

APPENDIX B: CARBON DIOXIDE CAPTURE TECHNOLOGY SHEETS

PRE-COMBUSTION SOLVENTS



CO₂ CAPTURE FROM IGCC GAS STREAMS USING AC-ABC PROCESS

primary project goals

SRI International is developing, for integrated gasification combined cycle (IGCC)-based power plants, a carbon dioxide (CO₂) capture technology based on the use of a high-capacity and low-cost aqueous ammoniated solution containing ammonium carbonate (AC), which reacts with CO₂ to form ammonium bicarbonate (ABC).

technical goals

- Test the technology on a bench-scale batch reactor to validate the concept.
- Determine the optimum operating conditions for a small pilot-scale reactor.
- Design and build a small pilot-scale reactor capable of continuous integrated operation.
- Perform pilot-scale tests to evaluate the process in a coal gasifier environment.
- Perform a technical and economic evaluation on the technology.

technical content

The technology is based on the use of an aqueous ammoniated solution containing AC, which reacts with CO₂ to form ABC.

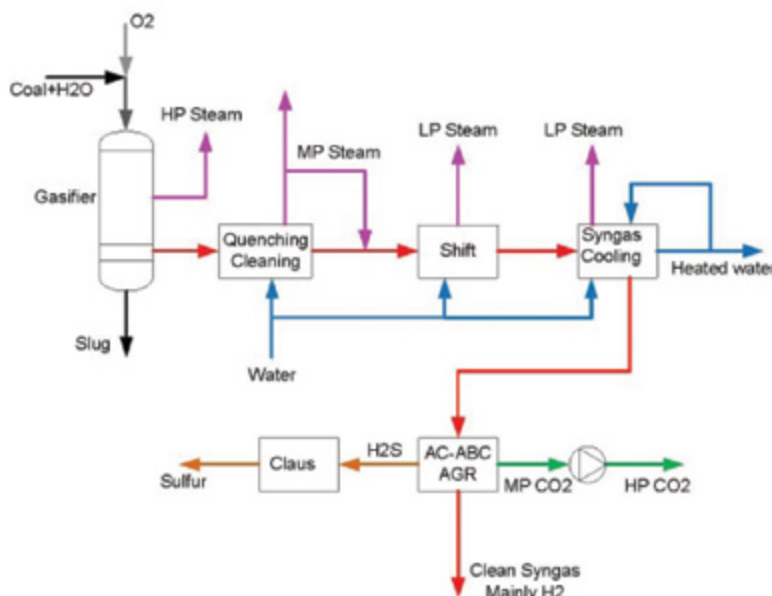


Figure 1: Acid Gas Removal in Gasification System

The concentrated ammoniated solution is used to capture CO₂ and hydrogen sulfide (H₂S) from synthesis gas (syngas) at high pressure. This technique reduces the size of the CO₂ stripper and operates at high pressure, reducing CO₂ compression needs; both reduce electric power consumption. AC has high net CO₂ loading, is a low-cost and readily

technology maturity:

Pilot-Scale Using Actual Syngas

project focus:

CO₂ Capture Using AC-ABC Process

participant:

SRI International

project number:

FE-0000896

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EIG, Inc.
Bechtel Hydrocarbon
Technology Solutions, Inc.
National Carbon
Capture Center

performance period:

9/30/09 – 12/31/13

available reagent, and requires little solvent makeup; the solubility of hydrogen (H_2), carbon monoxide (CO), and methane (CH_4) in absorber solution is extremely low.

B-8

The project, in its first phase, constructed a bench-scale batch reactor unit to test the technology at SRI's facility in California. Testing was performed to validate the concept and to determine the optimum operating conditions.

Absorber testing was conducted to first determine the solubility of shifted-gas components (H_2 , CO , nitrogen [N_2], argon [Ar]), then to determine the reactivity of CO_2 and H_2S ; mixed-gas testing was performed to determine the relative reaction kinetics.

Regenerator testing was conducted to determine CO_2 and H_2S release characteristics, as well as the relative kinetics of CO_2 and H_2S release. Optimal operating conditions derived in bench-scale testing will be used at the pilot-scale test.

