



ESCUELA DE INGENIERÍA  
FACULTAD DE INGENIERÍA

EDUCACIÓN  
PROFESIONAL

# Captura y utilización de dióxido de carbono

El gran paso hacia la carbono  
neutralidad

Roberto Canales y Junior Lorenzo





PRESENTAN:



**Roberto Canales Muñoz**



**Junior Lorenzo Llanes**



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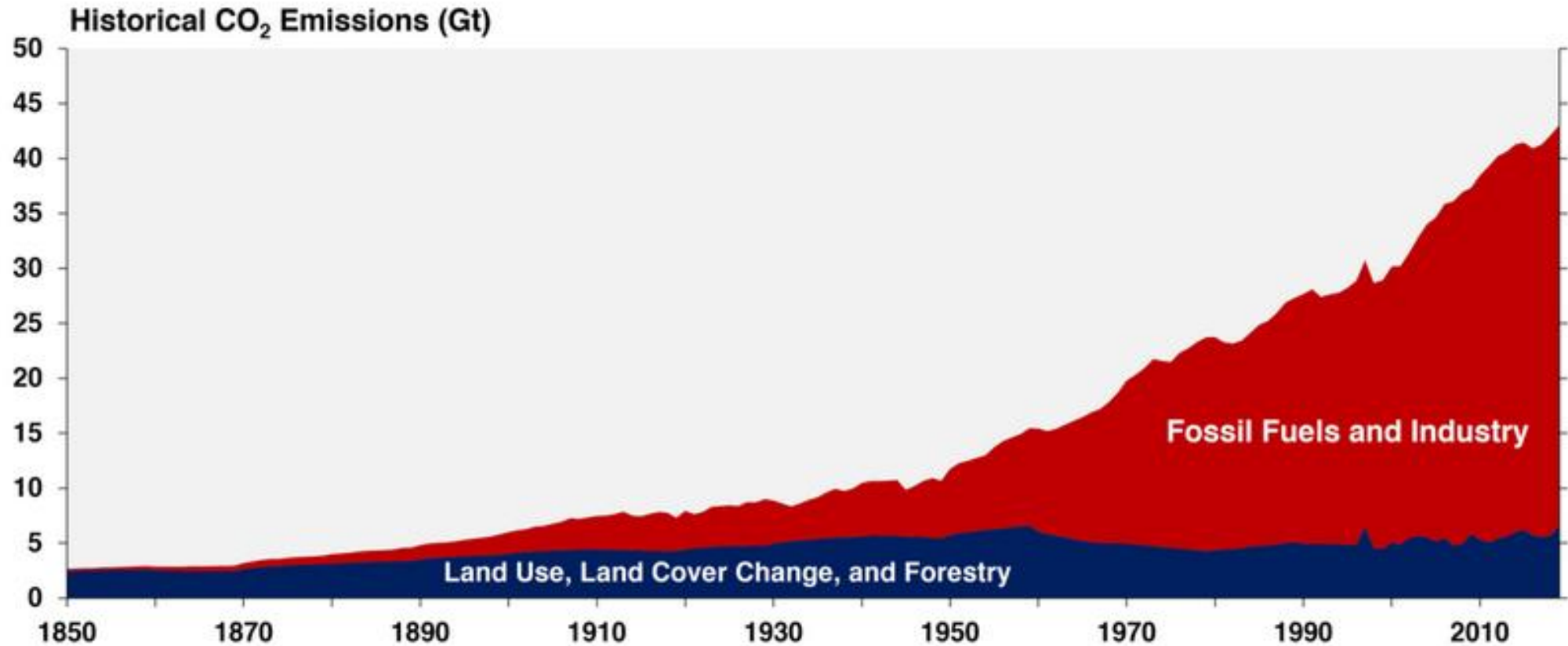
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## ¿Cómo se ven las emisiones históricas?



Datos desde Grupo Intergubernamental de Expertos sobre el Cambio Climático (2022); Basado en las emisiones globales de 2019

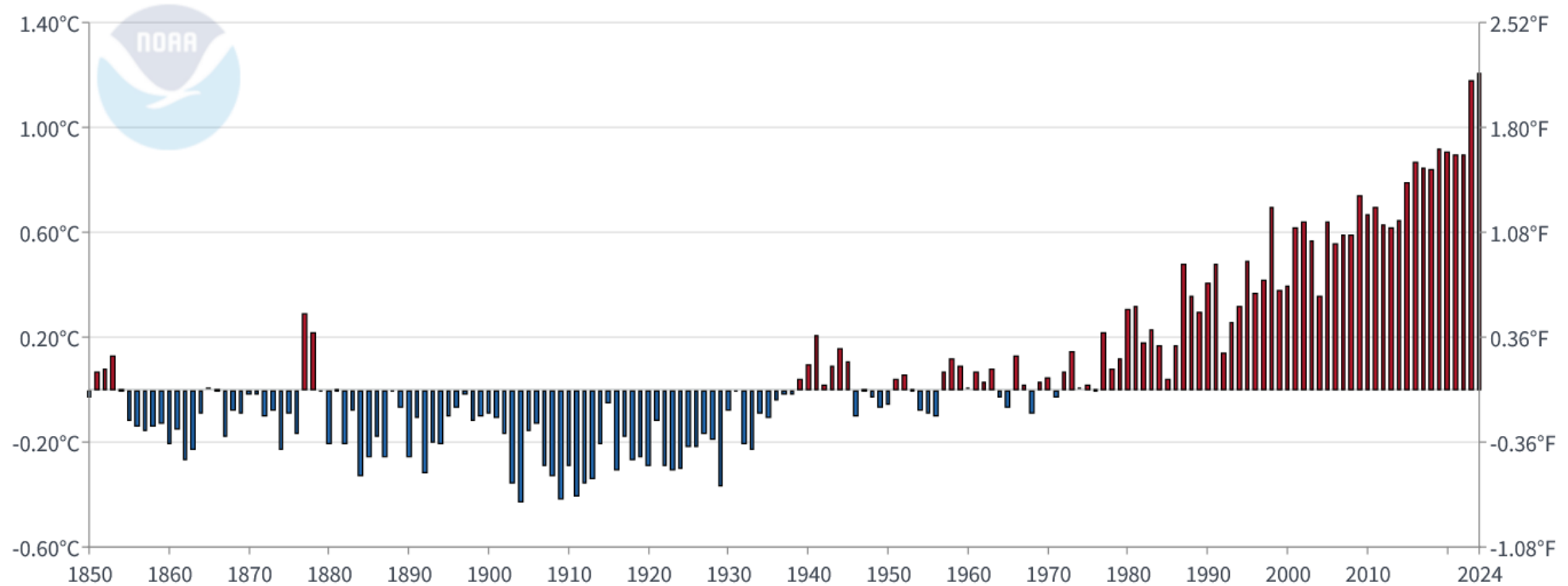
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# Emisión de gases de invernadero

## Correlación entre emisiones y promedio de temperatura global

### Global Land and Ocean

July Average Temperature Anomalies



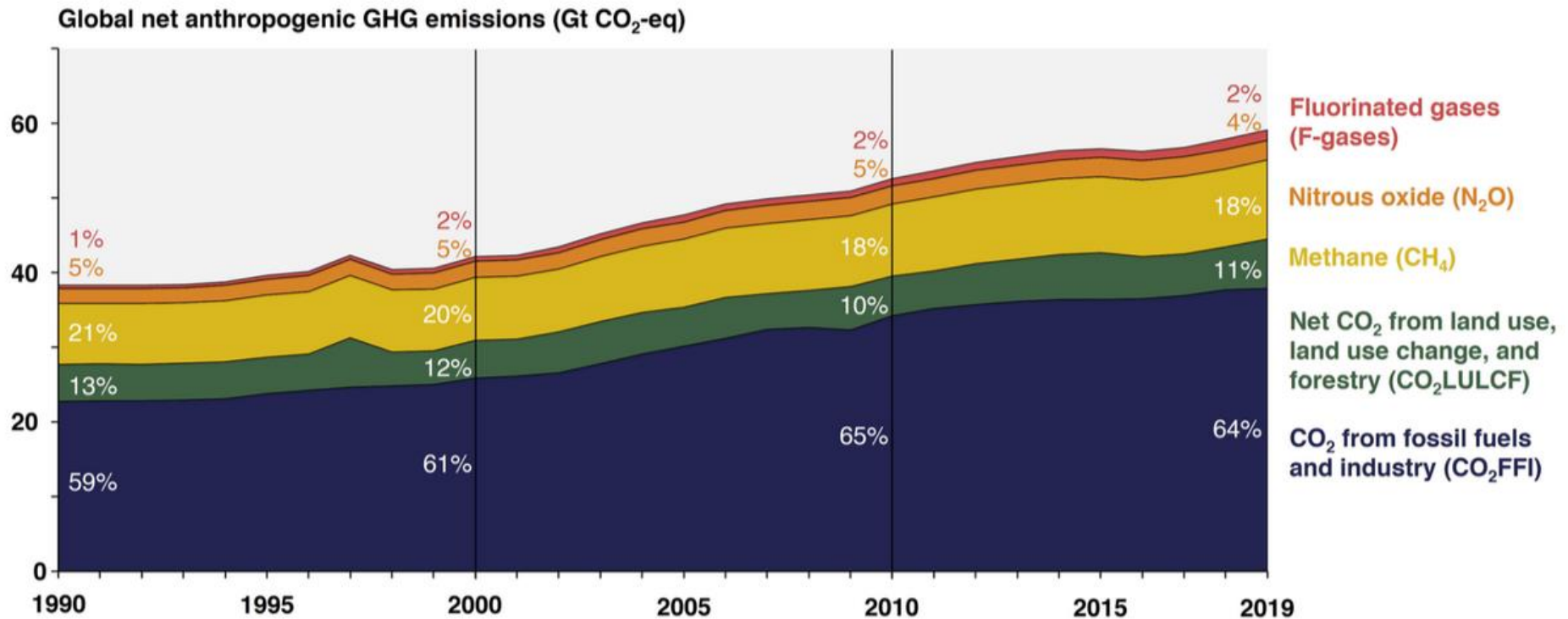
[https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/time-series/globe/land\\_ocean/1/7/1850-2024](https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/time-series/globe/land_ocean/1/7/1850-2024)

www.educacionprofesional.ing.uc.cl

# Emisión total de gases de invernadero

¿Por qué se habla principalmente de CO<sub>2</sub> como causante del calentamiento global?

$$Gt\ CO_2\text{-eq} = Gt_{gas} \cdot GWP$$



Datos desde Grupo Intergubernamental de Expertos sobre el Cambio Climático (2022); Basado en las emisiones globales de 2019

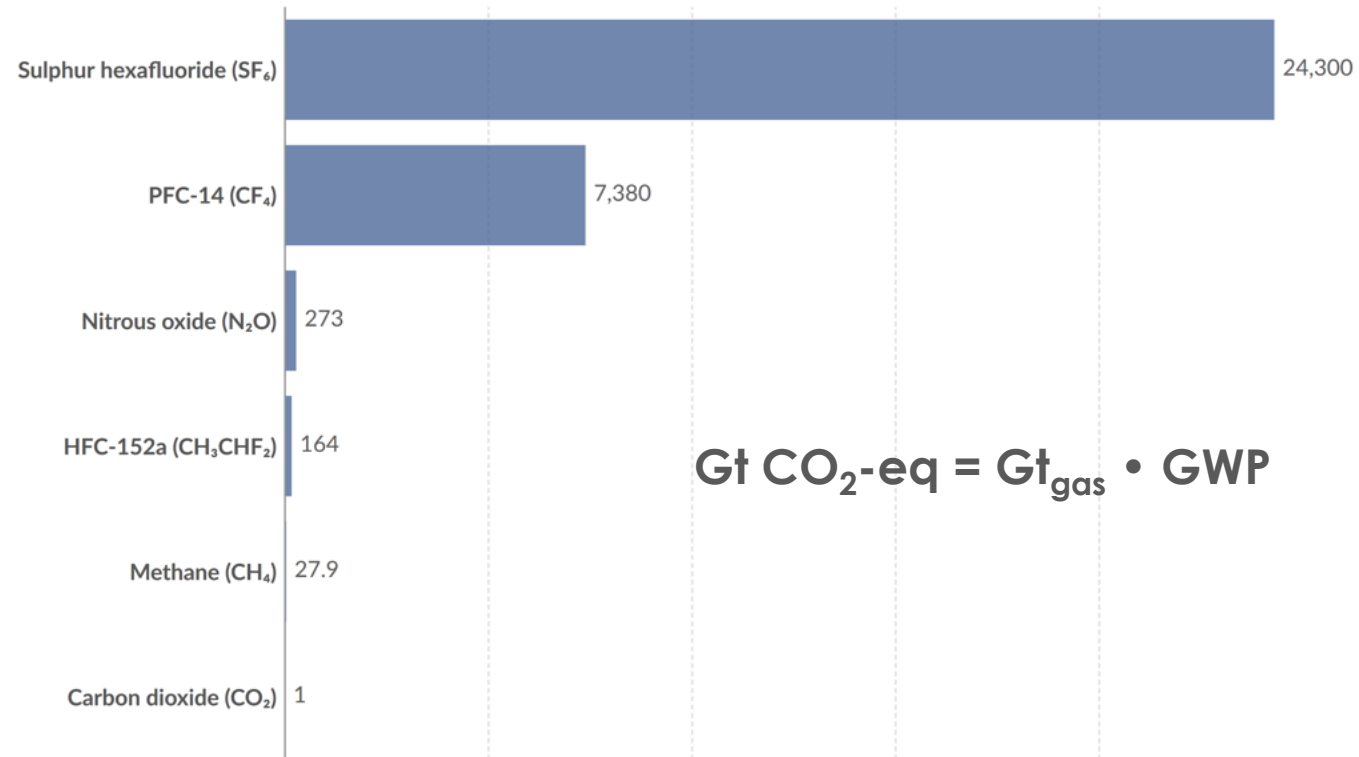
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# Potencial de calentamiento global (GWP)

## Global warming potential of greenhouse gases relative to CO<sub>2</sub>

Our World  
in Data

Global warming potential<sup>1</sup> measures the relative warming impact of one unit mass of a greenhouse gas relative to carbon dioxide over a 100-year timescale.



