Cryogenic Carbon Capture from Cement Production

primary project goal

Sustainable Energy Solutions LLC (SES) is partnering with Chart Industries Inc., Eagle Materials Inc., and FLSmidth Inc. to advance a cryogenic carbon capture (CCC) technology to demonstration scale (30 tonnes of carbon dioxide [CO_2] captured/day). The carbon capture unit is being installed at the Eagle Materials/Central Plains Cement Plant in Sugar Creek, Missouri.

technical goals

- Design and size all major process equipment.
- Finalize host site agreements and any required environmental or operational permits.
- Commission and construct the engineering-scale system.
- Operate the constructed system for at least two continuous months within a six-month testing period.
- Demonstrate that the system can achieve at least a 95% carbon capture rate with an exit CO_2 purity of 95% or more.
- Decommission the system and restore the host site to its pre-project state.

technical content

SES has developed a novel carbon capture process using cryogenic technology that exploits the different condensation/freezing points of the components of flue gases in order to separate and capture CO_2. A basic overview of the system is shown in Figure 1. The system works by first cooling the flue gas (state 1). The cooled gas is then sent to a separator (state 2), which removes the solid CO_2 precipitate from the flue gases. Finally, the solidified CO_2 melts under pressure and helps cool the incoming flue gas before being shipped out and stored or utilized (state 3), while the flue gases vent out the stack (state 4). A more detailed view of this system can be seen in Figure 2. The system has been previously demonstrated at skid-scale (1 tonne/day) at power plants, cement plants, heating plants, and several other field locations around the world. The current efforts focus on scaling this system to 30 tonnes/day and operating it over a period of at least two months.

The host site is the Central Plains Cement Plant in Sugar Creek, Missouri, owned and operated by Eagle Materials. This plant operates in two different modes: "raw mill up" (80% of the time) and "raw mill down" (20% of the time). In raw mill up mode, the temperature and CO_2 concentration of the flue gas are lower (90°C versus 220°C and 18% versus 24%), so the CCC system needs to adapt accordingly.

program area:
Point Source Carbon Capture

ending scale:
Small Pilot

application:
Post-Combustion Industrial PSC

key technology:
Novel Concepts

project focus:
Cryogenic-Based CO_2 Capture System for a Cement Production Plant

participant:
Sustainable Energy Solutions LLC (SES)

project number:
FE0032148

predecessor projects:
N/A

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partners:
Chart Industries; Eagle Materials; FLSmidth

