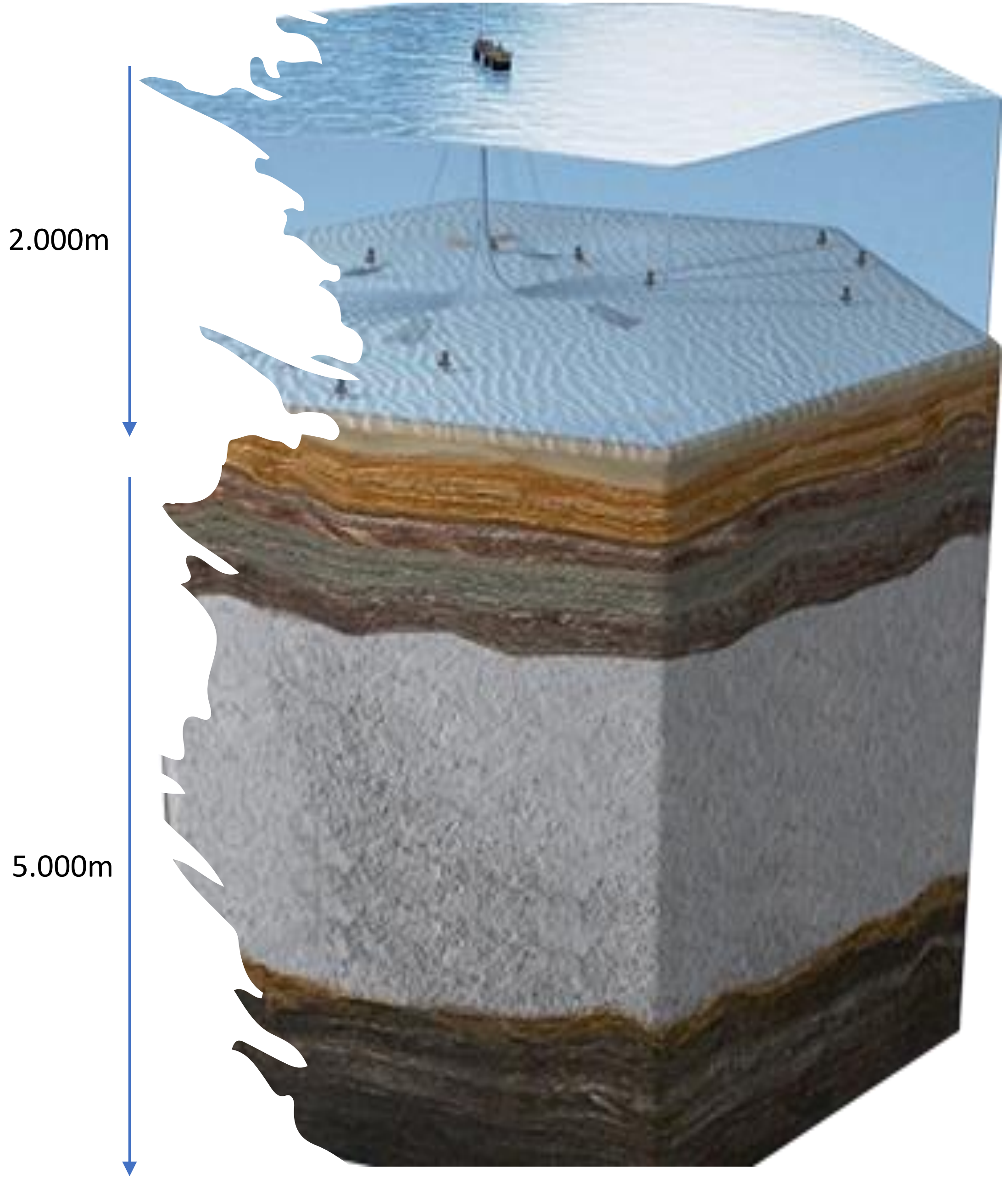
Pre-Salt
Oil and gas



https://petrobras.com.br/en/our-activities/performance-areas/oil-and-gas-exploration-and-production/pre-salt/


PETROBRAS 51
MAJURO


GRAND ANIVA
TUG
TUG
TUG
TUG


190th

DECARBONIZATION BY SUSTAINABLE HYDROGEN

Fabio Coral Fonseca

ipen

São Paulo, Brazil
September, 2nd , 2023

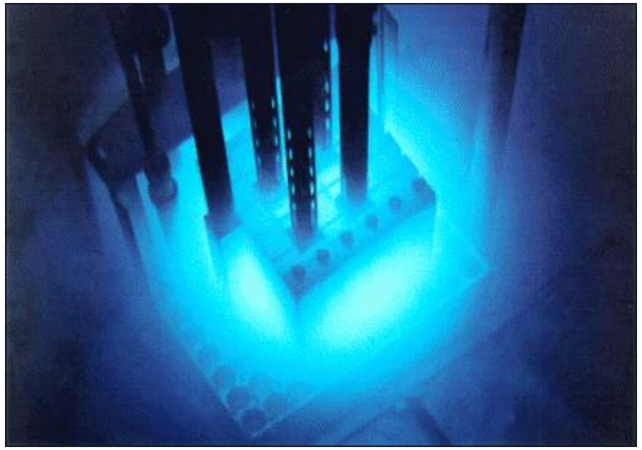
INFIERI

ipen

Instituto de Pesquisas Energéticas e Nucleares

Ciência e Tecnologia a serviço da vida

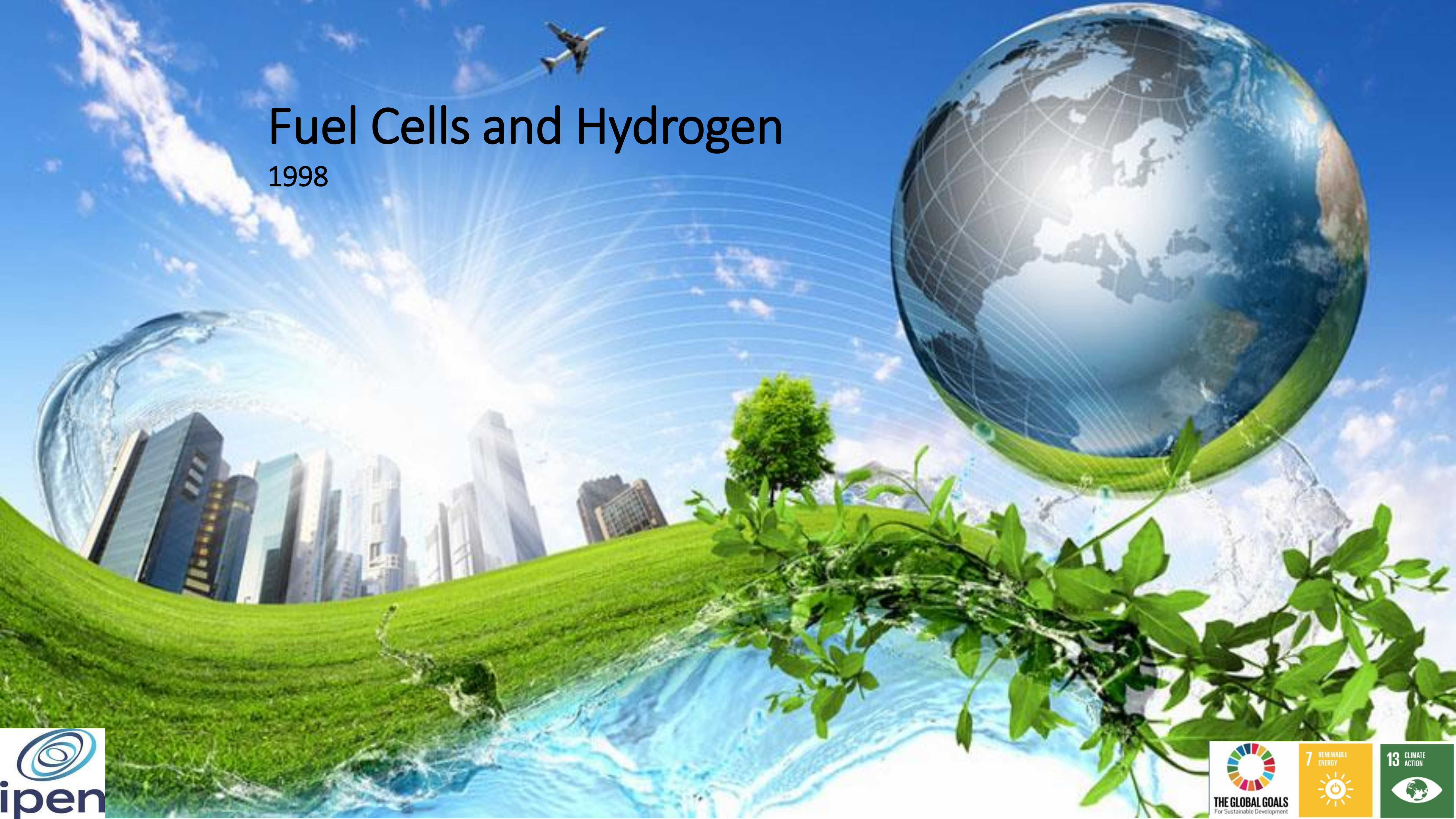
67 years

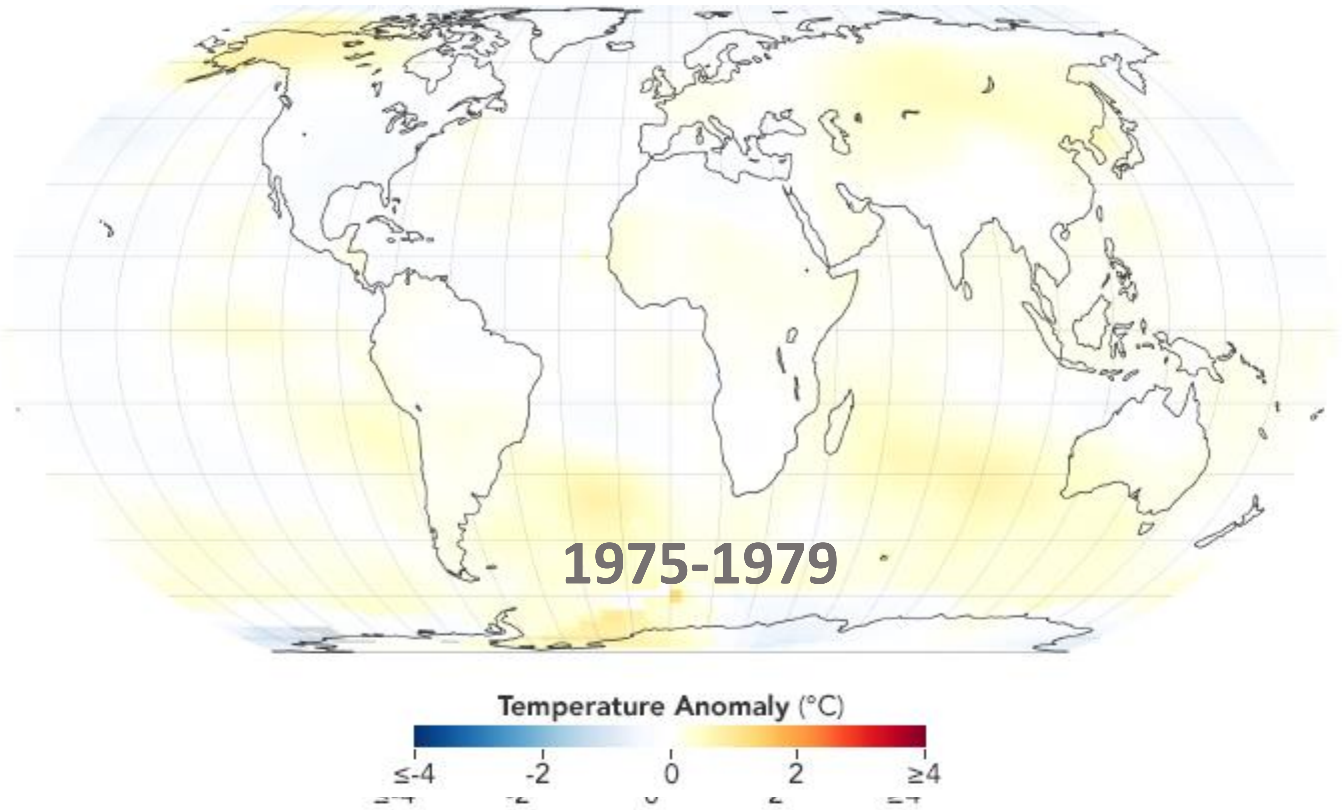


CNEN Comissão Nacional de Energia Nuclear

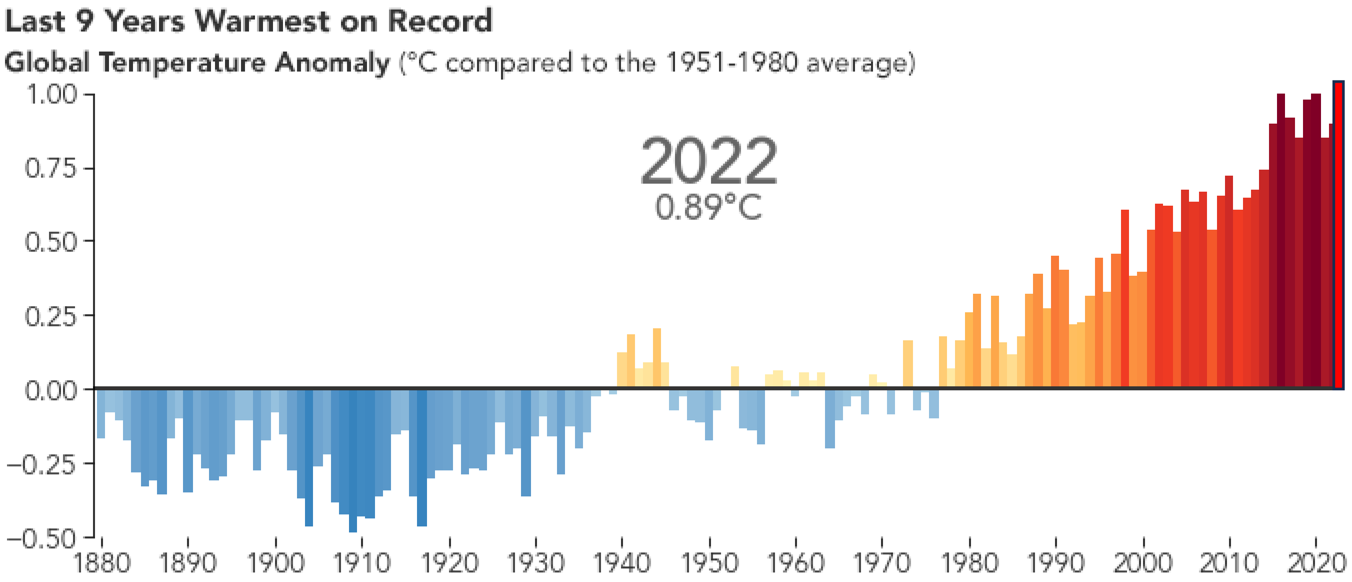
Fuel Cells and Hydrogen

1998





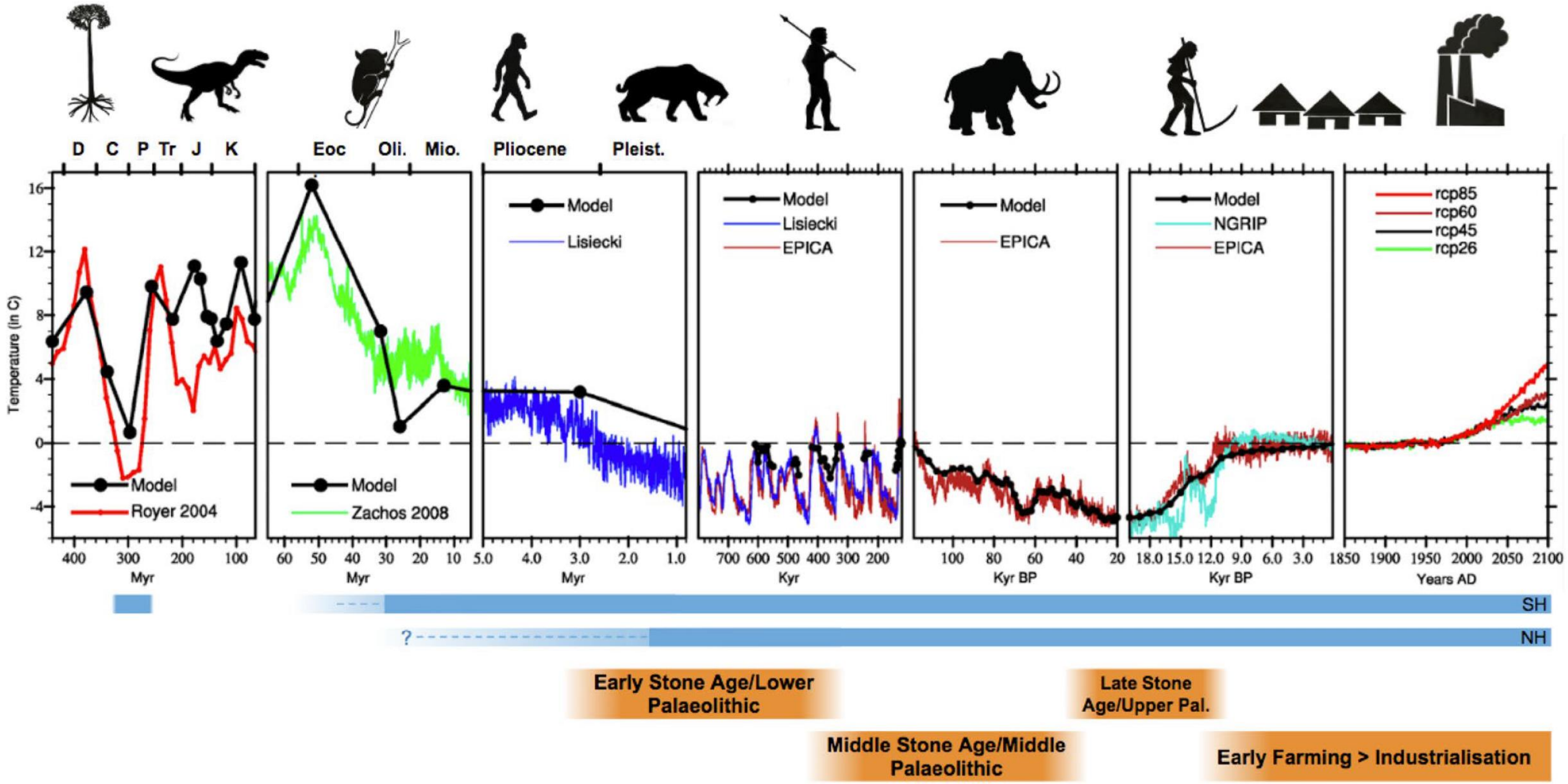
July 2023
+0.99 °C



NASA earth observatory

Climate Change Geological

A. M. Haywood et al.



Today's climate change

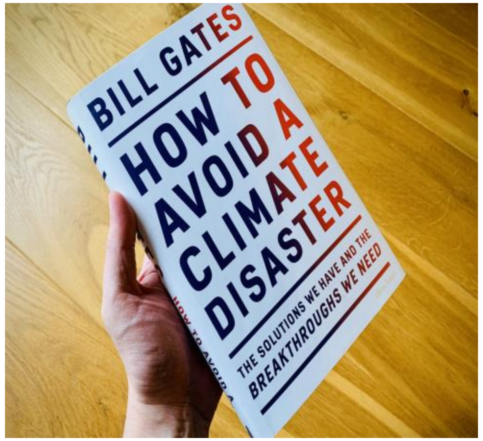
Comparable

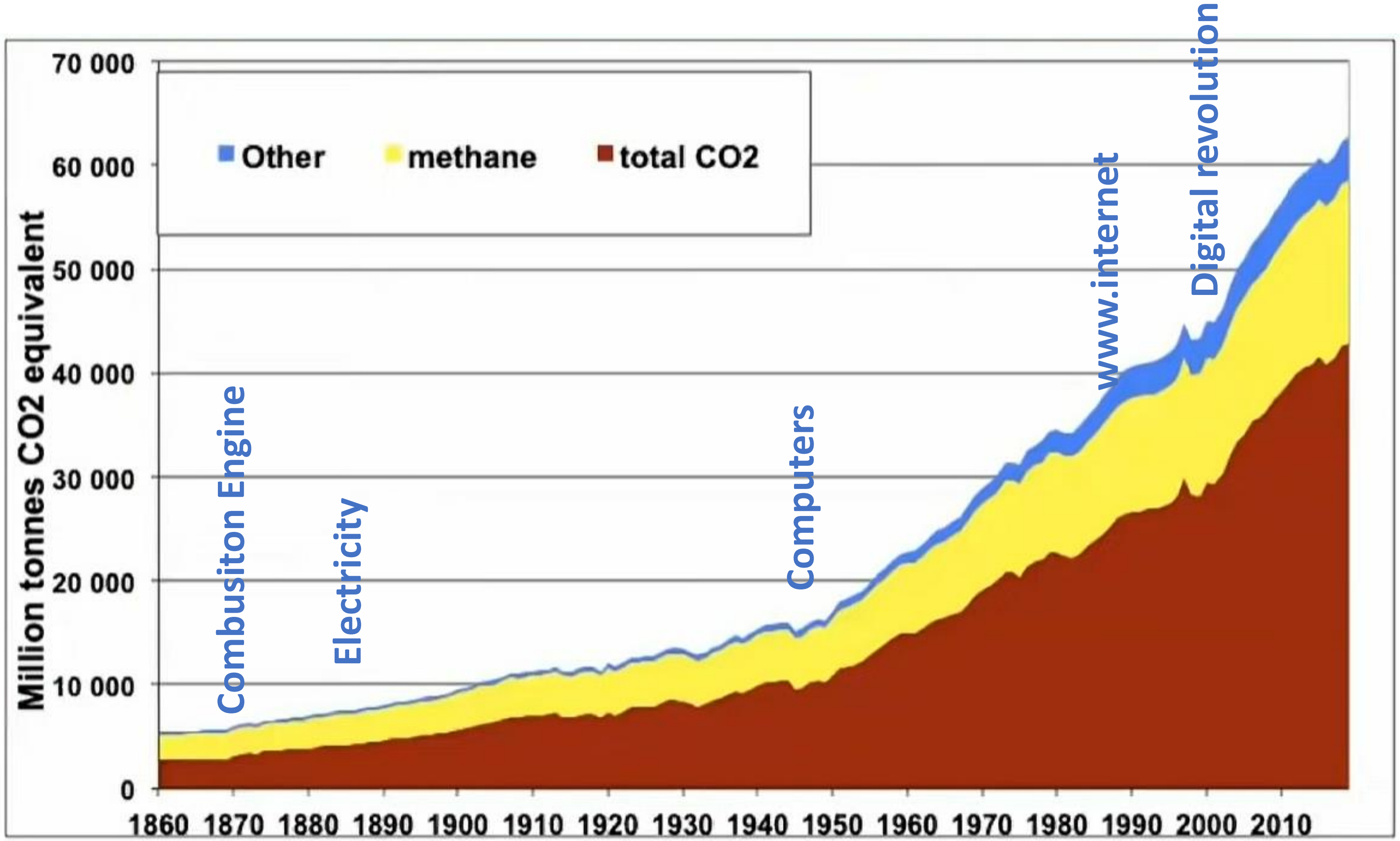
Faster

How does it impact us

?

