Transformational Sorbent-Based Process for a Substantial Reduction in the Cost of CO_2 Capture

primary project goal

InnoSepra LLC is developing a sorbent-based process using novel microporous materials to reduce the cost of carbon dioxide (CO_2) capture. The project includes identification of sorbent materials, process development, and lab-scale testing with simulated flue gas, culminating in bench-scale testing with actual flue gas at Technology Centre Mongstad (TCM).

technical goals

- Identify suitable materials through literature search and Monte Carlo simulations and produce/procure suitable materials for lab-scale testing.
- Complete lab-scale testing of multiple materials in simulated flue gas to determine CO_2 capture performance and downselect best materials.
- Simulate process to obtain heat and mass transfer parameters.
- Design and build the bench-scale test unit.
- Test the best identified materials on the bench-scale unit using actual flue gas at TCM.
- Perform engineering design and complete a techno-economic analysis (TEA) on the process for installation of the technology at a commercial 550-megawatt (MW) power plant to estimate CO_2 capture cost.

technical content

InnoSepra is developing a sorbent-based CO_2 capture process, utilizing physical sorbents based on microporous materials. These sorbents have low heats of adsorption (26–44 kJ/mole CO_2), high net CO_2 capacity (greater than 9 wt%), and high surface area-to-volume ratio (greater than 10 x 10^6 m^2/m^3). The combination of the process and sorbent materials provides capture performance similar to or better than amines, although needing much lower regeneration energy. The process schematic of the CO_2 capture process is shown in Figure 1. After the removal of moisture and sulfur oxides (SO_X) in a pretreatment system, the CO_2 is captured in an adsorber at 25–40°C. A high-purity CO_2 is produced during sorbent regeneration at 90–100°C. Some of the heat of adsorption is removed during the adsorption process; the remaining heat is removed during the cooling steps. Regeneration heat is supplied via low-pressure steam, as well as by utilizing other process waste heat in the system.

The first generation of the InnoSepra process using the physical sorbents was developed and tested at the bench-scale in a previous U.S. Department of Energy (DOE)-funded project (DE-FE0007948). Testing occurred at NRG Energy's Indian River Plant using actual flue gas, taken off the process after the dry flue gas desulfurization (FGD) unit, containing about 50 parts per million (ppm) sulfur dioxide (SO_2) and 10–12% CO_2, with 80–100 standard cubic feet per minute (scfm) flow rate. The adsorption test skid used at the testing at NRG is shown in

program area:
Point Source Carbon Capture

ending scale:
Bench Scale

application:
Post-Combustion Power Generation PSC

key technology:
Sorbents

project focus:
Low Regeneration Energy Sorbent Process for CO_2 Capture from Coal-Based Flue Gas

participant:
InnoSepra LLC

project number:
FE0031722

predecessor projects:
FE0007948
SC0010208

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Main Line Engineering; Plant Process Equipment; Arizona State University

start date:
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percent complete:
75%

Figure 2. Eight weeks of testing was completed showing 8–10.5 wt% net CO_2 capacity, greater than 94% CO_2 recovery, and greater than 98% purity.

