

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 66,300 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

CO₂ Capture & Liquefaction

Air Gases

Methanol

Natural Gas Treatment

Green Chemicals & Fuels

Turboexpanders

5

Manufacturing centers

17

Operating centers & front-end offices

183

Patent applications filed in 2023

A scenic landscape at sunset. The sun is low on the horizon, casting a warm orange glow over the scene. In the background, there are rugged mountains. A river flows through the middle ground, reflecting the sunset light. The foreground is a rocky, sloping hillside with some sparse vegetation.

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.

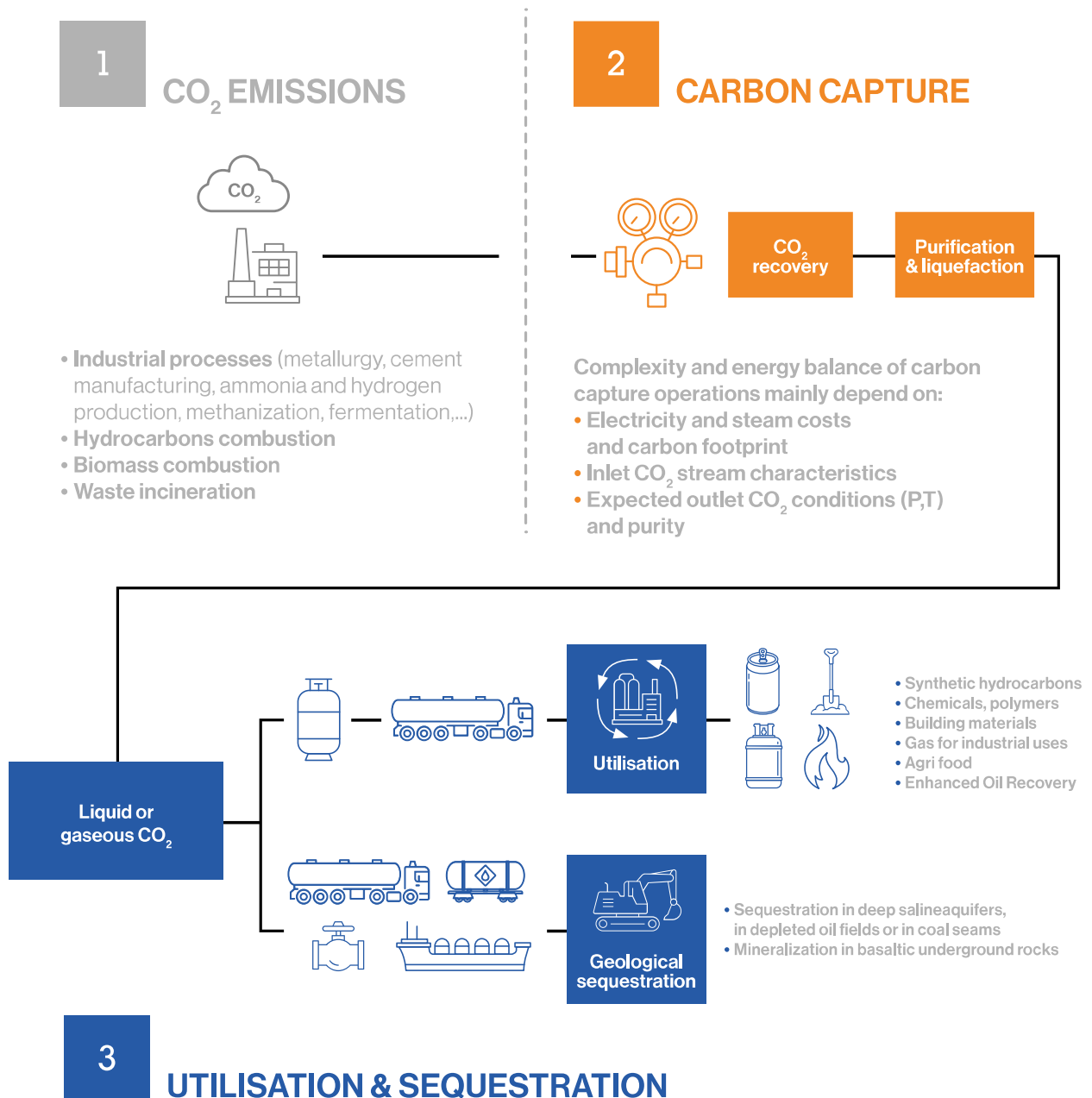
To reduce our own CO₂ emissions, we have set key milestones to reach carbon neutrality:

