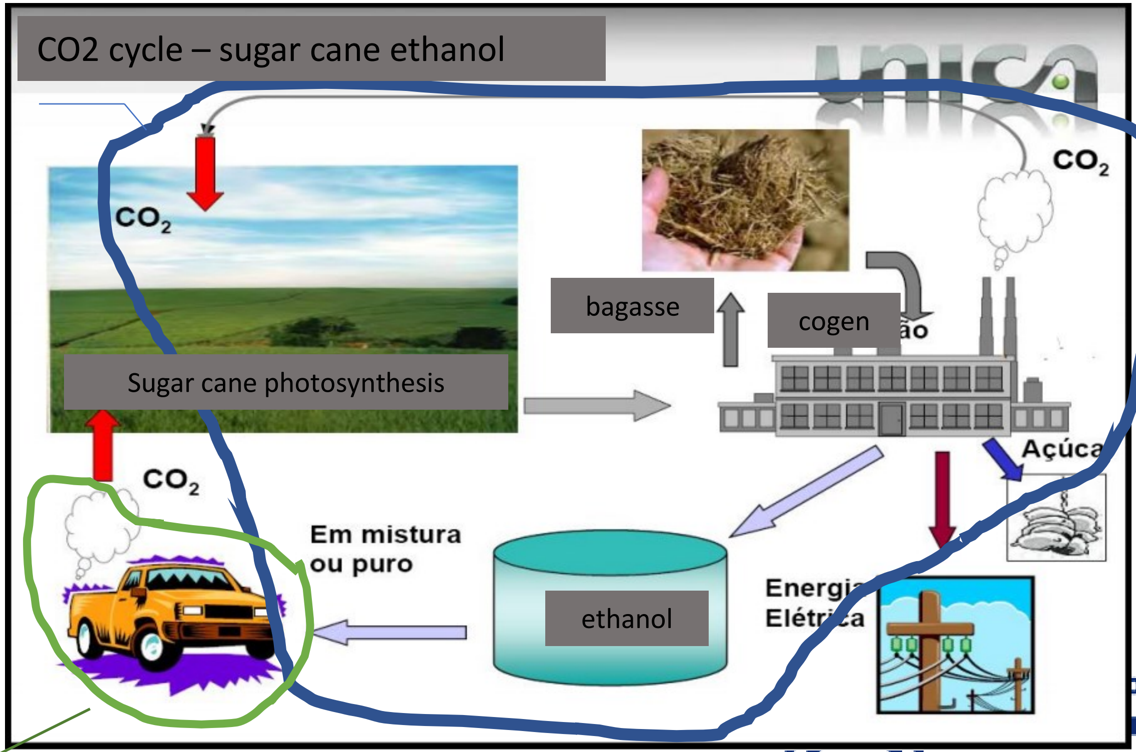
Renewable (bio) fuel scenario

WTT



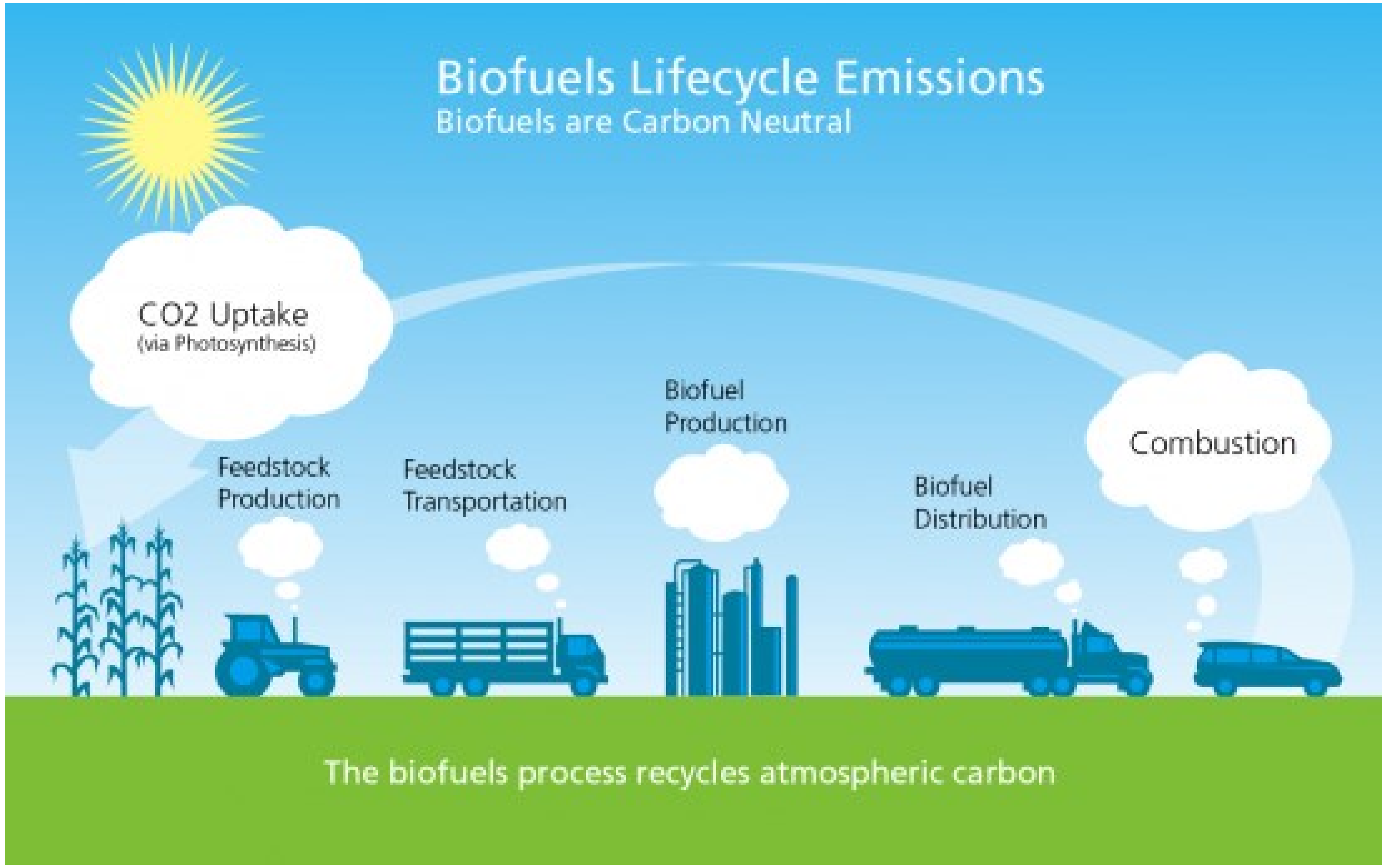
TTW

There is CO_2 capture from the atmosphere during biomass growth



WTT/TTW/WTW

Renewable (bio) fuel scenario



CO_2 sequestration from atmosphere during biomass growth

↑

CO_2 renewable
or
CO_2 biogenic*

↑

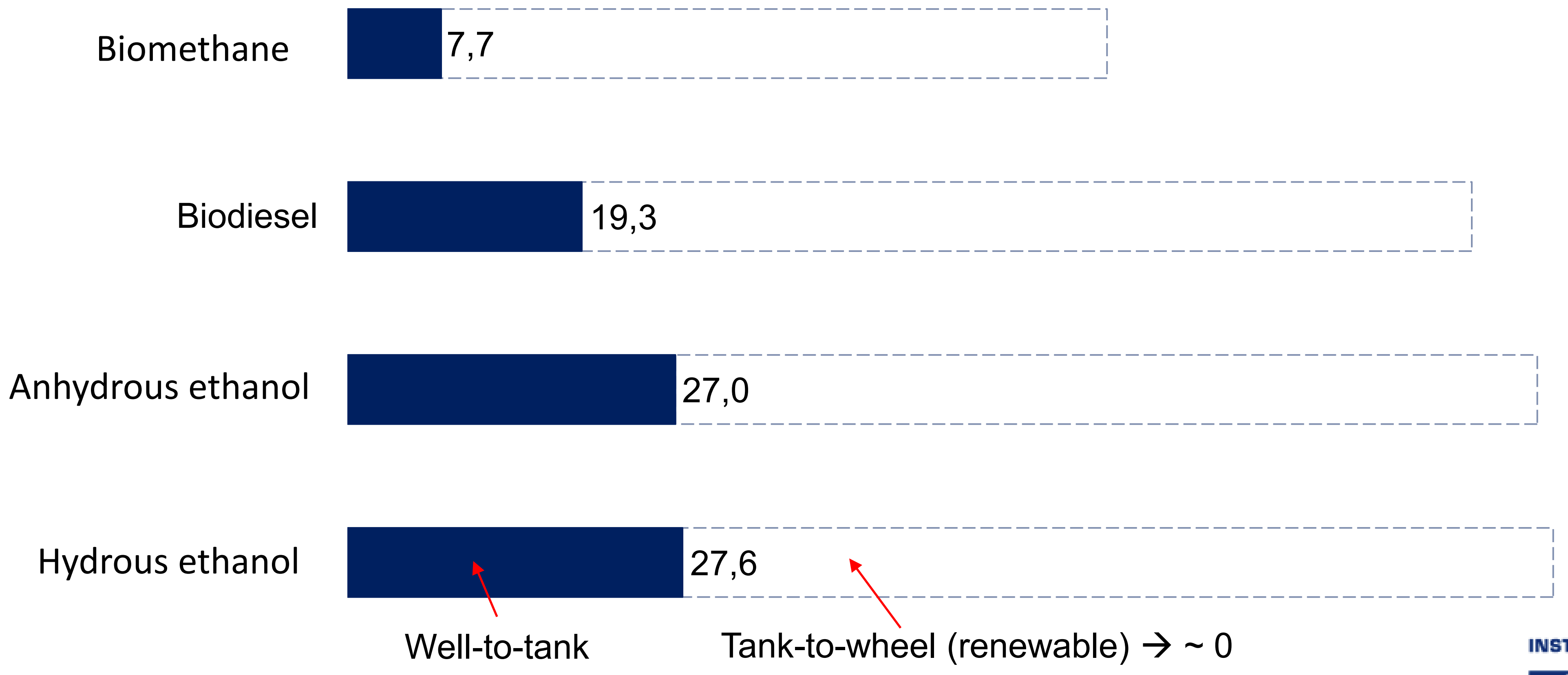
Tank-to-wheel

INSTITUTO MAUÁ DE TECNOLOGIA
MAUÁ

Cars and Climate: Scrutinizing the logic on biofuels (carsclimate.com).
* Biofuels made from waste are the business, says Academy - Royal Academy of Engineering (raeng.org.uk)