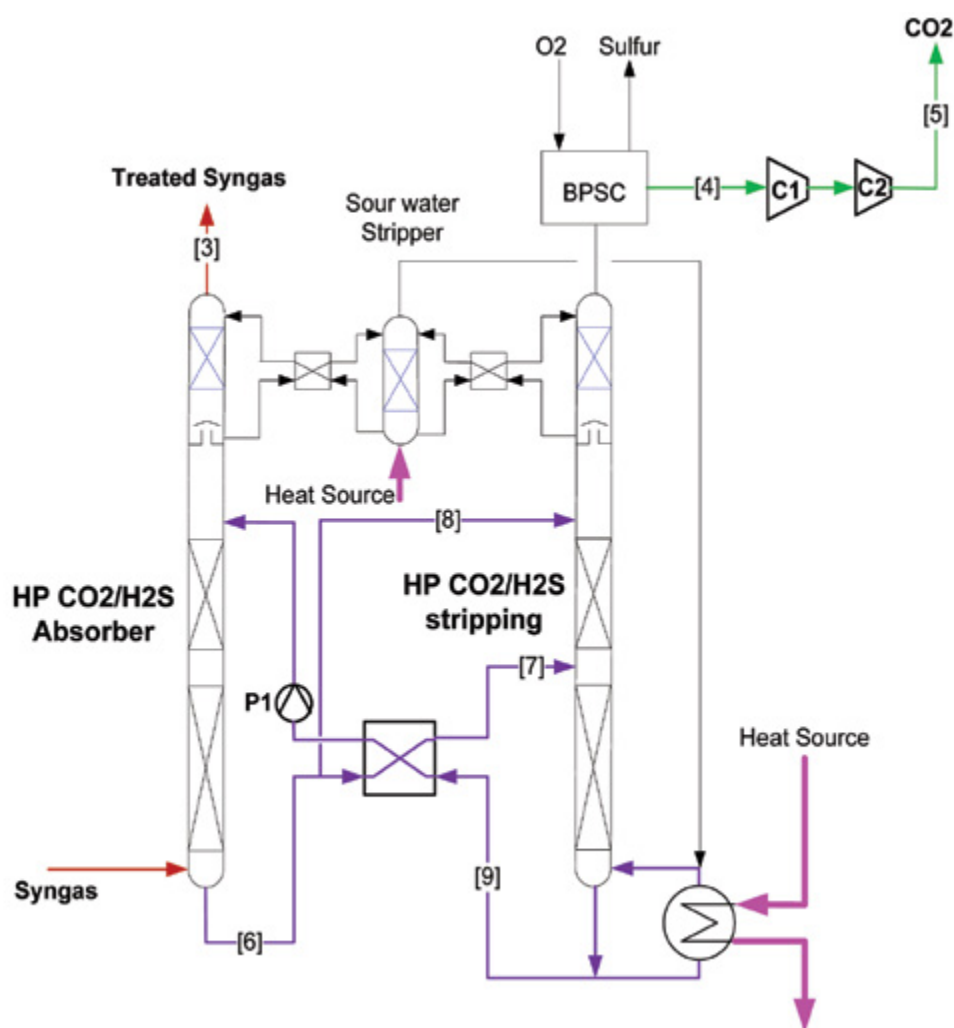


Figure 2: Schematic of the CO_2 and H_2S Capture System

Pilot-scale testing will be performed on a slipstream from the air-blown gasifier at the National Carbon Capture Center (NCCC) in Wilsonville, Alabama. SRI has designed a pilot-scale, continuous, integrated test system. The equipment is being procured and will be assembled. The pilot-scale test will emphasize stability of integrated operation. The effects of trace contaminants will be observed, as the pilot tests will use a gas stream from an operating gasifier that has undergone minimum cleanup and will contain trace contaminants.