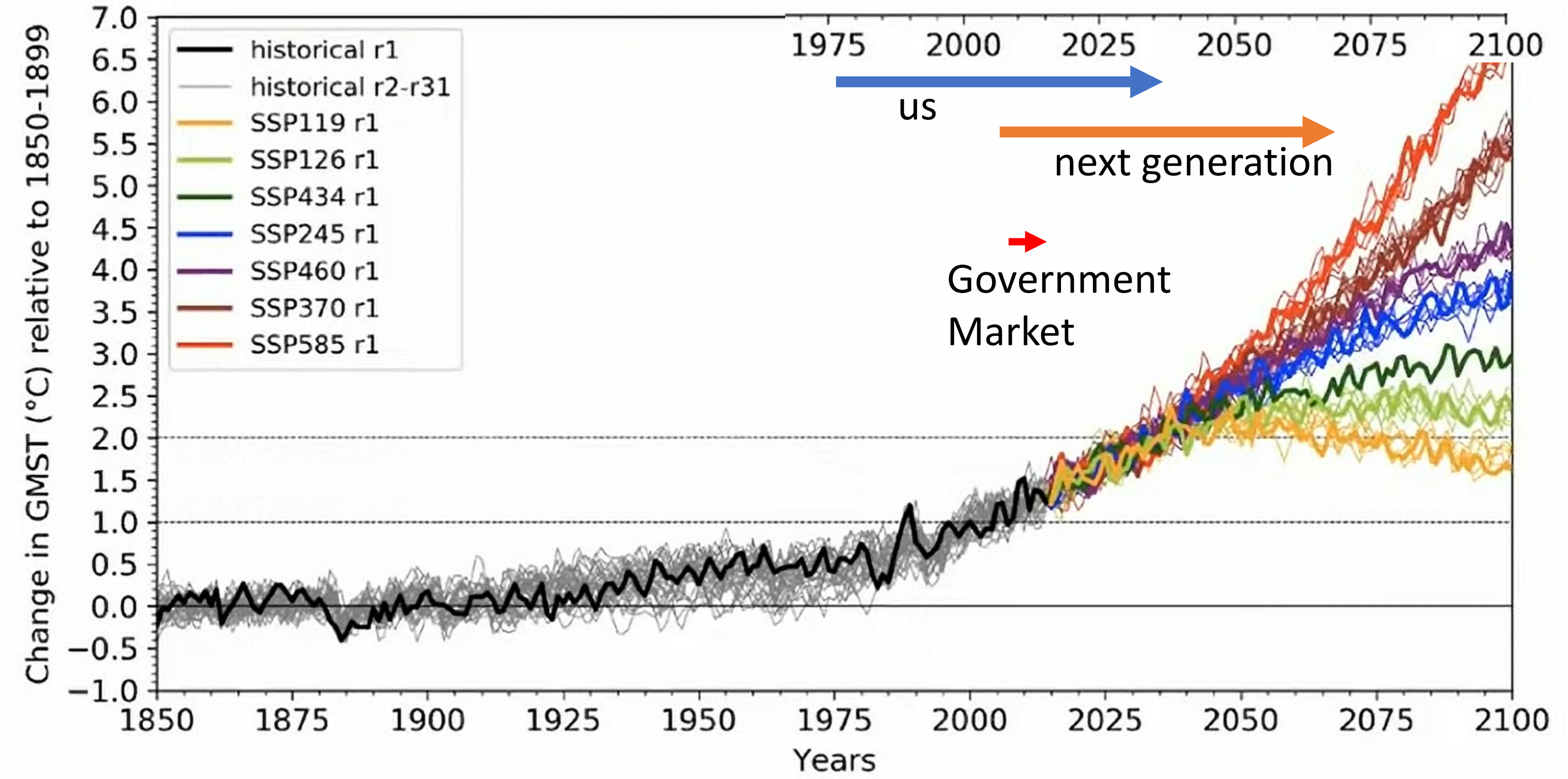
Climate Change x Technology





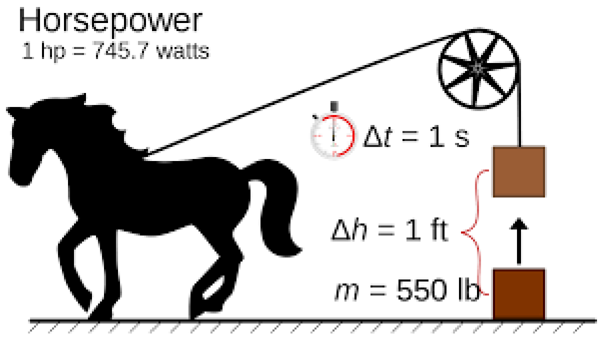
Greenhouse gases emissions by gas since 1860. Various data.

Climate Change x time



Climate model IPSL-CM6A-LR
Historical 1850-2014 / scenarios 2015-2100

Energy x Economy



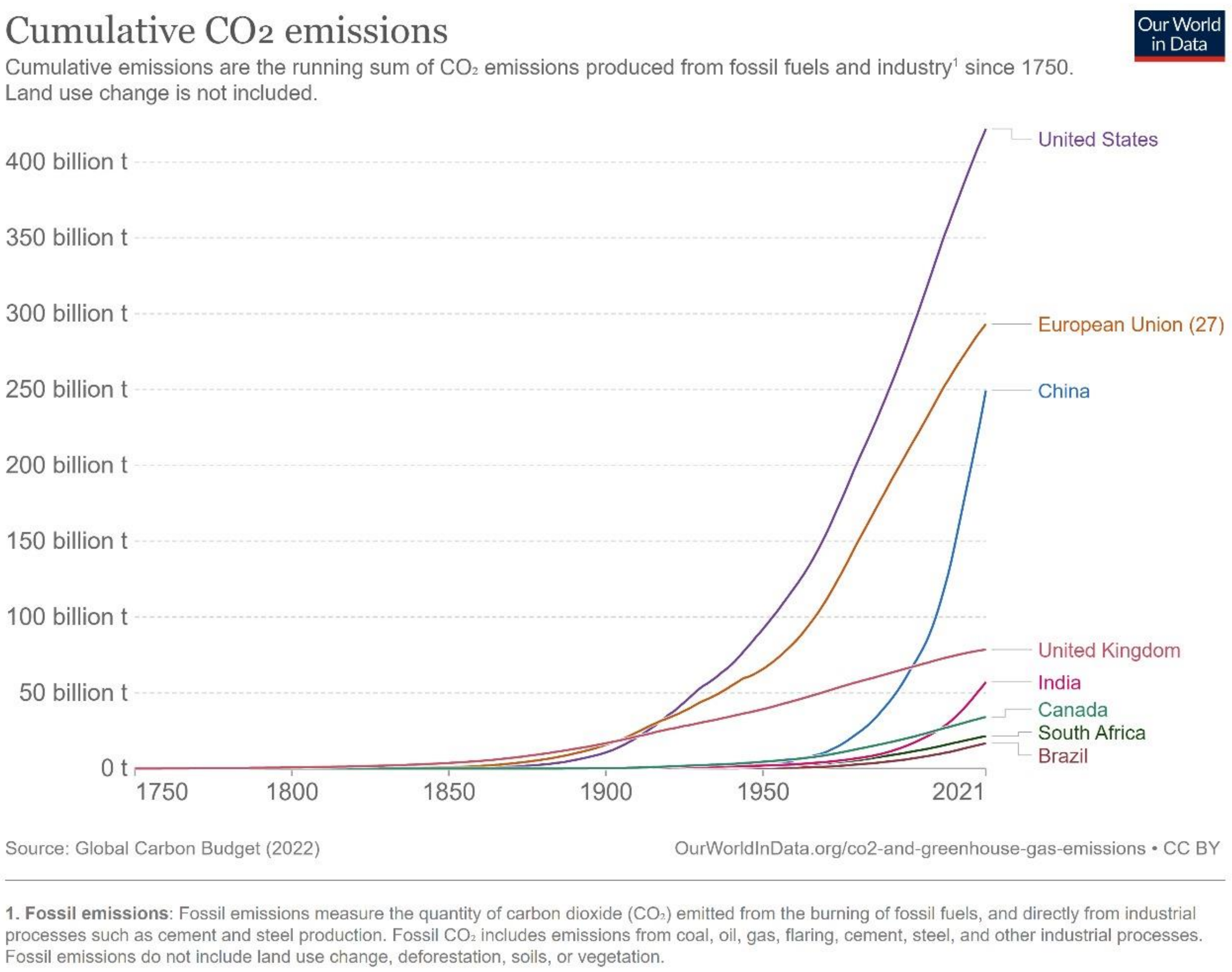
Gross domestic product (GDP) by world region

This data is adjusted for inflation and differences in the cost of living between countries.

Source: Maddison Project Database 2020 (Bolt and van Zanden, 2020)
Note: This data is expressed in international-$[1] at 2011 prices.

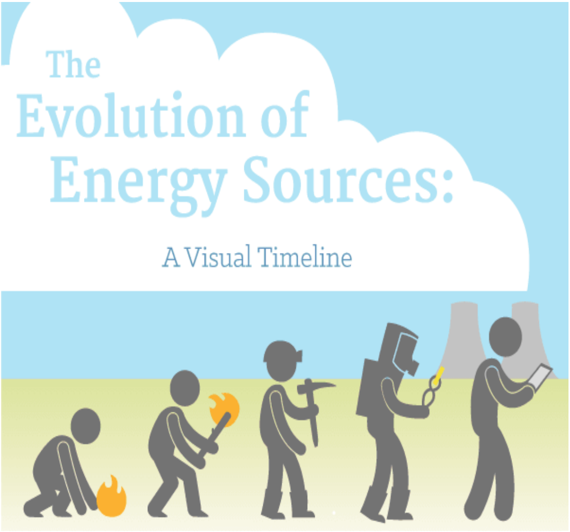
1. International dollars: International dollars are a hypothetical currency that is used to make meaningful comparisons of monetary indicators of living standards. Figures expressed in international dollars are adjusted for inflation within countries over time, and for differences in the cost of living between countries. The goal of such adjustments is to provide a unit whose purchasing power is held fixed over time and across countries, such that one international dollar can buy the same quantity and quality of goods and services no matter where or when it is spent. Read more in our article: What are Purchasing Power Parity adjustments and why do we need them?

