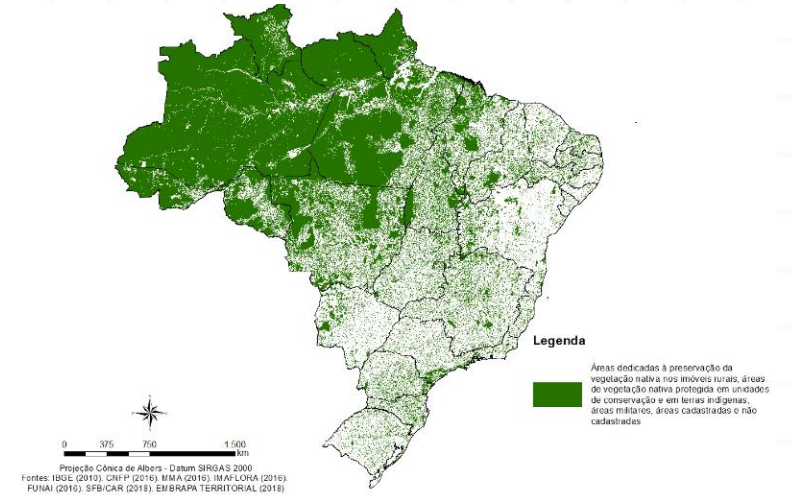


Sustainable Mobility: Learnings from Brazil

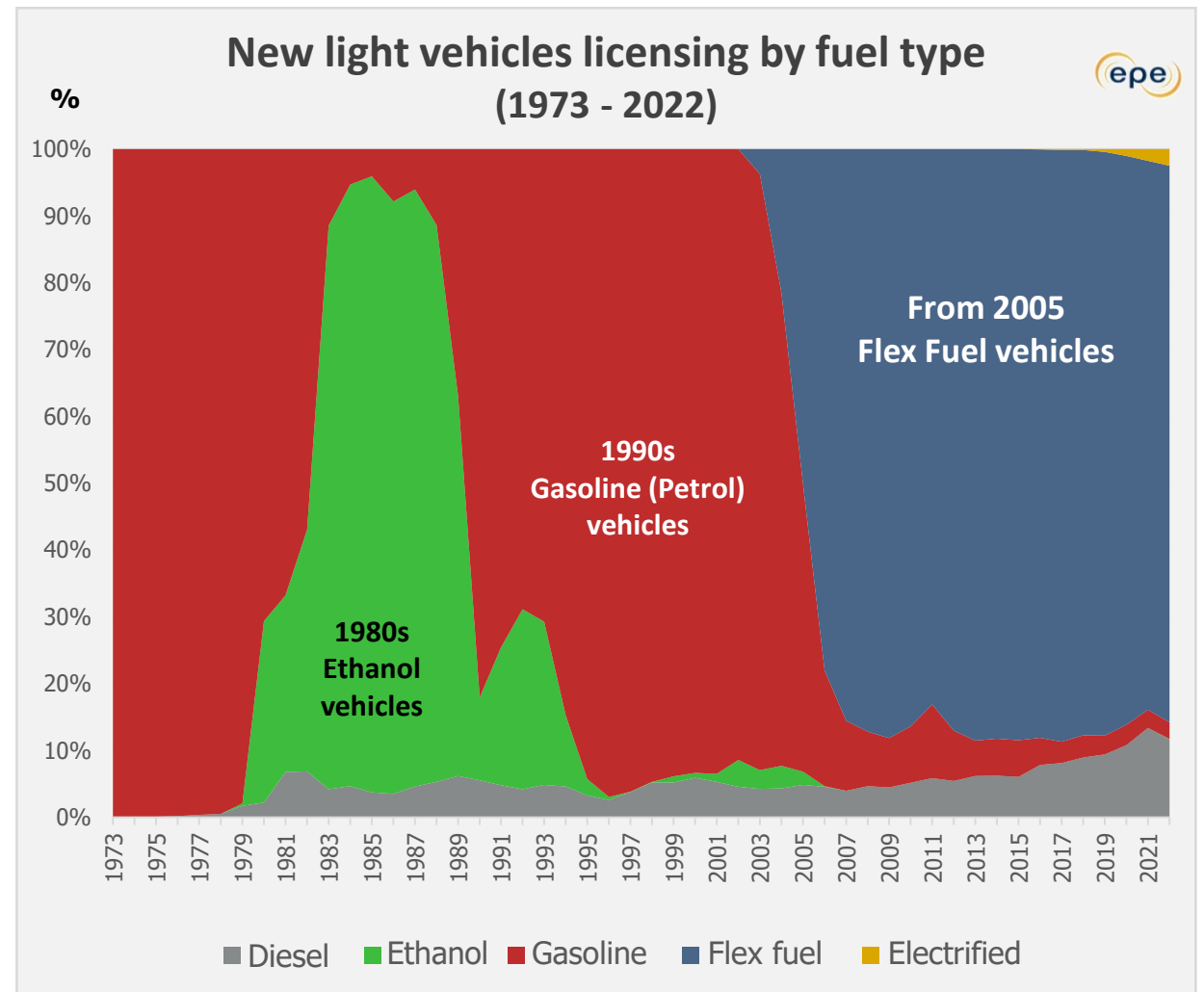
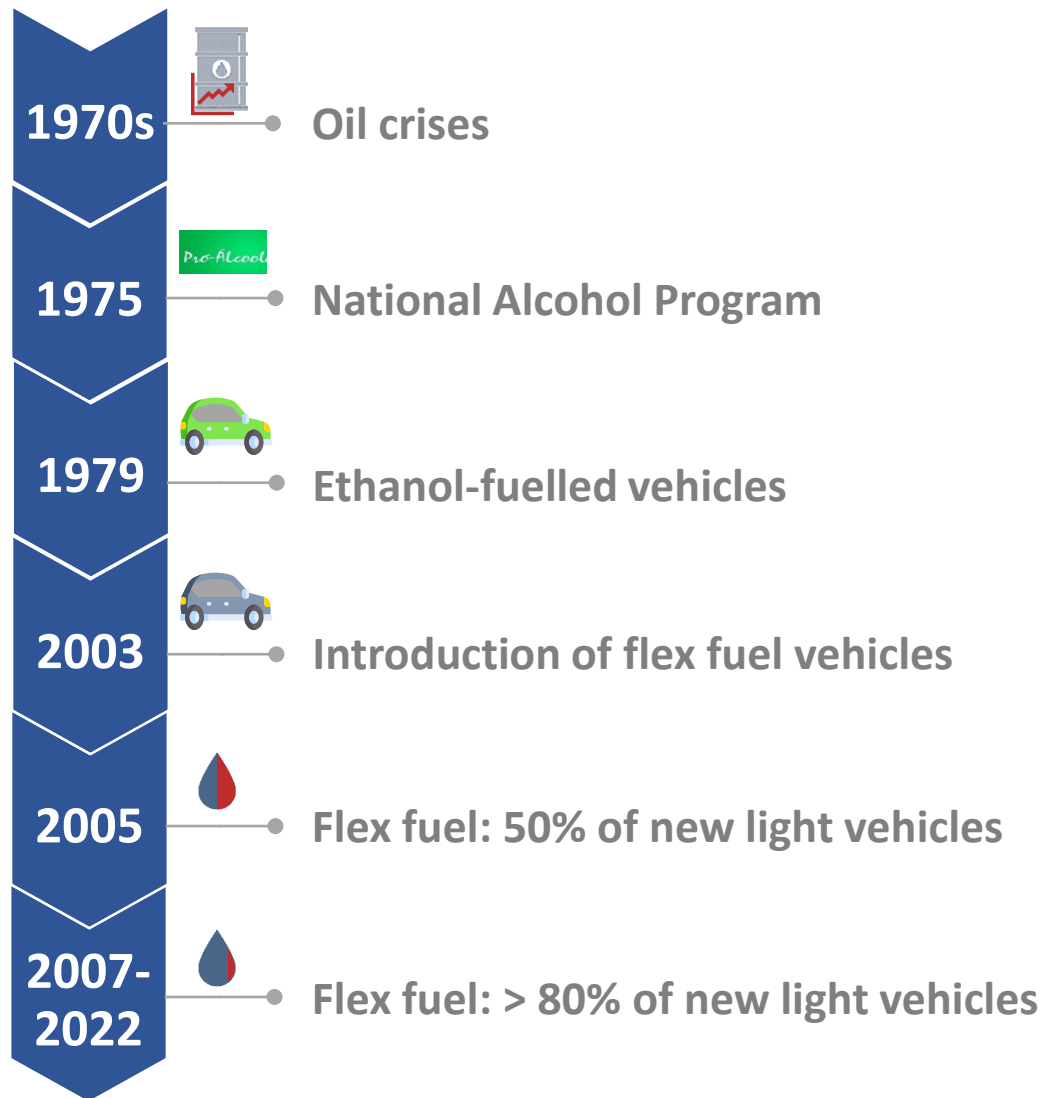


