Combined Carbon Capture Solution on Air Liquide South Texas Steam Methane Reformer

Agreement No. DE-FE0032181

2024 FECM/NETL Carbon Management Research Project Review Meeting

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Project Overview

"Combined Carbon Capture Solution on Air Liquide South Texas Steam Methane Reformer (SMR)"

Cooperative Agreement No.: DE-FE0032181

Period of Performance: 04/01/2023 – 10/31/2025

Project Funding: $7,376,441

Federal:	$5,878,261
Cost Share:	$1,498,180

Project Participants:

Electricore
Air Liquide Large Industries
Air Liquide Engineering & Construction

DOE Program Management Team

Program Manager: Mariah Young
Award Administrator: Carla Winaught
Agreements Officer: Angela Bosley

Project Objectives

Perform a front-end-engineering and design (FEED) study for a commercial scale advanced carbon capture system that would separate in excess of 95% of the total CO_2 emissions with 95% purity from an existing Steam Methane Reformer (SMR) facility in Corpus Christi, South Texas (host site). This plant has estimated annual CO_2 emissions of 490,000 metric tonnes at nameplate capacity. The proposed carbon capture system is a combination of Air Liquide's Cryocap™ H_2 technology and an amine system. The SMR produces hydrogen from a fuel gas source (combination of natural gas and refinery fuel gas) and the capture system will have a net carbon capture efficiency of >95% and a minimum impact on the levelized cost of hydrogen produced at a minimum of 99.97% purity.

Host Site: Air Liquide SMR in Corpus Christi

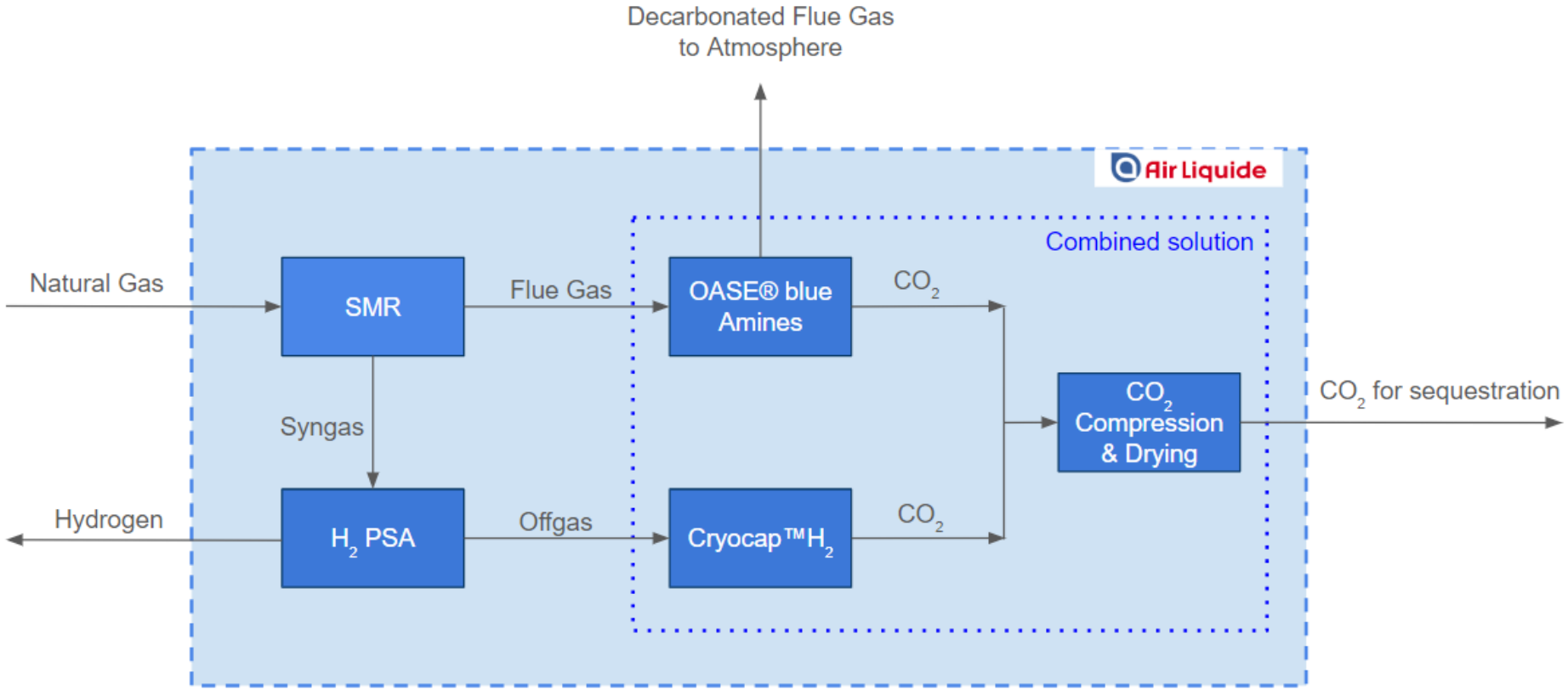
- Hydrogen Plant owned and operated by Air Liquide, in operation since Fall 1998
- The SMR supplies industry with gaseous Hydrogen via a pipeline system that services the greater South Texas area spanning from Bishop, TX all the way to the Three Rivers, TX region

