DECEMBER 2025

DEVELOPMENT AND ROLLOUT OF CARBON CAPTURE AND STORAGE (CCS) TECHNOLOGIES IN THE GLOBAL STEEL SECTOR

WORLDSTEEL BREAKTHROUGH TECHNOLOGY CONFERENCE

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Accelerating the deployment of CCS for a net-zero emissions future.

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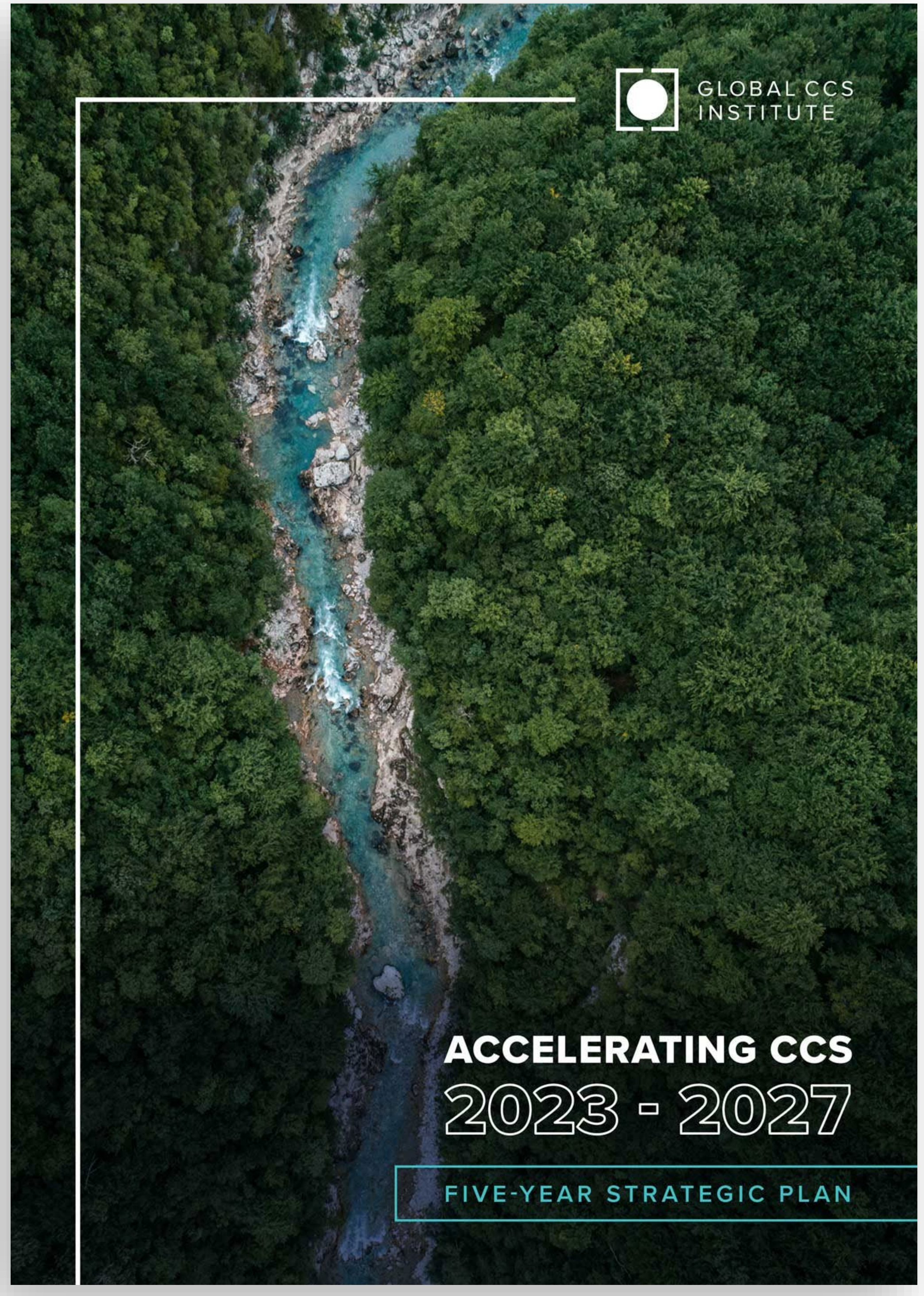
Over 200 members across governments, global corporations, private companies, research bodies, and NGOs, all committed to a net-zero future.

WHAT WE DO
Fact-based influential advocacy, catalytic thought leadership, authoritative knowledge sharing.



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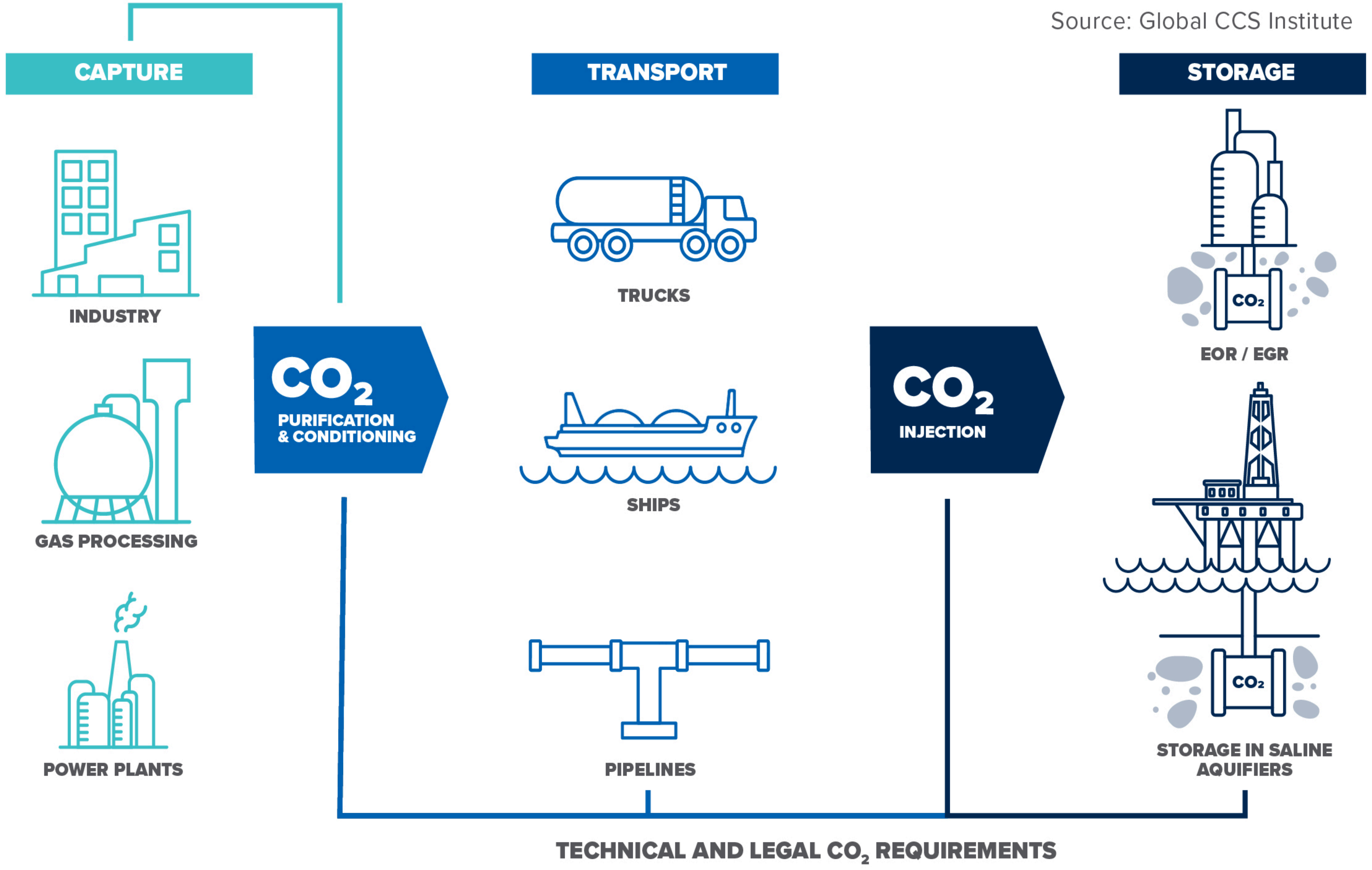
CCS IN THE GLOBAL STEEL SECTOR

