Dilute-Source Carbon Dioxide (CO_2) Capture: Management of Atmospheric Coal-Produced Legacy Emissions

primary project goals

Carbon Engineering Ltd. is developing advancements for their Direct Air Capture (DAC) technology to capture carbon dioxide (CO_2) from dilute CO_2 sources, including evaluating DAC for other coal-relevant sources, such as post-carbon capture and storage (CCS) flue gas, and to re-capture legacy atmospheric coal-based emissions. The DAC process uses a wet scrubbing air contactor, along with chemical processing steps, to produce pure CO_2 and remake the capture solution. The project will focus on applied research and development (R&D) at their pilot facility, along with a commercial readiness and cost-estimation evaluation.

technical goals

- Use Carbon Engineering's existing research pilot facility to perform component testing, sensitivity analysis, and sub-system optimization of the DAC technology.
- Conduct performance analysis and technology optimization based on laboratory, simulated, and pilot operations.
- Develop key engineering inputs for scale-up of DAC technology.
- Perform a techno-economic assessment (TEA) and applicability to coal stream study.

technical content

Carbon Engineering Ltd. has been developing this dilute-source CO_2 capture technology since 2009 to scrub CO_2 from atmospheric air present at concentrations of 400 parts per million (ppm). This project is aimed to further advance this DAC technology for atmospheric CO_2 concentrations, as well as evaluating the system's performance as applied to other coal-relevant dilute CO_2 sources, including post-CCS flue gas and re-capturing legacy atmospheric coal-based emissions.

The DAC process, shown in Figure 1, is based on the use of a wet scrubbing air contactor followed by several chemical processing steps. The chemistry of the process is shown in Figure 2. The aqueous potassium hydroxide (KOH) used in the air contactor is converted into aqueous potassium carbonate (K_2CO_3) when reacted with the CO_2 from the air. In the pellet reactor, the aqueous K_2CO_3 reacts with solid calcium hydroxide ($Ca(OH)_2$) from the slaker to regenerate the aqueous hydroxide, which is sent back to the air contactor, and calcium carbonate ($CaCO_3$) to be used in the calciner. In the calciner, at elevated temperature, the $CaCO_3$ decomposes into solid calcium oxide (CaO), releasing pure CO_2 from the process.

technology maturity:
Pilot-Scale

project focus:
Direct Air Capture from Dilute CO_2 Sources

participant:
Carbon Engineering Ltd.

project number:
FE0026861

predecessor projects:
N/A

NETL project manager:
Andrew Jones
andrew.jones@netl.doe.gov

principal investigator:
Jenny McCahill
Carbon Engineering Ltd.
jmccahill@carbonengineering.com

partners:
N/A

start date:
09.19.2016

percent complete:
100%

The CaO goes to the slaker where water is introduced, forming the $Ca(OH)_2$, which is sent to the pellet reactor, completing the cycle.