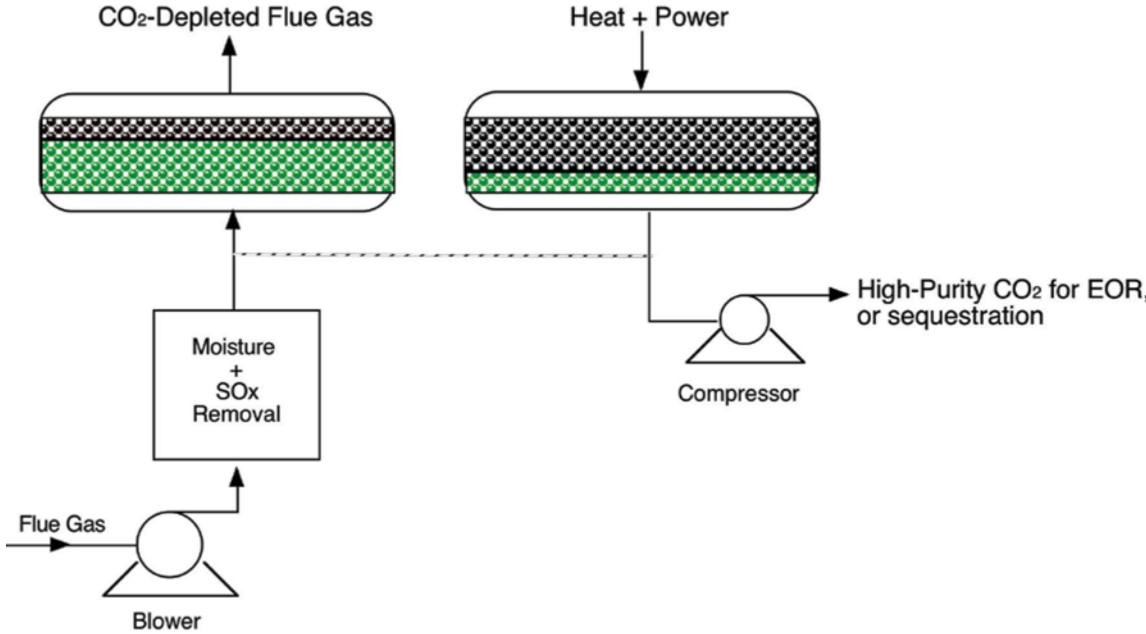

Figure 1: InnoSepra capture process schematic.

Figure 2: InnoSepra test skid used for testing at NRG Energy.

Projections based on detailed engineering evaluations show that at commercial scale, the first-generation process can reduce the power consumption for CO_2 capture by more than 40%, including CO_2 compression. There is about a 70% lower power loss due to steam extraction for the InnoSepra process compared to the amine process and approximately 48% reduction in capture cost compared to monoethanolamine (MEA).

In this project, InnoSepra is developing the second-generation process, which is simpler, with capital savings, compared to the first-generation process. In testing of the second-generation process at lab scale, an absolute energy requirement (excluding compression) of 1.6 gigajoule (GJ)/metric tonnes (MT) of CO_2 was obtained, which is 50% lower than the absolute energy requirement for an MEA-based capture process, and lower than the 2.1 GJ/MT obtained for the first-generation process of InnoSepra's technology in field testing. The lower energy requirement results from a breakthrough sorbent regeneration method. The lower absolute amount of regeneration energy coupled with lower regeneration temperature leads to a 78% lower power loss due to steam extraction compared to MEA. The key feature of the second-generation process is a significant reduction in the heating requirement (from 1.3–0.7 GJ/MT) through a combination of the sorbent selection and regeneration method. The project team is demonstrating the effectiveness of the InnoSepra sorbent-based post-combustion capture technology to achieve at least 90% CO_2 removal with greater than 98% purity. Suitable materials with at least 6 wt% CO_2 capture capacity were identified and downselected for subsequent testing in a newly constructed lab unit. Testing at lab scale, along with recently developed process simulations, helps support verification of the material properties and optimization of the process. This system shows potential to reduce the parasitic power required for regeneration by more than 65%, and the capital required by about 45%, leading to about 50% reduction in the CO_2 capture cost. A newly designed bench-scale testing unit has been designed and is being built. The unit will be shipped and tested at TCM at a scale greater than 100 scfm.

The sorbent and process parameters are provided in Table 1.

