Engineering Study of Svante's Solid Sorbent Post-Combustion CO_2 Capture Technology at a Linde Steam Methane Reforming H_2 Plant

primary project goal

Linde Inc., in coordination with Linde Engineering Americas, Linde Engineering Dresden, and Svante Inc., is conducting an initial engineering design of a commercial-scale carbon capture plant utilizing the Svante VeloxoTherm™ solid adsorbent carbon dioxide (CO_2) capture technology installed at an existing Linde-owned steam methane reforming (SMR) hydrogen (H_2) production plant in Port Arthur, Texas. The overall system is being designed to capture approximately 1,000,000 tonnes/year net CO_2 with at least 90% carbon capture efficiency while producing "blue" H_2 with 99.97% purity from natural gas.

technical goals

- Develop an initial engineering design and overall process design package for the CO_2 capture process integrated with the H_2 production facility.
- Prepare a capital cost estimate, including the cost of capture in $/tonne CO_2 net captured from the H_2 plant, and the levelized cost of hydrogen.
- Generate a commercial-scale TEA of this post-combustion capture technology.
- Complete a Technology Maturation Plan (TMP) and Environment, Health, and Safety (EH&S) Risk Assessment.

technical content

The VeloxoTherm process developed by Svante is comprised of a rapid cycle thermal swing adsorption (TSA) process that uses a patented architecture of structured adsorbent beds (SABs) and a novel process design and embodiment to capture CO_2 from industrial and natural gas-fired flue gas streams. SABs possess unique physical and transport properties, which serve to greatly improve the performance of gas separation, enabling fast cycle times and small equipment sizes that deliver attractive capture economics. Figure 1 shows the rotary adsorption machine (RAM) design at the core of the technology. Svante uses solid adsorbents that have very high surface-to-volume ratios, instead of liquid chemicals (amines or potassium hydroxide), to capture CO_2. A new class of advanced sorbent materials, metal organic framework (MOF)-based sorbent material (CALF-20), has been developed by Svante and lab-tested under U.S. Department of Energy (DOE) Cooperative Agreement No. DE-FE0031732, and is being field-tested (since January 2021) at a cement plant in Vancouver, Canada.

program area:
Point Source Carbon Capture

ending scale:
pre-FEED

application:
Post-Combustion Industrial PSC

key technology:
Sorbents

project focus:
Svante VeloxoTherm™ CO_2 Capture Technology Applied to SMR Plant

participant:
Linde Inc.

project number:
FE0032113

predecessor projects:
N/A

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Linde Engineering Americas; Linde Engineering; Dresden GmbH; Svante Inc.

