Enabling the biorefinery concept: how local context might affect strategy and technoeconomic viability

Guilherme Pessoa Nogueira
Ecosystem Assessment group
Biorefineries and Natural Resources division
Brazilian Biorenewables National Laboratory

lnbr brazilian biorenewables national laboratory
CNPEM Brazilian Center for Research in Energy and Materials
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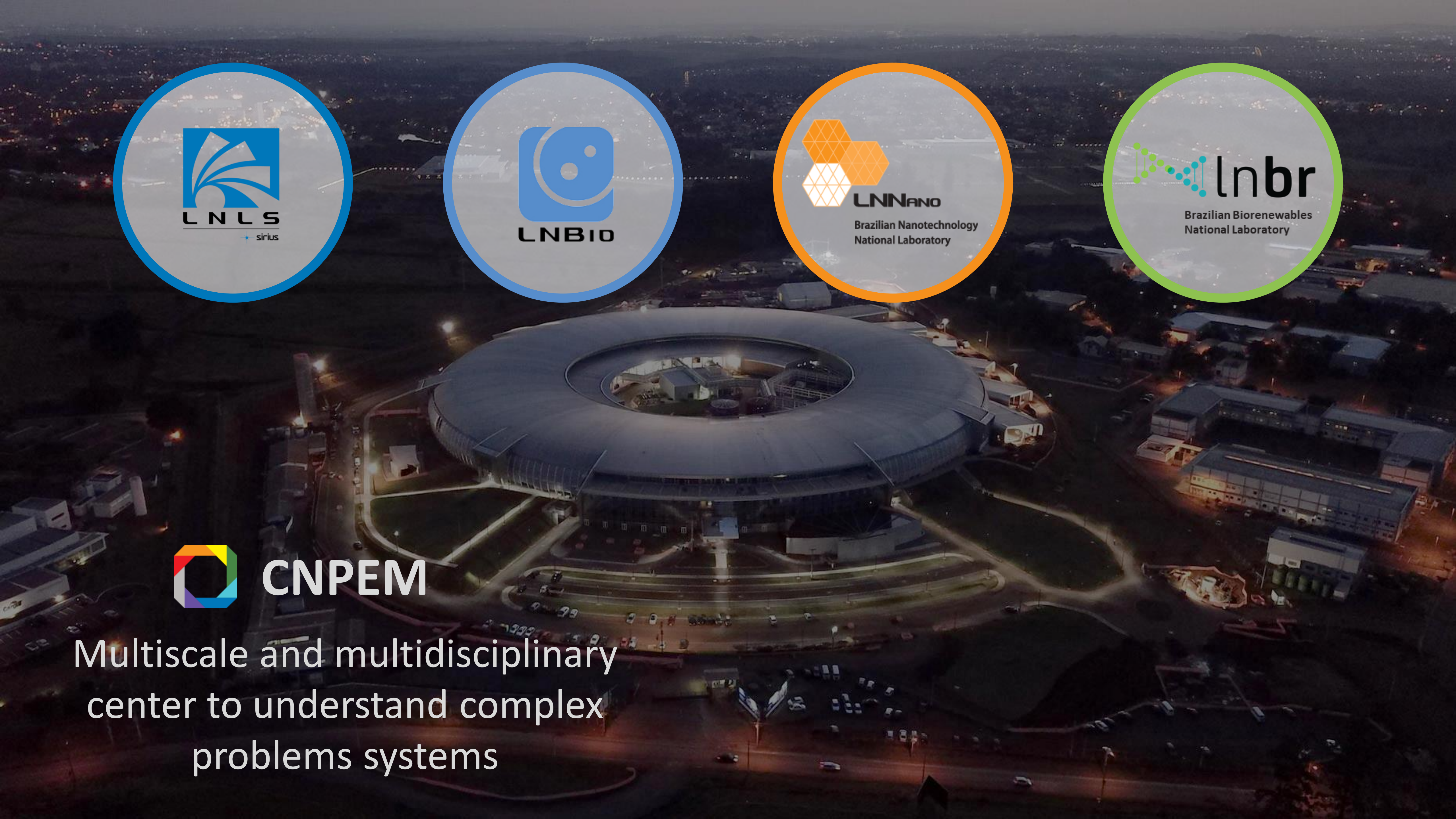
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sirius
LNBio
LNNano
Brazilian Nanotechnology National Laboratory
lnbr
Brazilian Biorenewables National Laboratory
CNPEM
Multiscale and multidisciplinary center to understand complex problems systems

R&D Programs

Renewable Energy

Agri-Environmental

Renewable Materials

Quantum Technologies

Health

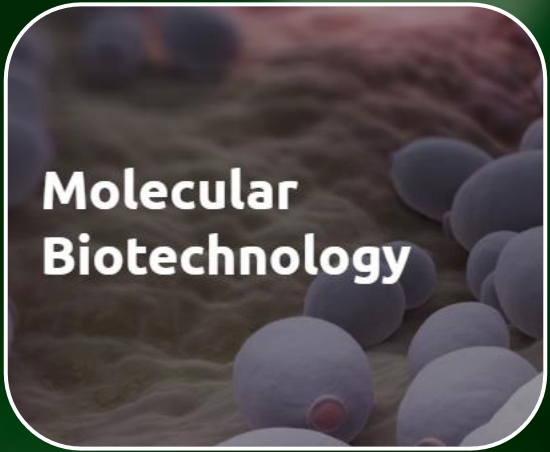
CNPEM

Building a new economy, capable of sustaining population growth and human well-being, is one of the major challenges of this century.

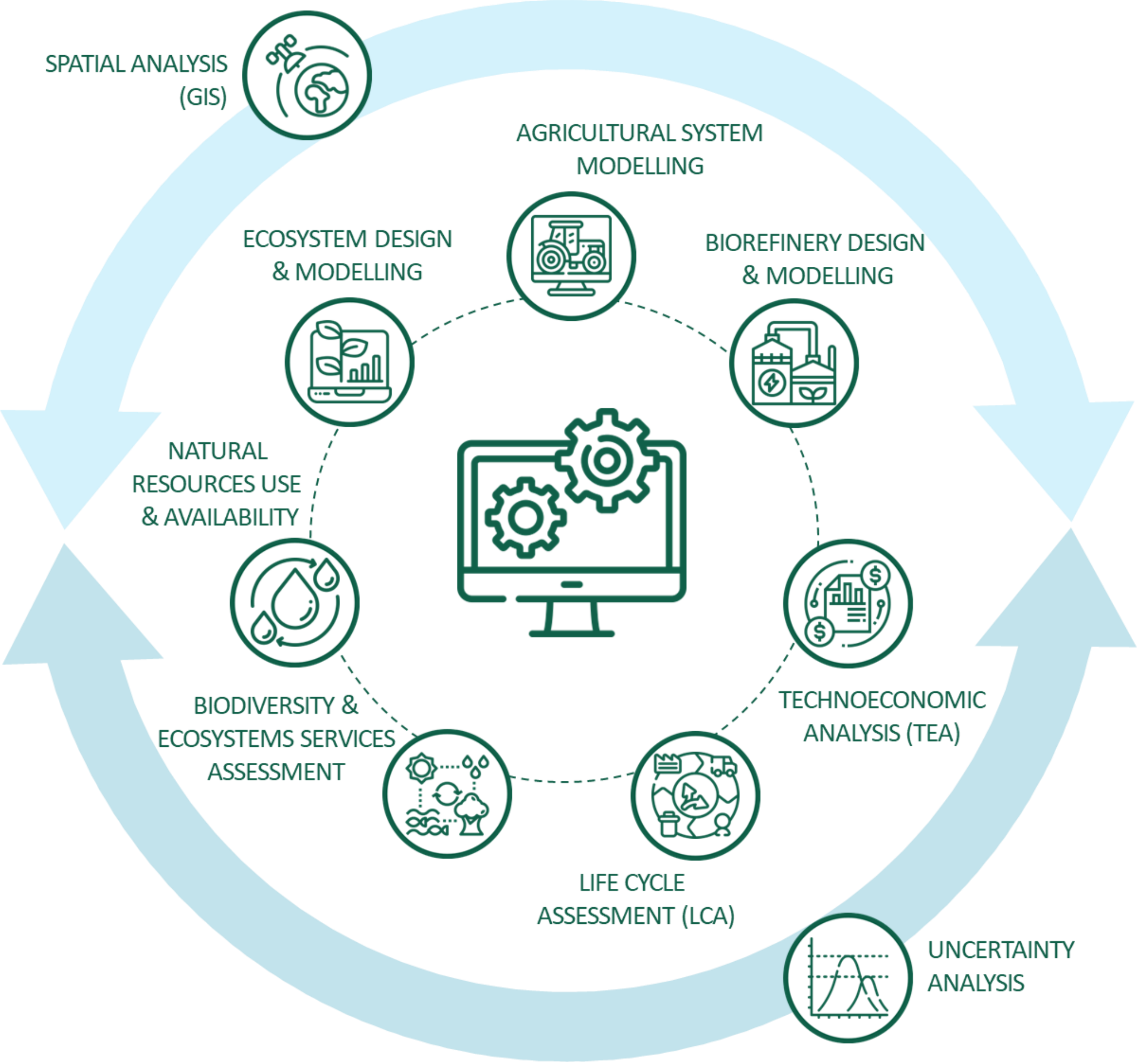
LNBR

Biotechnology to address scientific and technological challenges of sustainable economic development

- **Technologies Assessment Group (AT)**
- **Ecosystems Assessment Group (AE)**



Integrated Framework for Sustainability Assessment



What are we interessed in...

