USP

Research Centre for Greenhouse Gas Innovation

RCGI

- Foco na redução das emissões de gases de efeito estufa
- Suporte ao Brasil para o atingimento das Contribuições Nacionalmente Determinadas (NDCs) por meio de Pesquisa e Inovação
- Abordagem transdisciplinar: pesquisadores e especialistas de diversas áreas do conhecimento unem seus esforços para encontrar soluções
- Investimento de longo prazo em pesquisa
- Apoio ao Brasil na sua consolidação como potência global da energia renovável

USP

Research Centre for Greenhouse Gas Innovation

Etanol como Vetor para o Transporte de Hidrogênio

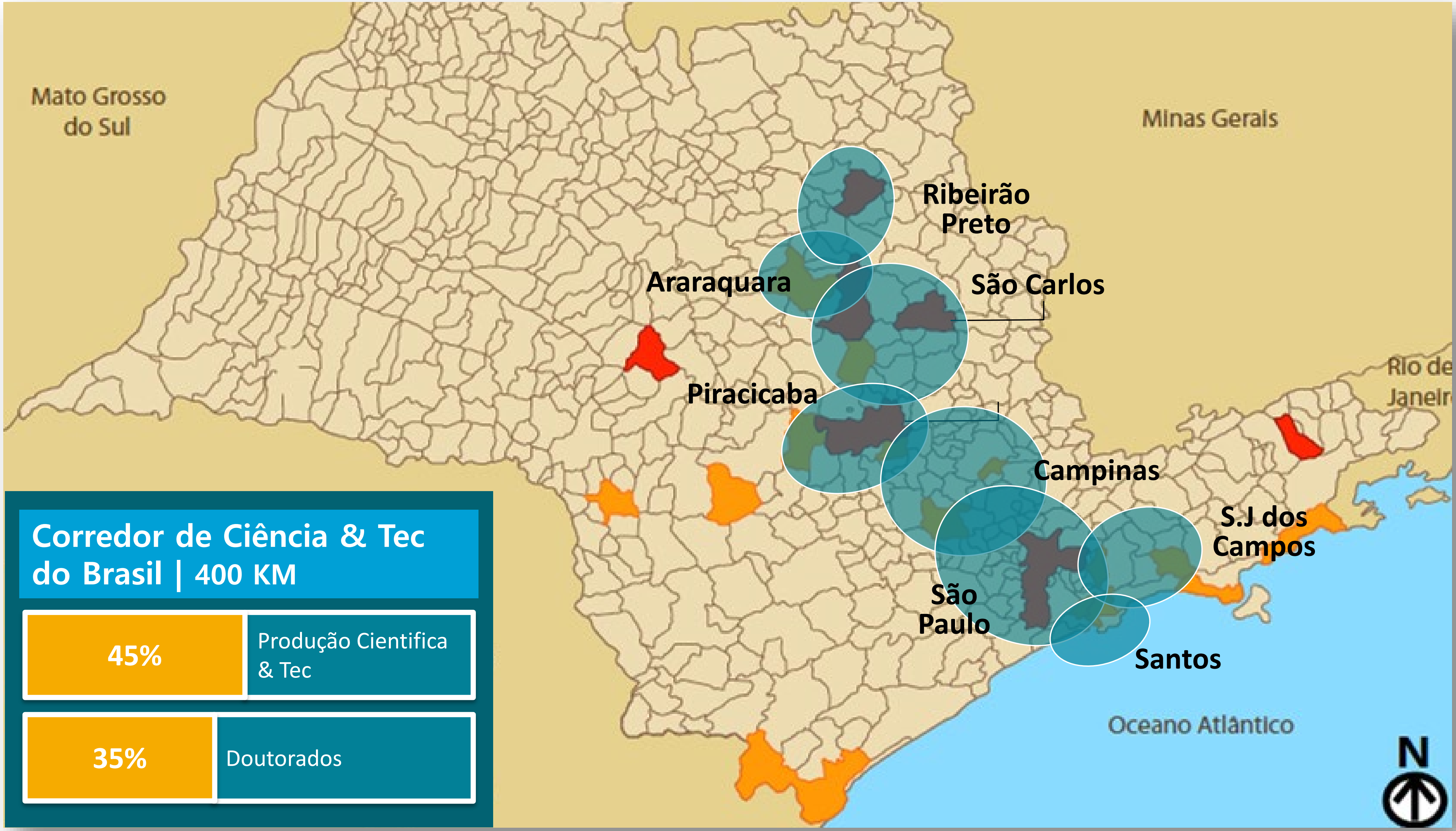
Thiago Lopes, Emílio Carlos Nelli Silva, Suani Coelho, Liane Rossi e Julio Romano Meneghini

Visita Senadores Comissão de H2
27/10/2023

Research Centre for Greenhouse Gas Innovation

University of São Paulo
BRAZIL

USP em Números	(2022)	(2023)
Posição Melhores Universidades (QS World)	115ª	85ª
Centros de Eng.FAPESP	6	7
CEPIDs FAPESP	9	11
Unidades EMBRAPII	7	9
Convênios	82	124 (R$ 169M)
Empresas Incubadas	149	179
Empresas DNA-USP	2687	2798
Orçamento	R$7,5 B	R$8,4 B


Mato Grosso do Sul
Minas Gerais
Rio de Janeir
Ribeirão Preto
Araraquara
São Carlos
Piracicaba
Campinas
S.J dos Campos
São Paulo
Santos
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N
Corredor de Ciência & Tec do Brasil | 400 KM
45%
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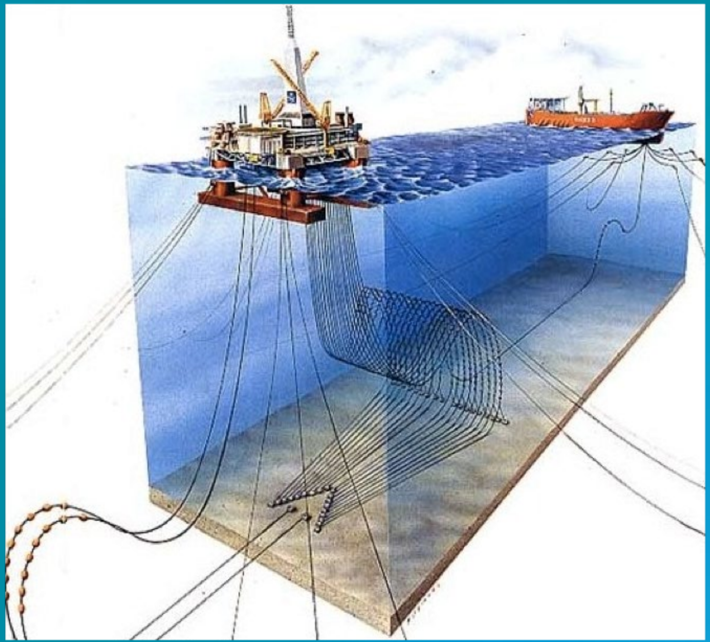
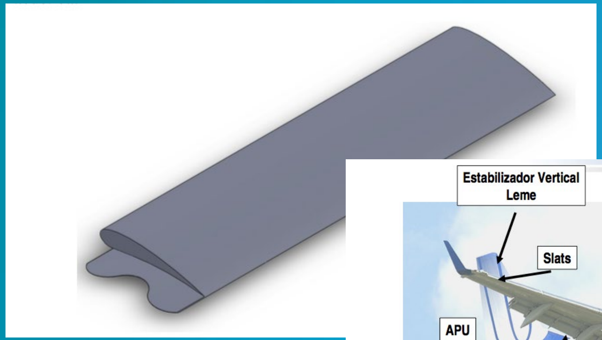
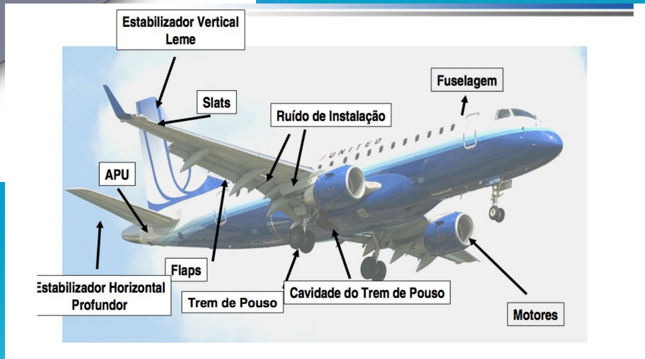
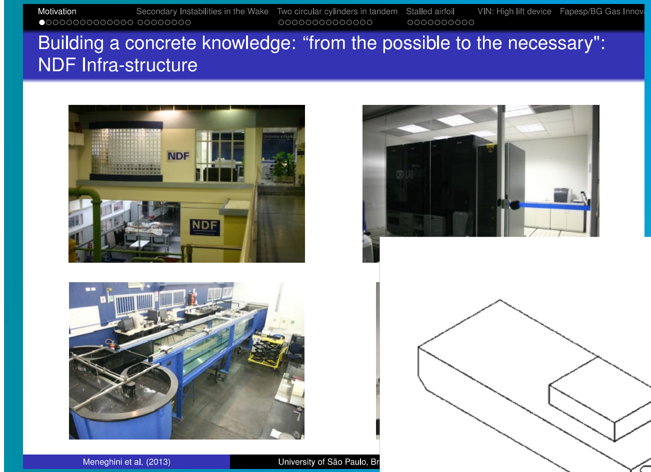
35%
Doutorados