Combined Solution

The carbon capture system proposed is an economically efficient combination of capture:

- from the H_2 pressure swing adsorption (PSA) tail gas with the proprietary Air Liquide technology - **Cryocap™ H_2**
- and from the SMR stack flue gas with the **BASF OASE® blue Amine** technology

The captured CO_2 will be pipeline grade for a proposed geological storage site near the SMR.



Scientific/Technical Merits

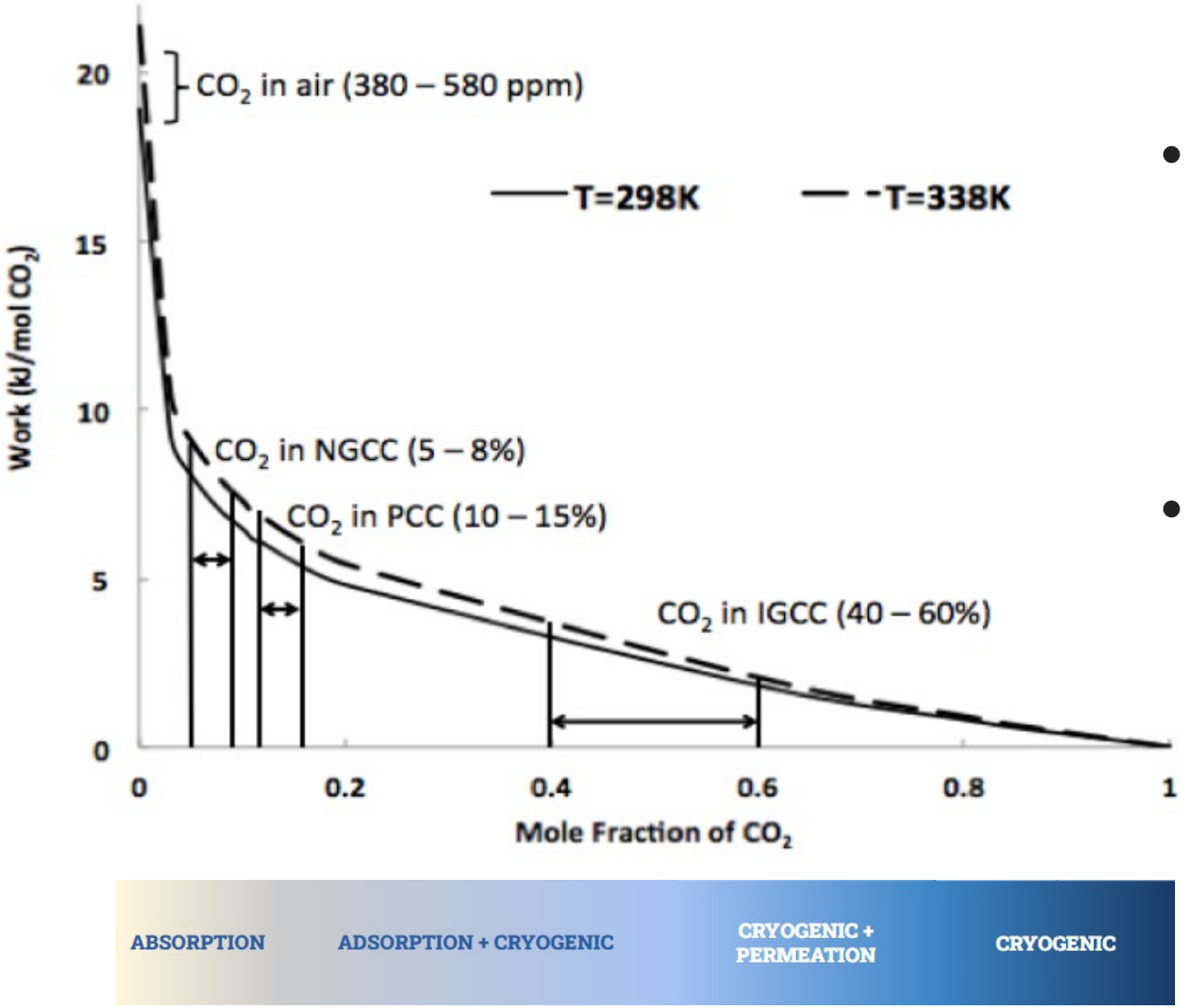
1. CO_2 capture from the H_2 PSA Tail Gas (~55% of overall CO_2 emissions) with the **Cryocap™ H_2,** integrating compression, cryogenic, and membrane "bricks" in an efficient and **environmentally sustainable** way, since it only requires **electricity which can be supplied by renewables**