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percent complete:
17%

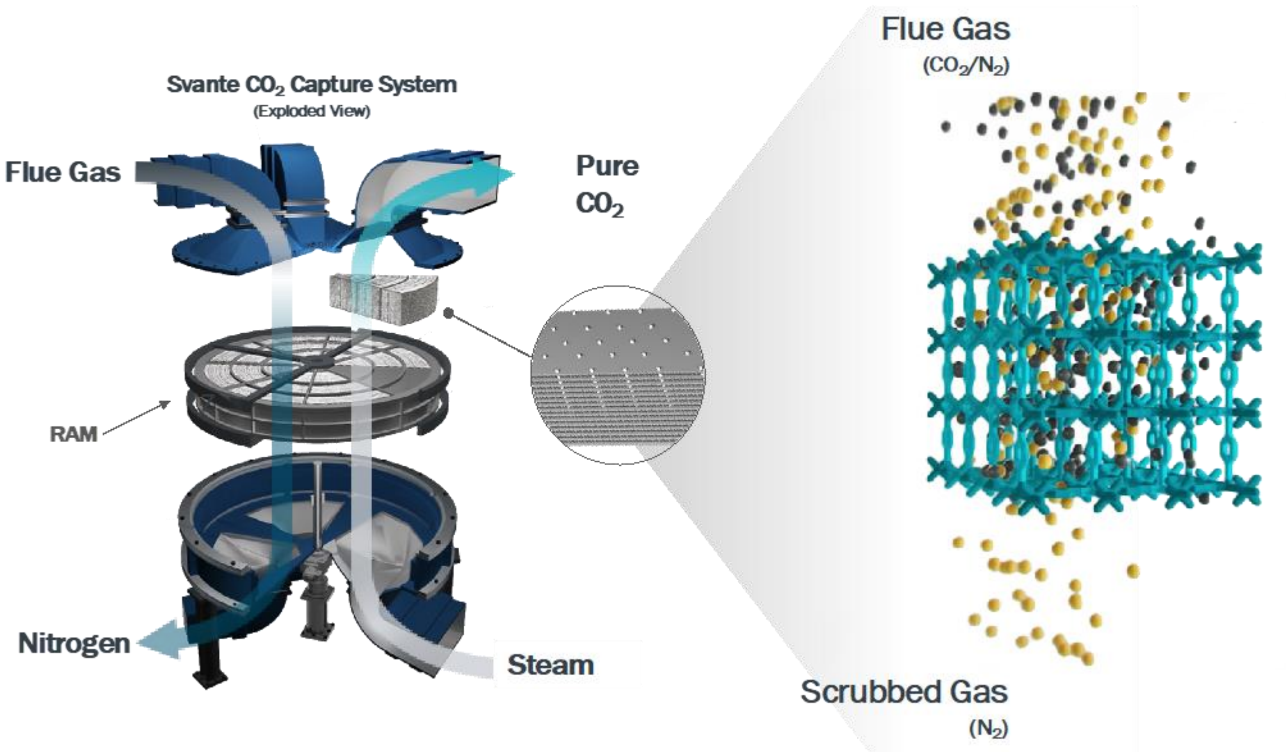

Figure 1: VeloxoTherm™ rotary adsorption machine.

This sorbent material exhibits unique resistance to sulfur oxide (SO_X), nitrogen oxide (NO_X), and oxygen impurities, as well as moisture swing. The VeloxoTherm process has been scaled-up to 30 TPD of CO_2 and is undergoing demonstration with flue gas derived from natural gas combustion at Cenovus in Canada using a first-generation sorbent material of amine-doped silica. In this project, the team plans to leverage the design and learnings from the Cenovus 30 TPD project to improve the performance and flexibility of a second-of-a-kind (SOAK) engineering-scale plant (400 Series) using CALF-20 MOF sorbent material.

The project team is developing an engineering design package comprised of the core technology; process units inside the battery limits (ISBL) of the CO_2 capture unit, such as flue gas conditioning and CO_2 product purification; and balance of plant components outside the battery limits (OSBL) of the capture plant.

TABLE 1: SORBENT PROCESS PARAMETERS

Sorbent	Units	Current R&D Value	Target R&D Value
Weight/Bed Volume	kg/m^3	350-380	350-380
Bulk Density	kg/m^3	N/A	N/A
Adsorbent Particle Diameter	mm	0.31-0.35	0.31-0.35
Particle Void Fraction	m^3/m^3	N/A	N/A
Wetted sheet area/bed volume	m^2/m^3	2300-2500	2300-2500
Solid Heat Capacity @ STP	kJ/kg-K	1.4-1.6	1.4-1.6
Thermal Conductivity	W/m^{o}K	0.25-0.35	0.25-0.35
Manufacturing Cost for Sorbent	$/kg	30-35	20-25
Adsorption			
Pressure	Bar (a)	1–1.1	1–1.1
Temperature	°C	50	50
Equilibrium Loading – 20% CO_2	g mol CO_2/kg	1.7-1.9	1.7-1.9
Heat of Adsorption	kJ/mol CO_2	35-38	35-38
Desorption			

Pressure	Bar(a)	0.8-1.0		0.8-1.0
Temperature	°C	120-140		120-140
Equilibrium CO_2 Loading	g mol CO_2/kg	0.3-0.4		0.3-0.4
Heat of Desorption	kJ/mol CO_2	35-38		35-38
Proposed Module Design		*(for equipment developers)*		
Flow Arrangement/Operation		Rapid Cycle rotary valve moving bed		
Flue Gas Flowrate	kg/hr	596,000		
CO_2 Recovery, Purity, and Pressure	% / % / bar	90-95	95	150

Definitions:

STP – Standard Temperature and Pressure (15°C, 1 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. 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.

Desorption – The conditions of interest for desorption are those that prevail at minimum sorbent loading. Operating pressure and temperature for the desorber/stripper are process-dependent.

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.

Packing Density – Ratio of the laminated sorbent composite sheet area/filter bed volume.

Equilibrium Loading – The basis for CO_2 loadings is mass of dry, sorbent measured with 20% CO_2 in N_2 mixture without moisture.

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

Chemical/Physical Sorbent Mechanism – Physisorption.

Sorbent Contaminant Resistance – High oxidation resistance below 50 ppm SO_X and NO_X.

Sorbent Attrition and Thermal/Hydrothermal Stability – Very stable under direct steam regeneration.

Flue Gas Pretreatment Requirements – Conventional direct contact cooler.

Sorbent Make-Up Requirements – Three- to five-year year lifetime without bed replacement.

Waste Streams Generated – No chemicals in VeloxoTherm exhaust gas, water treatment system blowdown.

