

Hidrogênio Verde

O setor de Hidrogênio Verde e o desenvolvimento da tecnologia.

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Audiência Pública -
CEHV
Brasília
Maio de 2023



MINISTÉRIO DA
AGRICULTURA E
PECUÁRIA

GOVERNO FEDERAL
BRASIL
UNIÃO E RECONSTRUÇÃO

Hidrogênio

O que é?
Quais os tipos?
Quais os usos?



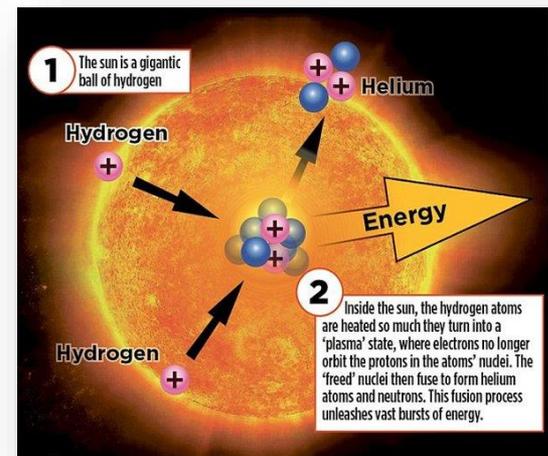
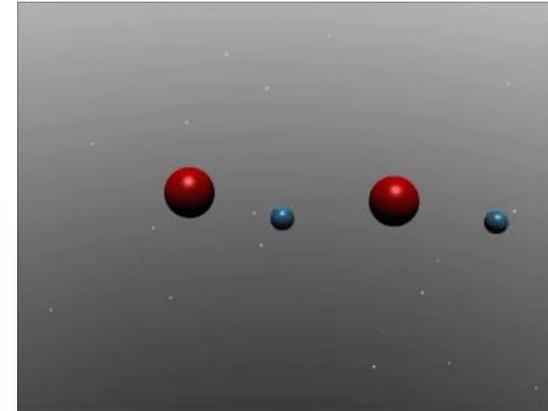
Hidrogênio

1
H
hydrogen
1.0080
± 0.0002

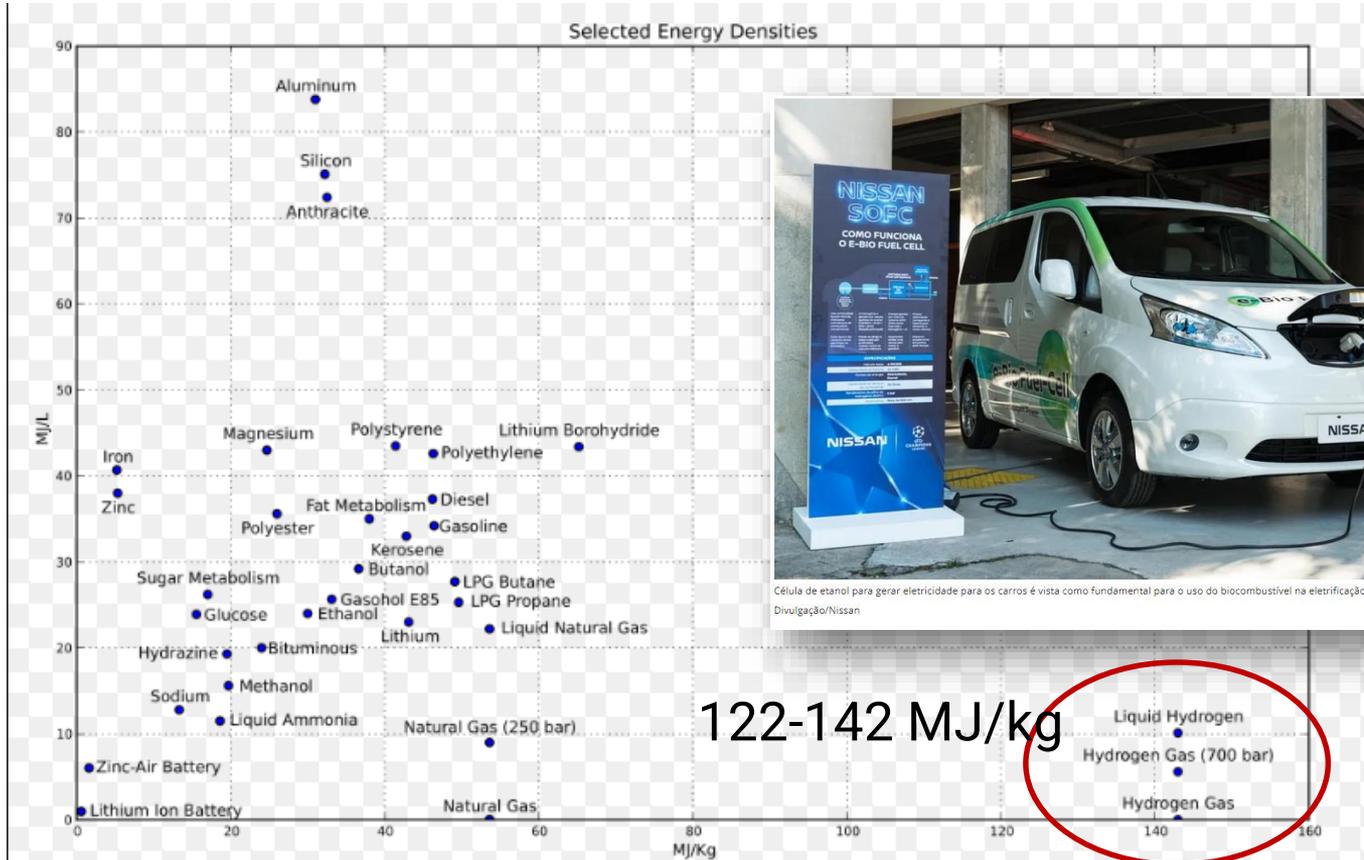
Altamente abundante
Baixa disponibilidade

IUPAC Periodic Table of the Elements

Key:																																																																																										
atomic number		Symbol		name		abbreviated standard		atomic weight																																																																																		
1	H	hydrogen	1.0080	± 0.0002														2	He	helium	4.0026	± 0.0001																																																																				
3	Li	lithium	6.94	± 0.0001	4	Be	beryllium	9.0122	± 0.0001									5	B	boron	10.81	± 0.002	6	C	carbon	12.011	± 0.002	7	N	nitrogen	14.007	± 0.001	8	O	oxygen	15.999	± 0.001	9	F	fluorine	18.998	± 0.001	10	Ne	neon	20.180	± 0.001																																											
11	Na	sodium	22.990	± 0.0002	12	Mg	magnesium	24.305	± 0.0002									13	Al	aluminium	26.982	± 0.0001	14	Si	silicon	28.085	± 0.001	15	P	phosphorus	30.974	± 0.001	16	S	sulfur	32.06	± 0.002	17	Cl	chlorine	35.45	± 0.001	18	Ar	argon	39.95	± 0.001																																											
19	K	potassium	39.098	± 0.001	20	Ca	calcium	40.078	± 0.004	21	Sc	scandium	44.956	± 0.001	22	Ti	titanium	47.867	± 0.001	23	V	vanadium	50.942	± 0.001	24	Cr	chromium	51.996	± 0.001	25	Mn	manganese	54.938	± 0.002	26	Fe	iron	55.845	± 0.002	27	Co	cobalt	58.933	± 0.001	28	Ni	nickel	58.693	± 0.001	29	Cu	copper	63.546	± 0.003	30	Zn	zinc	65.38	± 0.002	31	Ga	gallium	69.723	± 0.001	32	Ge	germanium	72.630	± 0.008	33	As	arsenic	74.922	± 0.001	34	Se	selenium	78.971	± 0.008	35	Br	bromine	79.904	± 0.003	36	Kr	krypton	83.798	± 0.002	
37	Rb	rubidium	85.468	± 0.001	38	Sr	strontium	87.62	± 0.001	39	Y	yttrium	88.906	± 0.002	40	Zr	zirconium	91.224	± 0.001	41	Nb	niobium	92.906	± 0.001	42	Mo	molybdenum	95.96	± 0.01	43	Tc	technetium	[97]		44	Ru	ruthenium	101.07	± 0.02	45	Rh	rhodium	102.91	± 0.01	46	Pd	palladium	106.42	± 0.01	47	Ag	silver	107.87	± 0.01	48	Cd	cadmium	112.41	± 0.01	49	In	indium	114.82	± 0.01	50	Sn	tin	118.71	± 0.01	51	Sb	antimony	121.76	± 0.01	52	Te	tellurium	127.60	± 0.03	53	I	iodine	126.91	± 0.01	54	Xe	xenon	131.29	± 0.01	
55	Cs	caesium	132.91	± 0.01	56	Ba	barium	137.33	± 0.01	57-71	lanthanoids					72	Hf	hafnium	178.49	± 0.01	73	Ta	tantalum	180.95	± 0.01	74	W	tungsten	183.84	± 0.01	75	Re	rhenium	186.21	± 0.03	76	Os	osmium	190.23	± 0.01	77	Ir	iridium	192.22	± 0.02	78	Pt	platinum	195.08	± 0.01	79	Au	gold	196.97	± 0.01	80	Hg	mercury	200.59	± 0.01	81	Tl	thallium	204.38	± 0.01	82	Pb	lead	207.2	± 1.1	83	Bi	bismuth	208.98	± 0.01	84	Po	polonium	[209]		85	At	astatine	[210]		86	Rn	radon	[222]	
87	Fr	francium	[223]		88	Ra	radium	[226]		89-103	actinoids					104	Rf	rutherfordium	[261]		105	Db	dubnium	[262]		106	Sg	seaborgium	[263]		107	Bh	bohrium	[264]		108	Hs	hassium	[265]		109	Mt	meitnerium	[266]		110	Ds	darmstadtium	[267]		111	Rg	roentgenium	[268]		112	Cn	copernicium	[269]		113	Nh	nihonium	[270]		114	Fl	flerovium	[271]		115	Mc	moscovium	[272]		116	Lv	livermorium	[273]		117	Ts	tennessine	[274]		118	Og	oganesone	[276]	
57	La	lanthanum	138.91	± 0.01	58	Ce	cerium	140.12	± 0.01	59	Pr	praseodymium	140.91	± 0.01	60	Nd	neodymium	144.24	± 0.01	61	Pm	promethium	[145]		62	Sm	samarium	150.36	± 0.02	63	Eu	europlum	151.96	± 0.01	64	Gd	gadolinium	157.25	± 0.03	65	Tb	terbium	158.93	± 0.01	66	Dy	dysprosium	162.50	± 0.01	67	Ho	holmium	164.93	± 0.01	68	Er	erbium	167.26	± 0.01	69	Tm	thulium	168.93	± 0.01	70	Yb	ytterbium	173.05	± 0.01	71	Lu	lutetium	174.97	± 0.01																
89	Ac	actinium	[227]		90	Th	thorium	232.04	± 0.01	91	Pa	protactinium	231.04	± 0.01	92	U	uranium	238.03	± 0.01	93	Np	neptunium	[237]		94	Pu	plutonium	[244]		95	Am	americium	[243]		96	Cm	curium	[247]		97	Bk	berkelium	[247]		98	Cf	californium	[251]		99	Es	einsteinium	[252]		100	Fm	fermium	[257]		101	Md	mendeleevium	[258]		102	No	nobelium	[259]		103	Lr	lawrencium	[262]																	