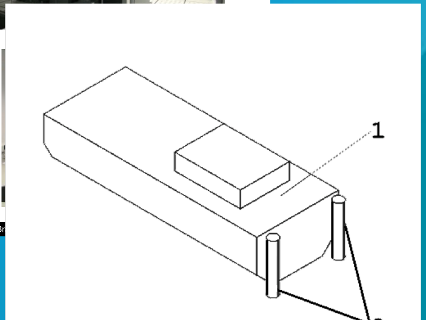
Importância das Parcerias Público-Privadas em Pesquisa, Desenvolvimento e Inovação

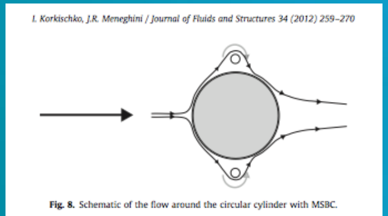












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Financiadores Fundadores

Shell

FAPESP

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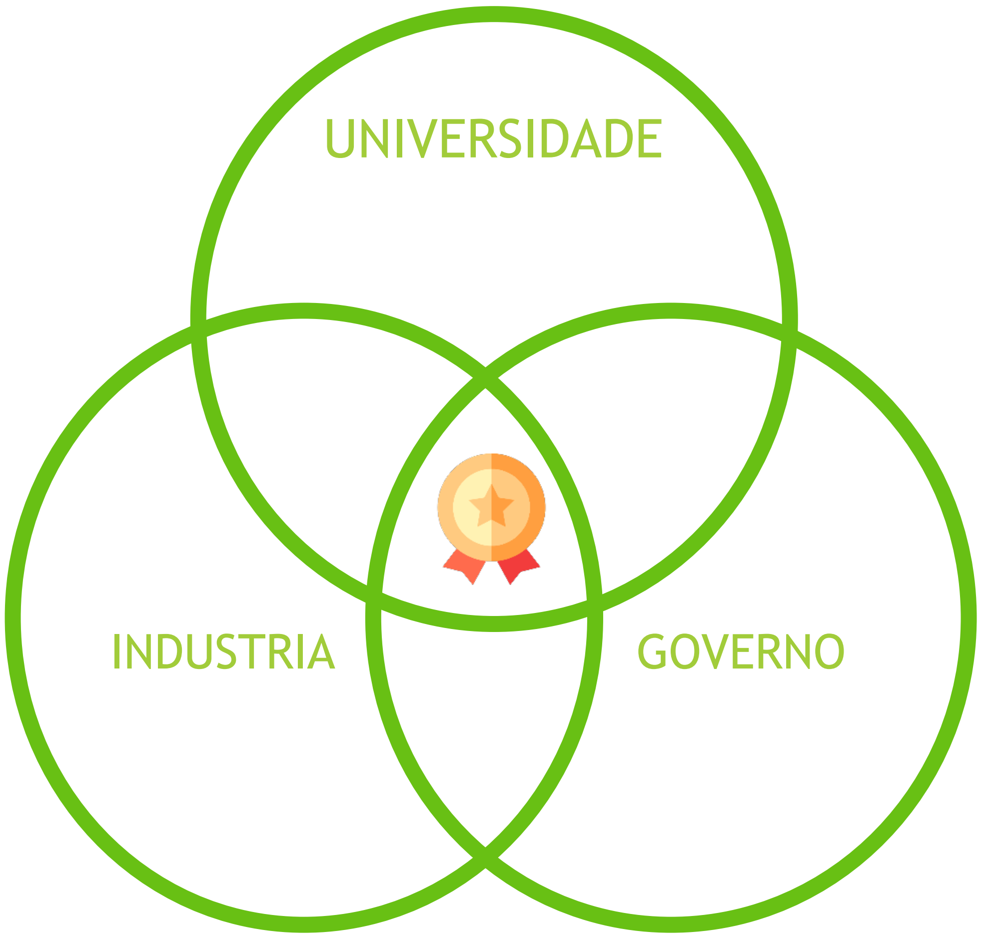
Sede do RCGI na
UNIVERSIDADE DE SÃO PAULO

Research Centre for Greenhouse Gas Innovation

Hélice Tríplice Interações Estratégicas

Ideias de novos produtos
Inovação

Financiamento e
Demandas estratégicas



Financiadores fundadores:

USP

FAPESP

Financiadores:

TotalEnergies

PETRONAS

Repsol Sinopec Brasil

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BR PETROBRAS

eneva

Instituições Parceiras:

SÃO PAULO GOVERNO DO ESTADO

anp Agência Nacional do Petróleo, Gás Natural e Biocombustíveis

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POLI USP

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THE UNIVERSITY OF QUEENSLAND AUSTRALIA

UNIVERSITY OF OXFORD

SUSTAINABLE GAS INSTITUTE Founded by BG Group

CISTAR NSF Engineering Research Center Center for Innovative and Strategic Transformation of Alkane Resources

P/O/E/T/S CENTER FOR POWER OPTIMIZATION OF ELECTRO-THERMAL SYSTEMS

SAVE THE DATE

Energy Transition
RESEARCH & INNOVATION

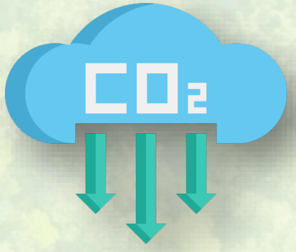
SÃO PAULO, BRAZIL | NOVEMBER 7-9, 2023

Research Centre for Greenhouse Gas Innovation

Sponsored by Shell

ROTAS PARA O BRASIL ALCANÇAR A NEUTRALIDADE DE CARBONO

Em terra



Matriz energética favorável

Novas fontes renováveis

Soluções baseadas na natureza

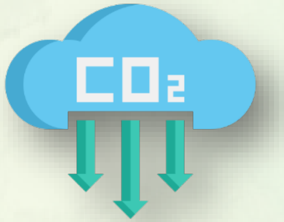
Silvicultura, Agricultura, Pastagem

Bioenergia, Biocombustíveis

Utilização e armazenamento de captura de carbono

Indústria Pesada e Transporte

No Mar



Gás & petróleo

Transporte marítimo

Energia renovável do oceano

Utilização e armazenamento de captura de carbono

Hidrogênio

Metano e Hidrogênio para produtos

Energia Renovável do Oceano

Na terra + No Mar

Brasil tem a oportunidade de se tornar neutro ou negativo em GEE e uma potência global em energia renovável

Programas do RCGI

NBS

Como **incorporar** Soluções Baseadas na Natureza para reduzir o CO2?