start date:
02.01.2022

percent complete:
2%

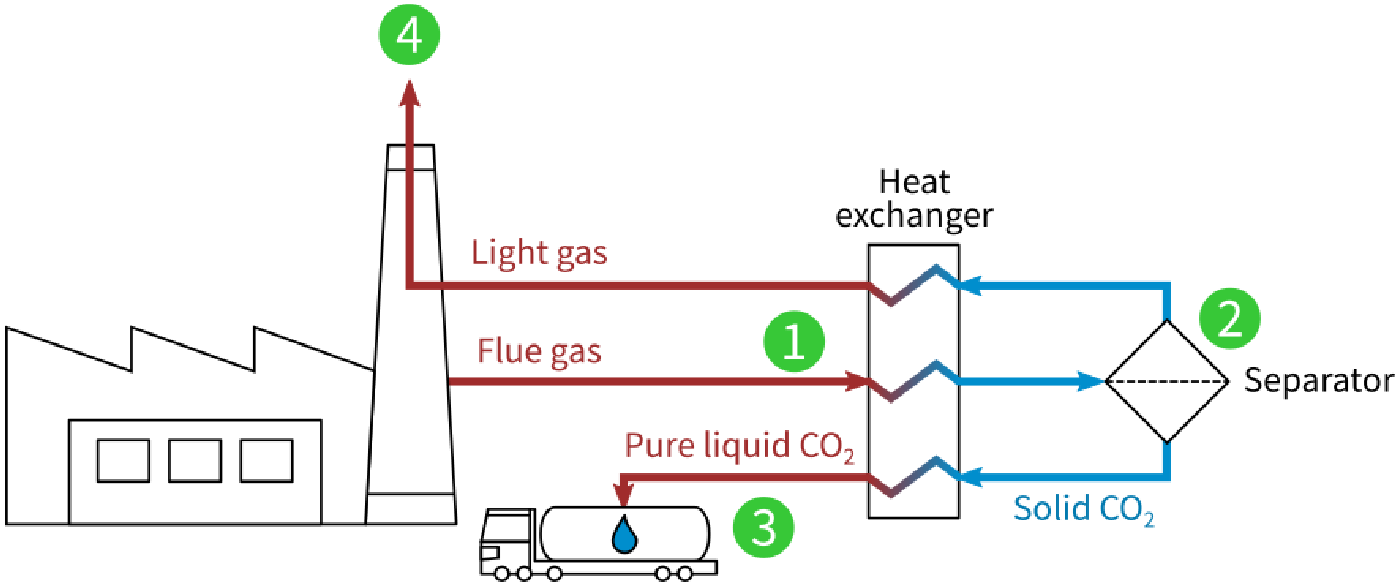

Figure 1: Simplified plant diagram.