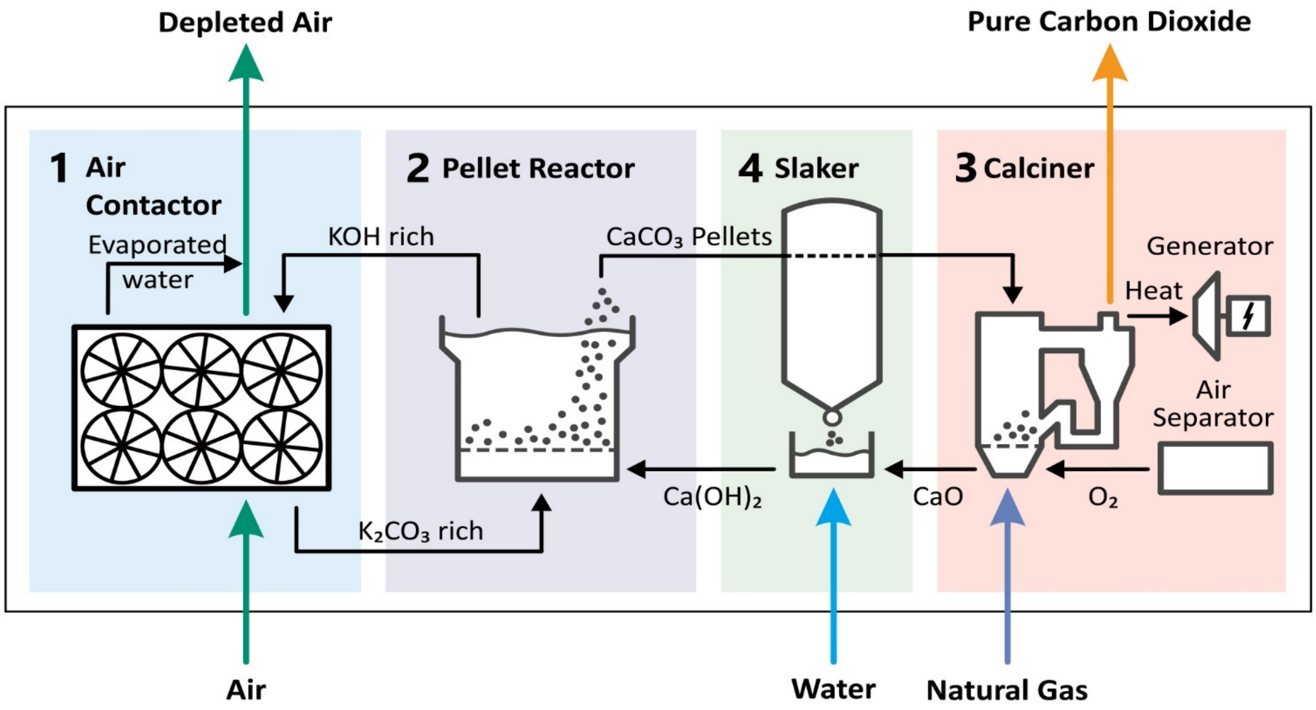

Figure 1: Schematic of the DAC process.