Por que tanto interesse no Hidrogênio?



Tipos de Hidrogênio

Quem já ouviu falar sobre isso?
Assunto em discussão, envolve reserva de mercado...



	Terminology	Technology	Feedstock/ Electricity source
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind Solar Hydro Geothermal Tidal
	Purple/Pink Hydrogen		Nuclear
	Yellow Hydrogen		Mixed-origin grid energy
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS Gasification + CCUS	Natural gas coal
	Turquoise Hydrogen	Pyrolysis	Natural gas
	Grey Hydrogen	Natural gas reforming	
	Brown Hydrogen	Gasification	Brown coal (lignite)
	Black Hydrogen		Black coal

➔ Padrão estabelecido pela Europa

Metano do biogás x metano do gás natural

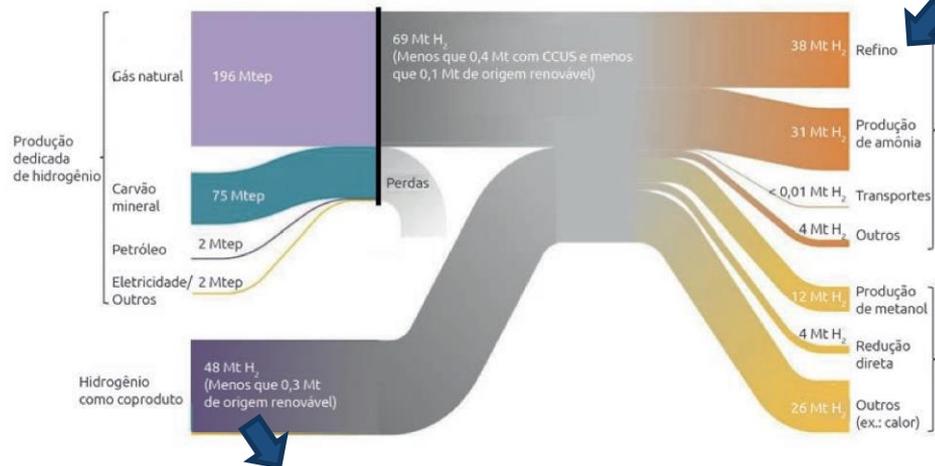
HIDROGÊNIO MUSGO: oriundo da biomassa

Biomassa residual lignocelulósica

* GHG footprint given as a general guide but it is accepted that each category can be higher in some cases.

CCSU = captura e aprisionamento do CO2

Oferta e demanda Hidrogênio?



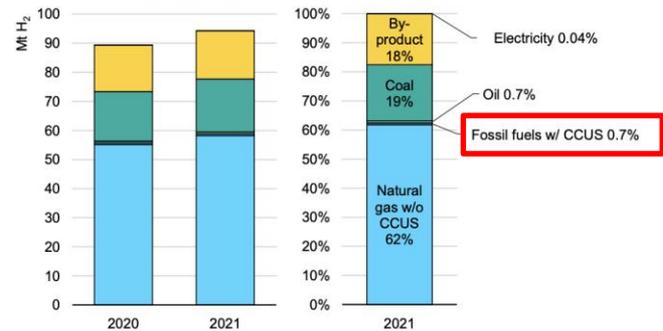
Uso em refinarias



Fertilizantes

Obtido em refinarias

Hydrogen production mix, 2020 and 2021



IEA. All rights reserved.

ote: CCUS = carbon capture, utilisation and storage.

94 Mt em 2021

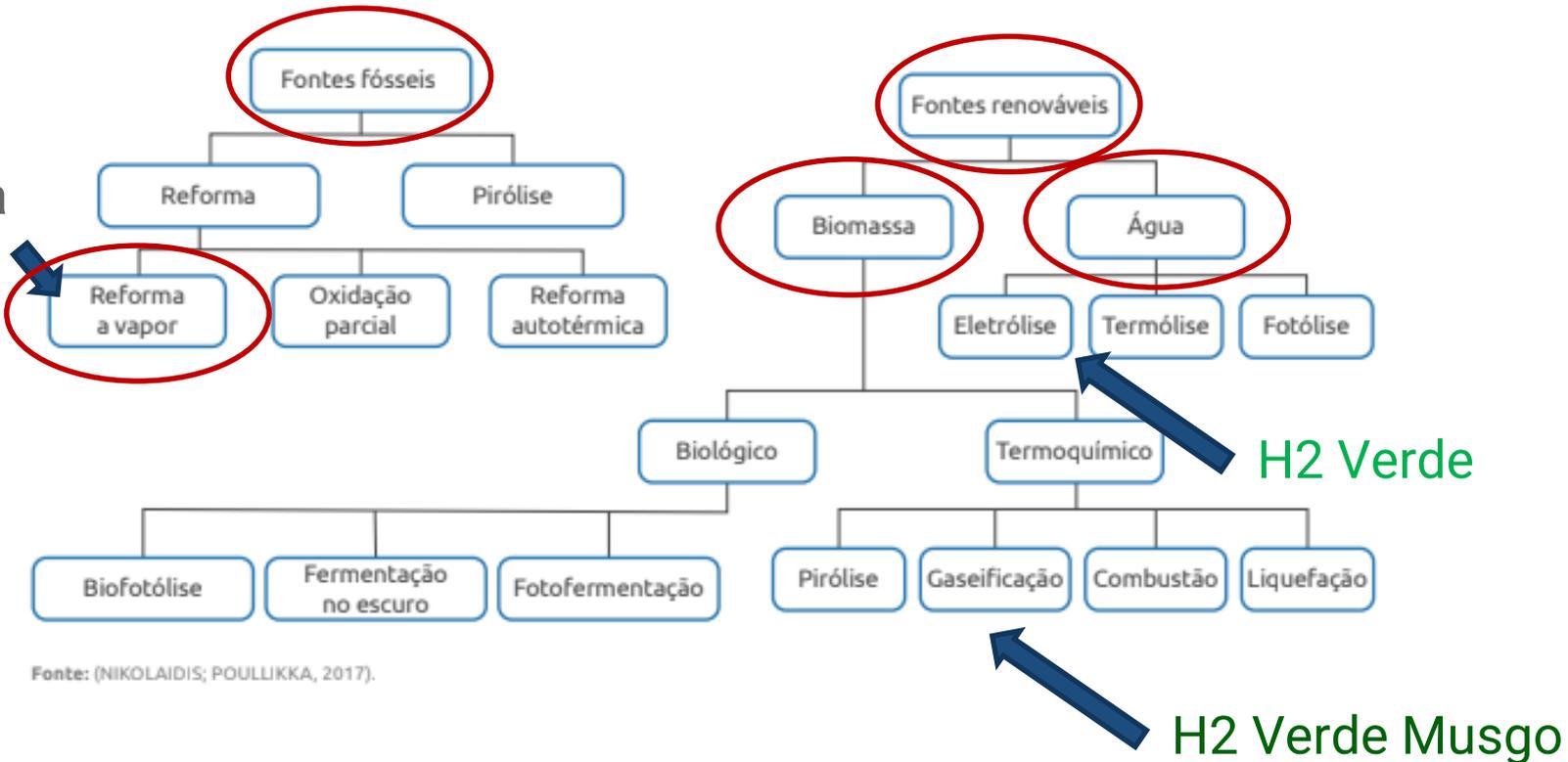
Fonte: EPE, 2021.

Fonte:



Como o Hidrogênio é obtido?

H2 Cinza
H2 Azul
(CCSU)



Fonte: (NIKOLAIDIS; POULLIKKA, 2017).

