

# Cryocap™

Carbon Capture technologies



# Air Liquide Group

## A world leader in gases, technologies and services for industry and healthcare

Air Liquide is present in 60 countries with 66,500 employees and serves more than 4 million customers and patients. Oxygen, nitrogen and hydrogen are essential small molecules for life, matter and energy. They embody Air Liquide's scientific territory and have been at the core of the Group's activities since its creation in 1902.

Taking action today while preparing the future is at the heart of Air Liquide's strategy. With ADVANCE, its strategic plan for 2025, Air Liquide is targeting a global performance, combining financial and extra-financial dimensions. Positioned on new markets, the Group benefits from major assets such as its business model combining resilience and strength, its ability to innovate and its technological expertise.

The Group develops solutions contributing to climate and the energy transition—particularly with hydrogen—and takes action to progress in areas of healthcare, digital and high technologies.



# Air Liquide Engineering & Construction

## A technology partner of choice

Air Liquide Engineering & Construction builds the Group's production units (mainly air gas separation and renewable/low carbon Hydrogen) and provides external customers with efficient, sustainable, customized technology and process solutions.

Our core expertise in industrial gas, energy conversion and gas purification, enables customers to optimize natural resources.

We cover the entire project life-cycle: license engineering services / proprietary equipment, high-end engineering & design capabilities, project management & execution services. In addition, we also offer efficient customer services through our worldwide set-up.

As a technology partner, customers benefit from our research and development to achieve energy transition goals.



## Our full suite of Technologies

Electrolyzers

Low carbon Hydrogen & Ammonia

Hydrogen Liquefaction

CO<sub>2</sub> Capture & Liquefaction

Air Gases

Methanol

Natural Gas Treatment

Green Chemicals & Fuels

Turboexpanders

5

Manufacturing Centers incl. one JV Gigafactory

13

Countries with Technology & Execution Centers & front-end offices

174

Patent applications filed in 2024

# Advancing for a sustainable future

Air Liquide is deeply committed to creating a positive impact on both the environment and society. Our strategy and actions are designed to address crucial challenges the world faces today, where we can make an impact and thus invent a sustainable future.

Climate, health, energy, mobility, sovereignty, the digital revolution... There are many global societal challenges that call for immediate – and collective – responses.

## **At Air Liquide, we are ready.**

Ready to deploy our solutions wherever they are needed, and ready to accelerate whenever the situation requires it. Whether it is supporting our customers on their decarbonization journey, deploying hydrogen to make mobility more sustainable, or contributing to the growth of digital technologies, we offer concrete solutions to help society move forward.

To reduce our own CO<sub>2</sub> emissions, we have set key milestones to reach carbon neutrality:

- by 2025, -30% reduction in Carbon Intensity
- by 2035, a -33% reduction in absolute Scopes 1 & 2 emissions
- by 2050, reach carbon neutrality across the entire value chain.

# Longstanding experience in CO<sub>2</sub> management

Air Liquide has a longstanding experience in CO<sub>2</sub> management, from capture, purification and liquefaction to storage and transport from various sources.

Air Liquide can also upgrade the recovered CO<sub>2</sub> and provide it to various markets, such as the agri-food industry (carbonation, preservation, and refrigerated transport), water treatment, chemicals...

1

## CO<sub>2</sub> EMISSIONS



- Industrial processes (metallurgy, cement manufacturing, ammonia and hydrogen production, methanization, fermentation,...)
- Hydrocarbons combustion
- Biomass combustion
- Waste incineration

2

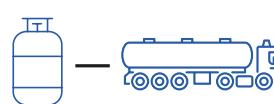
## CARBON CAPTURE



Complexity and energy balance of carbon capture operations mainly depend on:

- Electricity and steam costs and carbon footprint
- Inlet CO<sub>2</sub> stream characteristics
- Expected outlet CO<sub>2</sub> conditions (P,T) and purity

Liquid or gaseous CO<sub>2</sub>



### Utilisation



- Synthetic hydrocarbons
- Chemicals, polymers
- Building materials
- Gas for industrial uses
- Agri food
- Enhanced Oil Recovery



### Geological sequestration

- Sequestration in deep saline aquifers, in depleted oil fields or in coal seams
- Mineralization in basaltic underground rocks