1. CO_2 capture from the flue gas stack (~45% of the overall emissions) with an optimized amine setup leveraging a high level of heat integration and using the efficient **BASF OASE® blue** solvent. This combination minimizes the thermal energy required for the amine regeneration and uses the available heat from the SMR process **without adding an extra boiler**

1. H_2 recovered from the Cryocap™ H_2 provides a **gain in efficiency** at the same H_2 production rate, therefore positively impacting the carbon intensity

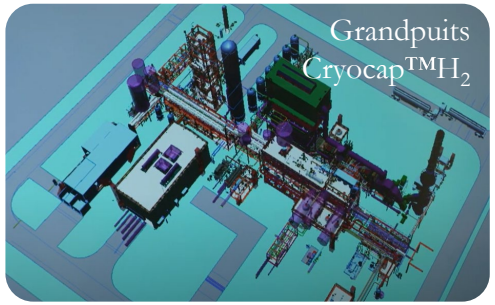
1. A configuration that **maximizes** the CO_2 capture rate **(> 95%)** and the economics related to 45Q

Minimum work of separation and separation technologies



- Minimum work of separation decreases as CO_2 content increases:
  - Carbon capture on **<15% CO_2** sources ⇒ energy intensive, **absorption** processes are more efficient
  - Carbon capture on **>15% CO_2** sources ⇒ less energy intensive, other separation processes (**adsorption, membranes, cryogenics**) become more efficient
- Combined solution Amines + Cryocap™ is adapted to the dual process points of CO_2 capture

