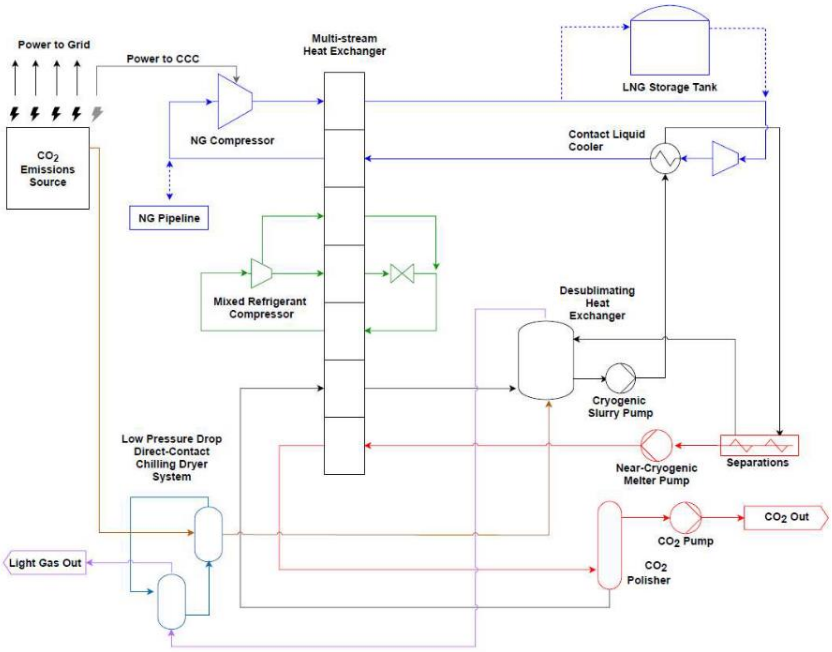
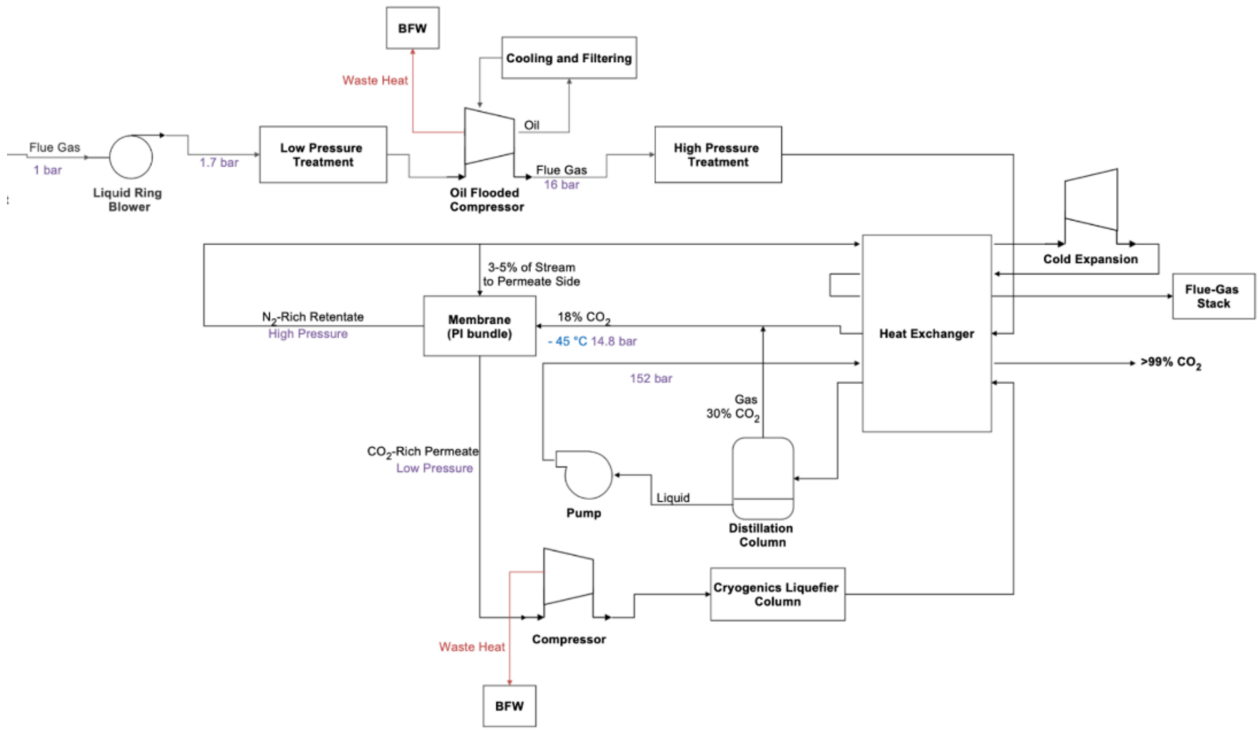
CRYOGENIC CARBON CAPTURE