BECCS

Como **produzir** biocombustíveis com intensidade negativa de carbono?

CCU

Como **criar e implantar cadeias** de valor que desbloqueiam novos produtos de carbono?

GHG

Como **desenvolver** novas tecnologias para reduzir as emissões de gases de efeito estufa?

Advocacy

Como **desenvolver tecnologias** de redução de CO2 com o apoio da padronização, regulamentação e aceitação social?

InnovaPower

Como **construir** soluções de longo prazo centradas na descarbonização dos sistemas elétricos de potência?

Decarbonization

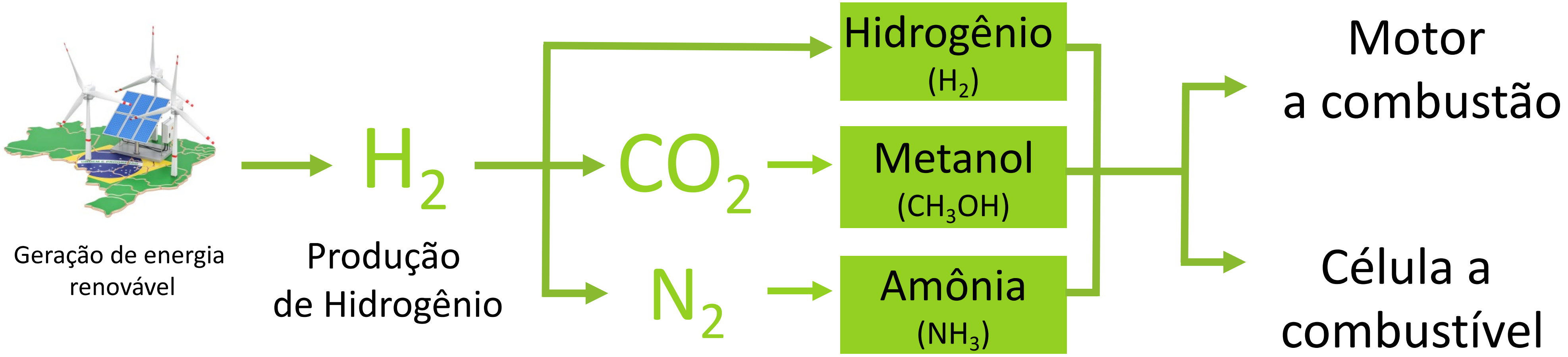
Como **contribuir** com tecnologias voltadas para um futuro descarbonizado?

Centre 2 Centre

Como **estabelecer parcerias** entre centros ao redor do mundo preocupados com soluções para melhorar nosso meio ambiente?

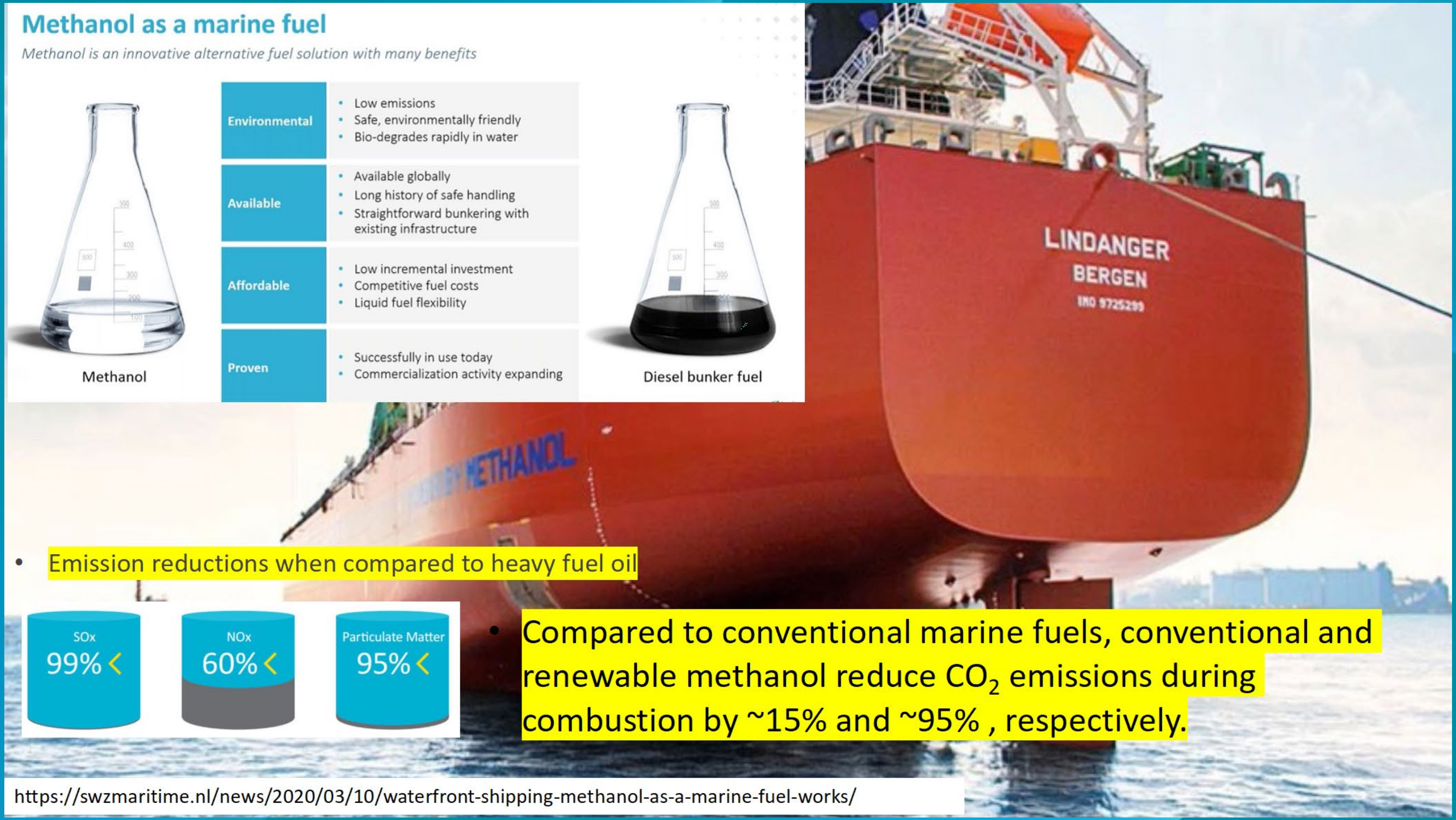
Captura e Utilização de Carbono

Combustíveis verdes do futuro



- O metanol é líquido em temperatura ambiente, enquanto H_2 e NH_3 são gases.
- O metanol é biodegradável, possui alta octanagem (109 RON) e não produz fuligem.
- Se produzido de fontes renováveis, o metanol pode apoiar a descarbonização a longo prazo.