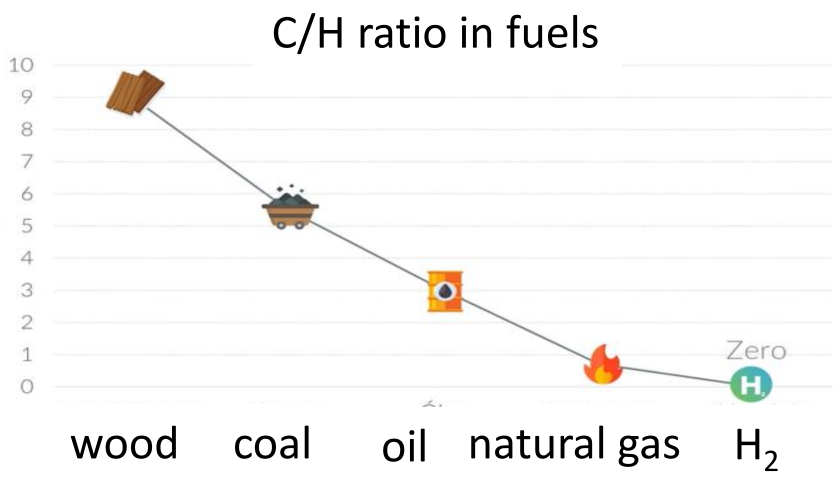
Emissions x Economy

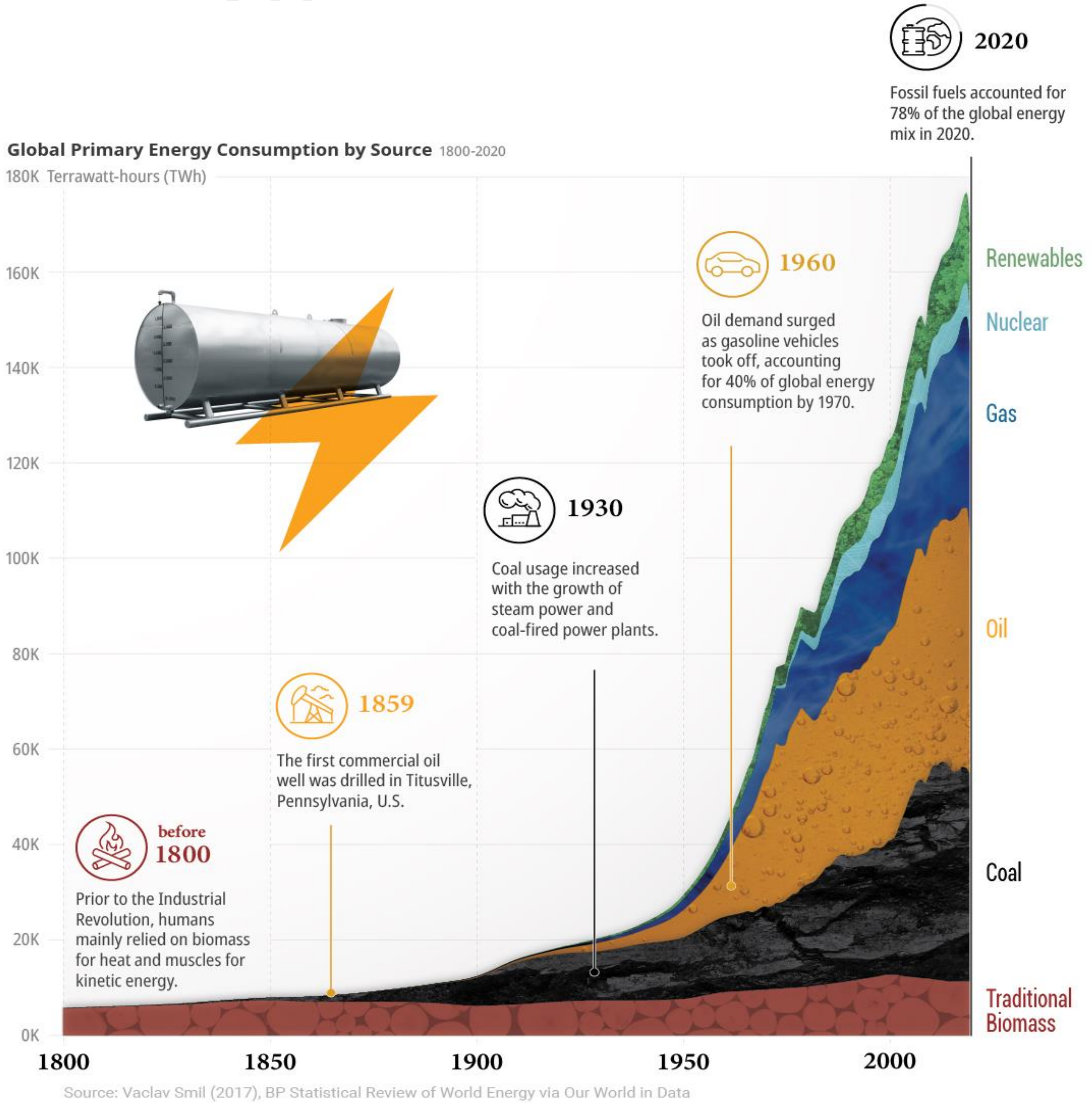


THE HISTORY OF

Energy *Transitions*

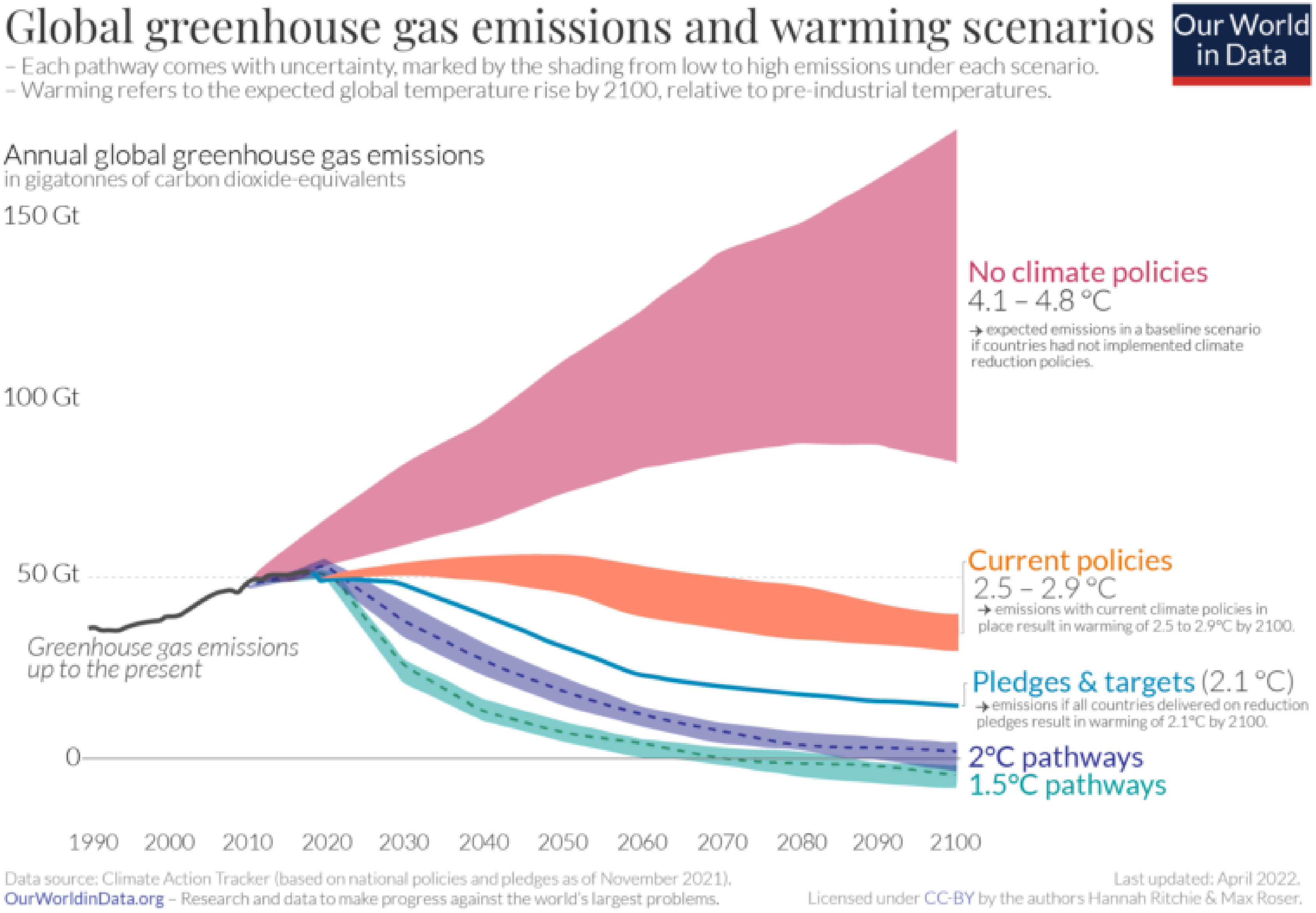


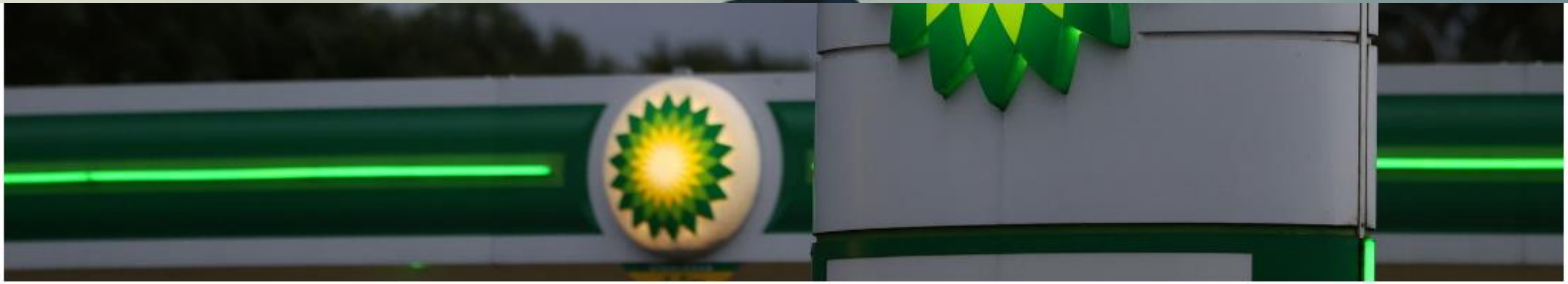




Since 2020

Instead of
decrease 6 - 7%, we
increased 4 - 5%





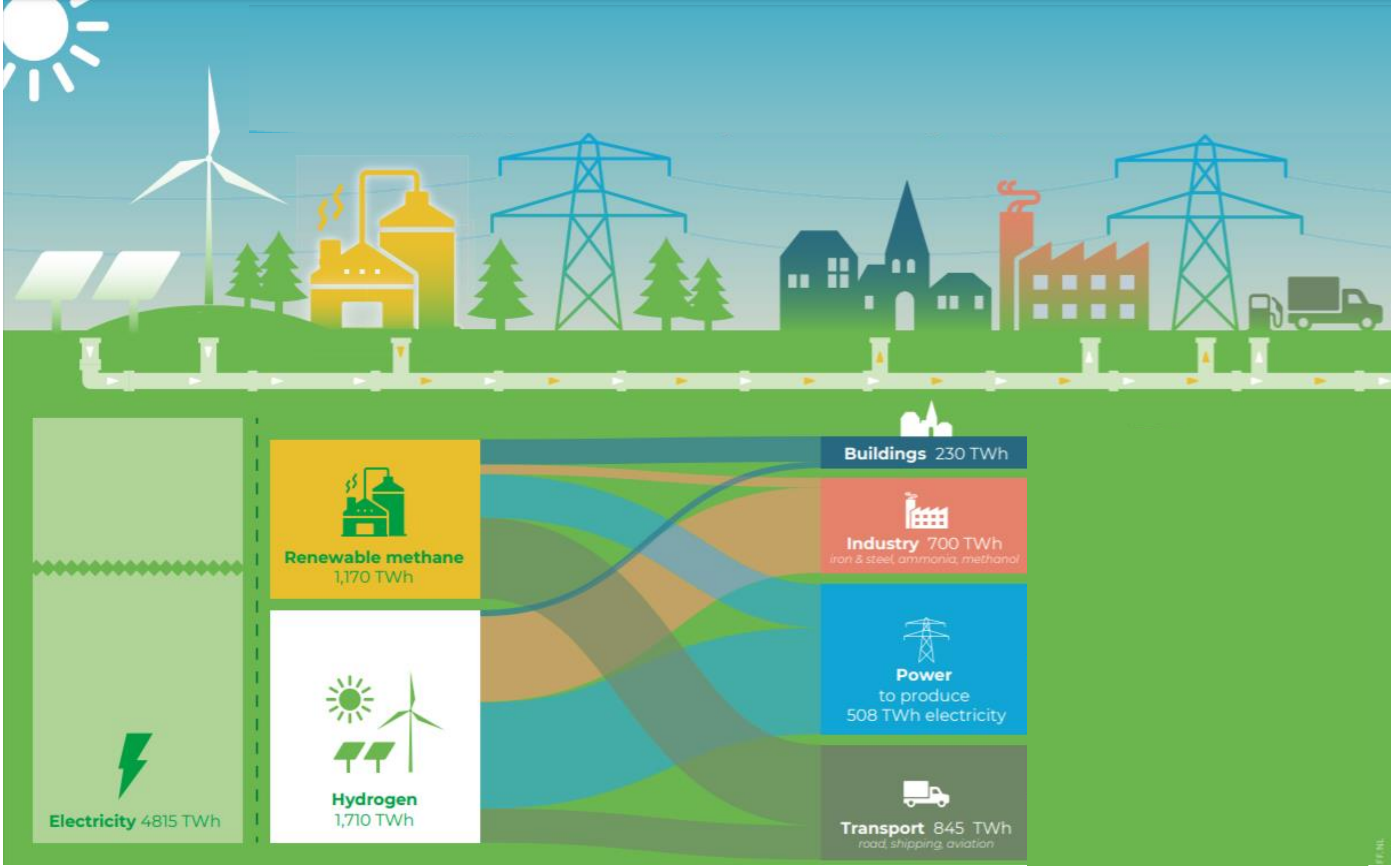
OIL AND GAS NEWS

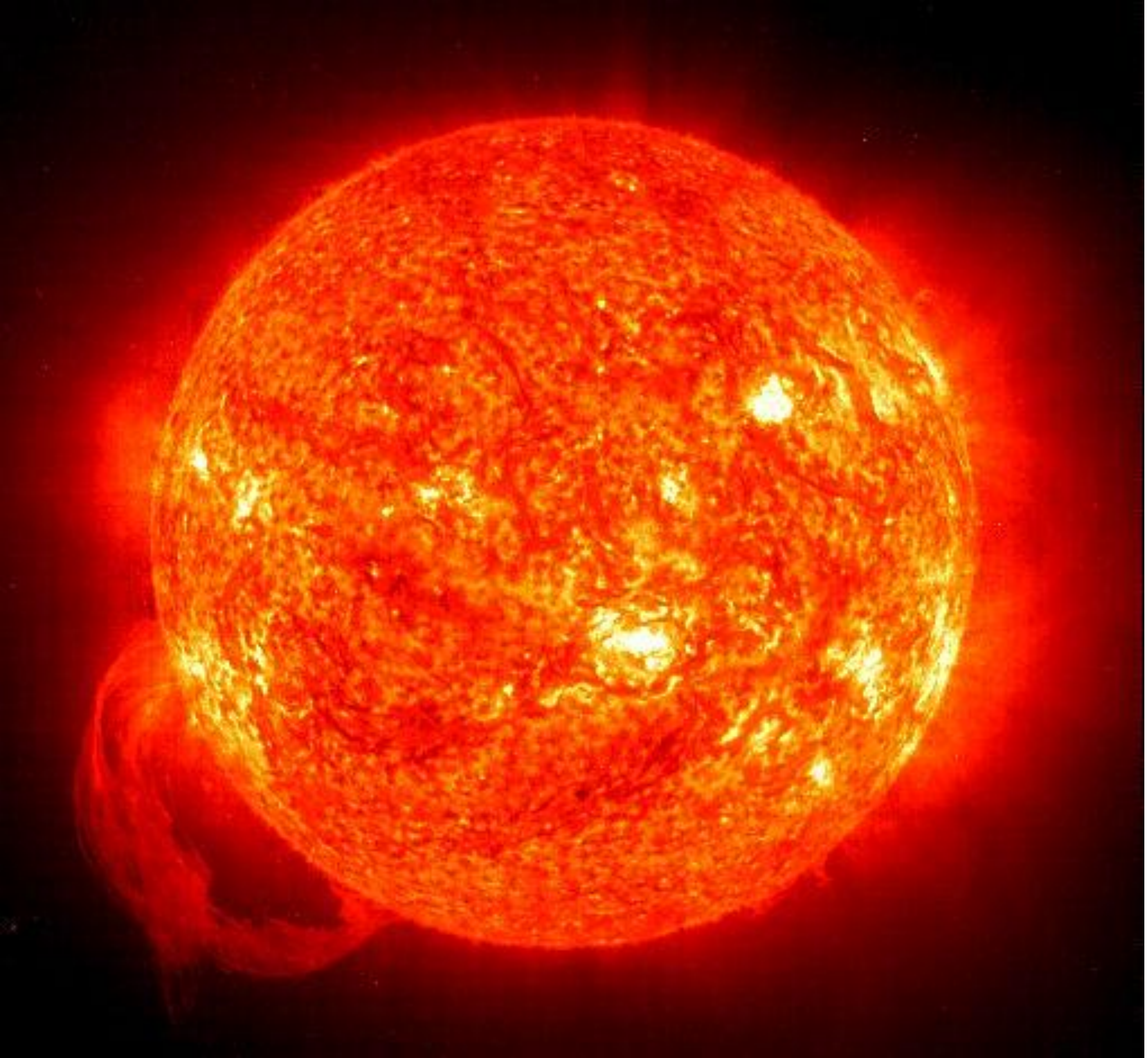
Despite Government Pledges, Fossil Fuel Subsidies Reach Record $1.3 Trillion, Casting Doubt on Climate Commitments

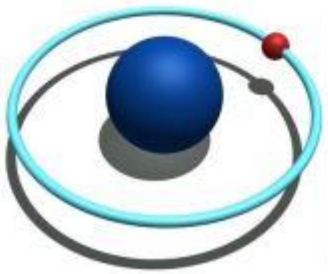
Posted 25/08/2023 12:49


Energy Revolution
Energy Transition

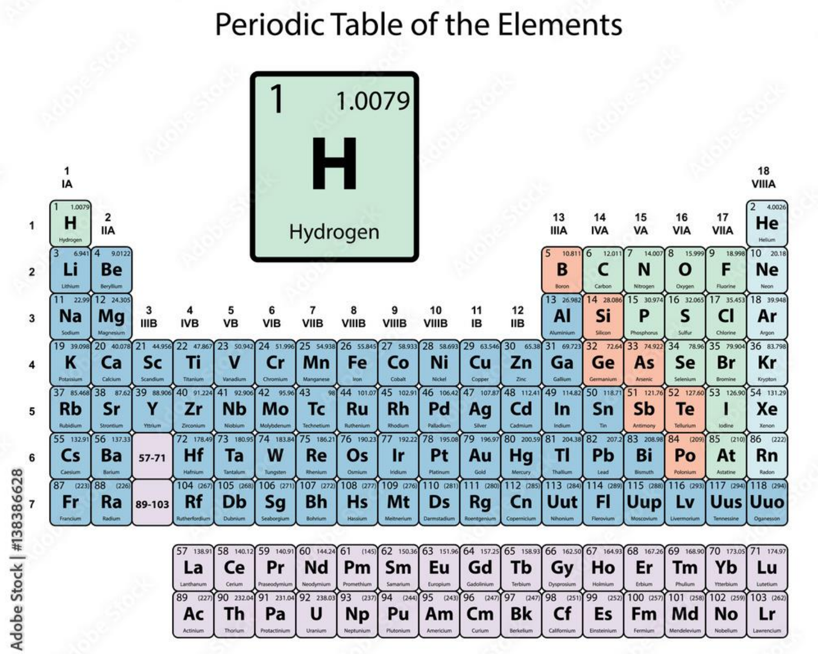
New Energies





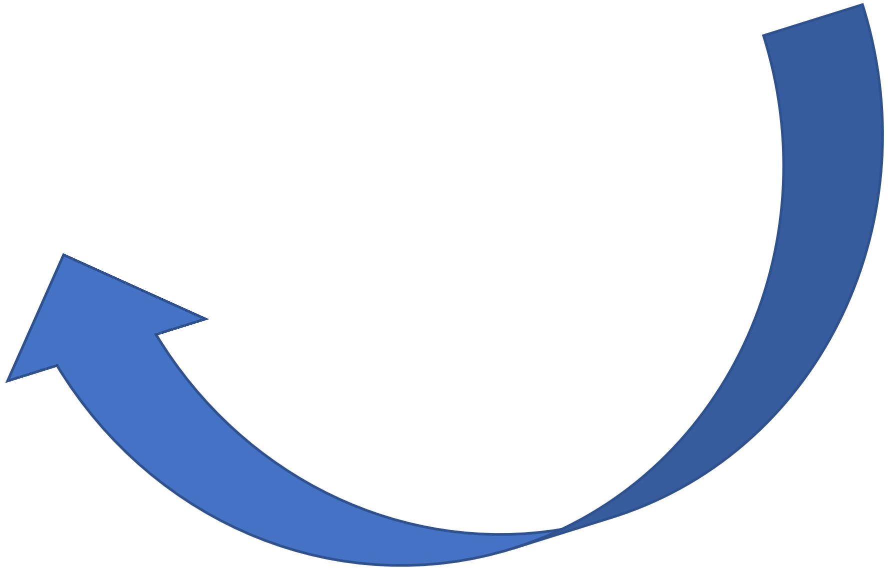



1
H
Hydrogen
1.00794

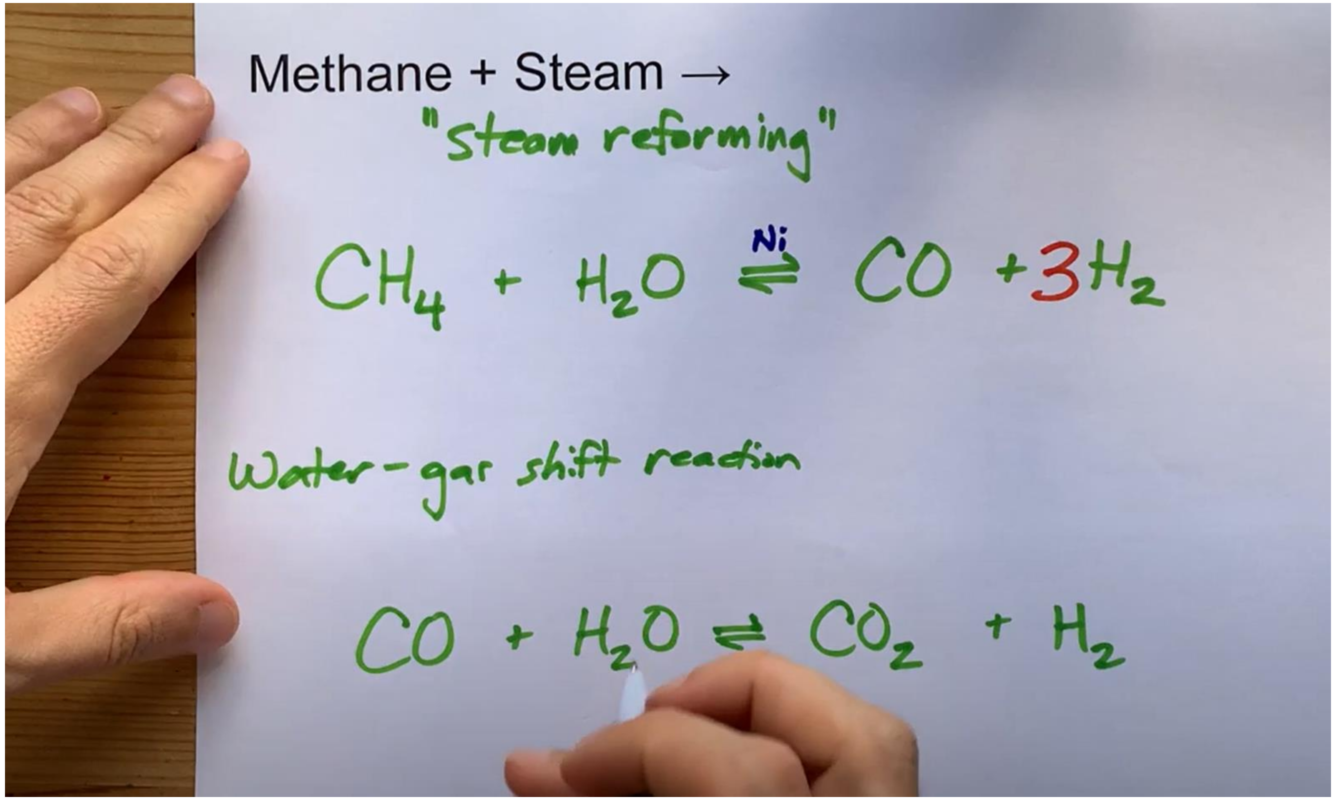

Periodic Table of the Elements
1
1.0079
H
Hydrogen
H He
Li Be B C N O F Ne
Na Mg Al Si P S Cl Ar
K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
Cs Ba 57-71 Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
Fr Ra 89-103 Rf Db Sg Bh Hs Mt Ds Rg Cn Uut Fl Uup Lv Uus Uuo
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Ac Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr
Adobe Stock | #138386628

H_2 on Earth

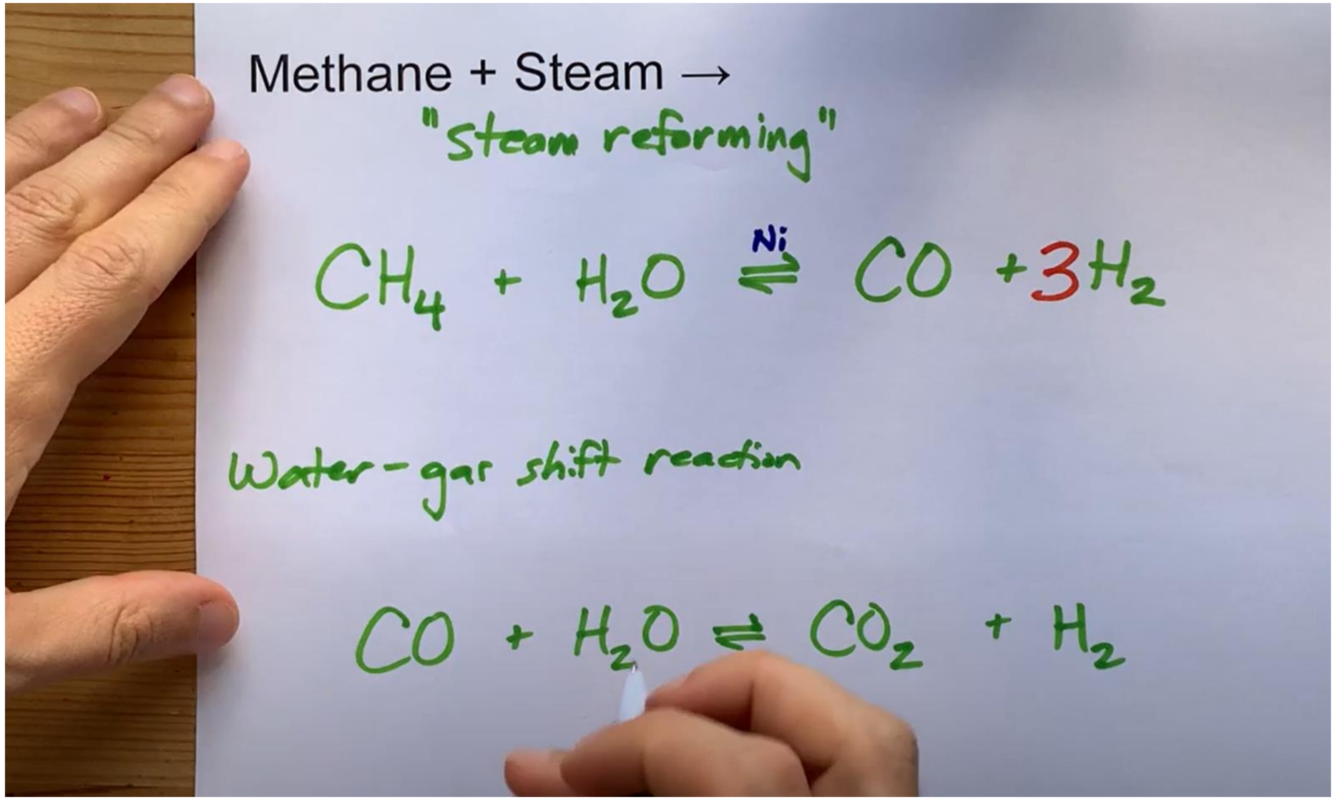
H_2O



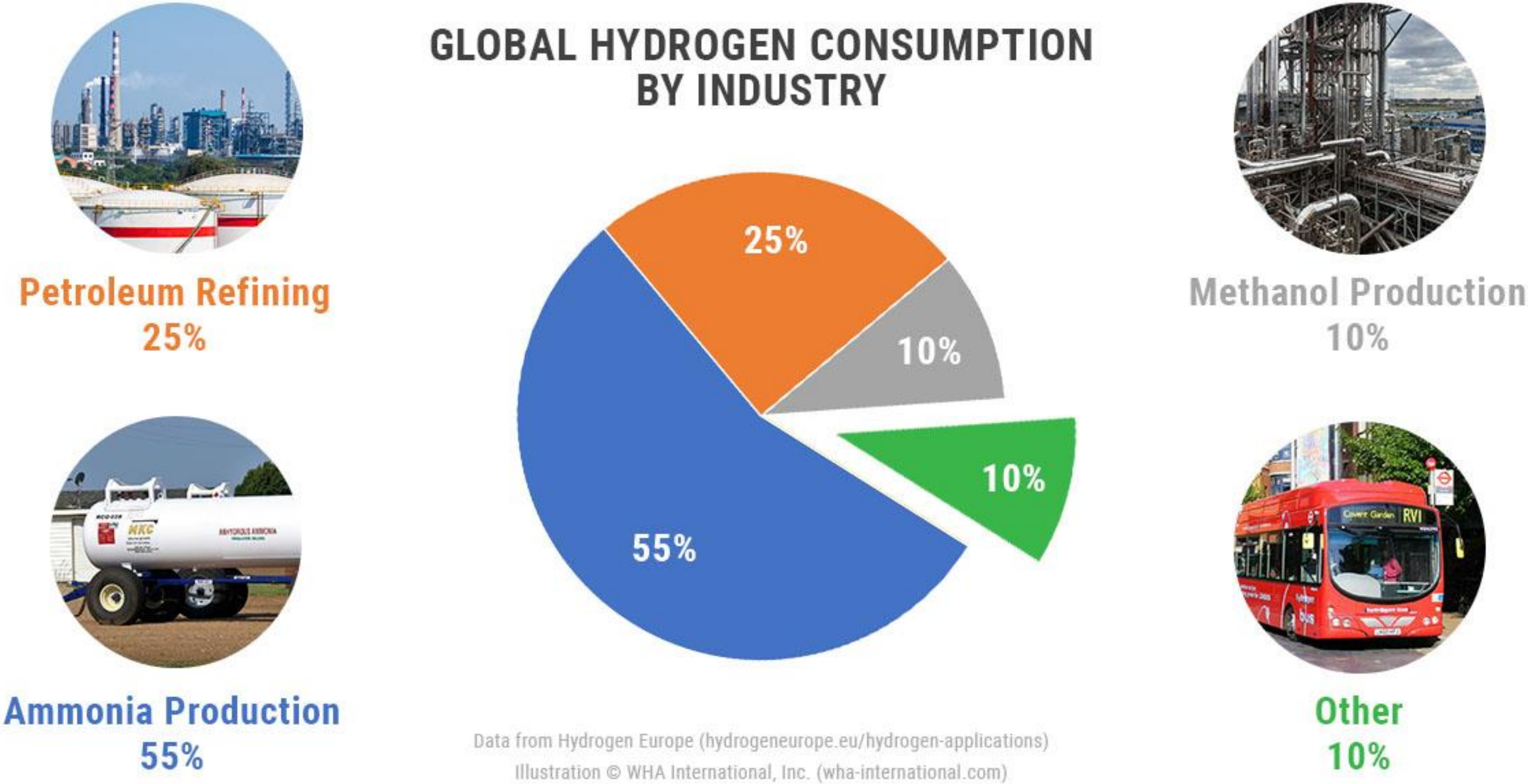
H_2 Production



H_2 Production

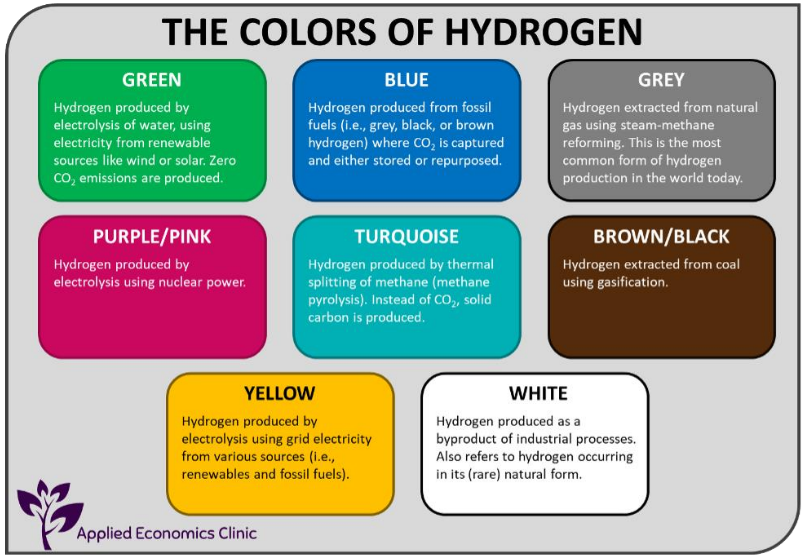


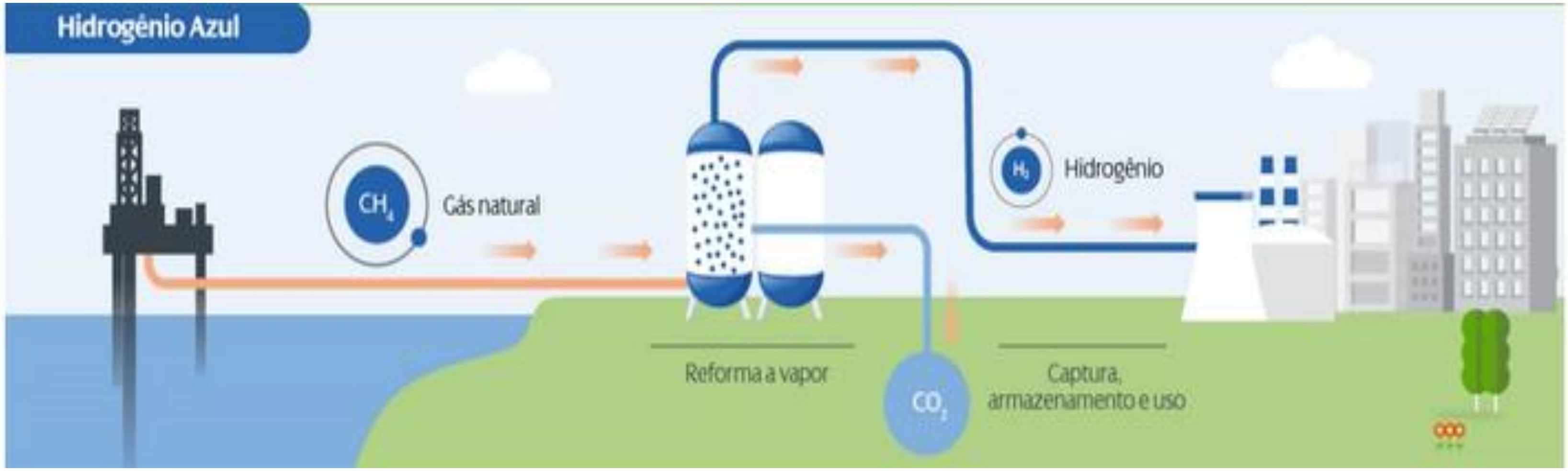
CO_2 Emissions


GLOBAL HYDROGEN CONSUMPTION
BY INDUSTRY
25%
10%
10%
55%
Petroleum Refining
25%
Ammonia Production
55%
Methanol Production
10%
Other
10%
Data from Hydrogen Europe (hydrogeneurope.eu/hydrogen-applications)
Illustration © WHA International, Inc. (wha-international.com)