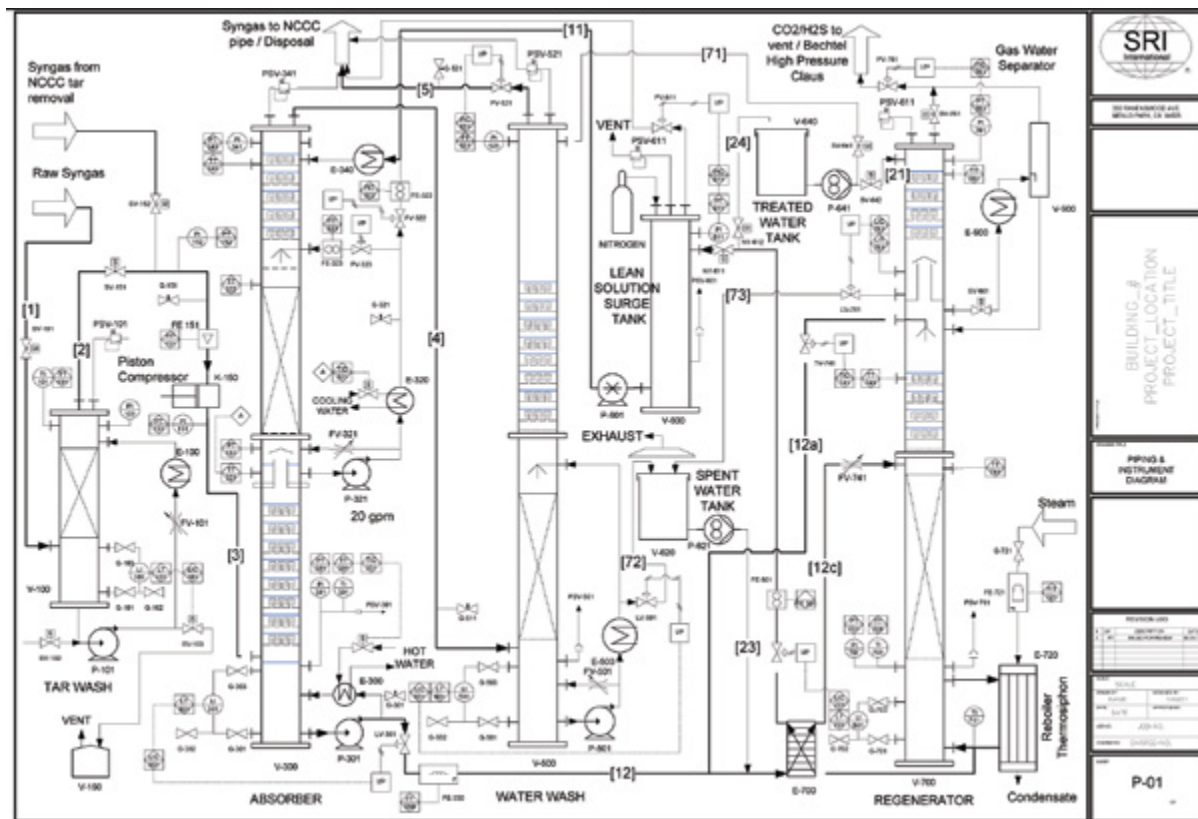


Figure 3: Pilot-Scale Integrated Testing (Preliminary)

A technical and economic analysis was performed using Aspen and GT-Pro programs to generate the equipment sizing and heat and material flows; DOE cost models; and a base case, 750-MW nominal IGCC plant without CO₂ capture to compare the AC-ABC process with a similar-size plant using CO₂ capture with a Selexol subsystem.

TABLE 1: SOLVENT PARAMETERS

	Units	Current R&D Value	Target R&D Value
Pure Solvents			
Molecular Weight	mol ⁻¹	Nominal 18	Nominal 18
Normal Boiling Point	°C	Varies with pressure: 100°C at 1 atm	Varies with pressure: 100°C at 1 atm
Normal Freezing Point	°C	Nominal 0°C, varies with composition	Nominal 0°C, varies with composition
Vapor Pressure @ 15°C	bar	NH ₃ vapor pressure varies with composition and temperature,	NH ₃ vapor pressure varies with composition and temperature
Manufacturing Cost for Solvent	\$/kg		Cost of anhydrous ammonia typically \$200 to \$400/ton
Working Solution			
Concentration	kg/kg	0.1 kg NH ₃ /kg	0.15 kg NH ₃ /kg
Specific Gravity (15°C/15°C)	-	1.1	1.1
Specific Heat Capacity @ STP	kJ/kg-K	3.5	3.5
Viscosity @ STP	cP	Nominal 1	Nominal 1

