Pilot-Scale Evaluation of an Advanced Carbon Sorbent-Based Process for Post-Combustion Carbon Capture

2015 NETL CO2 Capture Technology Meeting June 23 – 26, 2015, Pittsburgh, PA.

Project Overview

- Participants:
  - DOE-NETL
  - SRI International, Menlo Park, CA
  - ATMI, Inc., Danbury, CT
  - Linde, LLC, Murray Hill, NJ
  - EPRI, Palo Alto, CA
  - National Carbon Capture Center, Wilsonville, AL
- Period of Performance:
  - 10-1-2013 through 3-31-2018
- Funding:
  - U.S.: Department of Energy: $10.3M
  - Cost share: $2.6M
  - Total: $12.9M

Project Objectives

- Demonstrate the advanced carbon sorbent-based post-combustion capture technology in a 0.5 MWe slip-stream pilot plant.
- Achieve >90% carbon dioxide (CO2) removal from coal-derived flue gas.
- Demonstrate significant progress toward the achievement of the U.S. Department of Energy (DOE) cost target of <$40/ton of CO2 captured.

Team Member Roles

Team Member	Role
SRI International	Project management; reactor design; testing; data analysis; technical and economic evaluation
Linde, LLC	Detailed engineering, construction, test unit installation, testing, and dismantling, technical and economic evaluation
ATMI, Inc.	Sorbent development; industry perspective; process commercialization
Electric Power Research Institute (EPRI)	Collection and analysis of slip stream samples; Electric power industry perspective
National Carbon Capture Center	Host site for slipstream testing

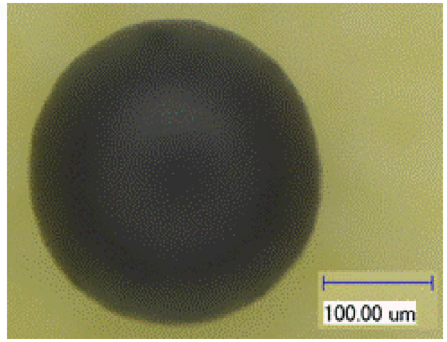
Technology Background: Basic Principles

- Physical adsorption of CO2 from flue gas on a selective and high capacity carbon sorbent.
- Ability to achieve rapid adsorption and desorption rates (no solid state diffusion limit).
- Minimize thermal energy requirements.
- Ability to produce pure CO2 stream suitable for compression and pipe line transportation.
- A continuous, falling micro-bead sorbent reactor geometry integrates the adsorber and stripper in a single vertical column.
  - Provides a low pressure drop for gas flow and minimize physical handling of the sorbent.

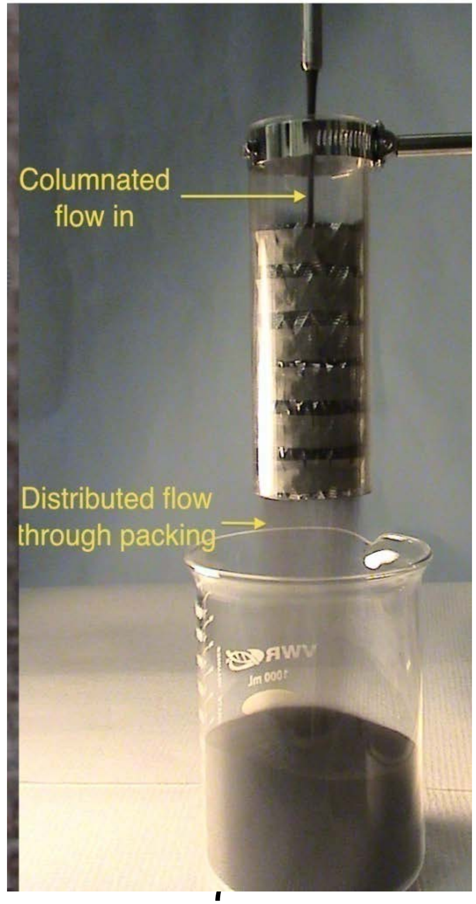
Background: Sorbent Chemical Properties

- High CO_2 capacity:
  - The sorbent has a high capacity for CO_2 adsorption (20 wt% at 1 atm CO_2) and good selectivity for CO_2 over other flue gas components.
- Rapid adsorption and desorption rates:
  - The adsorption of CO_2 occurs on the nanopores of the sorbent with very low activation energy (<5kJ/mole), allowing rapid cycling of the sorbent.
- Low heat of adsorption and desorption:
  - A relatively low heat of sorption (26 to 28 kJ/mole).

