Industrial Carbon Capture from a Cement Facility Using the Cryocap™ FG Process
(DE-FE0032136)

U.S. Department of Energy, National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 15–19, 2022

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Diagram showing the cryocap process: Flue gas is treated and CO₂ is extracted.
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Project Overview & Objectives

• **Cooperative Agreement No.** DE-FE0032136

• **Total Funding:** $4,999,585
  – DOE: $3,999,585
  – Non-DOE: $1,000,000
  – Cost Share: 20%

• **Performance Period:**
  April 1, 2022–September 30, 2023
  18 months, 1 Budget Period

• **Main objective:** To execute and complete a front-end engineering and design (FEED) study for a commercial-scale, carbon capture system that separates 95% of the total CO2 emissions at Holcim Ste Genevieve Cement Plant using Air Liquide’s Pressure Swing Adsorption (PSA) assisted Cryocap™ FG technology
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TECHNOLOGY BACKGROUND
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™ XLL
CO₂ liquefaction
Cryocap™ FG: CO₂ Capture from Flue Gas

- Suitable for Cement, Lime, SMR (flue gas), FCC, ...
- PSA as a preconcentration brick
- HSE friendly (no chemicals and no flammables)
- Electricity powered (no steam needed)
- Compact & Flexible footprint: Compressors, PSA and Coldbox can be located in 3 different plots
- NOₓ Smart Management
- Gaseous or liquid CO₂
- CO₂ capture rate: 95%+
Cryocap™: 15+ years of legacy

Conceptual Studies | Individual Technology Testing | Comprehensive Pilot testing | FEEDs & Operating Plant | FEEDs & Operating Plant

- **GREEN SMR TF**
  - CRYOCAP™ H₂
  - Year: 2006

- **SBS 2**
  - 75 tpd CO₂
  - Dust filtration
  - Year: 2008

- **CALLIDE**
  - 75 tpd CO₂
  - CRYOCAP™ Oxy
  - Year: 2008

- **TOTAL LACQ**
  - 240 tpd CO₂
  - Driers
  - Year: 2008

- **MELLUS PILOT**
  - 70 tpd CO₂
  - CRYOCAP™ Steel
  - Year: 2012

- **CALLIDE**
  - 75 tpd CO₂
  - CRYOCAP™ Oxy
  - Year: 2012

- **CIUDEN**
  - 200 / 10 tpd CO₂
  - CRYOCAP™ Oxy
  - Year: 2012

- **FLORANGE FEED**
  - 3700 tpd CO₂
  - CRYOCAP™ Steel
  - Year: 2012

- **PORT JÉRÔME**
  - 300 tpd CO₂
  - CRYOCAP™ H₂
  - Year: 2015

- **FUTUREGEN 2.0 FEED**
  - 3200 tpd CO₂
  - CRYOCAP™ Oxy
  - Year: 2015

- **FUTUREGEN 2.0 FEED**
  - 3200 tpd CO₂
  - CRYOCAP™ Oxy
  - Year: 2015

- **STEELANOL**
  - 800 tpd CO₂
  - CRYOCAP™ Steel
  - Year: 2020

- **ZEELAND REFINERY**
  - 2400 tpd CO₂
  - CRYOCAP™ FG
  - Year: 2021

- **ST. GENEVIEVE DOE FEED**
  - 10 000 tpd CO₂
  - CRYOCAP™ FG
Typical block Flow Diagram of Process

*Liquid product not being produced for project design
Industrial Carbon Capture from a Cement Facility Using the Cryocap™ FG Process

HOST SITE
Holcim Ste. Genevieve Cement Plant

*Part of Holcim’s focus on reducing carbon footprint*

- Located in Bloomsdale, Missouri
- The largest single cement kiln in the world, commissioned in 2009
- Annual cement production capacity of 4.5 million metric tons
- A 4,000-acre site contains more than 100 years of limestone supply, in addition to 2,000 acres conservation area
Excellent Host Site for Industrial Carbon Capture