Synthetic fertilizer and pesticides are fossil fuels

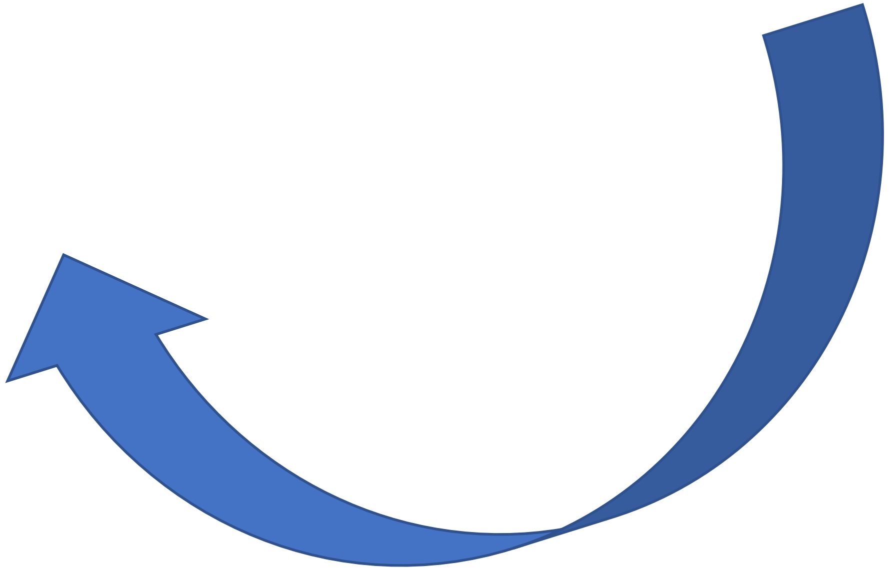
H_2 in colors

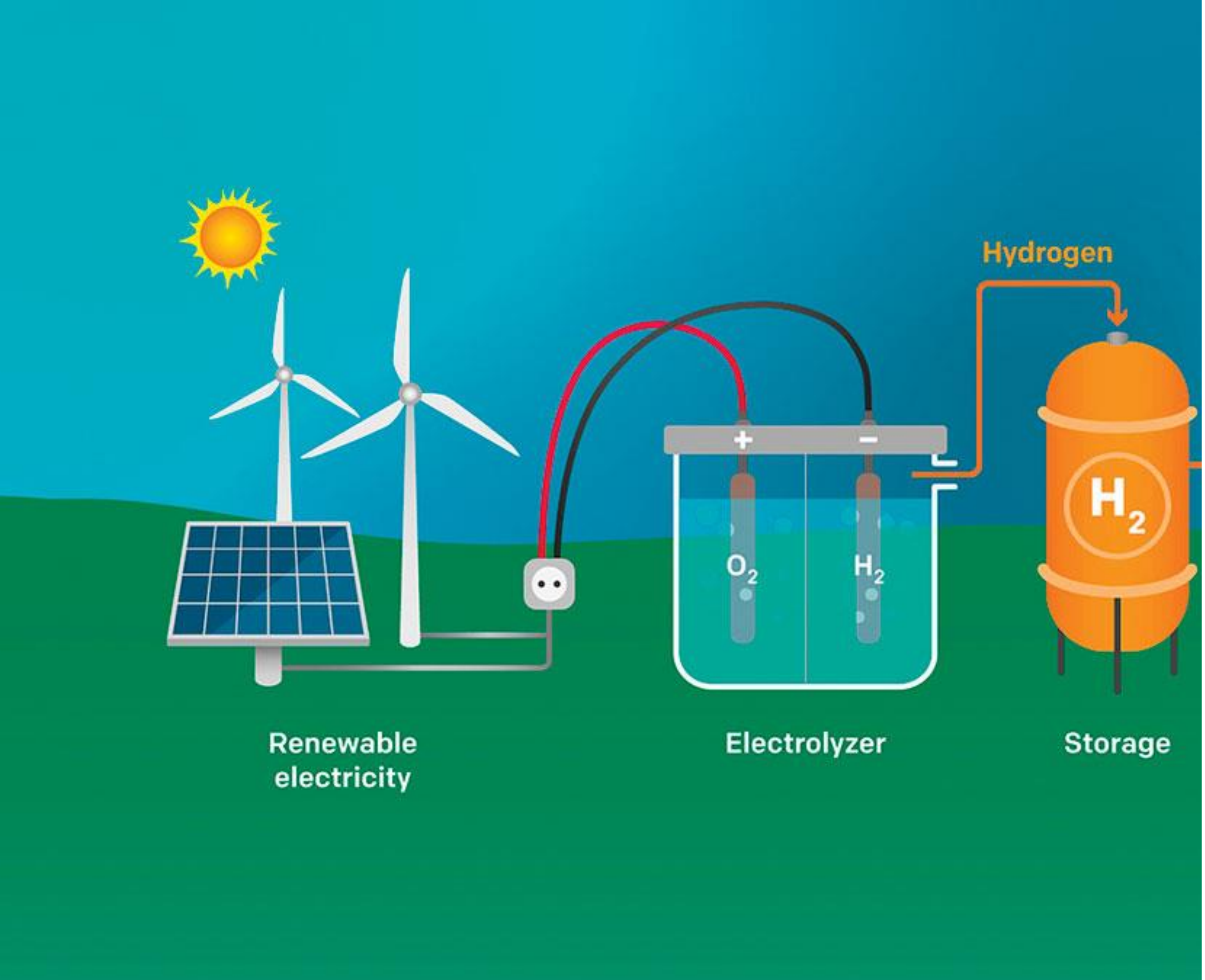

THE COLORS OF HYDROGEN
GREEN
Hydrogen produced by electrolysis of water, using electricity from renewable sources like wind or solar. Zero CO2 emissions are produced.
BLUE
Hydrogen produced from fossil fuels (i.e., grey, black, or brown hydrogen) where CO2 is captured and either stored or repurposed.
GREY
Hydrogen extracted from natural gas using steam-methane reforming. This is the most common form of hydrogen production in the world today.
PURPLE/PINK
Hydrogen produced by electrolysis using nuclear power.
TURQUOISE
Hydrogen produced by thermal splitting of methane (methane pyrolysis). Instead of CO2, solid carbon is produced.
BROWN/BLACK
Hydrogen extracted from coal using gasification.
YELLOW
Hydrogen produced by electrolysis using grid electricity from various sources (i.e., renewables and fossil fuels).
WHITE
Hydrogen produced as a byproduct of industrial processes. Also refers to hydrogen occurring in its (rare) natural form.
Applied Economics Clinic


Hidrogênio Azul
CH4
Gás natural
H2
Hidrogênio
Reforma a vapor
CO2
Captura, armazenamento e uso

H_2 on Earth

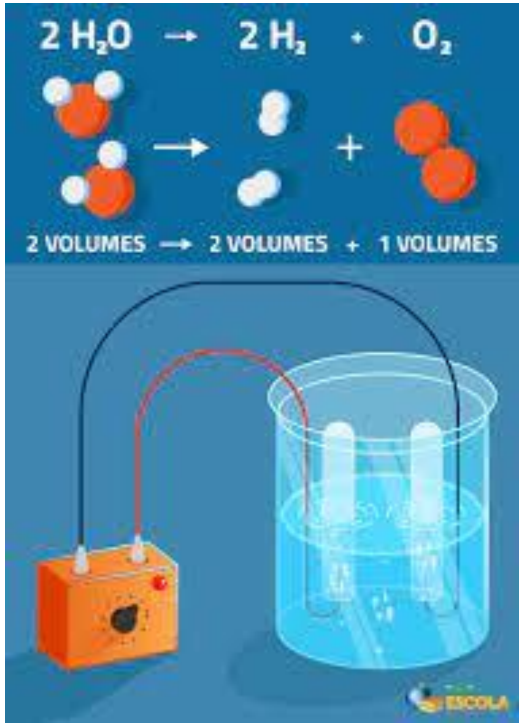
H_2O





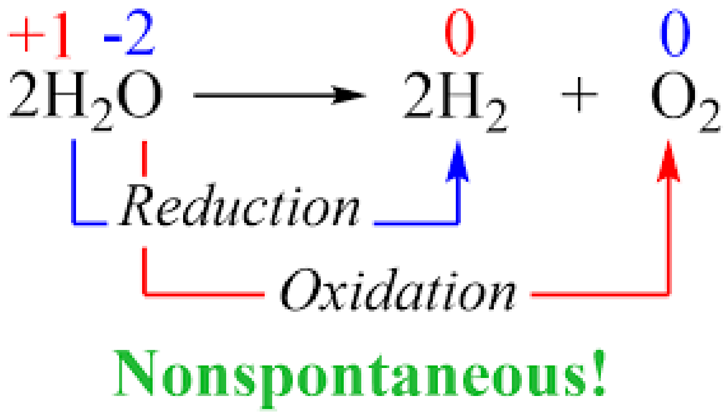
1.3 V

Water Electrolysis



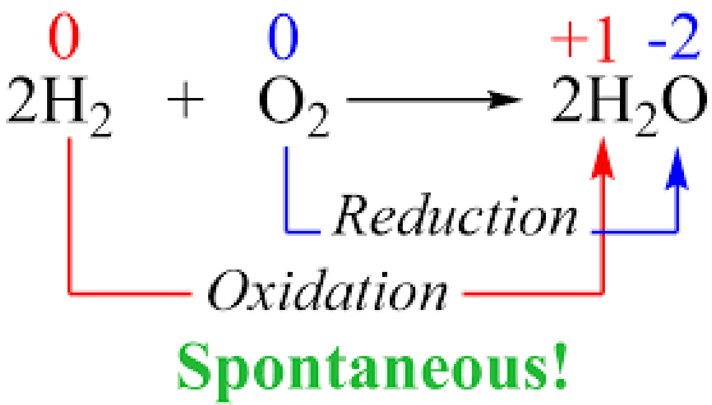
1.3 V

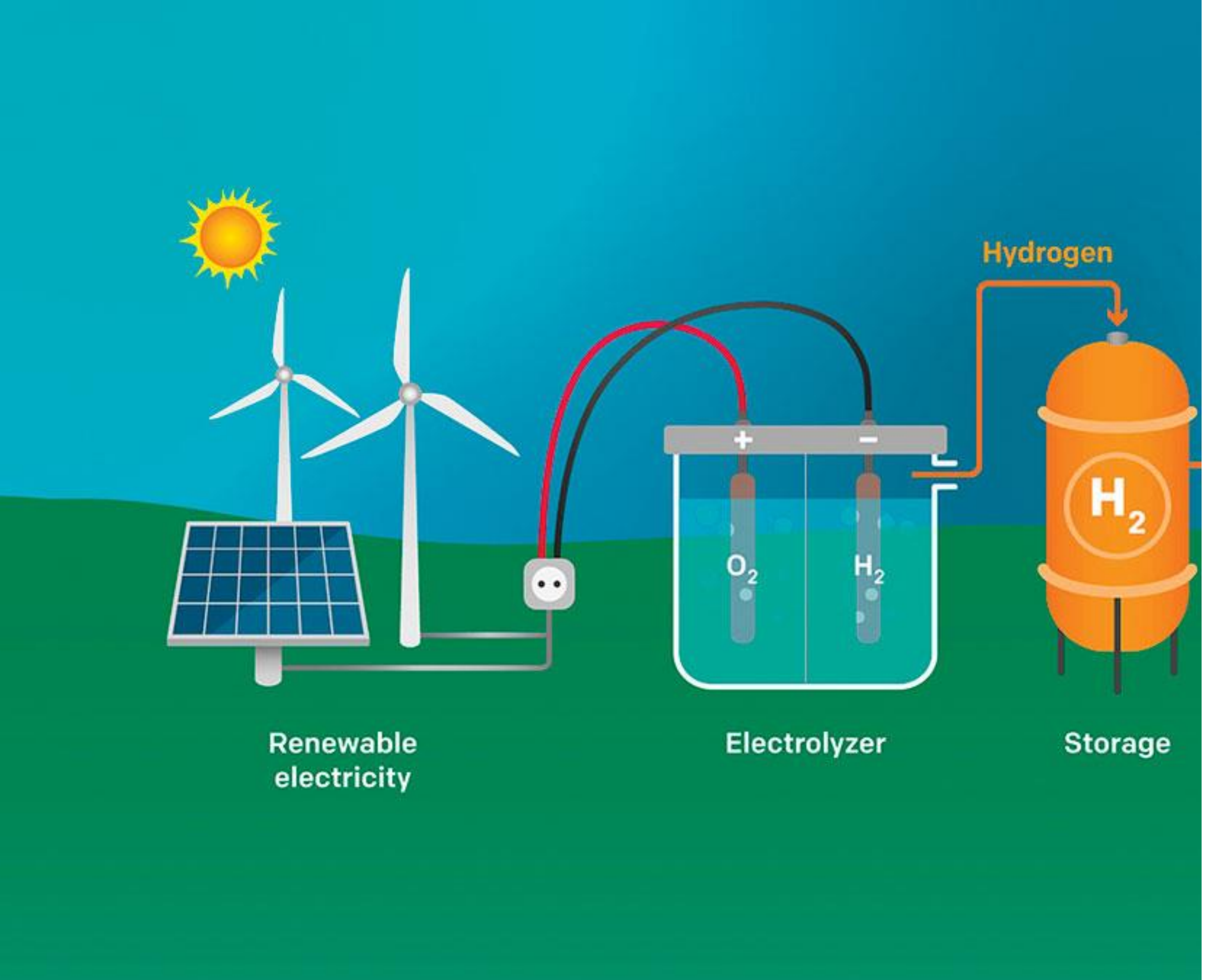
Water Electrolysis



1.2 V

Fuel Cell





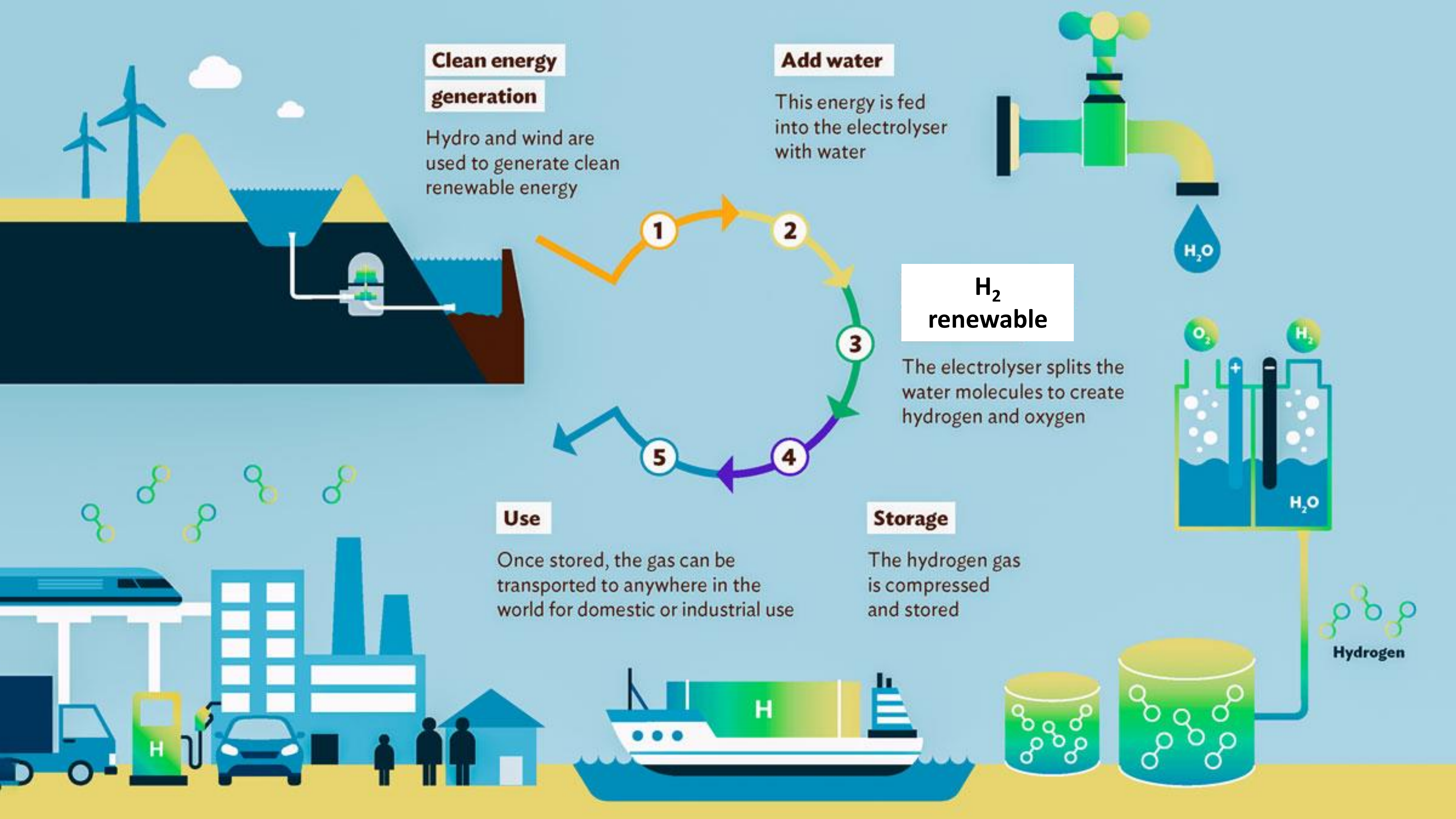
Electricity

Transport

Industry

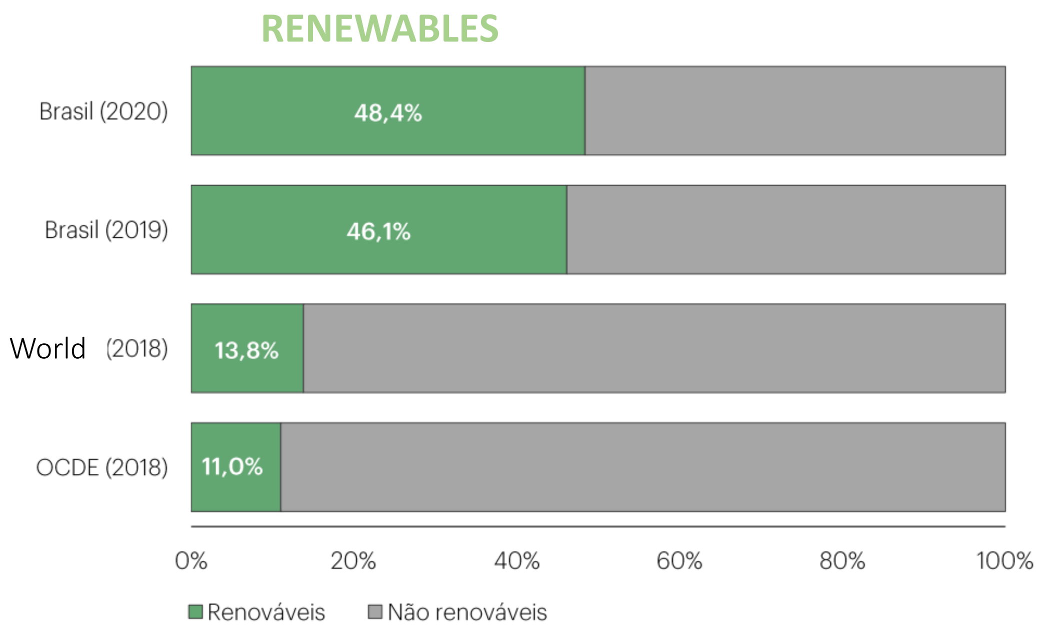
Agriculture

Sustainable H_2


Clean energy generation
Hydro and wind are used to generate clean renewable energy
Add water
This energy is fed into the electrolyser with water
H_2O
H_2 renewable
O_2
H_2
1
2
3
The electrolyser splits the water molecules to create hydrogen and oxygen
4
5
H_2O
Use
Once stored, the gas can be transported to anywhere in the world for domestic or industrial use
Storage
The hydrogen gas is compressed and stored
Hydrogen
H
H

Sustainable H_2

Brazilian Energy Mix



GDP (US$ million) by country

	Country/Territory	Region	IMF[10][12]	
			Estimate	Year
1	United States	Americas	25,346,805	2022
2	China	Asia	19,911,593	[n 2]2022
3	Japan	Asia	4,912,147	2022
4	Germany	Europe	4,256,540	2022
5	India	Asia	3,534,743	2022
6	United Kingdom	Europe	3,376,003	2022
7	France	Europe	2,936,702	2022
8	Canada	Americas	2,221,218	2022
9	Italy	Europe	2,058,330	2022
10	Brazil	Americas	1,833,274	2022
11	Russia	Europe	1,829,050	2022
12	South Korea	Asia	1,804,680	2022
13	Australia	Oceania	1,748,334	2022
14	Iran	Asia	1,739,012	2022
15	Spain	Europe	1,435,560	2022

Brazilian Energy Mix

2020

RENEWABLES 48,4%

sugar cane

Biomassa da Cana
19,1%

hydro

Hidráulica[1]
12,6%

wood

Lenha e Carvão Vegetal
8,9%

Outras renováveis
7,7%

NON RENEWABLES 51,6%

Petróleo e derivados
33,1%

Gás Natural
11,8%

Carvão Mineral
4,9%

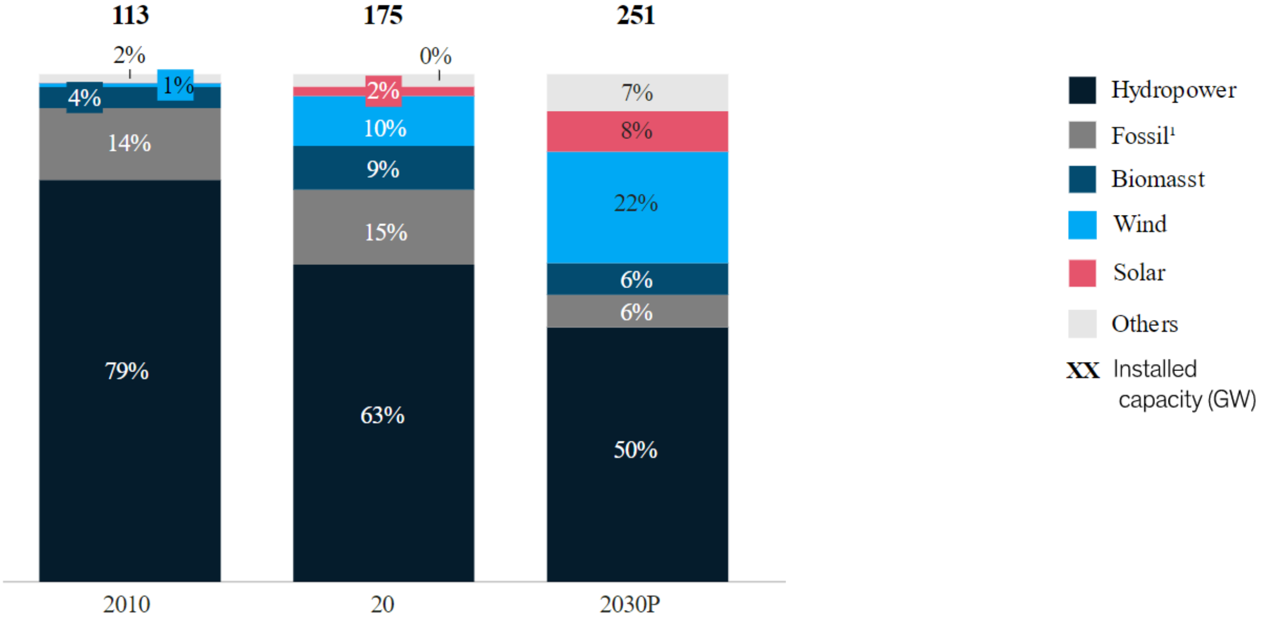
Urânio
1,3%

Outras não renováveis
0,6%

Electricity in Brazil

Brazil has a clean generation infrastructure with only ~15% of installed capacity from fossil