Process Models

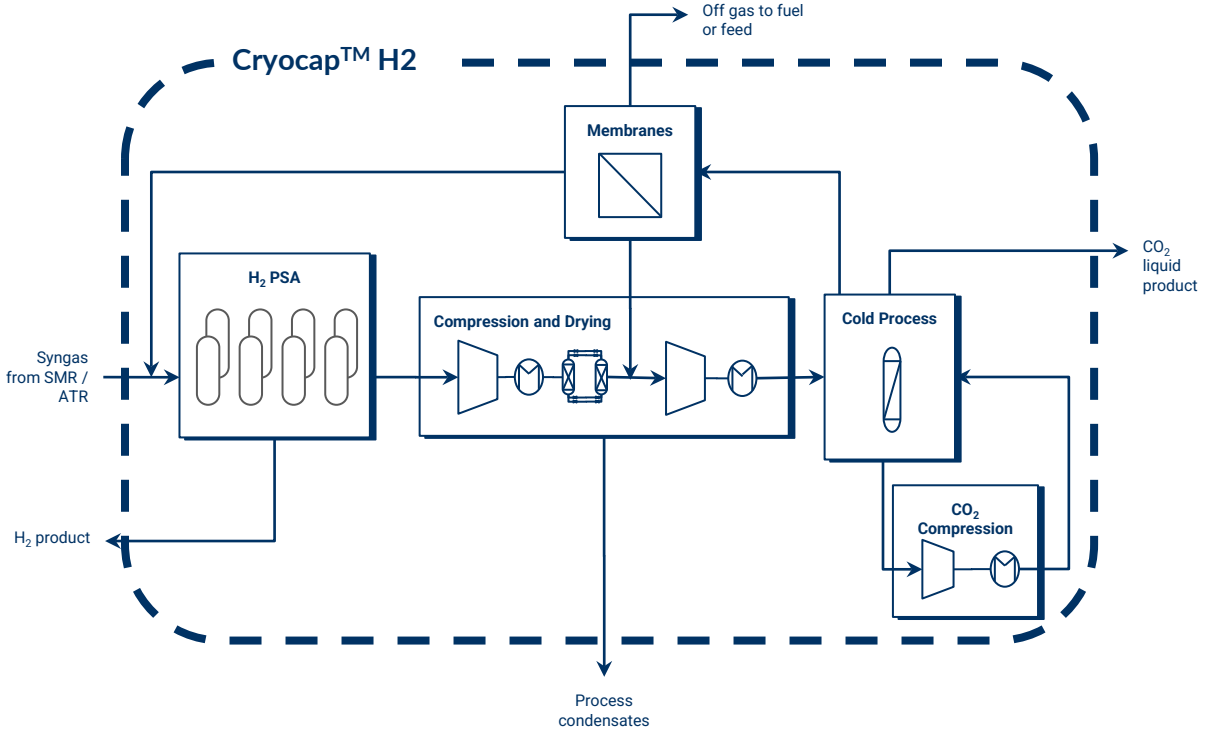


- **Cryocap™ H_2**: in-house proprietary simulation tools used to design Air Liquide industrial plants:
  - **Port-Jerome, France**: 300tpd food-grade CO_2, operating reliably since 2015
  - **Grandpuits, France**: > 300tpd food-grade CO_2, start-up in 2025
  - **Porthos, Netherlands**: > 1800tpd CO_2, geological storage under the North Sea, start-up in 2026
- **Amine OASE® blue**: BASF's OASE Connect tool is based on BASF'S process modelling software (CHEMASIM) which has been used to design several industrial plants:

Location	CO_2 Removal (mtpd)	Flue gas	Type	Status
Europe	7.5	Coal based power plant	Pilot	Start-up in 2009
America	30	Coal based power plant	Pilot (DOE)	Start-up in 2015
Europe	120	Lime kiln & off-gases	Commercial	Start-up in 2018
Europe	135	Lime kiln	Commercial	Under construction (Start-up in 2024)
US	200	Coal based power plant	Demo (DOE)	Start-up in 2024
Europe	240	Cement plant	Commercial	FID taken in Q1 2023

Cryocap™ H_2 Main Features

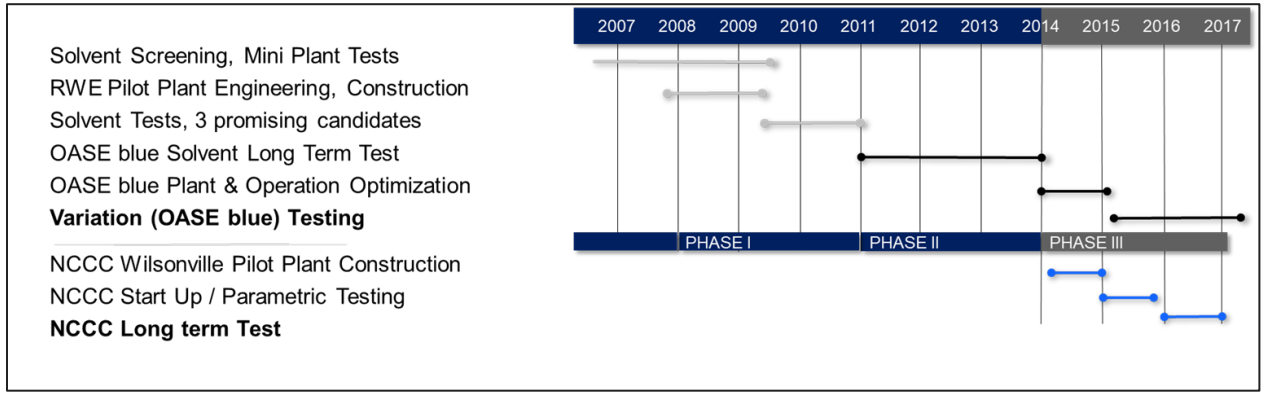
- **A proven solution for Industry** to separate CO_2 from the tail gas of H_2 PSA
  - **Retrofit** of existing H_2 plants (SMR, ATR) possible with **extra H_2 recovered by 10 to 20%**
- **HSE-friendly:** electricity-powered, no chemicals, no flammables
- Designed as **packages and modules**: flexible plot plant and ease of installation
- **Dry pure gaseous or liquid CO_2 ready for geological storage**, via pipeline or ship transportation



OASE® blue by BASF Main Features

- **A commercially available solution** with **continuing innovation**
  - **2nd generation solvent** developed by BASF over 10^+ years
  - **Continuing development** by BASF through innovation:
    - process optimizations,
    - further solvent consumption reduction,
    - lower CO_2 capture costs.