Captura e Utilização de Carbono

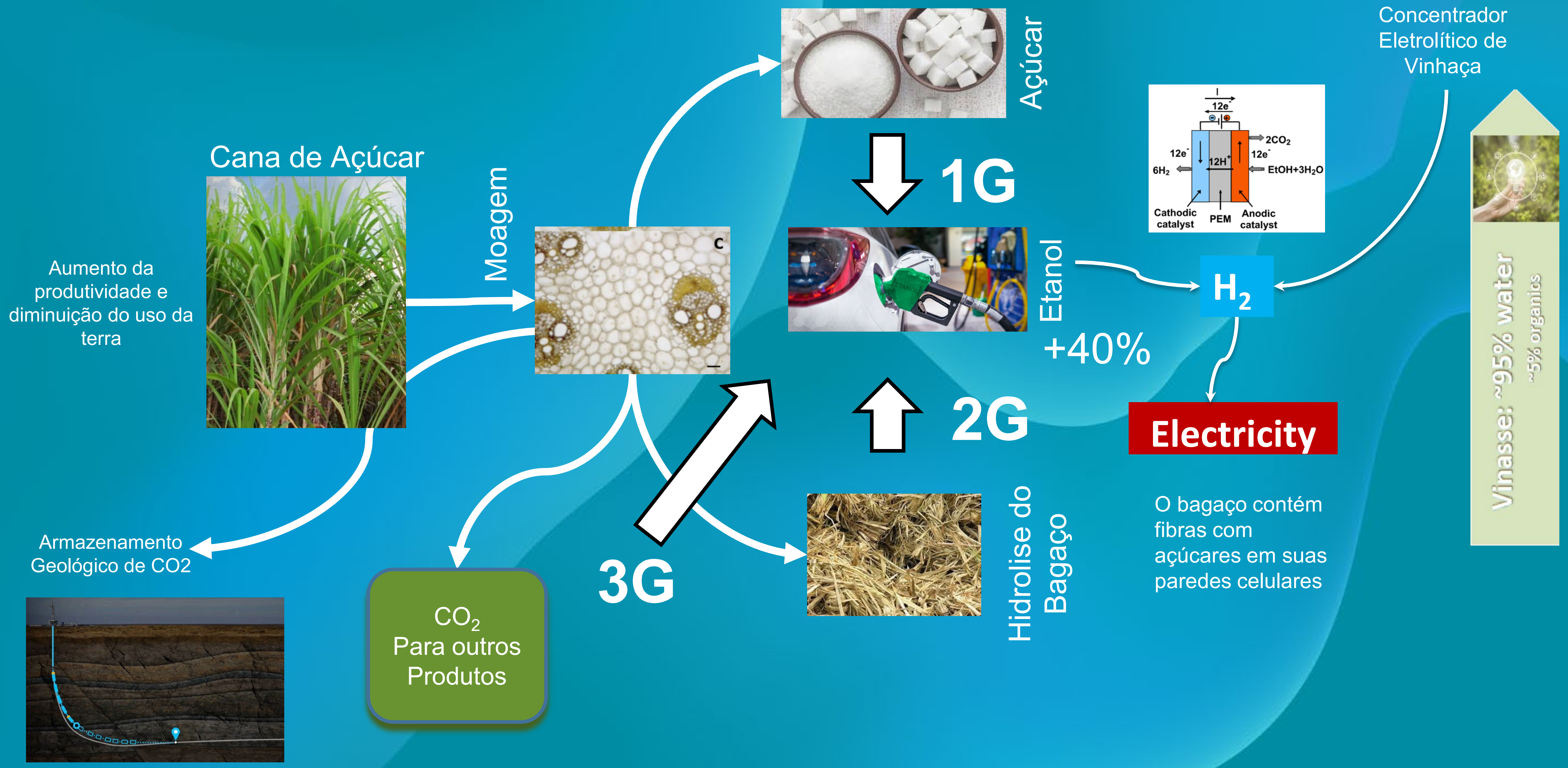


- Emission reductions when compared to heavy fuel oil

- Compared to conventional marine fuels, conventional and renewable methanol reduce CO_2 emissions during combustion by ~15% and ~95% , respectively.

https://swzmaritime.nl/news/2020/03/10/waterfront-shipping-methanol-as-a-marine-fuel-works/

Bioenergia com Captura e Armazenamento de Carbono



$EtOH^{Sink}$ ---- $H_2^{Abatement}$

BR E1G: 24.8 g CO_2/MJ_{fuel}
Source: JEC 2014

BR E1+2G: 17 g CO_2/MJ_{fuel}
Calculated based on Wang 2014

possible

CA: -25.7 g CO_2/MJ_{fuel}
Calculated based on California Ethanol and Power Carbon Balance, Life Cycle Associates, 2013.

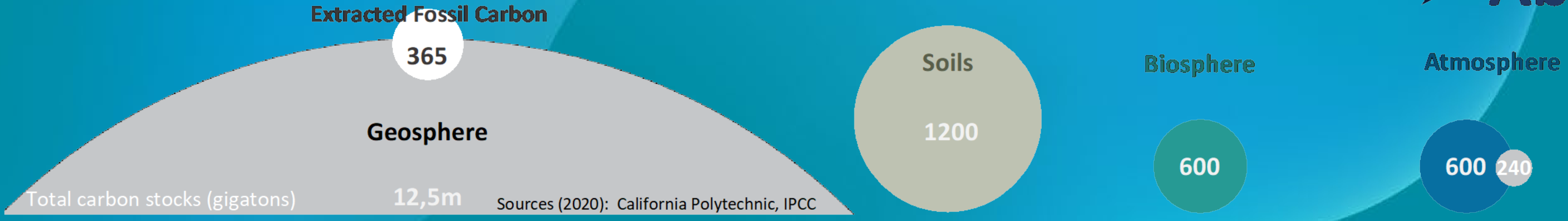
Only sinks can solve cumulative emissions