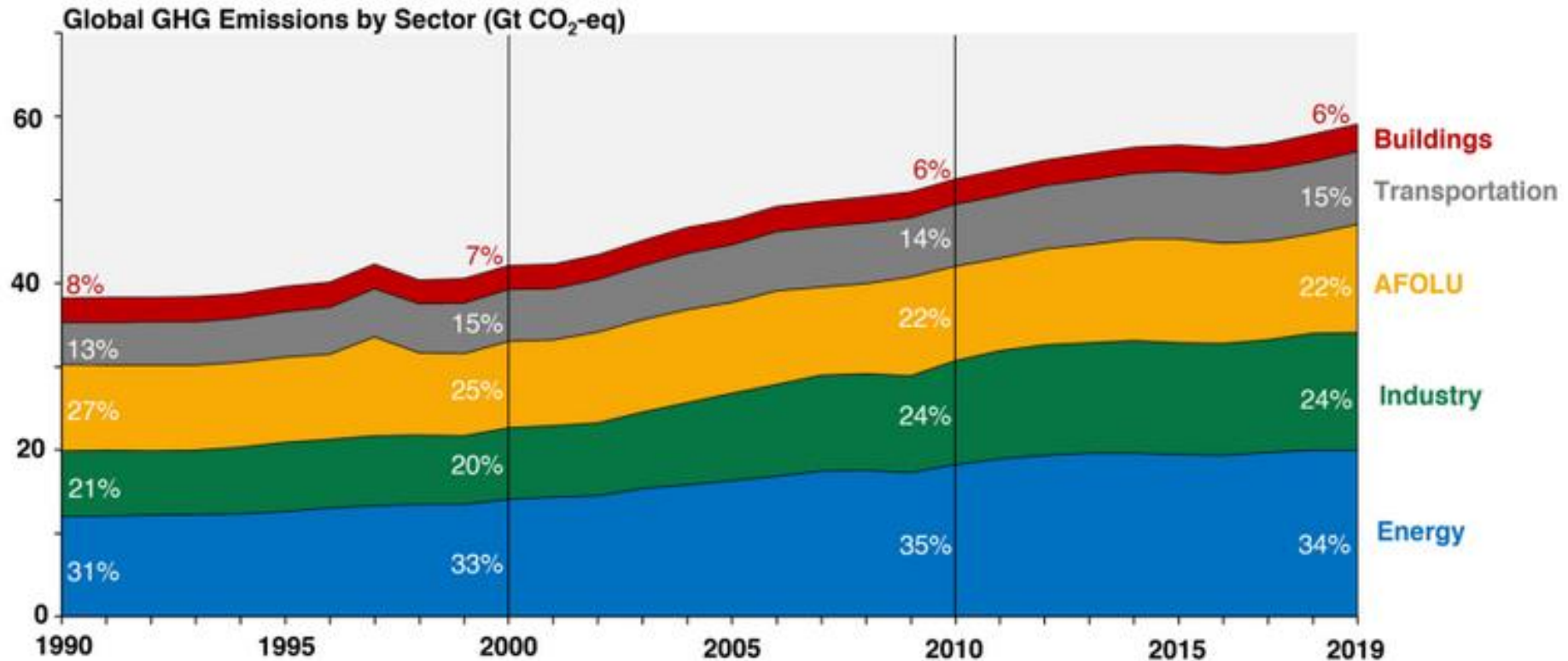
$$Gt\ CO_2\text{-eq} = Gt_{gas} \cdot GWP$$

Data source: IPCC (2021)

OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

# Emisión de gases de invernadero

## ¿Cómo se ve la distribución de emisiones por sector?



Datos desde Grupo Intergubernamental de Expertos sobre el Cambio Climático (2022); Basado en las emisiones globales de 2019

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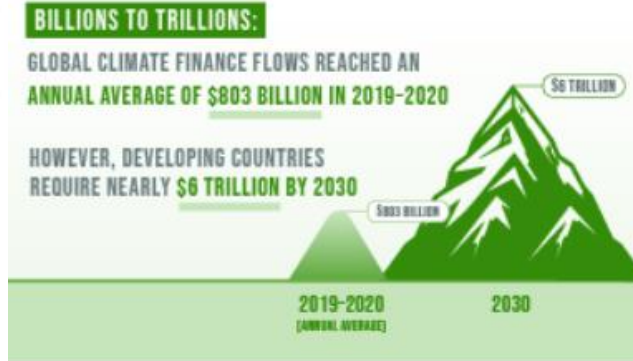
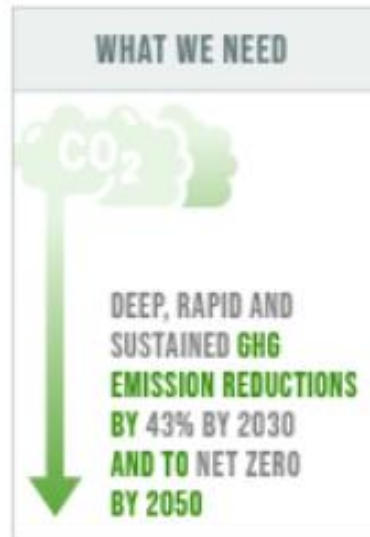
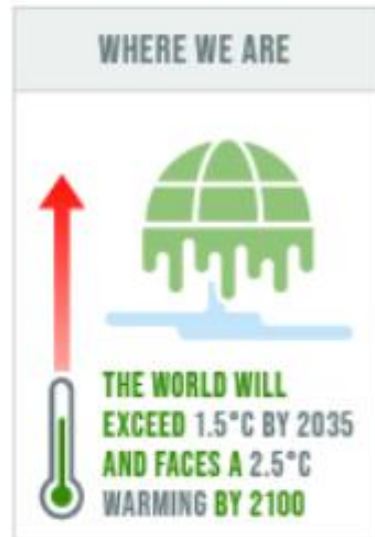


# Objetivos de desarrollo sustentable: Reporte 2023

Goals

# 13

## Take urgent action to combat climate change and its impacts



<https://sdgs.un.org/goals/goal13>

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[www.educacionprofesional.ing.uc.cl](http://www.educacionprofesional.ing.uc.cl)

# Acuerdo de París (2015)

Tratado internacional sobre cambio climático de la COP21

Limitar incremento de temperatura global a 2°C con respecto a era pre-industrial, preferentemente 1,5°C como máximo

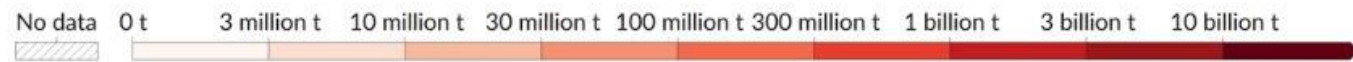
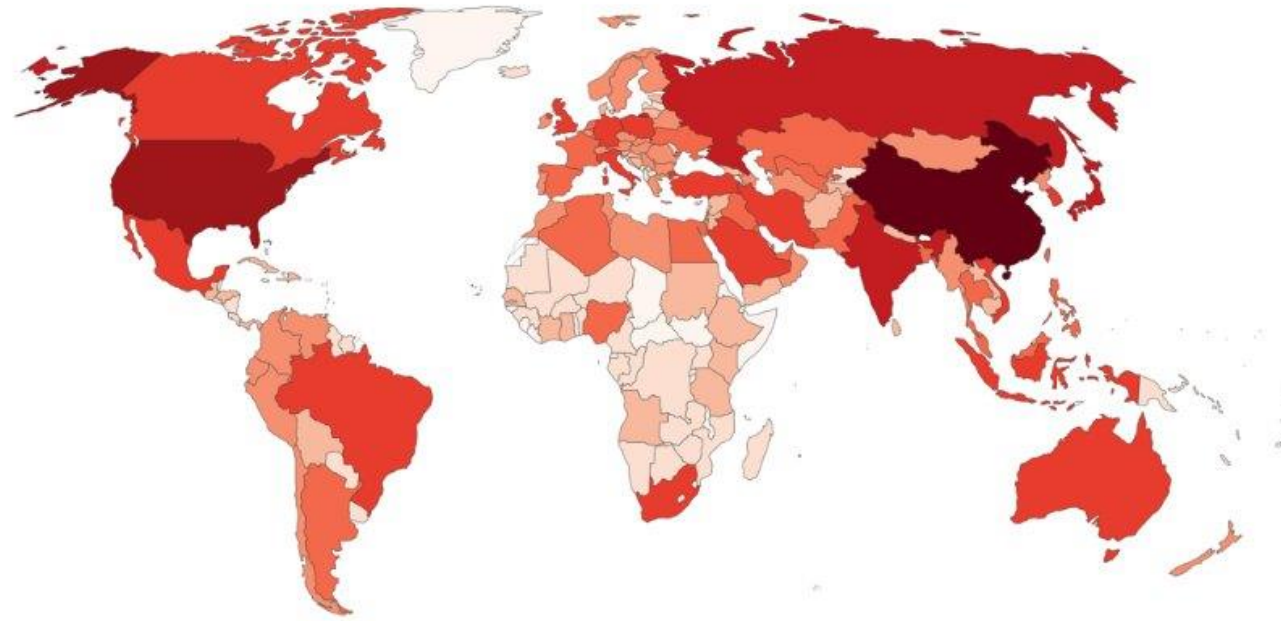


# Emisiones globales

## Annual CO<sub>2</sub> emissions, 2022

Carbon dioxide (CO<sub>2</sub>) emissions from fossil fuels and industry<sup>1</sup>. Land-use change is not included.