Ethanol 1G / 2G

New Biomasses

Integration with other biomasses

Anaerobic Digestion

Alternative biofuels

Bioplastics and materials

Aviation fuels

Green Chemistry

... but not necessarily limited to

Enabling the Biorefinery Concept

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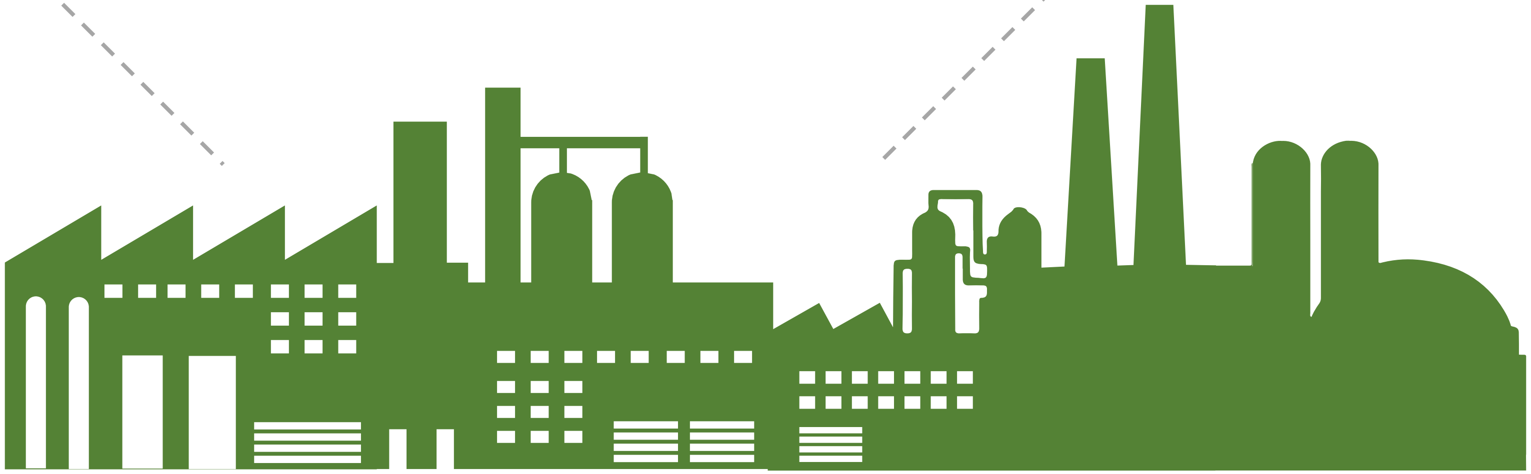
01 Biomass supply

- Sustainably cultivated (for dedicated crops)
- Use of residual biomass/feedstocks

03 Value-chain integration

- Use of renewable inputs and energy sources
- Optimize energy and mass balances to reduce external dependence



02 Feedstock valorization

- Use of the most biomass fractions as possible
- Improvement of conversion efficiencies

04 Product portfolio expansion

- Reduce economic risk
- Increase production flexibility

Enabling the Biorefinery Concept

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01 Biomass supply

- Sustainably cultivated (for dedicated crops)
- Use of residual biomass/feedstocks

Mostly related to site-specific conditions for supply and logistics

03 Value-chain integration

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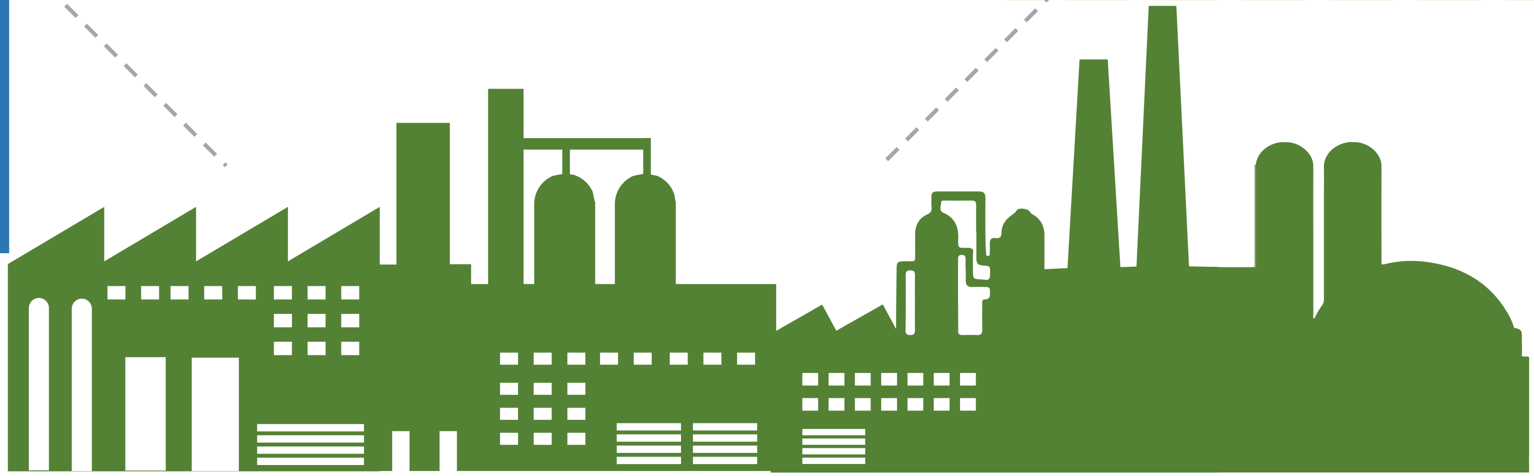
- Optimize energy and mass balances to reduce external dependence



Mostly related to conversion technologies and general market (either local or global)

02 Feedstock valorization

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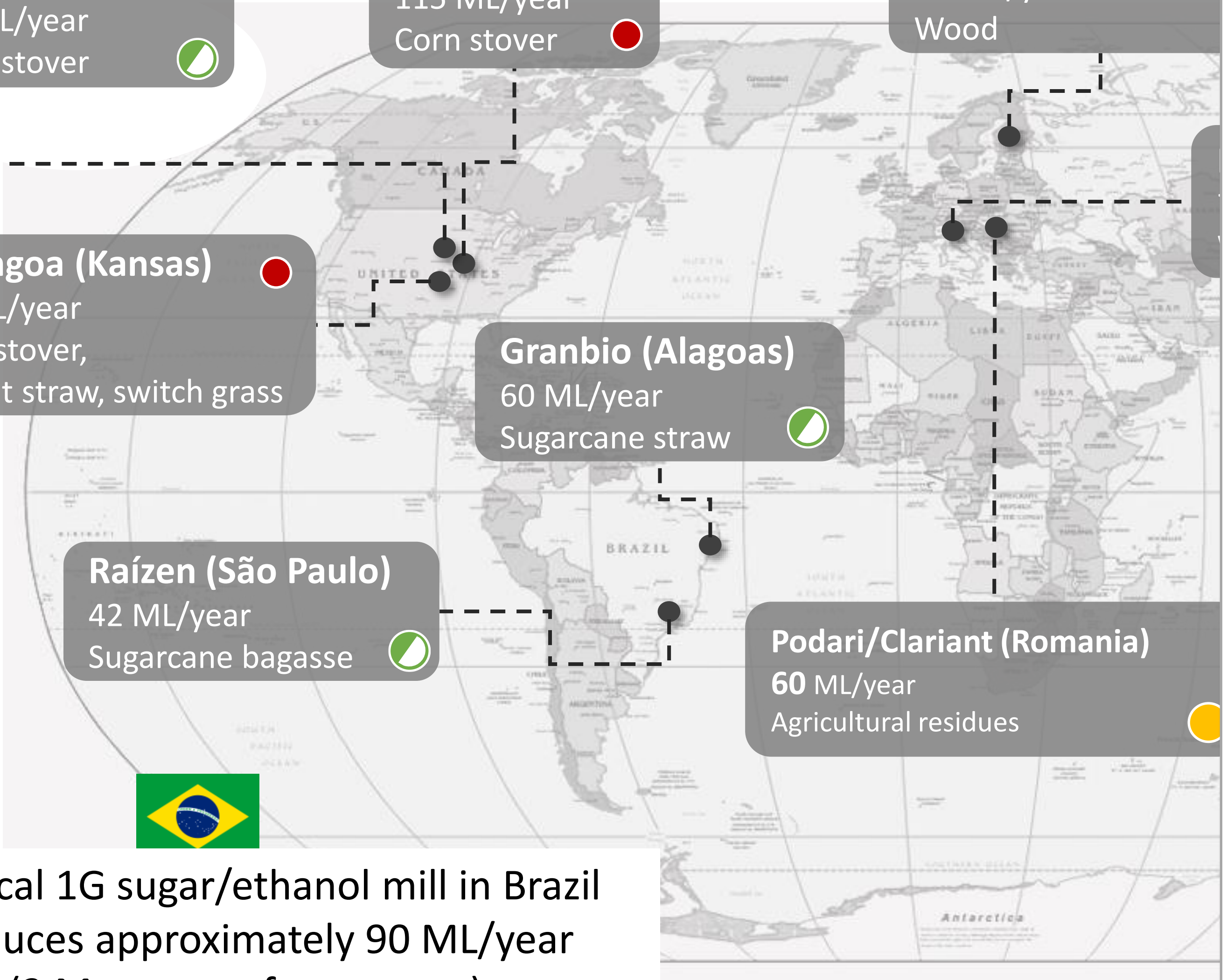
Let's take the Cellulosic Ethanol example