Background: Sorbent Physical Properties



- Mechanical robustness for long lifetime:
  - Hard and attrition resistant; Unusually tough for a high surface area (1600 m2/g) porous solid.
  - ASTM Test D-5757: Attrition resistance very high.
  - Field test for 7000 cycles – No noticeable attrition.
- Spherical morphology of the sorbent granules:
  - Sorbent spheres (100 to 300 µm) allows a smooth flow.
  - This free-flowing, liquid-like characteristic allows the use of commercially available structural packing.
- Low heat capacity:
  - The low heat capacity of the sorbent (1 J/g/K) and low density (1 g/cm3) minimizes the thermal energy needed to heat the sorbent to the regeneration temperature.
- High thermal conductivity:
  - The thermal conductivity of 0.8 W/m-K enables rapid thermal equilibrium between the sorbent surface and interior.



Background: Previous Bench-Scale Tests

- Performed a 135 h test with a flue gas from a coal-fired boiler at the University of Toledo
- The system was able to reduce the CO_2 level from 4.5% to <0.05% (fully regenerated sorbent).
- We achieved steady-state operation with 90% capture efficiency with >98% CO_2 purity in the product gas.
- Sorbent flow: Smooth; Typical cycle time: ~1 min.
- No significant operational issues were observed (except for cold-weather related problems – not process related).
- Tests were terminated when the boiler was shut down.

Project Schedule

- Three Budget Periods
  - BP1: 15 months – extended by 12 months
  - BP2: 12 months
  - BP3: 15 months
- At the end of each BP with continuation applications due; Go/No Go decisions by DOE.