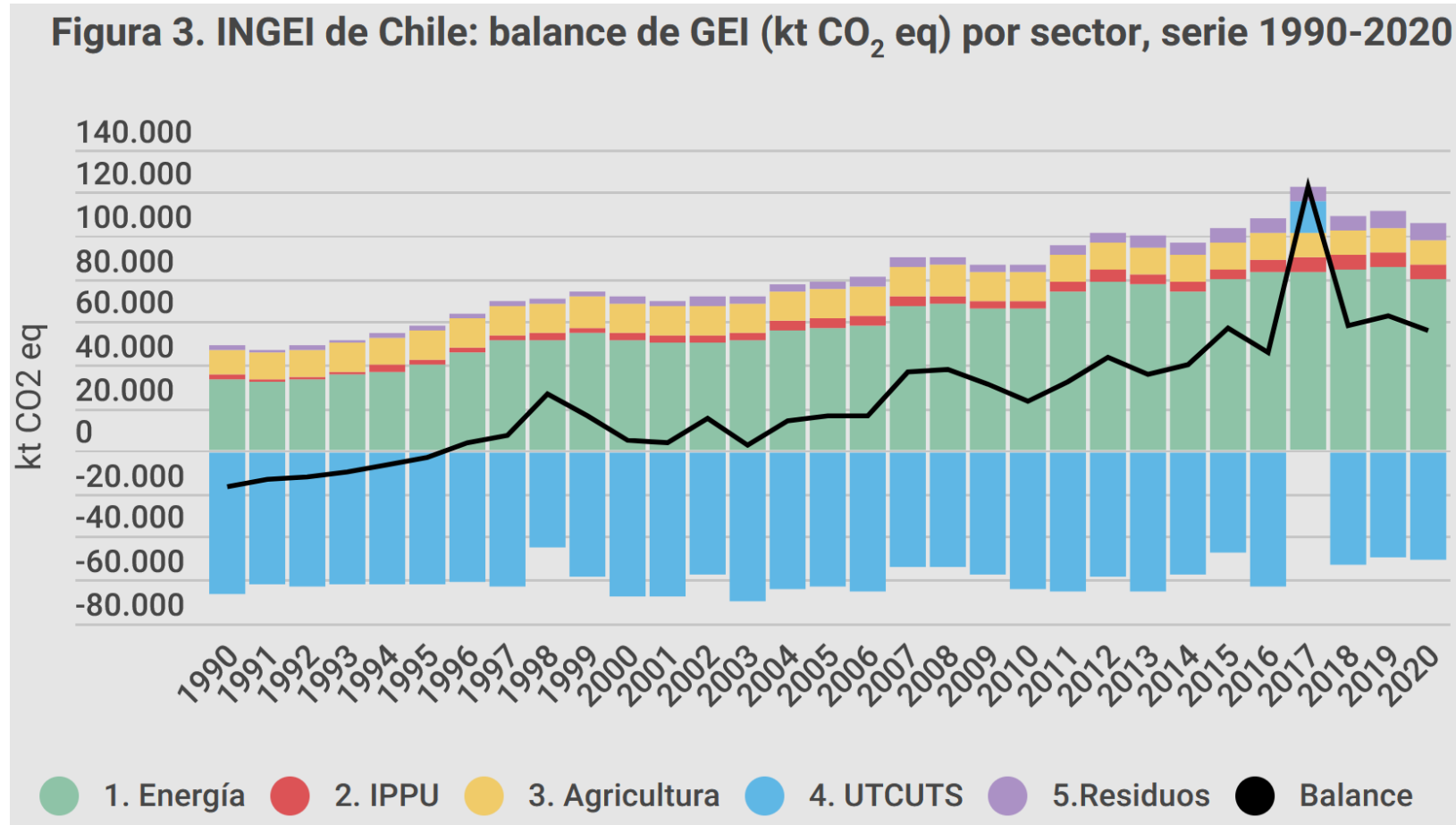
Our World  
in Data



Data source: Global Carbon Budget (2023)

OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

# Emisiones en Chile



# ¿Para qué podríamos capturar CO<sub>2</sub> en Chile?



De acuerdo con el ranking [Climatescope de Bloomberg 2023](#), Chile es una de las tres economías a nivel mundial más atractivas para la inversión en energías limpias. Además, se calcula que la Estrategia Nacional de Hidrógeno Verde permitirá oportunidades de inversión por US \$475 mil millones en los próximos diez años.

<https://www.marcachile.cl/si-es-hidrogeno-verde-el-mundo-comienza-por-chile/>



## HIF Cabo Negro e-Fuels Facility

The plant will use renewable energy from the wind and a process called electrolysis to produce green hydrogen. The project will also capture CO<sub>2</sub> from biomass, industrial sources or directly from the atmosphere, and use a process of synthesis to combine the CO<sub>2</sub> and hydrogen to produce e-Fuels, including carbon neutral methanol (e-Methanol), gasoline (e-Gasoline) and carbon neutral Liquefied Gas (e-LG).

### Quick Facts



384 MW Plant



175,000 tons/year of e-Methanol



215,000 tons CO<sub>2</sub> captured/year

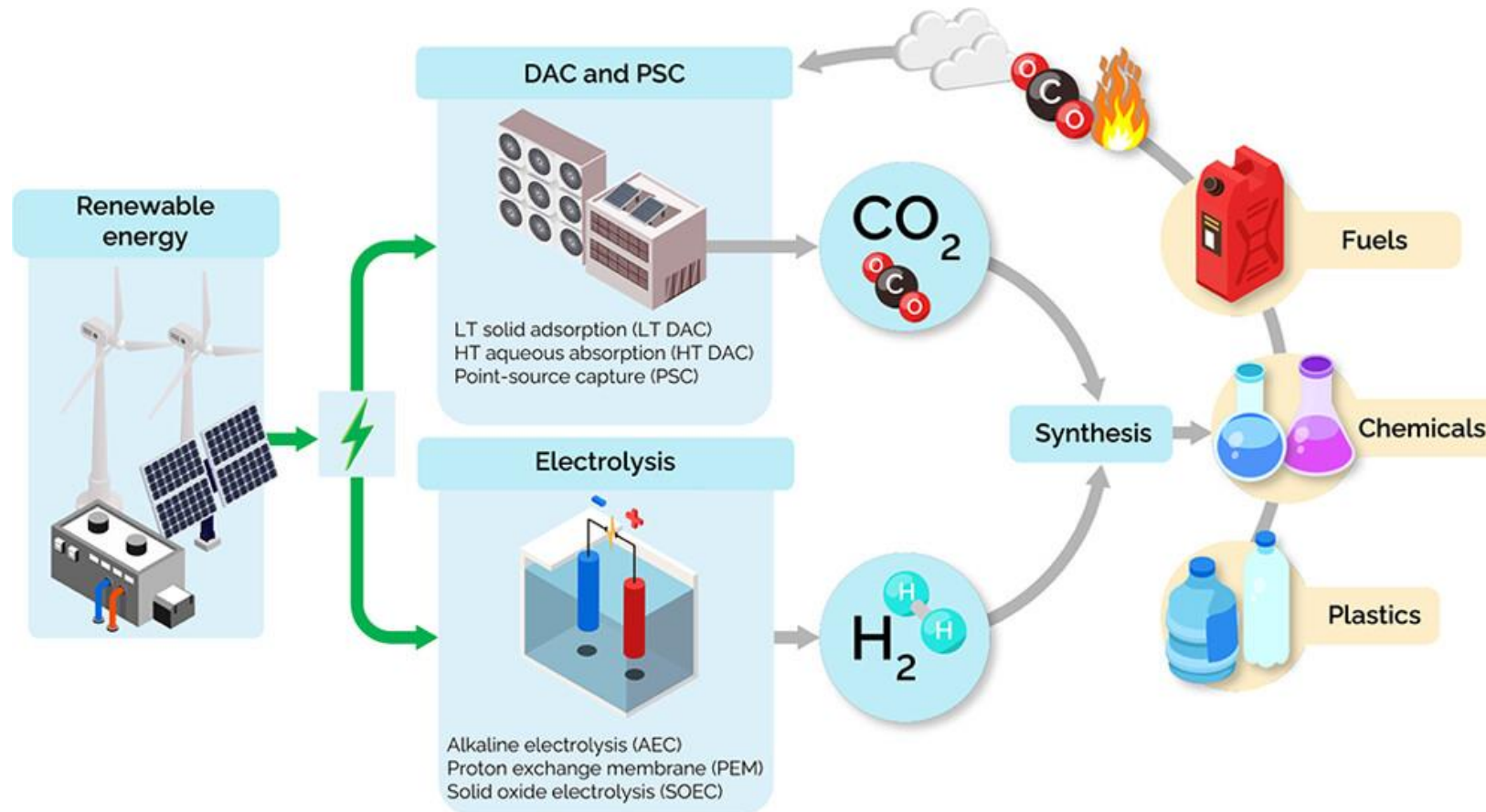


242 MW electrolyzer capacity

<https://hifglobal.com/region/hif-latam>

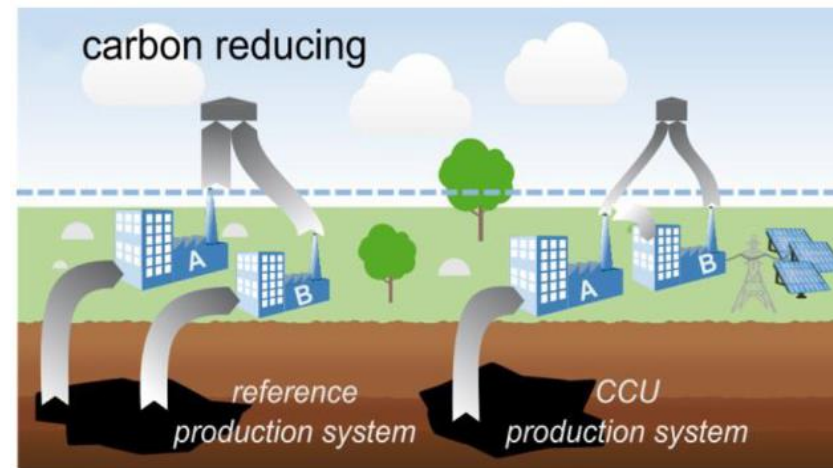
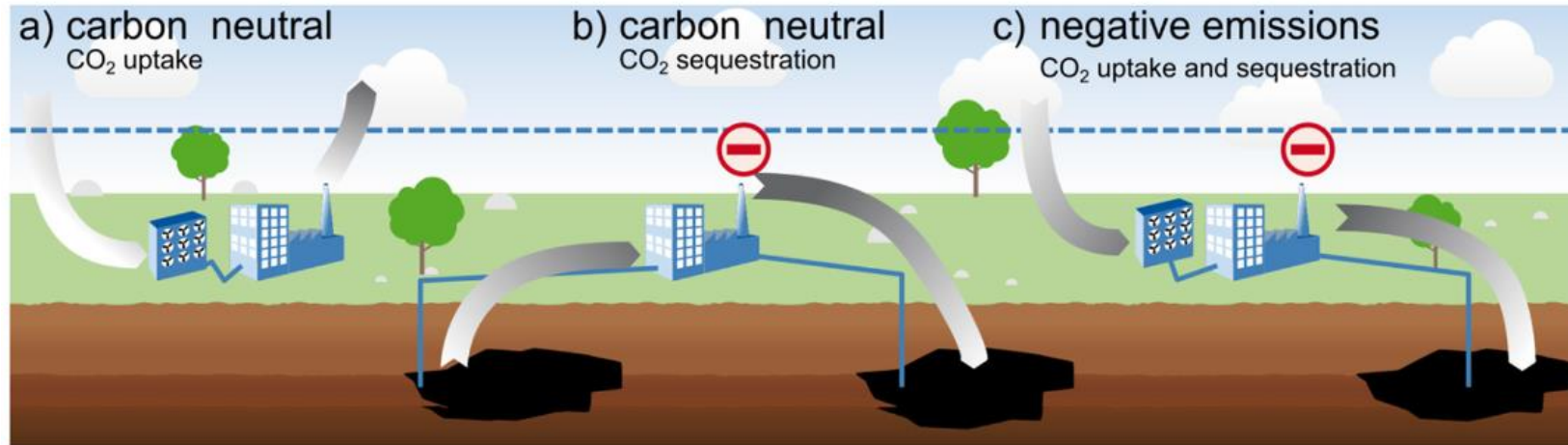
[www.educacionprofesional.ing.uc.cl](http://www.educacionprofesional.ing.uc.cl)