Carbon Capture using cryogenic method is a post-combustion technology designed to reduce carbon emissions from various industrial sources. There are several different configurations of the cryogenic carbon capture process. One notable process cools the gases to very low temperatures, specifically to the frost or desublimation point of CO_2 (between -100°C and -135°C), to separate CO_2 as a solid, as shown in the figure on the right.[1] In this process, the CO_2 is first separated from other gases and then pressurized. The solid CO_2 is then warmed to produce a high-purity, pressurized CO_2 stream. In another configuration, the CO_2-containing stream is first compressed and then directed to a cold process. In this stage, CO_2 is separated from other components of the feed gas and purified through partial condensation and distillation as shown in the figure below.[2] Some of the impurities removed during the cryogenic process are recycled back to the plant's inlet. The final CO_2 product is either compressed to the desired pressure (resulting in a gaseous or supercritical state) or recondensed and extracted as a liquid. This technology offers several benefits, including high CO_2 recovery rates of up to 99%, CO_2 purity levels exceeding 99%, and lower energy consumption compared to other carbon capture technologies. Additionally, it can remove other pollutants such as SOx, NOx, and mercury from flue gases. It applies to lower CO_2 concentration point sources, as it can be integrated with other capture systems to increase CO_2 concentration. However, the initial investment and operational costs can be high, although it aims to be more cost-effective than competing technologies. **The information shown in this info sheet belongs mainly to the CRYOCAP™ technology from Air Liquide, as it is publicly available.**[3]



Cryogenic carbon capture process



Air Liquide Cryocap™ process

TECHNICAL ASPECTS (all % are volume-based)

Point Sources: Steam-methane reforming, cement/lime, steel blast furnace, refineries, waste incineration/biomass power plant, pulp & paper, and iron and Steel.[4]

CO_2 concentration range: 15-95%[4]

CO_2 capture efficiency: 99%[4]

CO_2 purity: 95%[3] (CO_2 pipeline standards)

Min. feed gas pressure: 1 bar[2] (typical), 4 bar for Cryocap™ FG[5]

Max. feed gas temperature: 30 °C

Typical scale: Medium-large (> 100.000 tCO_2/yr)[6]

Primary energy source: Electricity[4]

Impurity tolerance: High tolerance to common flue gas impurities, such as SOx and NOx. [6]

FUNCTION IN CCU VALUE CHAIN

- Capture high-purity CO_2 in liquid form.
- Removes impurities, eliminating the need for separate pretreatment steps (NOx and SOx).

LIMITATIONS

- High energy demand due to cryogenic cooling and compression.
- Capital-intensive equipment, such as refrigeration systems and heat exchangers.
- Pretreatment requirements for water and PM.

ENERGY

- Electricity is the main energy source.
- Cooling the flue gas is the most energy-intensive step.
- Integrated heat recovery enhances overall energy efficiency.

CONSUMABLES

- Refrigerants are used in a closed-loop system, minimizing loss.