Prof. Suani Coelho (with the contribution of MSc Danilo Perecin)

Institute of Energy and Environment

University of São Paulo, Brazil

The story starts in the 1970s



Sources: EPE; ANFAVEA

Flex fuel vehicles enable E100

1975-1990:

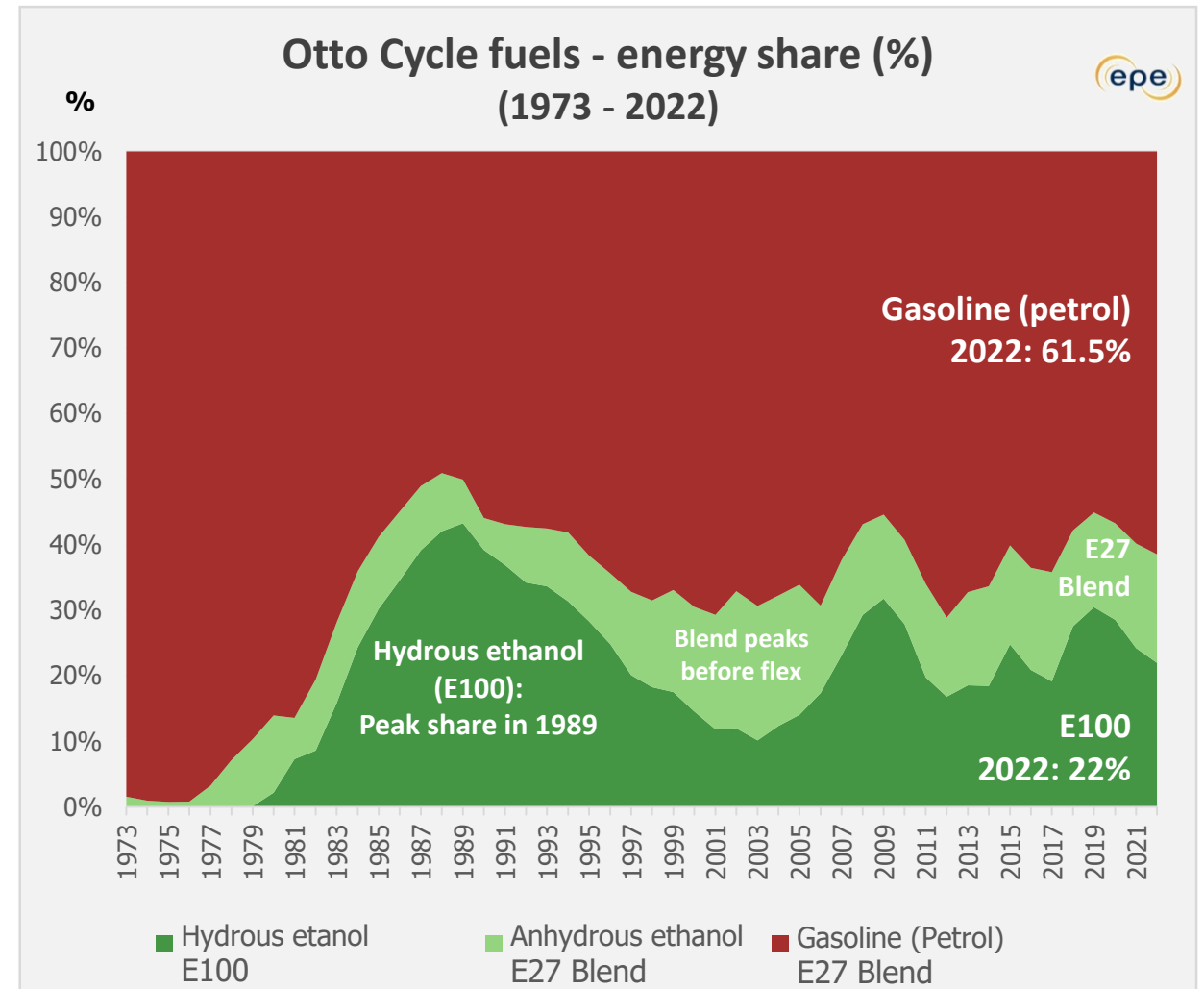
Direct subsidies to ethanol producers (price fixing) and to ethanol vehicle manufacturers

Currently:

No direct subsidies

Tax differentiation applied for Federal and State taxes (usually lower tax rates for ethanol)

Recently, on top of tax differentiation: a carbon market for the emissions reductions from biofuels (RenovaBio)