# Captura e hidrogenación de CO<sub>2</sub>



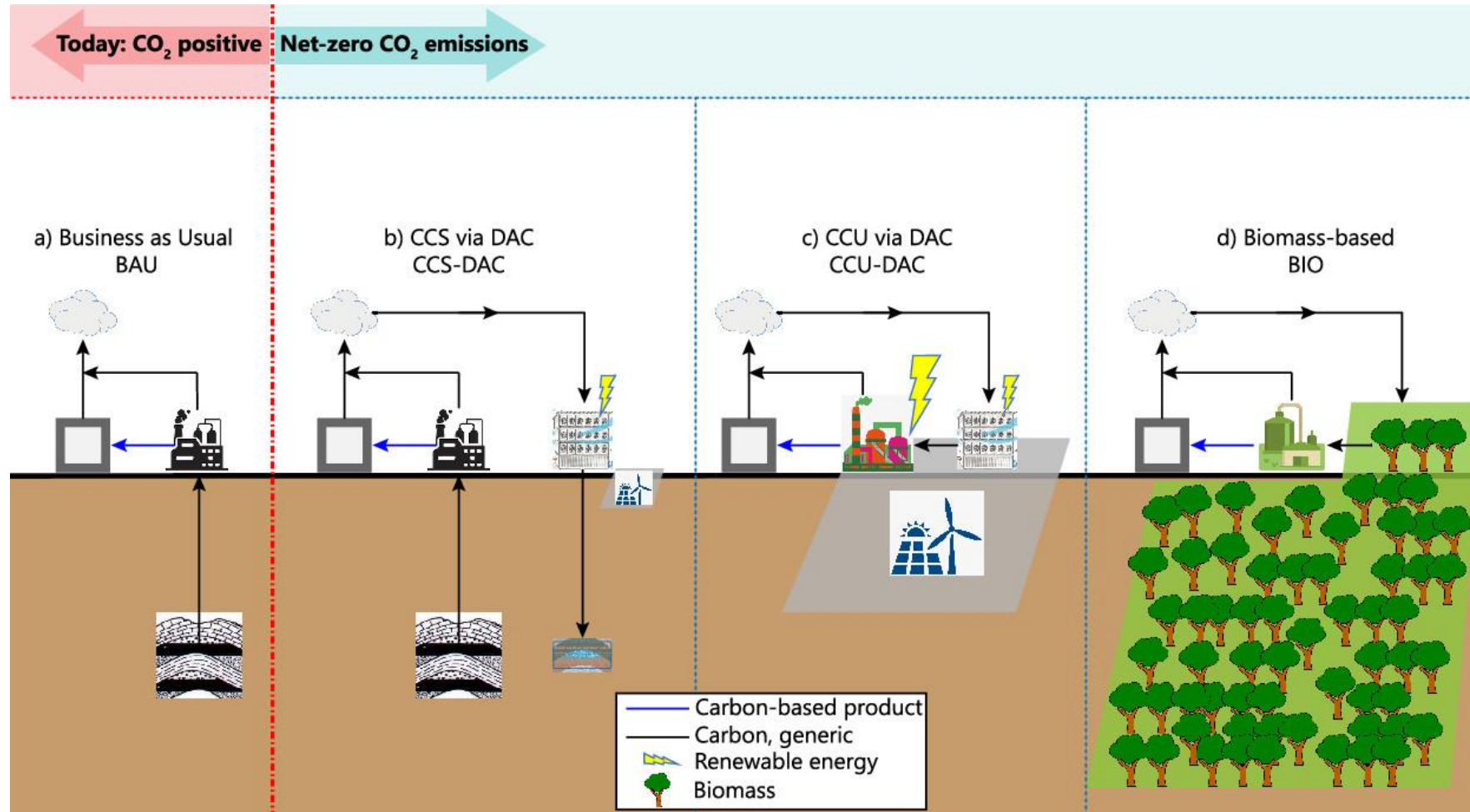
Allgoewer, L. et al., Cost-Effective Locations for Producing Fuels and Chemicals from Carbon Dioxide and Low-Carbon Hydrogen in the Future, *Industrial & Engineering Chemistry Research* 2024 63 (31), 13660-13676

# Antecedentes de Captura de CO<sub>2</sub>



Müller, L. J., et al. (2020). "A Guideline for Life Cycle Assessment of Carbon Capture and Utilization." [Frontiers in Energy Research](#) 8.

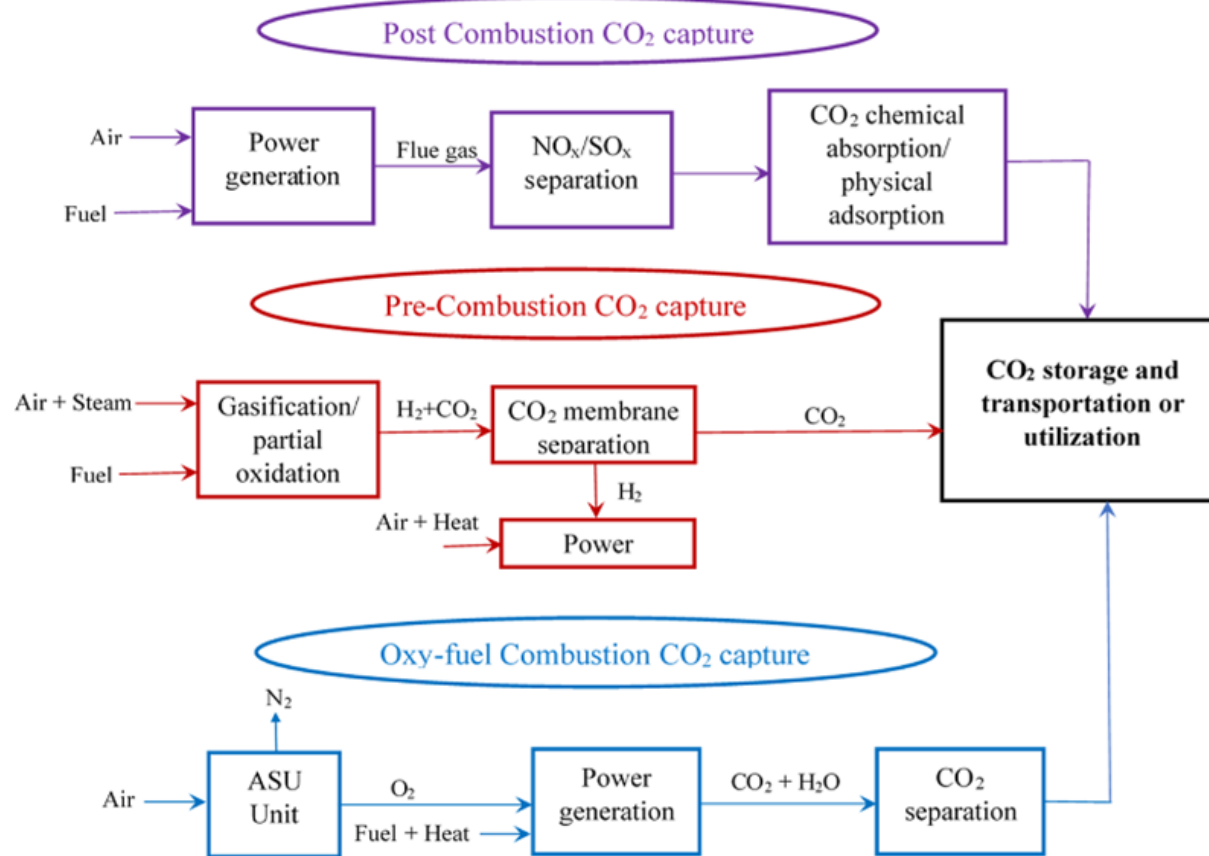
# Captura directa del aire (DAC)



Gabrielli, P., The Role of Carbon Capture and Utilization, Carbon Capture and Storage, and Biomass to Enable a Net-Zero-CO<sub>2</sub> Emissions Chemical Industry, *Industrial & Engineering Chemistry Research* 2020 59 (15), 7033-7045



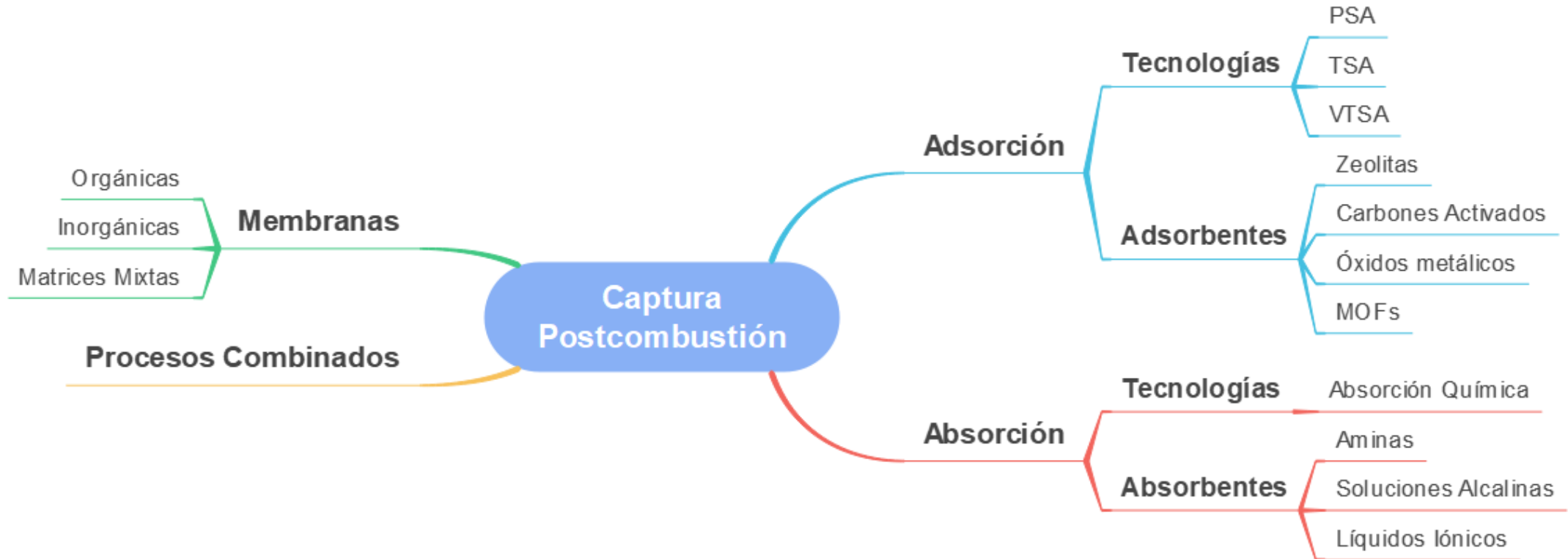
# Tecnologías de Captura de CO<sub>2</sub>



Jiang et al. (2024). Emerging Technologies Review: Carbon Capture and Conversion to Methane and Methanol.

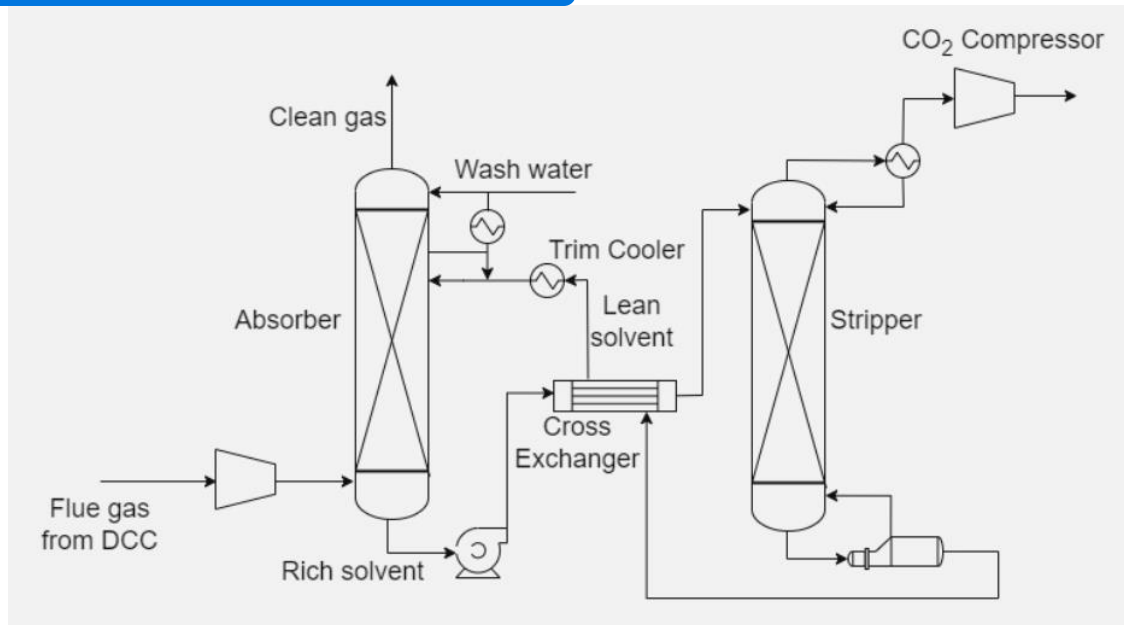
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# Tecnologías de Captura de CO<sub>2</sub>