3

## UTILISATION & SEQUESTRATION

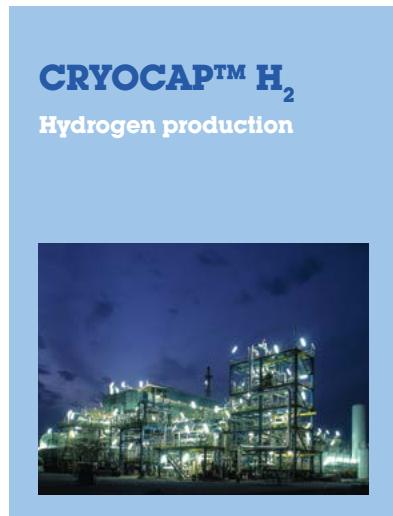
# Cryocap™

## A complete product range to capture and/or liquefy CO<sub>2</sub> from industrial gas streams

### A world premiere

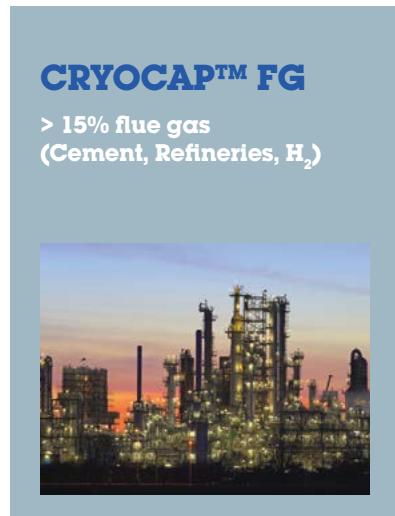
Cryocap™ is a technological innovation for CO<sub>2</sub> capture that is unique in the world, using a cryogenic process (involving low temperatures to separate gases).

Cryocap™ can be adapted to specific applications combining a variety of Air Liquide technologies.



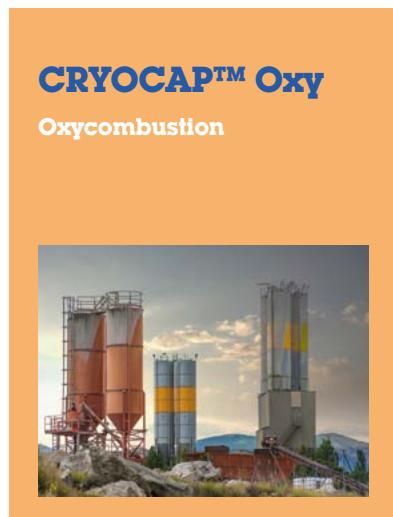
#### CRYOCAP™ H<sub>2</sub>

Hydrogen production



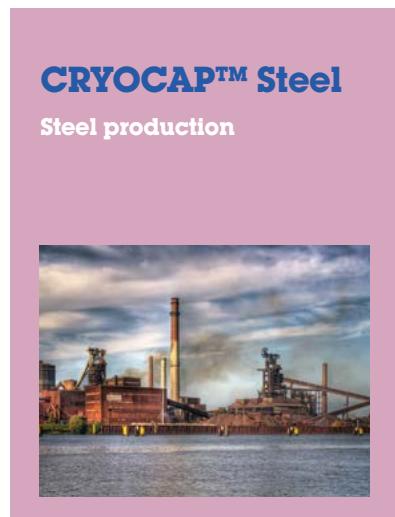
#### CRYOCAP™ FG

> 15% flue gas  
(Cement, Refineries, H<sub>2</sub>)



