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

2014 NETL CO_2 Capture Technology Meeting
July 29 – August 1, 2014, Pittsburgh, PA.

Project Overview

- Participants:
  - DOE-National Energy Technology Center
  - 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 3-31-2017
- Funding:
  - U.S.: Department of Energy: $10,326,835
  - Cost share: $2,587,587
  - Total: $12,914,422

Project Objectives

- Demonstrate the advanced carbon sorbent-based post-combustion capture technology in a 1 MWe slip-stream pilot plant.
- Achieve >90% carbon dioxide (CO_2) 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 CO_2 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

Basic Principles

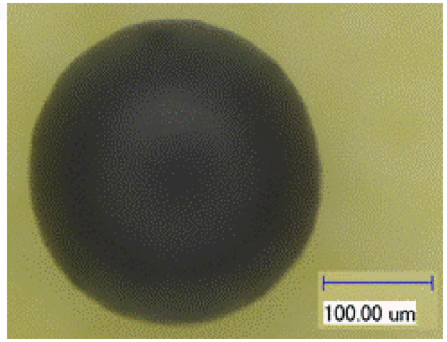
- Physical adsorption of CO_2 from flue gas on a selective and high capacity carbon sorbent.
- Ability to achieve rapid adsorption and desorption rates (no solid state diffusion limit).
- Minimize thermal energy requirements.
- Ability to produce pure CO_2 stream suitable for compression and pipe line 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.

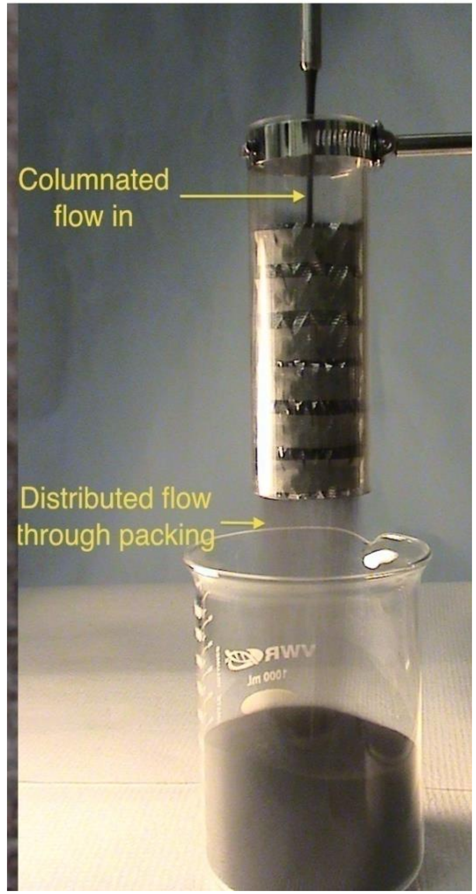
Sorbent – Chemical Properties

- 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).

Sorbent – Physical Properties

- Mechanical robustness for long lifetime:
  - Hard and attrition resistant; Unusually tough for a high surface area (1600 m^2/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/cm^3) 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.