Brazil electricity in stalled capacity by source (%)



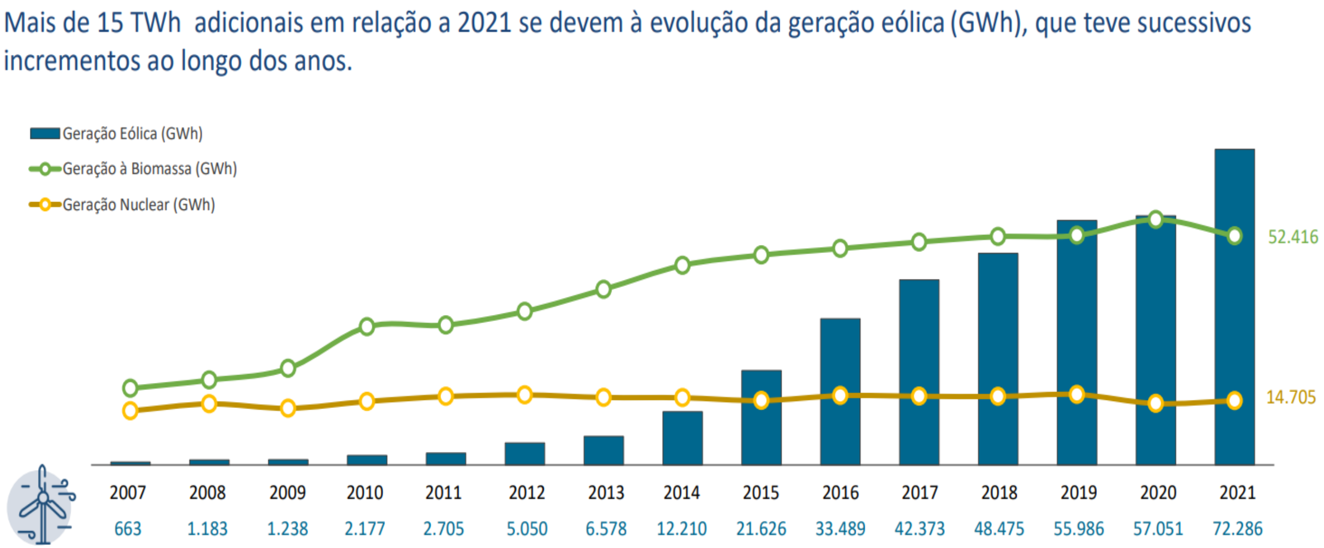
2021

180 GW

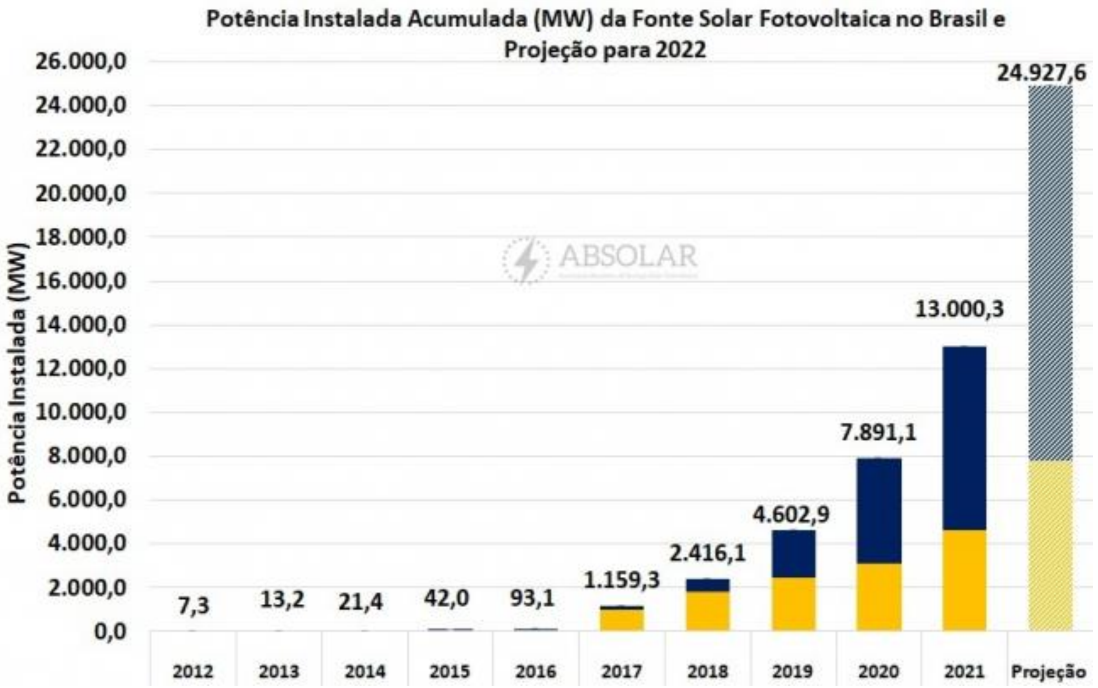
84% Renewable

Renewables in Brazil

Wind

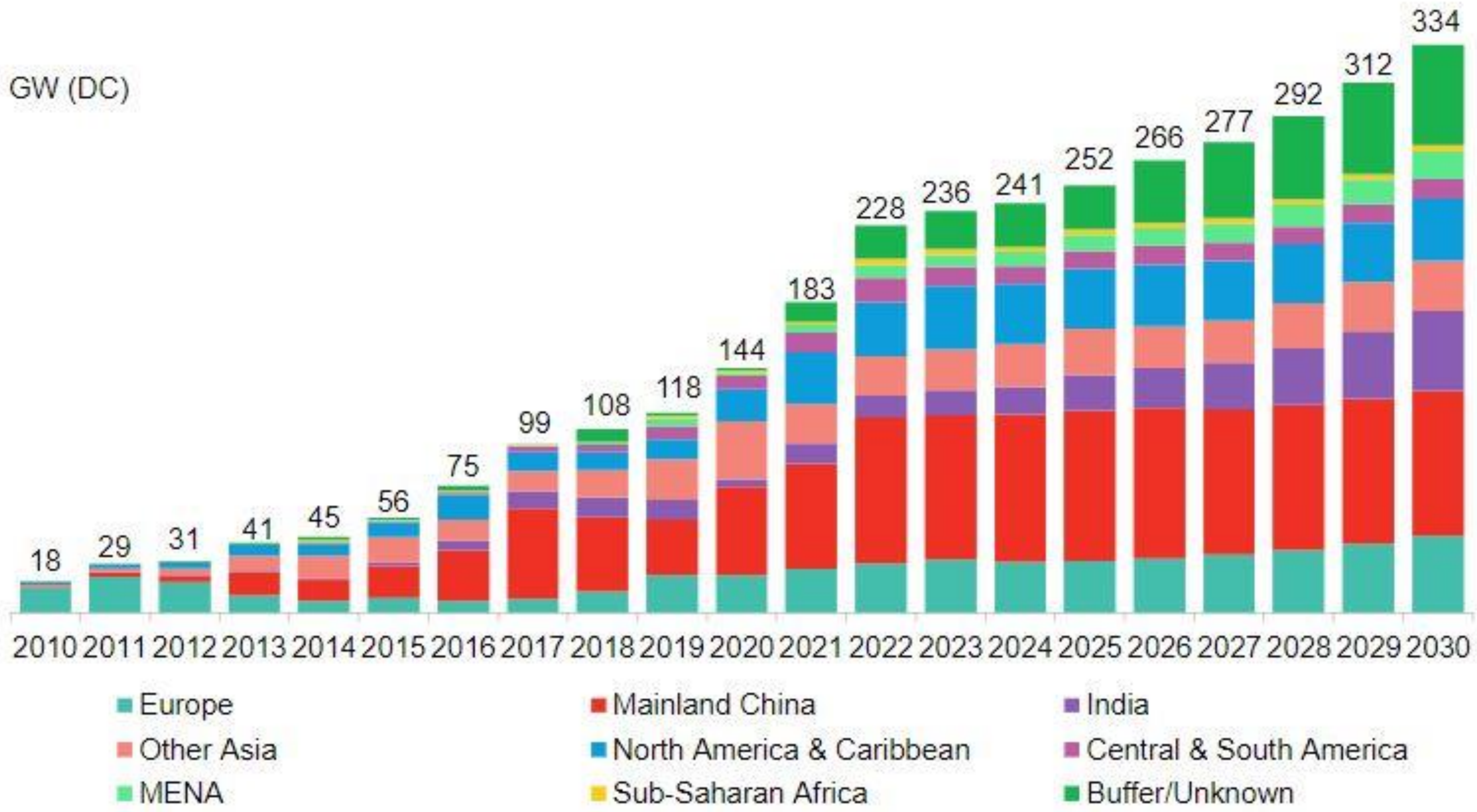


Photovoltaic



Total potential for renewable energy should not be an issue in 2040, as by then the main potential sources, wind and solar, should be able to supply 100% of the demand for green hydrogen.

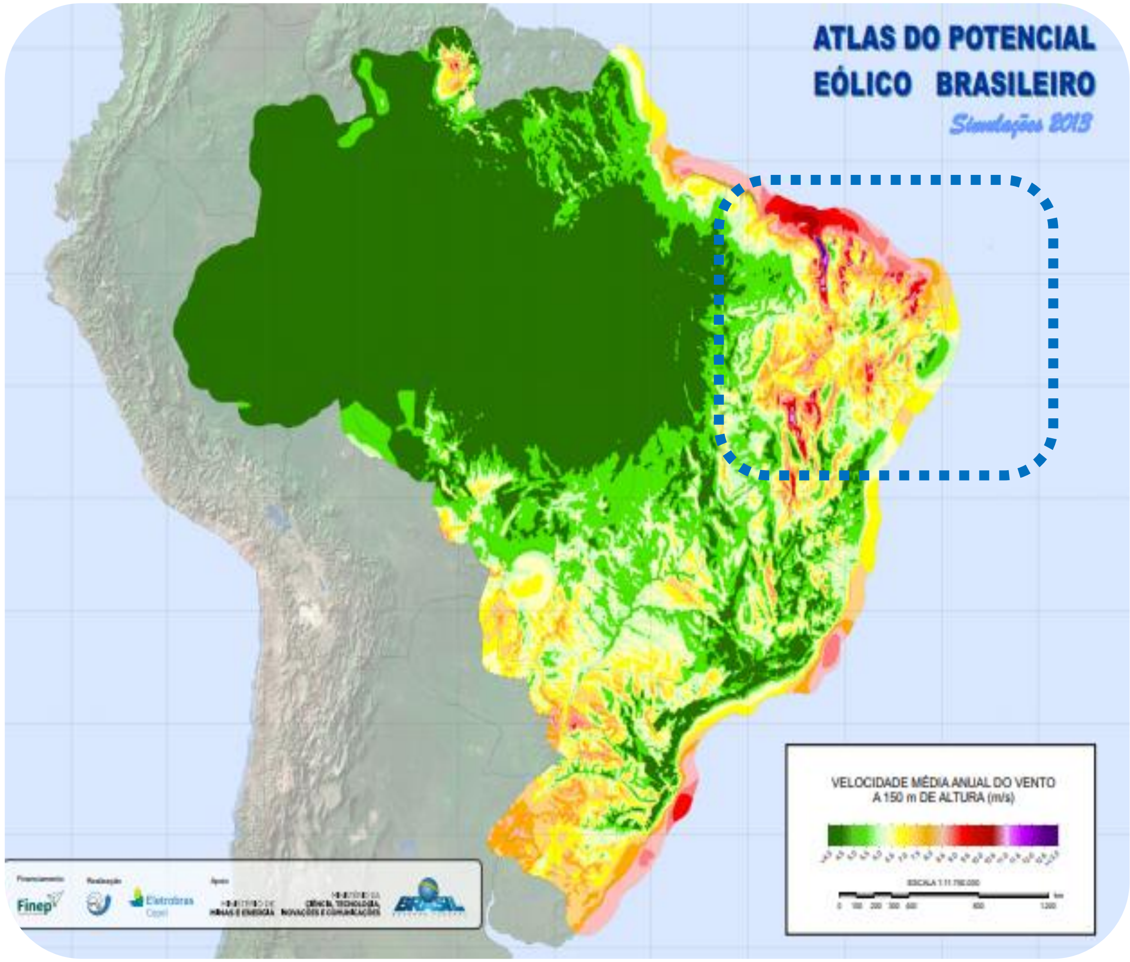
Figure 1: Global PV installation estimate and forecast, as of January 2022



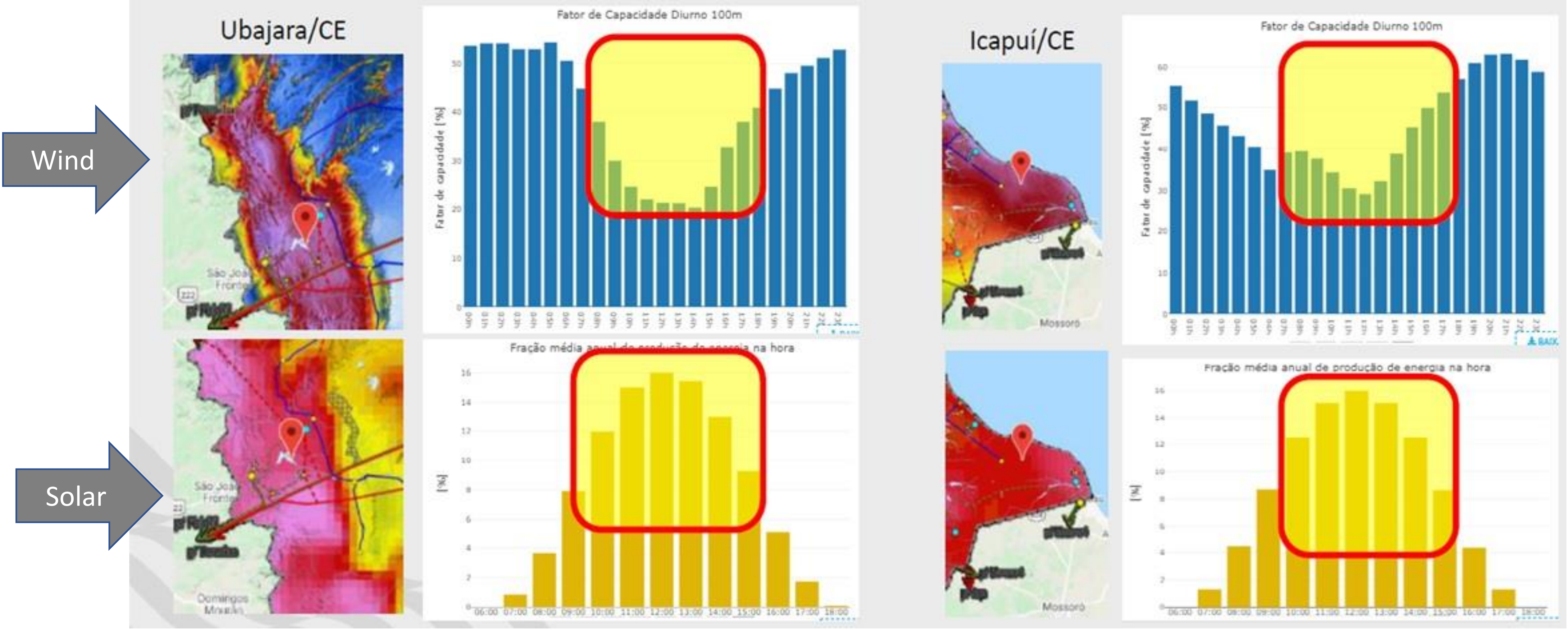
Source: BloombergNEF

Solar PV and Wind

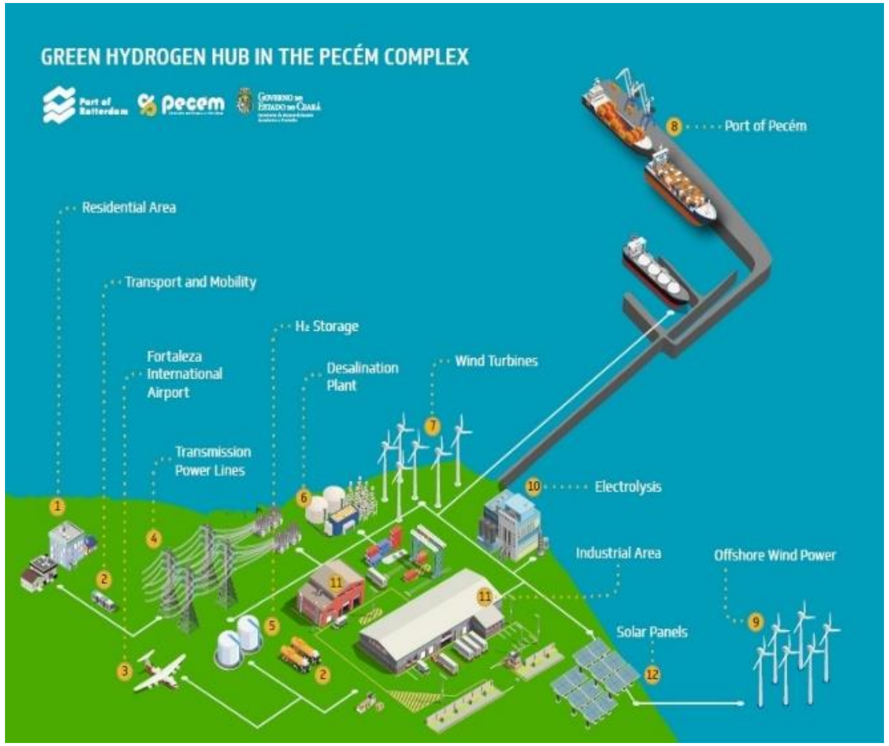
Wind



Solar PV


Wind
Solar
Ubajara/CE
Icapuí/CE
Fator de Capacidade Diurno 100m
Fator de capacidade [%]
Fração média anual de produção de energia na hora
[%]
Mossoró

Pecém - CE
Hidrogênio



GOVERNO DO ESTADO DO CEARÁ
Secretaria do Desenvolvimento Econômico e Trabalho

FONTE: SEDET / CE
www.sedet.ce.gov.br

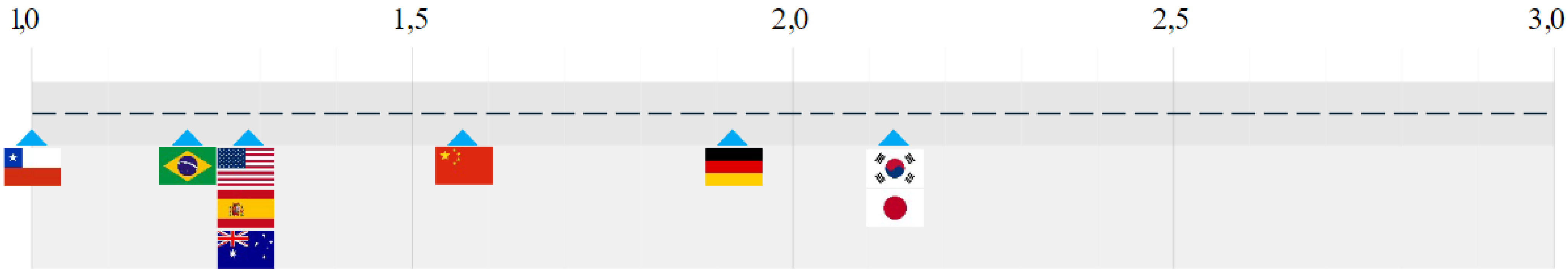
Privileged Geographic Localization:

Best location in Brazils North and Northeast. Close to the most important world markets.