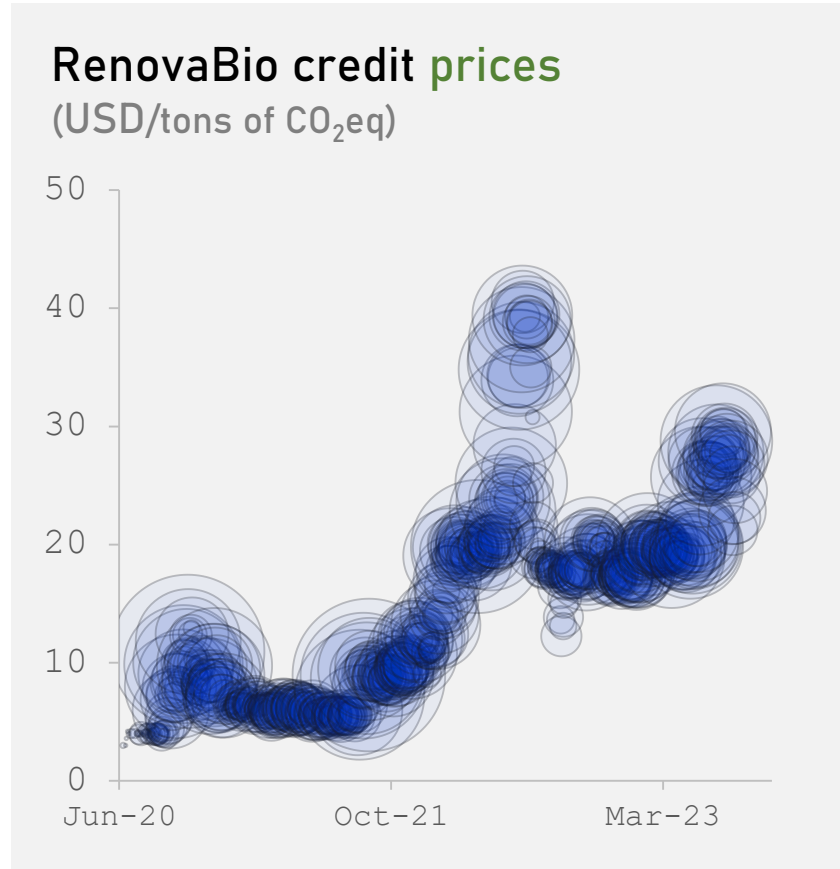


Source: EPE

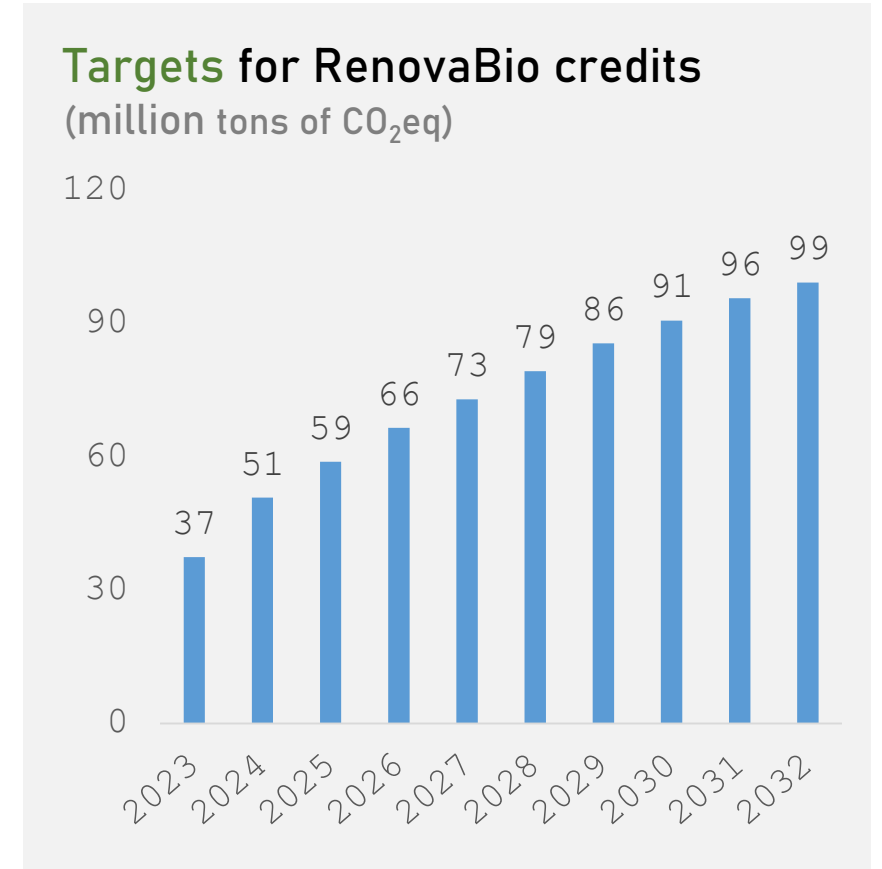
A carbon price signal for biofuel producers

In 2020, Brazil implemented a carbon credit scheme for the emissions reductions from biofuels in transport: **RenovaBio**

Credits are awarded in line with the **carbon intensity** of each biofuel producer – assessed on an individual basis (LCA)

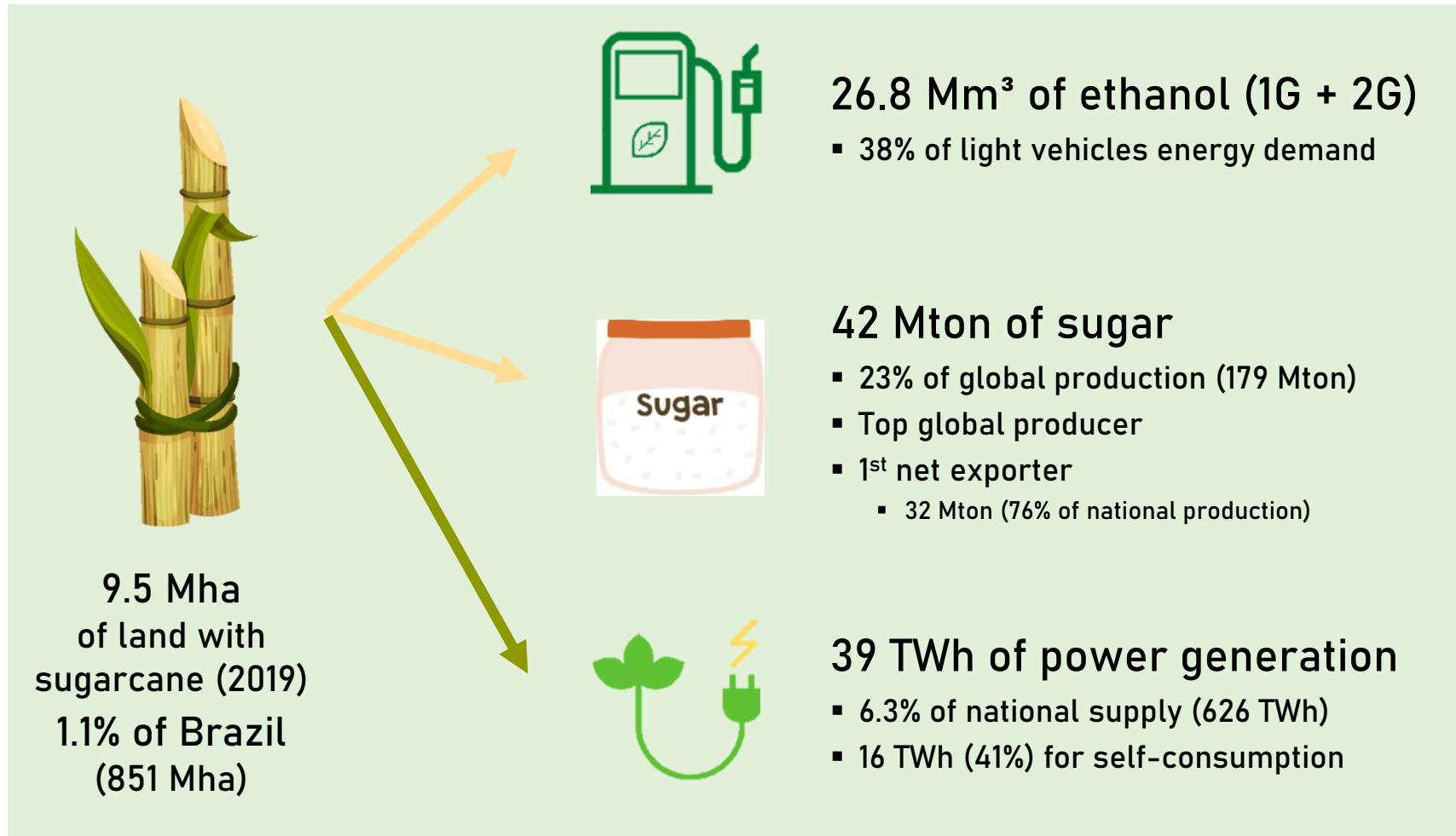


2022/23 prices: 20 to 30 USD/tCO₂
can support the adoption of new technologies



Growing targets require:
production expansion, more certification, **carbon intensity improvements**

Sugarcane products include ethanol



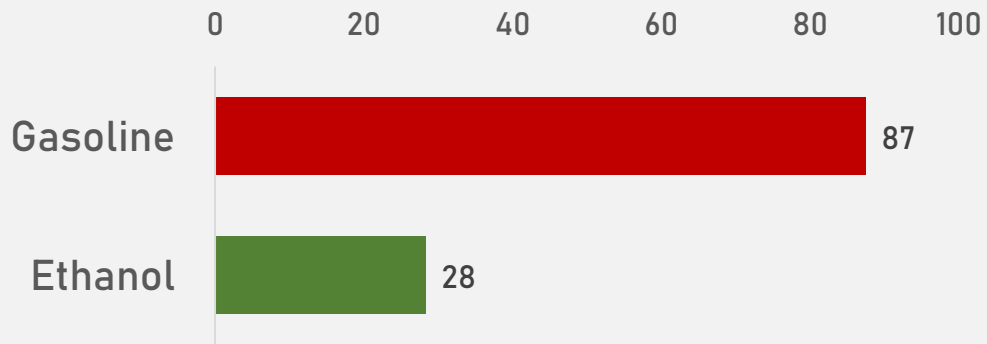
+ Ethanol growth from corn

- 4 Mm³ of ethanol in 2022
- Double-cropping system: 75% of corn is produced in the same area as soybeans
- Less than 10% of Brazilian corn is processed for ethanol, while over 40% is exported