WTT/TTW/WTW

Carbon intensity of Brazilian biofuels [gCO2eqv/MJ]

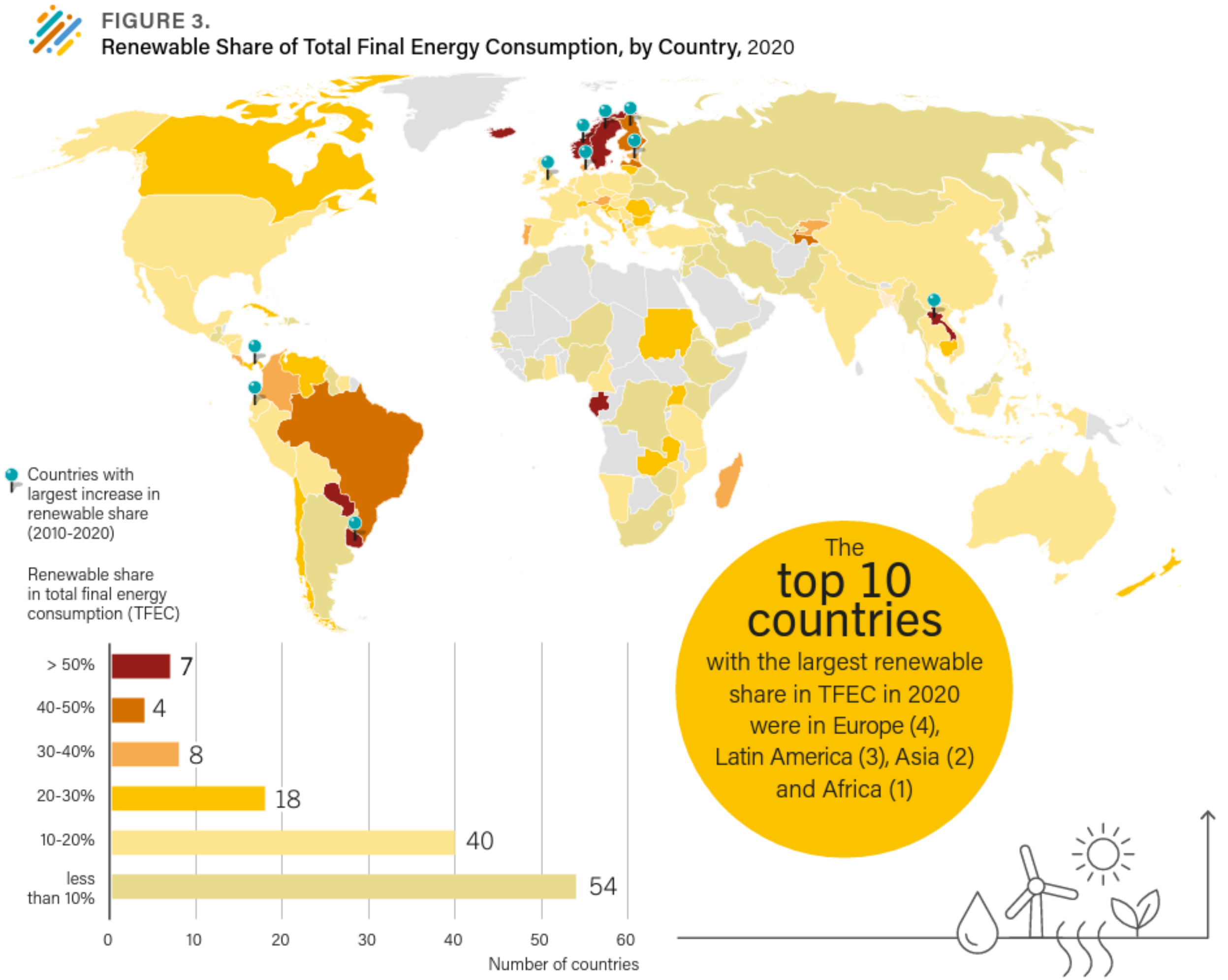


INSTITUTO MAUÁ DE TECNOLOGIA

Painel de Certificação do Observatório da Cana (Observatório da Cana). Acesso no dia 31 de maio de 2021.
Pedrozo, Vinicus – Curso biocombustíveis SAE IMT 2022

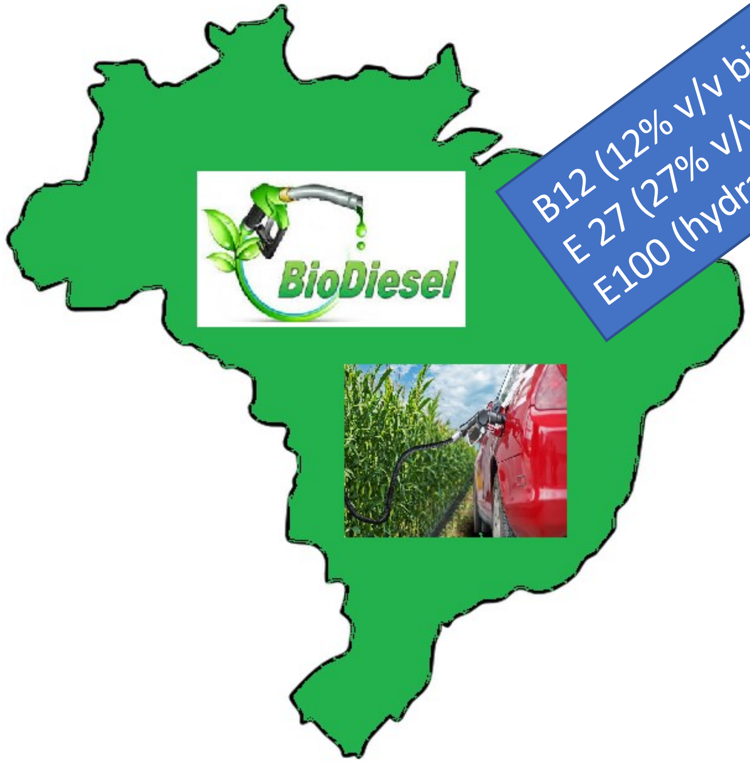
Where are we today in Brazil

Share of renewables in energy matrix



Renewables 2021 Global Status Report
http://www.ren21.net/gsr-2021/

Fuels for transportation



- B12 (12% v/v biodiesel)
- E 27 (27% v/v ethanol mix with gasoline)
- E100 (hydrated ethanol)

INSTITUTO MAUÁ DE TECNOLOGIA
MAUÁ

Where we are today in Brazil

Volume of bioethanol already in use – Brazil 2017-2021 [billion liters]

Brazilian "gasohol" contains 27% v/v of anhydrous ethanol → **E27**
Hydrous ethanol sold in gas stations → **E100**