- 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 CO₂ management

Air Liquide has a longstanding experience in CO₂ management, from capture, purification and liquefaction to storage and transport from various sources.

Air Liquide can also upgrade the recovered CO₂ and provide it to various markets, such as the agri-food industry (carbonation, preservation, and refrigerated transport), water treatment, chemicals...



Cryocap™

A complete product range
to capture and/or liquefy CO₂
from industrial gas streams

A world premiere

Cryocap™ is a technological innovation for CO₂ 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™ H₂

Hydrogen production



CRYOCAP™ FG

> 15% flue gas
(Cement, Refineries, H₂)



CRYOCAP™ Oxy

Oxycombustion



CRYOCAP™ Steel

Steel production



CRYOCAP™ LQ

CO₂ liquefaction

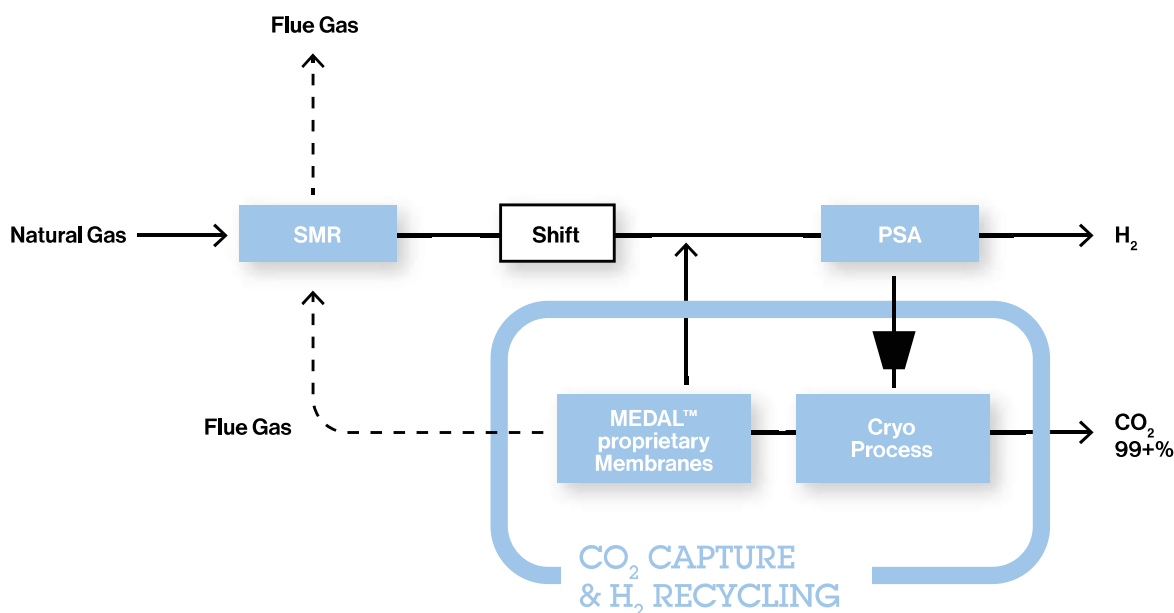




Cryocap™ H₂

Capturing CO₂ while boosting H₂

- Combination of Membrane and Cryogenics technologies
- Extra H₂ production by 10 to 20%
- Avoided CO₂ cost reduction: up to 40% compared to MDEA
- Gaseous or liquid CO₂
- >95% capture from syngas (up to 60% overall SMR emissions)