10-year development roadmap of OASE® blue by BASF



- **Reduced OPEX**:
  - **High stability** towards O_2
  - **Low Solvent Losses**
  - **Low regeneration duty**: specific energy 2.3 to 2.7 GJ/t of CO_2, depending on inlet gas flow rate and pressure
- CO_2 produced up to **2.5 bara** w/o compression, **purity up to 99.9%**
- **Flexible operating range**
- **Reduced Emission with the OASE® aerozone**

  The OASE® aerozone is a proprietary and patented design proven to reduce aerosol driven emissions and amine losses from the CO_2 capture process. Tested for over 54,000 hours, the configuration has the capability to achieve very low emissions levels even in the presence of high amounts of aerosol particles in the flue gas.

Technical Approach

Complete a FEED package for a CO_2 process scheme adequate to capture more than 95% of the SMR's annual CO_2 emissions. The FEED will include the design and optimization of the SMR plant, carbon capture calculations, mass and energy balances, technology integration, and possible process optimizations. In addition, the team will also develop the plant layout (equipment and utility requirements, vendor quotations, etc.).

A capital cost estimate for the CO_2 capture plant will be provided, as well as an estimate of the cost of capture in $/ton CO_2 captured and the LCOH. The captured CO_2 will be purified to specifications sufficient for geological sequestration.

Project Success Criteria includes:

- Completed FEED study for a commercial-scale, advanced carbon capture system that separates 95% of the total CO_2 emissions with 95% CO_2 purity from the existing Steam Methane Reformer (SMR) facility.
- The commercial industrial plant produces hydrogen of minimum 99.97% purity.
- The advanced carbon capture system separates at least 95% of the units estimated 490,000 metric tonnes of CO_2 emissions at nameplate capacity, with minimum impact on the levelized cost of hydrogen, suitable for long duration carbon storage or CO_2 conversion/utilization into long-lasting products.

Progress and Current Status

The project team executed a modification to the cooperative agreement; effectively changing the host site facility of the FEED Study. The change in host site caused a delay to program start up. The project was formally kicked off in May 2024.

The technical work for the FEED Study is underway with the first set of deliverables due in the next quarter.

Completed Tasks include:

- Updated Project Management Plan (PMP)
- Completion of Workforce Readiness Plan (RMP)
- Completion of Preliminary Technology Maturation Plan (TMP)
- Start of Task 2 FEED Study

Lessons Learned

In July 2023, the team requested a change to the host site facility selected for conducting the FEED Study.

a. Following award negotiations, Air Liquide (subrecipient and host site) identified a significant material impact to the originally planned project in Northern California driven by changes in the regulatory environment and markets.
b. Clarity around these developments were unlikely to occur at pace with the FEED Study decoupling project timelines and significantly delaying the Final Investment Decision (FID) at the onset of the study.
c. In the interest of avoiding spend on a project with high uncertainty, the team reviewed several alternative sites within the Air Liquide fleet and identified the Air Liquide Corpus Christi SMR as the ideal alternative host site for the FEED study. Working with the NETL, a revised application for the project was proposed and submitted to the NETL. A modified cooperative agreement was executed on March 27, 2024 to formally change the host site facility.

This project will build upon the progress already achieved in partnership with DOE to strategically address the growing interest in industrial carbon capture systems (CCS). Results of the project will provide a better understanding of the capital and operating costs of CCS which will enable the broader implementation of these technologies in the hydrogen (H_2) production sector.