Renewable fuel volumetric content for passenger car around 50%

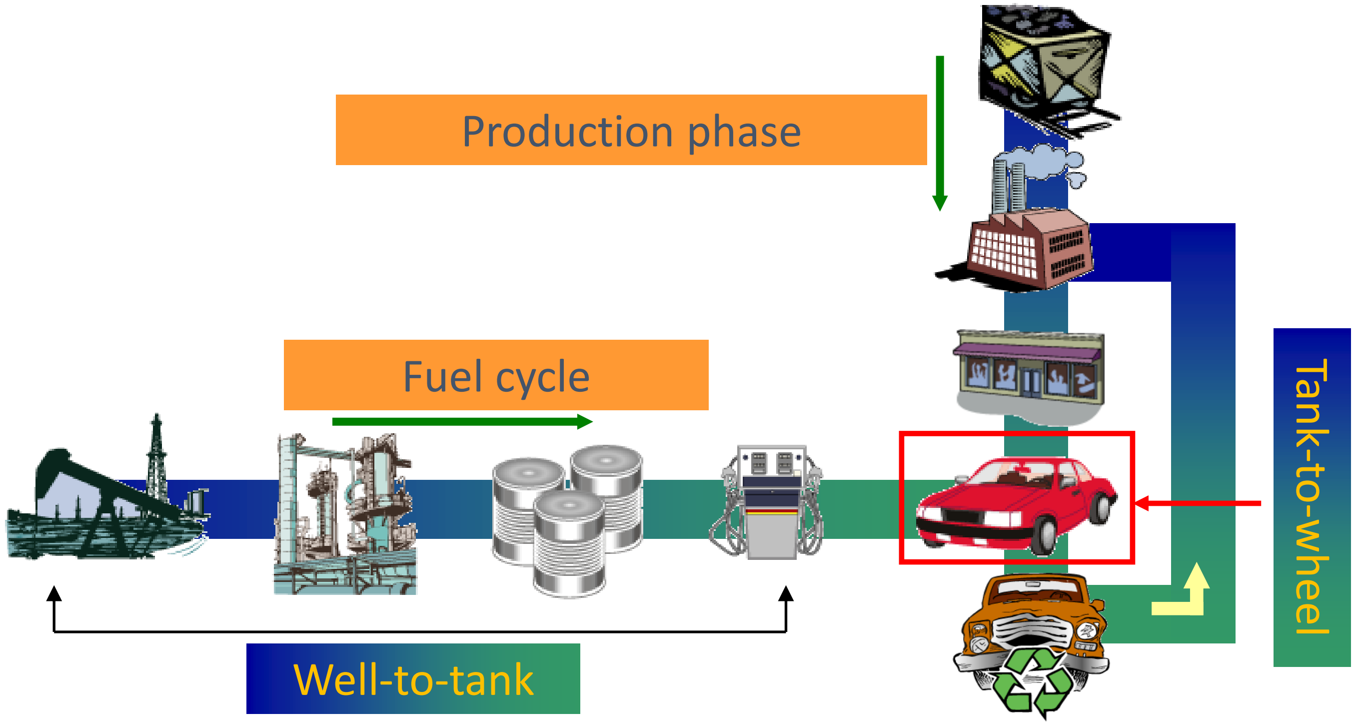
Fernando Fusco Rovai, Sonia Regina da Cal Seixas, Carlos Eduardo Keutenedjian Mady - Regional energy policies for electrifying car fleets / Energy 2023

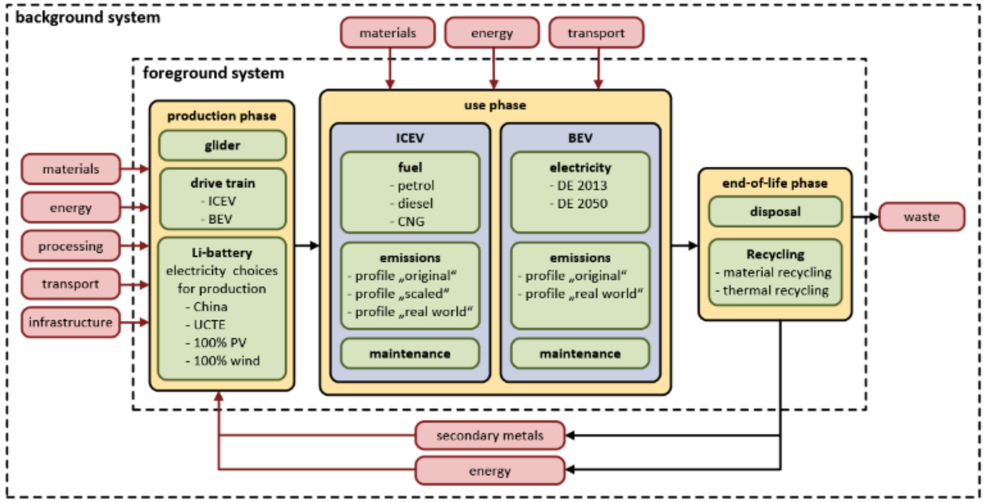
INSTITUTO MAUÁ DE TECNOLOGIA
MAUÁ

Life cycle assessment

CO_2 generated during vehicle production and recycling phases

- LCA – *life cycle assessment*
- *From the cradle to the grave*





Wang, M. - Well-to-Wheels Analysis of Vehicle/Fuel Systems – Argonne National Lab – 2006

Helmers, E.; Dietz, J.; Weiss, M. - Sensitivity Analysis in the Life-Cycle Assessment of Electric vs. Combustion Engine Cars under Approximate Real-World Conditions. 2020, https://doi.org/10.3390/su12031241

INSTITUTO MAUÁ DE TECNOLOGIA

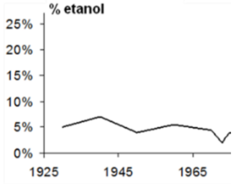
History of ethanol in Brazil

Ethanol as a fuel component in Brazil

1538 → Martim Afonso de Souza

1908 -1930 → Henry Ford (1908) T-model in Brazil

1938 → Federal Law 737 5% ethanol in gasoline



1973 → First oil crises

1975 → National Alcohol Program

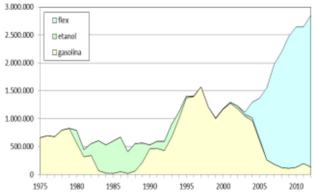

Sai, enfim, o programa do álcool

Távora explica pontos básicos

→ **1979** → Second oil crises 100% hydrous ethanol vehicles

Autonomous mills (only ethanol)

1985 → > 90% produced ethanol cars



1986 → Drop of oil price to USD 17/brl

1989-90 → Crisis in ethanol market


A TRIBUNA 95

Postos fecham e provocam revolta

Combustíveis sobem 27%

→ **2003** → 1st FFV launched

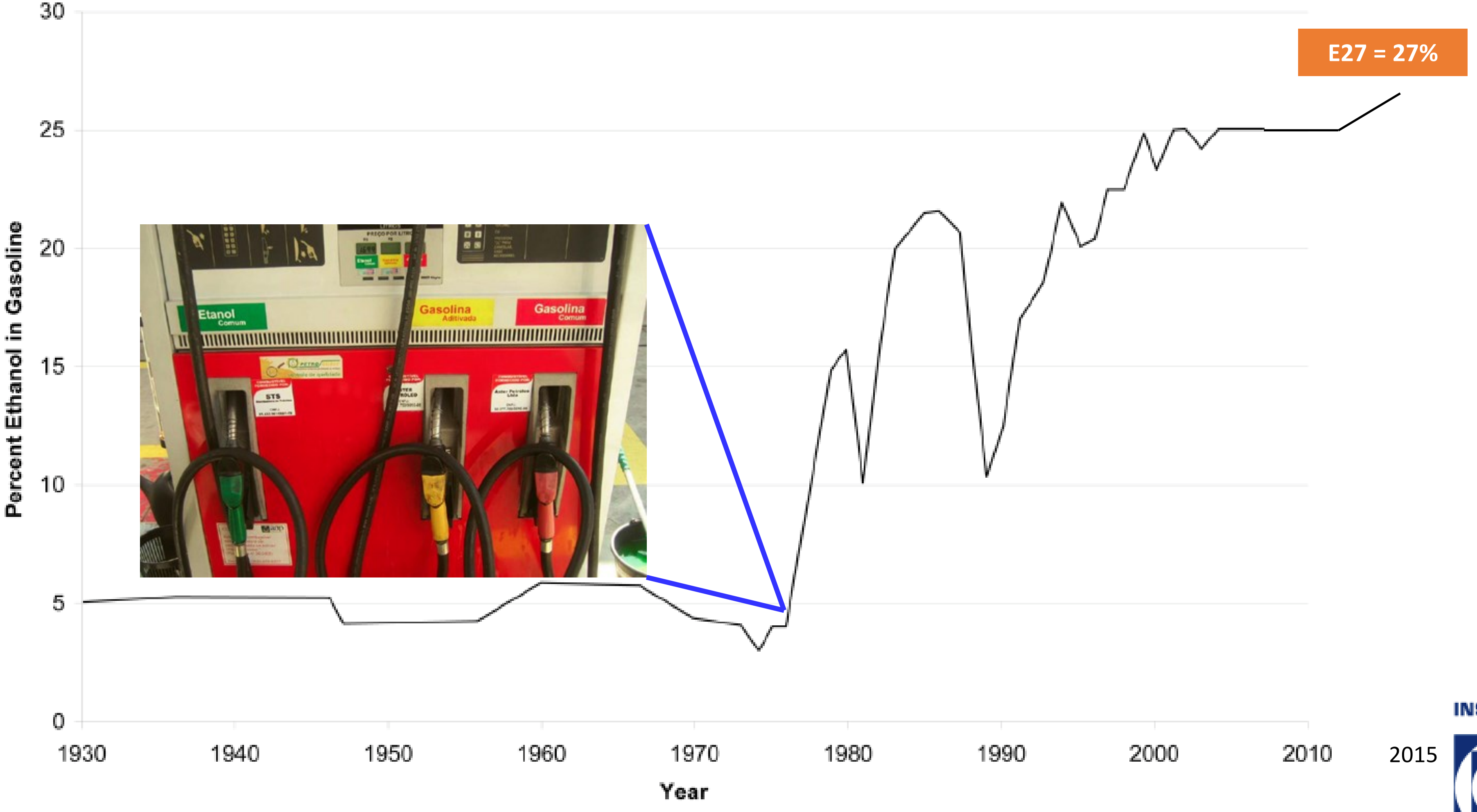
→

INSTITUTO MAUÁ DE TECNOLOGIA

MAUÁ

History of ethanol in Brazil

Evolution of Ethanol Content in Brazilian Gasoline



INSTITUTO MAUÁ DE TECNOLOGIA
MAUÁ

Source: Bioenergy & Sustainability: bridging the gaps, 2015 SCOPE – Chapter 8 http://bioenfapesp.org/scopebioenergy/index.php