- The need for CCS in the global steel sector
- Key CO_2 capture technologies for the steel sector
- Capture cost drivers
- CCS as pathway to lower cost clean H_2 for hydrogen-based steel
- Review of commercial and demonstration CCS projects in iron & steel facilities
- Case studies

CCS AT A GLANCE



Industries such as steel plants produce CO_2 in dilute form and at low pressure.

CO_2 capture separates CO_2 from other flue gases to above 95% purity.

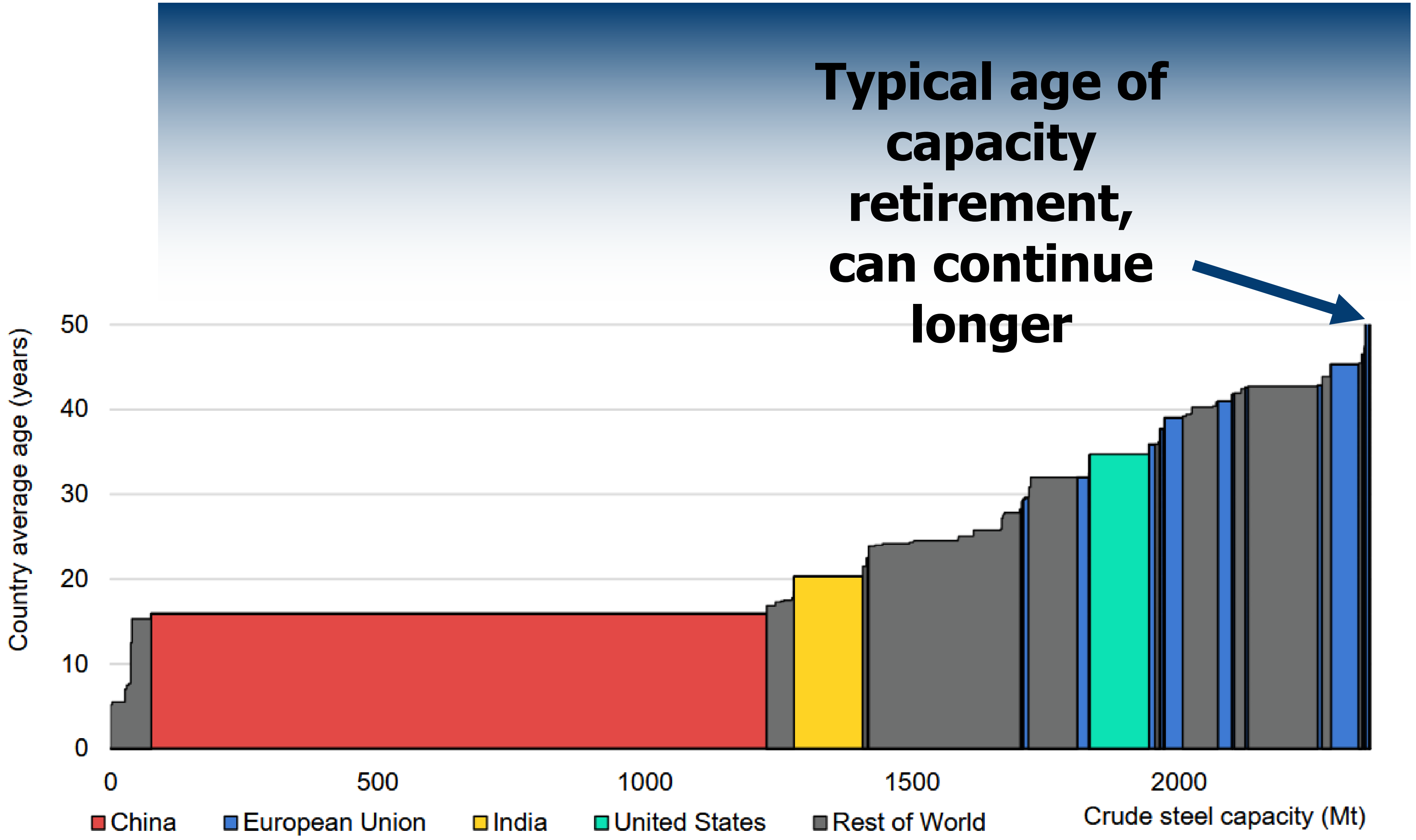
Conditioning can remove impurities (N_2, O_2, H_2S/SO_2, trace metals, particulates)

Compress CO_2 to high pressure and store in secure geological formations.
Transport and storage infrastructure can be shared with other industries.

Capture is harder for more dilute CO_2 streams, easier for more concentrated ones.

Today's focus is on capturing CO_2 in steel plants and H_2 production for new steel facilities.

WHY CCS? LARGE GHG FOOTPRINT, YOUNG FLEET



Notes: Capacity data are from the OECD steelmaking capacity database and average ages of assets are based on the Global Infrastructure Emission Database. Age and capacity data is from 2019.

Sources: OECD (2024); He et al. (2021); and Xu (2023).

Iron/steel industry responsible for 7-9% of global GHG emissions

Large fraction of global steel production is in younger plants.

Typical retirement age is 50+ years.

Unlikely that these newer facilities will be replaced with new low-emissions alternatives.

CCS provides the ability to retrofit existing steel plants with deep CO_2 emissions reductions.

CCS is also a pathway to low-emissions hydrogen for H_2-based DRI.