Fonte:

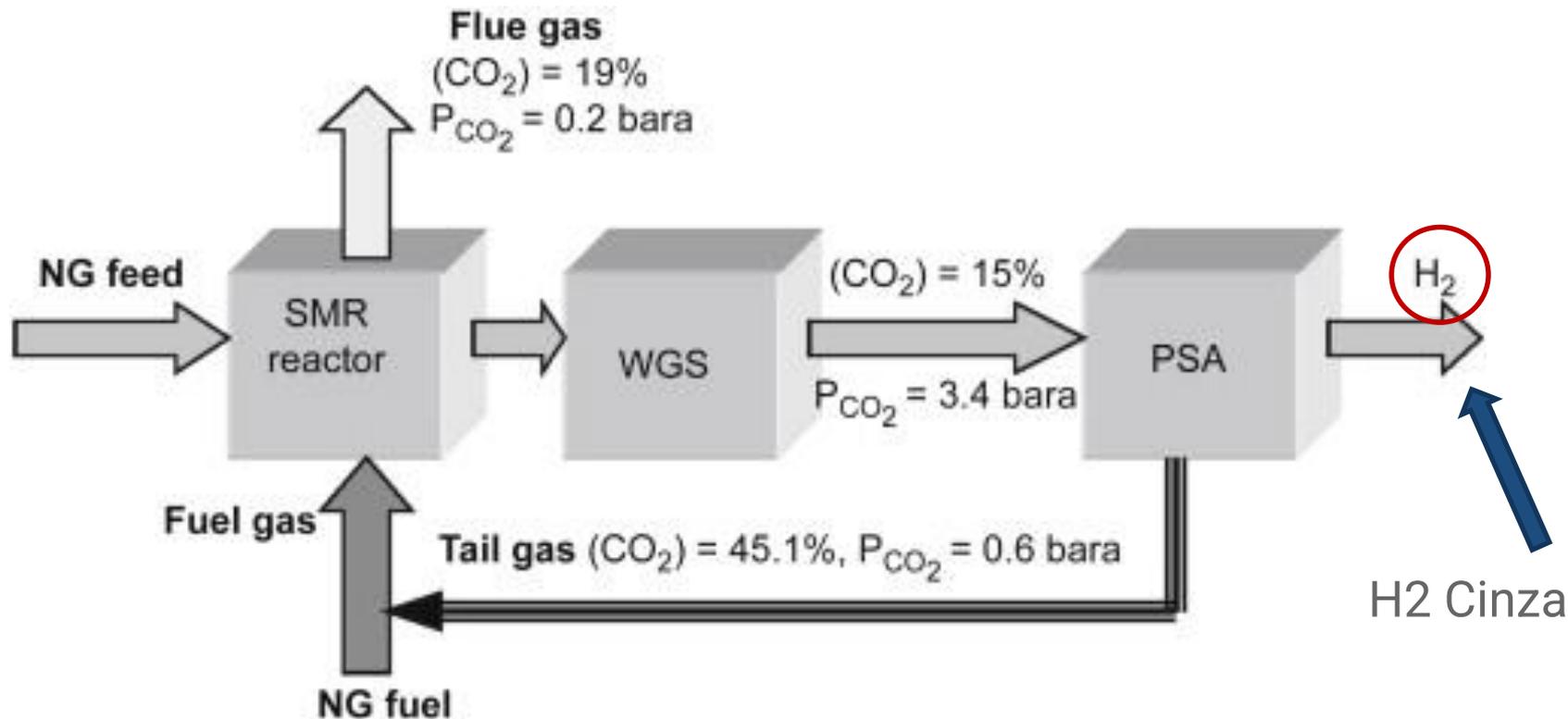


Tecnologias de produção H2 sustentável

H2 Azul

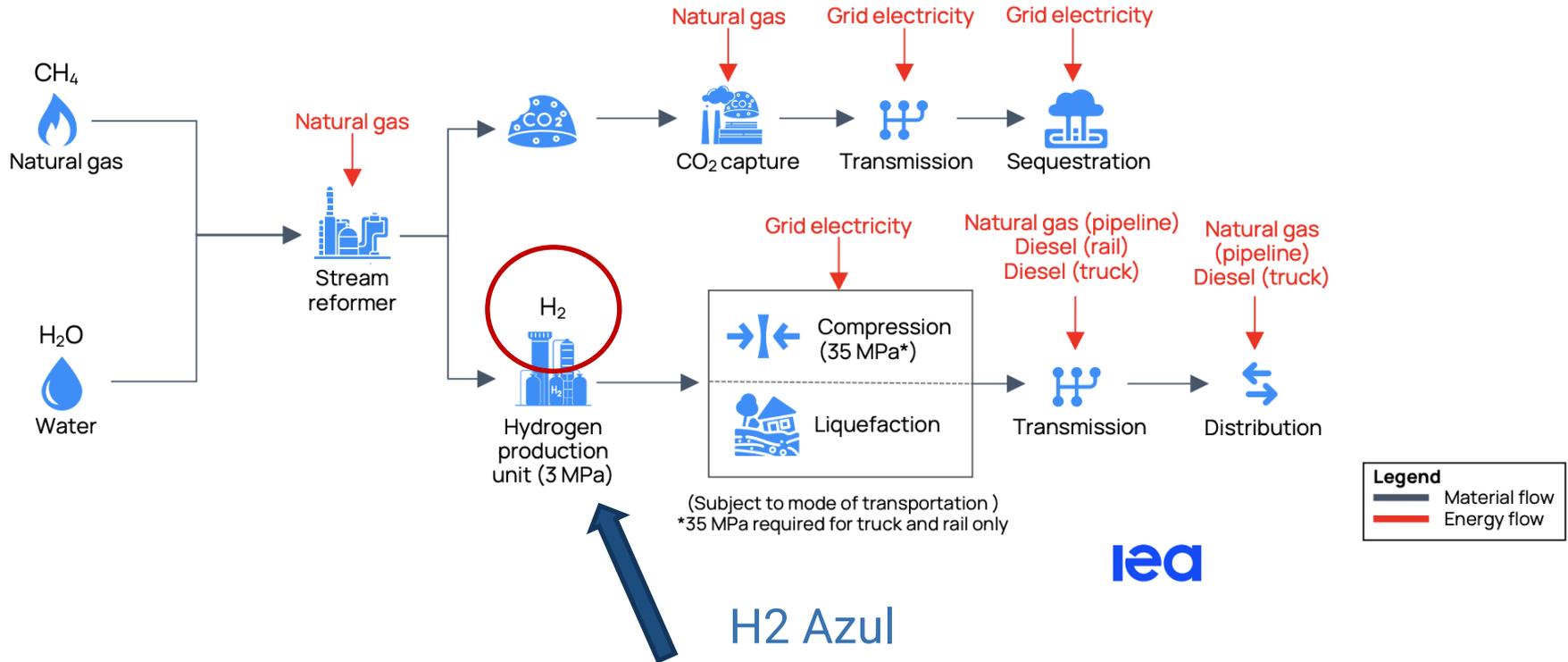
	METHANE REFORMING WITH CCS "BLUE HYDROGEN"	PYROLYSIS "TURQUOISE HYDROGEN"	ELECTROLYSIS "GREEN HYDROGEN"
Overview	Reacts methane with water, resulting in the primary formation of hydrogen and gaseous CO ₂	Decomposition of methane in the absence of air/ oxygen, resulting in the primary formation of hydrogen and solid carbon	Splits water with electricity, resulting in the formation of hydrogen and oxygen
Handling of carbon/CO ₂	Requires CO ₂ generated by the process to be captured	Produces "carbon black," a form of solid carbon	Does not produce any CO ₂ or solid carbon
Variants	<ul style="list-style-type: none"> » Steam methane reforming (SMR): Methane combustion with air (TRL 9)¹³ » Auto-thermal reforming (ATR): Methane combustion with pure oxygen and a catalyst (TRL 8)¹⁴ » Electric steam methane reforming (ESMR): Methane heated with electricity (TRL 6)¹⁵ 	<ul style="list-style-type: none"> » Thermal decomposition: Methane decomposition at over 1000°C (TRL 5) » Plasma decomposition: Plasma torch decomposition up to 2000°C (TRL 9) » Catalytic decomposition: Catalyst decomposition under 1000°C (TRL 5) 	<ul style="list-style-type: none"> » Alkaline electrolysis: Uses alkaline material for electrolysis (TRL 9) » Proton exchange membrane (PEM): Uses polymer material for electrolysis (TRL 9) » Solid oxide electrolyzer cell (SOEC): Uses solid oxide material for electrolysis (TRL 8)

Reforma a vapor do metano (SMR)



Reforma a vapor do metano + CCSU

FIGURE 14 - Steam methane reforming process



Reforma a vapor do metano (SMR)

FIGURE 13 - Methane reforming parameters summary

	STEAM METHANE REFORMING (SMR)	AUTOTRHERMAL REFORMING (ATR)	ELECTRIC STEAM METHANE REFORMING (ESMR)
Hydrogen produced (GJ)	1	1	1
Electrical energy (kWh)	-7.75	19.0	61.2
Natural gas (MJ)	1,235	1,207	1,008
CO ₂ capture rate (%)	60	94	98.6
CCS electrical energy (kWh)	5.3	3.2	7.8
CCS natural gas (MJ)	104	0	0

Baixo consumo de eletricidade

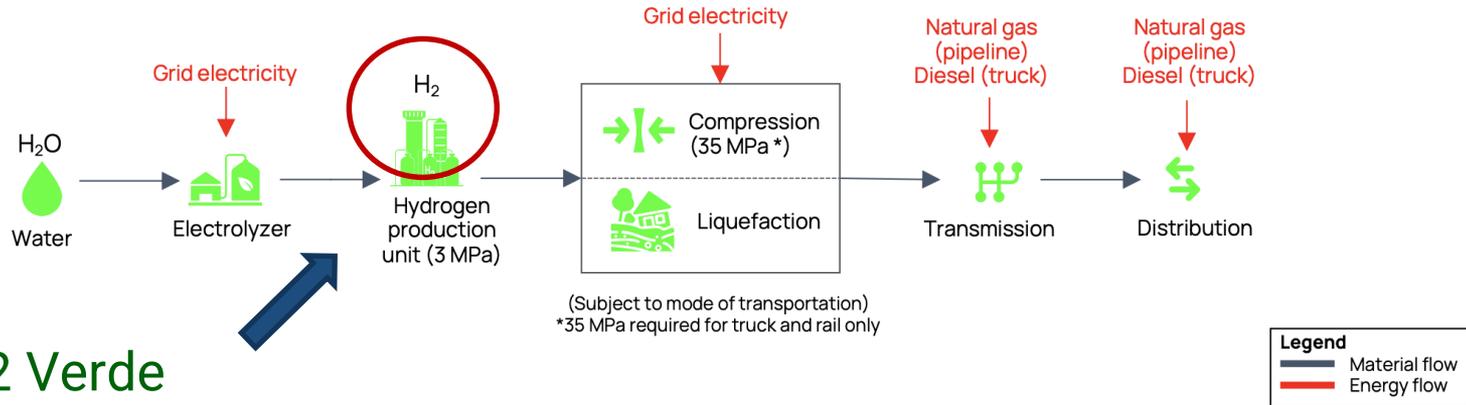
Tecnologias de produção H2 sustentável

H2 Verde

	METHANE REFORMING WITH CCS "BLUE HYDROGEN"	PYROLYSIS "TURQUOISE HYDROGEN"	ELECTROLYSIS "GREEN HYDROGEN"
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Eletrólise alcalina