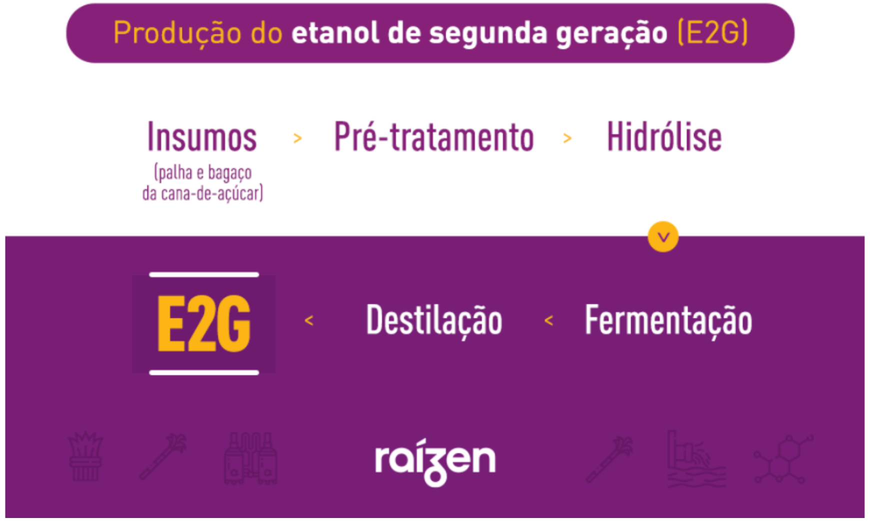
Bioethanol from sugar cane

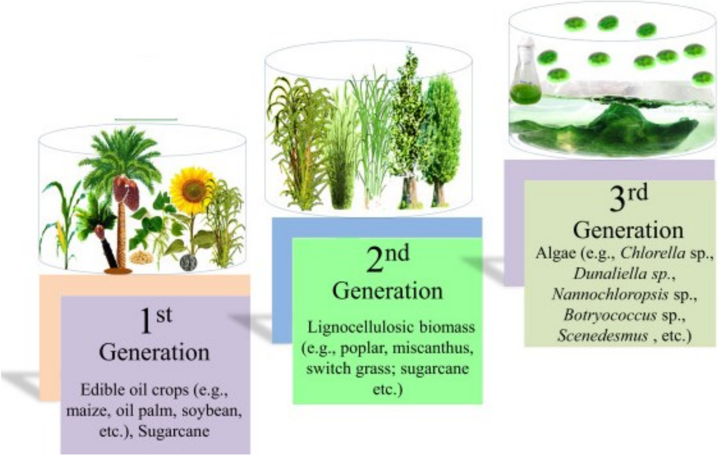
1st and 2nd generation ethanol


11 de nov. de 2022

Raízen Announces 5 New Plants to Produce Second Generation Ethanol (E2G)

This Monday, November 7th, the Brazilian Raízen - joint venture between Cosan S.A. and Shell plc, announced the signing of a contract of 3,3 billion euros to provide approximately 3,3 billion liters of Second Generation Ethanol (E2G, from brazilian portuguese Etanol de Segunda Geração) to Shell through the





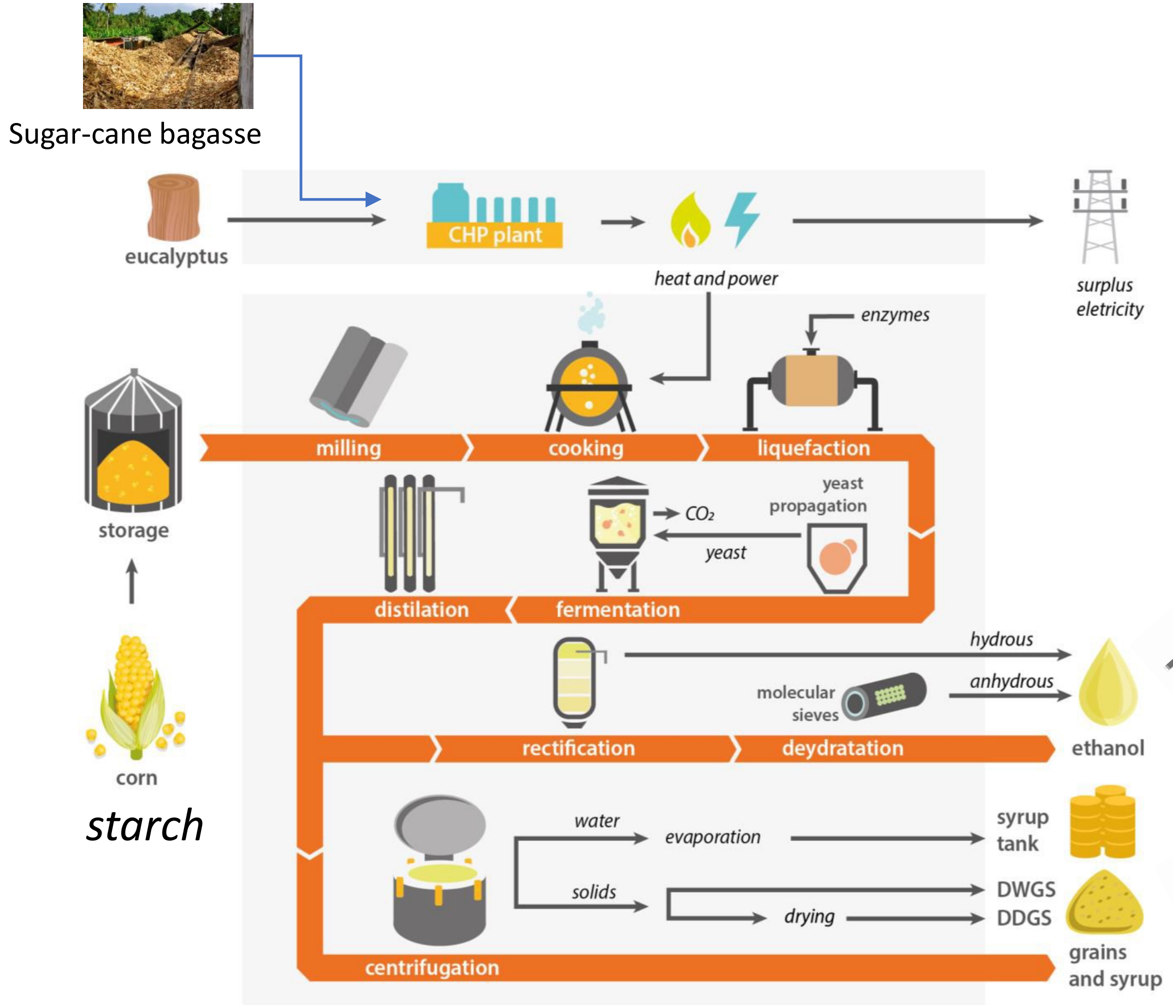
Cogo, Carlos – 15° Simpósio de Máquias Agrícolas SAE – 2023

www.raizen.com.br

Bioenergy from sugarcane [livro eletrônico] / organização Marcos Fava Neves , Rafael Bordonal Kalaki. -- 2020. ISBN 978-65-993349-0-0

Bioethanol from corn

Ethanol and DDGs (typically used as a protein-rich animal feed)



Gas station

Food for animals

- storage
- coupling with animal growth

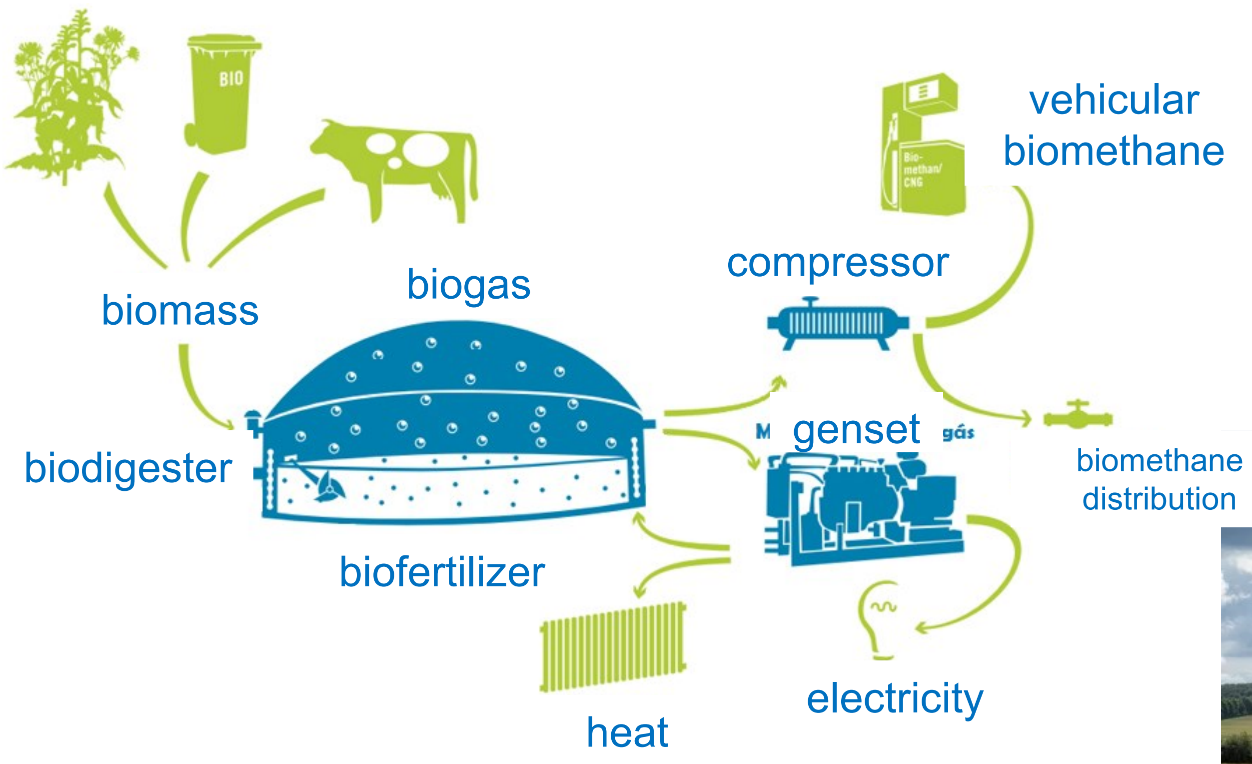
INSTITUTO MAUÁ DE TECNOLOGIA

MAUÁ

Adapted from "Biocombustíveis e a descarbonização da atmosfera", Dr. Carolina Grassi (RSB) à AEA no dia 15 de março de 2021.
Cogo, Carlos – 15º Simpósio de Máquias Agrícolas SAE - 2023