Price H_2

Brazil is among the most competitive green H2 export players globally

LCOH Benchmark, 2030 US D/ kgH2



Countries deep dives
(specific sites with internal studies from each country)

Source: Team Analysis

McKinsey & Company

H2Brasil

USD 15 – 20 billion opportunity
by 2040

Up to 2030, € 430 billion invested in H_2 in Europe

FIGURE 8 - PILLARS OF THE NATIONAL HYDROGEN PROGRAM

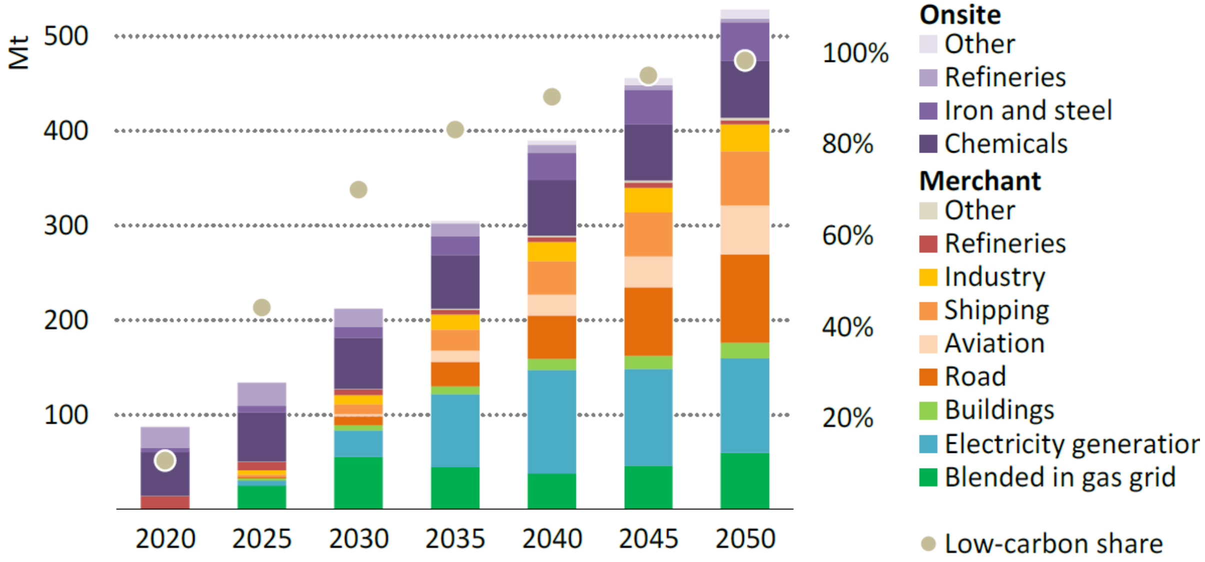
Net Zero by 2050

A Roadmap for the Global Energy Sector

International Energy Agency

Global hydrogen use expands from less than 90 Mt in 2020 to more than 200 Mt in 2030

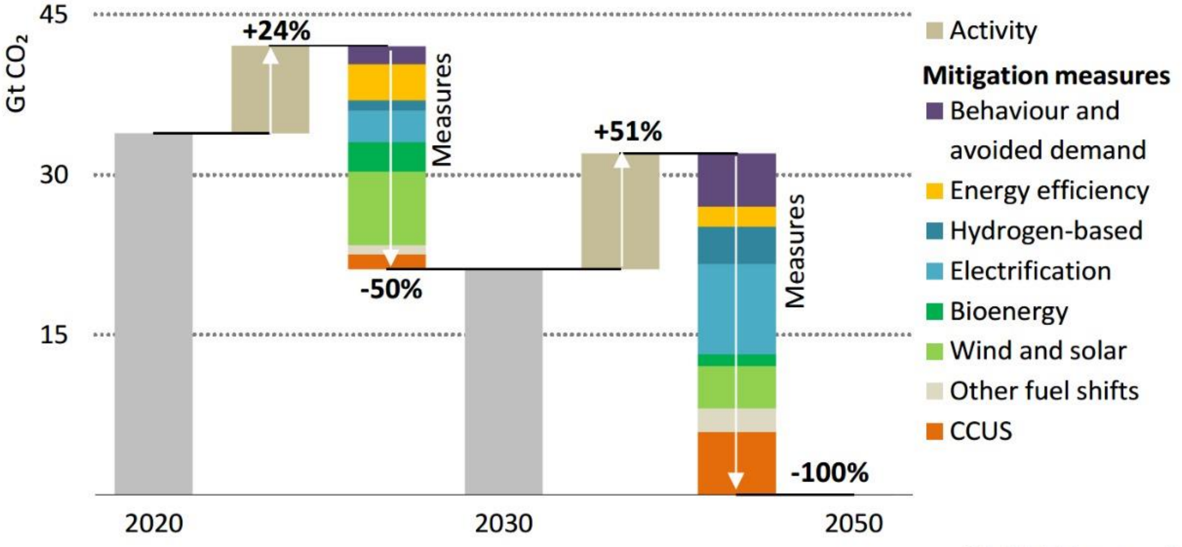
Figure 2.19 ▷ Global hydrogen and hydrogen-based fuel use in the NZE



The initial focus for hydrogen is to convert existing uses to low-carbon hydrogen; hydrogen and hydrogen-based fuels then expand across all end-uses

Note: Includes hydrogen and hydrogen contained in ammonia and synthetic fuels.

Figure 2.12 ▷ Emissions reductions by mitigation measure in the NZE, 2020-2050



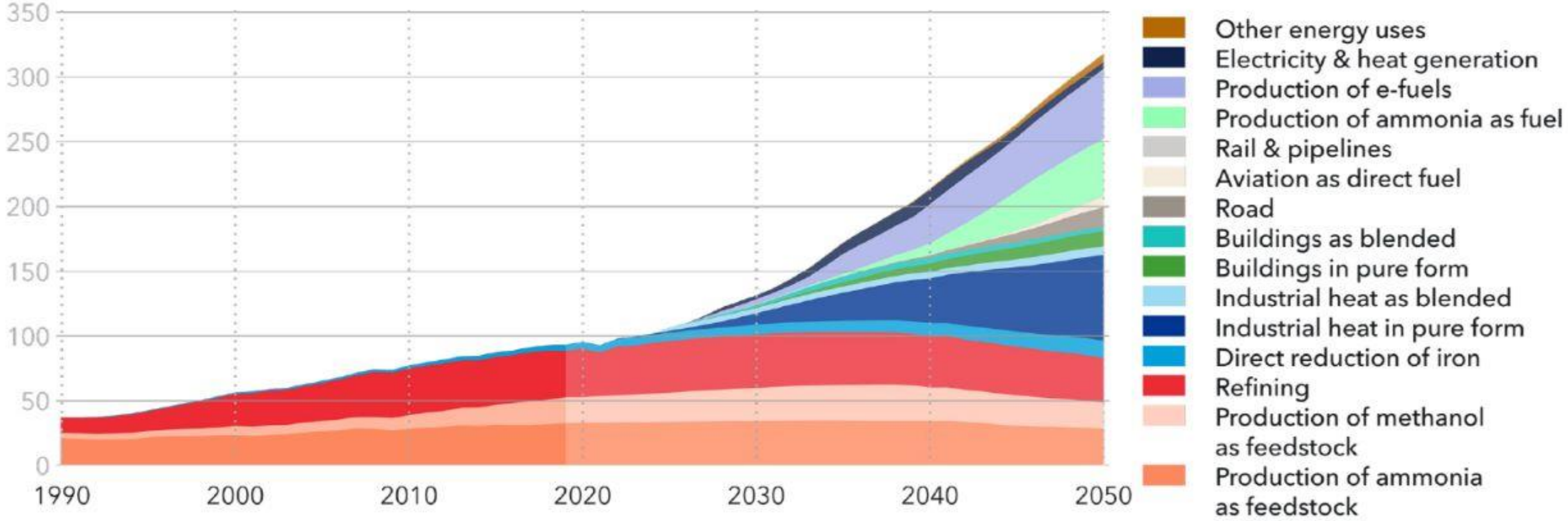
Solar, wind and energy efficiency deliver around half of emissions reductions to 2030 in the NZE, while electrification, CCUS and hydrogen ramp up thereafter

Notes: Activity = energy service demand changes from economic and population growth. Behaviour = energy service demand changes from user decisions, e.g. changing heating temperatures. Avoided demand = energy service demand changes from technology developments, e.g. digitalisation. Other fuel shifts = switching from coal and oil to natural gas, nuclear, hydropower, geothermal, concentrating solar power or marine.

FIGURE 5.1

Global hydrogen demand by sector

Units: MtH_2/yr



Does not include hydrogen use in residual form from industrial processes. Historical data sources: IEA Future of Hydrogen (2019), IEA Global Hydrogen Review (2021), USGS Mineral Commodity Summaries (1990-2022), IFA (2022)

Ethanol and Hydrogen

Ethanol in Brazil

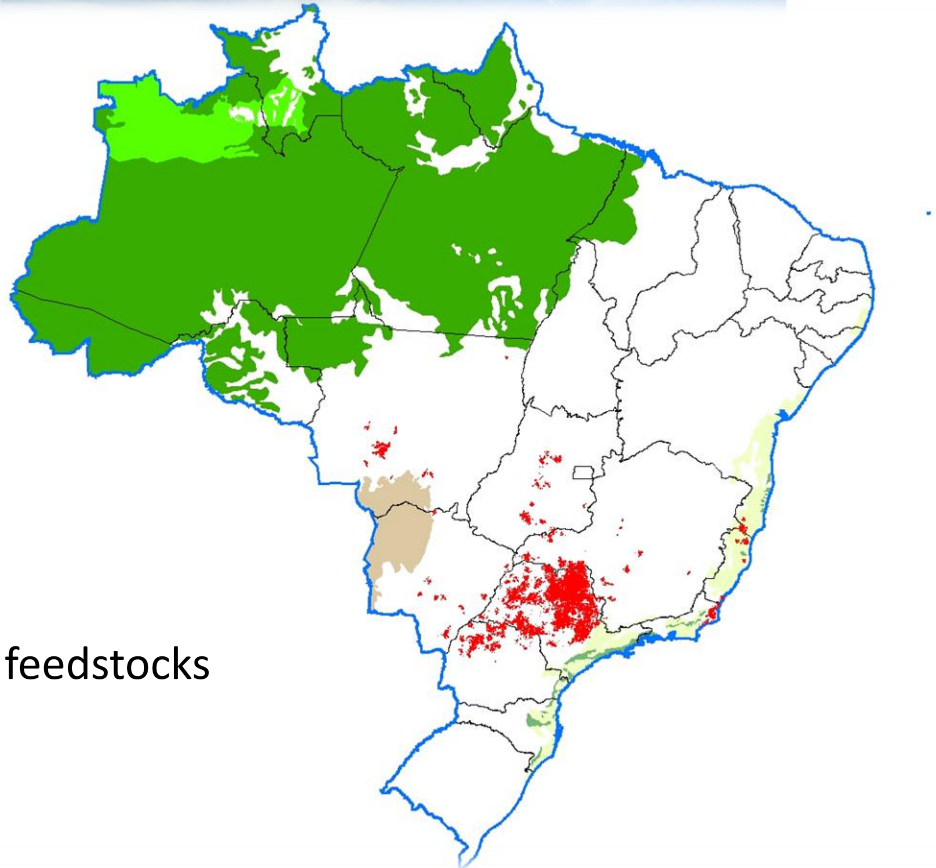
- Non -toxic

- Efficient and available biofuel

- No composition variation

- No sulphur contamination

Ethanol in Brazil



- Renewable
- No competition with food crops
- Much more eficiente than other feedstocks
    - Productivity/area
    - Cost
    - Energetic balance (7 J / 1 J)

Ethanol in Brazil

SIGNIFICANT REDUCTION IN EMISSIONS

nature COMMUNICATIONS

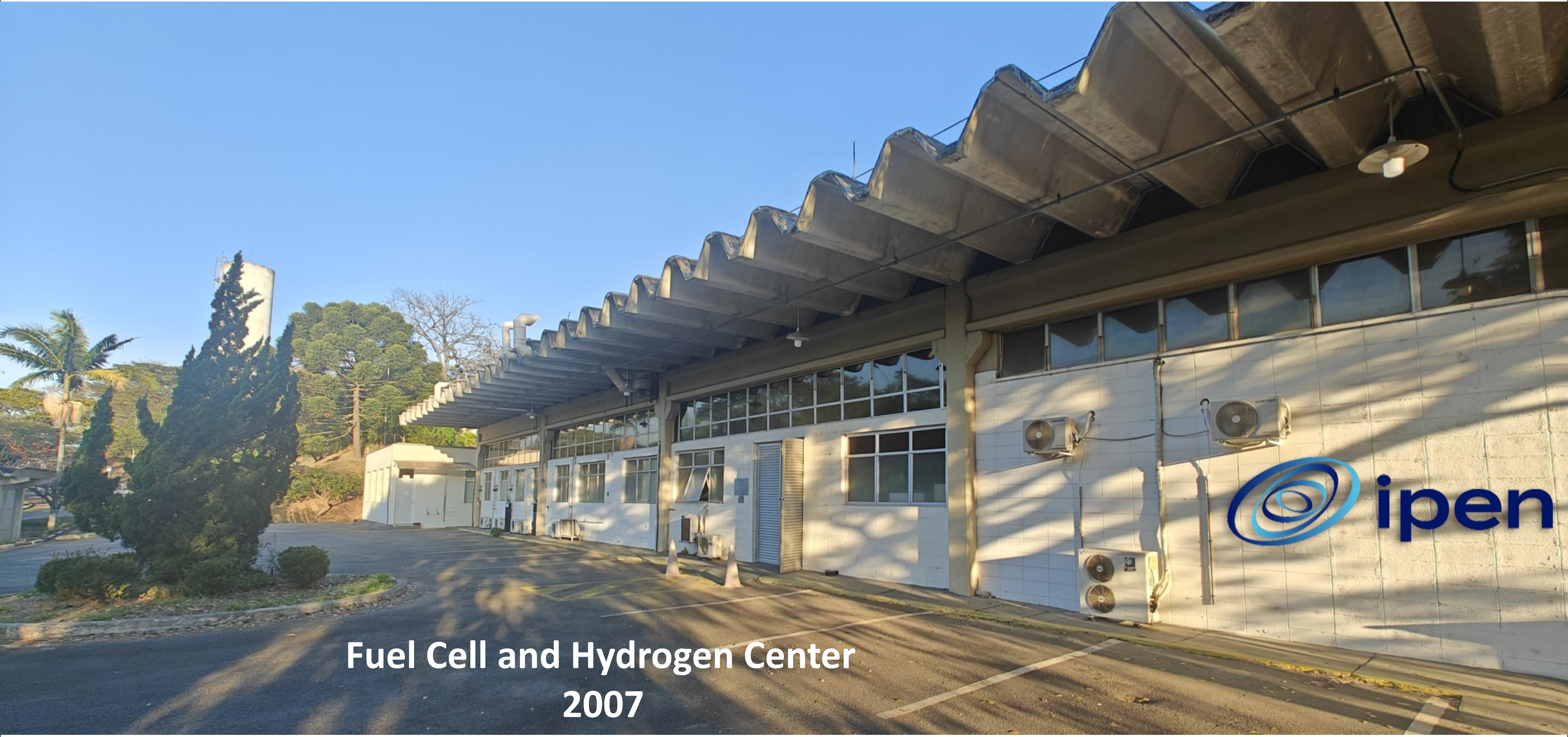
Reduced ultrafine particle levels in São Paulo's atmosphere during shifts from gasoline to ethanol use

- 90% of new cars are fuel-flex

“Ethanol, with its high energy density, likely production from renewable sources and ease of storage and transportation, is <u>almost the ideal</u> combustible for fuel cells…”

nature materials

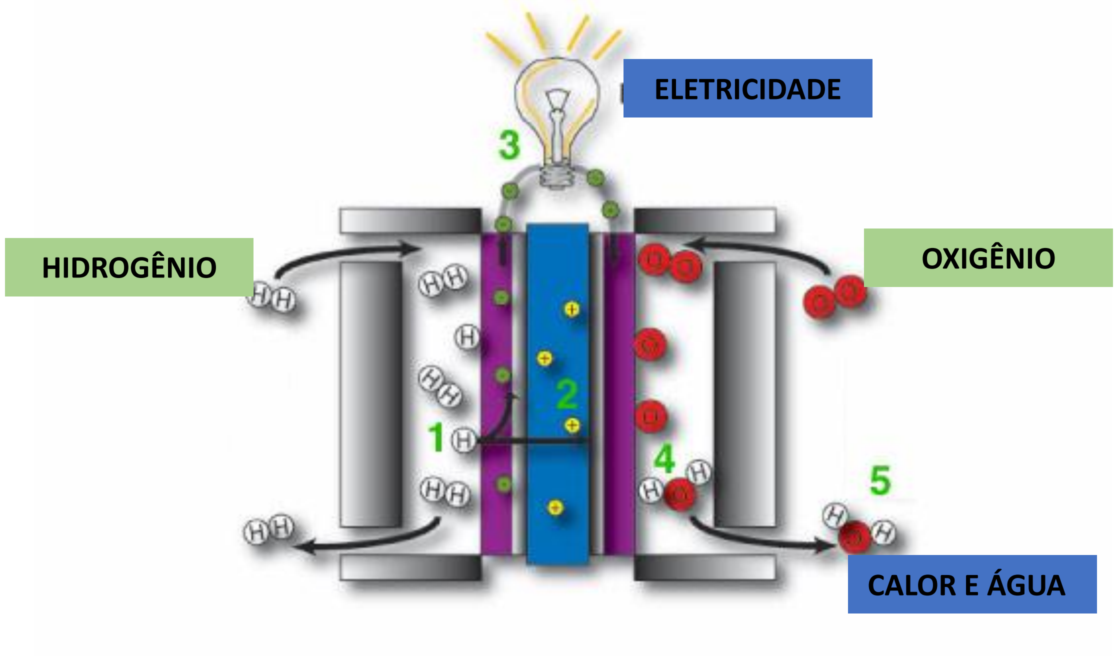
A. Kowal, et al (2009)


ipen
Fuel Cell and Hydrogen Center
2007

Células a Combustível

Fuel Cells

Conversão <u>direta</u> da energia química de um combustível em eletricidade



PEMFC	$H_2 \rightarrow 2H^+ + 2e^-$		$H^+ \rightarrow$		$2H^+ + \frac{1}{2}O_2 + 2e^- \rightarrow H_2O$
SOFC	$2O^{2-} + 2H_2 \rightarrow 2H_2O + 4e^-$		$\leftarrow 2O^{2-}$		$O_2 + 4e^- \rightarrow 2O^{2-}$

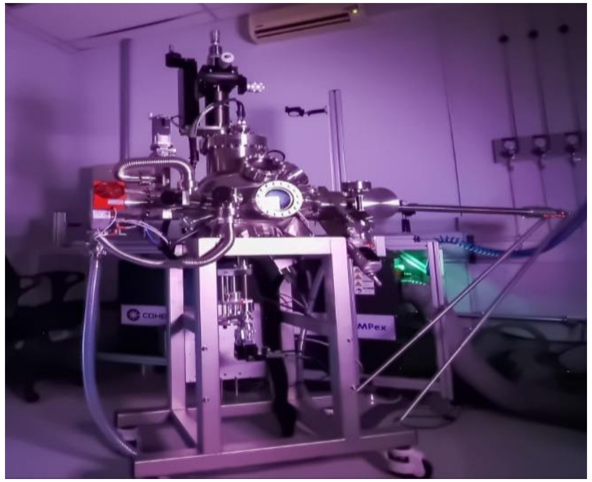
80°C

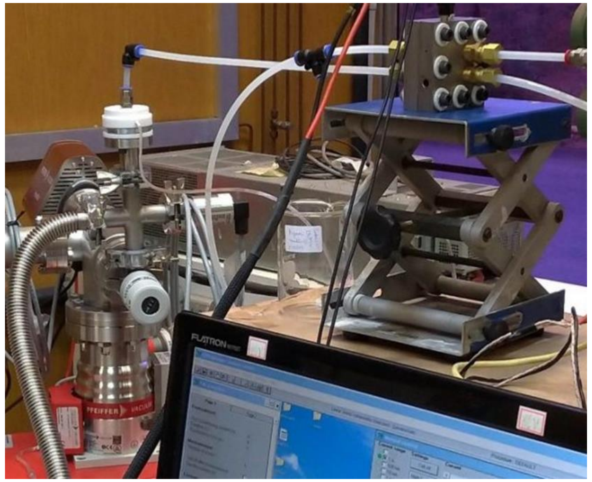
800°C

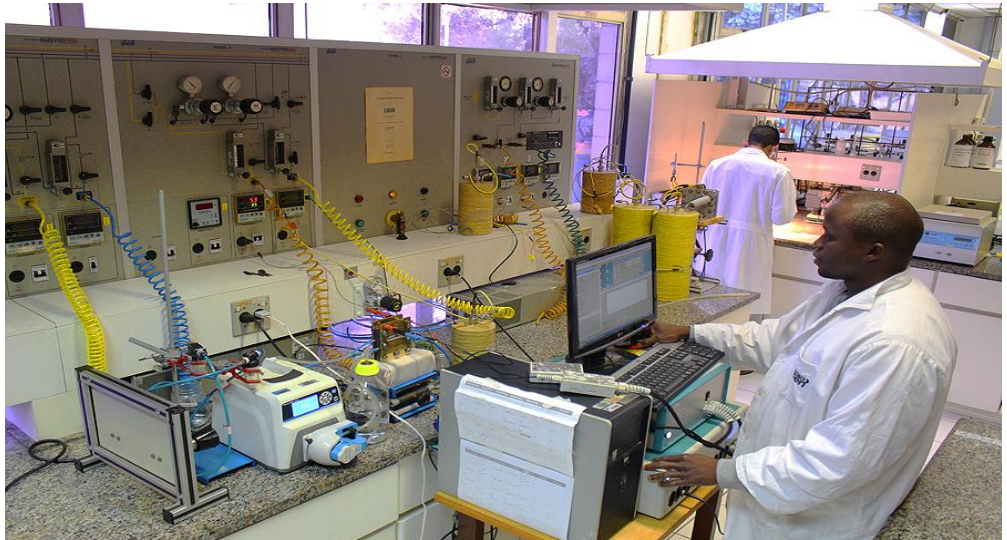
Células a Combustível

Fuel Cells

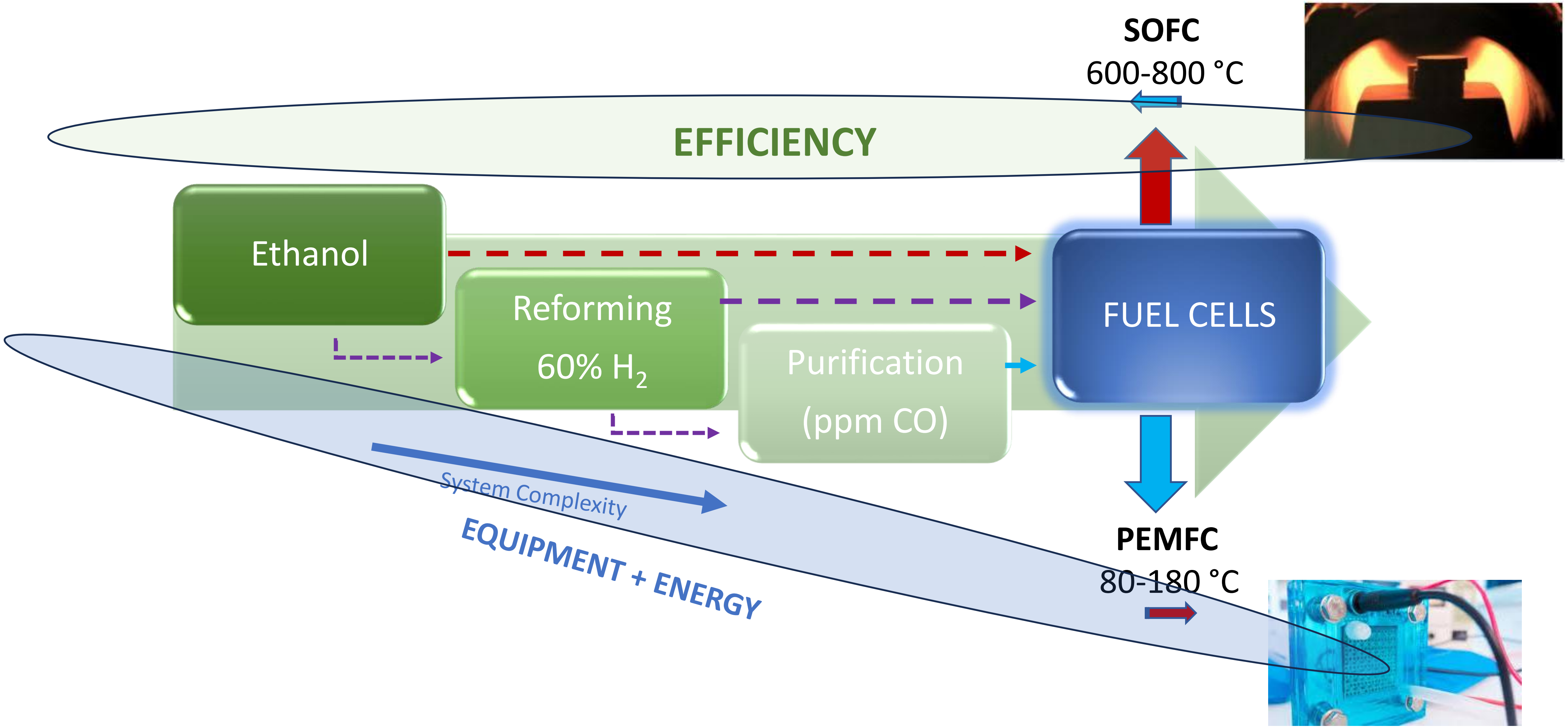
FACILITIES

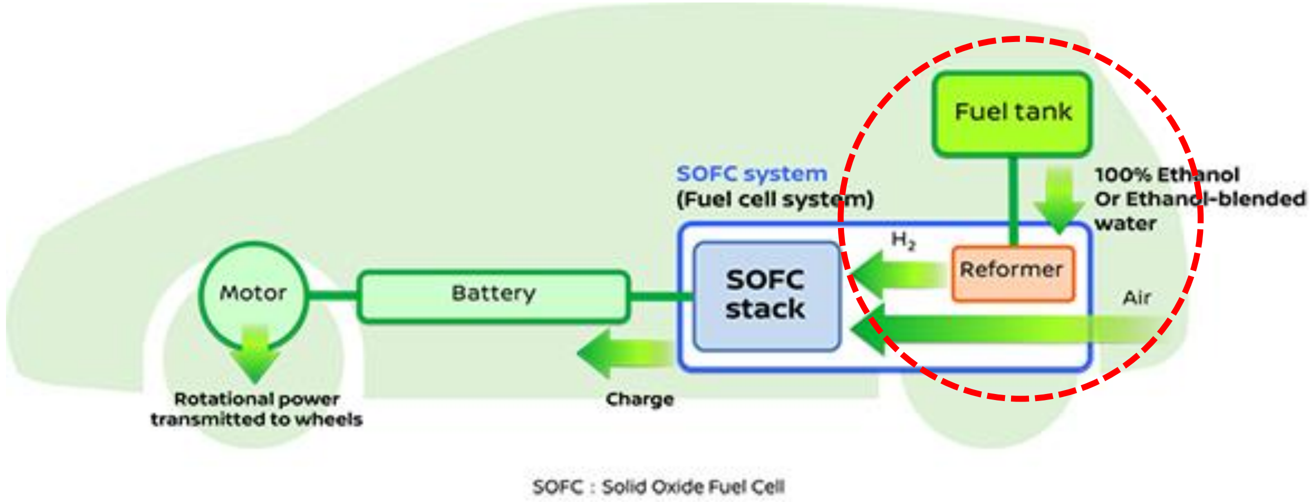






Ethanol to Electricity





$$C_2H_5OH + 3H_2O \rightarrow 2CO_2 + 6H_2$$

Ethanol Steam Reforming

Direct Ethanol Fuel Cell Vehicule

ON BOARD ELECTRICITY GENERATION FROM A LIQUID RENEWABLE FUEL

ETHANOL + ½ O_2 → ELECTRICITY + H_2O

- HIGH PURITY H_2
- Distributed H2

- Fast recharge
- CO_2 neutral
- High efficiency

Direct Ethanol Fuel Cell Vehicule

ON BOARD ELECTRICITY GENERATION FROM A LIQUID RENEWABLE FUEL

ETHANOL + ½ O_2 → ELECTRICITY + H_2O

ENJOY SÃO PAULO

Obrigado!

