

## Final Report of the Prefeasibility Study for CO<sub>2</sub> Capture and Storage (CCS) at IMERYS

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### 1. Introduction and Study Objectives

The study is part of global ambitions for **decarbonization and carbon neutrality by 2050**, where **Carbon Capture and Storage (CCS)** is considered a key technology. **IMERYS Aluminates** commissioned **Technip Energies** to carry out a feasibility study comparing different **CO<sub>2</sub> capture technologies** from emission sources at its Dunkerque site.

The main objectives of the study are to:

- Evaluate the performance of two CO<sub>2</sub> capture technologies considering the project design basis.
- Perform a preliminary sizing of the units.
- Identify and quantify requirements for utilities, catalysts/chemicals, and effluents.
- Develop schedules for **Level 1 FEED and EPC phases**.
- Establish a preliminary layout ensuring economical and optimal integration within the existing site.
- Provide a **Class 5 cost estimate** (using a high-level methodology based on general characteristics and cost ratios).

#### Technologies Evaluated:

1. **Scenario 1:** Canopy by T.EN™ powered by **SHELL Cansolv®** (chemical absorption using an amine-based solvent).
2. **Scenario 2: Compact Membrane System (CMS)**, a physical adsorption technology by **Ardent**, combined with **cryogenic purification**.

The report is divided into two parts:

- **PART A:** CO<sub>2</sub> capture solution using **amine absorption** (current kiln configuration).
- **PART B:** CO<sub>2</sub> capture solution using **cryogenic purification and membrane adsorption**.

## 2. SCENARIO 1: Amine Absorption Solution (Current Configuration)

This scenario explores a **carbon capture solution for the current kiln configuration** using **SHELL CANSOLV® amine absorption**.

### 2.1 Technology and Flue Gas (FG) Analysis

- **Technology:** The **SHELL CANSOLV® capture system** is a regenerative process using a proprietary amine-based solvent (DC103). The technology has a **Technology Readiness Level (TRL) of 9**, meaning it is commercially proven.
- **Flue Gas (FG) Composition (Nominal):**  
The total FG flow rate is **72,846 Nm<sup>3</sup>/h (wet)**, with a **CO<sub>2</sub> concentration of 11.11 mol%**. Amine absorption is considered **very well suited (technically and economically)** for this CO<sub>2</sub> level.
- **Contaminants:** The FG contains high concentrations of contaminants (**NO<sub>x</sub> and SO<sub>x</sub>**).
  - **NO<sub>x</sub>:** The NO content is considered **extremely high** and above the **emission limit value (ELV)**, requiring **De-NO<sub>x</sub> treatment**.
  - **SO<sub>x</sub>:** The FG is **extremely concentrated in SO<sub>x</sub>**. **SO<sub>2</sub> removal** is required during pretreatment to protect the absorbent. **SO<sub>3</sub>** (assumed to be **1 vol.% of total SO<sub>x</sub>**) may form **acid mist**, requiring mitigation.

### 2.2 Process Flow Scheme

The proposed scheme consists of **pretreatment (Section 100)**, the **central SHELL CANSOLV® unit (Section 200)**, **CO<sub>2</sub> compression/conditioning/post-treatment (Section 300)**, and **aerosol mitigation (Section 400)**.

#### Pretreatment:

- **NO<sub>x</sub> Reduction: Selective Catalytic Reduction (SCR)** is preferred. The objective is to reduce NO<sub>x</sub> by **nearly 78%** to meet the ELV at the stack. To prevent the formation of **ammonium bisulfate (ABS)**, which deactivates the catalyst, the FG must be heated to at least **230°C**.
- **SO<sub>x</sub> Removal:** A **caustic wet scrubber** is selected for **SO<sub>x</sub> neutralization** and for **cooling/saturating the gas with water to 40°C** before the CO<sub>2</sub> absorber.

#### Carbon Capture Unit:

CO<sub>2</sub> is absorbed in the **absorber column**. The unit is designed to achieve a **high capture efficiency between 90% and 98%**. The **rich amine** is regenerated in a **stripping column**.

#### Post-Treatment and Mitigation:

- **CO<sub>2</sub> Dehydration: Molecular sieves** are used to adsorb water from the CO<sub>2</sub>-rich gas to meet the final product specifications.
- **Aerosol Mitigation: A Brownian Diffusion Unit (BDU)** is required to prevent **acid mist droplet carryover** to the stack, as the **SO<sub>3</sub> content is estimated to be above 1 ppmv**.

## 2.2. Summary of Performance (Nominal)

Caractéristique	Unité	Valeur
Débit Gaz Traité total	Nm <sup>3</sup> /h	60 930
Capture CO <sub>2</sub>	%mol	> <b>95</b>
Débit Produit CO <sub>2</sub>	kg/h	<b>15 090</b>
Pureté CO <sub>2</sub>	%mol	> <b>99,9</b>
Consommation Électrique	kW	4 426
Consommation de Vapeur	t/h	20
Eau de Refroidissement	m <sup>3</sup> /h	1 650
Empreinte au sol	m <sup>2</sup>	6 240 (130m x 48m)
Eaux Usées (Pre-Scrubber)	kg/h	3 390

## 3. SCENARIO 2: Membrane Adsorption and Cryogenic Purification Solution

This scenario studies a **CO<sub>2</sub> capture solution for a future configuration** with a **new kiln operating in oxy-combustion mode using natural gas (NG)**. The post-purification is based on a **standard cryogenic scheme**.