Energy and Consumables

Parameter	Value
Electricity (kWh/tCO_2)	FG: 410[5]; H_2: 320[6]*
*Equation***	**Y= 660exp(-1.868X)**[7]
	667 – 1444[8]
	248[9]***

**Cryocap™ FG and H_2*
***Cryocap™: X – CO_2 concentration and Y – electricity consumption*
****Cryogenic carbon capture – gas to solid*

COSTS

CAPEX: 28 - 31 €/tCO_2[10,11]
15 €/tCO_2[9]

Main CAPEX: Cold box and compressors.

OPEX: 15 - 30 €/tCO_2[11]
8 €/tCO_2[9]

Main OPEX: Electricity

CO_2 capture cost: 47 – 110 €/tCO_2[8] (2021 euros)

Cryocap™ H_2: 30 – 50 €/tCO_2[4]*
40 €/tCO_2[11] for 50% CO_2

Cryocap™ FG: 40 – 80 €/tCO_2[4]*
48 €/tCO_2[5] for 22% CO_2

Cryocap™ STEEL: 25 – 60 €/tCO_2[4]*

Cryocap™ OXY: 30 – 50 €/tCO_2[4]*

Cryogenic carbon capture: 23 €/tCO_2[9]

CO_2 avoidance cost: Cryocap™ H_2: avoided CO_2 cost reduction up to 40% compared to MDEA.[4]

Cryogenic carbon capture: 34 €/tCO_2[9]

**Ranges vary depending on CO_2 concentration and the scale of operation.*

[10,11]*Air Liquide's Port-Jérôme; capacity - 100 ktCO_2/yr; Cryocap™ H_2; 2014 euros; CAPEX estimation with 30 yr lifetime; discount rate – 7%; electricity price - 60 €/MWh; supercritical CO_2 product at 150 bar.*

[9]*Cryogenic carbon capture; 2021 euros; capture efficiency – 90%; delivery pressure – 150 bar; electricity price – 74 €/MWh; avoidance cost includes transport and storage cost; NG as refrigerant.*

ENVIRONMENTAL

CO_2 footprint: 230 kgCO_2eq/ton CO_2[12,13]

Spatial footprint: ~20,000 m² per 0.9 MtCO_2/yr[7]*

**Based on capture volume of 900 ktCO_2/yr and 5 acres area.*

Environmental issues: None, no by-product formation, solvent-free, no toxic or flammable gases used.

ENGINEERING

Maturity: FOAK Commercial system (TRL 8-9)[4]
Pilot plants and first commercial plants.

Retrofittability: Moderate[4,11]
This technology has a compact and flexible footprint to be retrofitted into existing industrial plants, contributing to a cost-effective solution.

Scalability: High
Well suited for a wide range of applications, allowing it to be adapted to different industrial settings due to its modularity.[4]

Process type: Cryogenic without solvents/sorbents and chemical reactions.

Deployment model: Only centralized. CO_2 separation occurs only in the cold box.

Technology flexibility: Hybridizing with other CO_2 capture technologies, such as PSA or membranes, is feasible. These technologies can be used to increase the CO_2 concentration at the upstream.

TECHNOLOGY PROVIDERS

- Cryocap™ by **Air Liquide**, France
  ***Cryocap™ H₂**: Capturing CO₂ while boosting H₂ production via steam-methane reforming (SMR)*
  ***Cryocap™ FG**: Capturing CO₂ from flue gases (cement plant), >=15% CO₂ content*
  ***Cryocap™ STEEL**: Capturing CO₂ while boosting efficiency (steel plant), 20-50% CO₂ content*
  ***Cryocap™ OXY**: Capture and purification of Oxycombustion (NG/coal/biomass waste), >40% CO₂ content*
- Cryogenic Carbon Capture™ by **Chart Industries**, United States
- Cryogenic capture by **Emicap**, Belgium
- FrostCC™ by **Carbon America**, United States

INNOVATIONS

Emicap (Belgium) developed a technology also suitable for small-scale capture (<100 ktCO_2/yr).

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PARTNERS

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