Source: IEA 2024; *Energy Technology Perspectives 2024*, https://www.iea.org/reports/energy-technology-perspectives-2024, License: CC BY 4.0

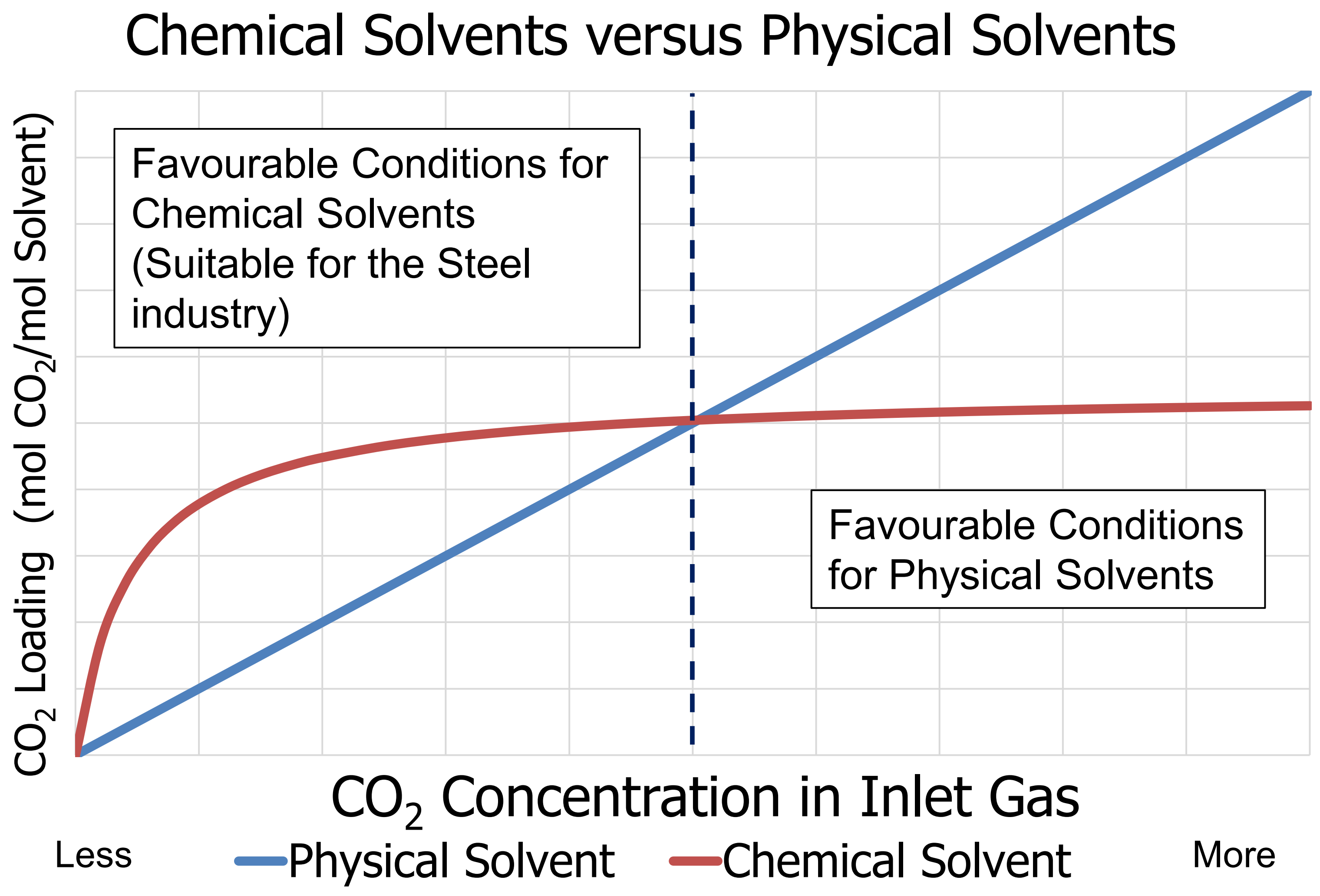
CAPTURE: SOLVENTS

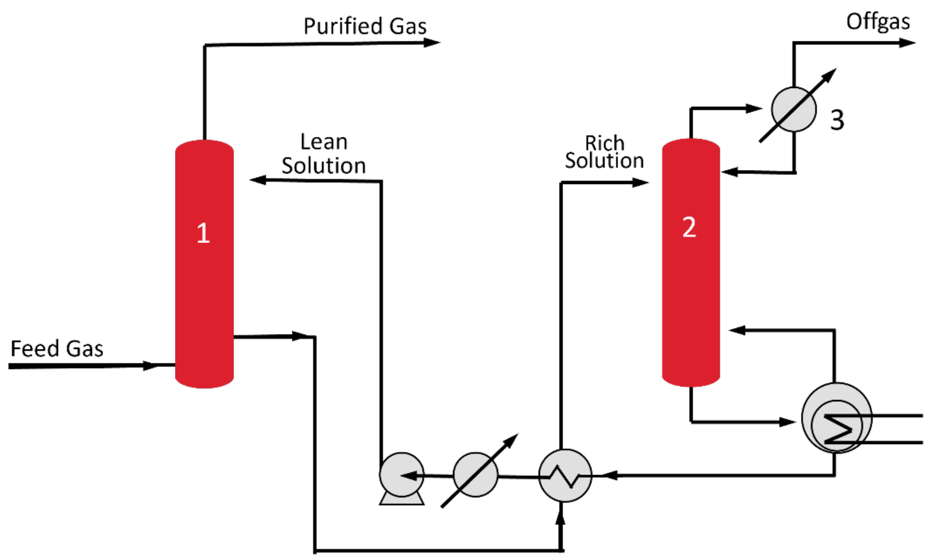
Chemical Solvents:

- Reactive solvents that enter into a chemical bond with CO_2 to separate it.
- Typical in lower CO_2 concentration applications.
- Heat is usually applied to release the CO_2 ("temperature swing").
- Most common – Amines, Hot Potassium Carbonate

Physical Solvents:

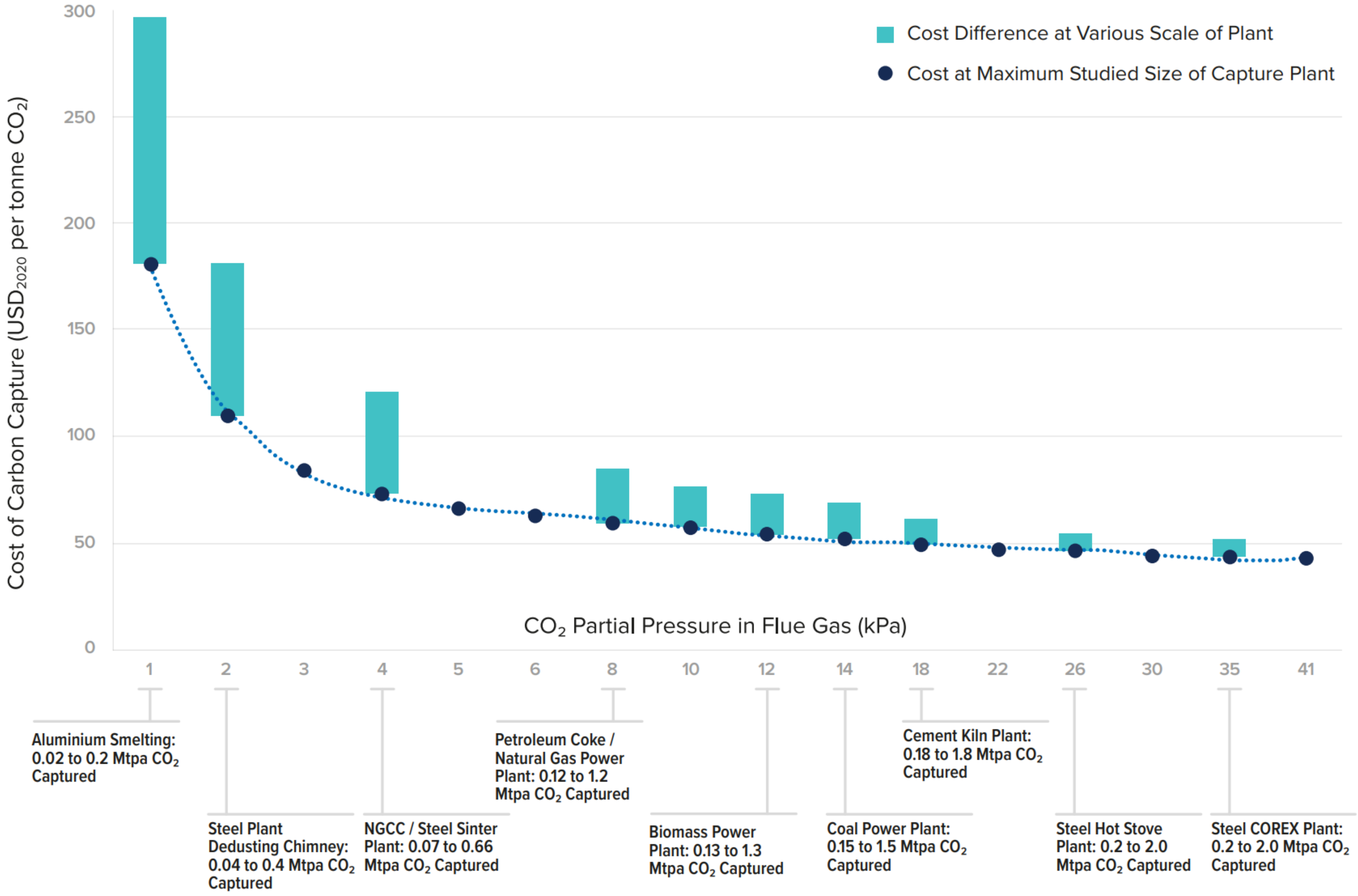
- Solvents that rely on the dissolution of CO_2 into the solvent through physical drivers such as pressure.
- Typically regenerated by reducing the pressure of the solvent ("pressure swing").
- Most common – Selexol, Rectisol





Honeywell – Amine Guard (Chemical Solvent)

BENCHMARK COSTS OF CAPTURE - SOLVENTS



Benchmark study of levelised (capex + opex) costs of CO2 capture using a benchmark solvent (MEA).

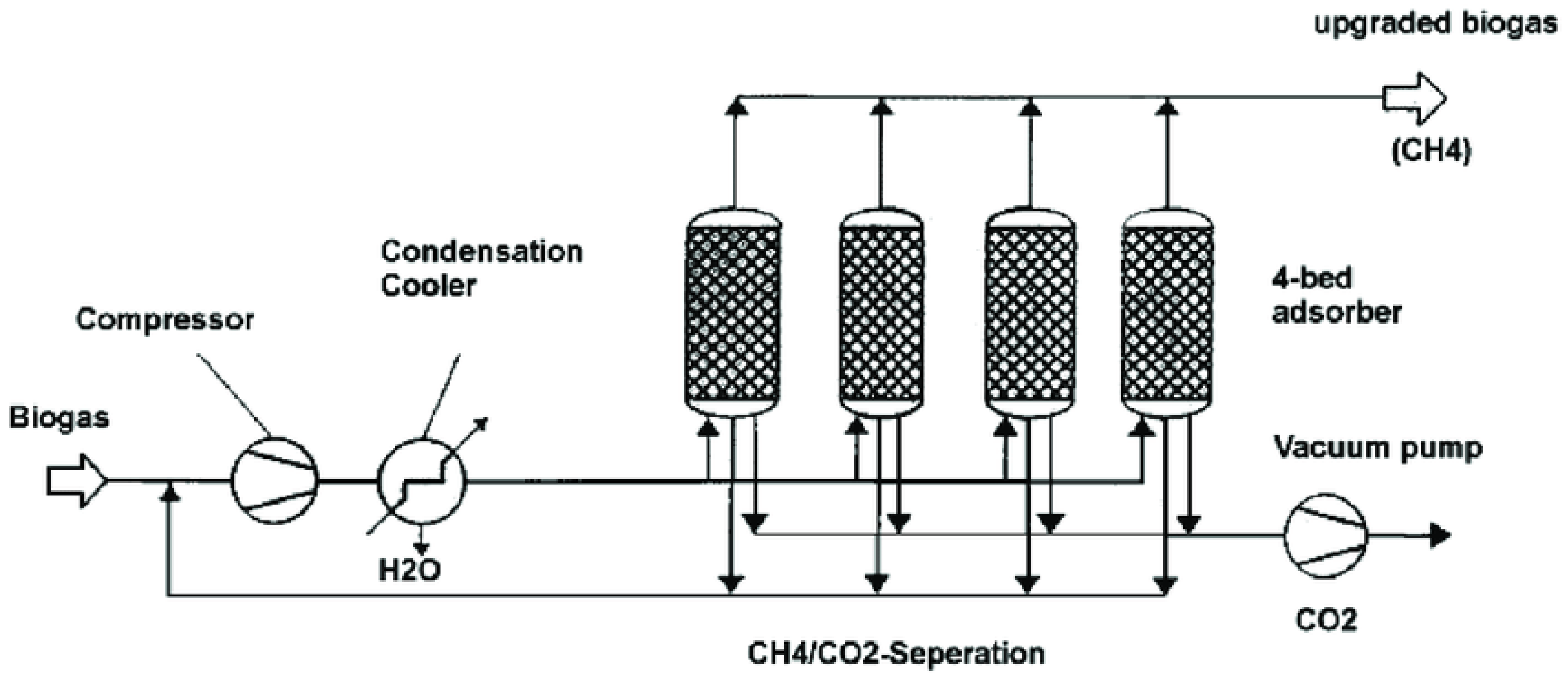
Costs fall as CO_2 partial pressure (concentration x pressure) goes up.

CO_2 scale also matters.

Other key cost impacts are costs of energy, impurities removal costs, and specific technology used.