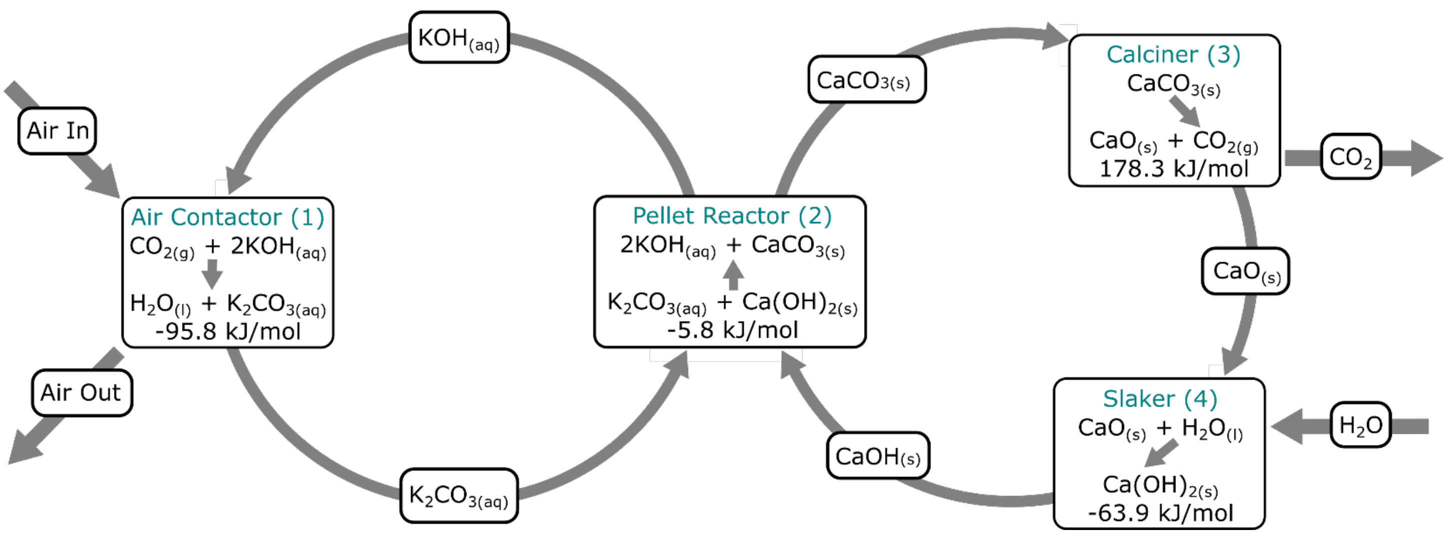

Figure 2: Chemistry of the DAC process.

Carbon Engineering has a DAC research pilot facility in Squamish (British Colombia, Canada), which has been used to support the testing in this project (Figure 3).

Figure 3: Pilot plant in Squamish, British Columbia.

The project team formulated a heat and mass balance for an industrial-scale plant scrubbing CO_2 directly from ambient air. Carbon Engineering's process scales-up to plant sizes capable of capturing 1,000,000 tonnes/year (t/yr) of CO_2, which are the most cost-effective due to economies of scale. Carbon Engineering's efforts were focused on taking results from the research pilot in Squamish, British Columbia, and utilizing them to design a first-of-a-kind plant that is expected to capture on order of 1,000,000 t/yr. The key items in the heat and mass balance are:

- All the power required by the equipment in the DAC plant is provided by a turbine.
- Steam to drive this turbine is partially generated by the hot flue gasses and CaO pellets leaving the calciner, and partially from the combustion of natural gas.
- All the CO_2 produced by the combustion of natural gas is also captured and delivered as product CO_2.
- Only fugitive emissions of CO_2 are lost to the atmosphere.
- The amount of CO_2 delivered is 50% larger than the CO_2 that was captured from the air, with the extra from the combustion of natural gas.
- The water that enters the system and is used to wash the pellets and fines is balanced by the amount of water that the absorber evaporates into the atmosphere.

The scope of work for the TEA included a design and cost estimate of a modified Carbon Engineering DAC plant used as a polishing unit on a modern commercial supercritical pulverized coal power plant that already removed 90% of the CO_2 produced using a conventional liquid amine-based CCS system.

The TEA indicates that using DAC technology to remove an additional 1 Mt/yr CO_2 (~9% of total CO_2 emitted) from the point source stack gases of a conventional coal-fired power plant equipped with a CO_2 removal (CDR) system increases the total cost of electricity (COE) by 16%.

TABLE 1: PROCESS PARAMETERS

Capture Solution	Units	Value
Nominal Concentrations – $K^+/OH^-/CO_3^{2-}$	mol/L	2.0/1.0/0.5
CO_2 Capture		
Delivered Feedstock (Upstream Air) (CO_2)	ppm	400
Downstream Air (CO_2)	ppm	~100
Air Contactor Mass Transfer Rate	mm/sec	1.0-1.3
Pressure Drop	Pa	~130
Air Velocity	m/s	1.4-1.7
CO_2 Release		
Pressure	bar	1
Temperature (Calcination)	°C	~900

STP – Standard temperature and pressure (15°C, 1 atmosphere [atm]).