FIGURE 17 - Electrolysis process material and energy flows



H2 Verde

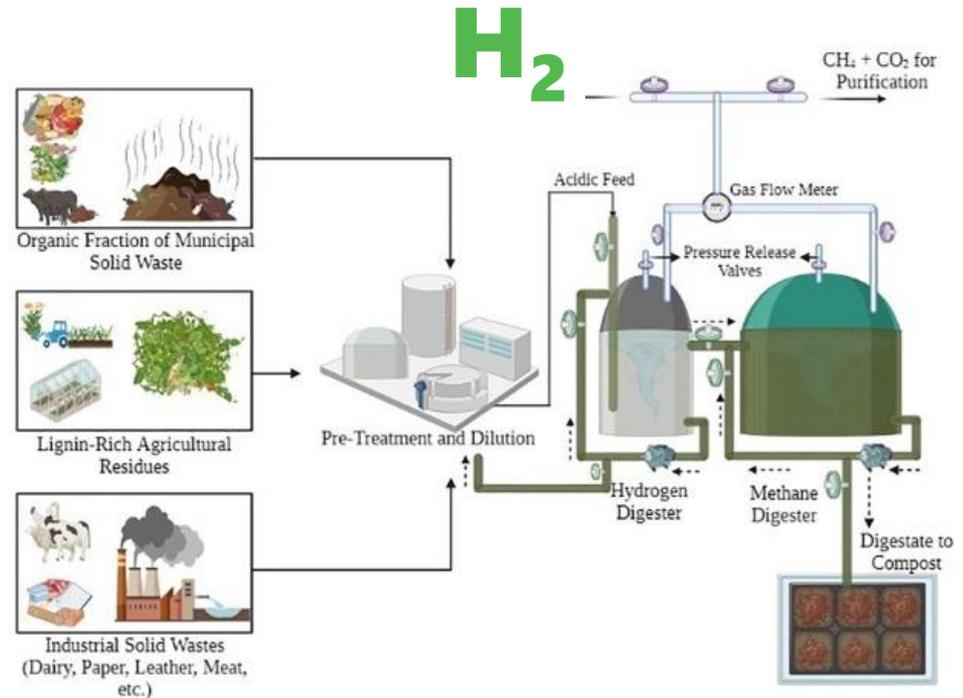
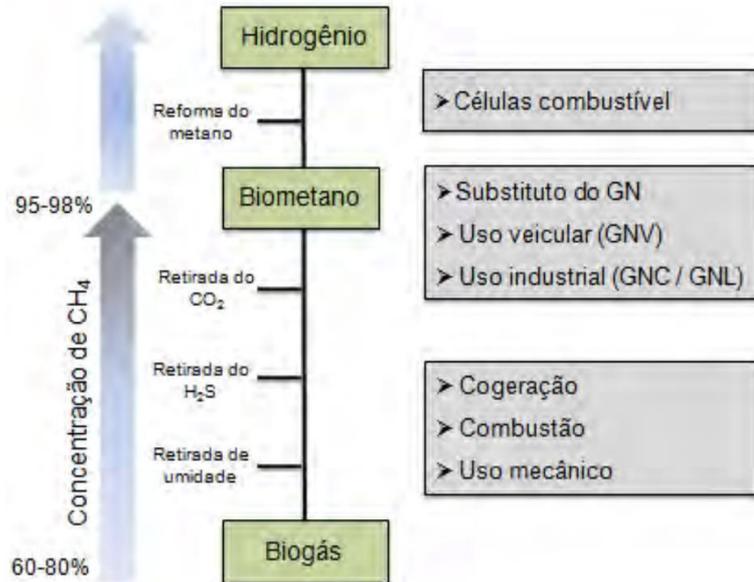
FIGURE 18 - Electrolysis parameters summary

Alto consumo de eletricidade

	ALKALINE ELECTROLYSIS	PEM ELECTROLYSIS	SOEC ELECTROLYSIS
Hydrogen produced (GJ)	1	1	1
Electricity (kWh)	381	360	282

Reforma a vapor do biogás/biometano

H₂

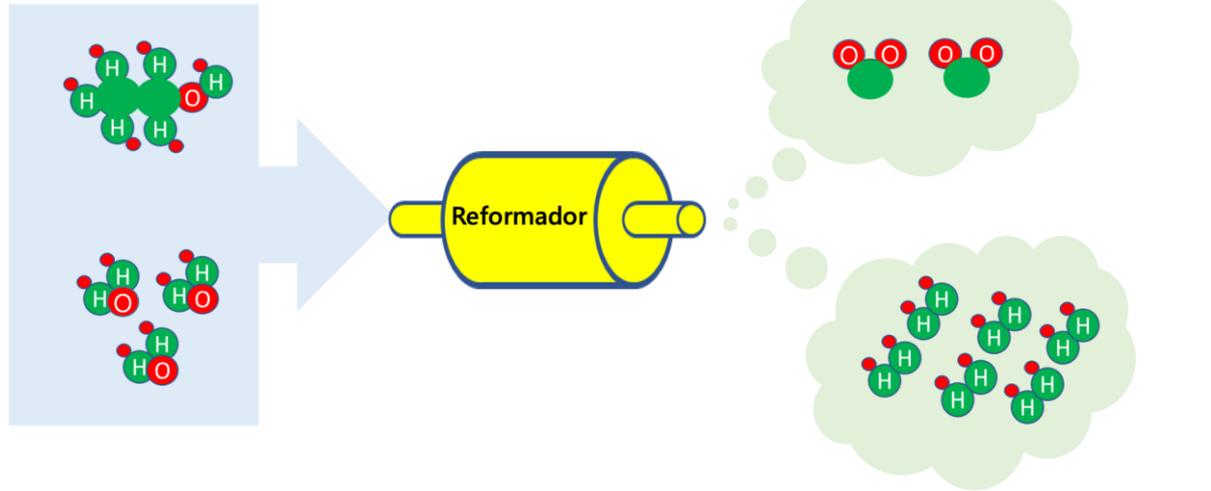
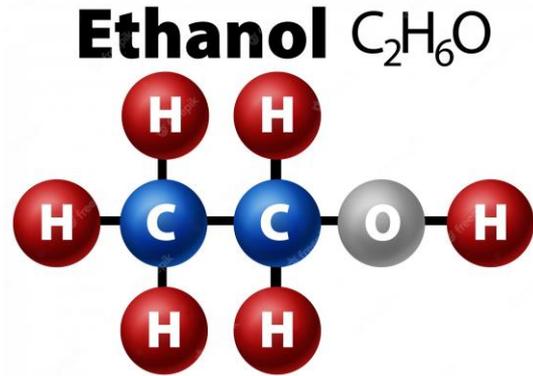


H₂ Verde Musgo

Reforma biogás/biometano

<https://doi.org/10.1016/j.fuel.2022.123449>

Reforma do etanol



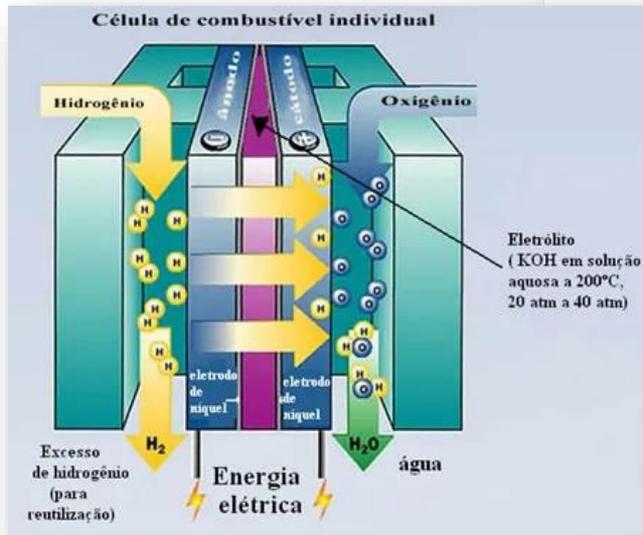
Reforma do etanol

Fonte: <https://agencia.fapesp.br/shell-raizen-hytron-usp-e-senai-firmam-parceria-para-a-conversao-de-etanol-em-hidrogenio/39548/>

H_2
H2 Verde Musgo

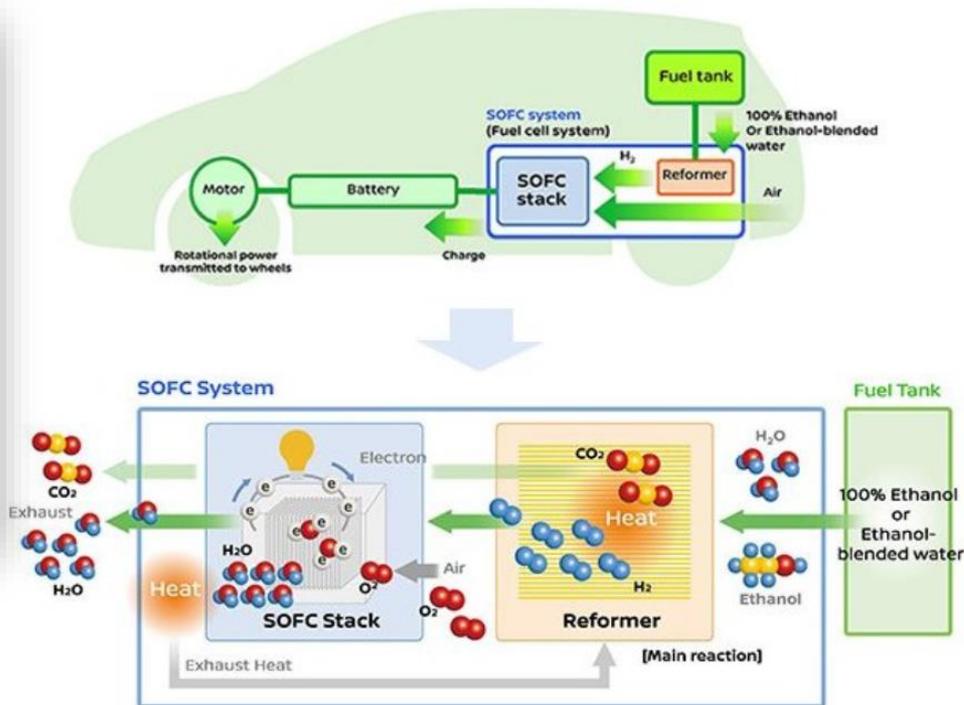
Células combustível: tradicional e a etanol