Commercial Plants (2014 - 2020)

Operating below full capacity



Poet-DSM (Iowa)
95 ML/year
Corn stover

DuPont (Iowa)
115 ML/year
Corn stover

Kajaani/St1 (Finlan
10 ML/year
Wood

Abengoa (Kansas)
95 ML/year
Corn stover,
Wheat straw, switch grass

Granbio (Alagoas)
60 ML/year
Sugarcane straw

Raízen (São Paulo)
42 ML/year
Sugarcane bagasse

Podari/Clariant (Romania)
60 ML/year
Agricultural residues

A typical 1G sugar/ethanol mill in Brazil produces approximately 90 ML/year (2 M tonnes of sugarcane)

Despite some technological hiccups, cellulosic ethanol is finally taking off in Brazil:

- Raízen plans to deploy 20 new facilities until 2030
- Brazilian 2G, however, is a little different than other countries

ISSUES & EVENTS

Whatever happened to cellulosic ethanol?

Technological immaturity, falling oil prices, overoptimistic investors, and regulatory uncertainty are blamed for the failure of a promising biofuel technology to perform as hoped.

Despite a decade and a half of big US federal investments in R&D and in pilot and demonstration plants, ethanol from noncrop biomass has yet to become a commercial reality in the US. Nor has that happened anywhere else in the world but Brazil.

Whether the technology can recover from the missteps of the past 15 years is an open question, but it has become ever more certain that sustainable biofuels are key to achieving global carbon neutrality by midcentury, according to the scientific consensus reflected in reports by the Intergovernmental Panel on Climate

85%. Ethanol advocates say the blend for conventional light-duty vehicles could be increased to 15% without harming drivetrains.

Roughly 40% of the annual US corn crop now goes to ethanol. Converting pasture or other lands to grow corn or other crops would result in the sudden release of large amounts of CO_2 from soils. That so-called carbon debt could take decades to pay back through photosynthesis by crops. The debt payoff time is debated in the scientific literature, but most analyses have identified that corn ethanol's life-cycle carbon intensity, in-

Kramer (2022), Physics Today

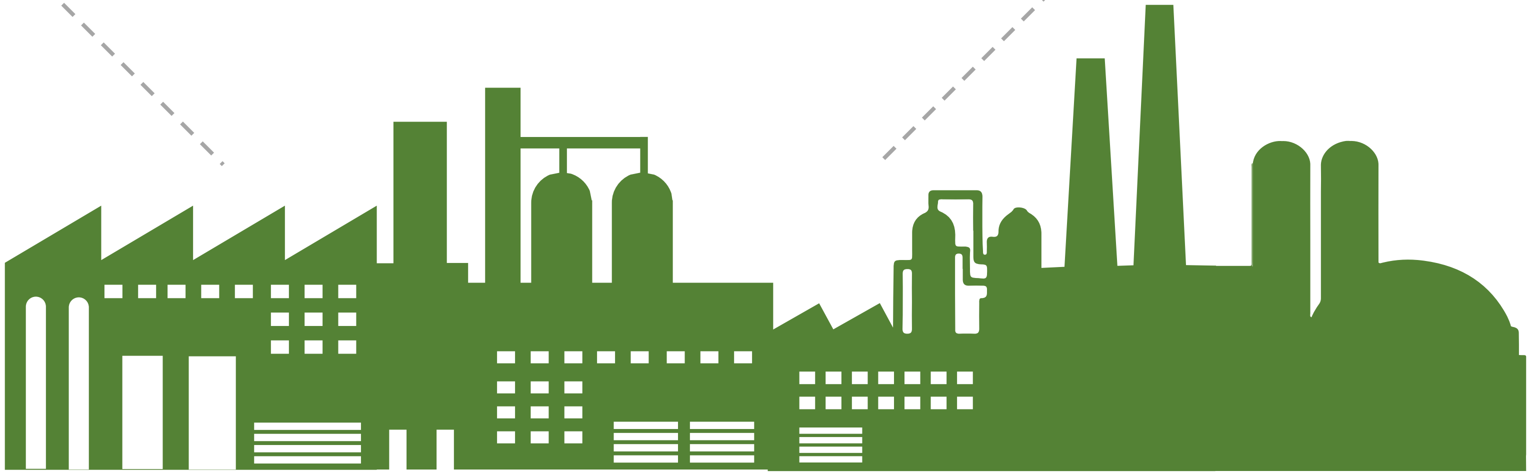
Brazil as a case study

01 Biomass supply

- Sugarcane as an example of suitable biomass
- Harvest residues exploration

03 Value-chain integration

- Reliance on fossil inputs
- Biorefinery location and local resources



02 Feedstock valorization

- Technological learning curve
- Biomass different fractions

04 Product portfolio expansion

- Coproduction of ethanol and electricity
- Carbon market as an additional revenue

Where everything started…

1975 - 1979

Phase I: creation and establishment of ProAlcool

1979 -1985

Phase II: consolidation of ProAlcool

1985 -1989

Phase III: expansion and constraints

1989 – 2000's

Phase IV: political uncertainty

2000's

Resumption of ethanol: "Second Era" of Proálcool

"ProEthanol" program

Source: Rosillo-Calle & Cortez (1998)
Stolf & Oliveira (2020)

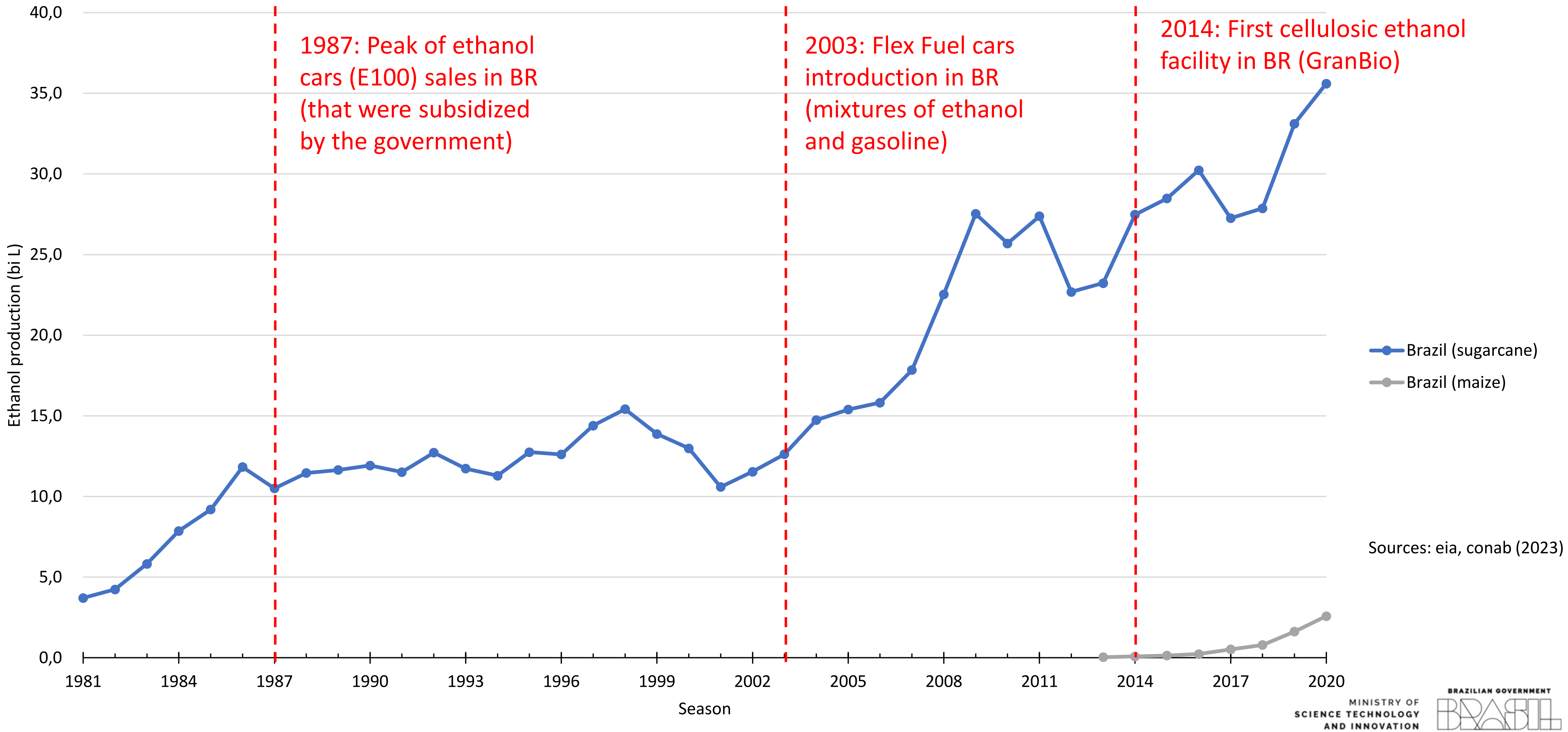
The ProAlcool program ("Pro-ethanol") was created as:

- an energy security strategy
- in response to the 1973 oil crisis

It hadn't an environmental bias, even though biofuels are attributed a lower carbon footprint

Fluctuation in oil and sugar prices, along with political uncertainty, led to its stagnation

From E100 to flex fuel cars



"ProEthanol" was also very timely…

ProAlcool program

- 1975 - 1979: Phase I: creation and establishment of ProAlcool
- 1979 -1985: Phase II: consolidation of ProAlcool
- 1985 -1989: Phase III: expansion and constraints
- 1989 – 2000's: Phase IV: political uncertainty
- **2000's: Resumption of ethanol: "Second Era" of Proálcool**

Environmental agenda

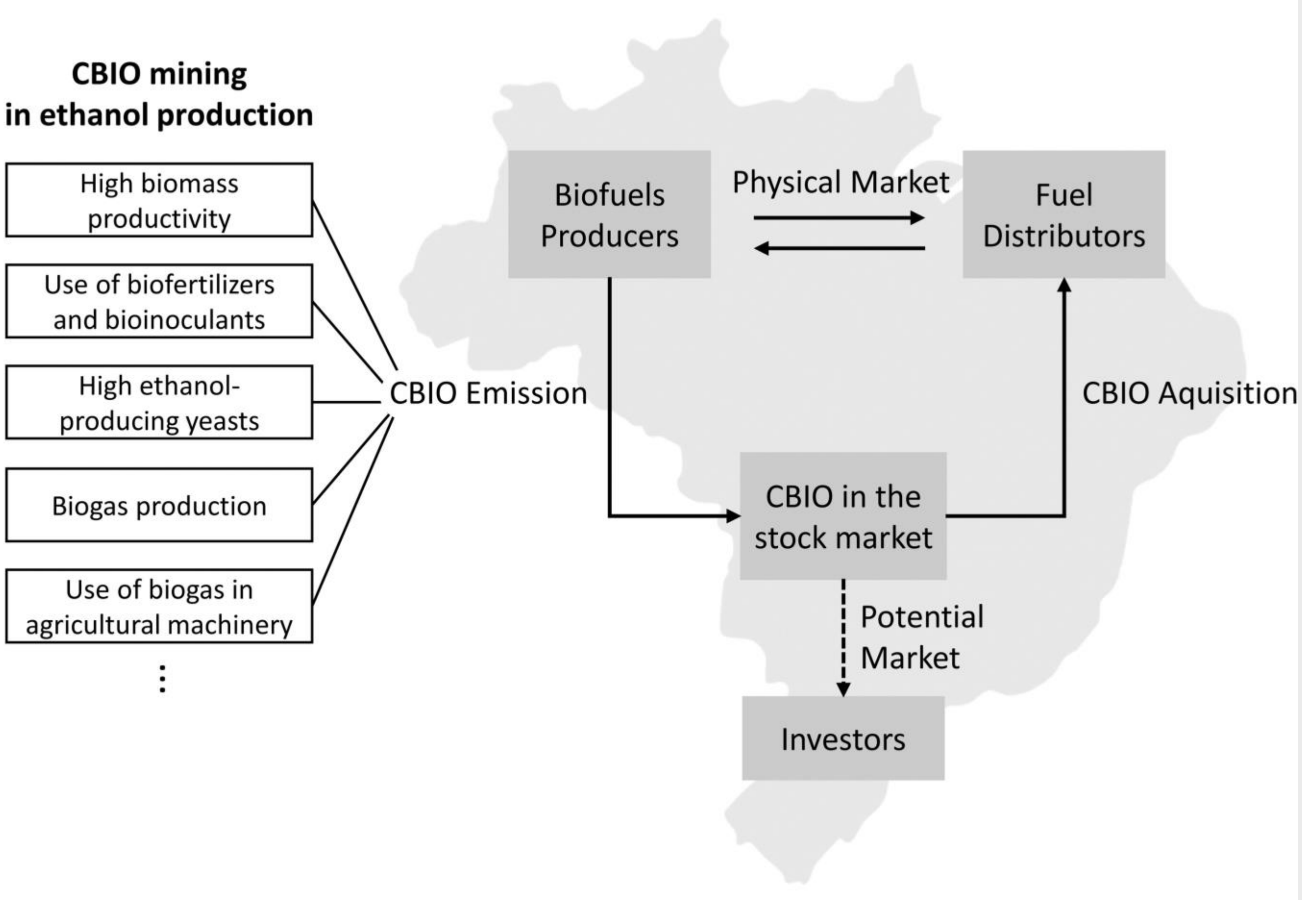
- 1972: Stockholm UN Conference
- 1979: Creation of the World Climate Program (WCP)
- 1985: IPCC precursor Advisory Group on Greenhouse Gases (AGGG)
- 1992: Rio 92 (UN Conference on Environment and Development – UNCED)
- 1997: Kyoto protocol

Introducing the environmental aspect

Brazilian Biofuels Policy (RenovaBio)

- Deployment: Dec. 2019;

- Carbon footprint calculated on a Life Cycle mindset;
- Biofuels GHG mitigation potential in substitution to fossil;
- Mitigation = carbon certificates (CBIO);
- CBIOs are trade over the stock market;
- Stimulates efficiency for biofuels producers.

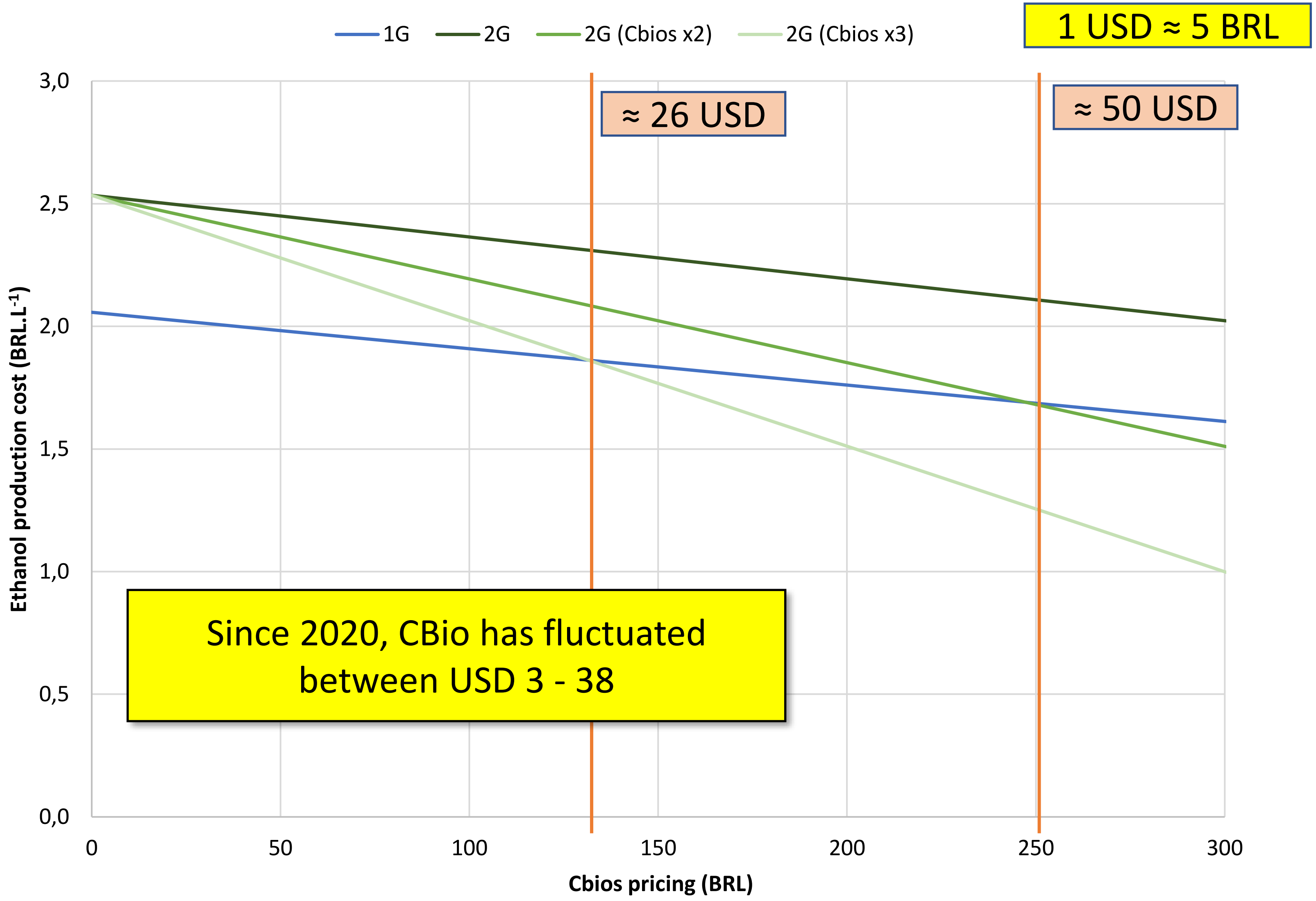


But what is the difference between 1G and 2G?