*World’s largest single kiln cement plant*

- Approximately 2.9 million tonne CO$_2$/yr
- Close to potential geological storage locations, i.e. the Illinois Corridor, where CarbonSAFE has highlighted significant storage potential
- Site is ~ 35 miles SW of Prairie State Generating Company (PSGC) site — a focus for geological storage as part of Phase III CarbonSAFE project
Possible Location of Capture Unit

Source: Google Earth
Industrial Carbon Capture from a Cement Facility Using the Cryocap™ FG Process

PROJECT MANAGEMENT
Management Structure

*Designed to enable transition to build/operate*

**HOLCIM**
Holcim (US) Inc.
Derick Dreyer
Host Site

**ILLINOIS**
PRIME CONTRACTOR
University of Illinois (UIUC)
Dr. Kevin O'Brien, PI
Dr. Hafiz Salih, Project Manager

**Advisory Board**
CarbonSAFE-Illinois (FE-0029381)
Prairie State Energy Campus, Marissa, IL (Host Site FE0031841)

**SUBAWARDEE**
Air Liquide
Engineering & Construction

Air Liquide US Inc.
Andrew Clarridge
ISBL design and costing

**SUBAWARDEE**
Visage Energy
Clean Energy Consulting

Daryl-Lynn Roberts
Social Justice Analysis,
Market Analysis

**Kiewit**
Kiewit Corporation
Bob Sletethaugh
Bryan Lofgreen, Alan Donovan
OSBL Design and Costing
## Project Timeline

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Overall Project Management</td>
<td>Fri 4/1/22</td>
<td>Fri 9/29/23</td>
</tr>
<tr>
<td>1.1 Project Management Plan</td>
<td>Fri 4/1/22</td>
<td>Fri 4/29/22</td>
</tr>
<tr>
<td>2.0 Initial Engineering Design</td>
<td>Fri 4/1/22</td>
<td>Fri 9/29/23</td>
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<tr>
<td>2.1 Design Basis</td>
<td>Fri 4/1/22</td>
<td>Thu 6/30/22</td>
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<tr>
<td>2.2 Preliminary Engineering</td>
<td>Fri 7/1/22</td>
<td>Thu 12/1/22</td>
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<tr>
<td>2.3 ISBL Engineering</td>
<td>Fri 12/2/22</td>
<td>Wed 5/31/23</td>
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<tr>
<td>2.4 OSBL Detailed Engineering</td>
<td>Fri 12/2/22</td>
<td>Wed 5/31/23</td>
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<td>2.5 HAZOP Review</td>
<td>Thu 6/1/23</td>
<td>Wed 8/2/23</td>
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<tr>
<td>2.6 Constructability Review</td>
<td>Thu 6/1/23</td>
<td>Fri 9/29/23</td>
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<tr>
<td>2.7 Cost Assessment</td>
<td>Thu 6/1/23</td>
<td>Fri 9/29/23</td>
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<tr>
<td>3.0 Business Case Analysis</td>
<td>Fri 7/1/22</td>
<td>Fri 9/29/23</td>
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<td>4.0 Technology EH&amp;S Risk Assessment</td>
<td>Fri 7/1/22</td>
<td>Fri 9/29/23</td>
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<td>5.0 Techno-Economic Analysis (TEA) and Life Cycle Analysis (LCA)</td>
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<tr>
<td>5.1 TEA Analysis</td>
<td>Fri 12/2/22</td>
<td>Fri 9/29/23</td>
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<tr>
<td>5.2 LCA Analysis</td>
<td>Fri 12/2/22</td>
<td>Fri 9/29/23</td>
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<tr>
<td>6.0 Preliminary Environmental Justice Analysis</td>
<td>Fri 7/1/22</td>
<td>Fri 9/29/23</td>
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<tr>
<td>7.0 Preliminary Economic Revitalization and Job Creation Outcomes Analysis</td>
<td>Fri 7/1/22</td>
<td>Fri 9/29/23</td>
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<tr>
<td>Budget Period</td>
<td>Task or Subtask Number</td>
<td>Milestone Title &amp; Description</td>
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<td>1.0</td>
<td>Updated Project Management Plan</td>
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<td>2.1</td>
<td>Project Design Basis Completed</td>
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<tr>
<td>1</td>
<td>2.5</td>
<td>HAZOP Completed</td>
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<tr>
<td>1</td>
<td>2.6</td>
<td>Constructability Review Complete</td>
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<tr>
<td>1</td>
<td>2.7</td>
<td>Project Cost Assessment</td>
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<tr>
<td>1</td>
<td>3.0</td>
<td>Business Case Analysis Completed</td>
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<tr>
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<td>4.0</td>
<td>EH&amp;S Analysis</td>
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<tr>
<td>1</td>
<td>5.0</td>
<td>TEA and LCA</td>
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<tr>
<td>1</td>
<td>6.0</td>
<td>Environmental Justice Analysis</td>
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<tr>
<td>1</td>
<td>7.0</td>
<td>Economic Revitalization and Job Creation Outcomes Analysis</td>
</tr>
<tr>
<td>Perceived Risk</td>
<td>Probability</td>
<td>Impact</td>
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<td>--------------------------------------------------------------------------------</td>
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<tr>
<td><strong>Financial</strong></td>
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</tbody>
</table>
| Cost share for project not obtained or insufficient                            | L           | H      | L       | • Cost share commitment letters obtained.  