Hidrogênio

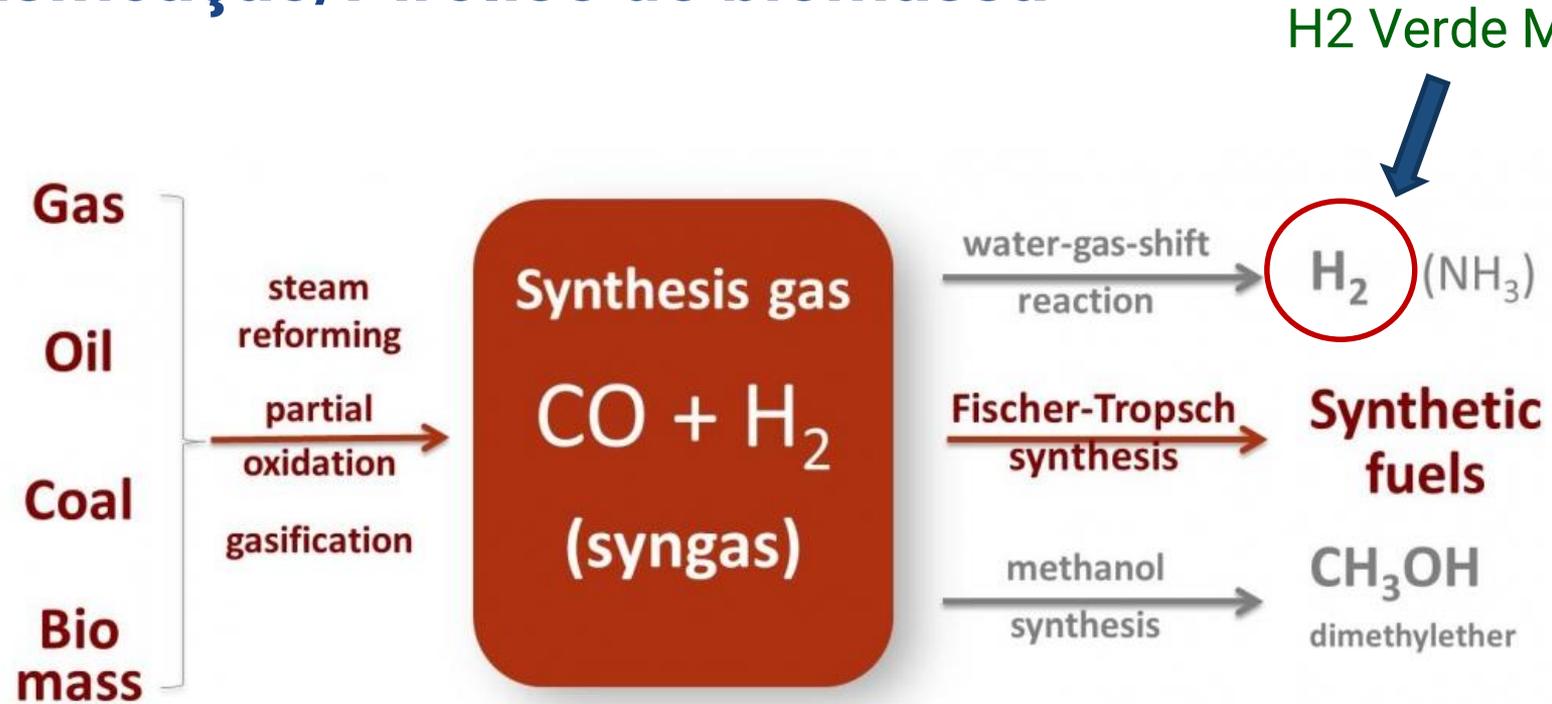


Pesquisa: Hidrogênio e eletricidade a partir do etanol

Com informações da Agência Fapesp - 12/08/2022



Gasificação/Pirólise de biomassa



Intensidade de carbono



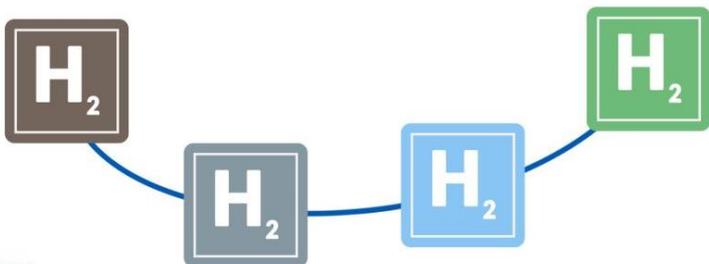
Sustentabilidade H₂ – emissões de CO₂

MARROM

- Produzido por meio da gaseificação do carvão
- Baixo custo, mas com muitos danos ao meio ambiente

VERDE

- Produzido por processos como a reforma do etanol, gás de biomassa ou pela eletrólise da água, usando energia renovável (eólica ou solar)
- Alto custo de produção



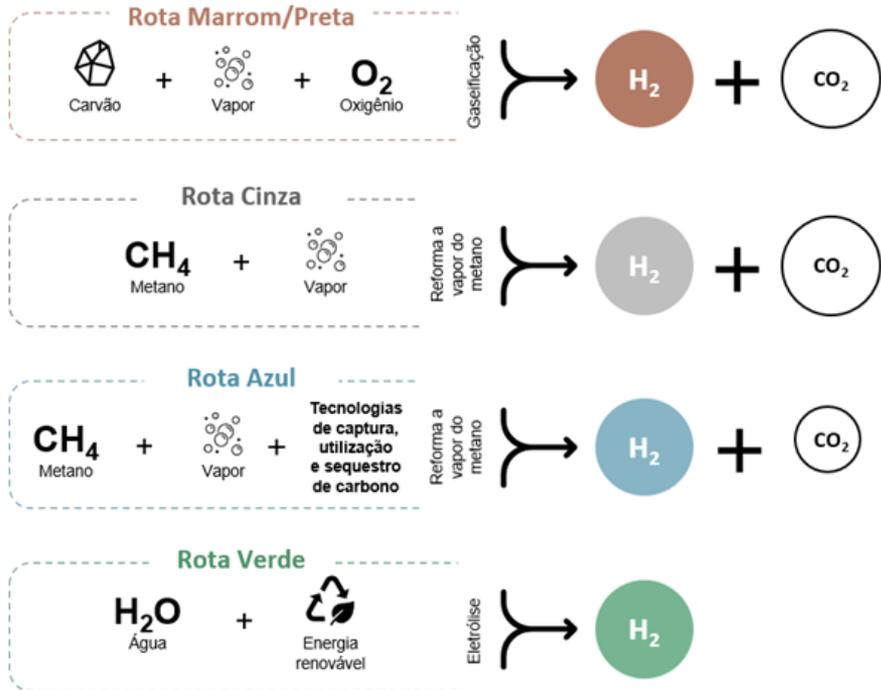
CINZA

- Produzido por combustíveis fósseis, como o gás natural
- Emite CO₂
- Amplamente utilizado no mundo
- Forma mais comum de produção
- Reforma a vapor do metano sem sequestro de emissões

AZUL

- Produzido com o emprego de gás natural, mas com a captura e o sequestro das emissões de carbono ou com seu reuso
- O CO₂ é capturado nas chaminés das indústrias e armazenado em local apropriado
- Baixa produção devido a falta de projetos de sequestro de carbono

Fonte: Governo Federal



Quanto menor a emissão de CO₂, mais sustentável é o H₂

Sustentabilidade H2 – emissões de CO2

Green or Blue—How Clean is Hydrogen?

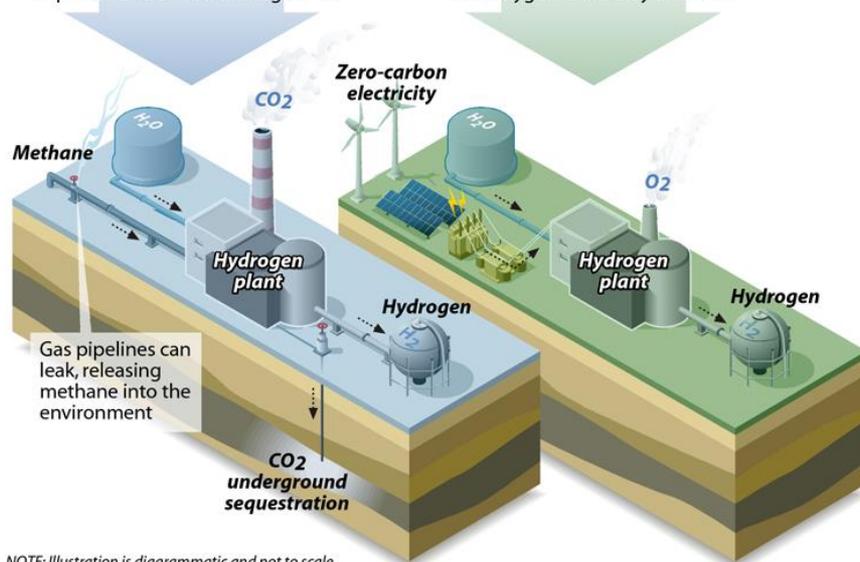
Hydrogen is a clean burning fuel, but its production requires electricity or fossil fuels. The climate benefits of so-called “blue hydrogen,” made with natural gas and carbon capture technology, can vary greatly depending on methane leaks and carbon capture rates.