Sources:
MapBiomass (2021); EPE (2023); CONAB (2021); USDA (2021)

Investing in new low-carbon solutions

Carbon intensity (CI) today (gCO₂/MJ)



Ethanol's supply chain emissions linked to:

- **Fertiliser** production and application
 - ↳ Future **low-carbon (or biomass-based) hydrogen** production
- **Diesel** use in machinery and transport
 - ↳ To be replaced by **self-produced biomethane**

Technologies for a lower CI ethanol



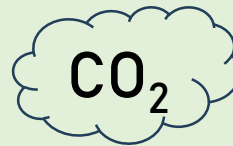
Biogas/Biomethane from residues

- **Mature** technology, diverse business models
 - CHP: 1 plant of 20 MWe
 - Gas grid injection, dedicated pipeline
 - **Replacing diesel** in trucks and machinery



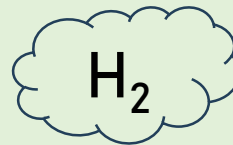
Second-generation ethanol

- Raizen Co. holds technological expertise
- 1 plant in operation, 4 under construction
 - >300,000 m³/year expected output



Biogenic carbon capture (**BECCS**)

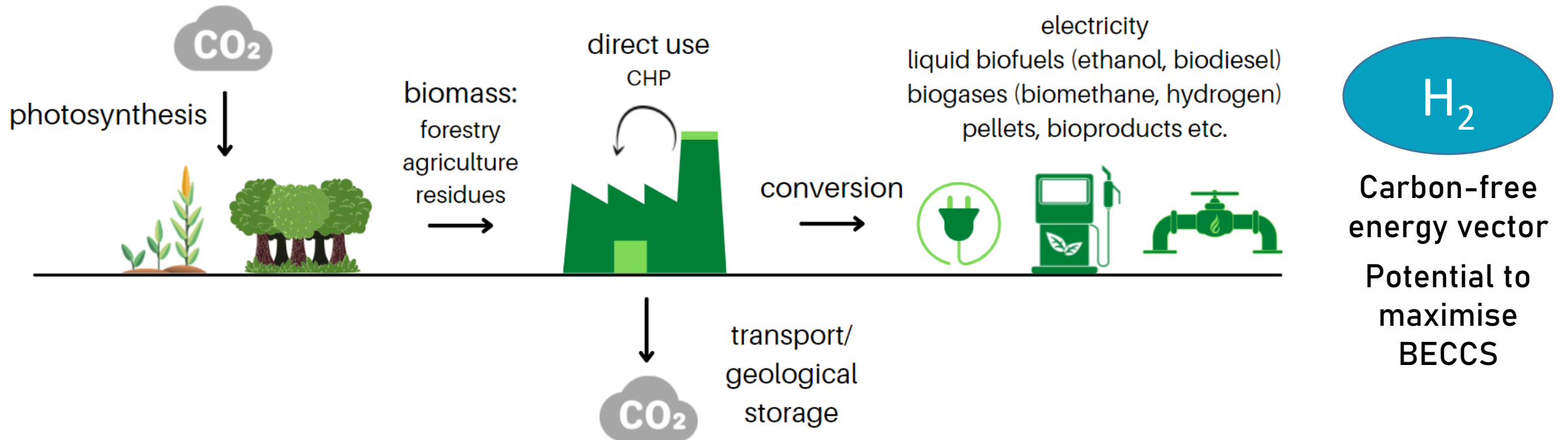
- High CO₂ concentration (>98%)
- ~ 25 MtCO₂ per year



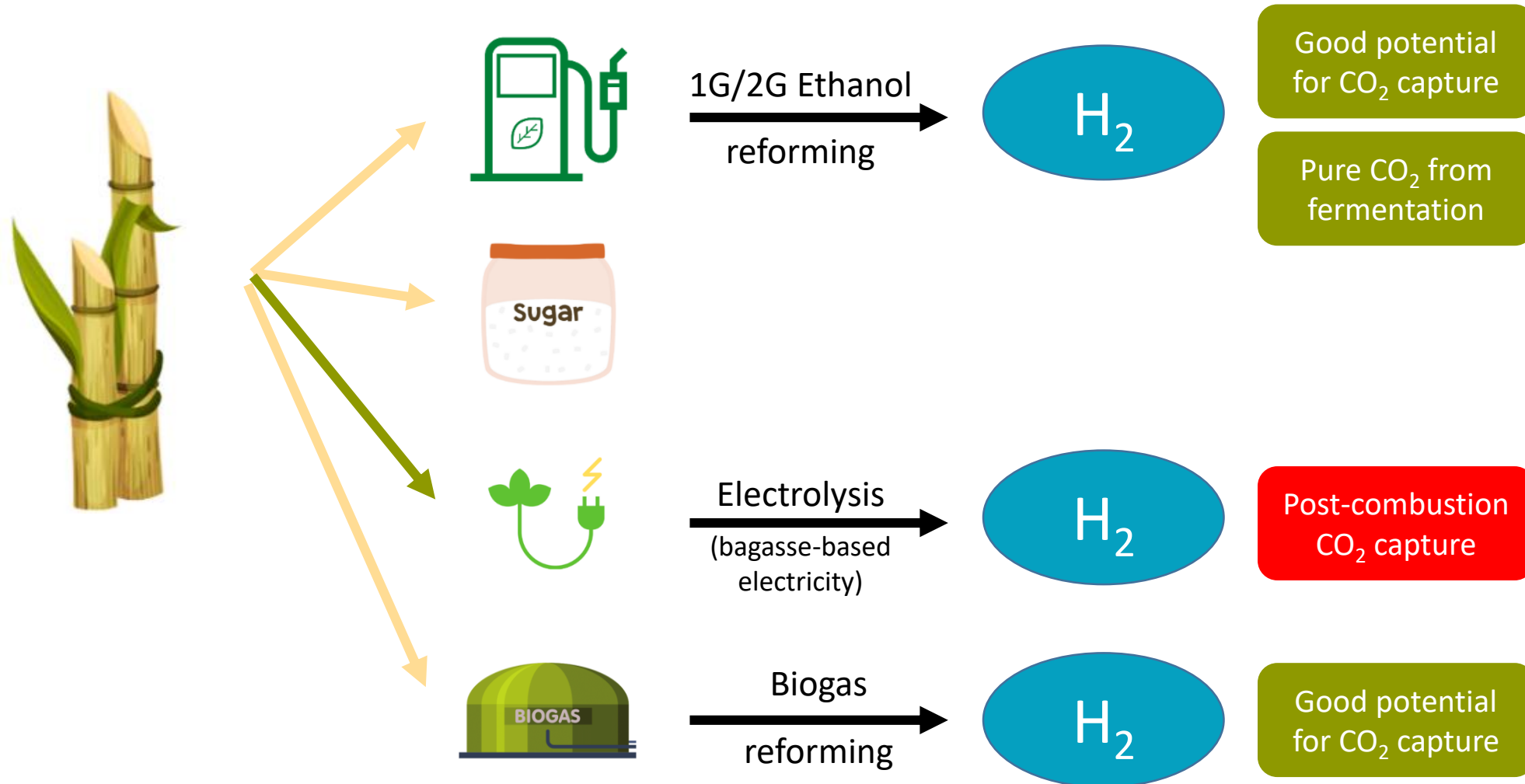
Hydrogen

- Different **routes**: electrolysis, biogas, ethanol
- Combination with CO₂ for synthetic fuels