TABLE 1: SORBENT PROCESS PARAMETERS

Sorbent	Units	Current R&D Value		Target R&D Value
True Density @ STP	kg/m^3	1,990		1,990
Bulk Density	kg/m^3	690		690
Average Particle Diameter	mm	1.5-3.0		0.5-1.5
Particle Void Fraction	m^3/m^3	0.45		0.45
Packing Density	m^2/m^3	1.79e8		1.79e8
Solid Heat Capacity @ STP	kJ/kg-K	0.96		0.96
Crush Strength	kg_f	2.9		2.9
Manufacturing Cost for Sorbent	$/kg	4.0		3.0-4.0
Adsorption				
Pressure	bar	1.15		1.1
Temperature	°C	25-32		25-32
Equilibrium Loading	g mol CO_2/kg	3.25		3.5-4.0
Heat of Adsorption	kJ/mol CO_2	38		38
Desorption				
Pressure	bar	0.3-1.0		0.3-1.0
Temperature	°C	100		90-110
Equilibrium CO_2 Loading	g mol CO_2/kg	1.0-1.5		1.0-1.5
Heat of Desorption	kJ/mol CO_2	38		38
Proposed Module Design		*(for equipment developers)*		
Flow Arrangement/Operation	—		fixed/cyclic	
Flue Gas Flowrate	kg/hr		2,320,000	
CO_2 Recovery, Purity, and Pressure	% / % / bar	90	99	1.0
Adsorber Pressure Drop	bar	0.14		0.10
Estimated Adsorber/Stripper Cost of Manufacturing and Installation	$\frac{\$}{kg/hr}$		336	

TABLE 2: POWER PLANT CARBON CAPTURE ECONOMICS

Economic Values	Units	Current R&D Value	Target R&D Value
Cost of Carbon Captured	$/tonne CO_2	35	30

Cost of Carbon Avoided	\$/tonne CO_2	39.5	31.5
Capital Expenditures	\$/ MWhr	53	45
Operating Expenditures	\$/ MWhr	14	12
Cost of Electricity	\$/MWhr	94	88

Definitions:

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

Sorbent – Adsorbate-free (i.e., CO_2-free) and dry material as used in adsorption/desorption cycle.

Manufacturing Cost for Sorbent – "Current" is market price of material, if applicable; "Target" is estimated manufacturing cost for new materials, or the estimated cost of bulk manufacturing for existing materials.

Adsorption – The conditions of interest for adsorption are those that prevail at maximum sorbent loading, which typically occurs at the bottom of the adsorption column. These may be assumed to be 1 atm total flue gas pressure (corresponding to a CO_2 partial pressure of 0.13 bar) and 40°C; however, measured data at other conditions are preferable to estimated data.

Desorption – The conditions of interest for desorption are those that prevail at minimum sorbent loading, which typically occurs at the bottom of the desorption column. Operating pressure and temperature for the desorber/stripper are process-dependent. Measured data at other conditions are preferable to estimated data.

Pressure – The pressure of CO_2 in equilibrium with the sorbent. If the vapor phase is pure CO_2, this is the total pressure; if it is a mixture of gases, this is the partial pressure of CO_2. Note that for a typical pulverized coal power plant, the total pressure of the flue gas is about 1 atm and the concentration of CO_2 is about 13.2%. Therefore, the partial pressure of CO_2 is roughly 0.132 atm or 0.130 bar.

Packing Density – Ratio of the active sorbent area to the bulk sorbent volume.

Loading – The basis for CO_2 loadings is mass of dry, adsorbate-free sorbent.

Flow Arrangement/Operation – Gas-solid module designs include fixed, fluidized, and moving bed, which result in either continuous, cyclic, or semi-regenerative operation.

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 FGD unit (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	135	13.17	17.25	66.44	2.34	0.80	42	74

Other Parameter Descriptions:

Chemical/Physical Sorbent Mechanism – The adsorption is physical sorption based on weak van der Waals forces. This leads to low heats of adsorption.

Sorbent Contaminant Resistance – Under normal operation, the sorbent is not irreversibly damaged by any contaminant in the flue gas. If substantial quantities of SO_2 are present in the feed to the CO_2 adsorption section, the sorbent may require higher than normal regeneration temperature to restore performance.

Sorbent Attrition and Thermal/Hydrothermal Stability – The process design protects the adsorbent from moisture and potential hydrothermal degradation. If moisture should break through onto the adsorbent, the adsorbent can be regenerated completely. The adsorbent is thermally stable at temperatures of more than 300°C.