14.61 $GtCO_2eq$
Source: Our World in Data

... speeded up if with abatement

Sink ←

→ **Abatement**



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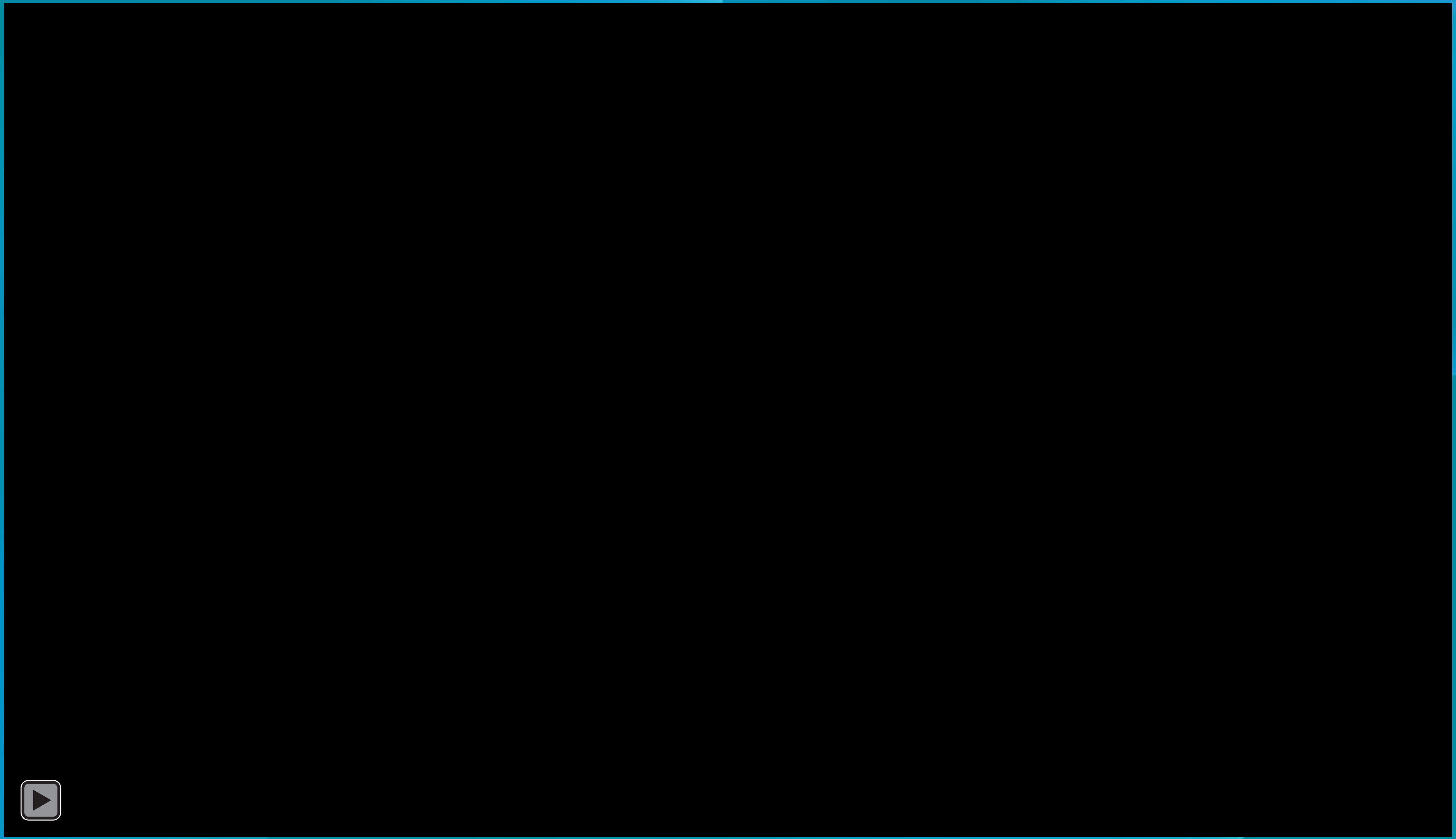
Etanol para Hidrogênio



Bioenergia com Captura e Armazenamento de Carbono

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 Change (IPCC) and other organizations.

"In order for biofuels to take their needed place in a sustainable world, the next decade has to be vastly more successful than the last," says Lee Lynd, an engineering professor at Dartmouth College who cofounded a failed cellulosic-ethanol startup named Mascoma. "We have got to do things differently, or from a climate change point of view, biofuels will have largely missed their opportunity."

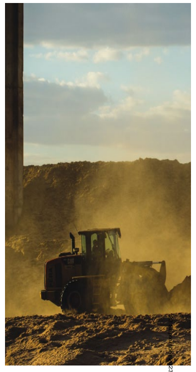
Today, the US is by far the largest producer of ethanol, accounting for roughly 55% of global output. Nearly all of it is made from corn. The US renewable fuel standard (RFS), enacted in a 2005 statute and expanded two years later, requires petroleum refiners to blend ethanol into each gallon of the gasoline they sell. The RFS spurred the rapid growth of the corn-ethanol industry. Yet since the RFS for corn ethanol is capped at 15 billion gallons per year, there is little incentive for further expansion of the business. Another limitation on growth is the so-called blend wall, the 10% limit on the ethanol content of gasoline fuels that automakers have set for all but the small fraction of US vehicles that are flex-fuel, capable of burning ethanol content up to 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, including both CO_2 emissions and those associated with growing, is considerably lower than that of gasoline.

But John DeCicco, emeritus professor at the University of Michigan's Energy Institute, notes that the values that are assigned to land-use change in different models are arbitrary, and some studies have established a lower carbon-intensity value for gasoline.

The case for cellulosic

Cellulosic, or nonstarch, biomass—crop residues, wood waste, grasses, and other plant matter—has long been seen as a more sustainable raw material for ethanol production. Much of the biomass could come from lands unsuitable for agriculture, thus minimizing land-use impacts. Theoretically, cellulosic ethanol offers a much larger reduction in carbon intensity than corn ethanol—as much as 80% below gasoline's, depending on variables such as the feedstock used and the processing method, according to Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies full-life-cycle emissions model. The GREET model calculates corn ethanol's carbon intensity to be 44% below gasoline's.



In a series of 2016 studies collectively known as the "billion-ton report," the Department of Energy estimated that 500 million tons of nonstarch biomass could be harvested or collected annually in the US without adversely affecting ecosystems. DeCicco is skeptical of the finding, which he says is based on a lot of favorable assumptions. If cellulosic ethanol had actually taken off, he argues, it would have unleashed a wave of land-use conversions as large agribusinesses moved into the business of cultivating energy crops. "If they have an incentive to harvest biomass from switchgrass, miscanthus, or rapidly growing trees like aspens, they will seek to do that on the best land they can obtain."

The lignocellulose that composes the leaves and stalks of plants is considerably more difficult to break down to alcohol than the readily fermentable starch in corn; it requires specialized enzymes or thermochemical technologies. The 2007 RFS included a specific mandate for cellulosic ethanol, reaching 16 billion gallons by 2022. But lawmakers vastly overestimated the readiness of cellulosic

RAÍZEN

RAÍZEN'S PLANT in Piracicaba, Brazil, is the world's o… cellulosic ethanol. Here, crushed sugarcane residue ca… into the processing plant. Raízen plans to build 20 suc…

technology, even as government and private money poured into R&D. The Environmental Protection Agency, which administers the RFS program, established a 2022 requirement for 630 million gallons of cellulosic biofuels.

DOE in 2007 established three bioenergy research centers at its national labs. A fourth center, headed by the University of Illinois at Urbana-Champaign, was added in 2017. In 2007, BP pledged $500 million over 10 years to fund an Energy Biosciences Institute, headquartered at the University of California, Berkeley. Chris Somerville, the institute's former director, says interest in biofuels fell in concert with plunging oil prices in 2014. "The bottom line is that to disrupt a cheap commodity business one needs to pay attention to all the sources of value. And to do that requires quite a lot of technical knowledge and know-how," he says. Large integrated oil companies such as BP could accomplish that, but "it will remain very challenging for

Their response was, 'It doesn't have to be different or good—it just has to be first.' And the assumption was that the world

nature climate change

LETTERS

PUBLISHED ONLINE: 23 OCTOBER 2017 | DOI: 10.1038/NCLIMATE3410

Brazilian sugarcane ethanol as an expandable green alternative to crude oil use

Deepak Jaiswal[1†], Amanda P. De Souza[1,2], Søren Larsen[3,4,5], David S. LeBauer[1,6], Fernando E. Miguez[7], Gerd Sparovek[3], Germán Bollero[8], Marcos S. Buckeridge[2] and Stephen P. Long[1,8,9,10]★

Reduction of CO_2 emissions will require a transition from fossil fuels to alternative energy sources. Expansion of Brazilian sugarcane ethanol[1,2] provides one near-term scalable solution to reduce CO_2 emissions from the global transport sector. In contrast to corn ethanol, the Brazilian sugarcane ethanol system may offset 86% of CO_2 emissions compared to oil use, and emissions resulting from land-use change to sugarcane are paid back in just 2–8 years[3,4]. But, it has been uncertain how much further expansion is possible given increasing demand for food and animal feed, climate change impacts and protection of natural ecosystems. We show that Brazilian sugarcane ethanol can provide the equivalent of 3.63–12.77 Mb d^{-1} of crude oil by 2045 under projected climate change while protecting forests under conservation[5] and accounting for future land demand for food and animal feed production. The corresponding range of CO_2 offsets is 0.55–2.0 Gigatons yr^{-1}. This would displace 3.8–13.7% of crude oil consumption and 1.5–5.6% of net CO_2 emission globally relative to data for 2014[6,7].