Kearns et. al (2021) Global CCS Institute

CAPTURE: ADSORBENTS & MEMBRANES



Mohanty 2019, DOI: 10.13140/RG.2.2.19418.49604

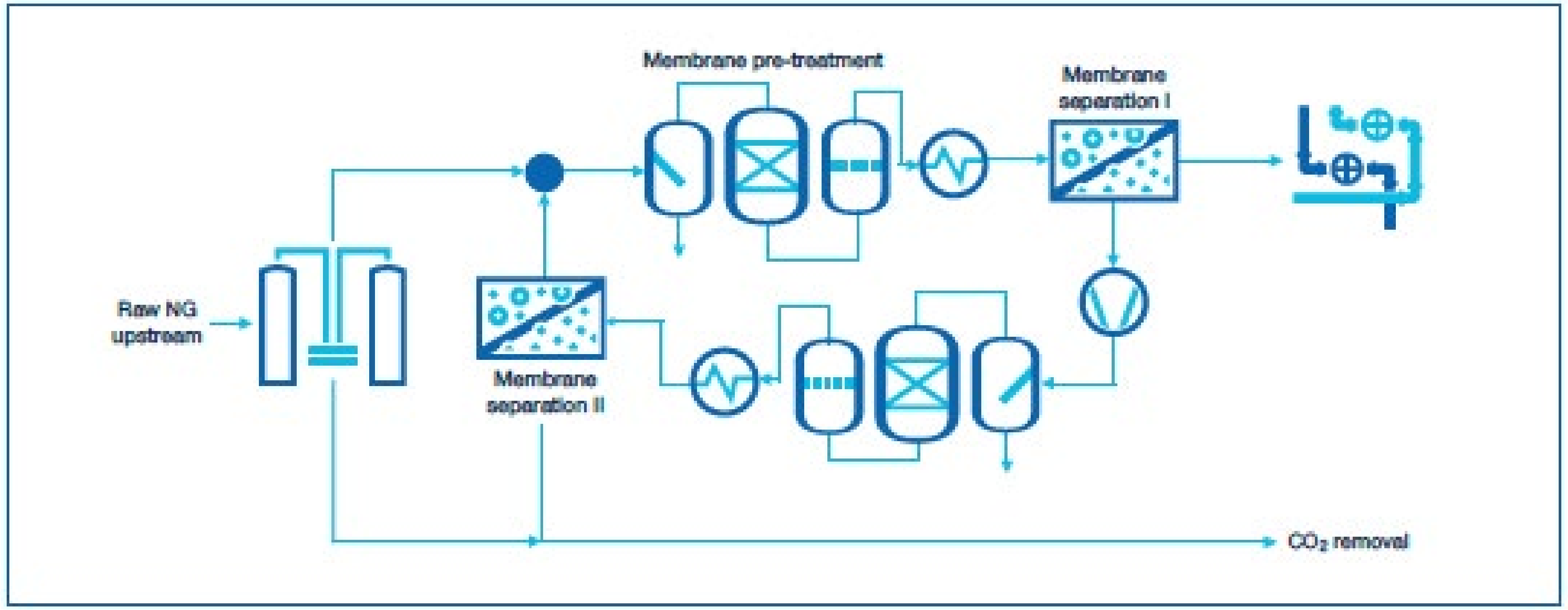
Adsorbents:

- Adsorbents are solid materials that have binding sites on the porous surface of the sorbent to remove CO_2 preferentially from a gas stream.
- Large surface area – Many binding sites.
- Chemical or physical binding – TSA, VSA or PSA

Membranes:

- A semi-permeable barrier that can separate parts of a gas mixture based on relative rates of mass transfer.
- The partial pressure of CO_2 and the overall pressure of the inlet gas drives the separation.

Linde – HiSELECT

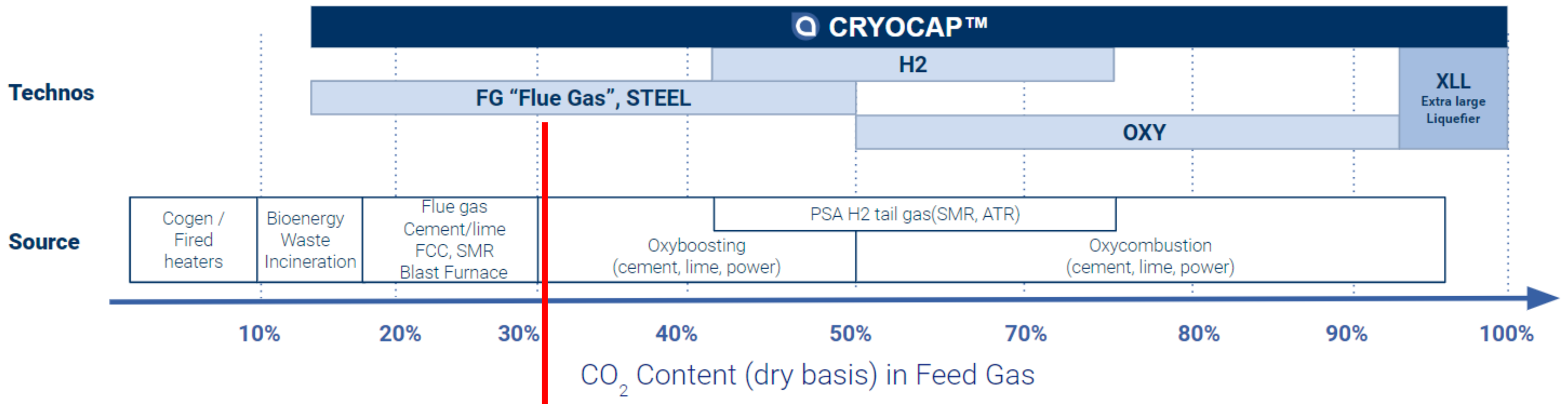


CAPTURE: CRYOGENIC

Cryogenics:

- Capture completed by condensing CO_2 from the other components of the flue gas.
- CO_2 has a different condensation point compared to other flue gas components (N_2, O_2, H_2O).
- Well below ambient temperature and at elevated pressure to avoid the formation of solid "dry ice".

Air Liquide cryogenic offerings for CO_2 capture and liquefaction

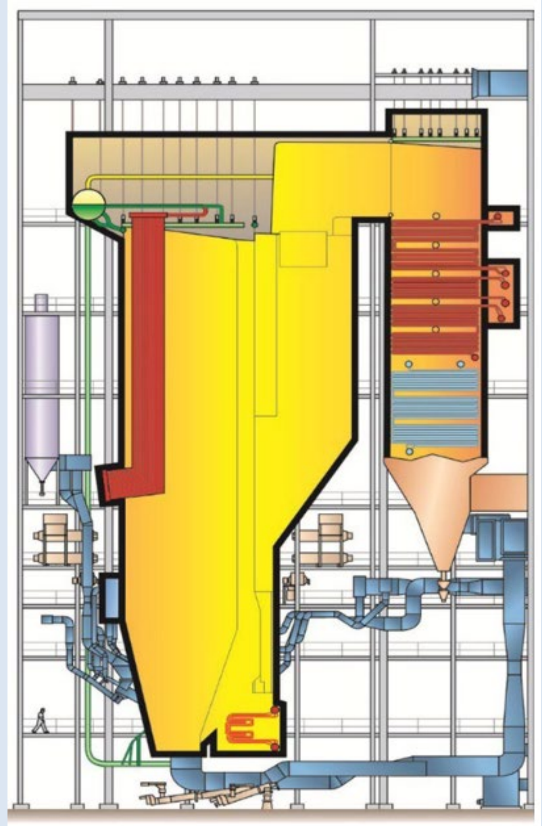


Air Liquide's Cryocap™Steel

CAPTURE: OXYCOMBUSTION & CHEMICAL LOOPING

- OxyBright
- Generates CO_2 rich synthetic air
- No Post combustion capture requirement