|                                                                              |             |        |         | • All entities providing cost share are financially sound. |
| **Cost/Schedule**                                                             |             |        |         |                                  |
| Project costs and/or schedule overruns                                         | L           | H      | L       | • Team has previous experience conducting DOE projects on budget and on time. |
| Tasks require significantly more time than expected                             | L           | H      | M       | • Experience from prior/ongoing projects were used to develop timelines that would meet DOE requirements. |
| **Technical / Scope**                                                          |             |        |         |                                  |
| Challenges in meeting required quality of CO₂ for intended transport and storage| L           | H      | M       | • Following first discussion on the Basis of Design between Air Liquide and Lafarge, no showstoppers have been identified to meet the typical NETL guidelines for sequestration ("Conceptual design for saline reservoir sequestration" of NETL CO₂ impurity design parameters document from January 2012)  
|                                                                              |             |        |         | • Design of the purification equipment following capitalization on various Air Liquide demonstration and commercial plants (Callide, Ciuden, Port Jerome, etc..) |
| Challenges in meeting 95% capture for total emissions                         | L           | M      | L       | • Design of the PSA and the cryogenic section optimized for high CO₂ recovery with adequate process margin to meet the recovery requirement  
|                                                                              |             |        |         | • Potential CO₂ losses in the carbon capture system to be tracked, including compressor seal losses for example |
| Availability of energy supply (i.e., sufficient waste heat from existing host site) | L           | H      | M       | • Selection Process launched early in collaboration with partners.  
|                                                                              |             |        |         | • Waste heat integration with cement plant limited (full electrical as a base case) but will be studied early during the FEED |
| Challenge in the design and manufacturing of large modules/equipment (9000tpd+ CO₂ capture) | L           | H      | L       | • Modularization strategy to be defined at the beginning of the FEED considering constructability, maximum shipping windows and manufacturers capabilities  
|                                                                              |             |        |         | • Considering several equipment in parallel vs one very large |
| Delayed supply of equipment offers for estimate                               | L           | M      | M       | • Procurement review started in a timely manner allowing for some delays in response time without affecting critical part of project.  
<p>|                                                                              |             |        |         | • Active dialogue with key suppliers to ensure that timeline is kept. |</p>
<table>
<thead>
<tr>
<th>Perceived Risk</th>
<th>Probability</th>
<th>Impact</th>
<th>Overall</th>
<th>Mitigation and Response Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrealistic planning base/assumptions in project schedule may result in delays of project implementation</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>• Clear and carefully planned timeline created in collaboration with designers and engineers.</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>• Scenario-based planning, using conservative assumptions and adequate contingency time for activities on the critical path of the project.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Bottom-up planning of individual activities.</td>
</tr>
<tr>
<td>Deficient project management may result in inefficiencies and delays</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>• Integrated, holistic project management set up.</td>
</tr>
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<td></td>
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<td></td>
<td>• Adequate allocation of experienced/qualified personnel to project management.</td>
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<td></td>
<td>• Detailed milestone planning.</td>
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<td></td>
<td>• Structured meeting, monitoring, and reporting structure to ensure real-time transparency.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Defined decision-making structures and processes.</td>
</tr>
<tr>
<td>Availability of key personnel for project</td>
<td>L</td>
<td>M</td>
<td>L</td>
<td>• Commitment received from partner organizations.</td>
</tr>
<tr>
<td>Uncertainty of permitting agencies and timelines</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>• Agencies and timelines known based on previous experience with FEED studies at host site.</td>
</tr>
</tbody>
</table>