TABLE 1: SOLVENT PARAMETERS

	Units	Current R&D Value	Target R&D Value
Adsorption			
Pressure	bar	20	50
Temperature	°C	25	25 – 40
Equilibrium CO ₂ Loading	mol/mol	Varies with the composition of the solution;	Varies with the composition of the solution
Heat of Absorption	kJ/mol CO ₂		40 to 60
Solution Viscosity	cP	Nominal 1	Nominal 1
Desorption			
Pressure	bar	30	30
Temperature	°C	<200°C	
Equilibrium CO ₂ Loading	mol/mol	Varies with the composition of the solution	Varies with the composition of the solution
Heat of Desorption	kJ/mol CO ₂		40 to 60
Proposed Module Design		<i>(for equipment developers)</i>	
Flue Gas Flowrate	kg/hr	225	N/A
CO ₂ Recovery, Purity, and Pressure	percent / percent / bar	90 percent, 99 percent, 30 bar	
Absorber Pressure Drop	bar	<1 bar	
Estimated Absorber/Stripper Cost of Manufacturing and Installation	$\frac{\$}{\text{kg/hr}}$		

Definitions:

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

Pure Solvent – Chemical agent(s), working alone or as a component of a working solution, responsible for enhanced CO₂ absorption (e.g., the amine monoethanolamine [MEA] in an aqueous solution).

Manufacturing Cost for Solvent – “Current” is market price of chemical, if applicable; “Target” is estimated manufacturing cost for new solvents, or the estimated cost of bulk manufacturing for existing solvents.

Working Solution – The solute-free (i.e., CO₂-free) liquid solution used as the working solvent in the absorption/desorption process (e.g., the liquid mixture of MEA and water).

Absorption – The conditions of interest for absorption are those that prevail at maximum solvent loading, which typically occurs at the bottom of the absorption column. These may be assumed to be 1 atm total flue-gas pressure (corresponding to a CO₂ 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 solvent loading, which typically occurs at the bottom of the desorption column. Operating pressure and temperature for the desorber/stripper are process-dependent (e.g., an MEA-based absorption system has a typical CO₂ partial pressure of 1.8 bar and a reboiler temperature of 120°C). Measured data at other conditions are preferable to estimated data.

Pressure – The pressure of CO₂ in equilibrium with the solution. If the vapor phase is pure CO₂, this is the total pressure; if it is a mixture of gases, this is the partial pressure of CO₂. Note that for a typical pulverized-coal power plant, the total pressure of the flue gas is about 1 atm and the concentration of CO₂ is about 13.2 percent. Therefore, the partial pressure of CO₂ is roughly 0.132 atm or 0.130 bar.

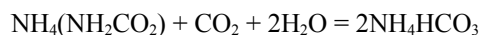
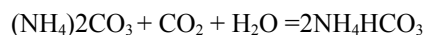
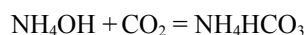
Concentration – Mass fraction of pure solvent in working solution.

Loading – The basis for CO₂ loadings is moles of pure solvent.

Estimated Cost – Basis is kg/hr of CO₂ in CO₂-rich product gas; assuming targets are met.

Other Parameter Descriptions:

Chemical/Physical Solvent Mechanism:



Solvent Contaminant Resistance – The solvent is expected to be resistant to several contaminants nominally present in an IGCC gas stream. Hydrogen sulfide reacts with the solvent, but it can be removed during the regeneration. The ammonia (NH₃) in the IGCC may negate any NH₃ loss from the solvent. The resistance of the solvent to trace metals is not known yet.

Solvent Foaming Tendency – Solvent foaming tendency was not observed in the bench-scale tests.