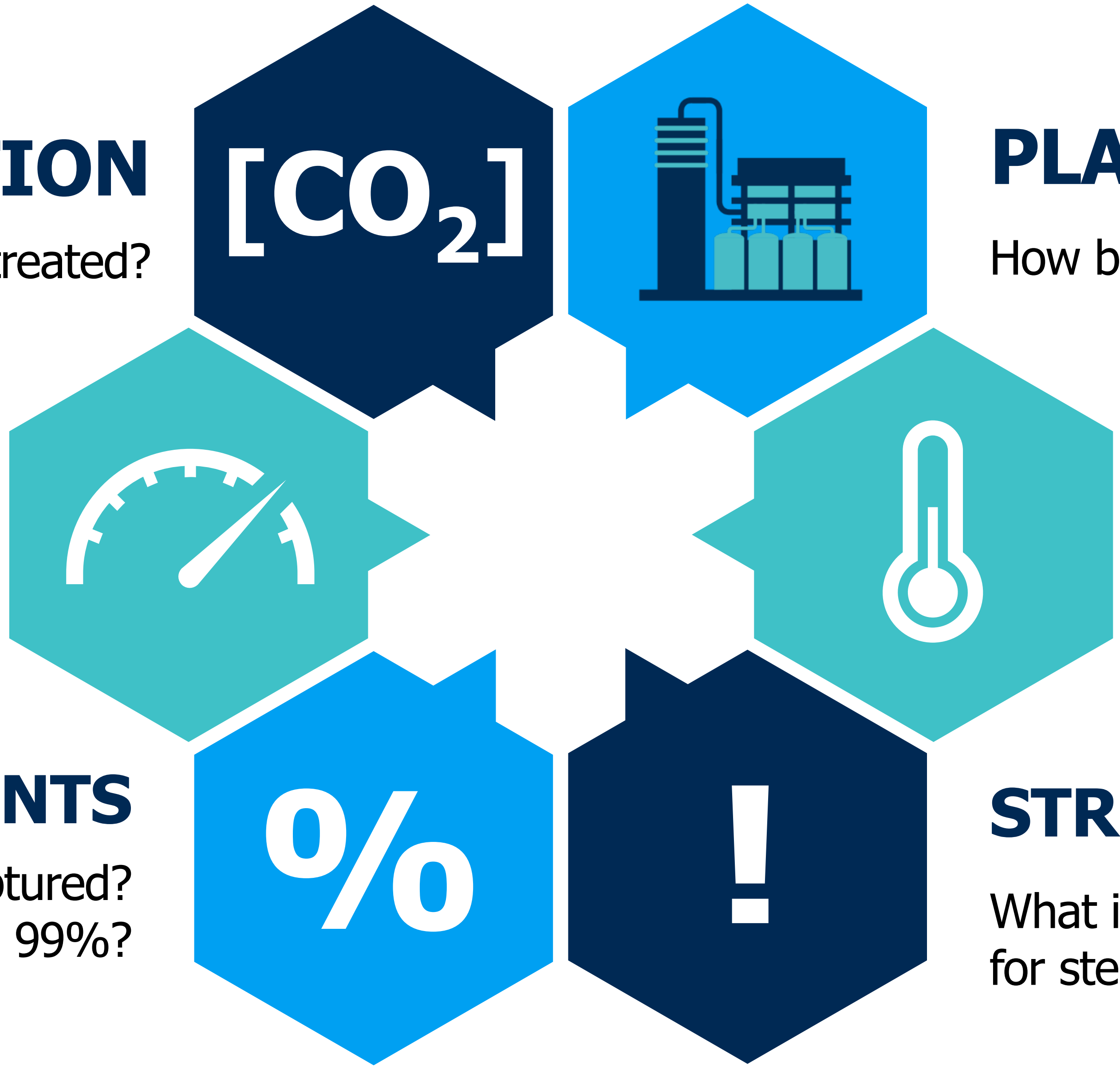
- Oxycombustion (Oxy+) solutions
- Commercially available



- Calcium Looping (Cal+)
- Source gases: >5% CO_2

TECH SELECTION CONSIDERATIONS

Technology selection is driven by project financial considerations and technology capabilities in the environment of the anticipated inlet stream.



CO_2 CONCENTRATION

How much CO_2 is in the stream to be treated?

PLANT SCALE

How big will the plant be?

STREAM PRESSURE

How high is the inlet pressure?

COOLING REQUIREMENTS

How much cooling is required?

CAPTURE REQUIREMENTS

What percentage of CO_2 needs to be captured?
90%? 95%? 99%?