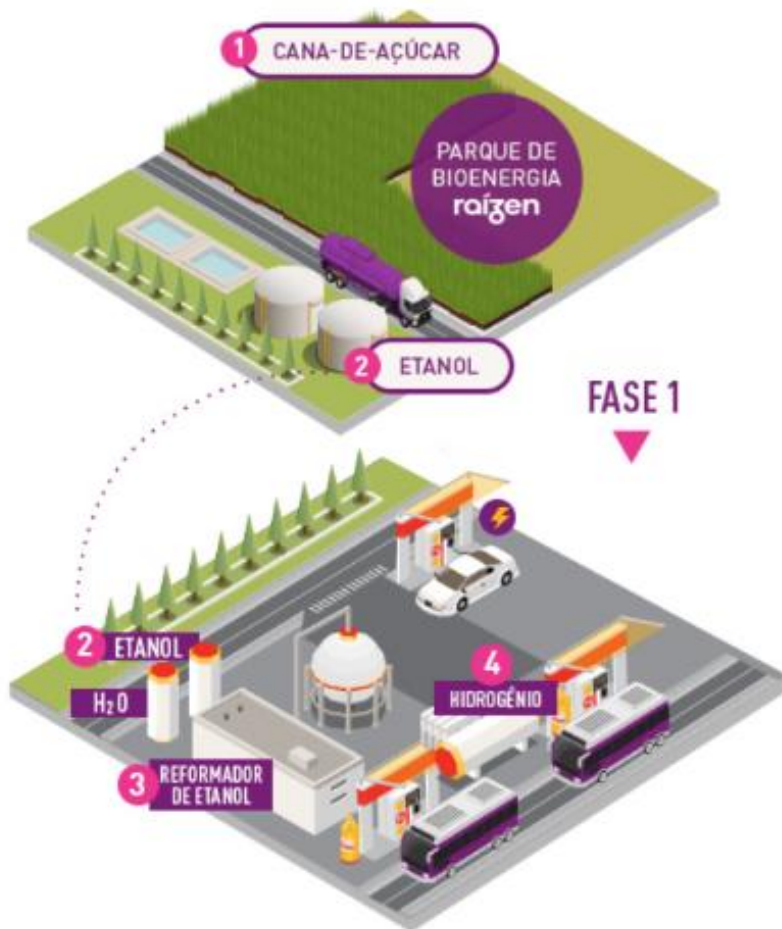
Rethinking existing bioenergy systems to deliver hydrogen and negative emissions (with BECCS)



Rethinking the portfolio towards H₂ w/ BECCS



Shell, Raizen, Hytron, Senai, USP: Partnership to Convert Ethanol Into Renewable Hydrogen



Four steps:

1. Sugarcane processing in the biorefinery produces ethanol
2. Ethanol is transported to the fuel station at USP and stored
3. Ethanol steam reforming produces hydrogen
 - 2 pilot plants of 5 kg/h H₂
 - ca. 38.5 L ethanol/h each
 - To be scaled-up (10 x)
4. Hydrogen is compressed and stored, ready for refuelling
 - Potential to supply 4 campus buses

Investment: USD 10 MM (Shell through RD&I funding)
Launch on August 10, 2023
Start-up on 2nd semester 2024

Ethanol production: future

Future of 2G ethanol in Brazil

from sugarcane bagasse and straw

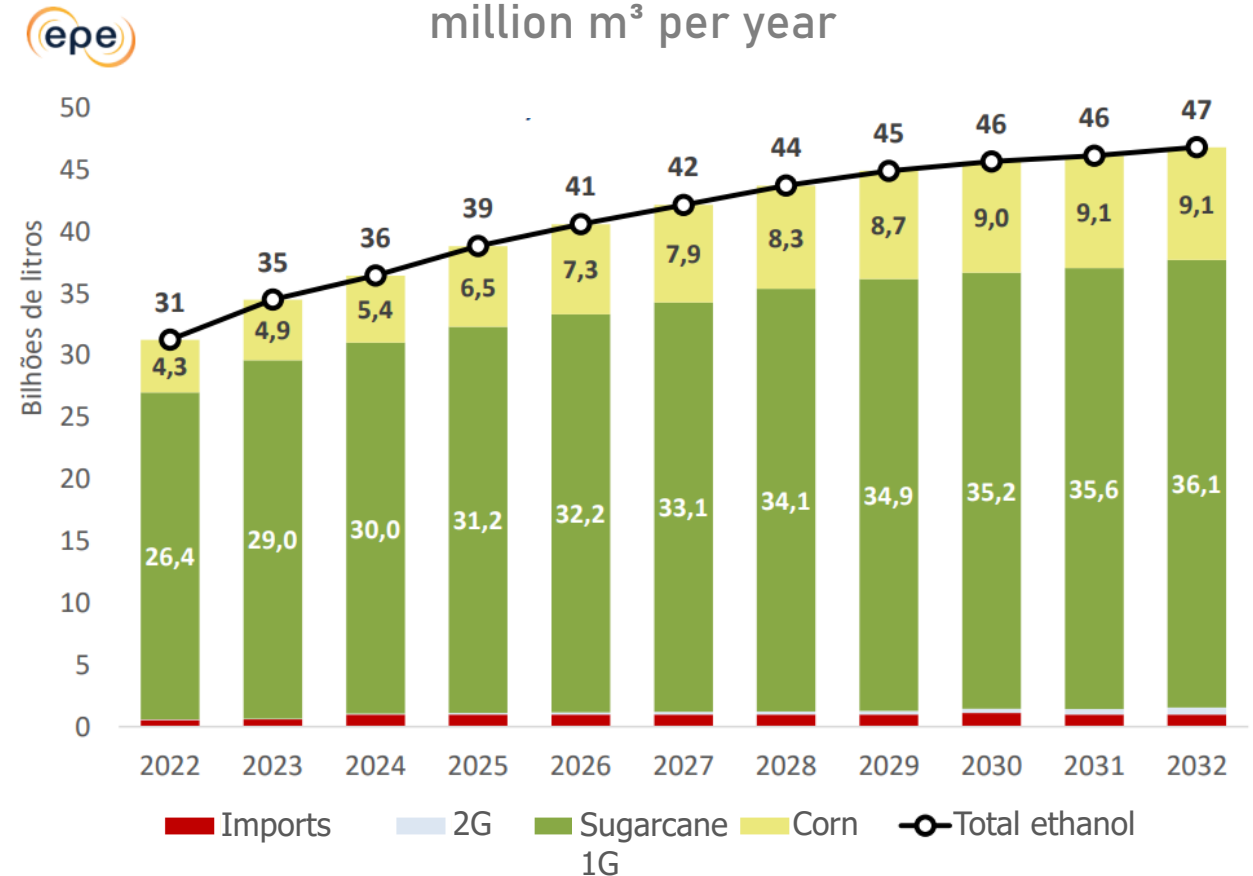
- In operation
35,000 m³/yr (Costa Pinto Mill)
- Under construction
300,000 m³/yr
in four new 2G plants (75,000 m³/yr each)
- Ethanol 1G + 2G = increase of 28% ethanol production per hectare (8,415 L/ha)

Expectation: biofuels for SAF

Total ethanol supply projection

Official source (EPE), 2023-2032

million m³ per year



Sources: EPE; Raízen (reproduced with permission)

Biogas and 2G ethanol: kicking off

Raízen Inaugurates Biogas Plant and Strengthens its Renewable Energy Portfolio

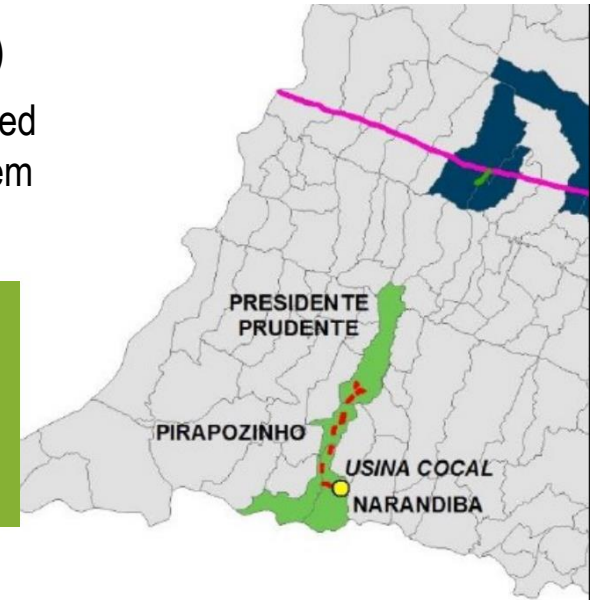
With an installed capacity of 21 MW, the new unit in the interior of São Paulo will produce electric energy using vinasse and filter cake, sugarcane by-products