BioCro model (Supplementary Fig. 2 and Supplementary Table 1). Rather than project yield from empirical relationships, BioCro simulates plant growth hour by hour on the basis of underlying

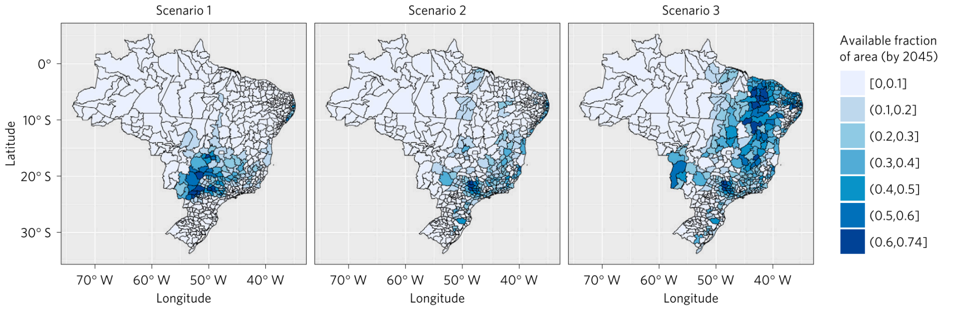


Figure 1 | The fraction of land available for sugarcane expansion by 2045 in each of the legally defined micro-regions of Brazil under the three land-use scenarios considered in this study. Brackets are inclusive and parenthesis are not inclusive in the legend for area fractions. $[x, y]$ represents $x \leq$ area fraction $\leq y$ and $(x, y]$ represents $x <$ area fraction $\leq y$.

Bioenergia com Captura e Armazenamento de Carbono

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CLEAN ENERGY FOR A GREENER FUTURE: BRAZILIAN PERSPECTIVE

(Background note prepared by Brazilian Academy of Science for S20 Thematic Conference on Clean Energy for a Greener Future - Agartala, 3-4 April 2023)

WORLD ENERGY SCENARIO

The scenario for generation and use of energy is undergoing strong changes due to the requirements to meet the commitments associated to reducing emissions in accordance with the Paris Agreement, and to achieving the 17 Sustainable Development Goals (SDGs). There is also a strong necessity to attend the more vulnerable populations that have no access to energy. In the clean energy transition process, considerations of social justice and equity in energy access are central.

Human activities in general require energy and both the wealth of a nation and the well-being of its respective populations are closely related to the energy available to it[1]. As the world moves towards achieving the 17 SDGs, more energy will be required, especially energy generated with low greenhouse gas (GHG) emissions. However, the expectation of energy growth should not obliterate efforts to reduce energy demand in the search for quality of life and social well-being in more parsimonious standards.

In the last twenty years, the world's annual energy consumption has increased from approximately 400 million TJ (tera Joule) to 600 million TJ. In the same period, world GDP increased from approximately US$ 34 trillion to US$ 97 trillion, indicating that, on average, for each increase of US$ 1.0 trillion in GDP, approximately 3 million TJ is required. By current standards, this growth comes mainly from non-renewable energy sources, mostly fossil fuels. The energy transition to renewable energy sources and the shift in development strategy towards less energy-intensive economic progress are today a global priority to ensure sustainable and socially fair growth.

Energy Supply

The world's energy supply indicates that approximately 80% of primary sources come from fossil fuels, major GHG generators, and this reality has not changed over the last twenty years despite the observed growth of renewable sources[2]. Although solar and wind generation are increasing globally, their shares in global supply are still very small (~2%). Additionally, the distribution of both generation and use of energy is very uneven across regions and across countries.

[1] https://doi.org/10.1108/INMR-02-2018-003
[2] https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser?country=WORLD&fuel=Energy%20supply&indicator=TESbySource

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CLEAN ENERGY TRENDS IN BRAZIL

For a sustainable and socially fair future, the global energy scenario requires changes that demand planning, financial resources, technological developments and public policies on different fronts. From the perspective of Brazil, some trends are listed below.

Decarbonization

The predominance of the use of fossil fuels in the world's electricity matrix justifies the great concern that exists in the decarbonization of the electricity supply. Although Brazil has an electrical matrix composed predominantly of renewable sources, thermoelectric plants often operate to provide energy security in the electricity supply, and emit large amounts of GHG.

Additionally, due to its large territorial extension, there are regions that are not part of the Brazilian interconnected electricity system. In the Amazon region, for example, there are a large number of locations where electricity is supplied by thermoelectric units that operate with diesel oil and emit large amounts of GHG. The supply of fuel to these plants in general involves complex transport logistics and high costs.

In both circumstances mentioned above, the use of hybrid systems with solar PV and/or wind generation together with energy storage, either through hydrogen or electrochemical storage, offers a viable alternative.

Additional decarbonization alternatives include: i) the capture and storage of CO2 originating from ethanol production and which is vented to the atmosphere by fermentation vats, BECCS (Bio-energy Carbon Capture and Storage); ii) CO2 storage both in pre-salt oil reservoirs and in saline domes also in the pre-salt layer; iii) storage in geological formations on land close to renewable fuel production plants.

Biomass

Brazil is a major producer of ethanol obtained from sugarcane. The production of second-generation ethanol, E2G, produced from straw, leaves and sugarcane bagasse, has been increasing. The production of 2G ethanol from other lignocellulosic plant biomasses such as corn and sorghum, among others, is also on rise.

E2G is a biofuel made from leftover waste from the E1G manufacturing process and from sugar, and its carbon footprint is 30% smaller than that of E1G. As E2G has the same chemical composition as E1G, it is possible to increase its productivity by up to 50%, without being necessary to increase the size of the planted area, since additional sugarcane is not needed to produce it.

There are several alternatives for the production of E2G and exploring different technologies in a context of carbon capture and storage (BECCS - Bio-energy Carbon Capture and Storage), can add greater competitiveness to Brazilian ethanol.

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Tel.: +55 21 3907-8100 | Email: abc@abc.org.br

Table 1 – Energy matrix in percentage of total energy generation (World 2020[3], Brazil 2021[4])

	World	Brazil
Oil and derivatives	29.5 %	34.4 %
Coal	26.8	5.6
Natural Gas	23.7	13.3
Biomass	9.8	25.1
Nuclear	5.0	1.3
Hydro	2.7	11.0
Others renewable	2.5	8.7
Wind	6.0	10.6
Biomass	2.5	8.2
Oil and derivatives	2.5	3.0
Geothermal	0.4	-
Waste	0.4	-
Tidal	0.004	-
Total	**100%**	**100%**