Port-Jerôme, an industrial reference

Cryocap™ H₂ is the only technique that enables the reduction of the CO₂ released during the production of hydrogen while also increasing this hydrogen production. The CO₂ in Port-Jérôme is further purified and liquefied to meet CO₂ 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 CO₂ production: 300 tons/day
- Zero impact on SMR availability demonstrated

CRYOCAP™ FG

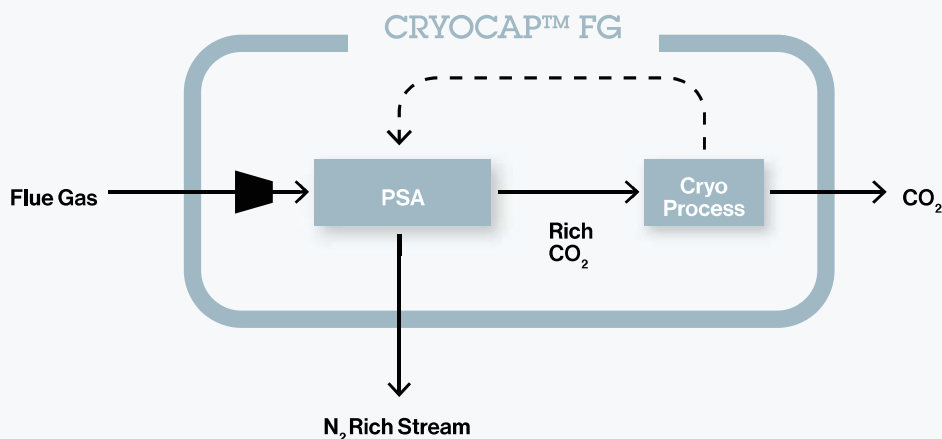
> 15% flue gas
(Cement, Refineries, H₂)



Cryocap™ FG

Capturing CO₂ from flue gases

- Suitable for SMR (flue gas), FCC, cement...: off gases with CO₂ content >=15%
- PSA-assisted CO₂ condensation
- Compact & flexible footprint: Compressors, PSA and cryo process can be located in 2 different plots
- Smart impurities management (high NO_x)
- Gaseous or liquid CO₂
- CO₂ capture rate: 85 to 95%



CRYOCAP™ Oxy

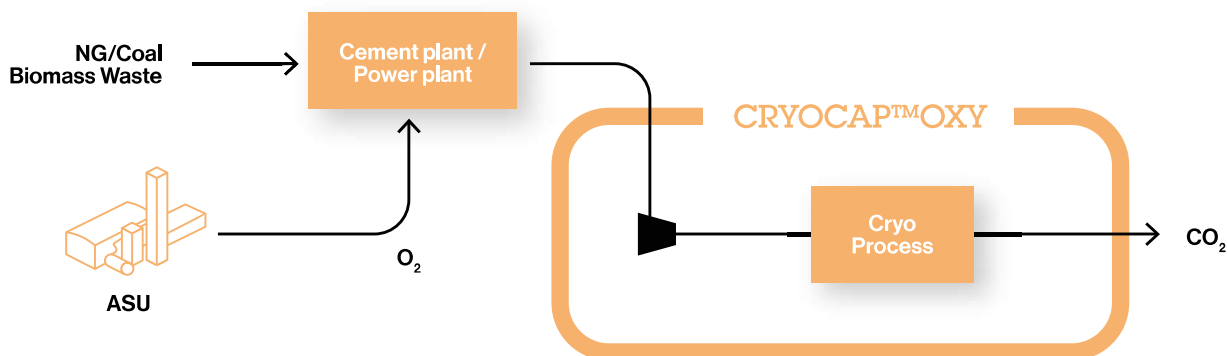
Oxycombustion



Cryocap™ Oxy

Capture and Purification for Oxycombustion

- Enriches Flue Gas above 60% CO₂
- Smart impurities management (high NO_x)
- Integration validated on different Oxy boilers
- Demonstrated on 3 plants (Callide, Ciuden, Total Lacq)
- Gaseous or Liquid CO₂
- CO₂ Capture rate: 90-98%
- Unique Technological bricks
 - Flue Gas Drying
 - Dust Filtration
 - Cryogenic Purification