### EH&S

**Management of emissions**

- L
- M
- L

- Capture subsystem provider has previously design systems to mitigate these issues.
- Leverage experience from previous projects to meet strict permit requirements.

### External Factor

**Issues related to COVID-19 delay execution**

- M
- H
- M

- Team has worked virtually for months.
- Communication process currently in place that uses remote work tools, e.g., Microsoft Teams.

**Negative Stakeholder response to proposed capture system/study**

- M
- M
- M

- Discussions with elected officials on similar projects have received positive support.
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DESIGN BASIS
## Design Basis Summary

<table>
<thead>
<tr>
<th>Factor</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Captured CO$_2$ product Specification</td>
<td>Established through review with CarbonSAFE team</td>
</tr>
<tr>
<td>Flue gas measurements</td>
<td>Measured under various operating conditions</td>
</tr>
<tr>
<td>Desulfurization approach</td>
<td>Integrated DCC system that uses caustic soda</td>
</tr>
<tr>
<td>Waste streams (volumes and types)</td>
<td>Identified and will review with regulators to determine permitting timeline and strategy</td>
</tr>
<tr>
<td>Electric sourcing for capture plant</td>
<td>Purchased from the grid</td>
</tr>
<tr>
<td>Transportation of components to the host site</td>
<td>Determined routes for shipping relevant equipment to the site</td>
</tr>
</tbody>
</table>
Environmental Justice Analysis

Objective: Analyze the impact of proposed CCS retrofit improvements to the existing industrial facility on the local/surrounding communities and assess the potential distribution of anticipated Justice40 benefits.

- Identified local communities that have been disproportionately impacted through Stakeholder Mapping process.
  - Primary focus is on St. Louis as the nearest large Disadvantaged Community (DAC) that has been traditionally marginalized/underserved.
  - After further analysis, other DAC communities, to the west of the host site, have now been included as well (Franklin, Madison, and Washington Counties).

- Performing social characterization of the surrounding counties.
  - Each have different metrics which should be distinctly analyzed.
  - Example: Several of the DAC counties have varying unemployment and energy burden metrics (5% vs. 10%).

- Facilitating the involvement of surrounding communities by encouraging information exchanges and mixture of engagement techniques (e.g. focus groups, small discussions, and educational workshops).
  - Engaging local community-based organizations that are focused on EJ issues from a granular level in the different counties and assessing current EJ community-based initiatives underway.
Summary

• Industrial capture FEED on track and on budget
• Design basis complete
• Moving into preliminary engineering
• Beginning Environmental Justice outreach
## Acknowledgements

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andy O’Palko, Jodi Collins</td>
<td>National Energy Technology Laboratory / U.S. Department of Energy</td>
</tr>
<tr>
<td>Vinod Patel, Jim Dexter, Stephanie Brownstein, Jason Dietsch, Melanie Keuhn, Scott Prause, Bajio Varghese Kaleeckal, Sebastiano Giardinella, Margaret Morrison</td>
<td>University of Illinois</td>
</tr>
<tr>
<td>Derick Dreyer, Erin Watson, Suhail Akhtar, Alessandro Ferrari, Fathesha Sheikh</td>
<td>Holcim Cement</td>
</tr>
<tr>
<td>Andrew Clarridge, Michelle Jones, Lindsey Turney, Ademola Oladinni, Abigail Bonifacio, Timothy Henderson, Pierre-Philippe Guerif</td>
<td>Air Liquide</td>
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<tr>
<td>Will Johnson, Daryl-Lynn Roberts</td>
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