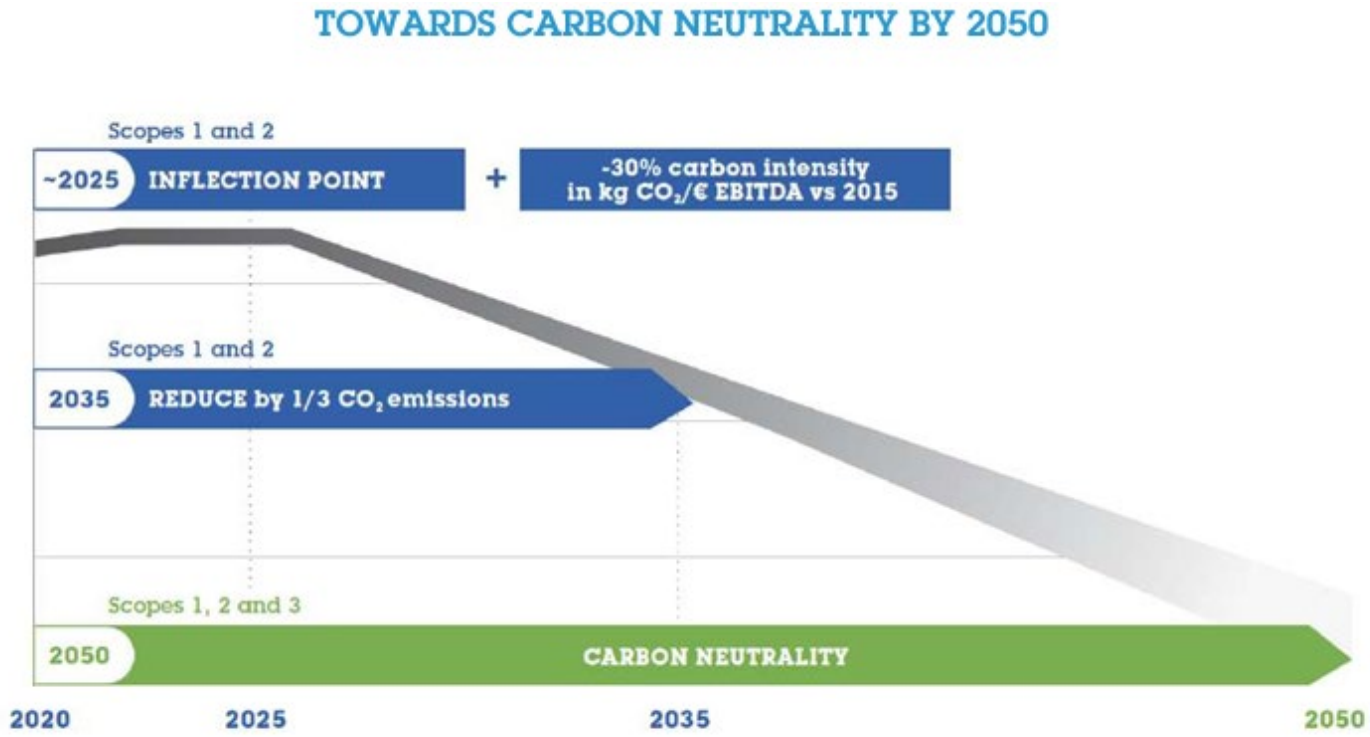
Plans for Future Testing/Development/Commercialization

Decarbonization of industry is a key pillar of Air Liquide's **ADVANCE* Strategy**. The Group's decarbonization goals are:

- 33% CO_2 reduction by 2035
- Net Zero by 2050

Amongst AL portfolio of technology and service solutions to support its customers' decarbonization efforts, the **Air Liquide Cryocap™** and **BASF OASE® blue** Licensed Technologies are well suited to decarbonize hydrogen production facilities like the Corpus Christ SMR.

The Technologies are commercial today with several projects in the portfolio at various stages in engineering and operation.



*ADVANCE is Air Liquide's 2022 - 2025 strategic plan. It places Sustainable Development at the heart of its strategy and combines financial and extra-financial (environmental and societal) performance, linking inseparably growth and sustainable future

Summary

The Cooperative Agreement was modified in early 2024 to account for a change in host site facility; the program was officially kicked-off with DOE in May 2024.

The team will utilize a unique combination of technologies, including Air Liquide's proprietary Cryocap™ H_2 technology, which has been developed over the last 18 years and has reached technology readiness level (TRL) 8. The Cryocap™ H_2 solution will be used in conjunction with a solvent based post combustion technology, BASF's OASE® blue.

The team has begun work on the FEED Study, including the initial project scope and design basis. The first set of deliverables completed under this program have been submitted to DOE for review and comment.

Successful completion of this project in 2025 includes the following:

- Execute and complete a FEED study for a commercial-scale, advanced carbon capture system that separates 95% of the total CO_2 emissions with 95% CO_2 purity from the existing SMR facility.
- The advanced carbon capture system separates at least 95% of the units estimated 490,000 tonnes of CO_2 emissions at nameplate capacity, with minimum impact on the levelized cost of hydrogen, suitable for long duration carbon storage or CO_2 conversion/utilization into long-lasting products.

Thank you

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