	First Generation (1G)	Cellulosic ethanol (2G)
Type of biomass	Dedicated crops	Dedicated crops (fibers) Residual biomass/crops
Technological maturity	Well established (decades of know-how)	In development (industrial learning curve)
Sugar source	Readilly available	Lignocellulosic matrix
Typical coproducts	Sugar Electricity	Electricity
Alternative fermentation coproducts	Yes	Yes
Lignocellulosic fractionation coproducts	-	Yes
Processing costs	Competitive with gasoline	More costly than 1G
Carbon footprint* ($gCO_2.MJ^{-1}$)	14-24	9-11

*Gasoline carbon footprint: 87.4 $gCO_2.MJ^{-1}$

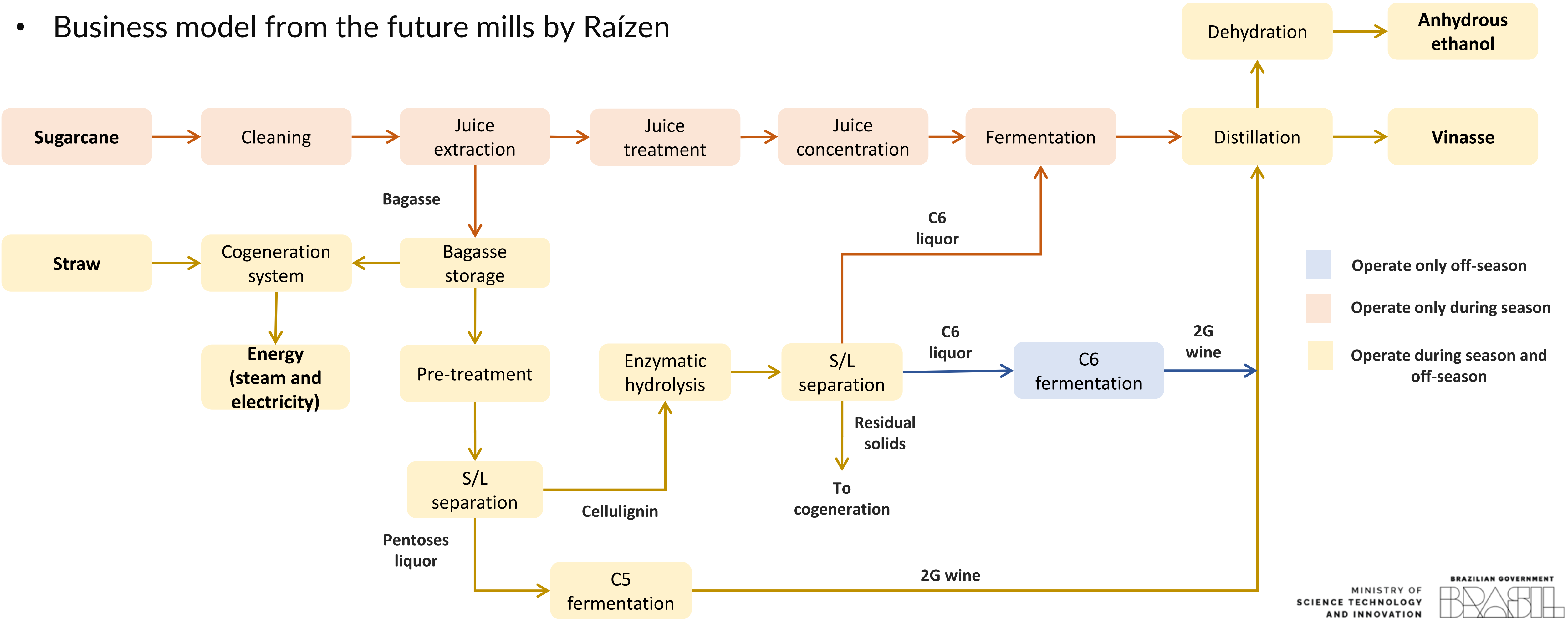
Current CBio mining is not enough to make 2G competitive



- 2G has a potential mitigation advantage over 1G;
- 2G only becomes competitive with CBio prices of over 2500 USD (!!)
- 2G would need bonuses to translate the additional mitigation into economic competitiveness

Integrating the best of both worlds

- Allows for increased ethanol productivity from the same agricultural land use
- Integrated fermentation and purification
- Dilutes financial risk of 2G
- Business model from the future mills by Raízen