Biomethane/Biogas

Huge potential



Biomethane/Biogas

Huge potential

Farming: 77% of all plants

- Big producers: USW and STP
- 11% of all plants but ~80% of total production.

Urban solid waste (USW)

Sewage treatment (STP)

INSTITUTO MAUÁ DE TECNOLOGIA
MAUÁ

Martis, M. E. S. - COMO 2022, Coburg - Mobile propulsion in South American Markets

Biodiesel and HVO

Biodiesel – Transesterification process
HVO – Fully compatible with fossil diesel

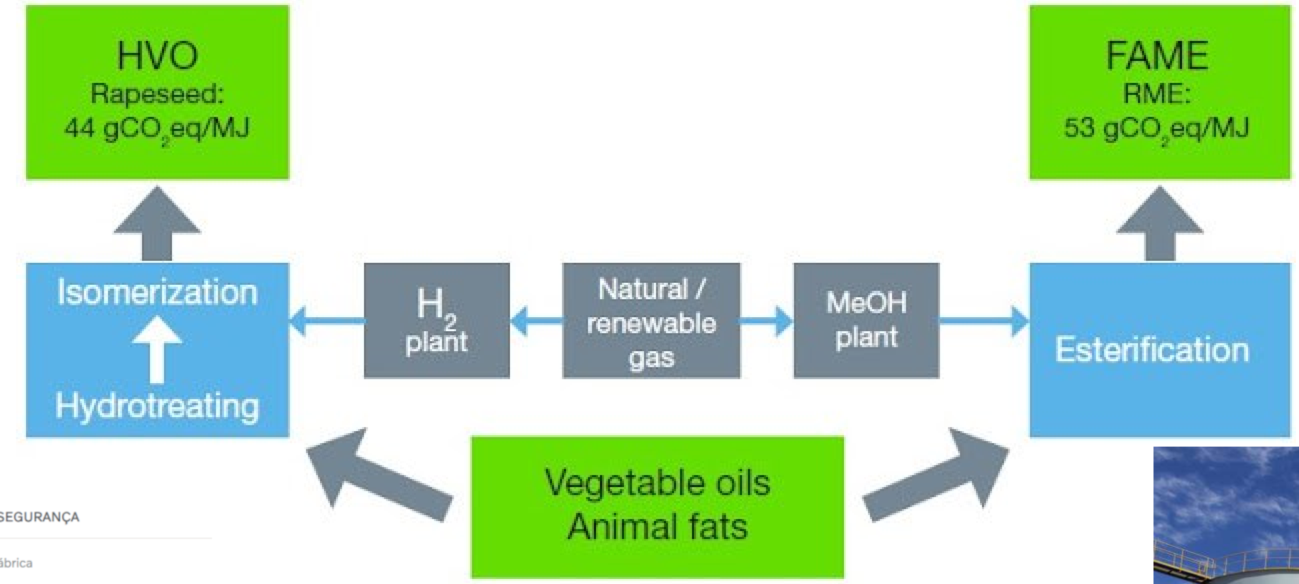
Petrobras comercializa primeiro lote de Diesel R5

31.out.2022

Compartilhar 2 Tweetar Compartilhar

Testes buscam identificar segmentos interessados no uso do combustível para redução das emissões de gases de efeito estufa

Foi concluída, em setembro, a primeira venda do Diesel R5 produzido pela Petrobras para testes comerciais. A produção, realizada na Refinaria Presidente Getúlio Vargas (Repar), em Araucária, chegou a um total de 1.500 m³. Trata-se de um importante passo para a venda regular e de maiores volumes do produto.



VOLVO CARREIRA NOTÍCIAS QUEM SOMOS SUSTENTABILIDADE E SEGURANÇA

Notícias › Volvo é a primeira a adotar diesel renovável R5 da Petrobras nos abastecimentos de fábrica

Press release

Volvo é a primeira a adotar diesel renovável R5 da Petrobras nos abastecimentos de fábrica

2023-08-24

A Volvo é a primeira montadora do Brasil a utilizar o novo diesel renovável R5 da Petrobras dentro de seu complexo industrial de Curitiba (PR), onde produz caminhões e chassis de ônibus.

SAF

Sustainable aviation fuel

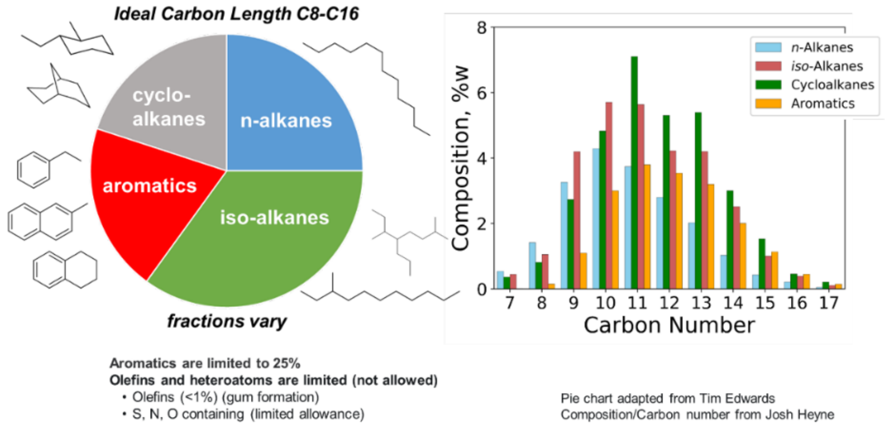
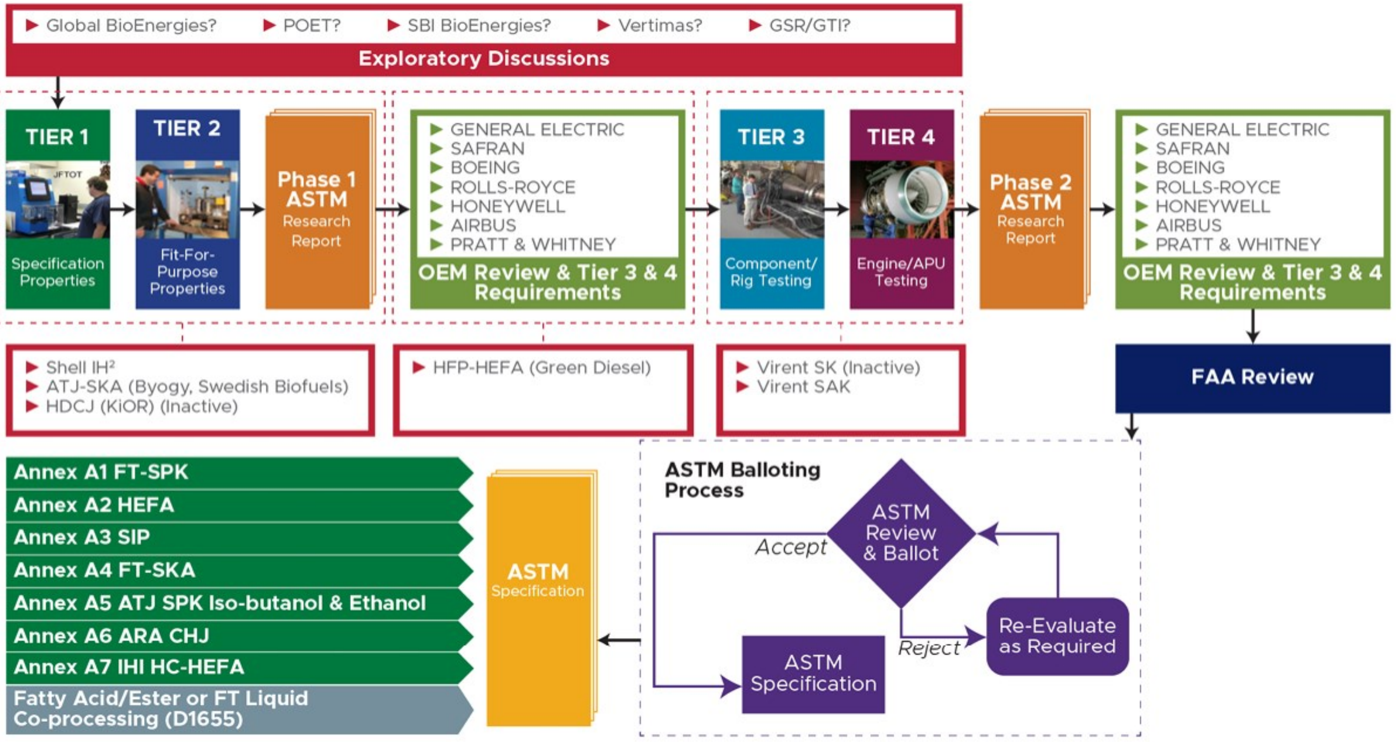


Figure 5. Composition of an average Jet A (POSF 10325) (Edwards 2017). *n*-Alkanes, iso-alkanes, cycloalkanes, and aromatics are approximately normally distributed across the carbon number range. A molecule with 11 to 12 carbons is approximately average.