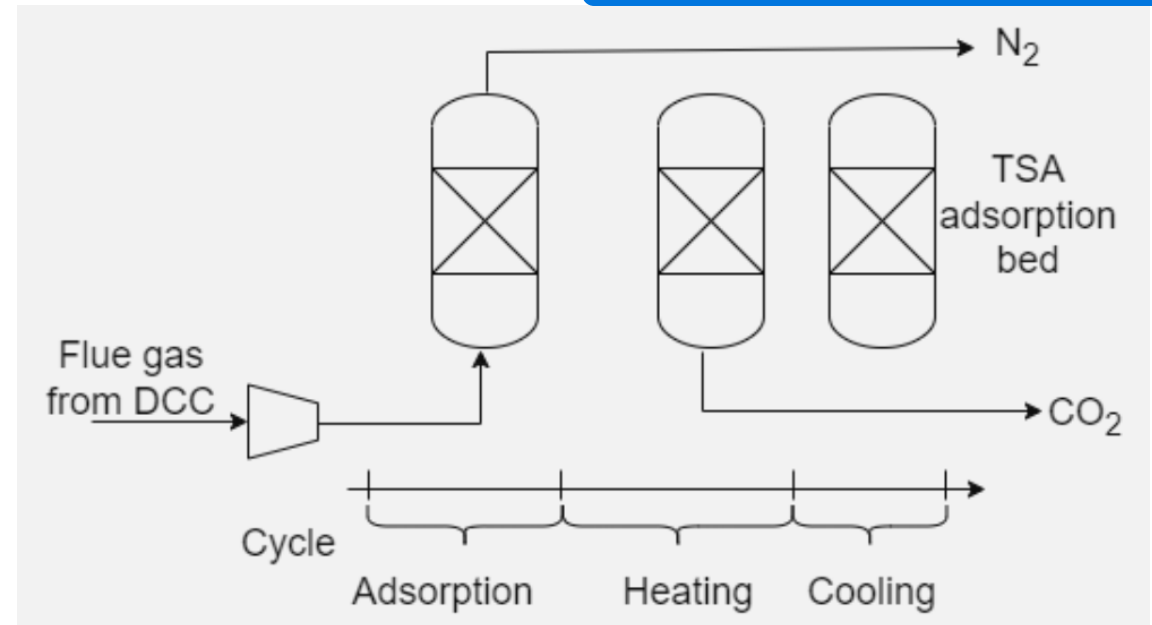


# Tecnologías de Captura de CO<sub>2</sub>

## Absorción Química

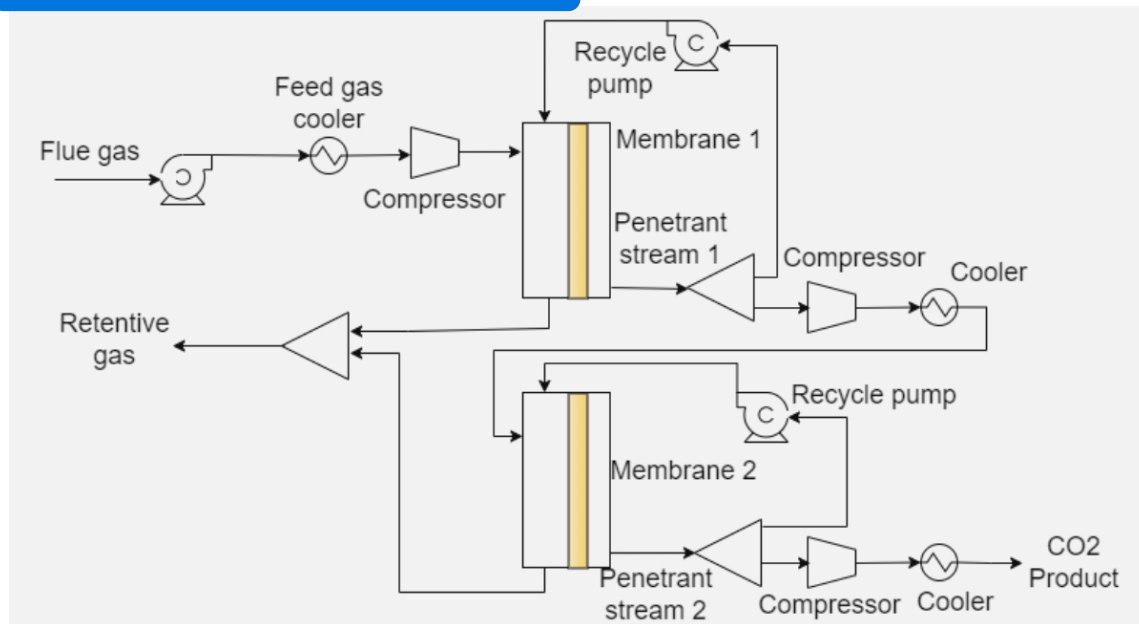


## Adsorción

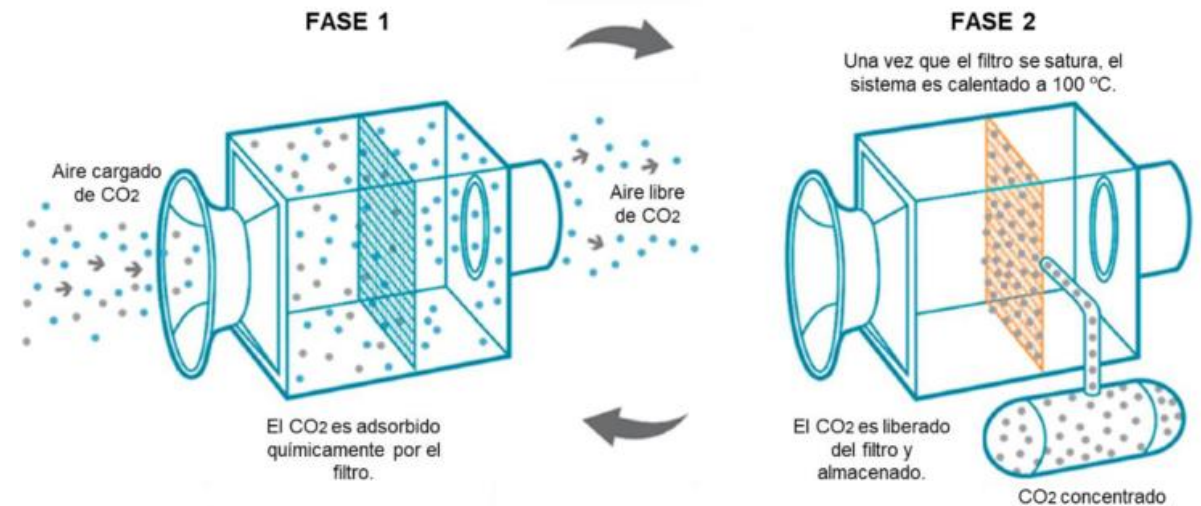


# Tecnologías de Captura de CO<sub>2</sub>

## Membranas



## Captura Directa del Aire



# Tecnologías de Captura de CO<sub>2</sub>



LINDE

## ADVANCED AMINE-BASED POST-COMBUSTION CO<sub>2</sub> CAPTURE (PCC)



[ccus@linde.com](mailto:ccus@linde.com)

[www.engineering.linde.com/CO<sub>2</sub>](http://www.engineering.linde.com/CO2)

### HIGHLIGHTS

- Compact footprint
- High CO<sub>2</sub> capture rate even at low CO<sub>2</sub> concentrations
- With a final CO<sub>2</sub> product purity of 99.9 vol% (dry), a further purification step may not be necessary
- 20% lower energy consumption and 20% lower circulation rate compared to MEA solution
- Low solvent degradation rate even at elevated oxygen content in flue gas, and therefore low solvent consumption rate
- Different options for energy and heat integration

### KEY DATA

TRL	9	Capture Rate Range (tpd)	200 - 7,000	Modular (Y/N)	Yes
Source CO <sub>2</sub> Concentration	3 - 25%	Energy Consumption (GJ/tCO <sub>2</sub> )	2.5 - 3.2	Capture Efficiency (%)	>95%
Number of Commercial Plants	>60	Number of Pilot Plants	3		
Target Industries	Cement & lime, power generation (natural gas, biomass, coal), iron & steel, petrochemical, oil & gas				

# Tecnologías de Captura de CO<sub>2</sub>



**LINDE**  
CO<sub>2</sub> PSA



[ccus@linde.com](mailto:ccus@linde.com) [www.engineering.linde.com/CO<sub>2</sub>](http://www.engineering.linde.com/CO2)

## HIGHLIGHTS

- Mature and robust purification technology
- Negligible electricity consumption
- No steam required for regeneration (thereby no additional CO<sub>2</sub> generation)
- No solvents are applied, so therefore no negative environmental impact due to the emission of solvent traces in exhausts or in the CO<sub>2</sub> product
- No extra cost for solvent makeup and handling
- Low CAPEX and OPEX technology

## KEY DATA

TRL	9	Capture Rate Range (tpd)	10 - 5,000	Modular (Y/N)	Yes
Source CO <sub>2</sub> Concentration	>7%	Energy Consumption (GJ/tCO <sub>2</sub> )	0 <sup>1</sup>	Capture Efficiency (%)	99%
Number of Commercial Plants	>15	Number of Pilot Plants	~		
Target Industries	Iron & steel, (petro-)chemical, cement & lime, oil & gas, hydrogen				

# Tecnologías de Captura de CO<sub>2</sub>

NUADA

**Nuada**  
Capturing the future

MOF-BASED VPSA PROCESS



[contact@nuadaCO<sub>2</sub>.com](mailto:contact@nuadaCO2.com)

[www.nuadaCO<sub>2</sub>.com](http://www.nuadaCO2.com)

## BENEFITS

- **Ultra-Energy Efficient:** The energy penalty for carbon capture is reduced by up to 80% compared to incumbent solutions.
- **No Complex Integration:** An end-of-pipe and fully electrified solution; no heat or steam required.
- **Wide Applicability:** CO<sub>2</sub> can be recovered from a broad spectrum of point sources and at different scales.
- **Mature Process Technology:** VPSA is a mature, proven and readily scalable separation technology that has been applied for decades at an industrial scale.
- **High-Purity CO<sub>2</sub> Product:** Purity up to 99% without extra purification step; No oxygen or solvent-based impurities in the CO<sub>2</sub> stream.
- **Dynamic Operation:** The rapid capture and release cycles provide flexibility to address operational challenges such as flue gas fluctuations or facilitate quick startups and shutdowns.

## KEY DATA

TRL	6	Capture Rate Range (tpd)	1 - 4,000	Modular (Y/N)	Yes
Source CO <sub>2</sub> Purity Range	>5%	Energy Consumption (GJ/tCO <sub>2</sub> )	0.7	Capture Efficiency (%)	>95%
Number of Commercial Plants	0	Number of Pilot Plants	2	Product CO <sub>2</sub> Purity	Up to 99%
Target Industries	Cement, Lime, Waste-to-Energy, Steel, Oil & Gas, Chemicals				

# Tecnologías de Captura de CO<sub>2</sub>



PETRONAS

PETRONAS

## MEMBRANE CONTACTOR (MBC)



✉ [khairul\\_rostani@petronas.com](mailto:khairul_rostani@petronas.com)

✉ [nanthini.raman@petronas.com](mailto:nanthini.raman@petronas.com)

### BENEFITS


- **Minimises Overall Carbon Footprint:** MBC's state-of-the-art multi-cartridge membrane contactor modules, achieve an impressive 50% reduction in the overall volume while maintaining high carbon capture efficiency, all within a compact design.
- **Tailored Solutions for Every Need:** MBC offers unparalleled scalability, allowing seamless adjustments to match the unique requirements of our clients. MBC adaptable nature ensures flexibility by catering to clients' evolving operational needs.
- **Competitive Cost to Capture:** Lower compression cost due to high regeneration pressure up to 5 barg, and lower solvent circulation rate up to 30%, as first of its kind modular technology. Aimed at achieving CO<sub>2</sub> capture for a competitive cost of US\$30-50 per tonne, MBC ensures maximum value for every investment.