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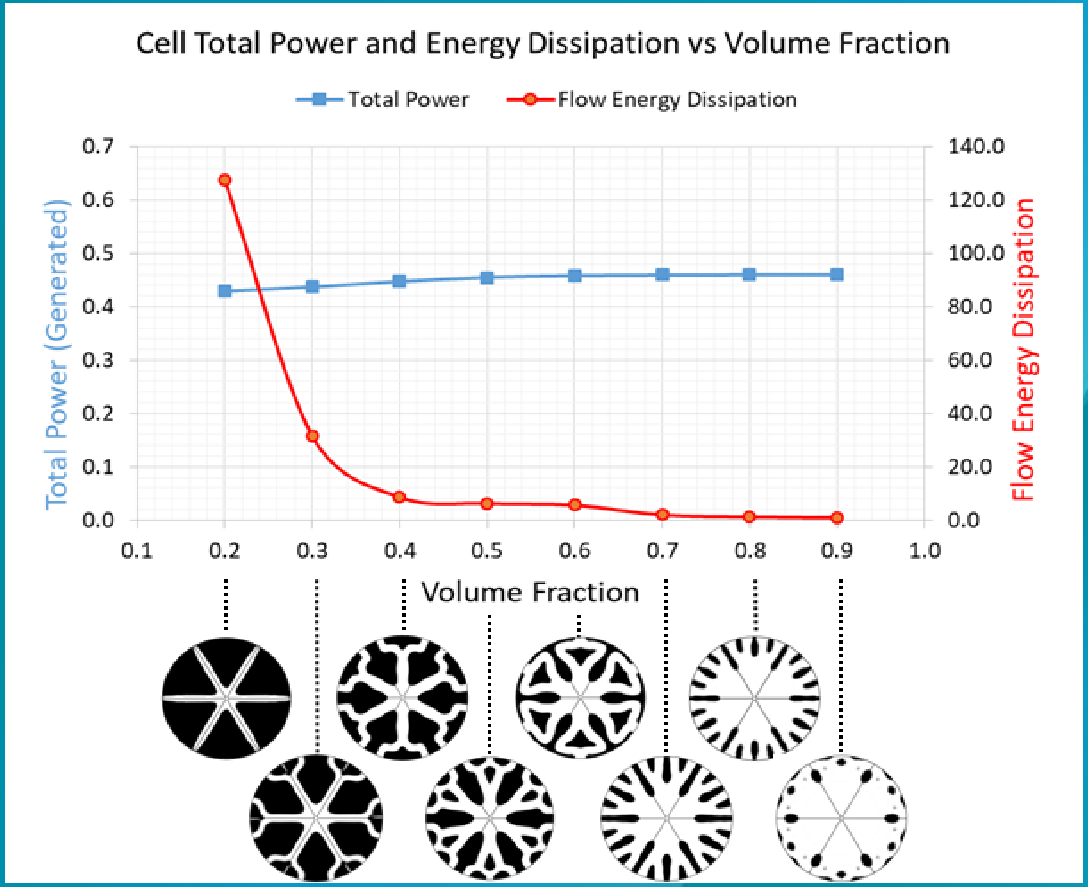
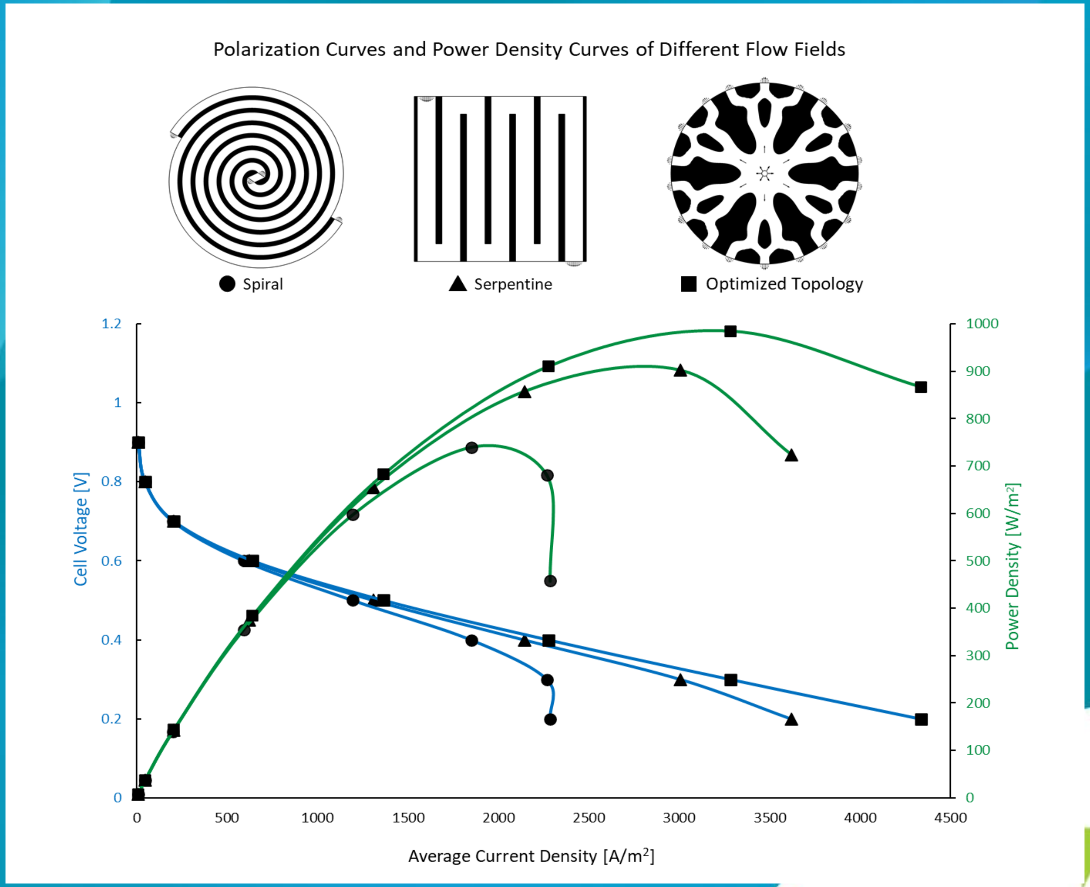
The contribution of Ricardo Rüther (UFSC) is gratefully acknowledged.