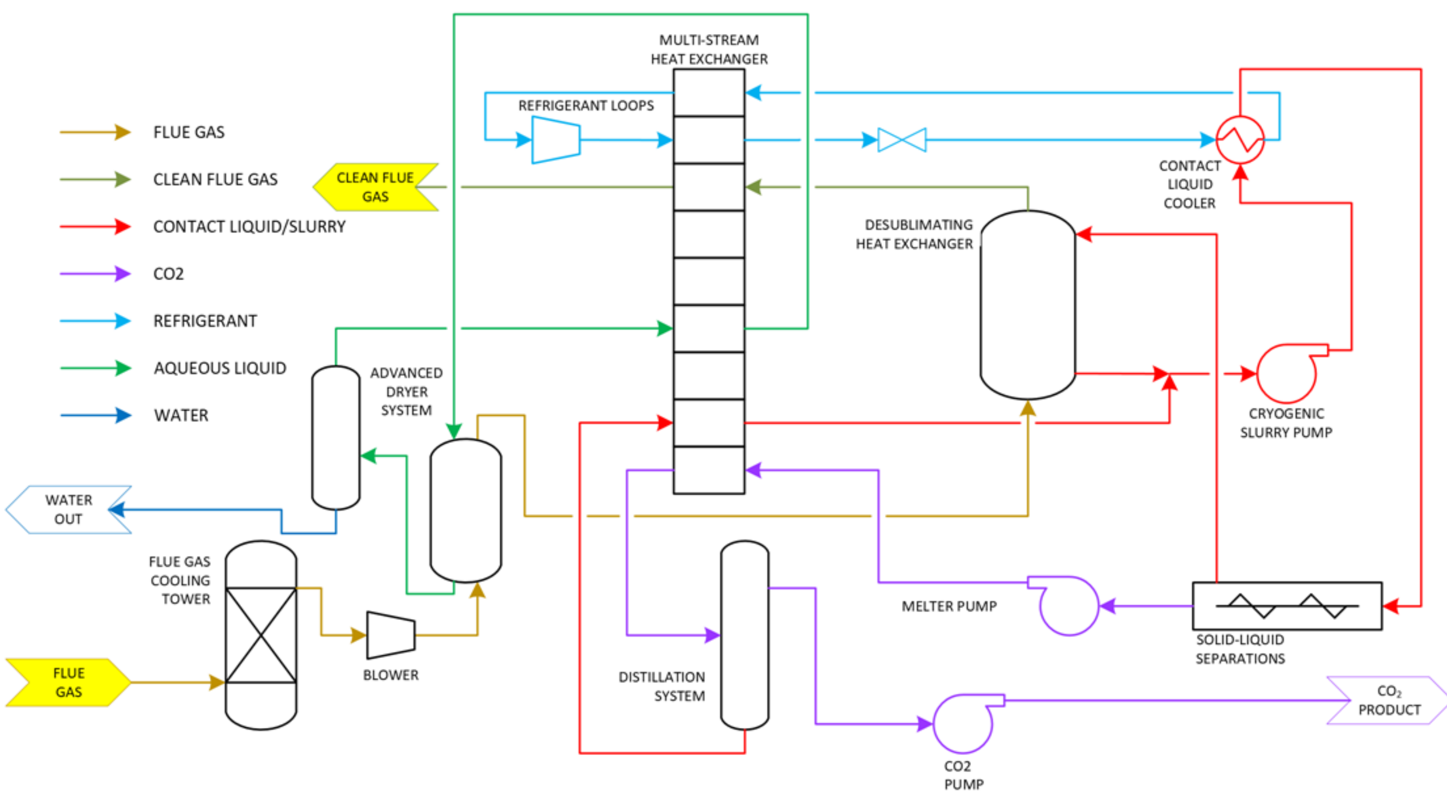

Figure 2: Schematic of CCC system.

Phase I project efforts include a hazard and operability (HAZOP) study and an environmental, health, and safety (EH&S) analysis following completion of the host site agreement. The purpose of these studies is to identify the environmental risks and safety of any future projects that plan to use the proposed capture system. Concurrent with these efforts is the initial design of the plant. Various process and instrumentation diagrams (P&IDs), as well as other detailed construction diagrams, are produced during this task. Finally, all necessary operating and environmental permits are secured in Phase I to ensure the construction phase can proceed.

Final products of Phase I work are: 1) the development of detailed flow simulations to ensure reliable performance and establish initial cost estimates and 2) the sourcing of all major equipment to be used during the construction phase.

Simulations are carried out using commercial Aspen Plus® software. An initial techno-economic analysis (TEA) also is conducted in Phase I.

Project tasks planned for Phase II include finalizing design choices and necessary approvals as well as initiating construction of the final system.

Project tasks planned for Phase III are to analyze the complete system over a six-month period and perform continuous operation for at least two of the six months; decommission the CCC system and restore the plant to its pre-project state; refine simulated models and TEA based on data obtained during testing; compare and reconcile differences in observed and predicted process performance. The current estimated results and target research and development (R&D) values for the costs of capture are shown in Table 1.

TABLE 1: INDUSTRIAL PLANT CARBON CAPTURE ECONOMICS

Economic Values	Units	Current R&D Value	Target R&D Value
Cost of Carbon Captured	\$/tonne CO_2	27	23
Cost of Carbon Avoided	\$/tonne CO_2	41	35
Capital Expenditures	\$/tonne CO_2	15	13
Operating Expenditures	\$/tonne CO_2	8	6

Definitions:

Cost of Carbon Captured – Projected cost of capture per mass of CO_2 captured under expected operating conditions.

Cost of Carbon Avoided – Projected cost of capture per mass of CO_2 avoided under expected operating conditions.

Capital Expenditures – Projected capital expenditures in dollars per tonne of CO_2 captured.

Operating Expenditures – Projected operating expenditures in dollars per tonne of CO_2 captured.

Estimated Cost – Basis is kg/hr of CO_2 in CO_2-rich product gas; assuming targets are met.

Flue Gas Assumptions – Unless noted, flue gas pressure, temperature, and composition leaving the flue gas desulfurization (FGD) unit (wet basis) should be assumed as:

Pressure	Temperature	Composition						
		vol%					ppmv	
psia	°F	CO_2	H_2O	N_2	O_2	Ar	SO_x	NO_x
14.7	135	13.17	17.25	66.44	2.34	0.80	42	74

Other Parameter Descriptions:

Waste Streams Generated – There is no waste stream generation inherent to the CCC process. The water used to cool the inlet flue gas comes in direct contact with the flue gas and may become contaminated with pollutants or particulate matter, which would require water treatment. No other waste streams are expected.

Process Design Concept – The 30 tonnes/day process will be functionally the same and include a similar equipment list as a larger-scale process or system. The process as designed for this site-specific application has a minimum target carbon capture rate of 95%, and a CO_2 purity target of 99.97%.

Proposed Module Design – SES is using a skid-based system design for this project, which allows much of the equipment to be built offsite and minimizes construction onsite. This system is shown in Figure 1. Chart Industries is supporting this skid-based design with both engineering support and in the construction of various coldboxes used in the system.