Flue Gas Pretreatment Requirements – No special flue gas pretreatment is required. A conventional FGD and a direct contact cooler (DCC) are sufficient for normal process operation.

Sorbent Makeup Requirements – Based on prior experience with similar sorbents in similar operating environments, the adsorbent life would be between five and 10 years. An adsorbent life of five years has been assumed to estimate the makeup requirements.

Waste Streams Generated – Except for the sorbents loaded with flue gas components, SO_X and mercury (Hg), no other waste streams are generated in the process. These can be disposed of as per current power plant practices for materials loaded with SO_X and Hg.

Process Design Concept – The commercial process configuration is shown in Figure 3. The adsorption equipment is modular in nature and five adsorption skids are needed for a 550-MW power plant. The rest of the process equipment, such as the feed blower, DCC, and the CO_2 compressor, is very similar to the amine process.

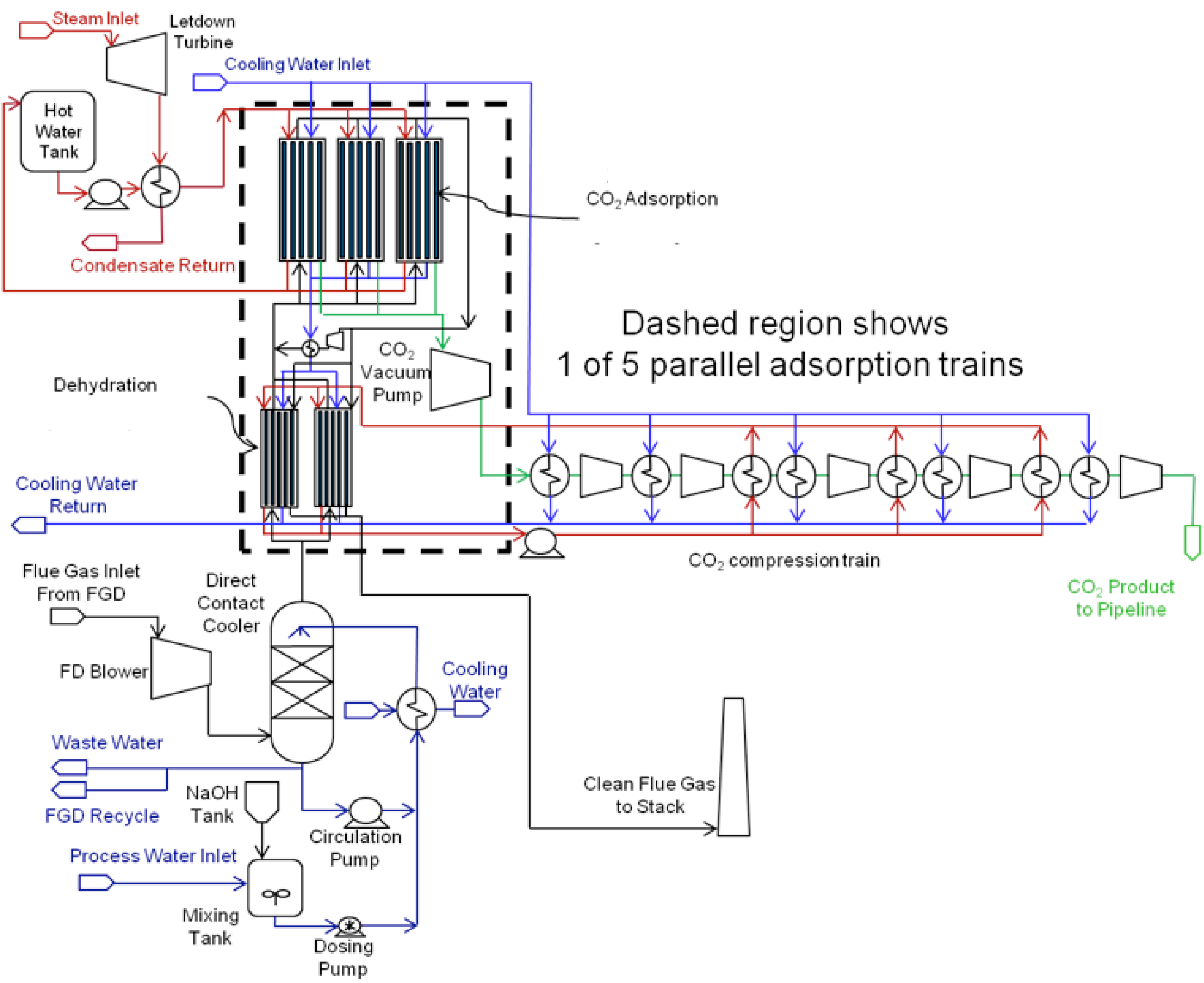

Figure 3: Commercial process configuration.

Proposed Module Design – The CO_2 capture modules will be designed to capture CO_2 from a 550-MW pulverized coal power plant. Multiple modules will be used to minimize field fabrication and maximize offsite fabrication. The separation skid will consist of a feed preparation section (flue gas compression and cooling), the CO_2 adsorption section (removal of impurities, CO_2 adsorption, and desorption), and the CO_2 compression section.

technology advantages

- The physical sorbents have a low heat of adsorption (approximately 0.8 GJ/MT).
- Combination of lower absolute amount of heat needed and lower steam extraction temperature leads to a 78% lower power loss compared to MEA.
- The process can produce high-purity CO_2 (greater than 98%) and recovery (greater than 90%).

- The estimated absolute energy required for the process, excluding compression, is 1.6 GJ/MT of CO_2, less than half of the absolute energy requirement for an MEA-based process.
- Regeneration energy can be utilized at approximately 110°C, compared to greater than 170°C for amines.