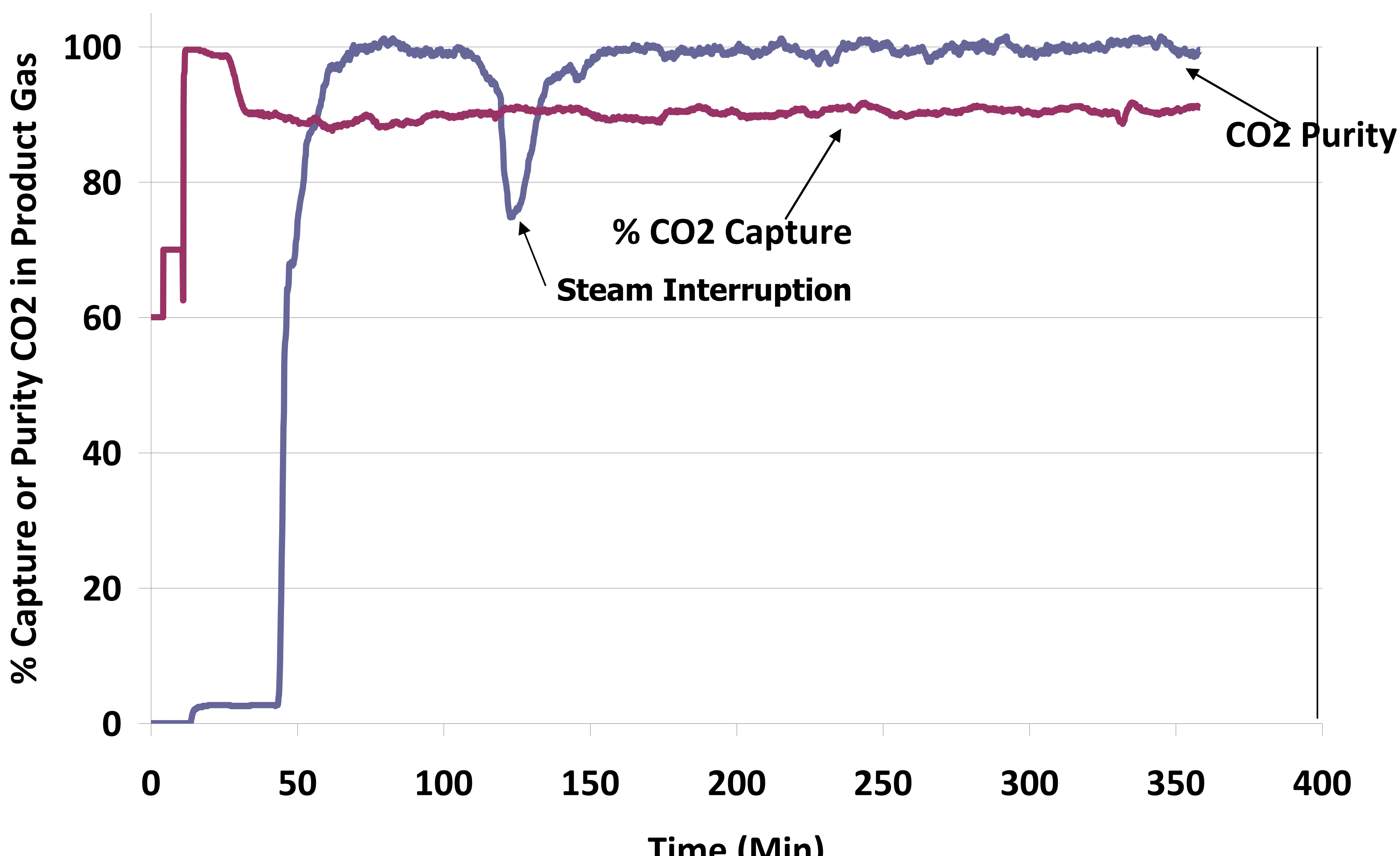




Summary of Previous Bench-Scale Tests

- 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.