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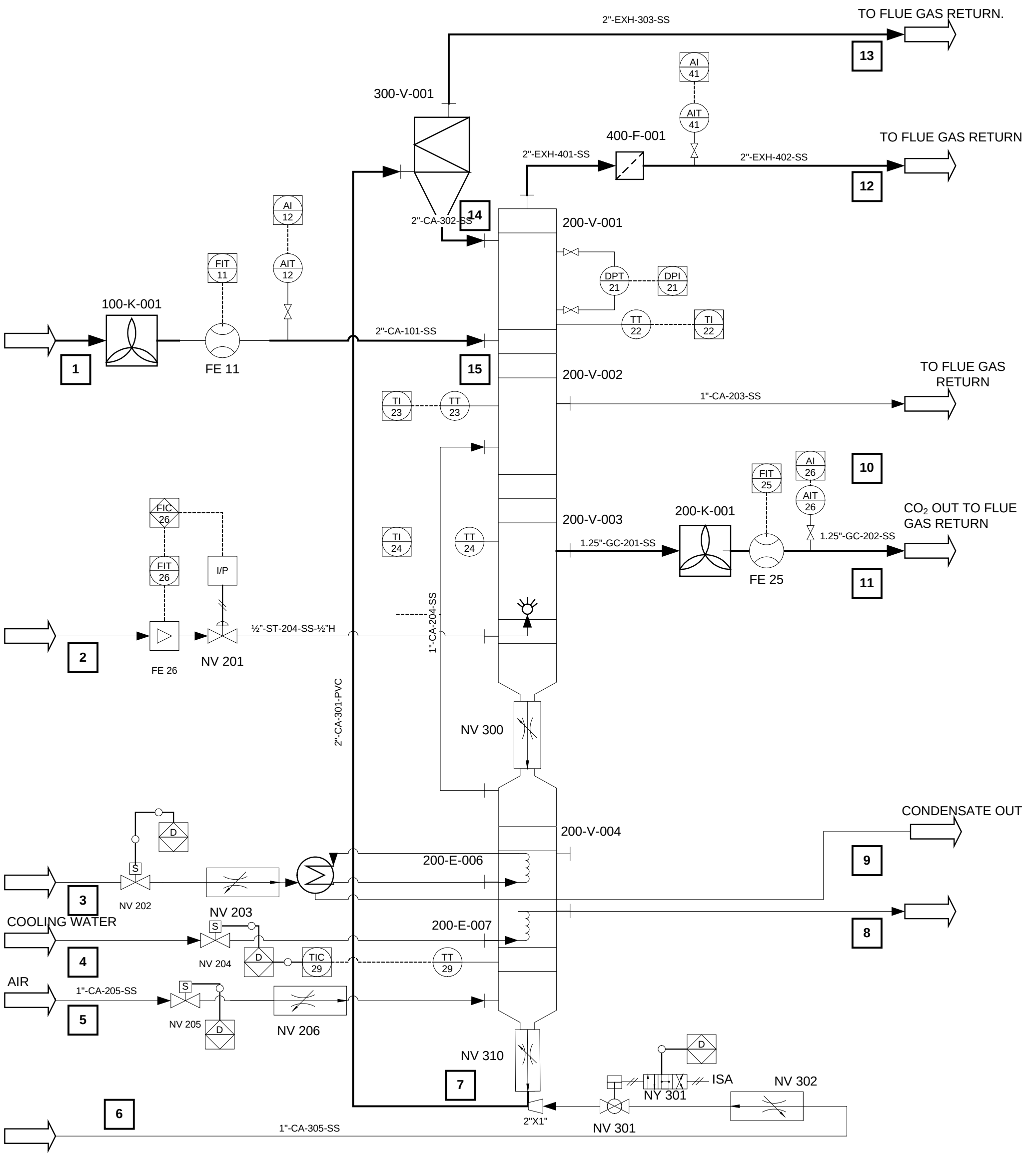
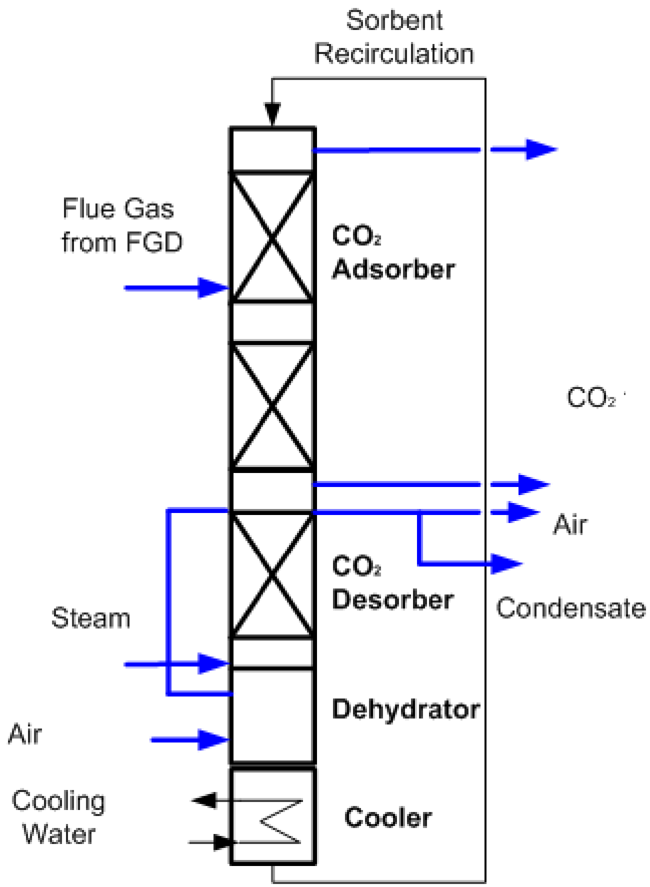
Budget Period 1 Activities