Cocal + GasBrasiliano (utility)

1st city in the world with a dedicated biomethane gas distribution system

- Pipeline length: 68 km (52 km steel, 16 km HDPE)
- 118,000 m³/day (potential)
- Investment:
 - 30 M\$ from GasBrasiliano
 - 130 M\$ from Cocal



Raízen announces plans for 2 new cellulosic ethanol projects

By Erin Voegelé | May 12, 2022

Brazil's Raízen makes massive bet on 2G ethanol and biogas

30 May 2022 | Reese Ewing

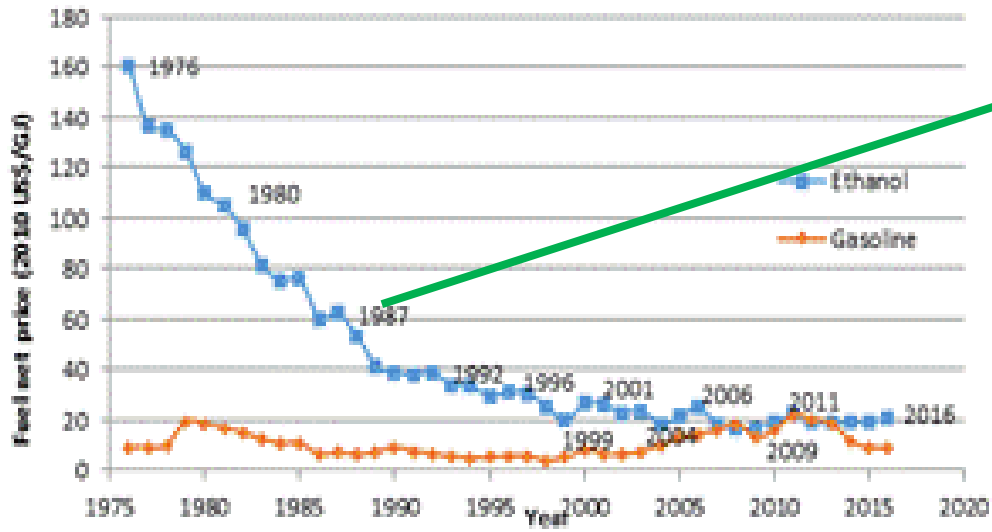
Gas distributors to help expand Brazil biogas supply

Last but not least...

Sustainability issues

Ethanol in Brazil: social/economic sustainability

Hydrous ethanol and gasoline net prices comparison (1976-2016)

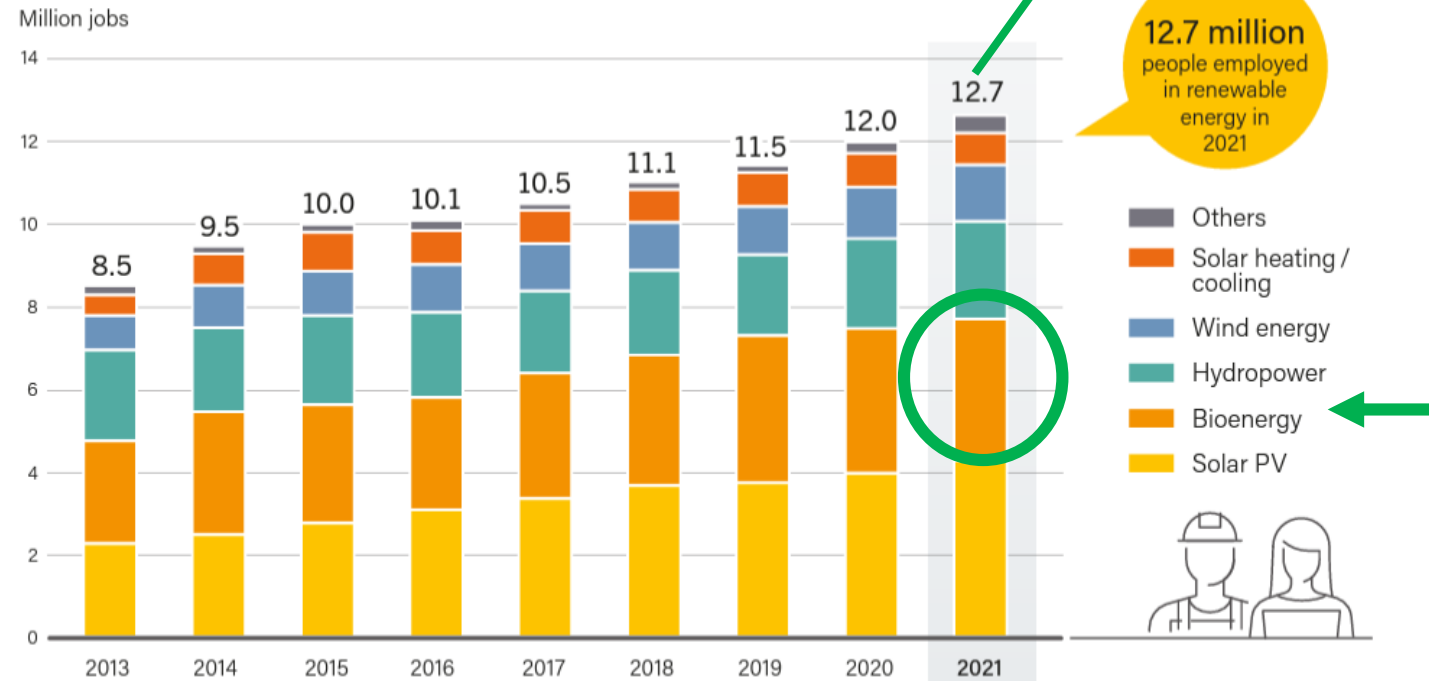


Reduction on ethanol production costs

Brazil 863,000 Jobs in biofuels sector

Source: J Goldemberg, P Guardabassi (IEE/USP), 2017

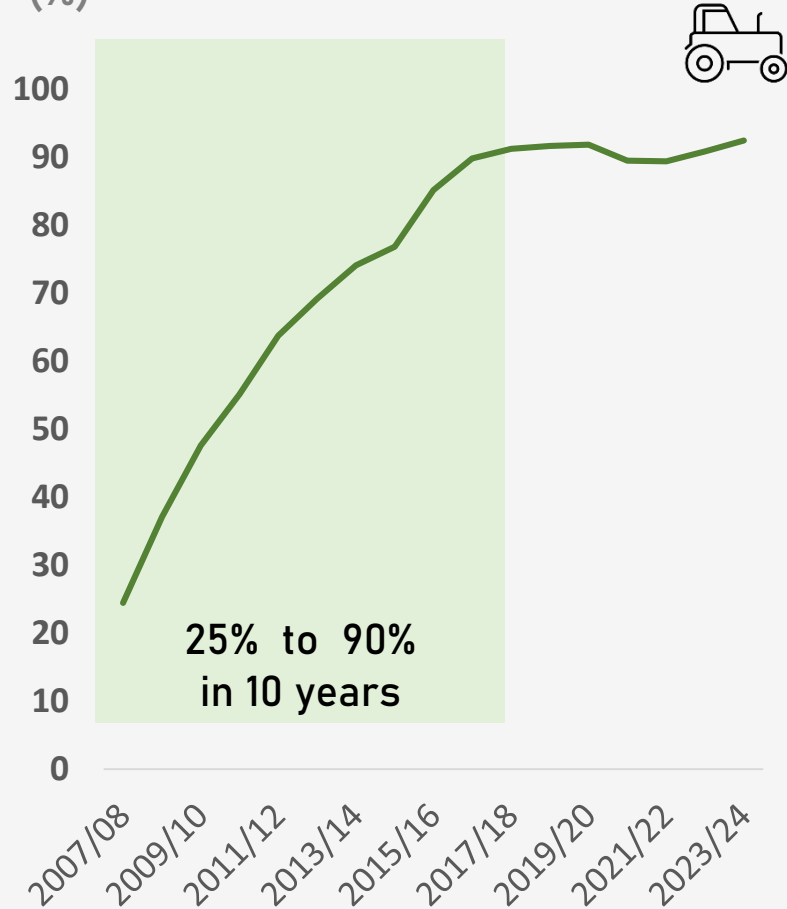
FIGURE 2. Global Renewable Energy Employment, by Technology, 2013-2021