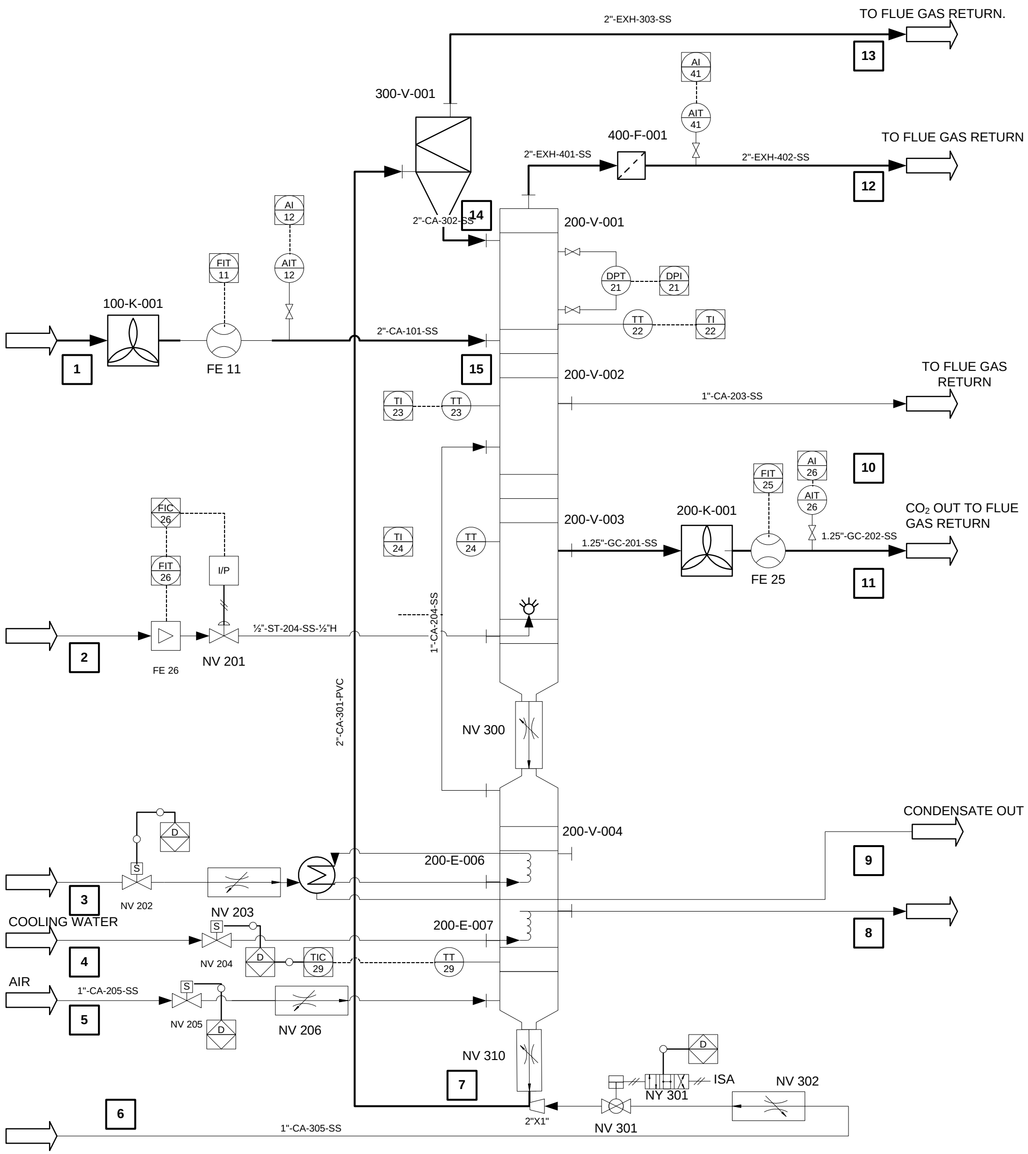
CO2 Capture Efficiency and Product Gas Purity

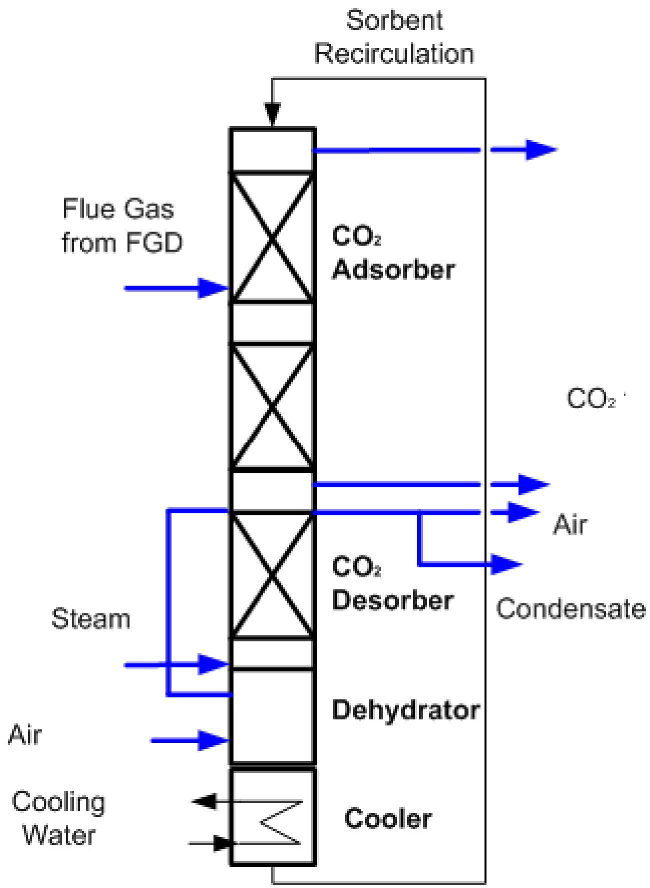


Current Testing at NCCC

- Testing with a flue gas from a PC-fired boiler.
- Test goal: 150 h of continuous operation; 600 h of total operation.
- Completed >250 h of operation.