### KEY DATA

TRL	5	Capture Rate Range (tpd)	10 - 600	Modular (Y/N)	Yes
Source CO <sub>2</sub> Purity Range	3 - 30%	Energy Consumption (GJ/tCO <sub>2</sub> )	<2.9	Capture Efficiency (%)	>95%
Number of Commercial Plants	~	Number of Pilot Plants	4	Pressure Drop	<0.2bar
Target Industries	Refineries, Hard-to-abate industries (Cement, Steel, Chemicals and Power & Gas Plants)				




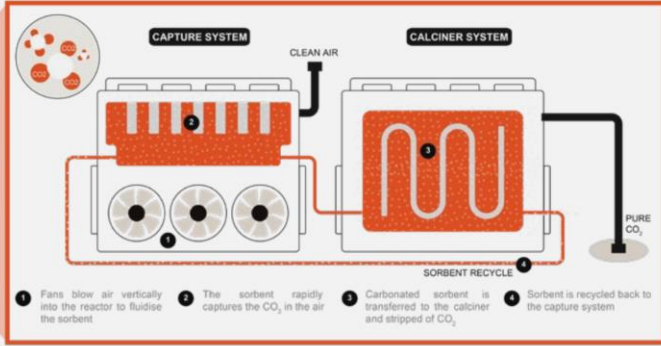
# Tecnologías de Captura de CO<sub>2</sub>



**AIRHIVE**

DIRECT AIR CAPTURE (DAC)





**CAPTURE SYSTEM**      **CALCINER SYSTEM**

CLEAN AIR      PURE CO<sub>2</sub>

SORBENT RECYCLE

- Fans blow air vertically into the reactor to fluidise the sorbent
- The sorbent rapidly captures the CO<sub>2</sub> in the air
- Carbonated sorbent is transferred to the calciner and stripped of CO<sub>2</sub>
- Sorbent is recycled back to the capture system

[hello@airhive.earth](mailto:hello@airhive.earth)

[www.airhive.earth](http://www.airhive.earth)

## BENEFITS

The Airhive DAC system is:

- **Fast:** The nano-structured sorbent removes 99% of CO<sub>2</sub> from the air in <0.1 seconds and fully saturates in under three hours.
- **Sustainable and easy to scale:** The technology is built on existing industrial equipment and supply chains, configured in new ways for DAC. The naturally abundant mineral sorbent is widely available, non-toxic and can be reused for many cycles of carbon removal.
- **Low-cost:** Estimated cost at pilot scale is <\$379 per net tCO<sub>2</sub> with pathways to estimate at-scale costs of \$93 per net tCO<sub>2</sub>.
- **Energy efficient:** The system is targeted at 1.5 MWh/tCO<sub>2</sub>, and can be fully powered by low carbon energy. It also has in-built thermochemical energy storage potential, allowing it to run when there is no external energy source available.

## KEY DATA

TRL	6	Capture Rate Range (tpd)	3.8 tpd/reactor	Modular (Y/N)	Yes
Source CO <sub>2</sub> Purity Range	~	Energy Consumption (GJ/tCO <sub>2</sub> )	3.6 (1 MWh/tCO <sub>2</sub> )	Capture Efficiency (%)	99%
Number of Commercial Plants	0	Number of Pilot Plants	3 (2 commercial)		
Target Industries	Chemicals, Food and Beverage, Green Fuels, CDR credit buyers				


# Tecnologías de Captura de CO<sub>2</sub>

**NOV** NOV – CO<sub>2</sub> CAPTURE  
POST-COMBUSTION CAPTURE  
FIBERGLASS DUCTING



[fgssales@nov.com](mailto:fgssales@nov.com) [www.nov.com/fgs](http://www.nov.com/fgs)

**NOV** NOV – CO<sub>2</sub> CAPTURE AND CONDITIONING  
TEMPERATURE SWING ADSORPTION (TSA)  
GAS DEHYDRATION



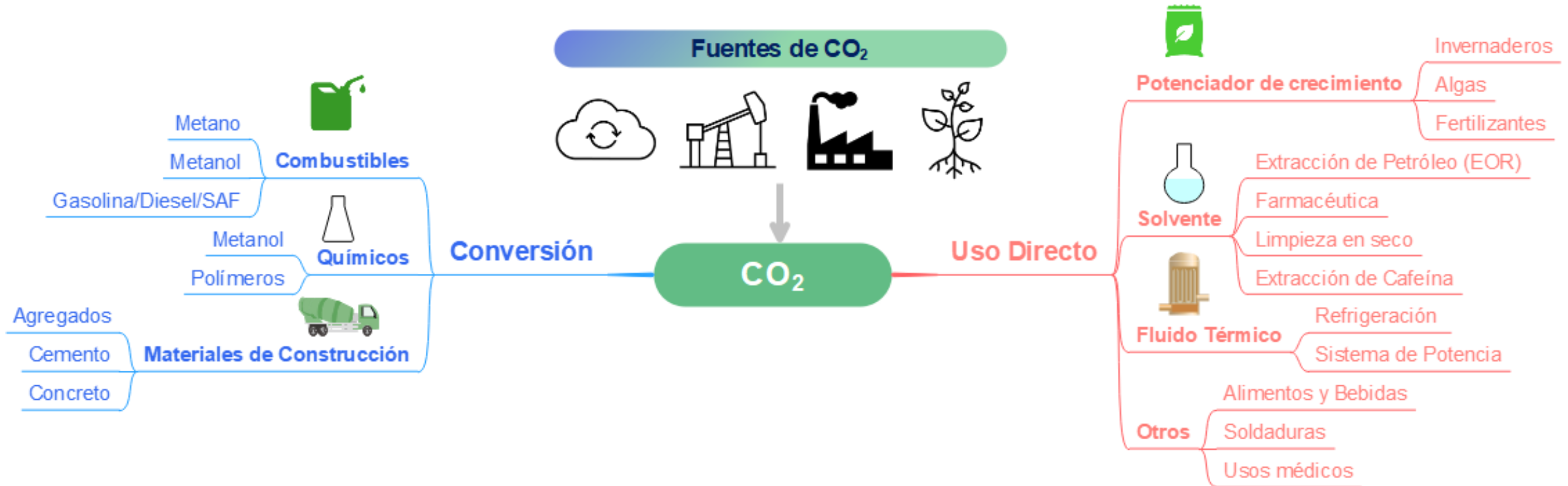
[corporatemarketing@nov.com](mailto:corporatemarketing@nov.com) [www.nov.com/ccus](http://www.nov.com/ccus)

**NOV** NOV – CO<sub>2</sub> CAPTURE AND CONDITIONING  
TRIETHYLENE GLYCOL (TEG) GAS  
DEHYDRATION



[corporatemarketing@nov.com](mailto:corporatemarketing@nov.com) [www.nov.com/ccus](http://www.nov.com/ccus)

# Alternativas de Valorización de CO<sub>2</sub>



# Alternativas de Valorización de CO<sub>2</sub>

## Achieving Unprecedented Carbon Dioxide Utilization in Concrete

- CO<sub>2</sub>Concrete™ products are projected to reduce the global warming potential (GWP) by at least 45% compared to OPC-concrete of equivalent performance grade

### Anodes from Coal Waste can Significantly Improve Anode Capacity when Compared to Graphite

- The CO<sub>2</sub>-to-concrete process was field tested at the Integrated Test Center in Gillette, Wyoming and a pilot-scale demonstration was performed at Plant Gaston (1,800 MW) which provides flue gas for the National Carbon Capture Center in Wilsonville, Alabama
- Approximately 15,000 blocks were carbonated
- Testing was successful with coal and natural gas flue gas without upfront CO<sub>2</sub> capture
- Achieved in excess of 75% CO<sub>2</sub> utilization efficiency
- CO<sub>2</sub>Concrete product complied with industry standard specifications. Production price parity was achieved with conventional concrete blocks



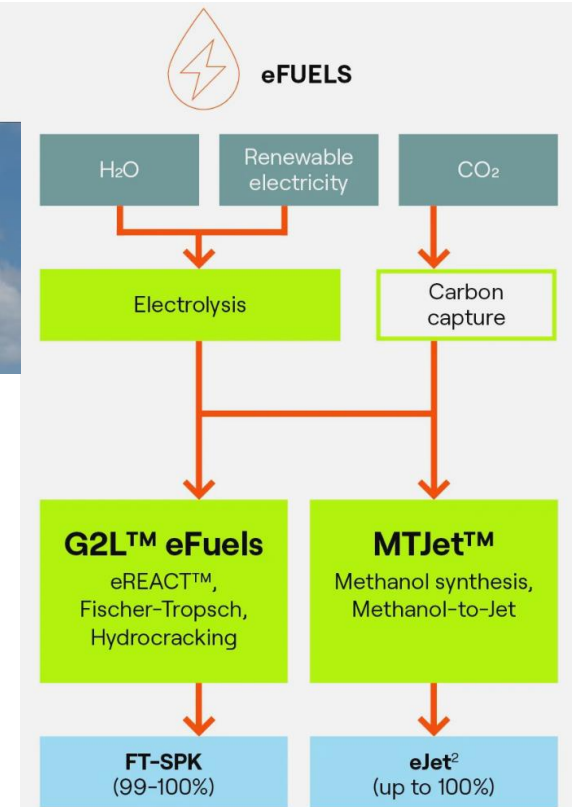
- ✓ Cement production emits nearly 10% of global CO<sub>2</sub>
- ✓ 0.9 tons of CO<sub>2</sub> are emitted per ton of cement produced; 4.5 billion tonnes of cement produced annually
- ✓ Global concrete market ~ \$1 trillion /year



Waste CO<sub>2</sub> is incorporated and locked into the CO<sub>2</sub>Concrete™ product.

<https://netl.doe.gov/carbon-management/carbon-conversion>

## MTJet™ Technology



The pathways to Sustainable Aviation Fuel | Topsoe

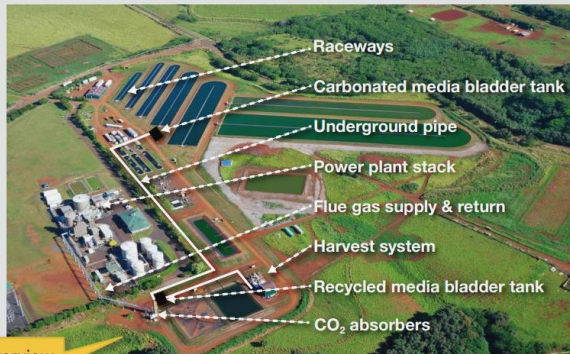
# Alternativas de Valorización de CO<sub>2</sub>

## Testing Integrated Capture and Conversion at Engineering Scale through Algae Cultivation

### Successfully Scaled the Integrated Algae Cultivation System to a 3.2 Acre Raceway

The 0.2 acre, 0.3 acre, and 3.2 acre-raceways were updated to improve scalability and productivity while using Global Algae's proprietary cultivation technology

- The integrated system, as shown to the right, includes power plant flue gas supply, CO<sub>2</sub> capture absorbers, algae cultivation raceways, harvesting system, and product processing systems.
- Parametric testing and integrated tests (~ten 7-day long tests) were performed using power plant CO<sub>2</sub> (~3.5% CO<sub>2</sub> concentration) with full media recycle.



Operations Overview

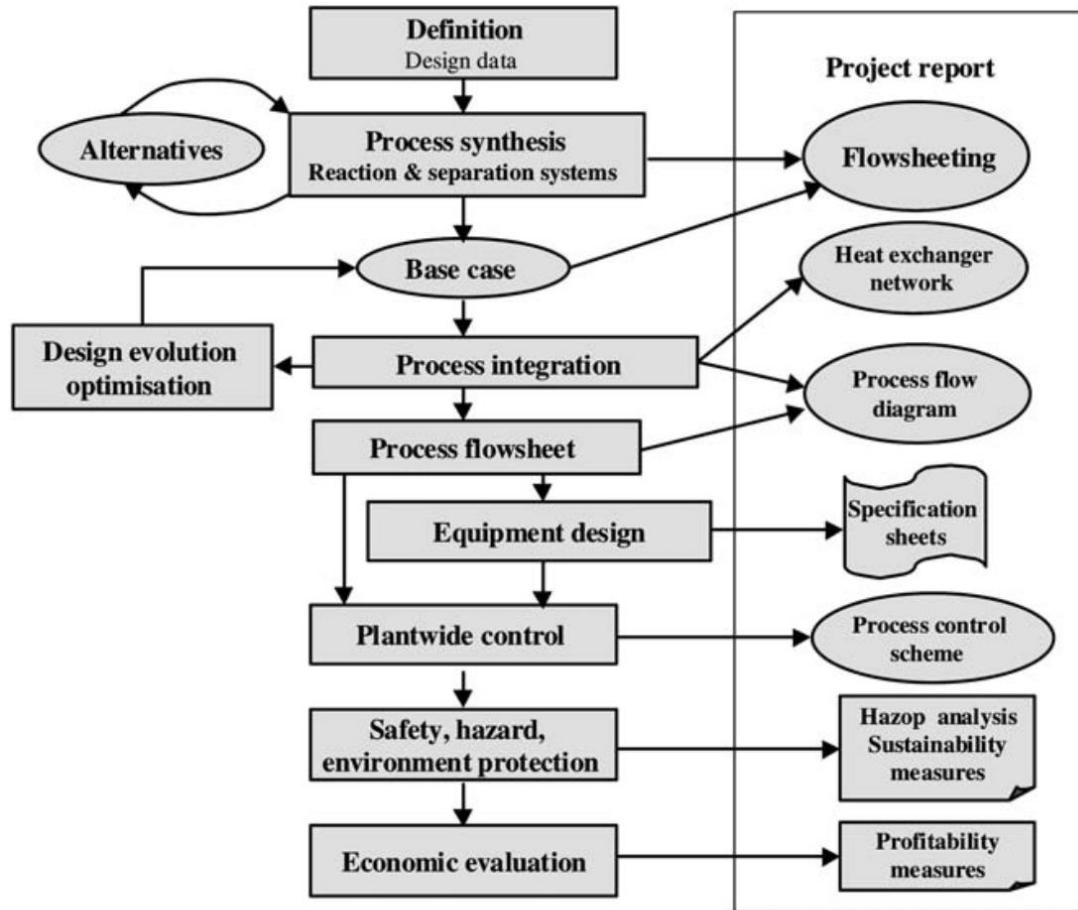
Flue gas CO<sub>2</sub> is incorporated and locked into bio-derived products.