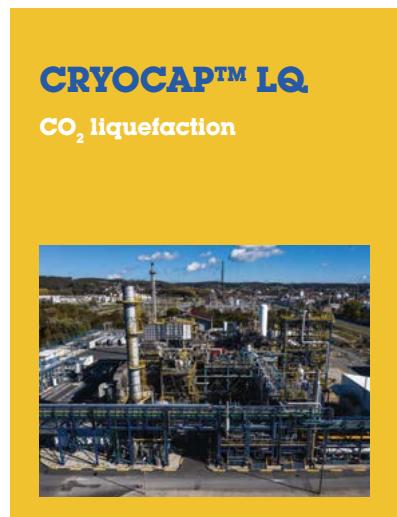
#### CRYOCAP™ Oxy

Oxycombustion



#### CRYOCAP™ Steel

Steel production



#### CRYOCAP™ LQ

CO<sub>2</sub> liquefaction

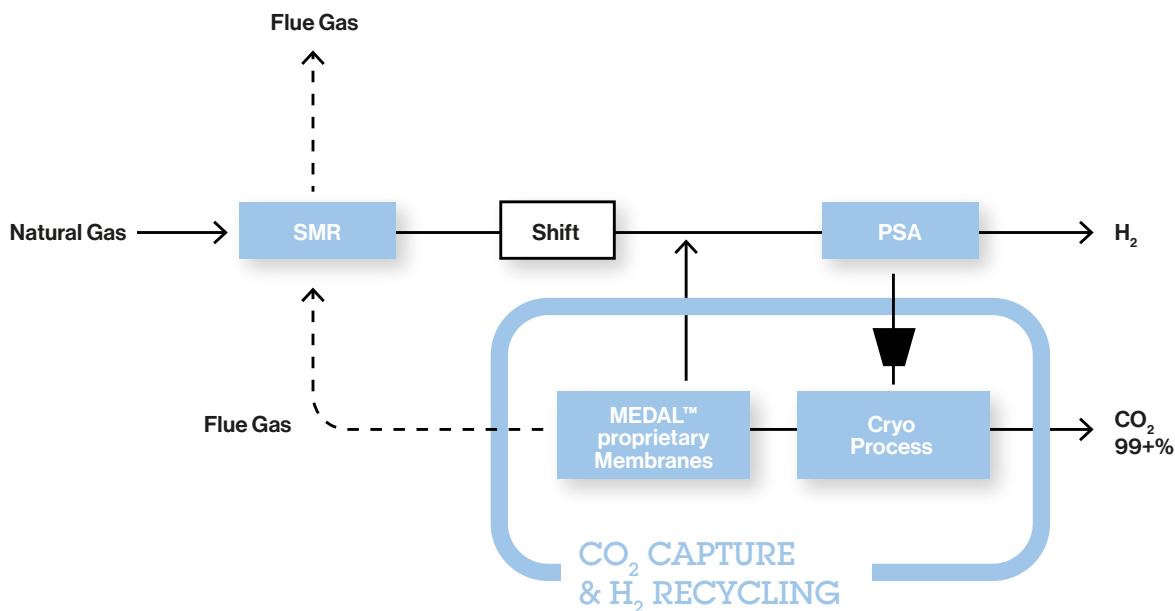


# Cryocap™ H<sub>2</sub>

## Capturing CO<sub>2</sub> while boosting H<sub>2</sub>

- Combination of Membrane and Cryogenics technologies
- Extra H<sub>2</sub> production by 10 to 20%
- Avoided CO<sub>2</sub> cost reduction: up to 40% compared to MDEA

- Gaseous or liquid CO<sub>2</sub>
- >95% capture from syngas (up to 60% overall SMR emissions)



## Port-Jérôme, an industrial reference

Cryocap™ H<sub>2</sub> is the only technique that enables the reduction of the CO<sub>2</sub> released during the production of hydrogen while also increasing this hydrogen production. The CO<sub>2</sub> in Port-Jérôme is further purified and liquefied to meet CO<sub>2</sub> needs of local industrial market (agri-food, water treatment, etc.).



- Port-Jérôme, Normandy, France
- Industrial size, fully upscalable
- Plant built, owned & operated by Air Liquide Group
- Start-up in first half of 2015.
- Highly reliable operation since its commissioning
- Liquid CO<sub>2</sub> production: 300 tons/day
- Zero impact on SMR availability demonstrated

## CRYOCAP™ FG

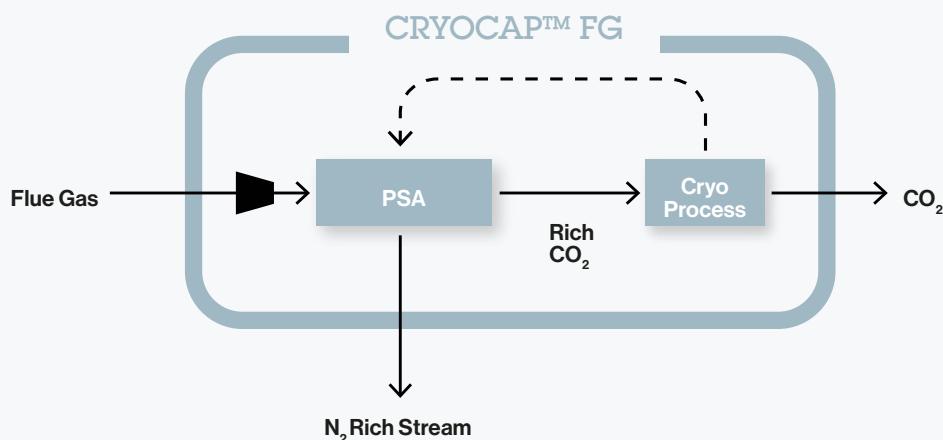
> 15% flue gas  
(Cement, Refineries, H<sub>2</sub>)