- Fuel energy density
- Compatibility with homologated airplanes
- Costs
- …



https://www.energy.gov/sites/prod/files/2020/09/f78/beto-sust-aviation-fuel-sep-2020.pdf

SAF – approved pathways

1

Fischer-Tropsch [FT]-Synthetic paraffinic kerosene [SPK] - was approved in June 2009 for up to a 50% blend with petroleum-derived jet fuel. FT-SPK is a mixture of iso- and n-alkanes derived from synthesis gas using the FT process. Syngas can be produced from reforming natural gas or from gasifying coal or **biomass**.

2

Hydroprocessed esters and fatty acids (HEFA) - Synthetic paraffinic kerosene [SPK] - was approved in July 2011 for up to a 50% blend with petroleum-derived jet fuel. The molecular composition of HEFA-SPK is similar to FT-SPK, consisting of iso- and n-alkanes. The alkanes are the product of **hydrotreating esters and fatty acids from fats, oils, and greases and from oilseed crops or algae**.

3

SIP - hydroprocessed fermented sugar-synthetic iso-paraffins - was approved in June 2014 for up to a 10% blend with petroleum-derived jet fuel. Unlike SPK from HEFA or FT, this is a single molecule, a 15-carbon hydrotreated sesquiterpene called farnesane, produced from fermentation of sugars. Today, the fermentation is done commercially **from sugar cane juice** and is used in higher-value applications, most commonly in personal care.

4

Alcohol-to-jet [ATJ]- Synthetic paraffinic kerosene [SPK] - was approved in April 2016 for SPK from iso-butanol (30% blend with petroleum) and expanded in April 2018 for SPK from ethanol and for fuel blends up to 50% with petroleum. ATJ-SPK consists of iso-alkanes of 8, 12, or 16 carbons when starting from iso-butanol. The iso-alkanes are highly branched and have lower DCNs than FT or HEFA, based on data from Gevo, Inc. The carbon number is broadened and the branching level can be significantly reduced, leading to a DCN similar to FT and HEFA when starting from **ethanol**.

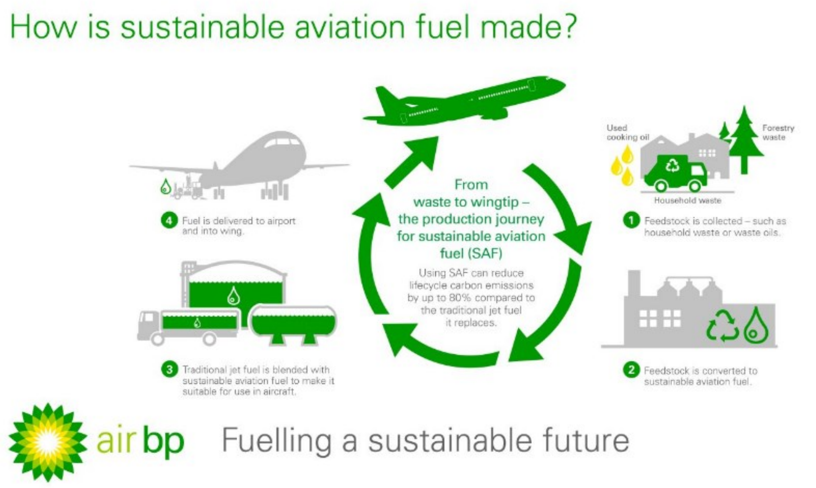
https://www.energy.gov/sites/prod/files/2020/09/f78/beto-sust-aviation-fuel-sep-2020.pdf

SAF – approved pathways

5 Applied Research Associates Catalytic Hydrothermolysis Jet, or ARA CHJ was approved in January 2020 as a 50% blend. The fuel is produced from **lipids** using a supercritical hydrothermal process, creating a blendstock that contains all four hydrocarbon families: n-, iso-, and cyclo-alkanes and aromatics.

6 HC-HEFA synthesized paraffinic kerosene [SPK] from hydroprocessed hydrocarbons, esters, and **fatty acids** was approved in 2020 as a 10% blend. This is specifically for **lipids** from an B. braunii algae that have been hydrocracking/hydroisomerization to remove all oxygen and saturate double bonds. The product is rich in iso-alkanes. This is the first approval through the fast track process.

7 ASTM D1655-20b allows coprocessing of up to 5% mono-, di-, and triglycerides, **free fatty acids**, and **fatty acid esters** or up to 5% of FT hydrocarbons. Hydrocracking/hydrotreating and fractionation are required. No other coprocessing in refineries is allowed for jet fuel



Possible raw materials

- Corn kernels
- Vegetable seeds (soybeans)
- Seaweed
- Other fats, oils and greases
- Agricultural waste
- Forest residues
- Wood mill waste
- Municipal solid waste
- Wet waste (manure, sewage treatment sludge)
- Dedicated energy crops.

https://www.energy.gov/sites/prod/files/2020/09/f78/beto-sust-aviation-fuel-sep-2020.pdf

INSTITUTO MAUÁ DE TECNOLOGIA

An example

Ethanol – piston type engine

Embraer / Neiva
Ipanema (EMB-203)

Engine: Lycoming 6 cylidners (IO-540)
320 hp @ 2700rpm ethanol

Fuel tank:
total: 292 liters
usable: 264 liters

E TECNOLOGIA
MAUÁ

https://agricultural.embraer.com/br/pt/ipanema-203
http://culturaaeronautica.blogspot.com/2014/09/motores-aeronauticos-movidos-etanol.html

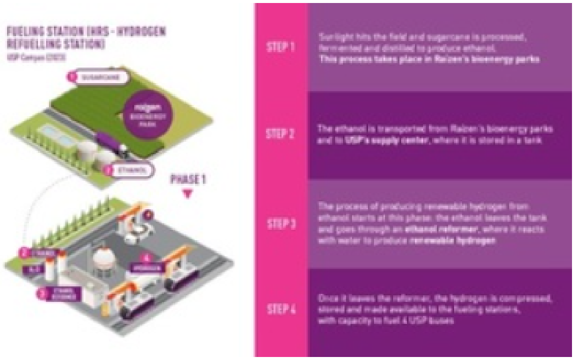
Technical challenges / new technologies

- H_2 production from ethanol – fuel reforming

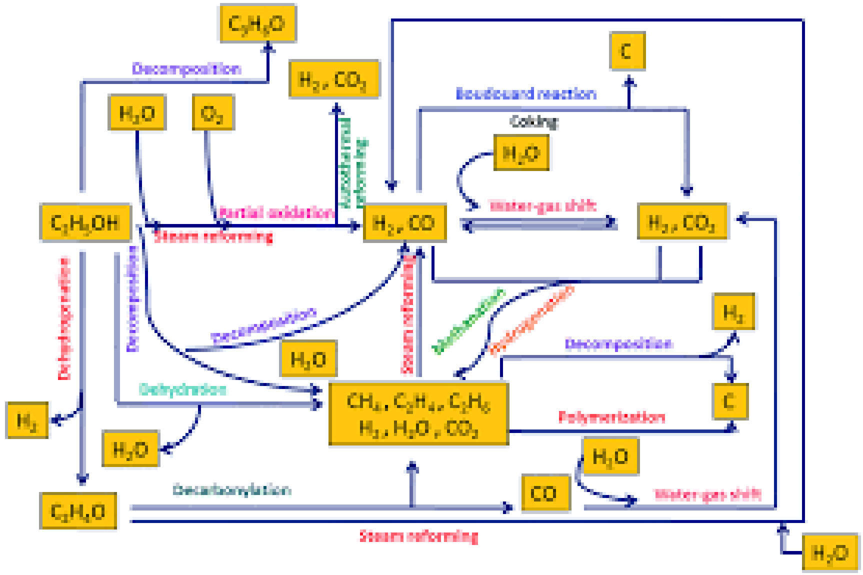
Shell announces partnership to convert ethanol into hydrogen

By Shell Brazil | September 02, 2022

Shell Brazil, Raízen, Hytron, University of São Paulo (USP) and SENAI CETIQT signed a cooperation agreement for the construction of two plants to produce renewable hydrogen (H2) from ethanol. The partnership aims to validate the production technology through the construction of two plants designed to produce 5 kg/h of hydrogen and, later, the implementation of a plant 10 times larger (44.5 kg/h). In addition, the agreement includes a hydrogen refueling station (HRS) on the USP campus, in the city of São Paulo. The buses used by students and visitors to the campus will no longer use diesel and traditional internal combustion engines but rather