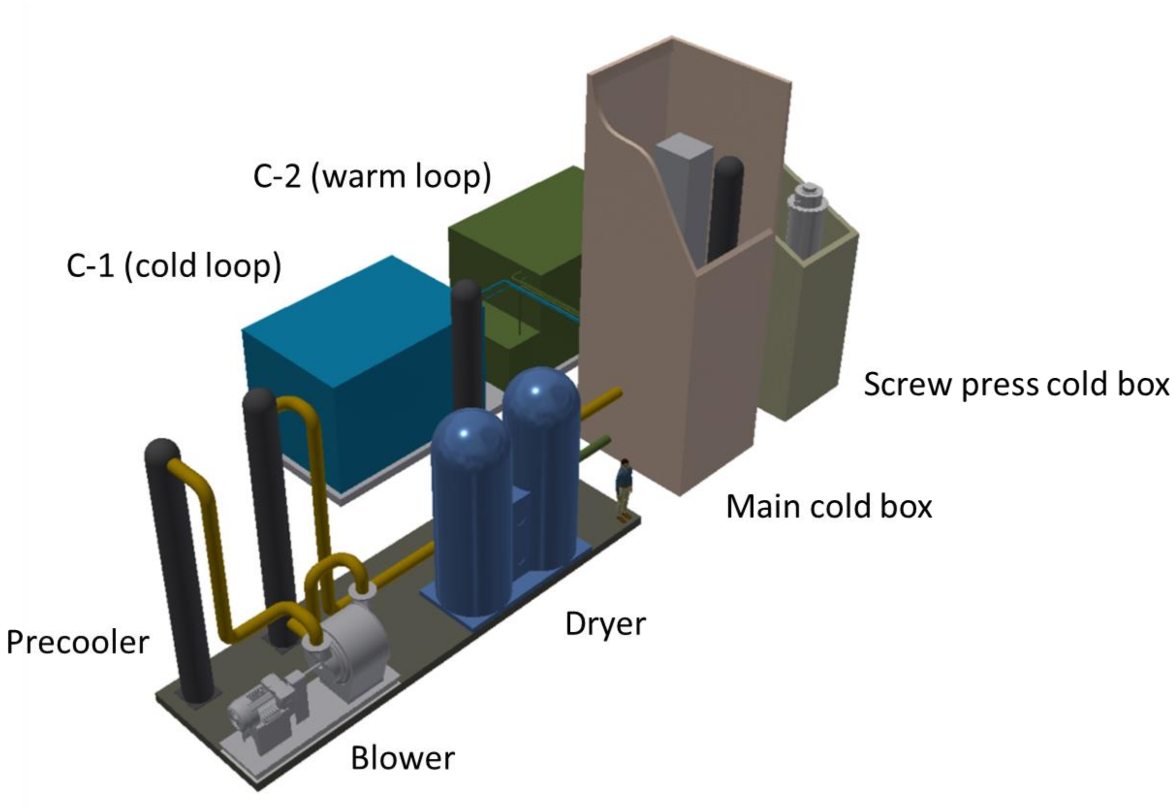

Figure 1: Preliminary design for skid-based CCC system.

technology advantages

- High carbon capture rate (95–99.7%).
- Easy to retrofit onto existing plants.
- Integrated grid-scale energy storage.
- Lower cost than traditional amine sorbents.
- Lower water usage than traditional amine sorbents.
- Robust operation with pollutants such as nitrogen oxide (NO_X) and sulfur oxide (SO_X) and partial co-capture of these pollutants.

R&D challenges

- Keeping energy usage low.
- Achieving continuous capture efficiency, even as cement plant changes operational modes.
- Scaling novel process equipment to small-industrial scale.

status

Project has commenced and a kickoff meeting was held on April 1, 2022.

available reports/technical papers/presentations

Stitt, K., 2022, "Cryogenic Carbon Capture from Cement Production." Project Kickoff Meeting. National Energy Technology Laboratory: Pittsburgh, PA. *https://netl.doe.gov/projects/plp-download.aspx?id=13130&filename=Cryogenic+Carbon+Capture+from+Cement+Production.pdf*.