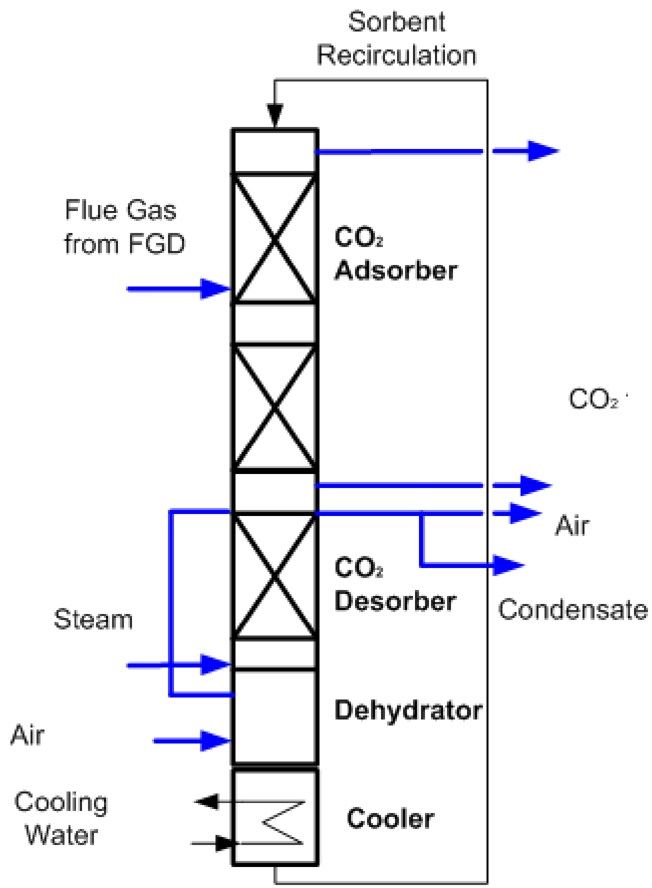
- Task 1: Program Management & Planning
- Task 2.0: Sorbent Testing at National Carbon Capture Center
- Task 3.0: Initial Techno-Economic Analysis
- **Decision Point – Go/No Go**
- Task 4.0: Sorbent Specification
- Task 5.0: 0.5 MWe Pilot Plant Design
- Task 6.0: Pilot Plant Safety Analysis
- Task 7.0: Pilot Plant Detailed Engineering and Cost Assessment
- **Decision Point – Go/No Go**