SOURCE: Shell Brazil



https://biomassmagazine.com/articles/19308/shell-announces-partnership-to-convert-ethanol-into-hydrogen

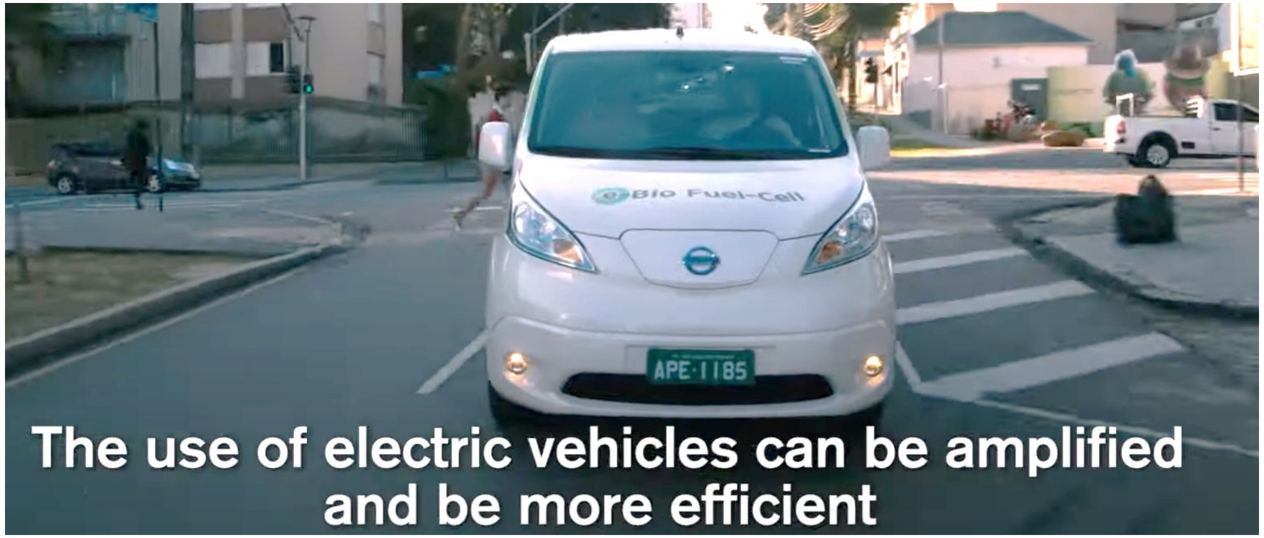
INSTITUTO MAUÁ DE TECNOLOGIA
MAUÁ

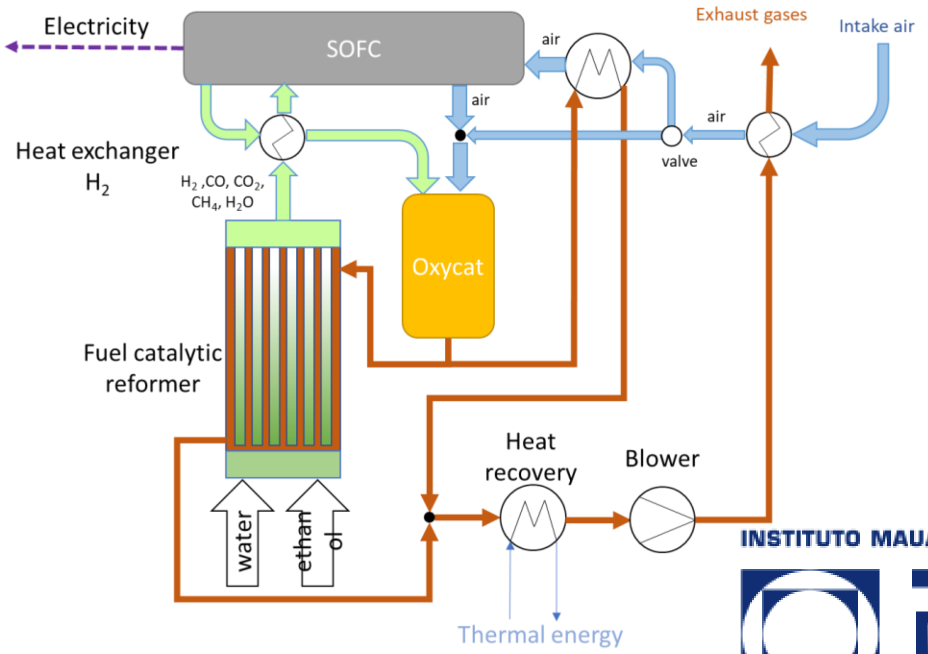
Technical challenges / new technologies

- H_2 production from ethanol – on-board fuel reforming using a SOFC

Advantages
- Fuel energy density
- Fast refueling
- Compatibility with electrification

Challenges
- Thermal management
- Warm-up time
- Packaging





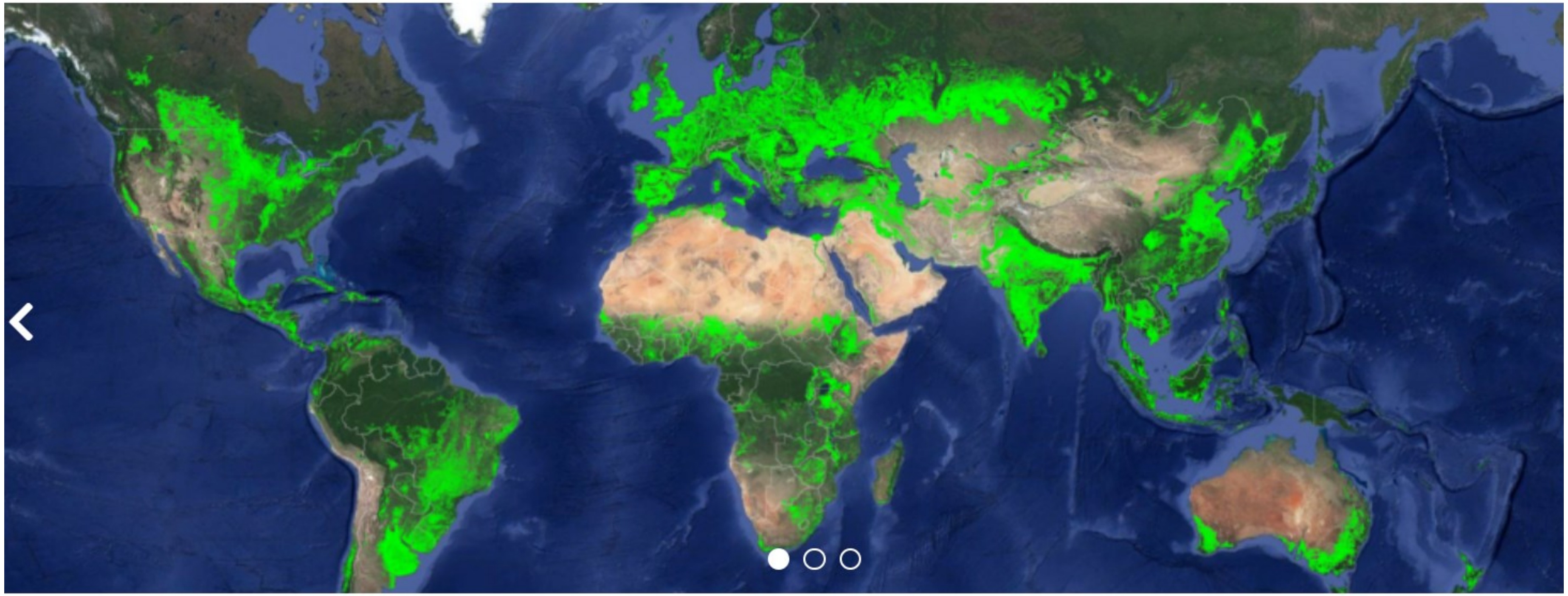
INSTITUTO MAUÁ DE TECNOLOGIA
MAUÁ

https://global.nissannews.com/en/releases/nissan-unveils-worlds-first-solid-oxide-fuel-cell-vehicle

Food versus fuel?

Global Food Security-Support Analysis Data at 30 m (GFSAD)

By [Western Geographic Science Center](#) March 26, 2018



Overview Science Multimedia Publications Web Tools News Partners

The GFSAD30 is a NASA funded project to provide high resolution global cropland data and their water use that contributes towards global food security in the twenty-first century.