CRYOCAP™ Steel

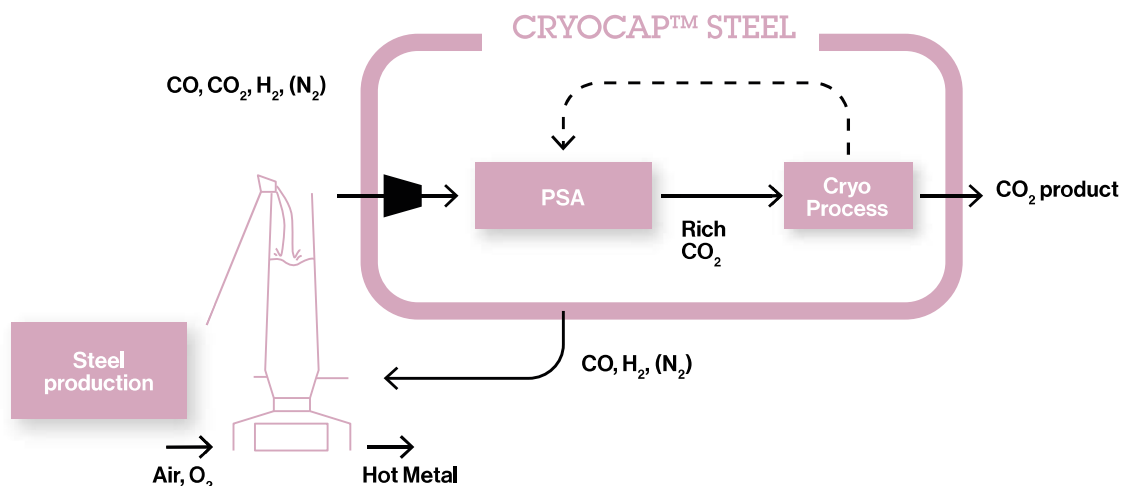
Steel production



Cryocap™ STEEL

Capturing CO₂ while boosting efficiency

- Retrofit and greenfield for ironmaking
- CO₂ source: 20-50%CO₂
- 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 CO₂
- CO₂ capture rate: 80 to 95%



CRYOCAP™ LQ

CO₂ liquefaction

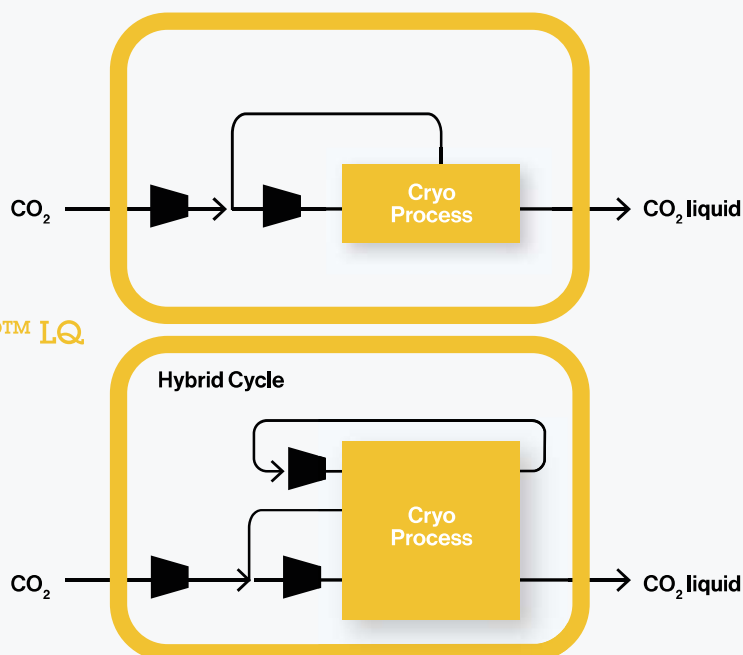


Cryocap™ LQ

Large scale CO₂ liquefaction

- 700 - 7000+ tpd
- Custom plant: flexible design
- Very low OPEX and very high CO₂ recovery
- Impurities final removal (e.g. O₂, ...)
- High compactness or very compact unit