System for Tests at NCCC

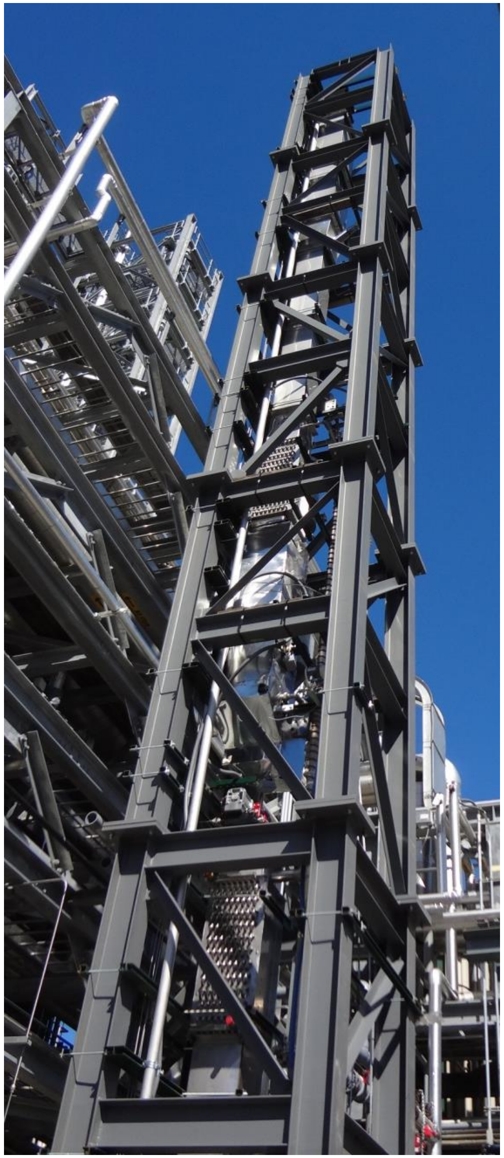


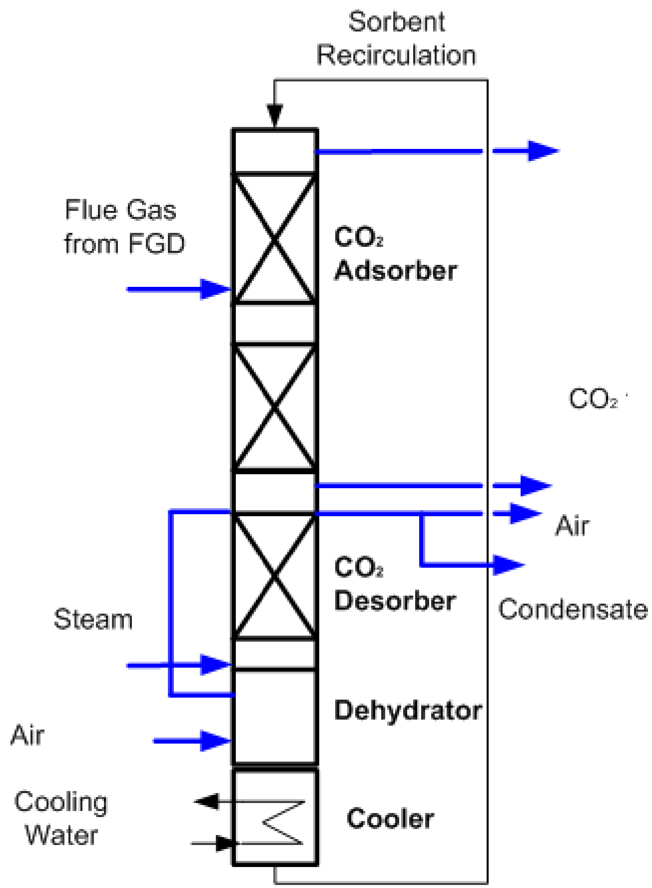


Design of Integrated Reactor for Testing at NCCC

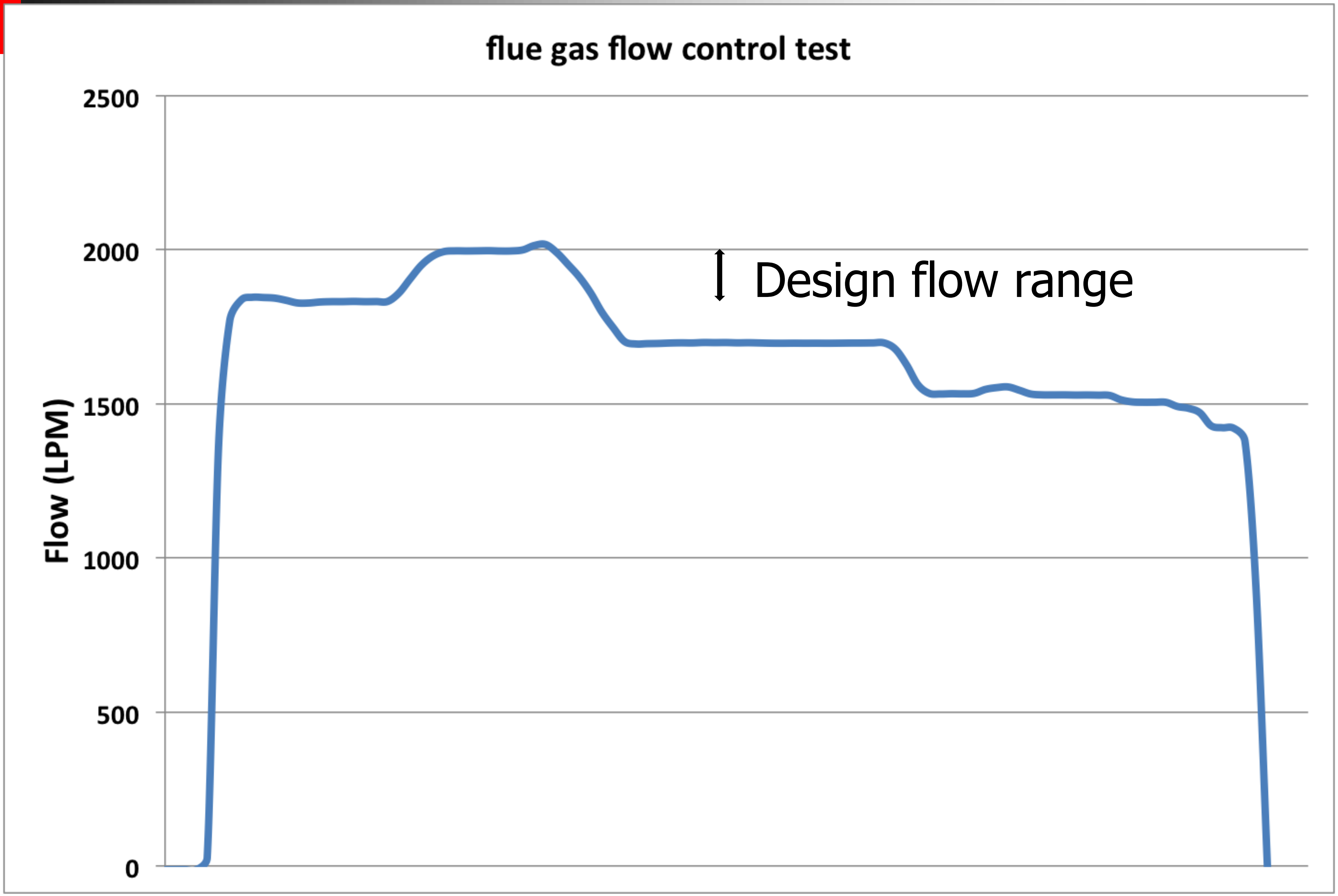
- System Dimensions:
  - 1.5 ft square x 50 ft tall
  - Adsorber: 15-ft tall; Stripper: 15-ft tall
- A heat exchanger to recover heat from hot, regenerated sorbent and use it to preheat the sorbent from the adsorber.
- Pneumatic transport of the sorbent microbeads.
- Nominal flue gas flow: 70 cfm.
- Goal: 90% CO_2 and >98% CO_2 purity.
- CO_2 capture capacity: ~1 ton/day.