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

CO_2 Laden Air (feed) Assumptions – Unless noted, gas pressure, temperature, and composition of feed (wet basis) should be assumed as:

		Composition						
Pressure	Temperature	vol%					ppmv	
psia	°F	CO_2	H_2O	N_2	O_2	Ar	SO_x	NO_x
14.7	32–68	0.04	Variable	78.09	20.95	0.93	trace	trace

Other Parameter Descriptions:

Chemical/Physical Solvent Mechanism – Strong aqueous hydroxide solution reacts with large volumes of atmospheric CO_2 across an extremely large, dispersed air contactor. The reaction forms K_2CO_3 in an aqueous, liquid solution that can easily be transported from the contactor to a central processing location. In addition, strong hydroxide solutions have fast reaction kinetics with CO_2, are robust against fouling, and have negligible volatility, meaning there is little risk when using it with atmospheric air.

Gas Pretreatment Requirements – No treatment of atmospheric air required.

Solvent Makeup Requirements – $CaCO_3$ (seed material) and small quantities of KOH makeup.

Waste Streams Generated – Minimal quantities of lime mud ($CaCO_3$) as fines and inerts.

Proposed Module Design – The DAC plant draws air through an air contactor, where it contacts a strong aqueous KOH solution. The CO_2 in the air reacts with the KOH to form a solution of K_2CO_3 and water, absorbing about three-quarters of the available CO_2.

The carbonate solution is transferred to a pellet reactor, where it contacts $Ca(OH)_2$, also known as hydrated lime, and precipitates $CaCO_3$ pellets through a process known as causticization.

The pellets are fed into a circulating fluidized bed and treated at ~900°C through a process known as calcination. The heat releases the CO_2 as a pure, gaseous stream, leaving CaO as byproduct. Heat for the calciner is provided by combusting natural gas with oxygen (known as "oxy-firing"), so that the combustion exhaust is pure CO_2 and water vapor, which can be combined with the CO_2 stream leaving the calciner. The resultant CaO from the calciner is fed into the slaker, where it combines with water to regenerate hydrated lime, which is then fed into the pellet reactor for reuse.

technology advantages

- Negative emission technology.
- Technology can manage CO_2 emissions from any dilute source.
- Highly scalable technology.

R&D challenges

- Compared to standard CCS, there is a higher thermodynamic barrier for dilute-source capture.
- Compared to standard CCS, a larger air volume must be processed for dilute-source capture.
- Controlling/minimizing aerosol emissions is a challenge.

status

Carbon Engineering has concluded TEA activities by working closely with BBA (Engineering company), and an external consultant (Keith Patch). The project has concluded.

available reports/technical papers/presentations

McCahill, J., "Dilute Source Carbon Dioxide (CO_2) Capture: Management of Atmospheric Coal-Produced Legacy Emissions," Final Briefing, Pittsburgh, PA, September 2019. *https://www.netl.doe.gov/projects/plp-download.aspx?id=16805&filename=FE0026861_Final%20Briefing_09-27-19.pdf*.

Souza, R., "Dilute Source Carbon Dioxide (CO_2) Capture: Management of Atmospheric Coal-Produced Legacy Emissions," 2018 NETL CO_2 Capture Technology Project Review Meeting, Pittsburgh, PA, August 2018. *https://www.netl.doe.gov/projects/plp-download.aspx?id=13378&filename=R-Souza-CarbonEng-Dilute-Source-CO2-Capture.pdf*.

Ritchie, J., "Dilute Source Carbon Dioxide (CO_2) Capture: Management of Atmospheric Coal-Produced Legacy Emissions," Project Continuation Application Review Meeting Presentation, September 2017.

Kahn, D., "Dilute Source Carbon Dioxide (CO_2) Capture: Management of Atmospheric Coal-Produced Legacy Emissions," 2017 NETL CO_2 Capture Technology Project Review Meeting, Pittsburgh, PA, August 2017. *https://www.netl.doe.gov/File%20Library/Events/2017/co2%20capture/2-Tuesday/D-Kahn-Carbon-Engrg-Dilute-Source-Carbon-Capture.pdf*.

Ritchie, J., "Dilute Source Carbon Dioxide (CO_2) Capture: Management of Atmospheric Coal-Produced Legacy Emissions," Project Kick-Off Meeting Presentation, March 2017.