Technological advances can bring costs down

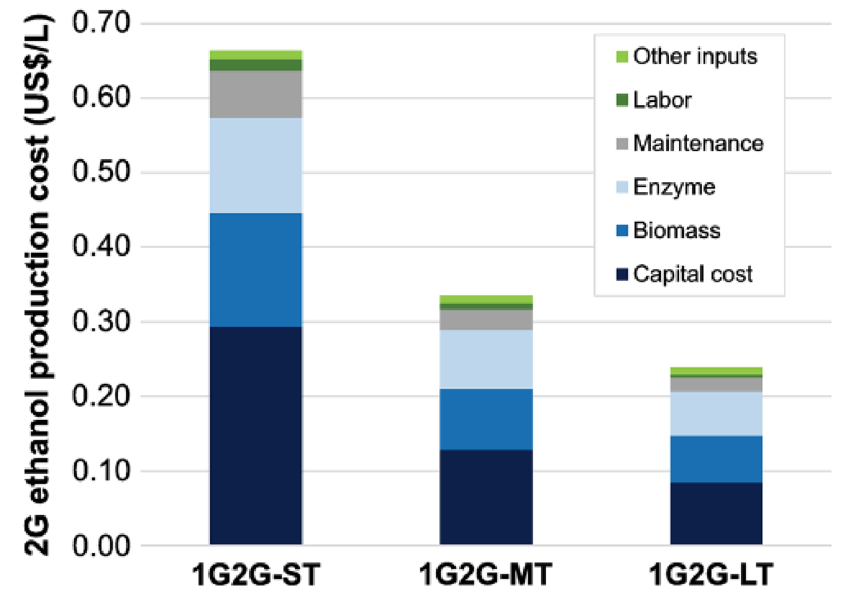


Fig. 3 Breakdown of 2G ethanol production costs

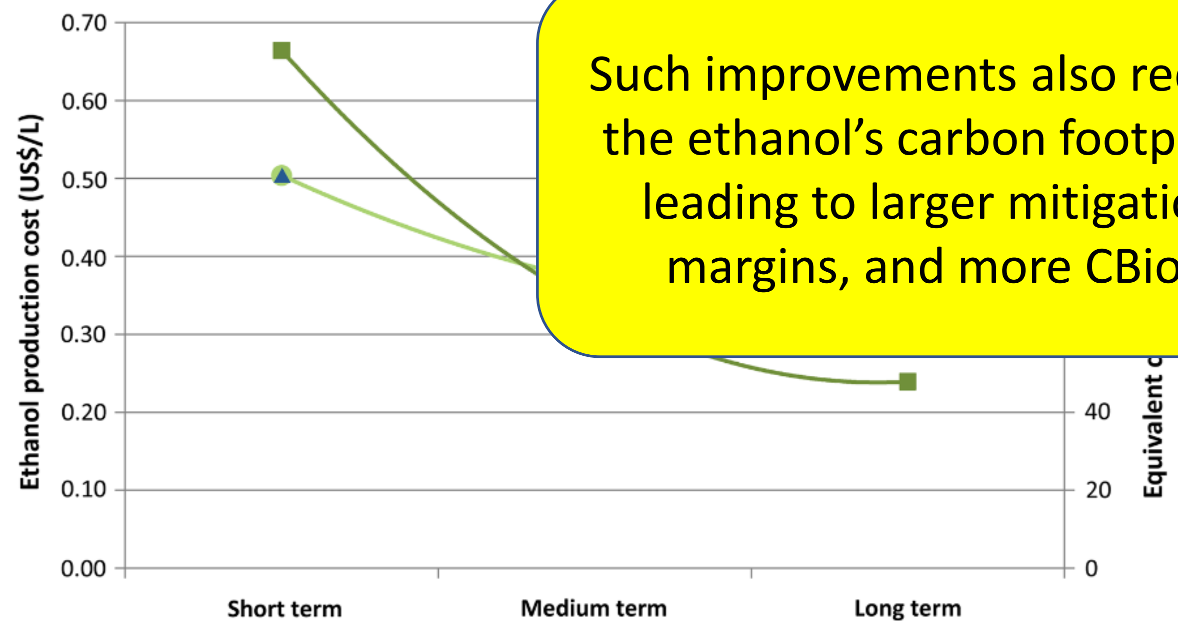


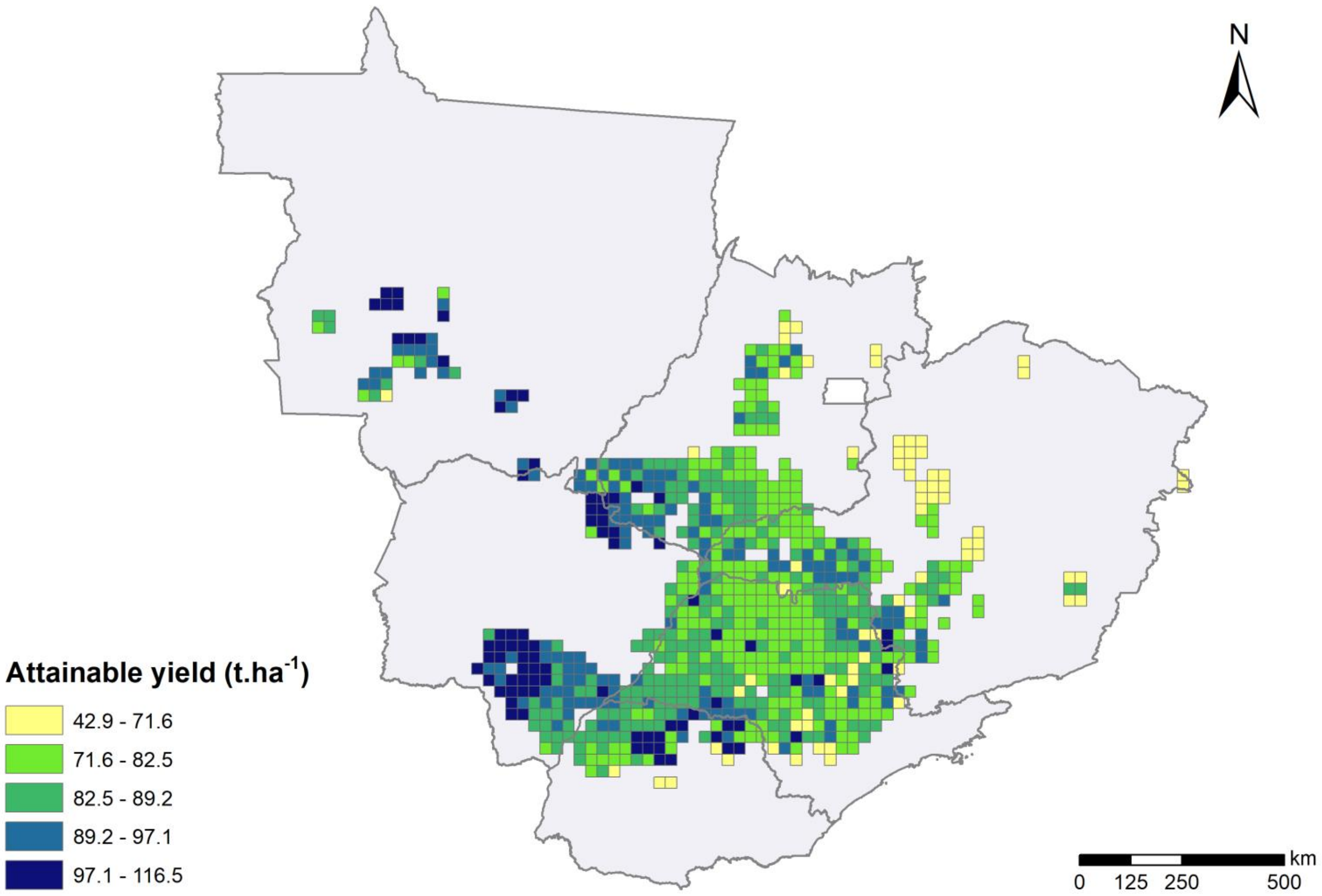
Fig. 2 Projection of 1G and 2G ethanol production costs

Such improvements also reduce the ethanol’s carbon footprint, leading to larger mitigation margins, and more CBios

Junqueira et al. (2017)

- Technological maturity leads to reduced capital cost investments and also operational costs
- The learning curve is essential to drive 2G economic competitivity in comparison to 1G
- Improvements in conversion efficiencies and process integration (AD and straw recovery)

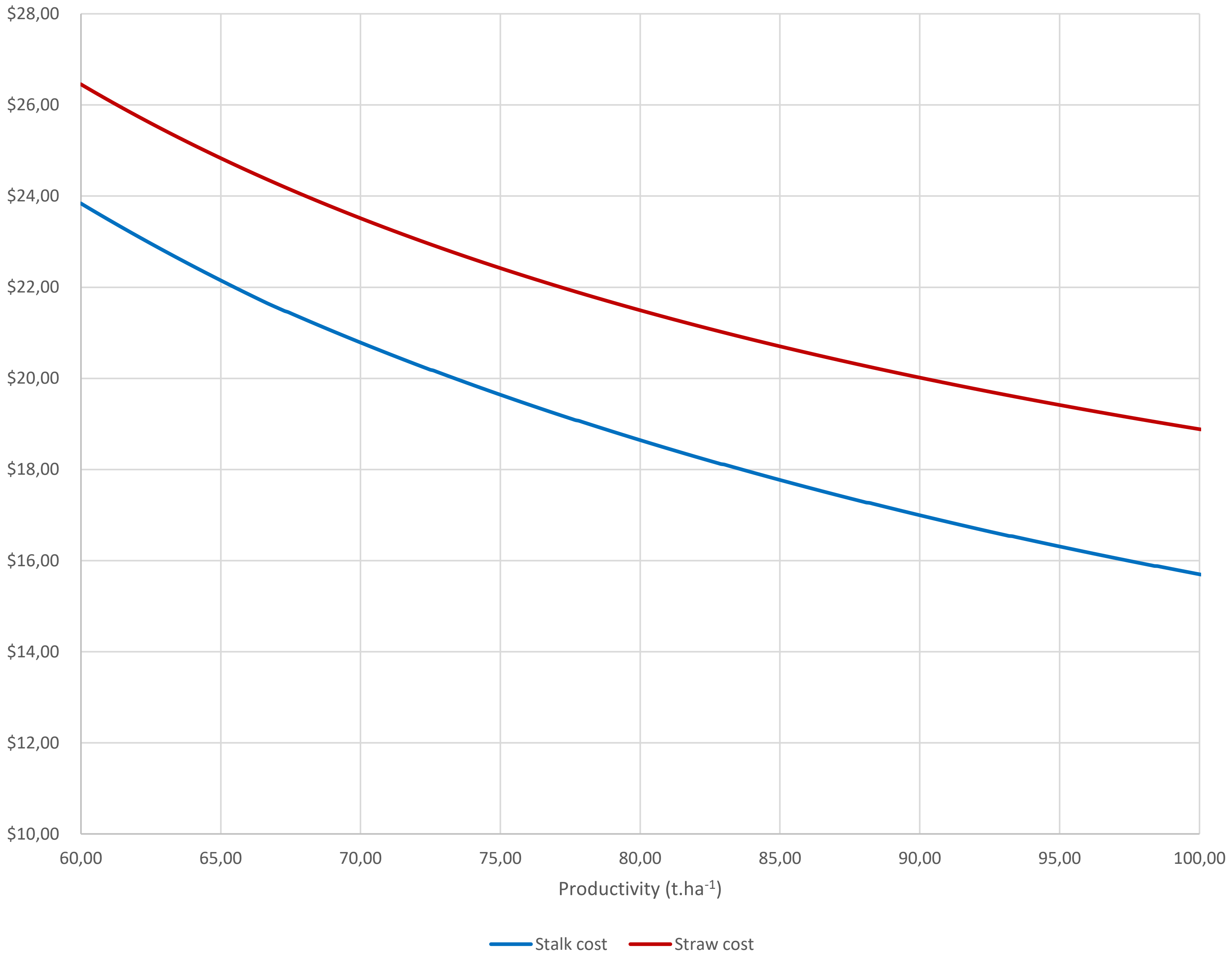
Sugarcane yield is site-specific...