### 3.1 Technology and Flue Gas (FG) Analysis

- **Technology:** The base case relies on **cryogenic purification**. The alternative case includes the addition of **ARDENT®'s Compact Membrane System (CMS)**. The **TRL for the membranes is 5**, indicating that further validation is required before full commercial deployment.
- **Flue Gas (FG) Composition (Nominal):**  
The total FG flow rate is **10,500 Nm<sup>3</sup>/h (wet)**, with a gas stream **very rich in CO<sub>2</sub> and H<sub>2</sub>O** (up to **70 mol% CO<sub>2</sub> after water condensation**).
- **Contaminants:** Contaminant analysis was not available, but **high concentrations are assumed**, requiring **significant SO<sub>x</sub> removal** and **specific De-NO<sub>x</sub> treatment** to meet the strict final CO<sub>2</sub> product specifications (**< 10 ppm mol NO<sub>x</sub>**). The **dust concentration is estimated at 60.3 mg/Nm<sup>3</sup>**, which is **incompatible with SCR without filtration**.

### 3.1 Process Flow Scheme (Base Case)

The process scheme consists of **pretreatment (Section 100)** and **CO<sub>2</sub> compression/conditioning/post-treatment (Section 300)**.

#### Pretreatment:

- **SO<sub>x</sub> Removal: Dry Sorbent Injection (DSI)** based on **sodium bicarbonate** is preferred, as it is **selective for SO<sub>3</sub>** and suitable for **temperatures above 180°C**. The selected case assumes **selective removal of >99% of SO<sub>3</sub>**, followed by a **downstream pre-scrubber**.
- **Dust Removal: Bag filters** are required due to the **dust concentration and the upstream DSI process**.

- **NOx Reduction:** SCR is also considered.
- **Caustic Scrubber:** Its main purpose is to **condense the large amount of water** contained in the FG.

#### Post-Treatment:

- **CO<sub>2</sub> Dehydration:** Molecular sieves.
- **Deoxygenation / Cryogenic Purification:** The **cryogenic post-purification unit (cold box)** is used to remove impurities such as **N<sub>2</sub>, O<sub>2</sub>, CO, and NO<sub>2</sub>** to achieve the required CO<sub>2</sub> purity.
- **Polishing Compression:** The purified CO<sub>2</sub> is **compressed to approximately 30 bar g**.
- **Inerts Purge:** The inert vapor stream (**N<sub>2</sub>/O<sub>2</sub>**) leaving the cryogenic post-purification contains a **significant fraction of CO<sub>2</sub> (~25 mol%)** and is purged to the atmosphere.

### 3.2. Summary of Performance (Nominal)

Caractéristique	Unité	Base Case (Cryo)	Alternate Case (Cryo + CMS)
Capture CO <sub>2</sub>	%mol	<b>84</b>	<b>&gt; 90</b>
Débit Produit CO <sub>2</sub>	kg/h	3 272	3 501
Pureté CO <sub>2</sub>	%mol	99,99	99,99
Consommation Électrique	kW	1 119	1 119
Production de Vapeur	t/h	- 0.553	- 0.553
Eau de Refroidissement	m <sup>3</sup> /h	387	387
Empreinte au sol	m <sup>2</sup>	3 854 (94m x 41m)	3 854 (94m x 41m)

#### Key Points for the Next Phase:

- **DeNOx Design:** The suitability of the DeNOx design for the **very high water content of the gas (75%)** is a major point of attention. **Shell Catalyst** indicated that such levels are beyond their experience and would require **R&D testing**.
- **Cryogenic Separation Feasibility:** The feasibility of the **cryogenic separation section** (low vapor flows) and the selection of technology for **rotating equipment** (small capacity may exclude centrifugal types) must be confirmed with suppliers.
- **Wastewater Treatment:** Wastewater will be **heavily loaded** in this scenario and must be considered for **mass balance allocation**.

### 4. General Conclusion

The prefeasibility study defined the **general concepts and main requirements** for both scenarios in just **10 weeks**. It provides a set of **preliminary information**, including **mass balance, utilities, effluents/chemicals, site footprint, plant operability, and a Class 5 cost estimate**.

This study serves as a **preparatory step for the final investment decision**. It should be followed by a **Process Design Package (PDP)** and a **Front-End Engineering Design (FEED) study** to improve the accuracy of the cost estimate (upgrading from **Class 5** to a higher class).

## RÉSUMÉ

### Study objective

The study aims to analyze the **feasibility of CO<sub>2</sub> capture and storage (CCS) solutions** at the **IMERYS Aluminates site in Dunkerque** to support **carbon neutrality objectives by 2050**. It compares two capture technologies, performs preliminary unit sizing, estimates utility requirements and costs (**Class 5**), and prepares for future engineering phases (**PDP and FEED**).

### Technologies Studied

1. **Scenario 1 – Chemical Amine Absorption (Shell Cansolv®)**
  - Suited for the **current kiln configuration**.
  - **Mature technology (TRL 9)**.
  - CO<sub>2</sub> capture using an amine solvent with **significant flue gas pretreatment** (NO<sub>x</sub> and SO<sub>x</sub> reduction).
  - **Performance**: >95% capture, CO<sub>2</sub> purity >99.9%, ~15 t/h CO<sub>2</sub> production.
  - **High energy requirements** (electricity, steam) and a relatively large installation.
2. **Scenario 2 – Membranes + Cryogenic Purification**
  - Designed for a **future kiln in natural gas oxy-combustion mode**.
  - Cryogenic technology is mature, but **membranes are still under development (TRL 5)**.
  - Flue gas is **very rich in CO<sub>2</sub> (~70%)**.
  - **Performance**: 84→90% capture, CO<sub>2</sub> purity 99.99%, production ~3.3–3.5 t/h.
  - **Lower energy consumption** but several technical uncertainties (NO<sub>x</sub> treatment, cryogenic feasibility, effluent management).

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