BLUE HYDROGEN

combines natural gas with steam to produce hydrogen and carbon dioxide. Some or most of the CO₂ is captured and stored underground.

GREEN HYDROGEN

uses electrolysis to separate hydrogen and oxygen from water. Energy used for this process is from renewable sources and oxygen is the only emission.



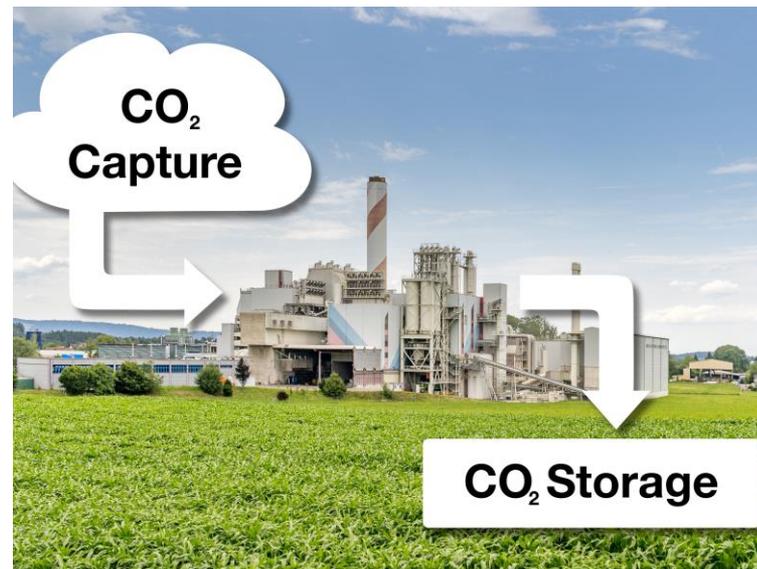
NOTE: Illustration is diagrammatic and not to scale.

SOURCES: Gasunie; Columbia University SIPA; S&P Global Market Intelligence; Sierra Club

PAUL HORN / Inside Climate News

H2 Verde

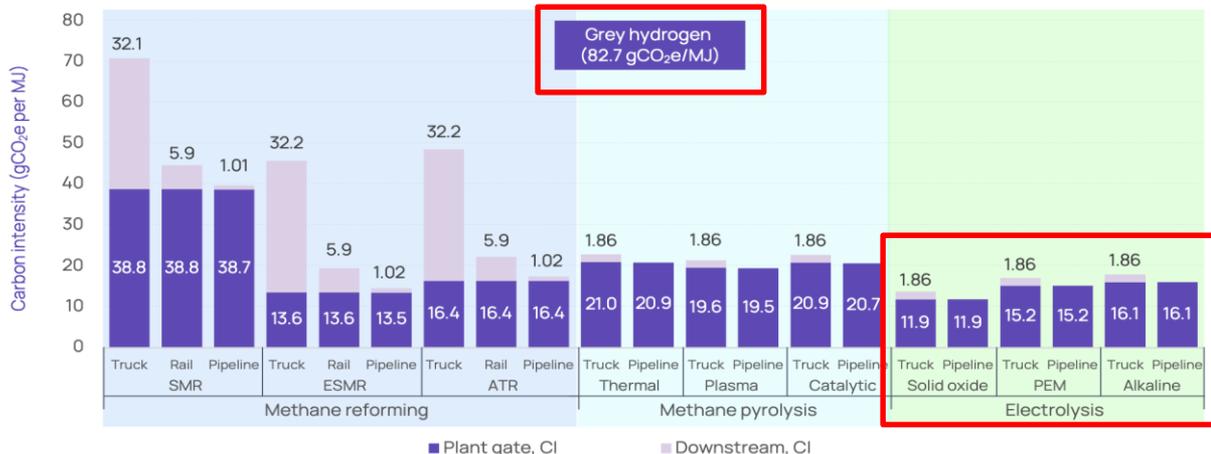
Não emite, mas também não captura



H2 Azul
(CCSU)

Sustentabilidade H2 – emissões de CO2

FIGURE 19 - CI for compressed hydrogen (plant gate and downstream CI separated)



1. PRODUÇÃO DE HIDROGÊNIO A PARTIR DA BIOMASSA

- Demanda mundial de H₂ em 2021 → 94M ton

Gaseificação da biomassa
0,31 a 8,63 kg CO₂/ kg H₂

Fonte fóssil
10,09 a 17,21 kg CO₂/ kg H₂

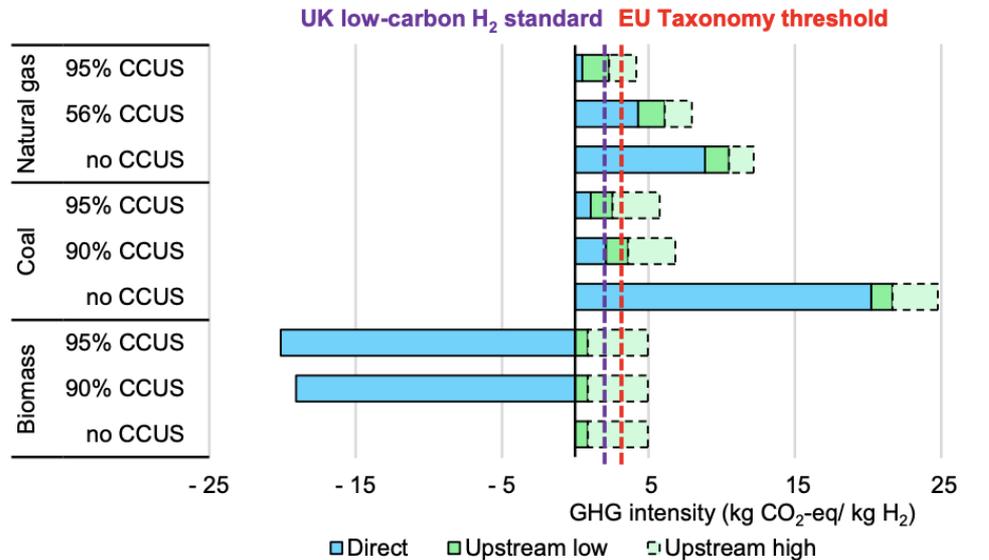
FIGURE 35 - Achievable cradle-to-plant-gate CI ranges in BC today

	LOW END CI: SOLID OXIDE ELECTROLYSIS	HIGH END CI: SMR + CCS (60% CO ₂ Capture)
Compressed hydrogen	11.9 gCO ₂ e/MJ	38.8 gCO ₂ e/MJ
Liquefied hydrogen	12.0 gCO ₂ e/MJ	40.1 gCO ₂ e/MJ

Quanto menor a emissão de CO₂, mais sustentável é o H₂

Sustentabilidade H2 – emissões de CO2

Direct and indirect GHG emissions from H₂ production



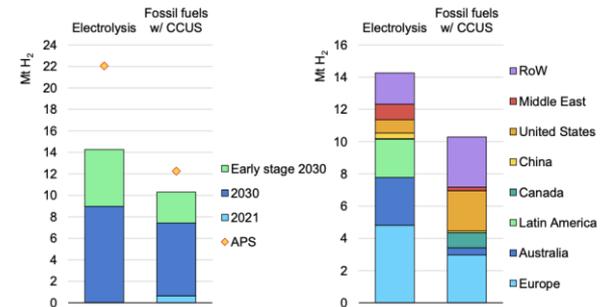
IEA. All rights reserved

Notes: UK = United Kingdom; EU = European Union; CCUS = carbon capture, utilisation and storage; GHG = greenhouse gas.

Sources: 10-90% range for upstream coal and gas GHG emissions from [IEA \(2019\)](#) and [IEA \(2022\)](#), respectively. Biomass supply chain emissions from the world range in [IEA \(2021\)](#) based on the GREET model.

Quanto menor a emissão de CO₂, mais sustentável é o H₂

Low-emission hydrogen production, 2020 and 2030



IEA. All rights reserved.

Notes: RoW = rest of world; APS = Announced Pledges Scenario. In the left figure, the blue columns for 2020 and 2030 refer to projects at advanced planning stages. The right figure includes both projects at advanced planning and early planning stages. Only projects with a disclosed start year for operation are included.
Source: [IEA, Hydrogen Projects Database \(2022\)](#).

Sustentabilidade H2 – emissões de CO2

	Terminology	Technology	Feedstock/ Electricity source	GHG footprint*
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind Solar Hydro Geothermal Tidal	Minimal
	Purple/Pink Hydrogen		Nuclear	
	Yellow Hydrogen		Mixed-origin grid energy	
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS Gasification + CCUS	Natural gas coal	Low
	Turquoise Hydrogen	Pyrolysis	Natural gas	Solid carbon (by-product)
	Grey Hydrogen	Natural gas reforming		Medium
	Brown Hydrogen	Gasification	Brown coal (lignite)	High
	Black Hydrogen		Black coal	

* GHG footprint given as a general guide but it is accepted that each category can be higher in some cases.