CRYOCAP™ LQ



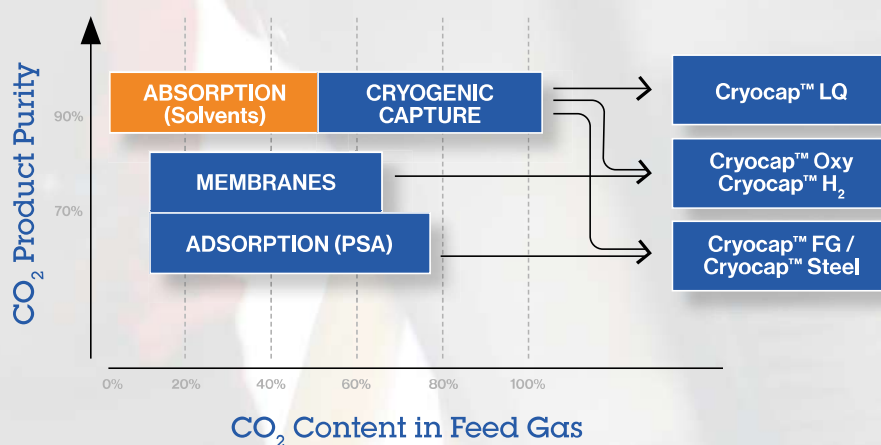
A unique value proposition for our customers:

- **Minimize the overall carbon footprint:** the products run mainly on electricity (almost no steam) and maximize the CO₂ avoided by reducing indirect CO₂ emissions, with high CO₂ recovery (90 to 95%, up to 98% with Cryocap™ Oxy and Cryocap™ H₂)
- **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% CO₂ (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 CO₂ at marginal extra cost and can meet the most stringent CO₂ specifications
- **Optimize space:** very compact solutions with flexible layout configuration and simplified infrastructure compared to steam based solutions
- **Improve productivity:** for some applications (H₂, 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 CO₂ content in the feed gas, CO₂ product specification and offering the possibility to valorize other molecules contained in the feed gas (eg. CO, H₂...)





Other technologies

Air Liquide Engineering & Construction also engineers solvent based technologies such as amine to capture CO₂ 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 CO₂ (99+%)

at low pressure, which can be combined with Cryocap™ LQ. For CO₂ capture on flue gases, amine technology remains the most competitive solution for low CO₂ 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 CO₂ 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 CO₂, 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% CO₂ capture from syngas possible, dry CO₂ 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% CO₂ capture from syngas possible, dry CO₂ capture ready (>98.5% purity)



Cryocap™ NG

Cryogenic distillation + membranes: the best of both worlds

- Optimised solution for CO₂ rich gas fields, integrating proprietary membrane technologies PEEK-Sep™ and Medal™
- Removing H₂O, H₂S, N₂, HC and Mercaptans with 99% + methane recovery
- High pressure CO₂ 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
H2 production, SMR	✓	✓	
H2 production, ATR	✓		
Cement / lime		✓	✓
Steel		✓	
Refineries (FCC)		✓	
Refineries (Ethylene Naphta Cracker)			
Coal / biomass power plant		✓	✓
Pulp & paper		✓	
Any application with CO ₂ concentration > 95% (from carbon capture units)			
Any application with CO ₂ concentration > 40% (Oxycombustion or alternate concentration process)			✓
Any combustion gas, waste incineration < 10%			



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™ H₂ 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 CO₂ 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 CO₂ over the first 10 years of operation, it will significantly contribute to the EU's goal of becoming climate neutral by 2050.

Besides combining CO₂ capture, liquefaction, transportation and storage on a large scale in the North Sea, the project includes several innovative technologies. Notably, for capturing the CO₂ from production plants, Air Liquide will use its patented Cryocap™ technology and, for drying the CO₂, BASF will apply its Sorbead® solution. The project is planned to be operational in 2025.

Air Liquide Cryocap™

References



Lhoist:

α 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 CO₂ from decomposition of limestone. The project for Lhoist would be able to reduce the CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emissions.



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