Installed Structure at NCCC Pad

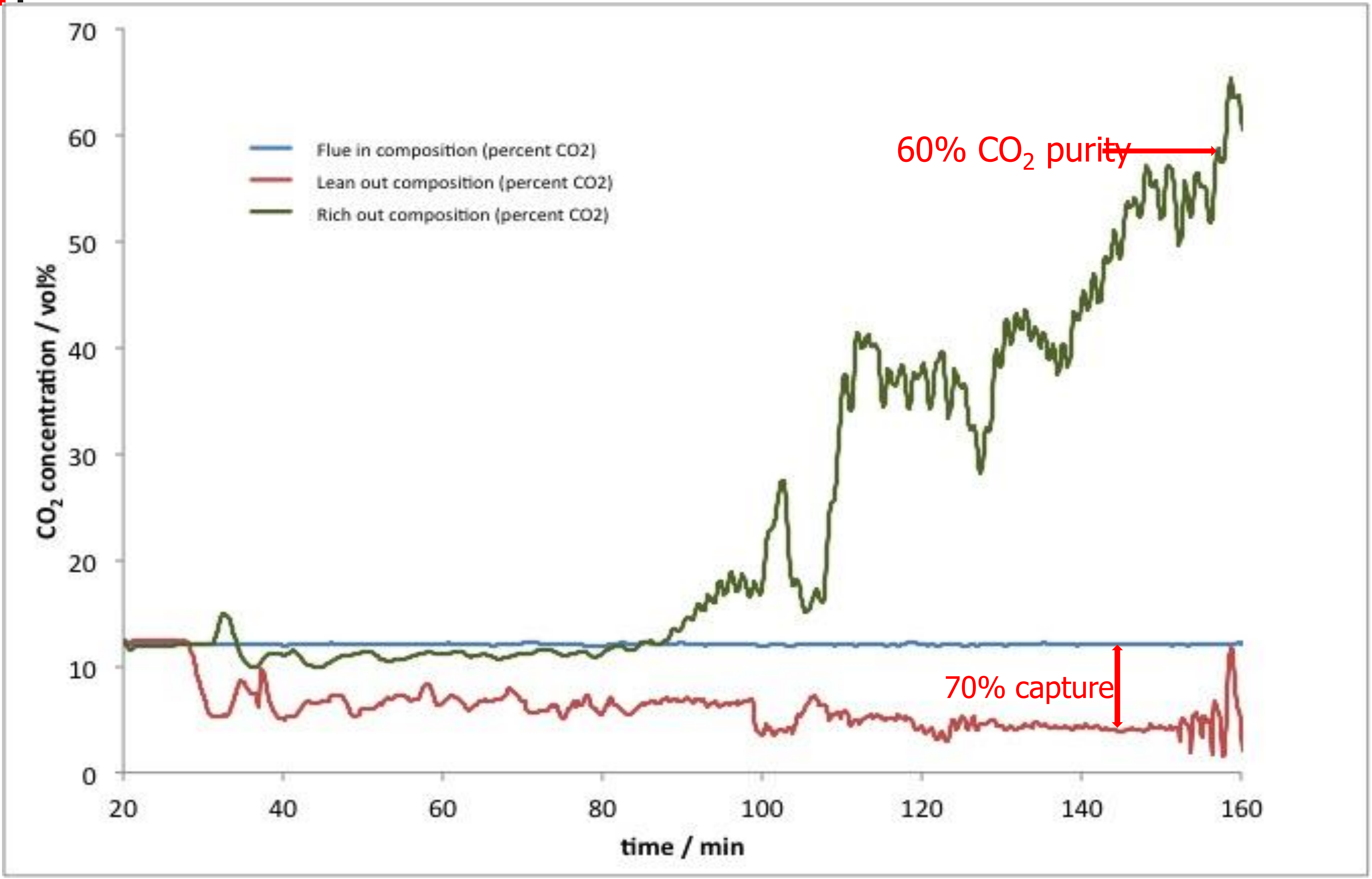




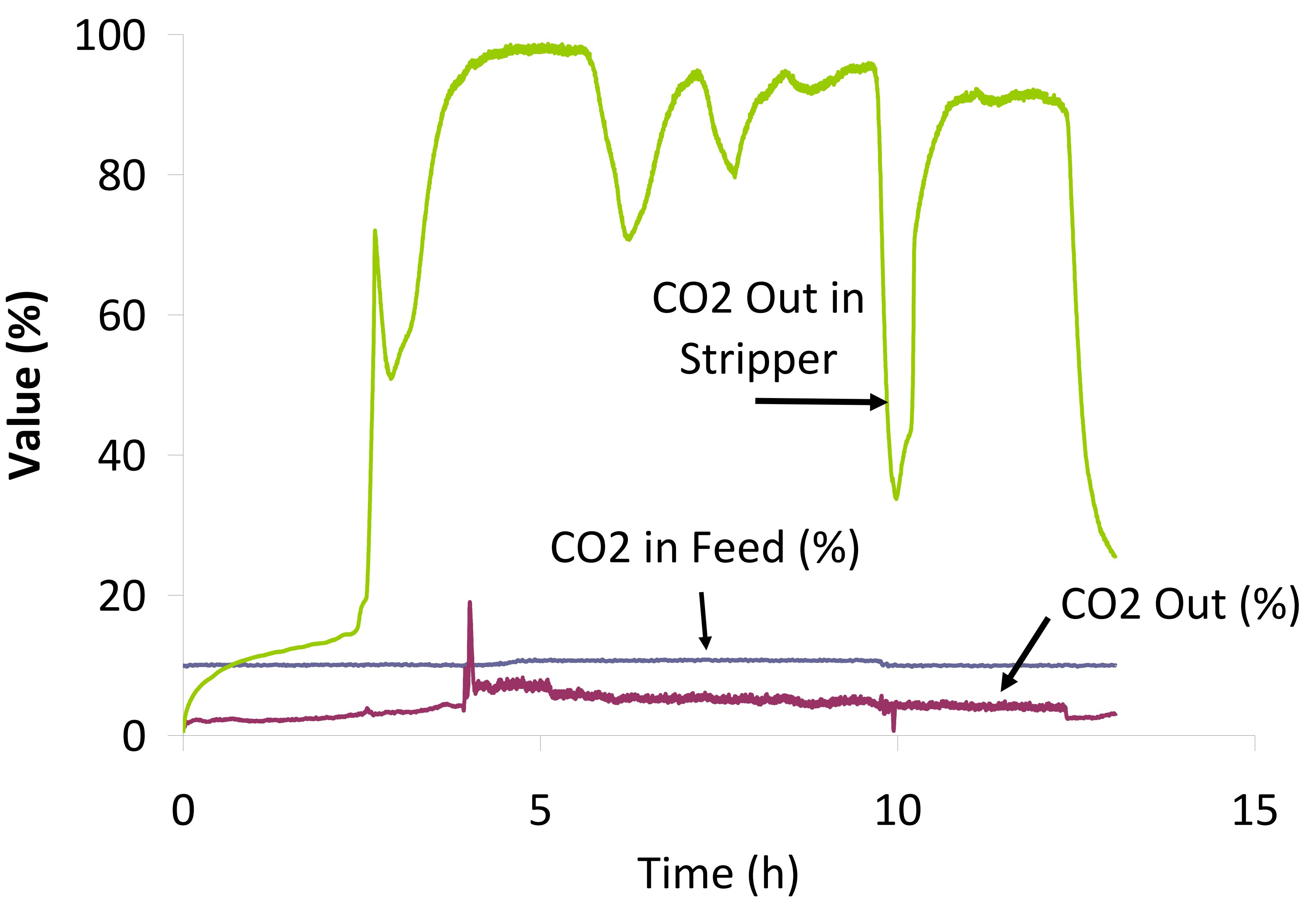
Flue Gas Flow



Initial Carbon Capture Efficiency and Purity



Carbon Capture Efficiency and Purity



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)

Project Schedule

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

Budget Period 1 Activities

- Task 1: Program Management & Planning
- Task 2.0: Sorbent Testing at National Carbon Capture Center – In progress
- Task 3.0: Initial Techno-Economic Analysis: In progress
- **Decision Point – Go/No Go**
- Task 4.0: Sorbent Specification
- Task 5.0: 1 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**

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
- 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

Acknowledgements

- SRI International:
  - Gopala Krishnan, Marc Hornbostel, Jordi Perez, Anoop Nagar
- ATMI Inc.
  - Joshua B. Sweeney, Melissa Petruska,
- Linde:
  - Krish Krishnamurthy, Makini Byron.
- EPRI (and First Energy):
  - Richard Rhudy, Abhoyjit Bhown
- National Carbon Capture Center:
  - Frank Morton, John Carroll.
- DOE-NETL:
  - Andrew Jones