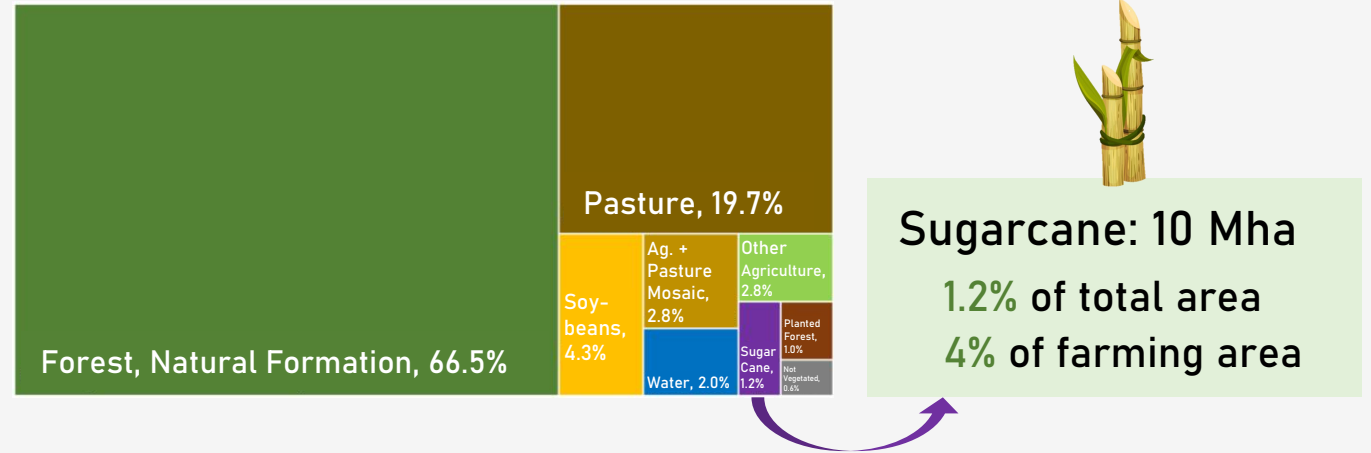
Sources: REN21. 2023. Renewables 2023 Global Status Report Collection, Economic & Social Value Creation; IRENA, 2022

Ethanol in Brazil: environmental sustainability

Sugarcane mechanised harvest (%)



Land use in Brazil (%)



Water use for sugarcane

- No freshwater use in irrigation
- Vinasse fertigation subject to environmental regulations
- Industrial water consumption: from 5 m³/t to <1 m³/t in 20 years

Ethanol in Brazil: environmental sustainability

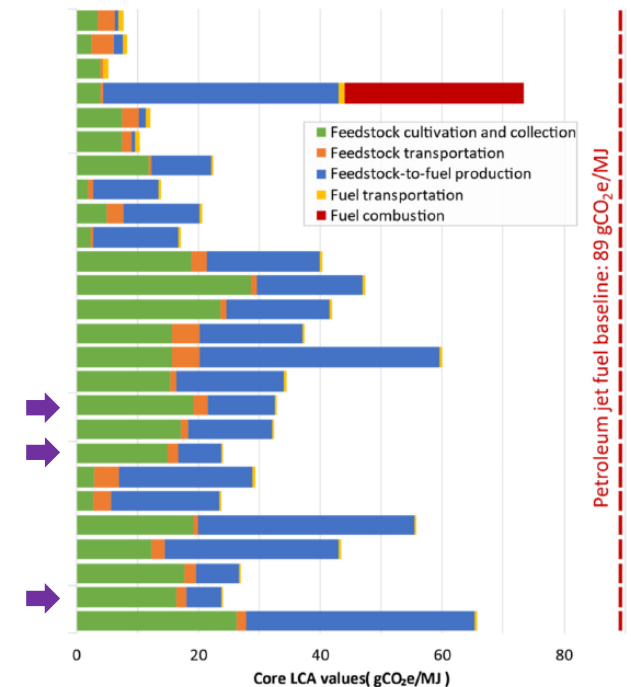
Areas cultivated with sugarcane in Brazil contributed to **remove 9.8 MtCO₂/yr** in the last 20 years

- Expansion mainly over poor quality pastures and other agricultural land uses
- Move to mechanised harvesting with significant residues left in the field
- Reduced expansion over natural vegetation (only 1.6%)

Considering all land use changes within sugarcane-producing **rural properties**, net removal is even larger: **17 MtCO₂/yr**, due to vegetation recovery

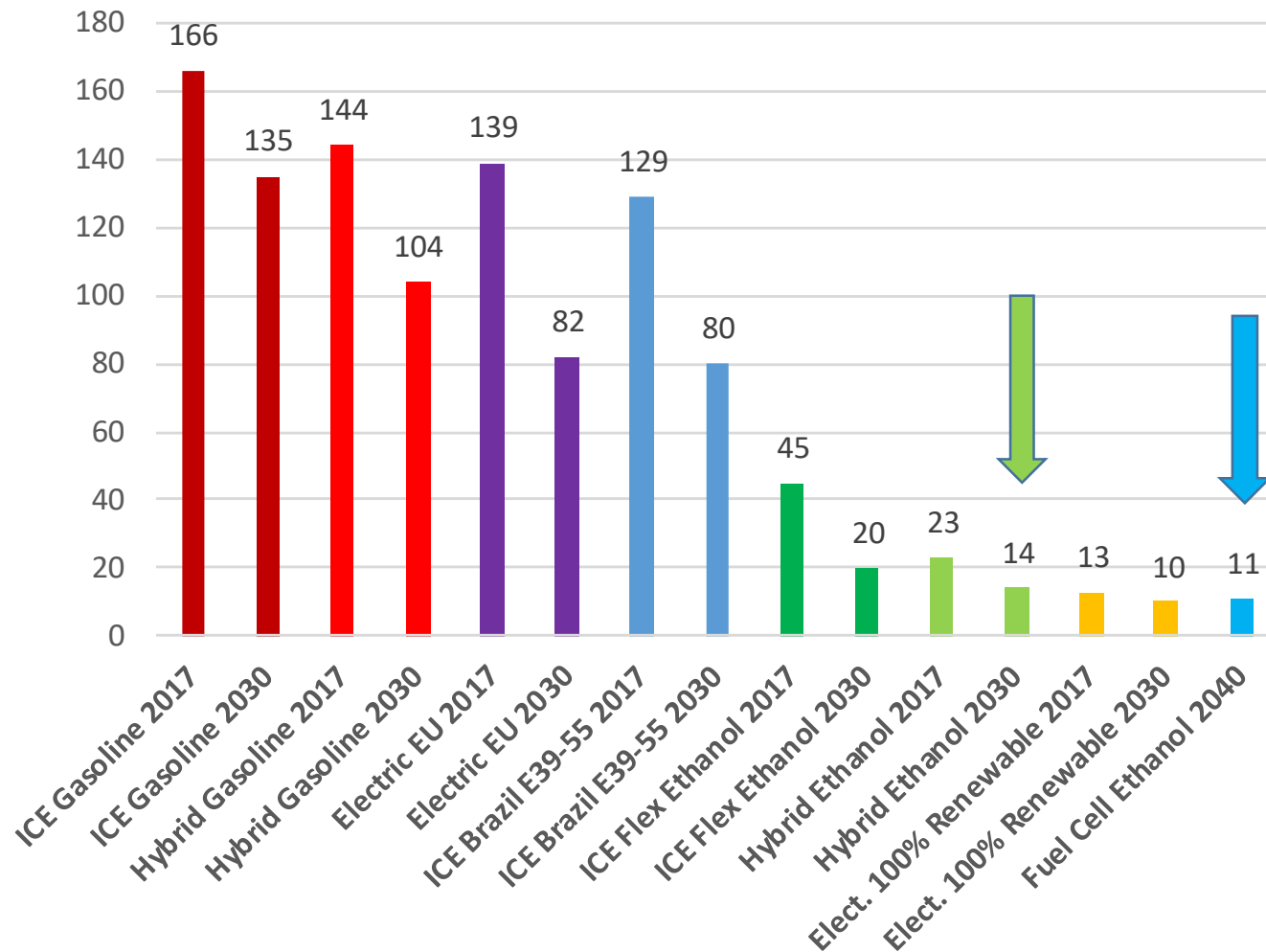
Sustainability **recognition**:

- Sugarcane-based Sustainable Aviation Fuel (SAF) has a low carbon footprint
- August 2023: Brazil's largest ethanol producer was awarded the **ISCC CORSIA Plus Certification** for ethanol use in SAF production



Well-to-wheel (WtW)

GHG Emissions by powertrain-fuel combination, 2017 & 2030 in gCO₂/km



**Ethanol used
in efficient vehicles
(hybrid or fuel cell)**

**is as low-carbon as a BEV
in a 100% renewable system**

**+ avoids large batteries
reducing vehicle production emissions
and avoiding investment
in new charging infrastructure**

Toyota flex hybrid vehicles in Brazil



Flex hybrid cars: the forefront of the Brazilian electrified segment

In 2019, Toyota launched the Corolla sedan, the 1st hybrid flex model in the world, manufactured exclusively in Brazil

2023: Toyota announces investments of BRL 1.63 billion (USD 0.33 billion) in the development of a new compact hybrid flex vehicle

Additional investment of BRL 61.8 million (USD 12.3 million) in updating other models

By 2025, Toyota plans to launch a hybrid version of every model in the fleet



Toyota Corolla – flex hybrid
<https://revistaautoesporte.globo.com/>

**1Q 2023 (1st quarter):
flex hybrid light vehicles had
39.7% market share among
electrified vehicles**

Source: ABVE – BRAZILIAN ELECTRIC VEHICLES ASSOCIATION
From: <https://www.poder360.com.br/conteudo-patrocinado/hibridos-flex-lideram-mercado-focado-na-descarbonizacao/>

Fuel cell system with on-board ethanol reformer to power a vehicle

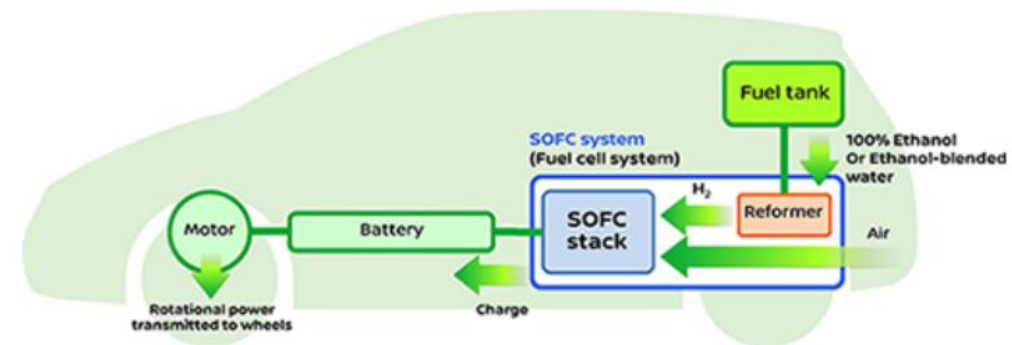
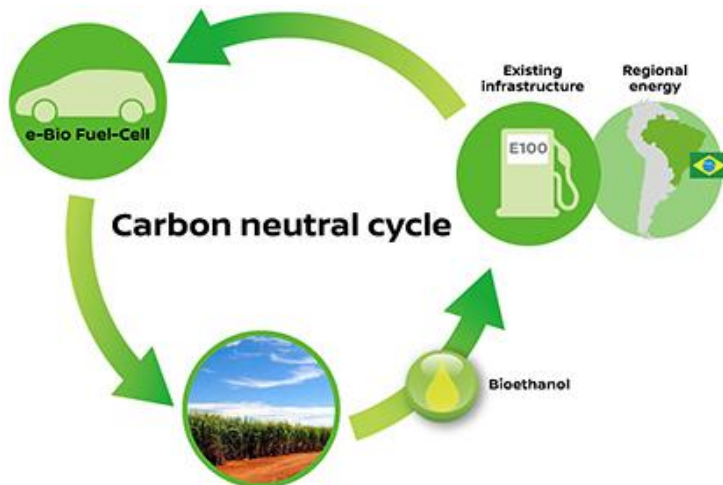


e-Bio Fuel-Cell:

A fuel cell system using bioethanol (anhydrous or hydrous ethanol) as a fuel source to generate electricity through the Solid-Oxide Fuel Cell (SOFC).

The generated electricity charges the battery which provides power to the vehicle.

Since 2019 under test – Nissan/IPEN



Nowadays, no pressure to accelerate towards BEVs

Brazil's official position: key arguments

from the Federal Energy Research Office (EPE)



1. Brazil's cities are **not at critical pollution levels**

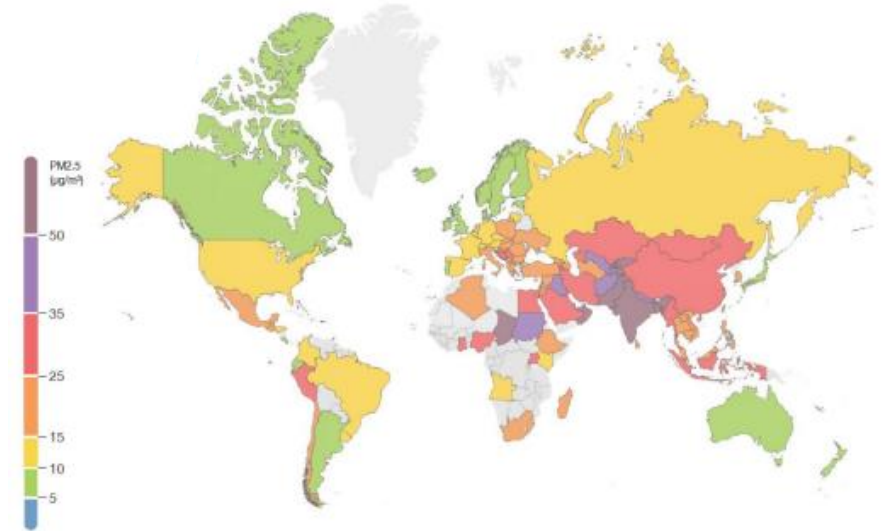


2. Not a key player in the global **technological race**



3. **Biofuels and flex-fuel** vehicles give an important leverage

- It can **wait** for technologies to mature and costs to decrease
- Opportunity to use its existing industrial facilities and **develop its own pathway** to decarbonisation



Most polluted cities
PM, in $\mu\text{g}/\text{m}^3$



Prof. Dra. Suani T. Coelho



Prof. Dr. José Goldemberg



Dr. Javier F. Escobar



Dra. Marilin M. dos Santos



Dra. Vanessa P. Garcilasso



Dr. Beethoven Narváez-Romo



Dra. Andrea Gutierrez-Gomez



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