<https://netl.doe.gov/carbon-management/carbon-conversion>



[Haru Oni \(hifglobal.com\)](https://www.hifglobal.com)

# Herramientas de Evaluación de Proyectos



El **Diseño de los Procesos Químicos** es un procedimiento que aplica e integra varias técnicas de ingeniería, economía y principios científicos para crear un proceso que fabrique un producto específico.

Figure 1.1 Outline of a design project.

# Herramientas de Evaluación de Proyectos



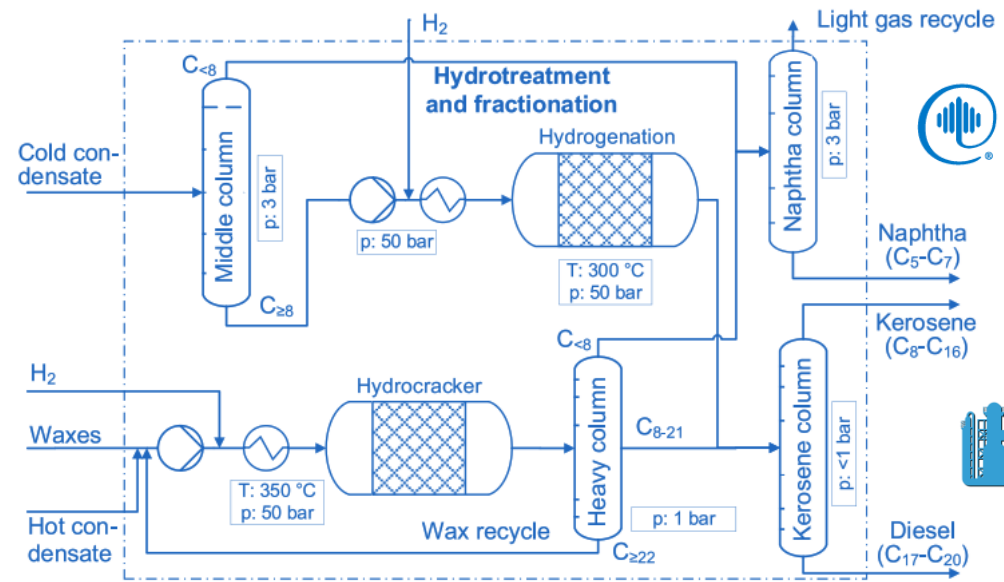
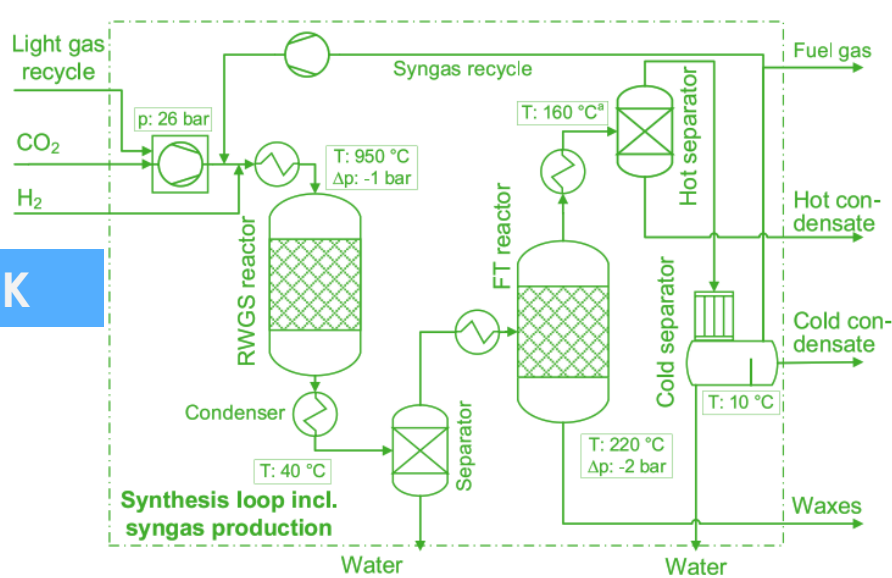
**Eficiencia**

**Energía**

**Medio Ambiente**

**Economía**

**FT-SPK**

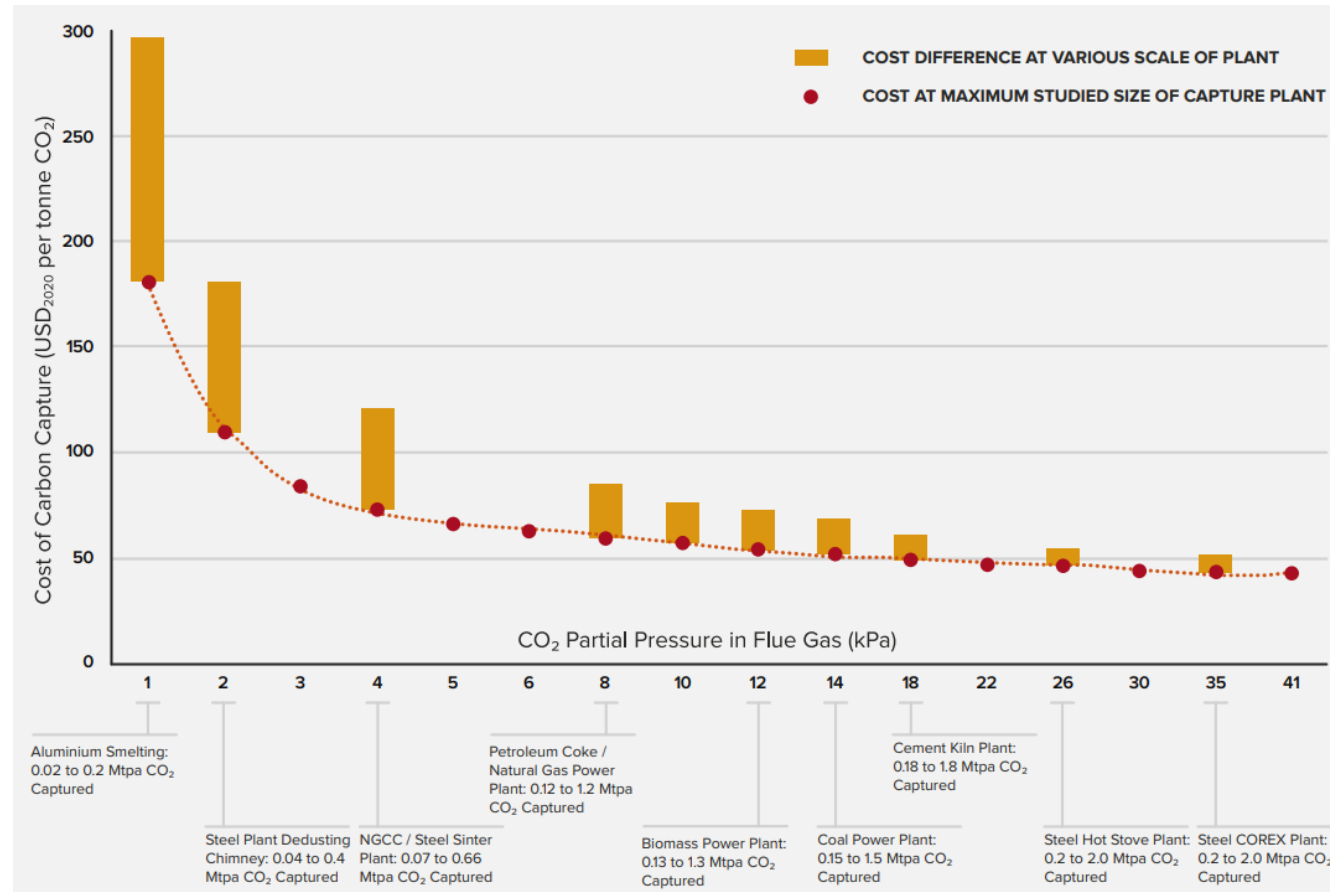


 **aspentech**

 **DWSIM**  
Chemical Process Simulator

**FT-SPK: Fischer-Tropsch Synthetic Paraffinic Kerosene**

# Herramientas de Evaluación de Proyectos





# Herramientas de Evaluación de Proyectos

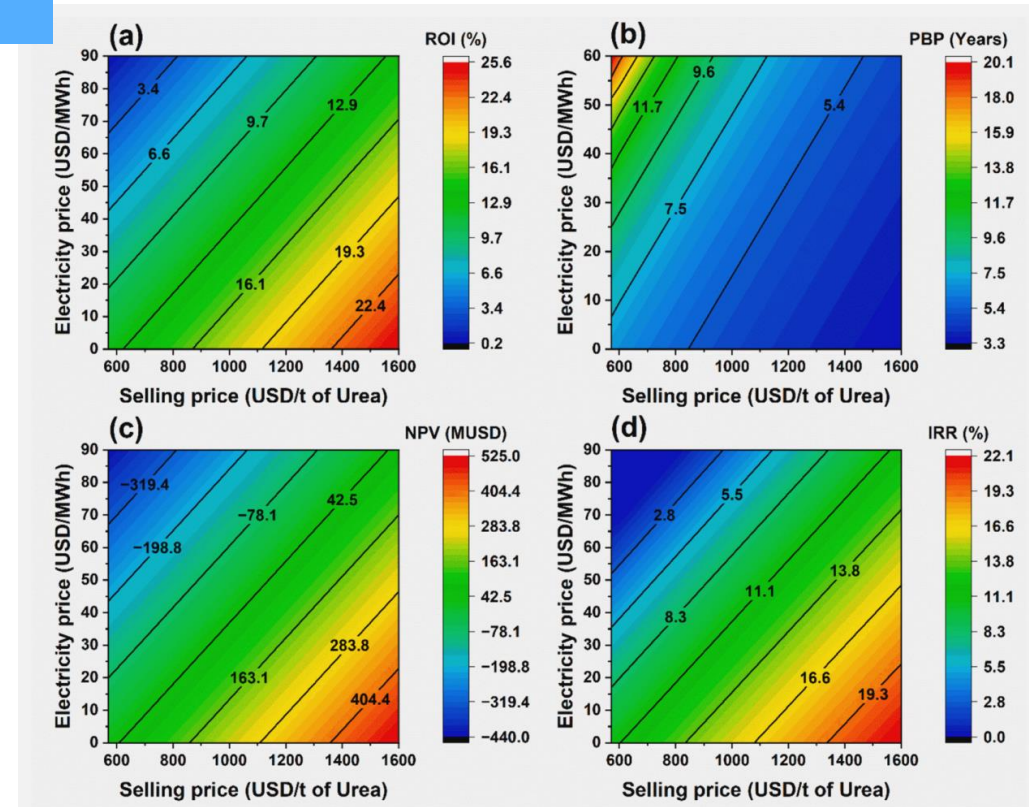
## Metanol

Methanol production costs in €/t as a function of the CO<sub>2</sub> price and H<sub>2</sub> net production costs. The numbers given are valid for the system size of 300 MW and the presented methodology. Current (fossil, year: 2018) methanol market price: 400 €/t [65]. The timeline for the hydrogen production costs is from IRENA [7].