Process Design Concept – Flowsheet/block flow diagram shown in Figure 2.

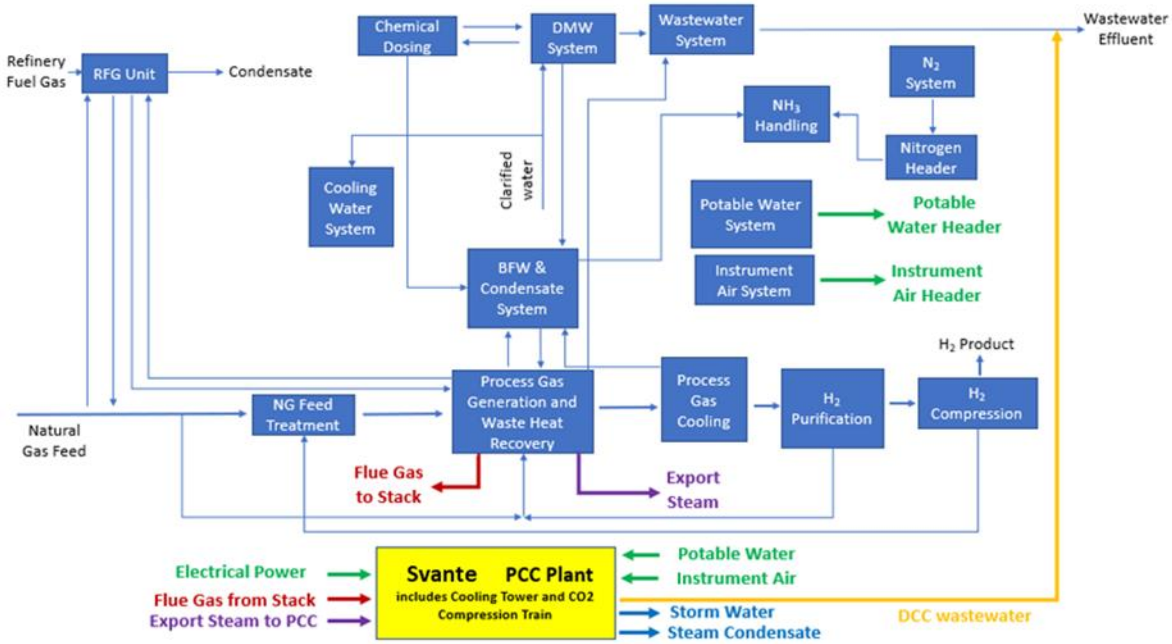

Figure 2: Flowsheet/block flow diagram of process.

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	50	30
Cost of Carbon Avoided	\$/tonne CO_2	Site specific	Site specific
Capital Expenditures	\$/TPD	70,000-80,000	60,000 to 70,000
Operating Expenditures	\$/tonne CO_2	26-28	20-23
Cost of Electricity	\$/ tonne CO_2	12-18	12-18

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 is site specific depending on the source of electricity and steam.

Capital Expenditures – Projected capital expenditures in dollars per tonne per day of capacity.

Operating Expenditures – Projected operating expenditures in dollars per unit of tonne of CO_2 produced including filter bed replacement and compression cost.

Cost of Electricity – Projected cost of electricity per unit of tonne of CO_2 produced for a range of price of electricity of 3.5 to 6 cents per kwh.

Scale of Validation of Technology Used in TEA – The technology numbers were validated for use in the preliminary TEA from pilot-scale data.

technology advantages

- Svante's technology has the potential to enable a 50% reduction in capital costs compared to first-generation approaches.
- Novel technology replaces large chemical solvent towers (conventional approach) with a single piece of compact equipment, significantly reducing capital expenses (CAPEX).

- Advanced sorbent material exhibits sharper temperature and pressure swing absorption and desorption, which allows for lower energy loads and faster kinetic rates.
- The proprietary material also exhibits unique resistance to SO_X and NO_X, oxygen impurities, and moisture swings.

R&D challenges

- Integration with operations at the SMR plant.
- Engineering-scale testing and analysis

status

Linde Inc. has completed their preliminary basis of design and process design package. The technology design and engineering efforts are currently underway.

available reports/technical papers/presentations

Nicki Stuckert, Bill Chesser – "SMR CO_2 Capture Engineering Study." Project kickoff meeting presentation [WebEx meeting] October 2021. *https://www.netl.doe.gov/projects/plp-download.aspx?id=11229&filename=Engineering+Study+of+Svante%27s+Solid+Sorbent+Post-Combustion+CO2+Capture+Technology+at+a+Linde+Steam+Methane+Reforming+H2+Plant.pdf*.