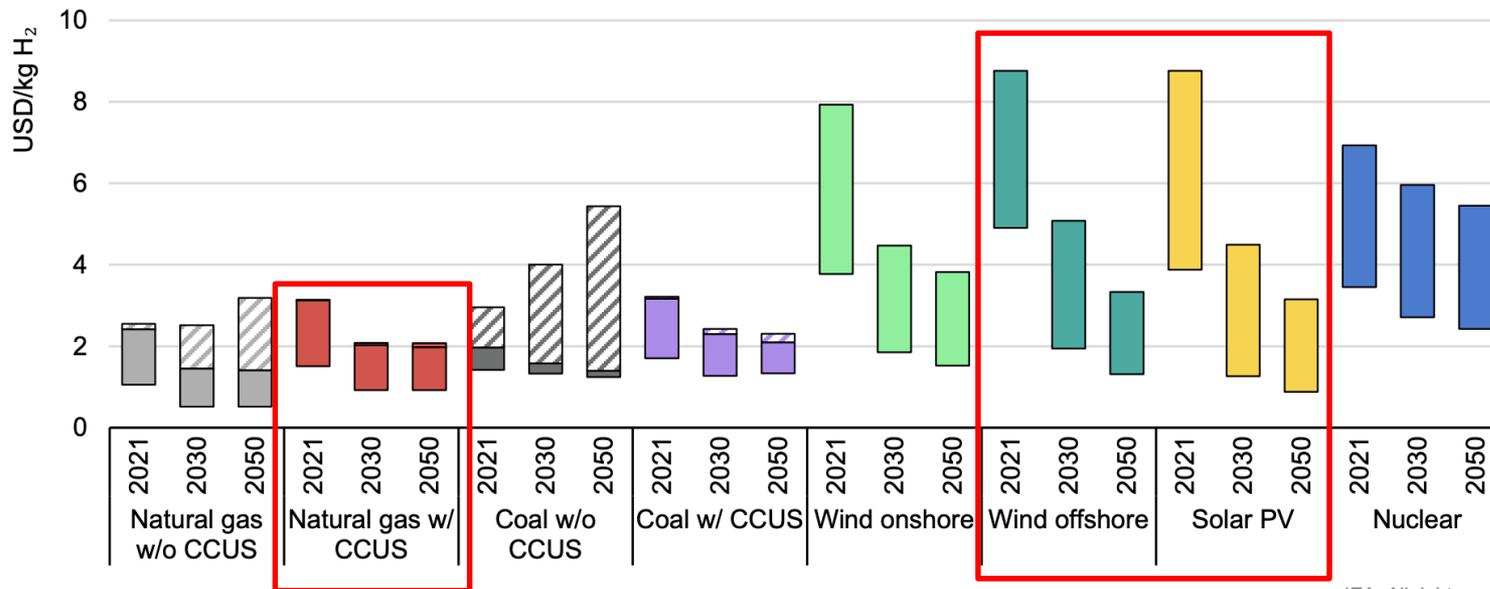
Verde Musgo	Reforma biometano e/ou etanol	Biomassa Biocombustíveis	MINIMA NEUTRA NEGATIVA
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A photograph of a large industrial facility, likely a refinery or chemical plant, at night. The scene is illuminated by numerous bright yellow lights, creating a stark contrast against the dark blue and black sky. Several tall, cylindrical towers and distillation columns are visible, along with a complex network of pipes, walkways, and structural steel. A prominent feature is a tall, slender tower with alternating red and white horizontal bands. The overall atmosphere is one of intense industrial activity.

**Nível de
prontidão e
custo das
tecnologias
para produção
de H₂**

Custos de produção do H2 com atuais tecnologias

Levelised cost of hydrogen production by technology in 2021 and in the Net Zero Emissions by 2050 Scenario, 2030 and 2050



IEA. All rights reserved.

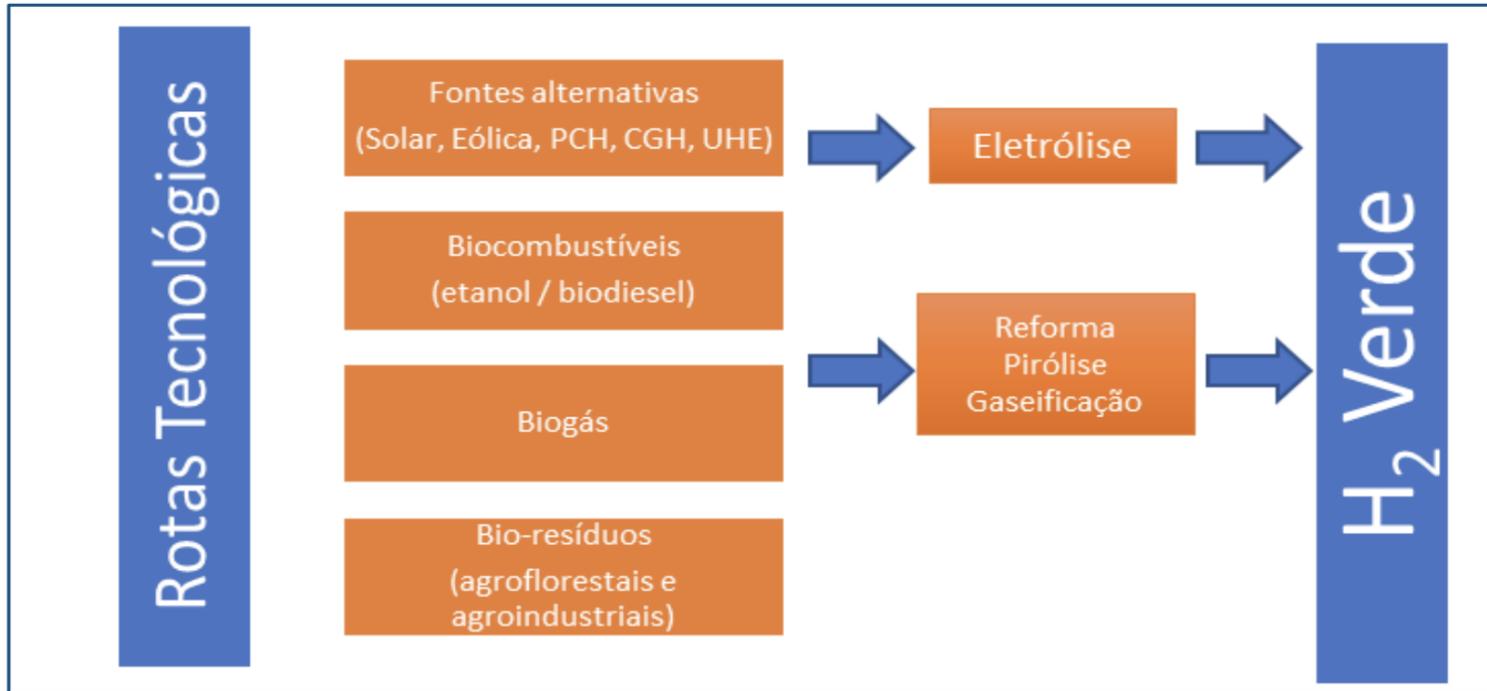
Notes: Ranges of production cost estimates reflect regional variations in costs and renewable resource conditions. The dashed areas reflect the CO₂ price impact, based on CO₂ prices ranging from USD 15/tonne CO₂ to USD 140/tonne CO₂ between regions in 2030 and USD 55/ tonne CO₂ to USD 250/ tonne CO₂ in 2050.

Sources: Based on data from McKinsey & Company and the Hydrogen Council; Council; [IRENA \(2020\)](#); [IEA GHG \(2014\)](#); [IEA GHG \(2017\)](#); [E4Tech \(2015\)](#); [Kawasaki Heavy Industries](#); [Element Energy \(2018\)](#).



Potencial do
Brasil para
produção de H₂
por diferentes
rotas tecnológicas

Rotas mais promissoras para produção de H₂ sustentável no Brasil



Várias alternativas tecnológicas são viáveis no país

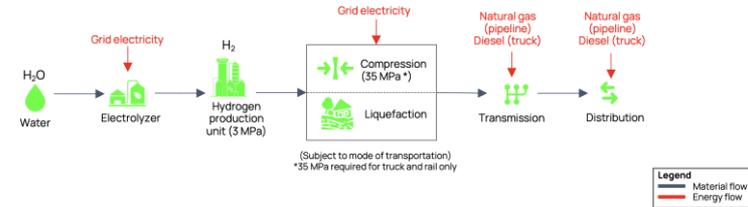
Eletrolise (eólico)



Figura 20 – Distribuição geográfica: geração eólica.
 Fonte: Sistema de Informações de Geração da ANEEL (SIGA).

Grande potencial no NE

FIGURE 17 - Electrolysis process material and energy flows



A força do Nordeste
 Os projetos de H2 verde e energias renováveis

Polo de Pernambuco (Suape)
 CTO: Suez, Oxy, Neomarex

Polo do Ceará (Pecém)
 Enxerg Energy Pte. Ltd.; Qur;
 Fortescue; Neomarex/ Iberdrola;
 Diferencial Energia; Ceres;
 H2Helium; Hytron; Engeq Brasil;
 TransHydrogen; White Martins/Linde;
 Total Green do Brasil; AES; Cactus Energia
 Verde; Casa dos Ventos; Stolthuven;
 H2 Green Power; Newway; Enel Green Power;
 H2F; Asia Brown; Iovener; Mitsui; Akupar; EDP

Polo do Rio Grande do Norte
 Pedra Grande; Maral (Ventos do Atlântico); Alisoos Potiguaras
 (Braxford Participações); Ventos Potiguaras (Internacional Energia);
 Jacti (Delta Wind Energy); Agua Marina (BlueFoot Energy do Brasil);
 Callerys (BlueFoot Energy do Brasil); Projeto Galathea (Covul Brazil)

Polo da Bahia (Camaçari)
 Uragal

Biomassa/biogás



Figura 25 – Produção de biogás. Fonte: CIBILOGAS (2019).