		NPC H <sub>2</sub> [€/kg]								
		2050		2030			2020			
CO <sub>2</sub> Price [€/t]	time	1	1.5	2	2.5	3	3.5	4	4.5	
		DAC	Industry	0	254	350	445	578	635	731
20	282		377	473	606	663	758	854	949	
40	310		405	500	634	691	786	881	977	
60	337		433	528	661	719	814	909	1004	
80	365		461	556	689	746	842	937	1032	
100	393		488	584	717	774	869	965	1060	
150	462		558	653	786	843	939	1034	1129	
200	532		627	722	856	913	1008	1103	1199	
300	670		766	861	994	1051	1147	1242	1337	
400	809	904	1000	1133	1190	1285	1381	1476		
500	948	1043	1138	1272	1329	1424	1519	1615		
800	1364	1459	1554	1688	1745	1840	1936	2031		
NPC range		MeOH production...								
<600 €/t		<b>Competitive</b> → Max. 150% of current price level								
>600 < 1200 €/t		<b>Possibly competitive</b> → Max. 300% of current price level								
>1200 €/t		<b>Not competitive</b> → More than 300% of current price level								

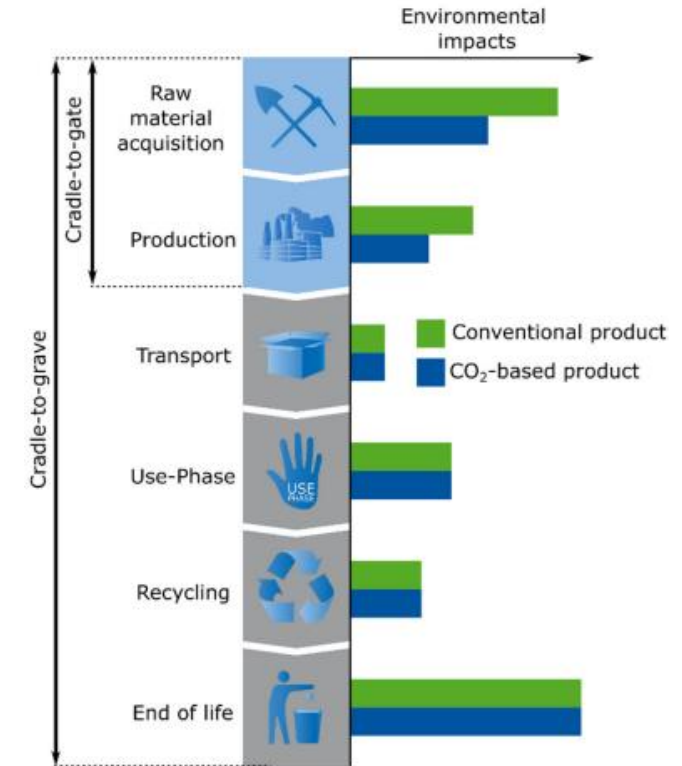
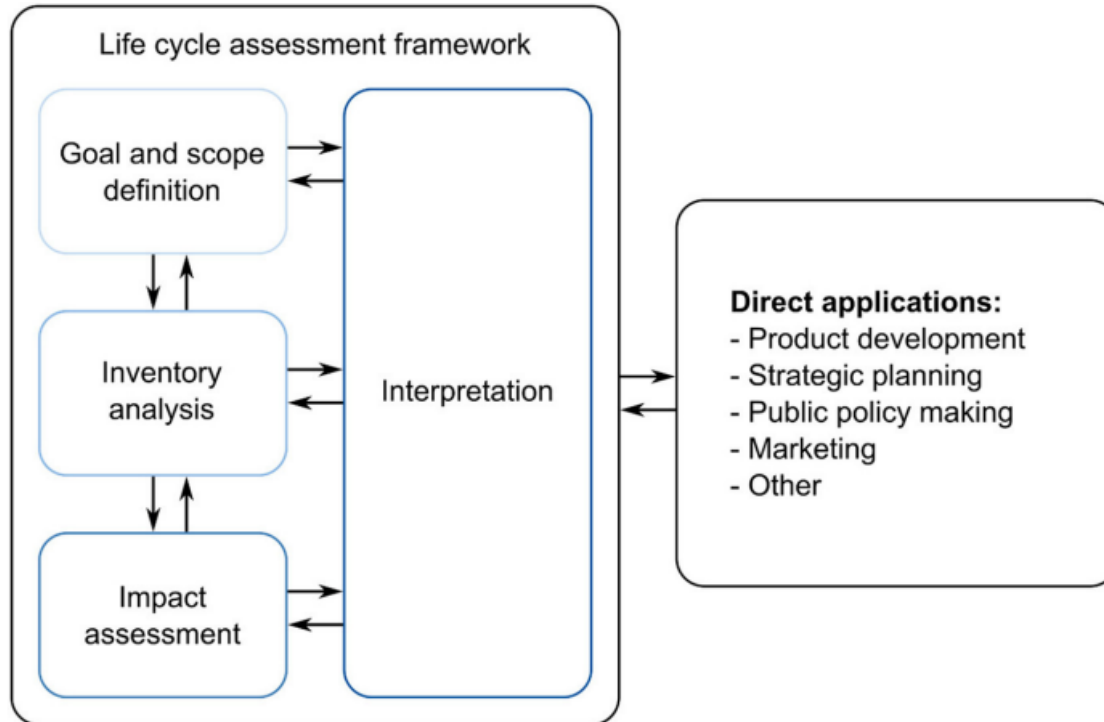
Schorn, F., et al. (2021). "Methanol as a renewable energy carrier: An assessment of production and transportation costs for selected global locations." *Advances in Applied Energy* 3: 100050.

## Urea



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# Herramientas de Evaluación de Proyectos

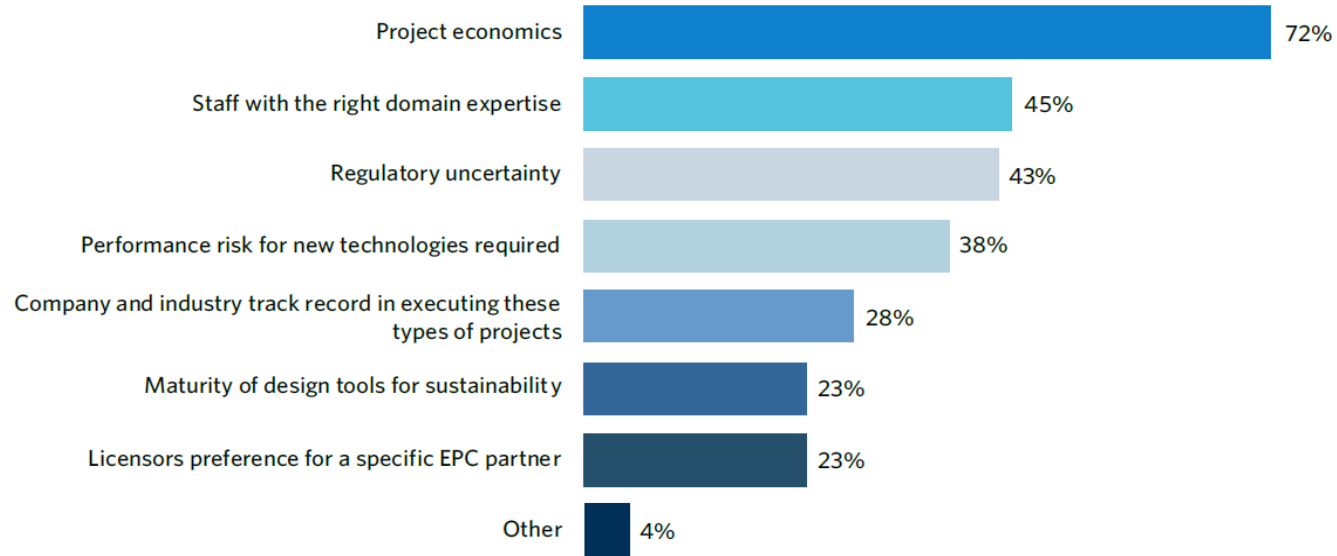
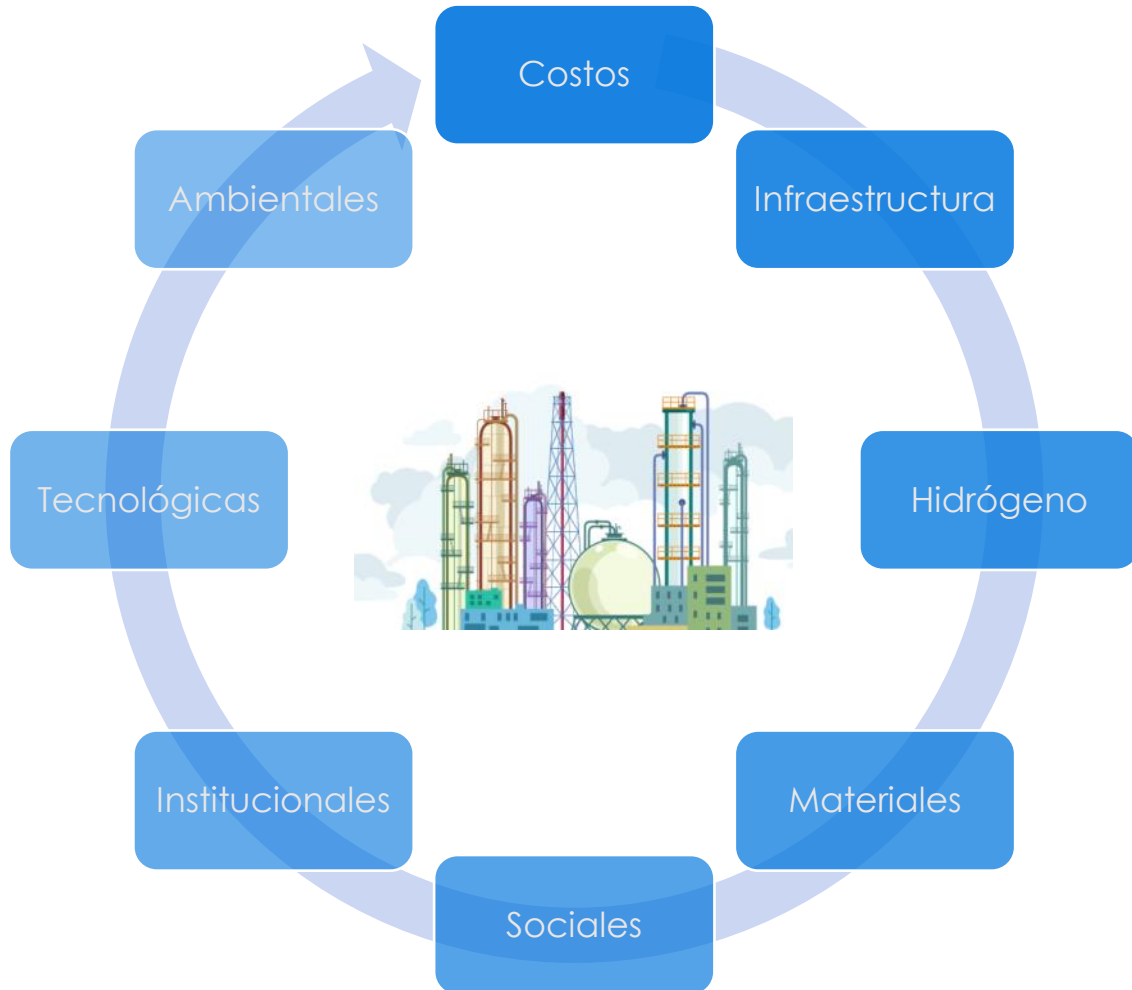


**FIGURE 3** | Illustration of a comparison of environmental impacts for products with identical chemical structure and composition over the entire life cycle. Impacts shown as bars on the x-axis only differ during the phases raw material acquisition and production and thus, comparative studies only have to consider these phases.

**FIGURE 2** | General framework for life cycle assessment (European Committee for Standardisation, 2009).

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# Barreras para Implementación



Aspen Tech Sustainability Global Survey, Febrero 2022

## Diplomado en Captura y utilización de CO<sub>2</sub>



### Curso 1

Emisiones,  
captura,  
almacenamiento  
y conversión de  
CO<sub>2</sub>



### Curso 2

Tecnologías de  
captura y  
conversión de  
CO<sub>2</sub>



### Curso 3

Análisis técnico-  
económico y  
marcos  
regulatorios de  
procesos de CO<sub>2</sub>



### Curso 4

Taller de  
evaluación de  
proyecto de CO<sub>2</sub>



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