## Cryocap™ FG

### Capturing CO<sub>2</sub> from flue gases

- Suitable for SMR (flue gas), FCC, cement...: off gasses with CO<sub>2</sub> content >=15%
- PSA-assisted CO<sub>2</sub> condensation
- Compact & flexible footprint: Compressors, PSA and cryo process can be located in 2 different plots
- Smart impurities management (high NOx)
- Gaseous or liquid CO<sub>2</sub>
- CO<sub>2</sub> capture rate: 85 to 95%



## CRYOCAP™ Oxy

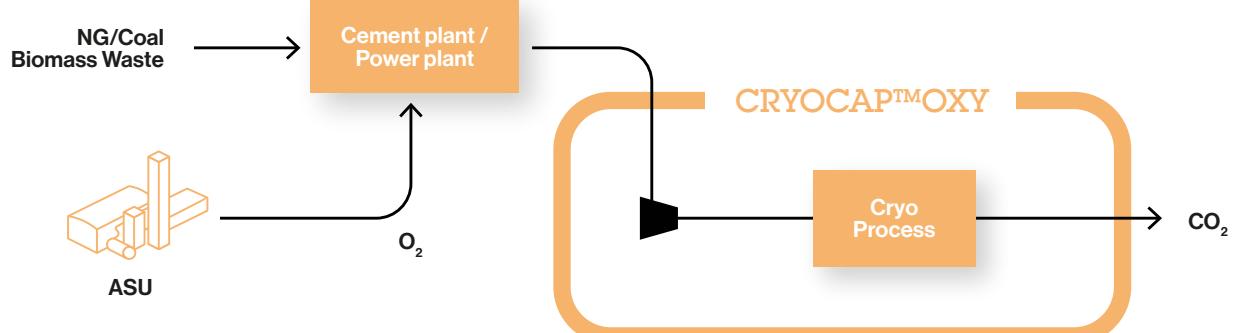
Oxycombustion



## Cryocap™ Oxy

### Capture and Purification for Oxycombustion

- Enriches Flue Gas above 60% CO<sub>2</sub>
- Smart impurities management (high NOx)
- Integration validated on different Oxy boilers
- Demonstrated on 3 plants (Callide, Ciuden, Total Lacq)
- Gaseous or Liquid CO<sub>2</sub>
- CO<sub>2</sub> Capture rate: 90-98%
- Unique Technological bricks
  - Flue Gas Drying
  - Dust Filtration
  - Cryogenic Purification