STREAM IMPURITIES

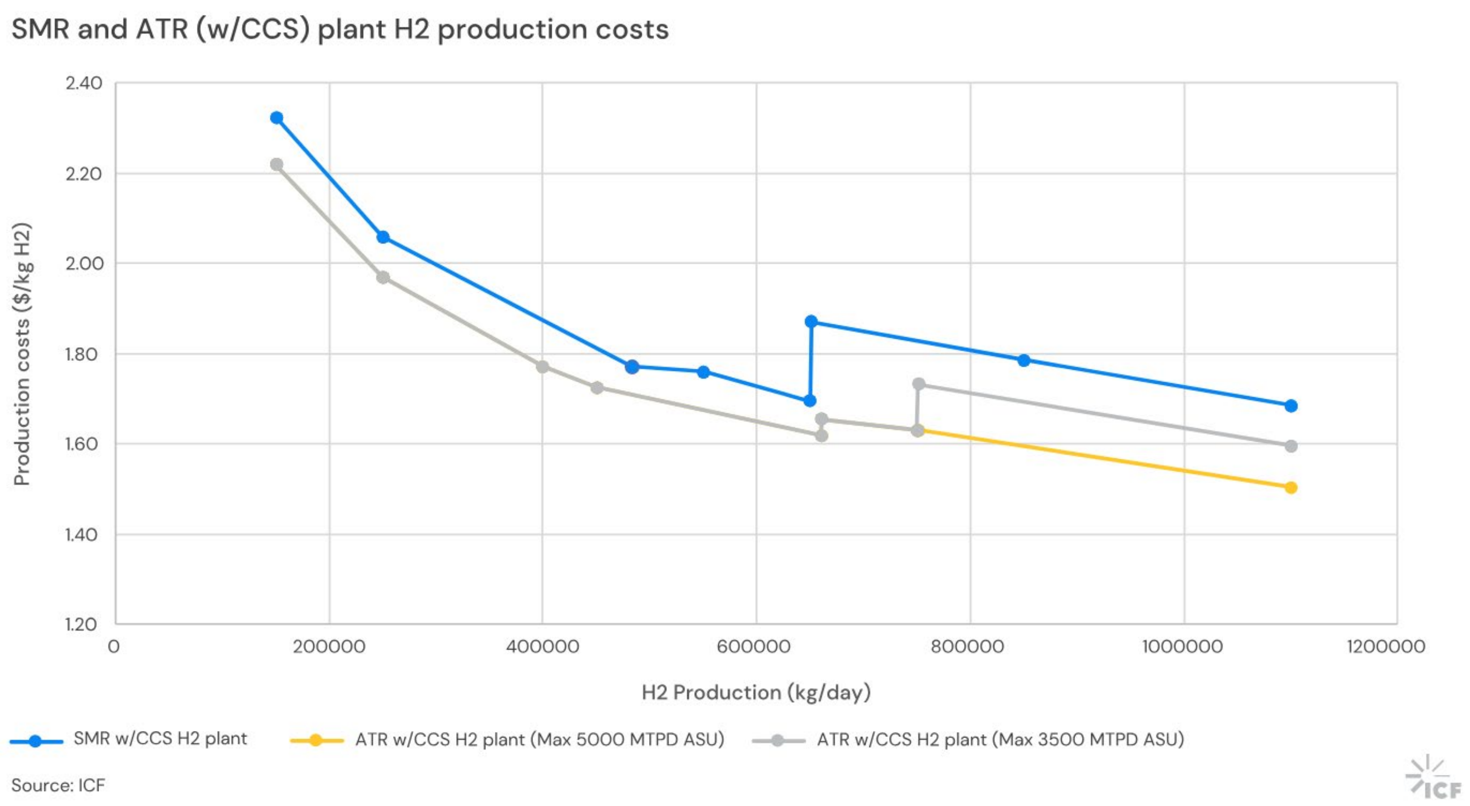
What impurities are present? Particularly relevant for steel sector applications

LOW-CARBON HYDROGEN WITH CCS: ENABLING H_2-BASED IRONMAKING

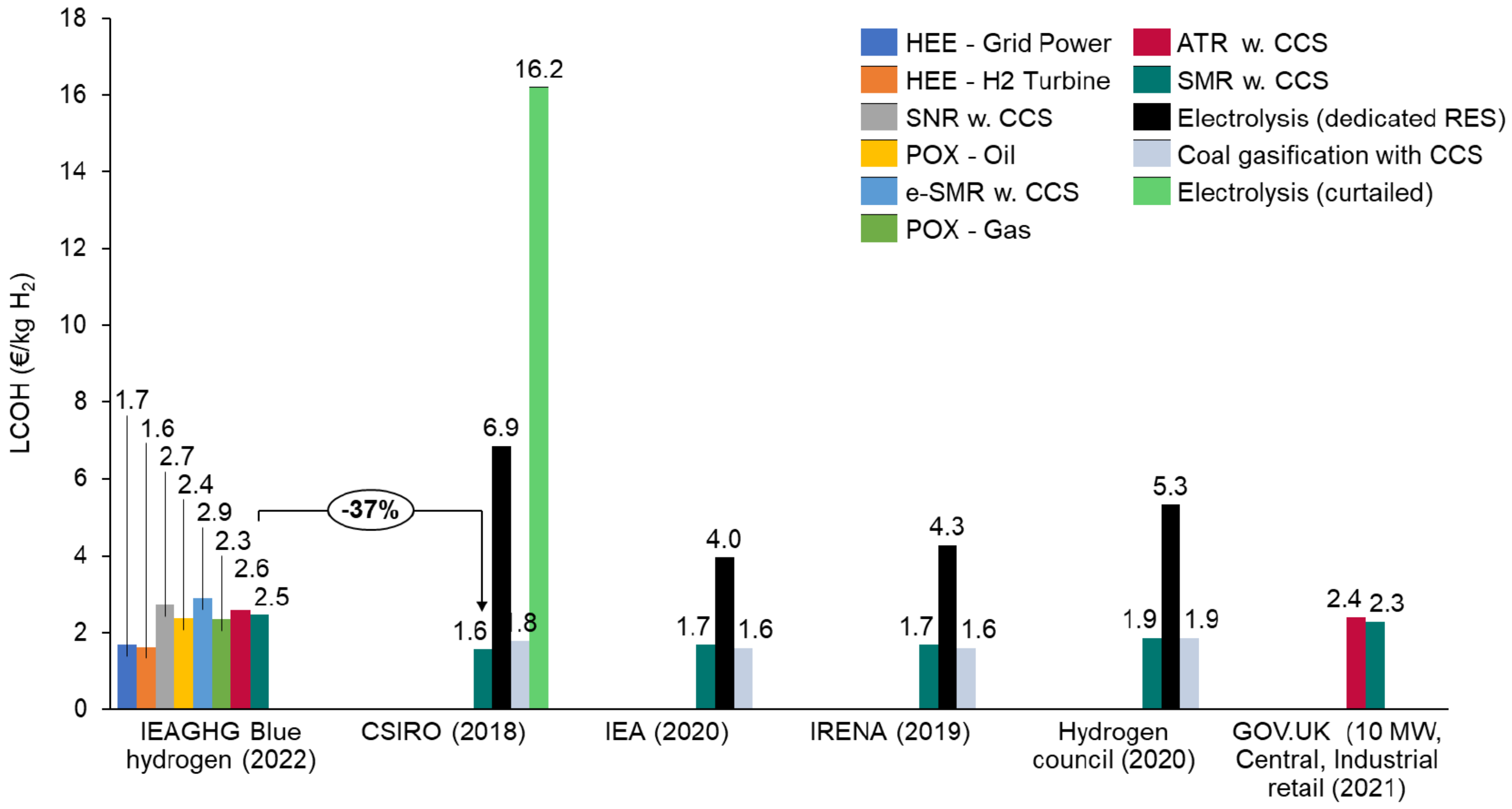
Cost comparison of low-carbon hydrogen technologies. ATR or SMR with CCS have a big cost advantage.