Typical yield for BR: 80 $t.ha^{-1}$

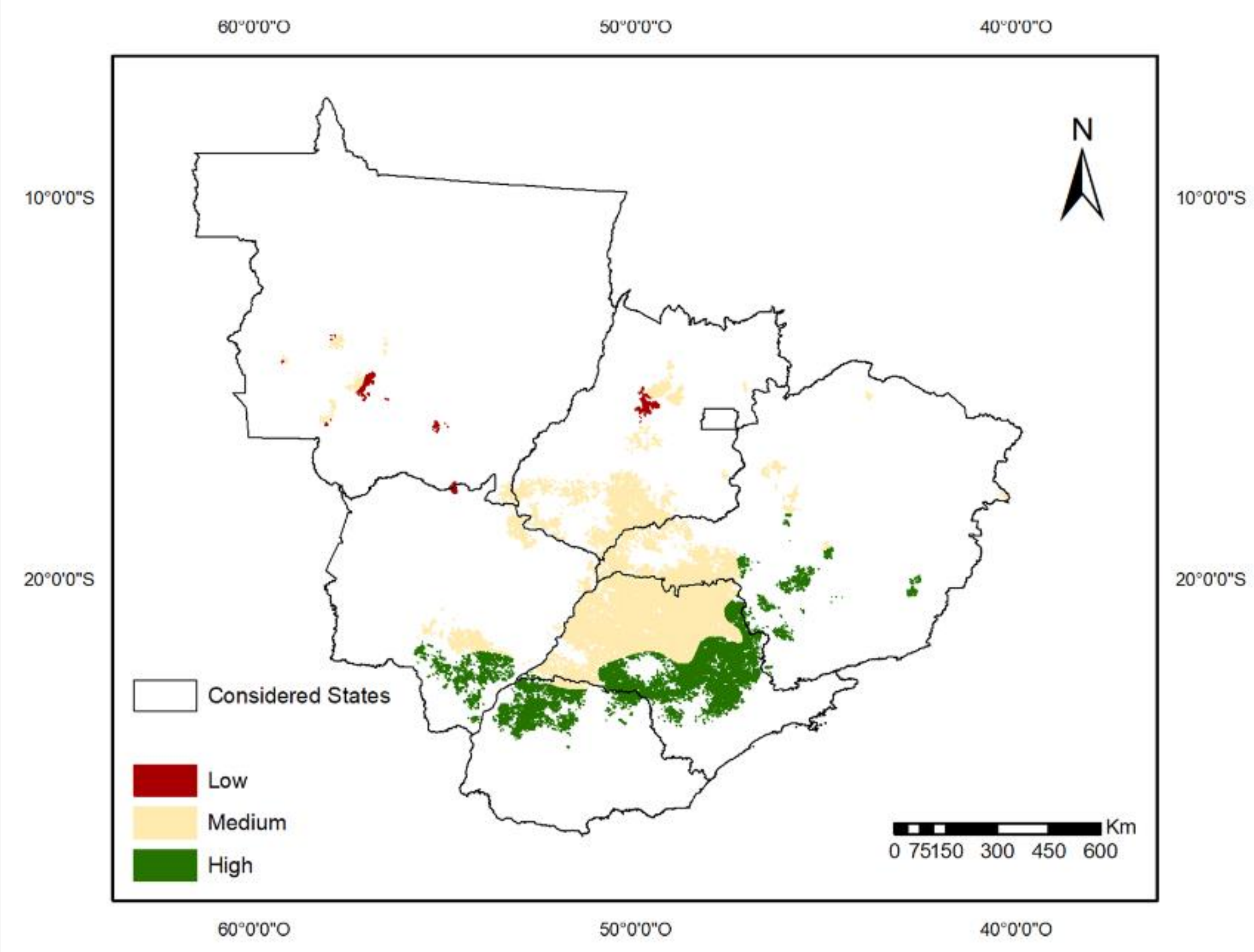
- Local edaphoclimatic conditions influence crop yield and agricultural practices
  - Rainfall
  - Temperatures
  - Sunlight incidence
  - Wind direction and strength
- Direct impact on costs and biomass carbon footprint

Effect of sugarcane yield over biomass pricing



- Stalk cost may vary up to 28% depending on yield
- Biomass costs accounts for around **18%** of production costs
- Harvest residues collection is also affected by location and yield

Straw recovery suitability maps



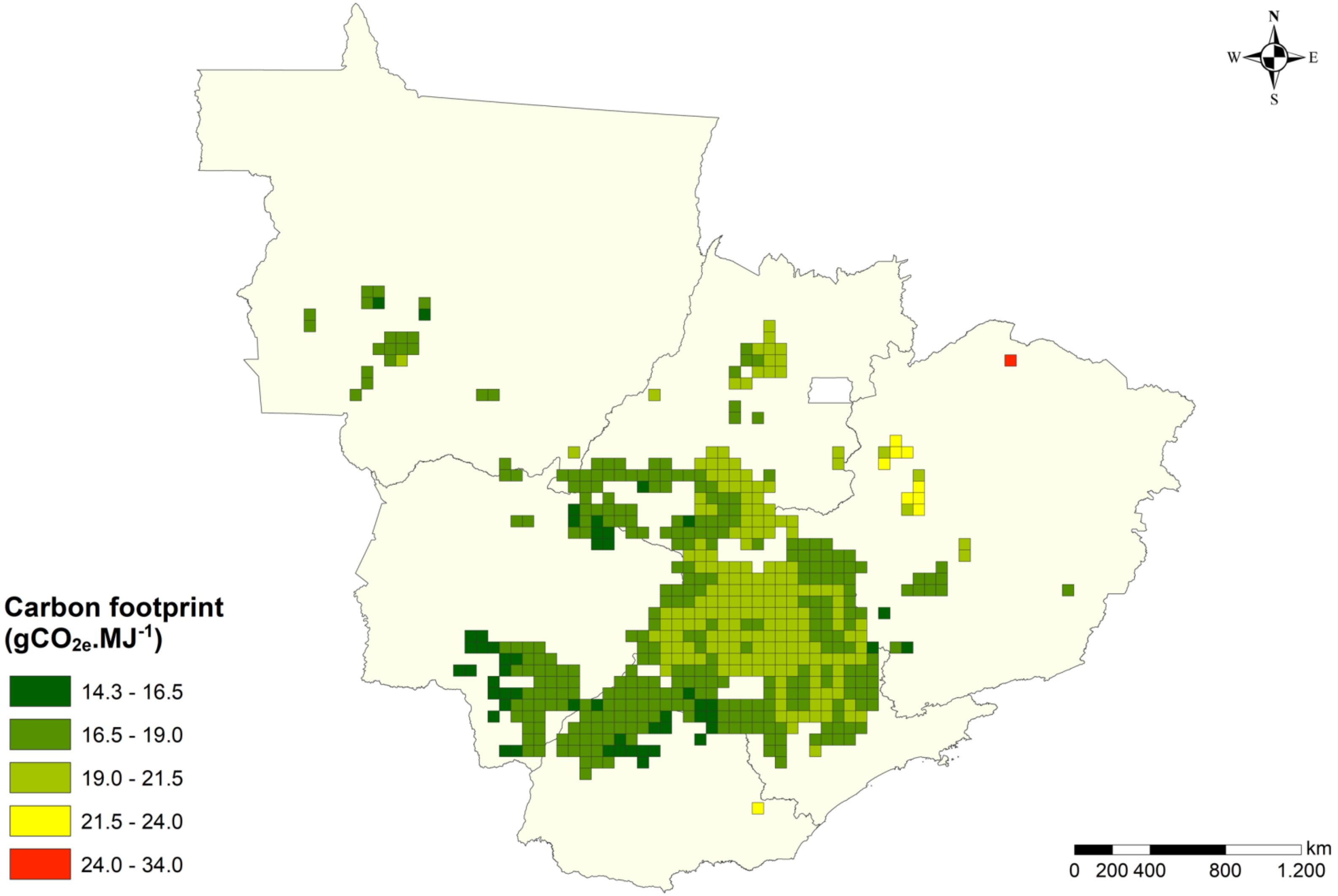
Souza et al. (2021)

- A minimum amount of straw should be maintained overground
  - Soil protection,
  - Water recycling
  - Other ecosystem services
- Suitability classes:
  - Low: at least 7 $t.ha^{-1}$
  - Medium: min. 4 $t.ha^{-1}$
  - High: min. 2 $t.ha^{-1}$
- Straw could be used to boost electricity generation and cellulosic ethanol production

So, carbon footprint varies spatially…

- Aside from sugarcane yield, other aspects are also site-specific
  - Land-use change
  - Risk to biodiversity
  - Water scarcity
- That might have a direct impact or carbon footprint or other impact categories