Fabio Coral Fonseca

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MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

GOVERNO FEDERAL BRASIL UNIÃO E RECONSTRUÇÃO

SÃO PAULO GOVERNO DO ESTADO

FAPESP FUNDAÇÃO DE AMPARO À PESQUISA DO ESTADO DE SÃO PAULO

CNPq Conselho Nacional de Desenvolvimento Científico e Tecnológico

Instituto de Pesquisas Energéticas e Nucleares

Fuel Cell and Hydrogen Center

Fuel Cell and Hydrogen Center

Since 1998 **IPEN** stablished a structured program for advancing **knowledge** and developing **technologies** for **fuel cells** and **renewable hydrogen**.

A multidisciplinary team, lead by internationally connected scientists, relies on modern facilities to carry cutting-edge research on materials for advanced electrochemical technologies focused on **sustainable power and chemicals generation** .

23 **years** R&D in H_2 and fuel cells

20 **Laboratories** - PEMFC, SOFC, and H_2

Team

4 Researchers

9 Technical and administrative staff,

+25 Post-docs and students

5 **patents**

+300 **publications**

+300 **USP graduate students** Completed PhD and MSc

Collaborators and Sponsors

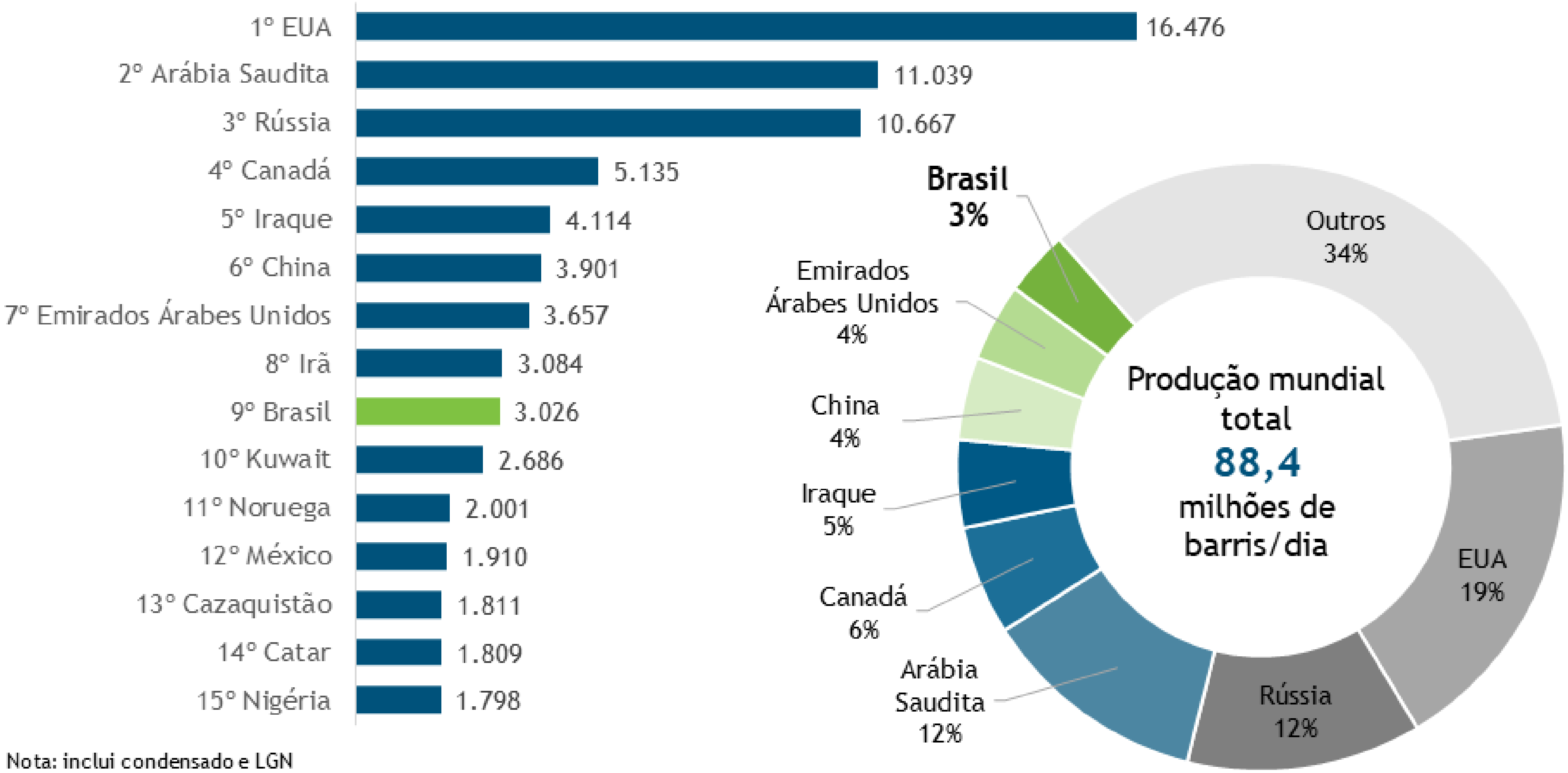
H_2 e Ethanol

- Biomass + etanol = H_2 Sustainable
- Biogas / bio CO_2 = e-fuels
- *Sustainable Aviation Fuel* (SAF)

Pré-sal
óleo e gás

Maiores produtores de petróleo em 2020

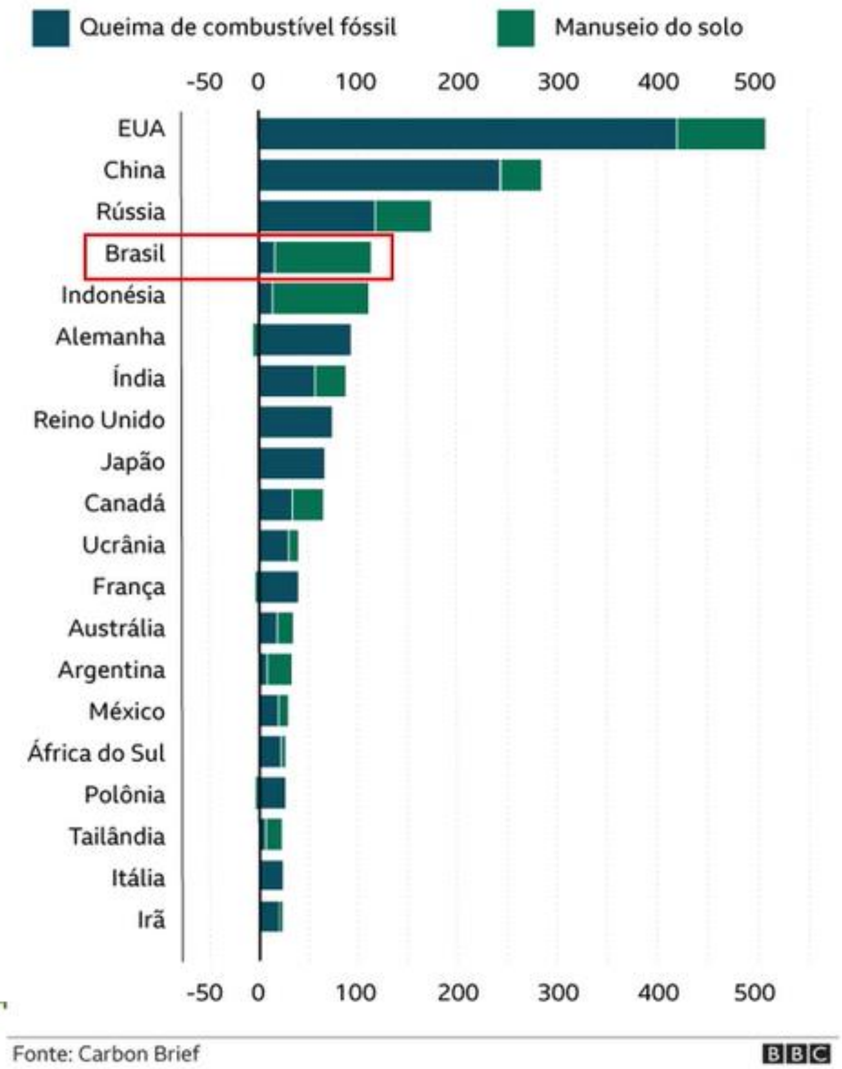
Mil barris por dia



Nota: inclui condensado e LGN
Atualização - Julho 2021
Fonte: Elaboração IBP com dados BP

Países com maior acúmulo de emissões de 1850 a 2021

Bilhões de toneladas de CO_2 de combustíveis fósseis, desmatamento e uso do solo



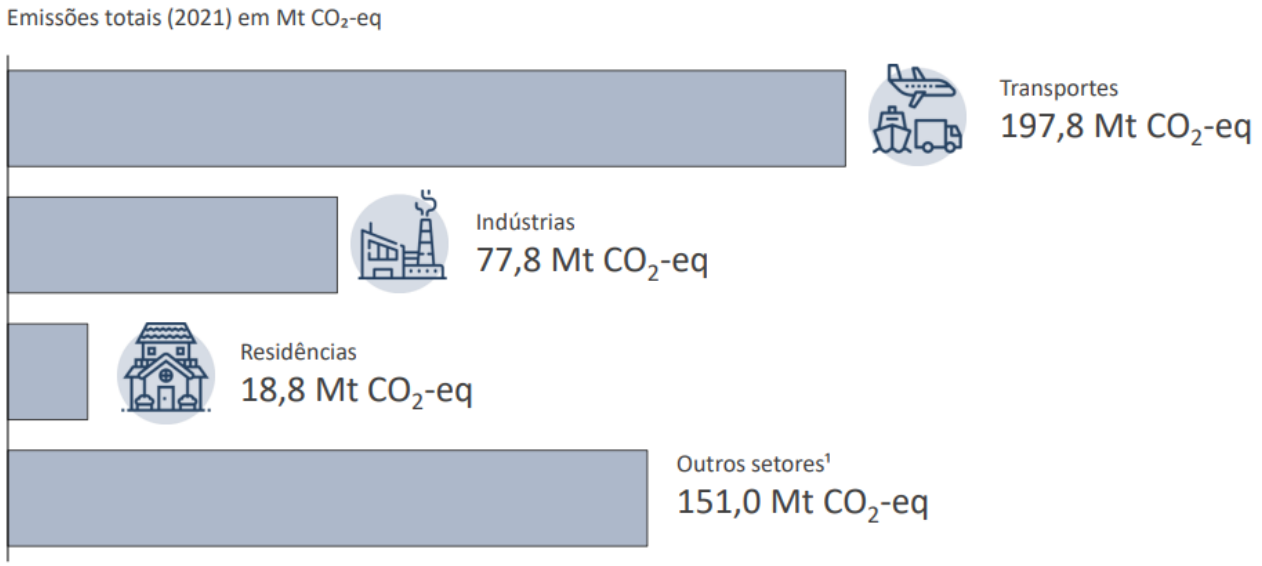
As Emissões Brasileiras

Em 2021, o **total de emissões** de CO_2 antrópicas associadas à matriz energética brasileira atingiu 445,4 milhões de toneladas de CO_2 equivalente.

2020
396,3 Mt CO_2-eq

2021
445,4 Mt CO_2-eq

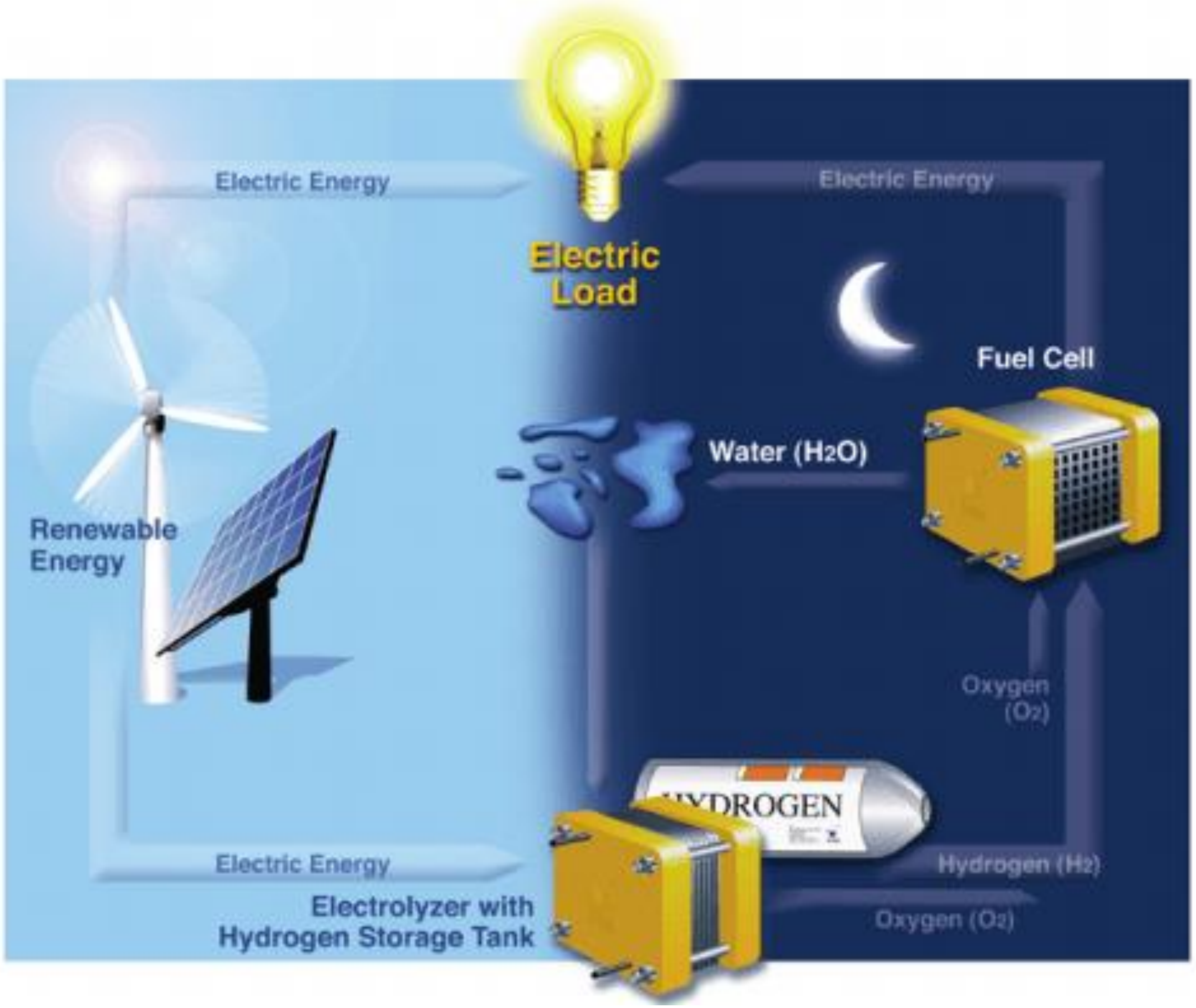
Aumento de 12,4%

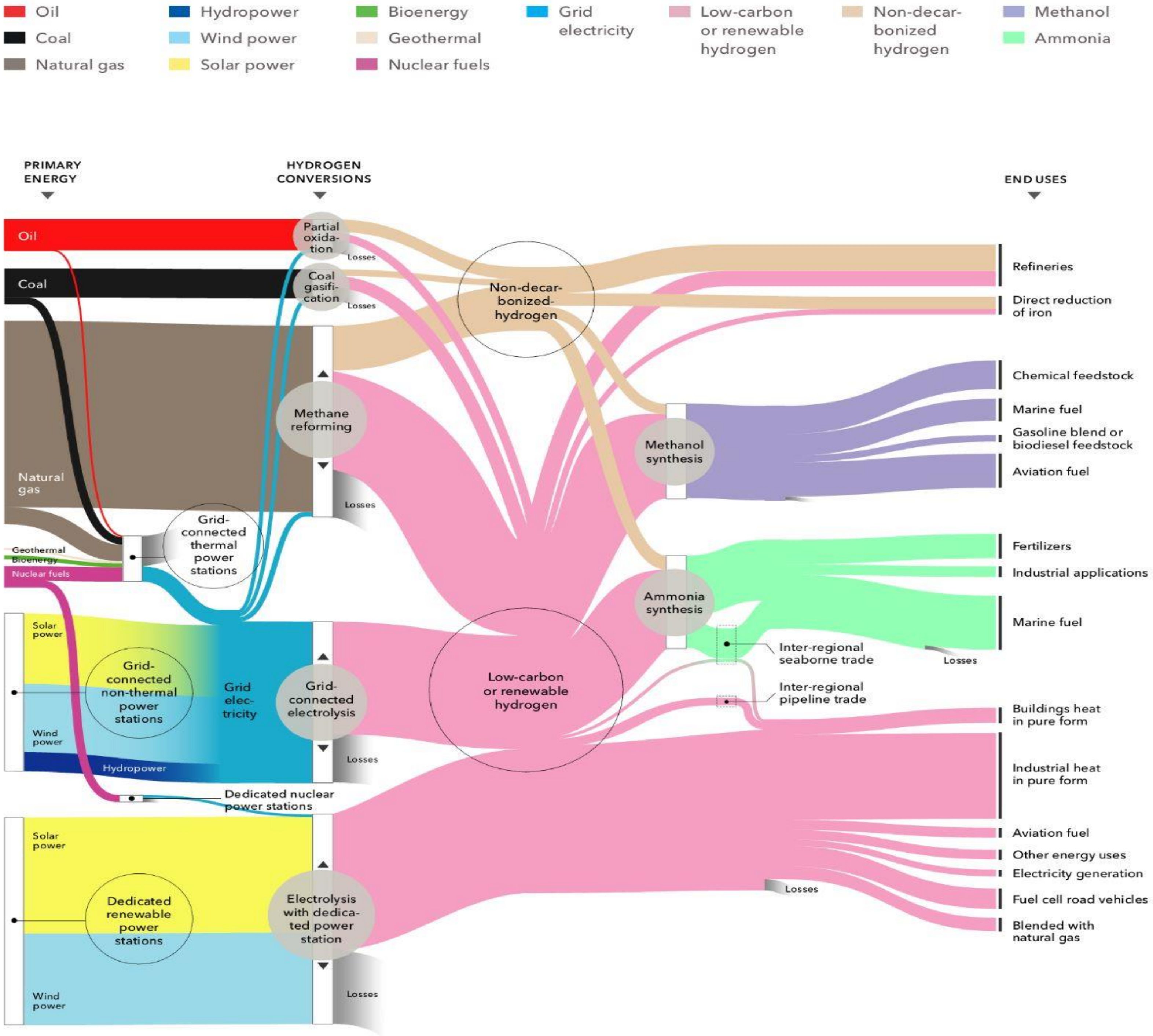


[1] Inclui os setores agropecuário, serviços, energético, elétrico e as emissões fugitivas

Células a Combustível

Fuel Cells - Electrolysers





Oil
Coal
Natural gas
Hydropower
Wind power
Solar power
Bioenergy
Geothermal
Nuclear fuels
Grid electricity
Low-carbon or renewable hydrogen
Non-decar-bonized hydrogen
Methanol
Ammonia
PRIMARY ENERGY
HYDROGEN CONVERSIONS
END USES
Partial oxida-tion
Coal gasifi-cation
Methane reforming
Grid-connected thermal power stations
Geothermal
Bioenergy
Nuclear fuels
Solar power
Grid-connected non-thermal power stations
Wind power
Hydropower
Grid elec-tricity
Grid-connected electrolysis
Dedicated nuclear power stations
Dedicated renewable power stations
Electrolysis with dedica-ted power station
Losses
Non-decar-bonized-hydrogen
Low-carbon or renewable hydrogen
Methanol synthesis
Ammonia synthesis
Inter-regional seaborne trade
Inter-regional pipeline trade
Refineries
Direct reduction of iron
Chemical feedstock
Marine fuel
Gasoline blend or biodiesel feedstock
Aviation fuel
Fertilizers
Industrial applications
Marine fuel
Buildings heat in pure form
Industrial heat in pure form
Aviation fuel
Other energy uses
Electricity generation
Fuel cell road vehicles
Blended with natural gas

DNV

Brazilian
Wind Offshore

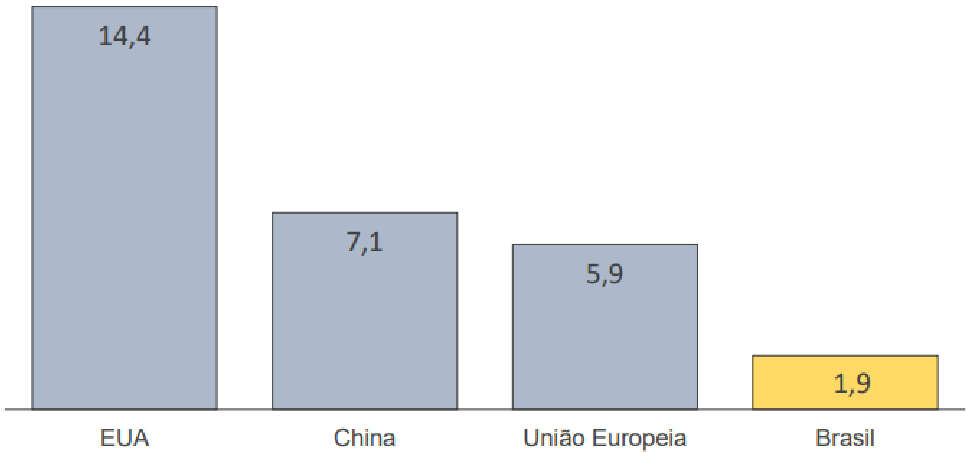
~130 GW?