Hydrogen pathways with indicative costs:

Steam-methane reforming (SMR) with CCS:	USD 1.70 – 2.35 / kg
Autothermal reforming (ATR) with CCS:	USD 1.50 – 2.29 / kg
Electrolysis-based H_2:	USD 4.60 – 18.50 / kg



Source: ICF
https://www.icf.com/insights/energy/comparing-costs-of-industrial-hydrogen-technologies



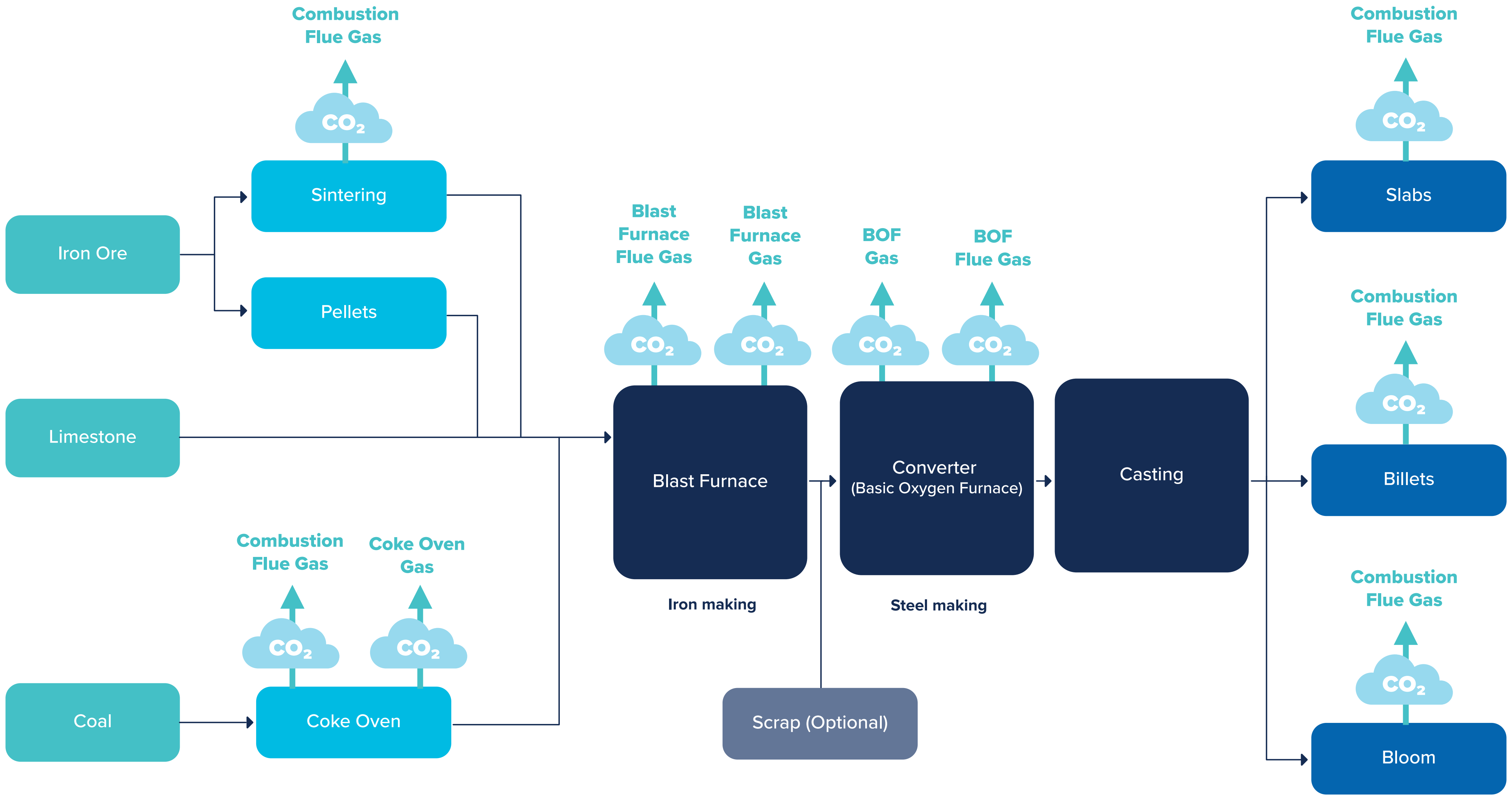
Source: ERM / IEAGHG
https://publications.ieaghg.org/technicalreports/2024-08%20Analysis%20of%20electrolytic%20hydrogen.pdf

COMMERCIAL CCS PROJECTS IN STEEL

Title	Status	Country	Operational Date	Facility Capture Rate (Mtpa)
ADNOC Al-Reyadah	Operational	United Arab Emirates	2016	0.8
Baotou Steel Phase 1	In Construction	China	2025	0.5
ArcelorMittal Texas	Advanced Development	USA	Under Evaluation	
Nucor Steel DRI	Advanced Development	USA	2026	0.8
Indiana Burns Habor Capture	Advanced Development	USA	Under Evaluation	2.8
Marcegaglia steel plant	Early Development	Italy	Under Evaluation	0.11
Offshore Sarawak CCS (multi sector)	Early Development	Japan	Under Evaluation	2.9
Rana Ferroglobe	Early Development	Norway	Under Evaluation	0.52
Rana Elkem	Early Development	Norway	Under Evaluation	1.5

CCS FOR BF/BOF FACILITIES

Point Source	CO_2 Range (mol%)
Blast Furnace Gas	20 – 25 mol%
Basic Oxygen Furnace Gas	15 – 20 mol%
BF Hot Stoves	15 – 30 mol%
Coke Oven Flue Gas	10 – 20 mol%



Flue gases of boilers and power plants fed with blast furnace gas/other precombustion off gasses often have higher CO_2 content than equivalent natural gas or coal boilers or power plants.

- Often >15 mol% CO_2, further capture opportunity.

BF/BOF – CAPTURE EXAMPLES

DMX™ Demonstration in Dunkirk (3D) (FRA)

- Demonstrated capture from blast furnace gases.
- Use of Axen's biphasic solvent.
- Ran from 2019 to Oct-2024 – 4,400 tpa capacity.

Axens DMX™ Carbon Capture Technology Demonstration plant at ArcelorMittal Dunkirk, France
Image courtesy of Axens

Steelanol (BEL)

- Capture and utilisation project (CCU).
- Using LanzaTech's biocatalyst capture & conversion system to generate ethanol.
- Product – Ethanol from blast furnace gases.

MHI Pilot Trials (BEL)

- Started 2024, trialling for two years.
- CO_2 sources – Blast furnace off gases and hot strip mill reheating furnace.

MHI CO_2MPACT CO_2 Capture System Pilot at ArcelorMittal Gent, Belgium. *Source below.*

MHI CO_2MPACT ArcelorMittal Image Source: https://corporate.arcelormittal.com/media/news-articles/trial-carbon-capture-unit-begins-operating-on-blast-furnace-at-arcelormittal-gent-belgium

DRI – CAPTURE EXAMPLES

Abu Dhabi Carbon Capture Company (UAE)

- CO_2 sourced from Emirates Steel DRI.
- 800 ktpa, 98 mol% CO_2 from the process.
- Operating since 2016.
- CO_2 is used for enhanced oil recovery (EOR)

Abu Dhabi Carbon Capture Company CO_2 Compression Facility

CCU – Ternium Puebla and Geurrero (MEX)

- Capture operating since at least 2008.
- Captured 1.7 million tonnes of CO_2 for the merchant market.
- Expansions have brought capture capacity to >250 ktpa.

Ternium CCU Facility in Mexico

Abu Dhabi Carbon Capture Company Image Source: https://fossil.energy.gov/archives/cslf/Projects/AlReyadah.html
Ternium CCU Image Source: https://iea.blob.core.windows.net/assets/imports/events/64/LowcarbonenergycasesatTernium.pdf

THANK YOU

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