System for Tests at NCCC

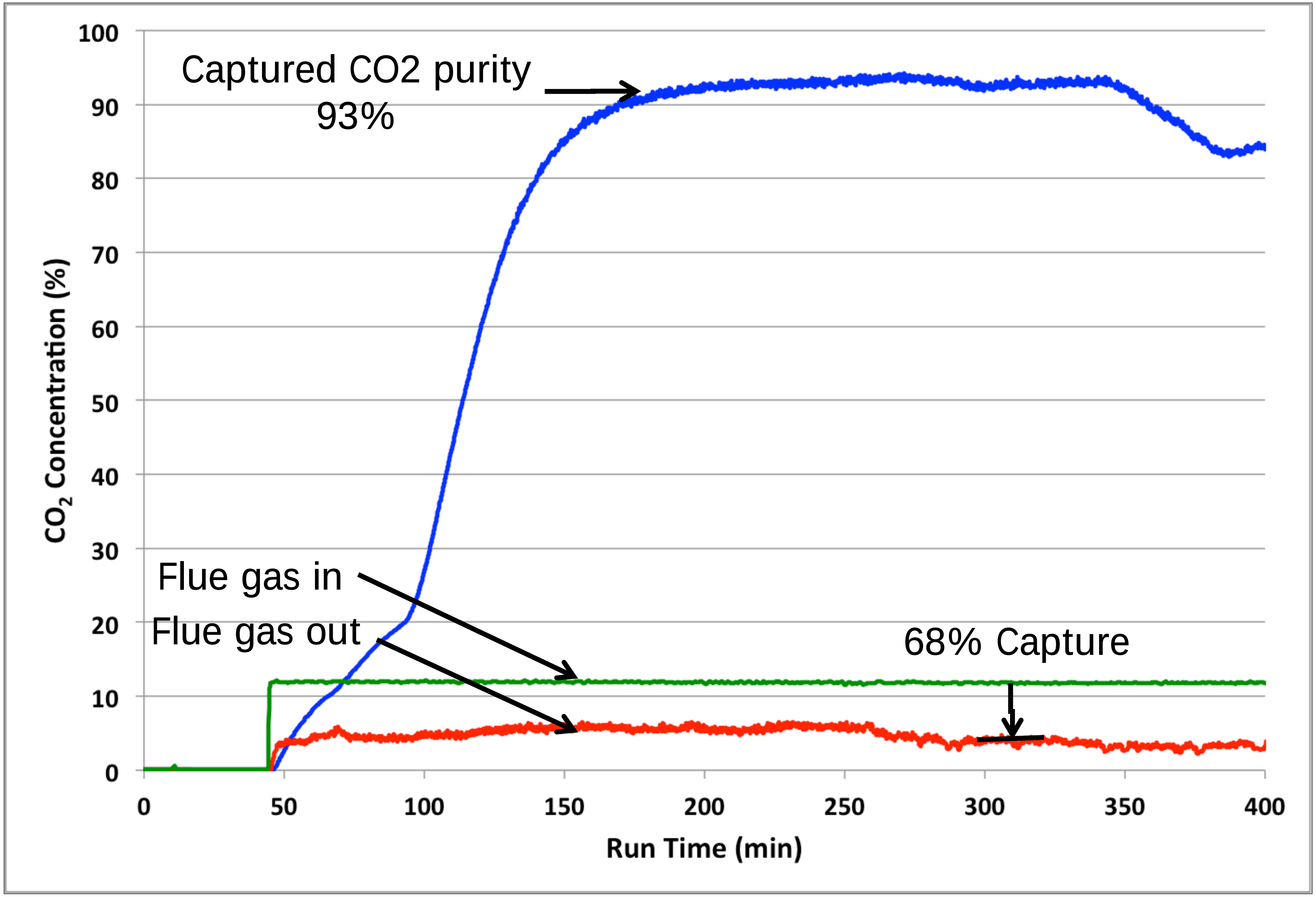




Installed Structure at NCCC Pad



Flue Gas Flow



Challenges at NCCC Testing

- Pneumatic lift operation
  - Disengagement at the top of the adsorber due to bouncy nature of the sorbent.
  - Use resilient material at the point of impact.
  - Used the structural packing as an impact separator.
- Pressure balance inside the column
  - The pressure at the flue gas feed and return points highly variable.
  - Caused instability in the column operation.
- Materials of construction
  - Corrosion at the stripper section (304 SS)

Preliminary TEA

Power Plant Cost Summary		No Capture	Econamine	Carbon Sorbent
Capacity Factor		0.85	0.85	0.85
Capital Charge Factor		0.12	0.12	0.12
20-year Levelization Factors				
Fuel		1.21	1.21	1.21
Non-Fuel Variable O&M		1.16	1.16	1.16
Fixed O&M		1.16	1.16	1.16
Plant Operating Life	years	30.00	30.00	30.00
Power Production @100% Capacity	GWh/yr	4818.16	4821.73	4809.36
Power Plant Capital	¢/kWh	3.84	7.32	5.68
Power Plant Fuel	¢/kWh	2.58	3.70	3.00
Variable Plant O&M	¢/kWh	0.73	1.24	1.12
Fixed Plant O&M	¢/kWh	0.95	1.56	1.20
Power Plant Total	¢/kWh	8.10	13.83	10.99
CO2 Transport and Storage	¢/kWh		1.02	0.83
BOTTOM LINE TOTAL	¢/kWh	8.10	14.85	11.82
Increase in COE	%	0.00	83.4%	45.9%
CO2 Emissions	lb/MWh		251.80	252.45
CO2 Captured	$/Tonne	0.00	66.17	44.99

SRI performed TEA: Cost of capture is $45/tonne

Linde LLC review of TEA in process

Current Activities

- Basic engineering design of 0.5 MW system near completion
  - Design basis, Process design, Equipment list, Piping and Instrumentation complete
- Initiated Safety Analysis and HazOp study
- About to start detailed engineering
- Detailed engineering and cost assessment to be complete by the end of the year

Budget Period 2 Activities

- Task 8.0: Pilot Plant Equipment Procurement and Fabrication
- Task 9.0: Civil and Structural Engineering
- Task 10.0: Pilot Plant Installation
- Task 11: Sorbent Production for Pilot Testing
- **Decision Point – Go / No Go**

Budget Period 3 Activities

- Task 12.0: Operation of the Pilot Plant
  - Subtask 12.1: Pilot Plant Commissioning
  - Subtask 12.2: Development of a Test Plan
  - Subtask 12.3: Parametric Testing
  - Subtask 12.4: Long Duration Testing
- Task 13.0: Final Technology Assessment
  - Subtask 13.1: Updated TEA
  - Subtask 13.2: Updated EH&S Risk Assessment
  - Subtask 13.3: Commercialization Plan
- Task 14.0: Pilot Plant Decommissioning

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