CO_2 Emissions

Emissões de CO_2 per capita

Emissões de CO_2 per capita (2019) em t CO_2/hab.

Fonte: Agência Internacional de Energia. Elaboração: EPE



2021
Emissões per capita brasileiras

2,1 t CO_2-eq/hab.

Fonte: EPE

Em média, na produção e no consumo de energia, cada brasileiro emite o equivalente a 13% de um americano, 32% de um cidadão da União Europeia e 27% chinês.

People
- 4 Principal investigators
- 6 Staff
- 35 students and post-docs

Research
- Polymer-based fuel cells
- Ceramic-based fuel cells
- H2 purification/production

e-Bio Fuel Cell

NISSAN

- Uses 100% ethanol, which is already widely available in Brazil, as fuel

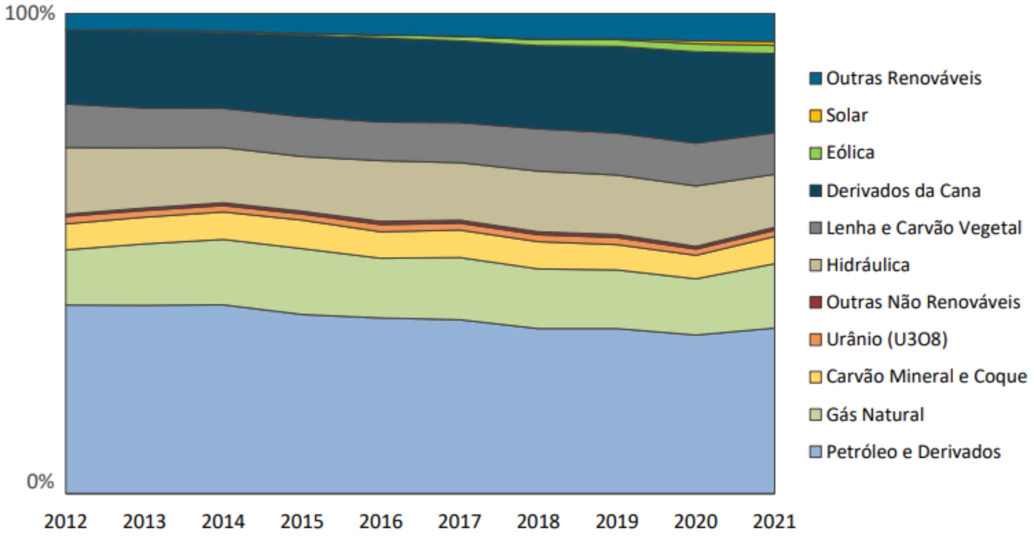
Specifications of research prototype vehicle

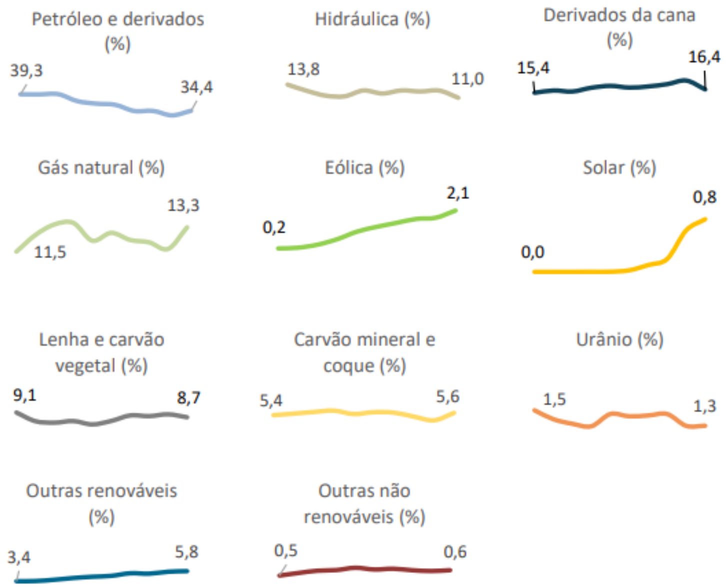
Features	Specs.
Base vehicle	e-NV200
Battery Capacity	24kWh
Powertrain	Electricity
	100% Ethanol
Fuel tank capacity	30L
SOFC power	5kW
Driving range	Over 600km

Note: specifications are for Nissan's research prototype vehicle, and are subject to change.

2018

Oferta Interna de Energia 2012-2021





Nota-se que houve uma redução da participação das renováveis na matriz energética entre 2012 e 2014 devido à queda da oferta hidráulica. A partir de 2015, as fontes renováveis retomam uma trajetória de crescimento com a expansão das ofertas de derivados da cana, eólica e biodiesel, atingindo 48,5% em 2020. No entanto, com a escassez hídrica de 2021, o patamar das renováveis recuou para 44,7%.

Emerging Industry

Electrolyser

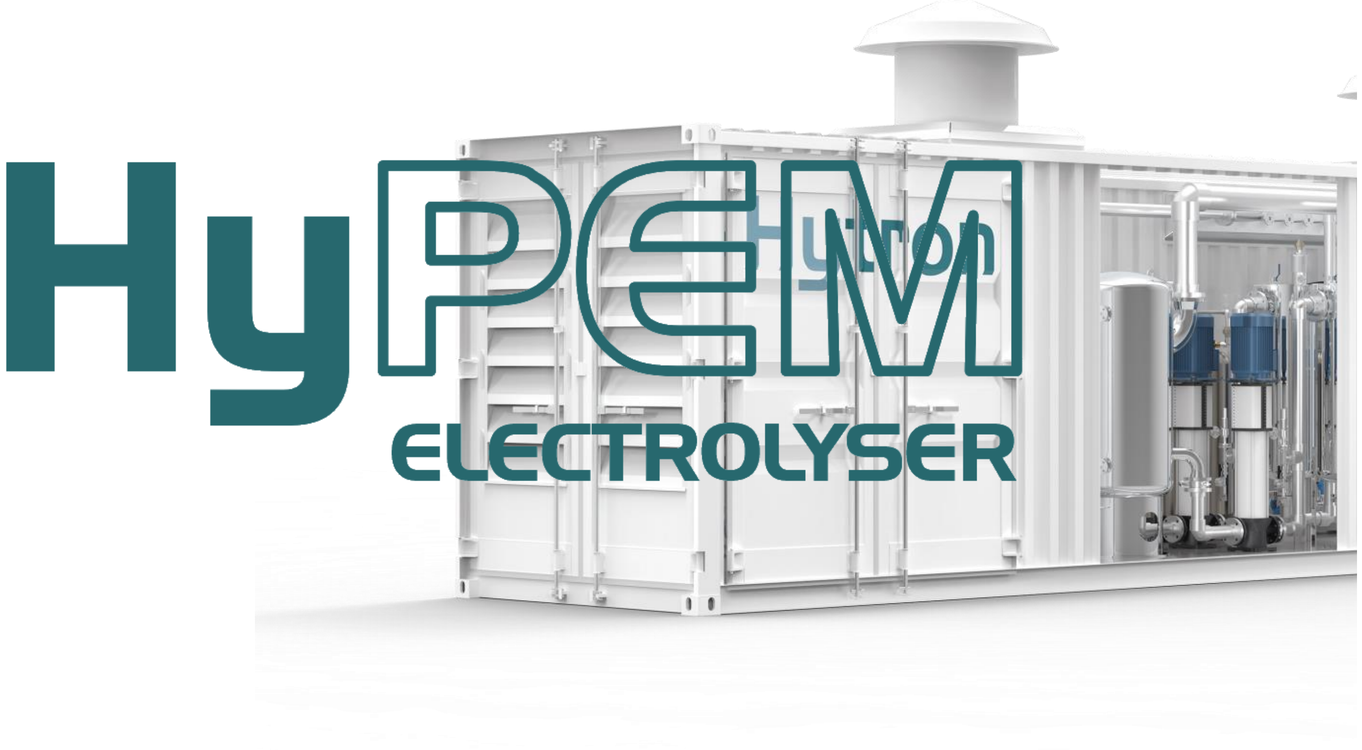
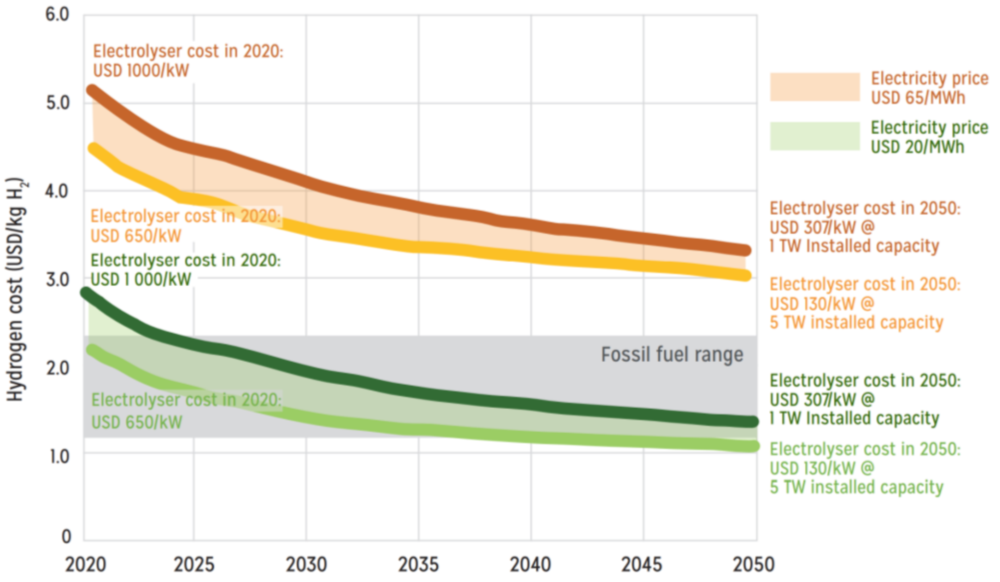


FIGURE 6 - PATH OF COST REDUCTION OF GREEN HYDROGEN AS A FUNCTION OF ELECTRICITY PRICE AND THE CAPEX OF ELECTROLYZERS



Note: Efficiency at nominal capacity is 65%, with a LHV of 51.2 kilowatt hour/kilogramme of hydrogen (kWh/kg H2) in 2020 and 76% (at an LHV of 43.8 kWh/kg H2) in 2050, a discount rate of 8% and a stack lifetime of 80 000 hours. The electrolyser investment cost for 2020 is USD 650-1000/kW. Electrolyser costs reach USD 130-307/kW as a result of 1-5 TW of capacity deployed by 2050.

Mensagem Final

- A transição energética é um grande desafio
  - há esperança
- O Brasil tem um enorme potencial para ser um protagonista na economia do H2
  - Eletricidade renovável e etanol
- Pesquisas terão papel fundamental na viabilização das novas tecnologias
  - materiais, componentes, pessoal, etc

Há pesquisa de ponta no país para continuar os avanços em curso!

NISSAN

e-Bio Fuel Cell

- Uses 100% ethanol, which is already widely available in Brazil, as fuel

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	100% Ethanol
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Driving range	Over 600km

Note: specifications are for Nissan's research prototype vehicle, and are subject to change.

2018

Ethanol as a Hydrogen Carrier

Advantages of Using Ethanol for H_2 Production

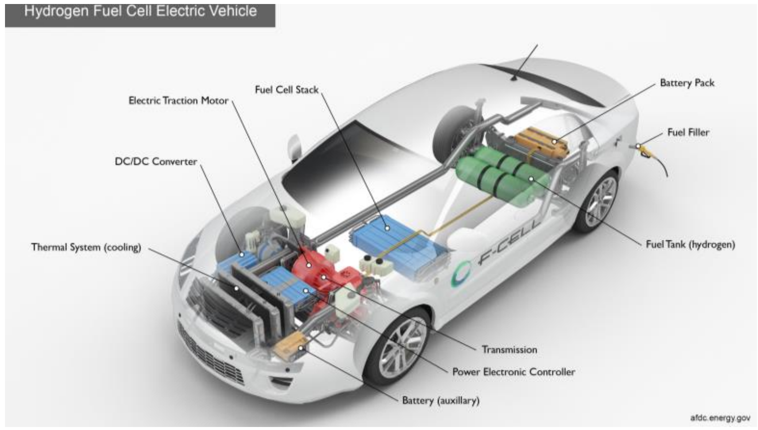
- Renewable fuel
- Easy storage and transportation (usual for the Brazilian case)
- value chain established
- It is not a toxic fuel
- Peak shaving production of Green H_2 (without itermitence)
- Enables local production of H_2 close to consumption
- Non toxic

Ethanol as a Hydrogen Carrier

Some Numbers from Ethanol Industry

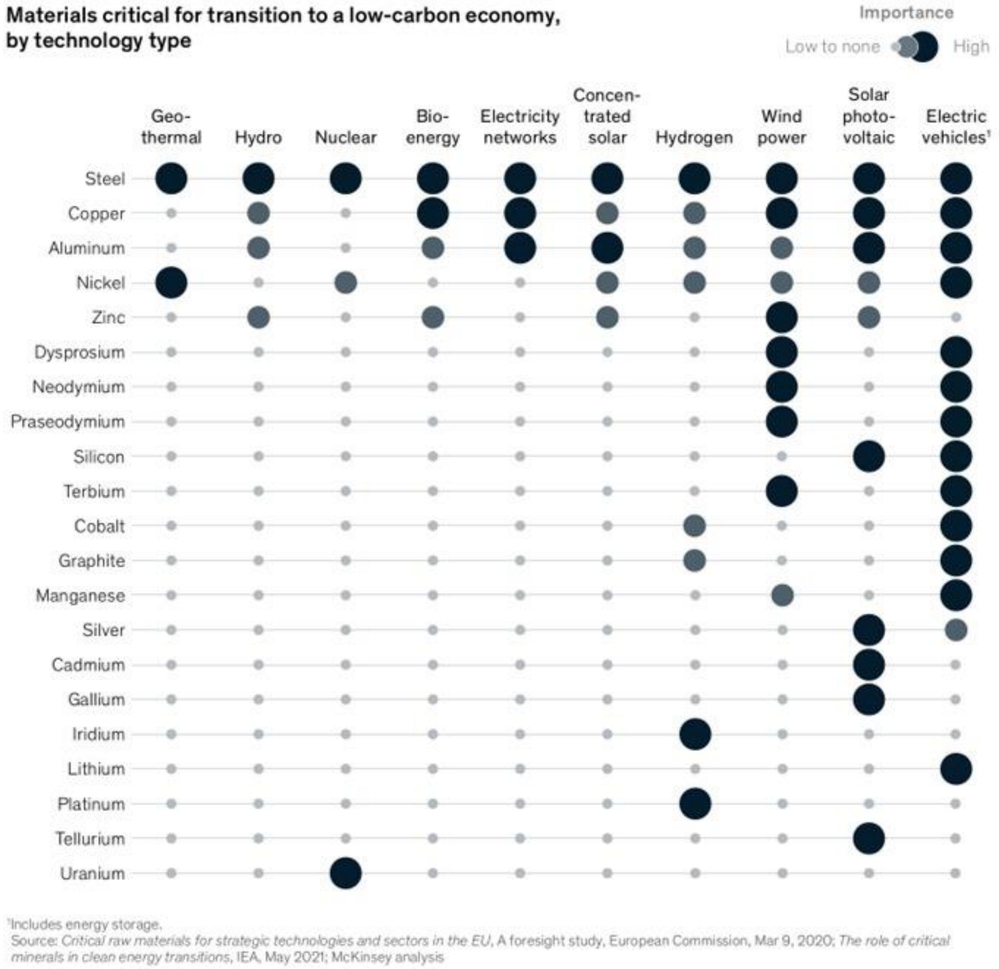
INPUT	QUANTITY	UNITS
Ethanol 1G	80	L / t (sugar cane)
Ethanol 2G	32	L / t (sugar cane)
Biogas	8,9	Nm^3 CH_4/ t (sugar cane)
E. Energy	49	kW / t (sugar cane)
Ethanol 1G + 2G	**15**	**kg H_2 / t (sugar cane)**
Biogas	**1,84**	**kg H_2 / t (sugar cane)**
E. Energy	**0,92**	**kg H_2 / t (sugar cane)**
Total	**17,76**	**kg H_2 / t (sugar cane)**
	198,91	**Nm^3 H_2 / t (sugar cane)**

CHARACTERISTICS WITH THE USE OF ETHANOL



- ✓ **7.6 liters of ethanol produces 1 kg of H_2 (Hytron Reformer)**
- ✓ H_2 storage in the car ranges from 5 kg to 7.5 kg H_2
- ✓ Autonomy: 1,360 km with 5,65 kg H_2 (Toyota Mirai Record)
- ✓ **ETHANOL Consumption: ~43 liters**
- ✓ 43 liters of Ethanol → 1,360 km (~31,6 km/L)
- ✓ **Refueling time: 6 min**

THIS IS JUST THE BEGINNING!


Materials critical for transition to a low-carbon economy, by technology type
Importance
Low to none
High
Geo-thermal
Hydro
Nuclear
Bio-energy
Electricity networks
Concen-trated solar
Hydrogen
Wind power
Solar photo-voltaic
Electric vehicles[1]
Steel
Copper
Aluminum
Nickel
Zinc
Dysprosium
Neodymium
Praseodymium
Silicon
Terbium
Cobalt
Graphite
Manganese
Silver
Cadmium
Gallium
Iridium
Lithium
Platinum
Tellurium
Uranium
[1]Includes energy storage.
Source: Critical raw materials for strategic technologies and sectors in the EU, A foresight study, European Commission, Mar 9, 2020; The role of critical minerals in clean energy transitions, IEA, May 2021; McKinsey analysis

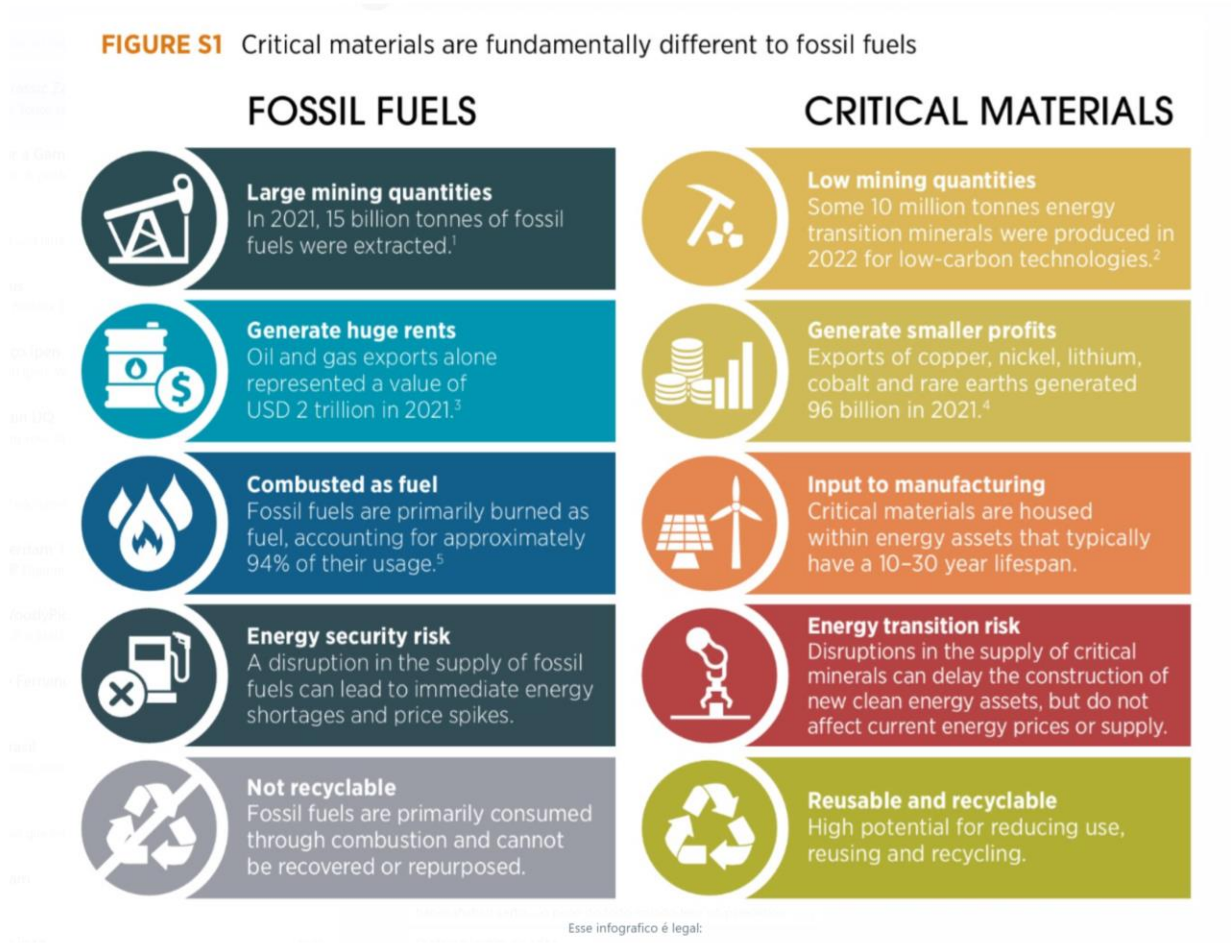


FIGURE S1 Critical materials are fundamentally different to fossil fuels
FOSSIL FUELS
CRITICAL MATERIALS
Large mining quantities
In 2021, 15 billion tonnes of fossil fuels were extracted.[1]
Low mining quantities
Some 10 million tonnes energy transition minerals were produced in 2022 for low-carbon technologies.[2]
Generate huge rents
Oil and gas exports alone represented a value of USD 2 trillion in 2021.[3]
Generate smaller profits
Exports of copper, nickel, lithium, cobalt and rare earths generated 96 billion in 2021.[4]
Combusted as fuel
Fossil fuels are primarily burned as fuel, accounting for approximately 94% of their usage.[5]
Input to manufacturing
Critical materials are housed within energy assets that typically have a 10–30 year lifespan.
Energy security risk
A disruption in the supply of fossil fuels can lead to immediate energy shortages and price spikes.
Energy transition risk
Disruptions in the supply of critical minerals can delay the construction of new clean energy assets, but do not affect current energy prices or supply.
Not recyclable
Fossil fuels are primarily consumed through combustion and cannot be recovered or repurposed.
Reusable and recyclable
High potential for reducing use, reusing and recycling.
Esse infografico é legal:

2018 -