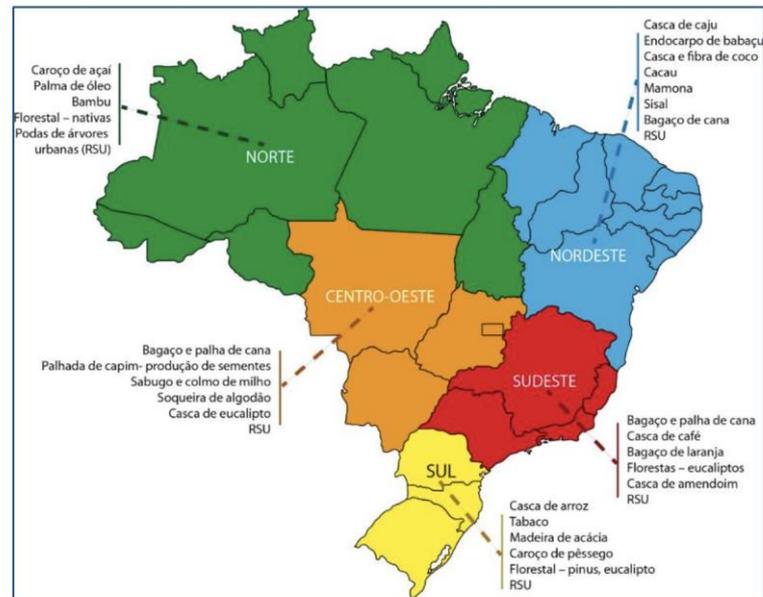
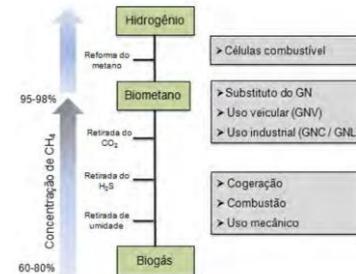


Figura 27 – Disponibilidade de resíduos nas diferentes regiões. Fonte: Jornal Brasileiro das Indústrias de Biomassa (2020).

Grande volume de resíduos e capacidade instalada de produção de biogás

Grande potencial de produção de biogás/biometano

Raízen confirma inauguração da planta de produção de biometano em 2023

Gazeta de Piracicaba (SP) - Publicado 24 Ago 2022 - 08:45



A Raízen apresentou ontem, 23, à imprensa a área onde está sendo construída a [primeira planta de produção de biometano de Piracicaba \(SP\)](#), com capacidade para 26 milhões de metros cúbicos por ano do gás natural renovável. Segundo a empresa, serão investidos R\$ 300 milhões na obra, em uma área de 300 mil metros quadrados, cuja produção já está totalmente vendida antecipadamente para a Volkswagen (setor automobilístico) e a Yara (setor de fertilizantes).

De acordo com a diretora agroindustrial da Raízen, Thaís Fornicola, a unidade deve entrar em operação em 2023 e integra o projeto da

A hora e a vez do Biogás e do Biometano

Por Redação Jornal Cana

Novas plantas para exploração dos produtos mostram que eles são cada vez mais parte dos planos das usinas de cana-de-açúcar

Raízen quer produzir biogás em todas suas usinas de etanol em dez anos

Empresa vê potencial para produzir 3 milhões de m³/dia de biogás nas suas 35 usinas de açúcar e etanol

Gabriel Chiappini — 6 de maio de 2022 - Atualizado em 27 de maio de 2022

Em Mercado de gás, Transição energética

AA

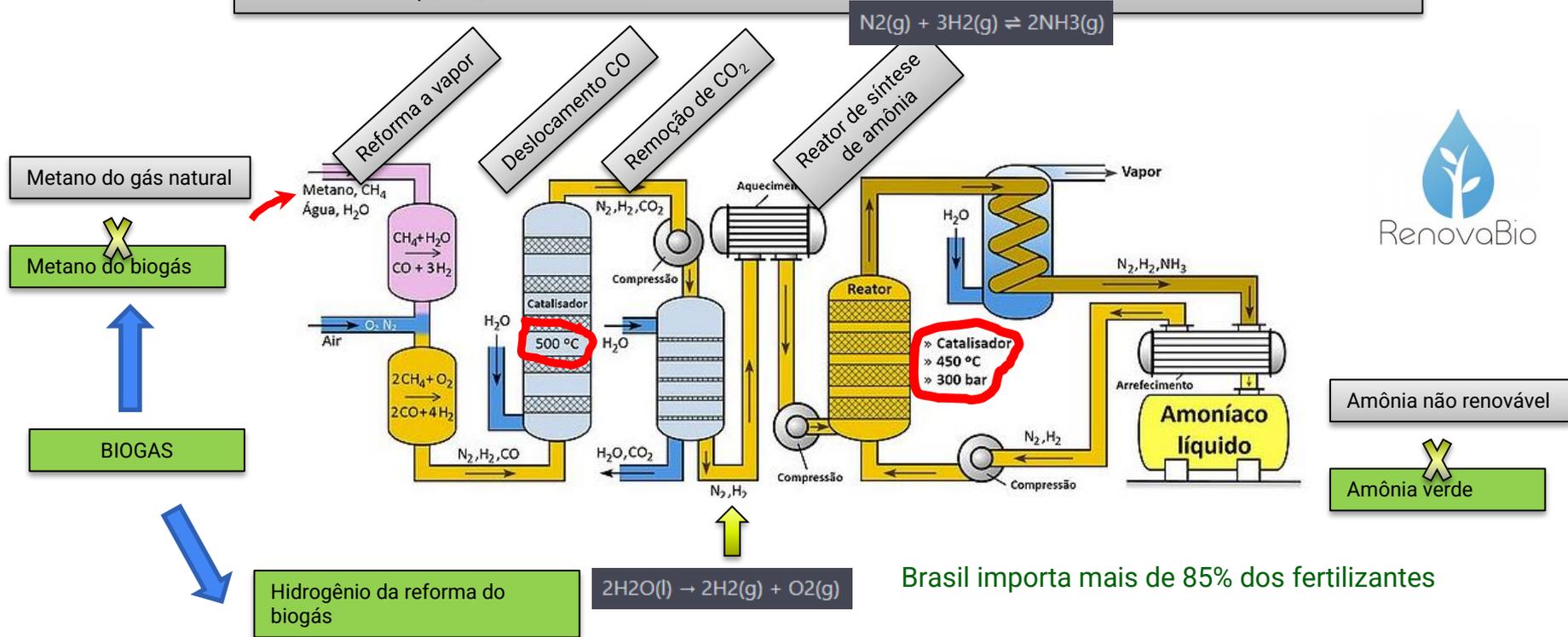


Produção de H2VM + fertilizantes nitrogenados (amônia)

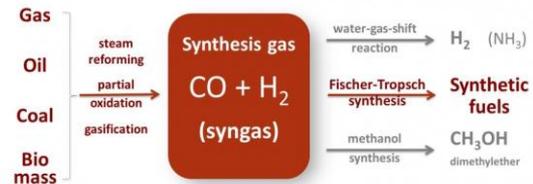
Processo Haber-Bosh

O processo foi desenvolvido laboratorialmente por [Fritz Haber](#) em 1908 e desenvolvido industrialmente por [Carl Bosch](#) entre 1912 e 1913.

Prêmio Nobel de Química em 1918 e 1931.



Biomassa



- Eucalipto *Eucalyptus*
- Pinus *Pine*
- Outros *Others*

FONTE: IBÁ E PÖYRY (2018) SOURCE: IBÁ AND PÖYRY (2018).

Grande volume de biomassa florestal

Etanol

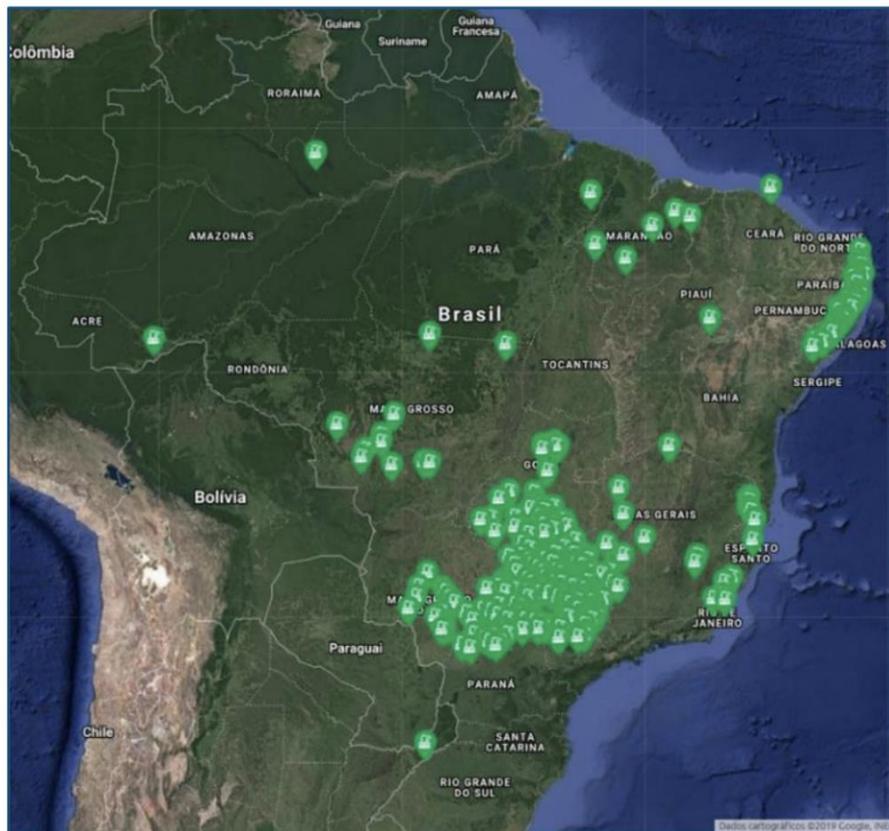
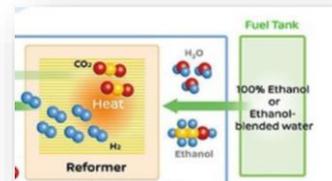


Figura 24 - Produção de etanol. Fonte: Infocana (2019).



País é dos líderes mundiais na produção de cana de açúcar com grande capacidade instalada de produção de etanol

Potential for hydrogen production in Brazil

Hydroelectric Power	Geothermal energy	Biogas
Solar Energy	Natural Hydrogen	Biodiesel
Wind Energy	Ethanol	Natural Gas
Ocean Energy	Biomass	Petroleum



Obrigado!

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