Gases de Efeito Estufa

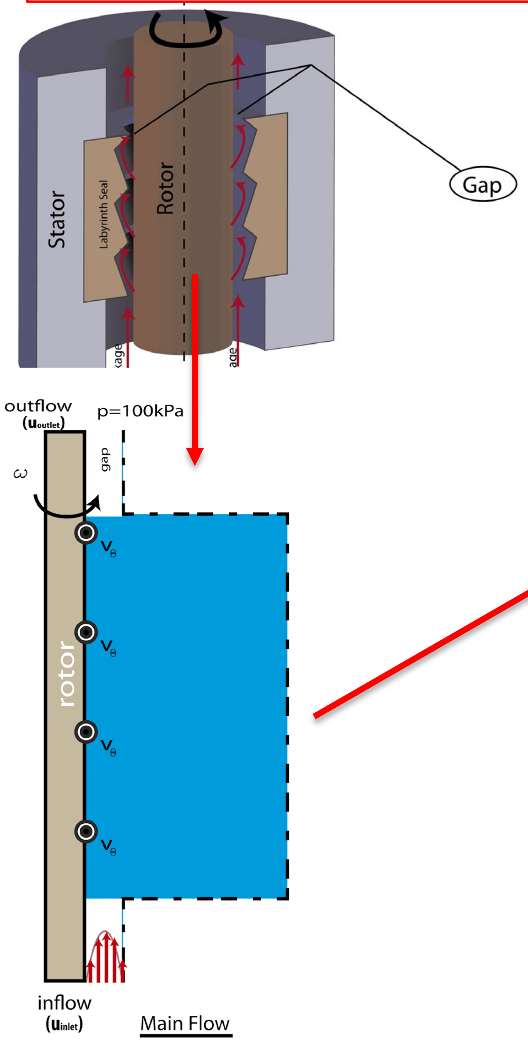


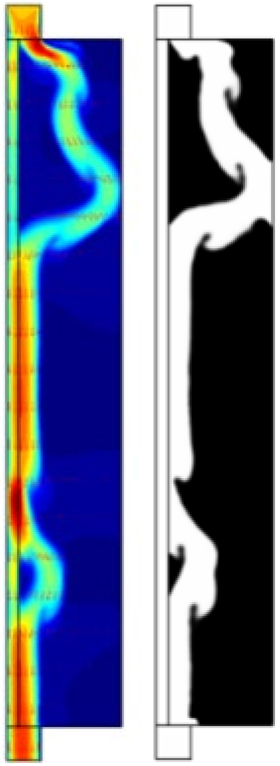


Research Centre for Greenhouse Gas Innovation

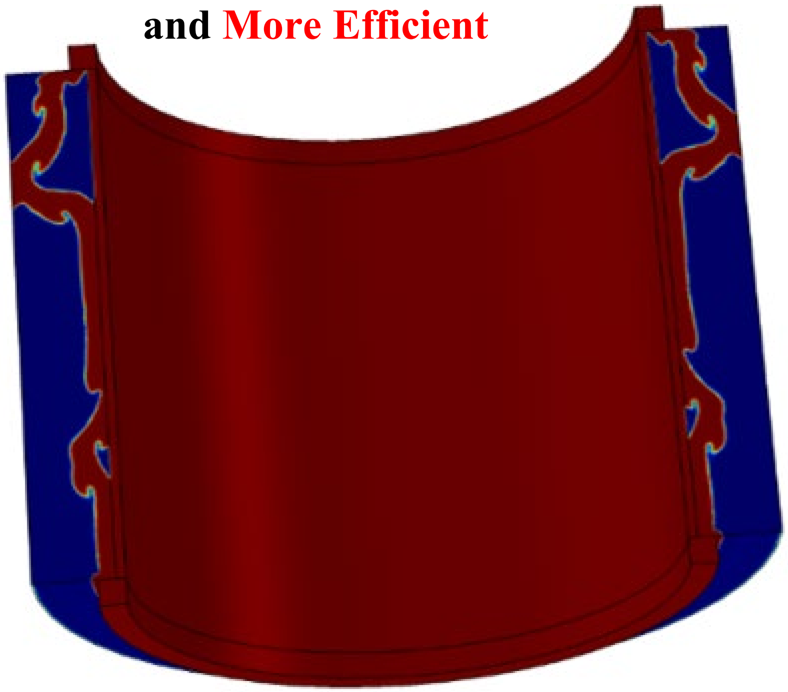
LABYRINTH SEAL DESIGN

Topology optimization Procedure





2D



3D

Labyrinth seal design for Methane Compressors Application

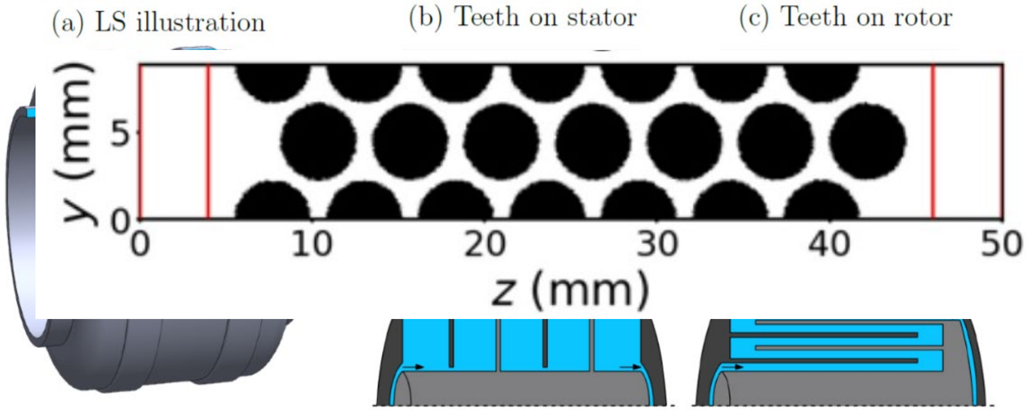
Objective function Diodicity

Compared to Traditional Model:
Less Leakage up to 50%
and More Efficient

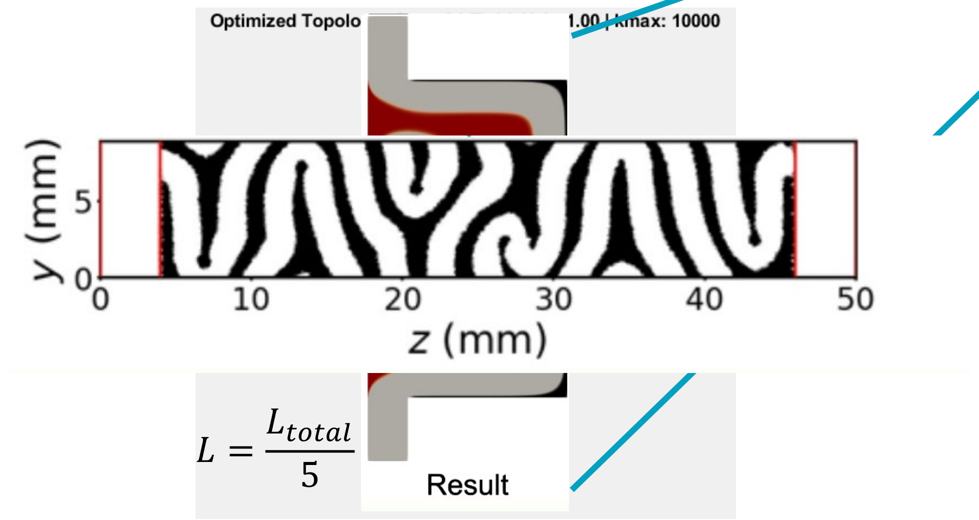
Rotation = 3000 rpm
Volume Constraint < 0.3

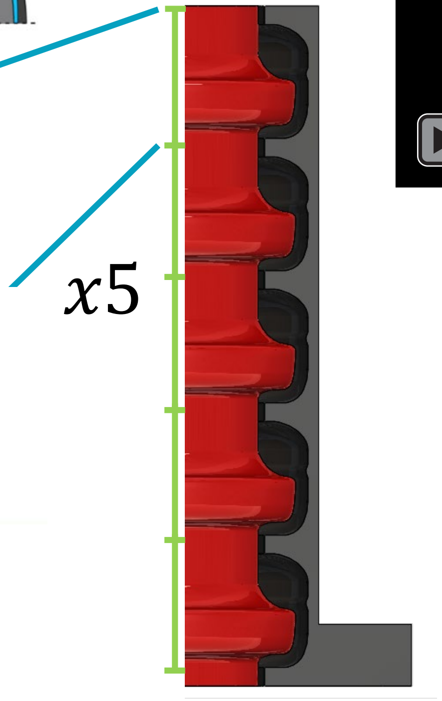
LABYRINTH SEAL DESIGN

Traditional Labyrinth Seals



Topology Optimization





Optimized Seal

Citação Final

“A emergência climática exige uma transformação urgente nas matrizes energéticas e nos modelos de uso da terra... O Brasil tem potencial para liderar essa transformação... contribuindo para um futuro mais próspero e resiliente.”

— Carlos Gilberto Carlotti Jr, Reitor da USP e Julio Romano Meneghini, Professor Titular da Escola Politécnica e Coordenador do RCGI. O Estado de S. Paulo 10/08/2023.

Projetos:

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