## CRYOCAP™ Steel

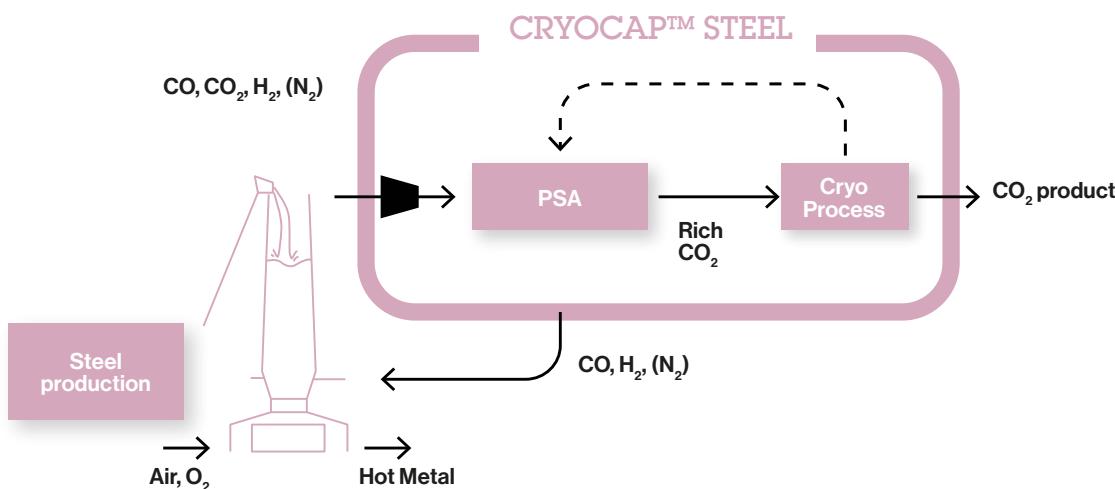
Steel production



## Cryocap™ STEEL

Capturing CO<sub>2</sub> while boosting efficiency

- Retrofit and greenfield for ironmaking
- CO<sub>2</sub> source: 20-50%CO<sub>2</sub>
- Up to -20% Coke consumption and up to +5% Hot Metal Produced
- 80 to 90% CO recovery
- Compact & Flexible footprint: Compressors, PSA and Coldbox can be located in 3 different plots
- Gaseous or liquid CO<sub>2</sub>
- CO<sub>2</sub> capture rate: 80 to 95%



## CRYOCAP™ LQ

CO<sub>2</sub> liquefaction

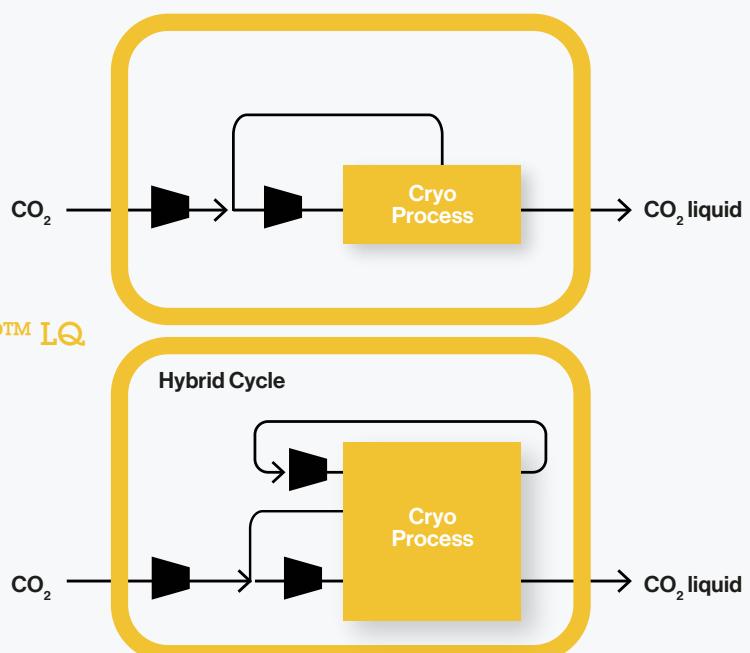


## Cryocap™ LQ

Large scale CO<sub>2</sub> liquefaction

- 700 - 7000+ tpd
- Custom plant: flexible design
- Very low OPEX and very high CO<sub>2</sub> recovery
- Impurities final removal (e.g. O<sub>2</sub>, ...)
- High compactness or very compact unit

## CRYOCAP™ LQ



# Cryocap™

## A unique value proposition for our customers:

- **Minimize the overall carbon footprint:**

the products run mainly on electricity (almost no steam) and maximize the CO<sub>2</sub> avoided by reducing indirect CO<sub>2</sub> emissions, with high CO<sub>2</sub> recovery (90 to 95%, up to 98% with Cryocap™ Oxy and Cryocap™ H<sub>2</sub>)

- **High intrinsic process efficiency:**

the technology bricks are used in their optimum range

- **Favour synergies:**

1-step capture and liquefaction for any stream containing >15% CO<sub>2</sub> (dry basis)

- **Safety and environment-friendly:**

no toxic or flammable gases used

- **Match the end specifications:**

all Cryocap™ produce either high pressure gaseous or liquid CO<sub>2</sub> at marginal extra cost and can meet the most stringent CO<sub>2</sub> specifications

- **Optimize space:**

very compact solutions with flexible layout configuration and simplified infrastructure compared to steam based solutions