Contacts

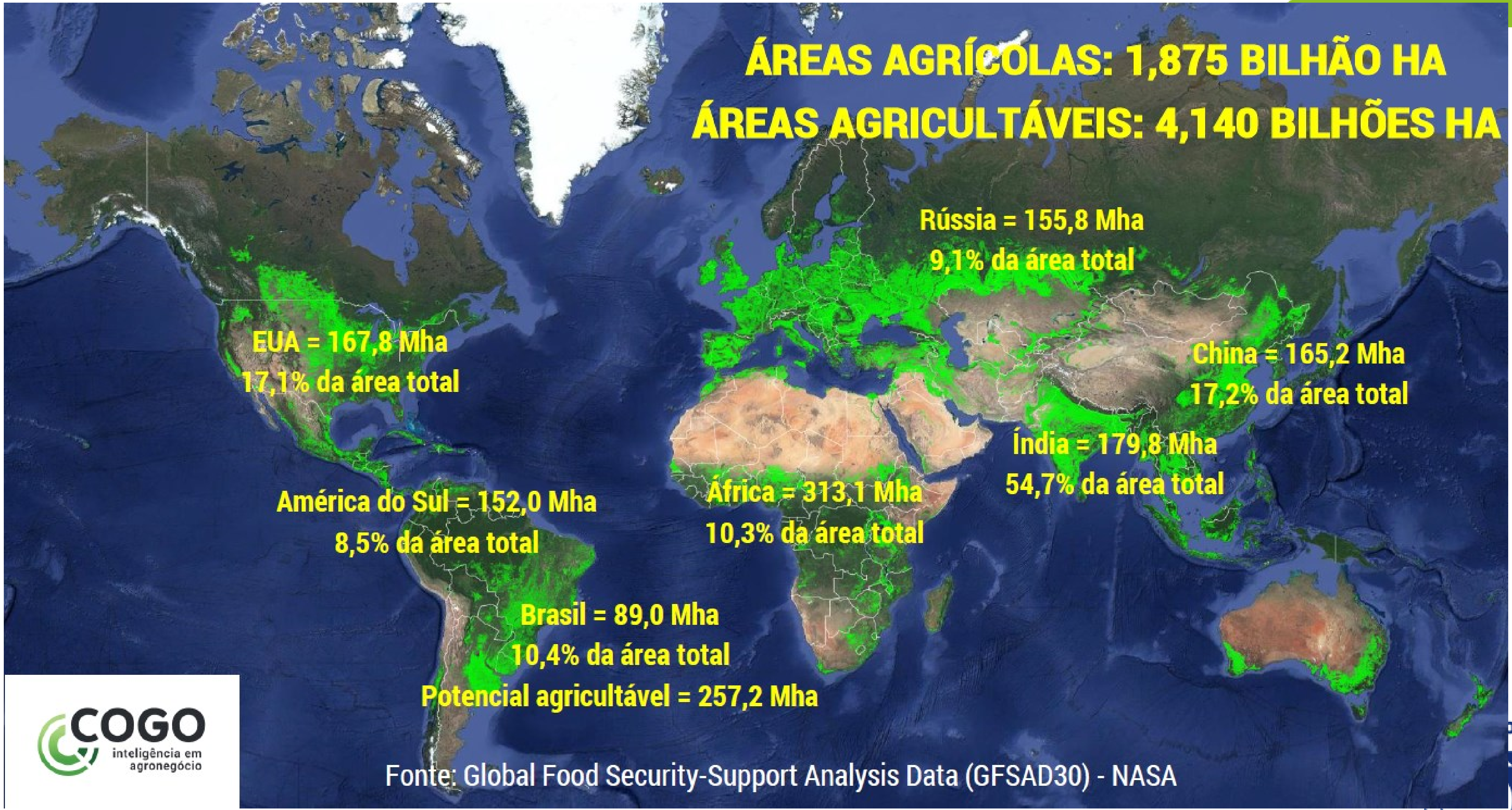
INSTITUTO MAUÁ DE TECNOLOGIA

MAUÁ

https://www.usgs.gov/centers/western-geographic-science-center/science/global-food-security-support-analysis-data-30-m

Cogo, Carlos – 15° Simpósio de Máquinas Agrícolas SAE – 2023 https://www.carloscogo.com.br/docs/agribusiness_rel_0753.pdf

Food versus fuel?



https://www.usgs.gov/centers/western-geographic-science-center/science/global-food-security-support-analysis-data-30-m

Cogo, Carlos – 15° Simpósio de Máquinas Agrícolas SAE – 2023 https://www.carloscogo.com.br/docs/agribusiness_rel_0753.pdf

Food versus fuel?

BRAZIL – PRODUCTION AND EXPORATION RANK – 2023 FORECAST					
COMMODITY	PRODUCTION	% GLOBAL PRODUCTION	EXPORTATION	% GLOBAL EXPORTATION
soybean	1º	41%	1º	57%
corn	3º	11%	1º	28%
coffee	1º	37%	1º	28%
sugar	1º	21%	1º	41%
ethanol	2º	30%	2º	8%
orange juice	1º	66%	1º	72%
cotton	4º	12%	2º	24%
rice	9º	2%	7º	2%
tobacco	2º	13%	1º	31%
cow meat	2º	18%	1º	25%
chicken meat	2º	14%	1º	34%
pork meat	4º	4%	4º	11%

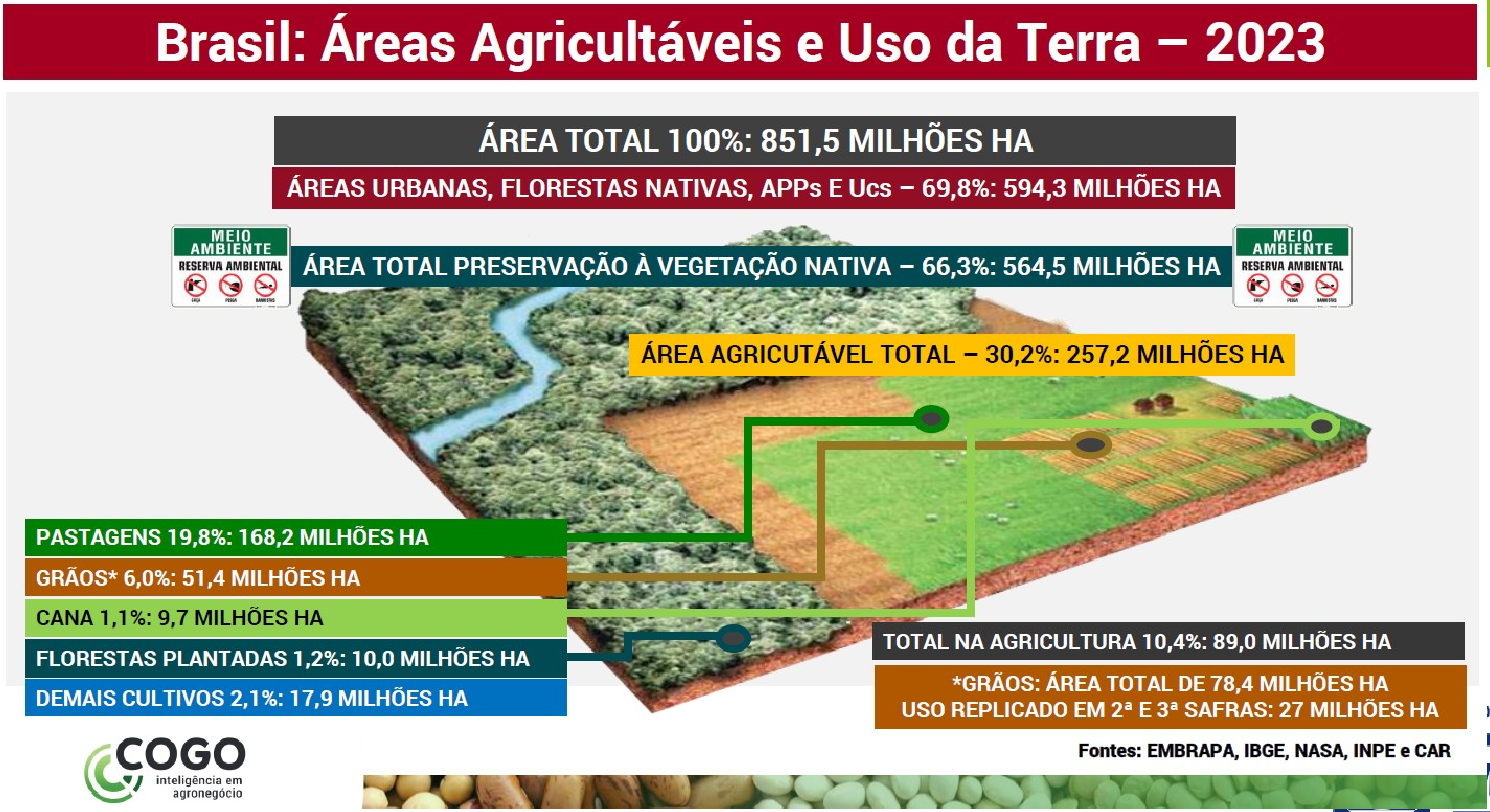
Fontes: FAO, OIC, OIA, USDA, ABPA, SECEX e ICAC

Elaboração: COGO INTELIGÊNCIA EM AGRONEGÓCIO

Cogo, Carlos – 15° Simpósio de Máquinas Agrícolas SAE – 2023 https://www.carloscogo.com.br/docs/agribusiness_rel_0753.pdf

TECNOLOGIA AUÁ

Food versus fuel?



Cogo, Carlos – 15° Simpósio de Máquinas Agrícolas SAE – 2023 https://www.carloscogo.com.br/docs/agribusiness_rel_0753.pdf

Conclusion

- Biofuels are an interesting route for a fast-track decarbonization of transportation sector
  - Liquid fuels with considerable energy density
  - Refueling infrastructure already available
  - Sinergy with other agricultural activities
  - Social benefits (employment possibilities for development countries)
  - “only quick way” for some sectors (aviation)
- Further research is required for advanced biofuel utilization
  - Fuel reforming for H2 production
    - On- and off-board
    - Direct reform (coupling to electricity conversion in fuel cells)

INSTITUTO MAUÁ DE TECNOLOGIA

Thank you!

Clayton@maua.br

INSTITUTO MAUÁ DE TECNOLOGIA

MAUÁ

Campus São Caetano do Sul
Praça Mauá, 01 - São Caetano do Sul - SP