- The process has a projected capture cost below $30/MT CO_2, excluding transportation, storage, and monitoring (TS&M) costs.

R&D challenges

- Heat management during both adsorption and regeneration.
- Maintaining heat transfer rate upon scale-up.
- Assuring effective moisture and contaminant removal from the flue gas prior to adsorption to prevent decrease in sorbent performance over time.

status

The project's first budget period has been completed, and the second budget period is in progress. Suitable materials were identified, downselected, and tested in a constructed lab-scale unit. Process models have been developed, and a detailed engineering design was completed for a bench-scale unit to be tested at TCM. Fabrication of the bench-scale unit will be followed by shipping to and testing at TCM, with a field-testing report and analysis to be subsequently completed.

available reports/technical papers/presentations

Jain, R. "Transformational Sorbent-Based Processes for a Substantial Reduction in the Cost of CO_2 Capture," Presented at the 2021 NETL Carbon Management Research Project Review Meeting, Pittsburgh, PA, August 2021. *https://netl.doe.gov/sites/default/files/netl-file/21CMOG_PSC_Jain.pdf*.

Jain, R. "Transformational Sorbent-Based Processes for a Substantial Reduction in the Cost of CO_2 Capture," Presented at the Budget Period 1 Meeting, Pittsburgh, PA, April 2021. *https://www.netl.doe.gov/projects/plp-download.aspx?id=10721&filename=Transformational+Sorbent-Based+Process+for+a+Substantial+Reduction+in+the+Cost+of+CO2+Capture.pdf*.

Jain, R. "Transformational Sorbent-Based Processes for a Substantial Reduction in the Cost of CO_2 Capture," Presented at the Project Kickoff Meeting, Pittsburgh, PA, September 2019. *https://www.netl.doe.gov/projects/plp-download.aspx?id=10719&filename=Transformational+Sorbent-Based+Process+for+a+Substantial+Reduction+in+the+Cost+of+CO2+Capture.pdf*.

Jain, R. "Transformational Sorbent-Based Processes for a Substantial Reduction in the Cost of CO_2 Capture," Presented at the 2019 NETL CO_2 Capture Technology Meeting, Pittsburgh, PA, August 2019. *https://netl.doe.gov/sites/default/files/netl-file/R-Jain-InnoSepra-Cost-Reduction-Capture.pdf*.