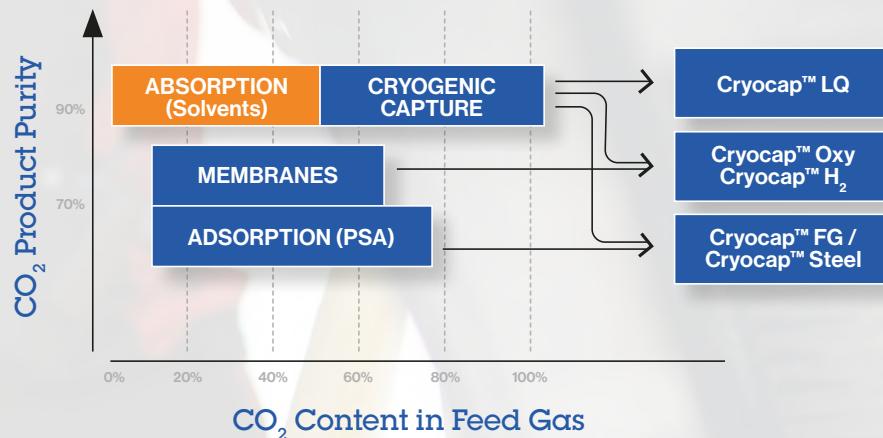
- **Improve productivity:**

for some applications (H<sub>2</sub>, Steel), adding our product improves the efficiency of the original process or enable to co-produce valuable molecules



## Combining technologies for lowering CAPEX and OPEX

Cryocap™ can be tailored to specific applications, combining Air Liquide core technologies (Cryogenics, Adsorption, Membranes), adapting to CO<sub>2</sub> content in the feed gas, CO<sub>2</sub> product specification and offering the possibility to valorize other molecules contained in the feed gas (eg. CO, H<sub>2</sub>...)





## Other technologies

Air Liquide Engineering & Construction also engineers solvent based technologies such as amine to capture CO<sub>2</sub> from synthesis gas or flue gas.

Through long term partnerships with the key amine license providers, Air Liquide installed 80+ units and benefits from its long term operational experience of amine units.

Considered as the industrial base case, amine technology can deliver high purity gaseous CO<sub>2</sub> (99+%)

at low pressure, which can be combined with Cryocap™ LQ. For CO<sub>2</sub> capture on flue gases, amine technology remains the most competitive solution for low CO<sub>2</sub> concentration (below 10%), provided availability of large amount of excess steam or high grade heat.

Air Liquide Engineering & Construction is also offering proprietary technologies for CO<sub>2</sub> capture from synthesis gas (Rectisol, Recticap) or from natural gas (Cryocap NG):



## Rectisol™

The world's leading synthesis gas purification process

- > 110 references and continuously improved throughout the last 75 years
- Selective removal of CO<sub>2</sub>, sulfur and trace components by physical absorption
- Fully referenced in all relevant scales and applications
- Inexpensive, available and chemically stable solvent (methanol)
- Low operating costs and high availability
- Know-how from AL's own operated plants and Rectisol™ demonstration unit
- >99% CO<sub>2</sub> capture from syngas possible, dry CO<sub>2</sub> capture ready (>98.5% purity)

## Recticap™

Rectisol™ optimized for blue hydrogen application

- Simplified Rectisol™ flowsheet - tuned for decarbonization of syngas
- Minimized regeneration steam requirement
- CAPEX and OPEX optimized
- Know-how from AL's own operated plants and Rectisol™ demonstration unit
- >95% CO<sub>2</sub> capture from syngas possible, dry CO<sub>2</sub> capture ready (>98.5% purity)

## Cryocap™ NG

Cryogenic distillation + membranes: the best of both worlds

- Optimised solution for CO<sub>2</sub> rich gas fields, integrating proprietary membrane technologies PEEK-Sep™ and Medal™
- Removing H<sub>2</sub>O, H<sub>2</sub>S, N<sub>2</sub>, HC and Mercaptans with 99% + methane recovery
- High pressure CO<sub>2</sub> ready for re-injection and permanent sequestration or EOR
- Small footprint for offshore application



# Cryocap™

Which Cryocap technology fits your needs

	CRYOCAP™ H2	CRYOCAP™ FG	CRYOCAP™ OXY
<b>H2 production, SMR</b>	✓	✓	
<b>H2 production, ATR</b>	✓		
<b>Cement / lime</b>		✓	✓
<b>Steel</b>		✓	
<b>Refineries (FCC)</b>		✓	
<b>Refineries</b> (Ethylene Naphta Cracker)			
<b>Coal / biomass power plant</b>		✓	✓
<b>Pulp &amp; paper</b>		✓	
<b>Any application with CO<sub>2</sub> concentration &gt; 95%</b> (from carbon capture units)			
<b>Any application with CO<sub>2</sub> concentration &gt; 40%</b> Oxycombustion or alternate concentration process			✓
<b>Any combustion gas, waste incineration &lt; 10%</b>			



**CRYOCAP™Steel**

**CRYOCAP™ LQ**

**Physical Absorption**  
Rectisol™ Recticap™

**Chemical Absorption**  
(amines)

✓

✓

✓

✓

✓

✓

✓

✓

✓

✓

# Air Liquide Cryocap™

## References



### Port-Jérôme:

#### the world's first carbon capture plant in operation in France

In 2015, Air Liquide started operating its first industrial deployment of the Cryocap™ H<sub>2</sub> technology at its installation in Port-Jérôme at the largest Steam Methane Reforming Hydrogen production unit operated by Air Liquide in France.