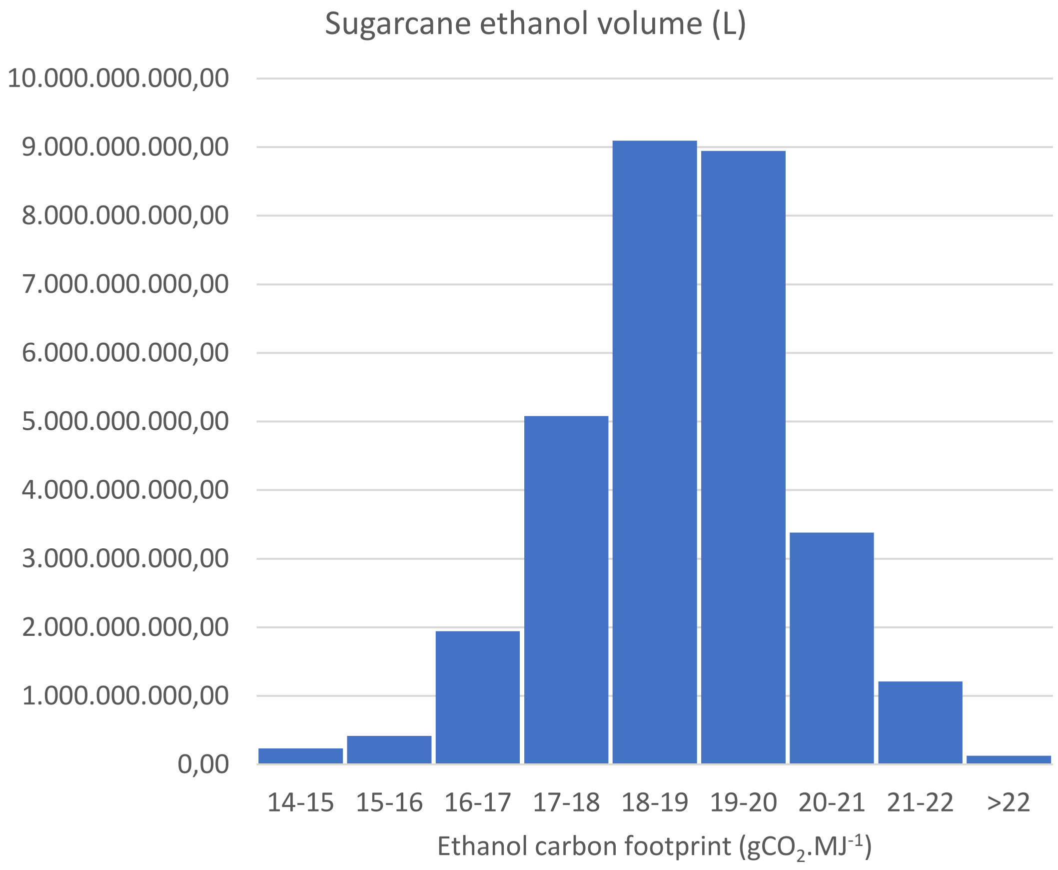
Ethanol’s carbon footprint in current sugarcane areas

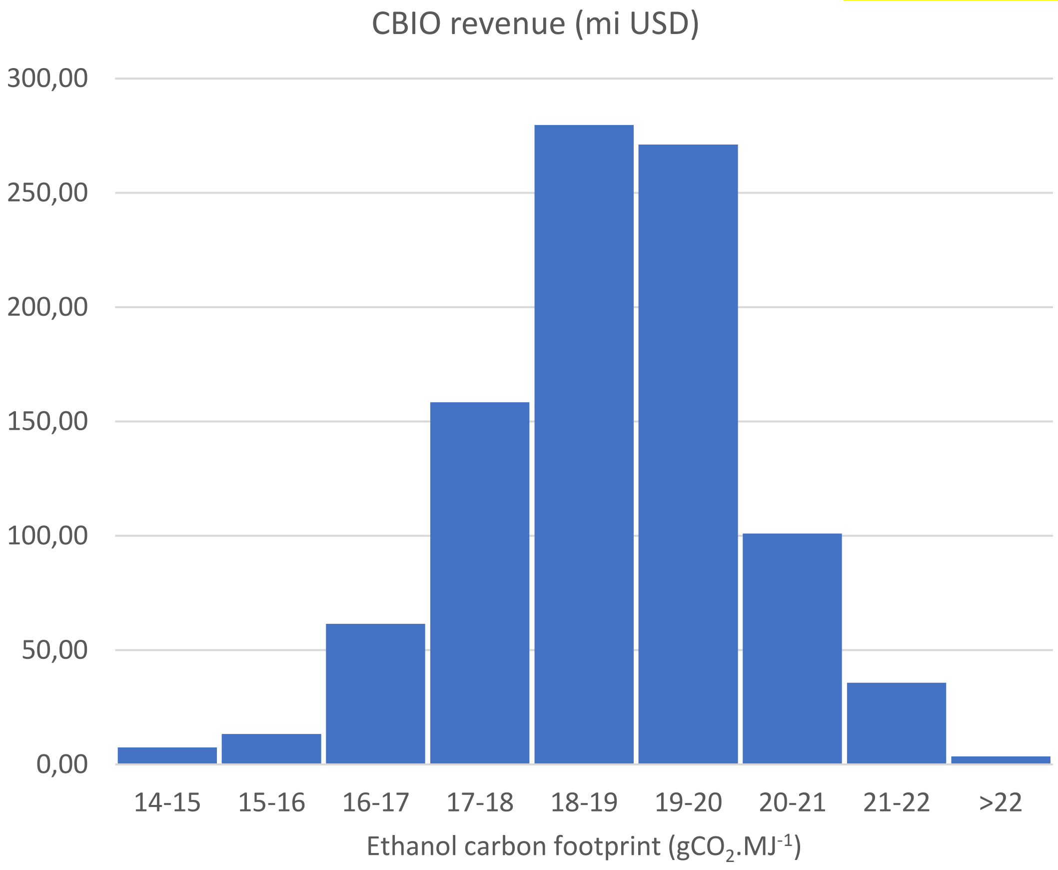


Petrielli et al. (2023)

Previous sugarcane expansion didn't take carbon footprint into account

CBIO = 20 USD





Sugarcane expansion to supply future ethanol demand could (and should) prioritize environmentally suitable areas

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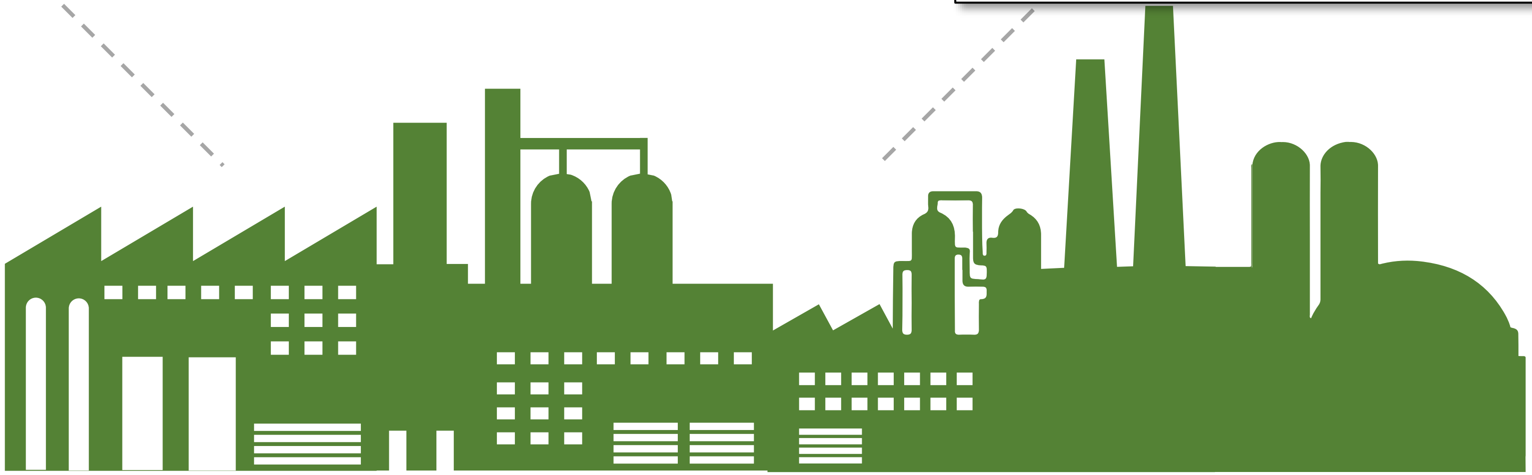
Take-home messages

01 Biomass supply

- Biomass supply and local suitability are key drivers
- Residual/low-cost biomasses are not ready-to-use solutions

03 Value-chain integration

- Location influences costs for biomass procurement and processing,
- The same applies to carbon footprint



02 Feedstock valorization

- 1G and 2G can coexist and benefit from their complementarity
- Technological learning curve is important to bring economic competitivity and lower carbon footprints

04 Product portfolio expansion

- Diversification can dilute risk and increase revenue
- We must go beyond ethanol and electricity
- The carbon market need to mature as well

Thank you

Guilherme Pessoa Nogueira
guilherme.nogueira@lnbr.cnpem.br
+55 (19) 3218-3137

cnpem.br

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