Flue Gas Pretreatment Requirements – The IGCC gas stream needs to undergo water-gas shift (WGS) reaction to convert CO to CO₂ and to be cooled to a temperature of 25 to 50°C.

Solvent Make-Up Requirements – The AC is a readily available commodity chemical and the make-up requirements are estimated to be small. However, the actual amount will be determined in the field test.

Waste Streams Generated – Ammonium sulfate solution from the capture of trace residual NH₃ in the gas.

Proposed Module Design – (Unless noted syngas pressure, temperature, and composition leaving WGS reactor and tar removal steps [wet basis]) should be assumed as follows (note that the gas will be compressed to 450 pounds per square inch gauge [psig]) before the absorber:

Pressure	165 psia
Temperature	95°F
Composition	
	vol percent
CO ₂	8.3
H ₂ O	7.6
N ₂	67.0
O ₂	0
Ar	N/A
	ppmv
H ₂ S	200
NH ₃	1,800

technology advantages

- Low-cost and stable reactive solution.
- Reactive solution has a high CO₂ loading capacity due, in part, to the formation of ABC solids during absorption.
- The CO₂ stripping in the AC-ABC process can be accomplished at elevated pressures in the range of 20 to 50 bar resulting in a 3 to 7.5 pressure ratio only to compress the gas to the pipeline pressure of 150 bar pressure.
- The AC-ABC process does not require compressors other than the CO₂ compressor.
- High CO₂ loading and high-pressure CO₂ stripper reduces the pumping power between the absorber and the regenerator.

- The AC-ABC process does not require high conversion of CO in the syngas feed.
- The hot syngas from the shift reactor can be used as the main heat source for the CO₂ stripping reducing the power output penalty.

R&D challenges

- Precipitation of solids could potentially foul packing and heat exchanger surfaces.
- Absorber operation at an elevated temperature could create excessive residual ammonia in the fuel gas stream leaving the absorber.
- Adequate separation of H₂S and CO₂ in the regenerator gas.

results to date/accomplishments

- Bench-scale mixed gas batch tests, in various gas compositions, were conducted. Carbon dioxide and H₂S capture rates were experimentally determined as a function of temperature, pressure, and solution and gas compositions. Data from regenerator experiments were used to determine the optimum regenerator conditions for the release of CO₂ and H₂S exclusively.
- The bench-scale tests demonstrated an efficient absorption of CO₂ and H₂S at elevated pressures without the need for sub-ambient operation. High-pressure CO₂ and concentrated H₂S streams can be released during the regeneration of loaded solution.
- The design of the pilot-scale continuous, integrated AC-ABC test system, designed to run on a coal-derived syngas, has been finalized.

next steps

Assemble the pilot-scale integrated AC-ABC unit and test the system using the gasifier gas stream at NCCC.

available reports/technical papers/presentations

“CO₂ Capture from IGCC Gas Streams Using AC-ABC Process,” presented at the 2012 NETL CO₂ Capture Technology Meeting, Pittsburgh, Pennsylvania, July 2012. <http://www.netl.doe.gov/File%20Library/Events/2012/CO2%20Capture%20Meeting/I-Jayaweera-SRI-AC-ABC-Process.pdf>.

“CO₂ Capture from IGCC Gas Streams Using AC-ABC Process,” presented at the 2011 NETL CO₂ Capture Technology Meeting, Pittsburgh, Pennsylvania, August 2011. <http://www.netl.doe.gov/File%20Library/Events/2011/co2capture/25Aug11-Jayaweera-SRI-AC-ABC-Process.pdf>.

“CO₂ Capture from IGCC Gas Streams Using AC-ABC Process,” presented at the 2010 NETL CO₂ Capture Technology Meeting, Pittsburgh, Pennsylvania, September 2010. <http://www.netl.doe.gov/File%20Library/Events/2010/co2capture/Gopala-Krishnan--FE0000896.pdf>.

“CO₂ Capture from IGCC Gas Streams Using the AC-ABC Process,” presented at the Pre-Combustion CO₂ Capture Kick-Off Meetings, Pittsburgh, Pennsylvania, November 2009.