Since the plant started operating, its operation has proved to be extremely reliable. In the course of the last years, Air Liquide has further optimized the plant's operation with, for example, the fast start-up automatic sequence.

Port-Jérôme is one of the 4 sites in Europe able to produce Hydrogen certified low carbon. It has been integrated as a pilot site for the project CertifHy, the first Guarantee of Origin (GO) platform for Green and Low-Carbon Hydrogen.





## Kairos@C:

### the world's largest cross-border carbon capture and storage (CCS) value chain in Antwerp

In November 2021, Air Liquide and BASF planned to develop the world's largest cross-border Carbon Capture and Storage (CCS) value chain.

The goal is to significantly reduce CO<sub>2</sub> emissions at the industrial cluster in the port of Antwerp. The joint project "Kairos@C" has been selected for funding by the European Commission through its Innovation Fund, as one of the seven large-scale projects out of more than 300 applications.

Kairos@C will be jointly developed by Air Liquide and BASF at its Antwerp chemical site. By avoiding 14.2 million tons of CO<sub>2</sub> over the first 10 years of operation, it will significantly contribute to the EU's goal of becoming climate neutral by 2050.

Besides combining CO<sub>2</sub> capture, liquefaction, transportation and storage on a large scale in the North Sea, the project includes several innovative technologies. Notably, for capturing the CO<sub>2</sub> from production plants, Air Liquide will use its patented Cryocap™ technology and, for drying the CO<sub>2</sub>, BASF will apply its Sorbead® solution. The project is planned to be operational in 2025.

# Air Liquide Cryocap™

## References



### Lhoist:

## a first-of-its-kind decarbonization project of lime production in France

In May, 2022, Air Liquide and Lhoist joined forces to launch a first-of-its-kind decarbonization project of lime production in France.

Air Liquide and Lhoist signed a Memorandum of Understanding (MoU) with the aim to decarbonize Lhoist's lime production plant located in Réty, in the Hauts-de-France region, using Air Liquide's innovative and proprietary Cryocap™ carbon capture technology.

In this context, Air Liquide and Lhoist have jointly applied for the European Innovation Fund large scale support scheme. This partnership is a new step in the creation of a low-carbon industrial ecosystem in the broader Dunkirk area.

Lime is one of the "hard-to-abate" industries as its production primarily generates CO<sub>2</sub> from decomposition of limestone. The project for Lhoist would be able to reduce the CO<sub>2</sub> emissions of the plant in Réty by more than 600,000 tons per year starting in 2028.

Air Liquide would build and operate a unit of its innovative and proprietary Cryocap™ FG (Flue Gas) technology to capture and purify 95% of the CO<sub>2</sub> arising from Lhoist's existing lime production unit in Réty.

Air Liquide's Cryocap™ technology would thus be used for the first time to decarbonize lime production in France.





## **EQIOM:**

### **developing one of the first carbon-neutral cement plants in Europe**

In April, 2022, Air Liquide and EQIOM joined forces in a project named "K6" with the aim to transform EQIOM's Lumbres plant into one of the first carbon-neutral cement plants in Europe.

Through the implementation of innovative technologies, the project aims to capture around 8 million tons of CO<sub>2</sub> over the first ten years of operation.

The K6 project has been awarded funding by the European Commission through its 2021 Innovation Fund call as one of seven industrial-scale projects out of more than 300 grant applications.

EQIOM will carry out a program of technological innovation and in-depth transformation of its existing cement production plant in Lumbres, France.

The solution aims to implement a First-of-a-Kind oxyfuel-ready kiln, powered with a high level of alternative fuel.

Air Liquide will support this initiative by supplying oxygen to EQIOM's production process and by leveraging its proprietary technology Cryocap™ Oxy to capture and liquefy the CO<sub>2</sub> emissions.





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