Eighth Annual Conference on Carbon Capture & Sequestration

Technical Session: Capture (Sorbents) 1

Update on RTI's Dry Carbonate Process: Carbon Dioxide Capture from Power Plant Flue Gas

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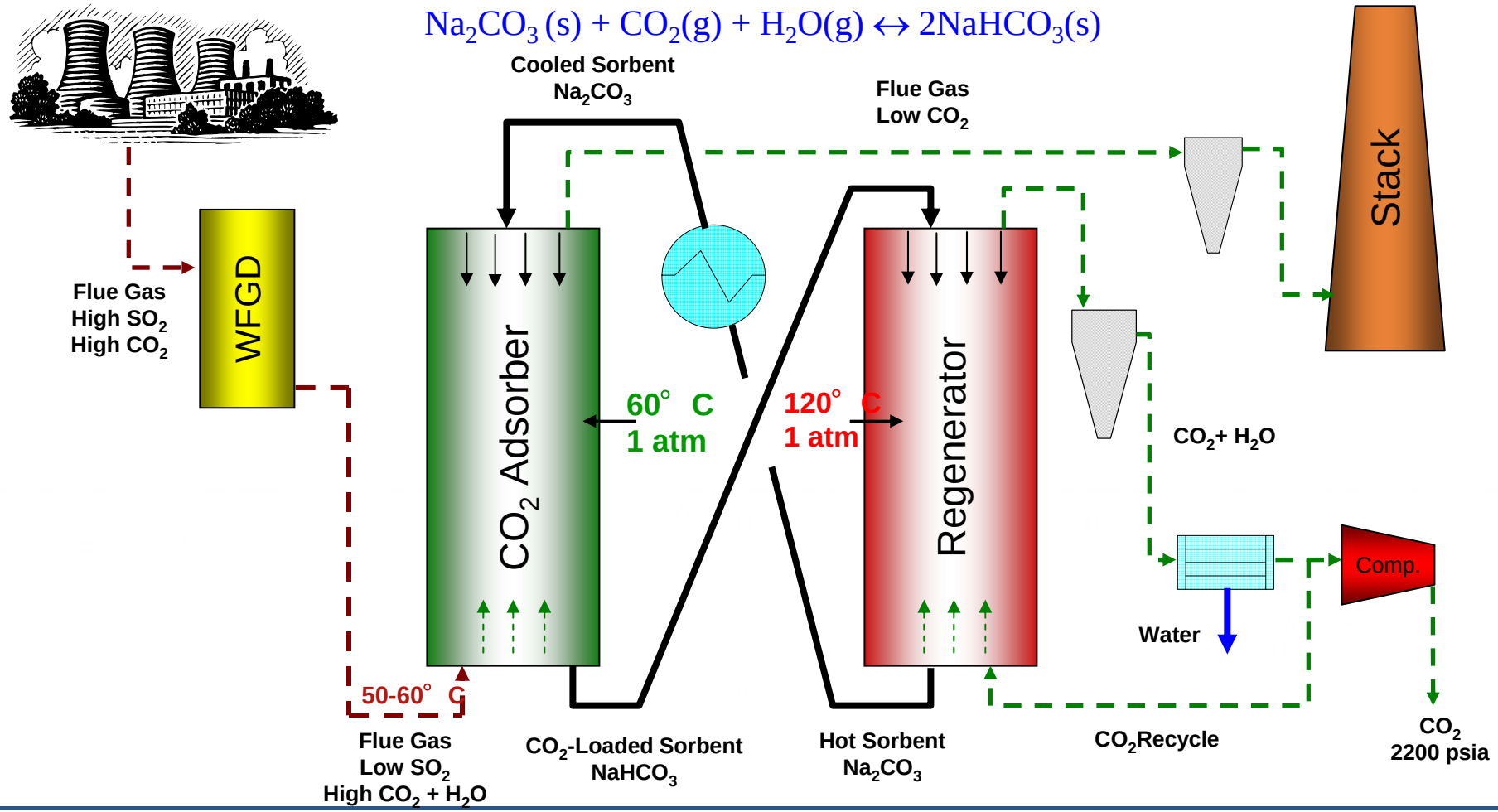
Project Overview

- **Description:** RTI is continuing the development of a dry sorbent-based, post-combustion CO_2 capture technology for retrofit in existing fossil fuel-fired power plants

- **Key technology features:**
  - Based on sodium carbonate / sodium bicarbonate chemistry
  - Thermal-swing, regenerable process
  - Process conditions: 60° C CO_2 capture; 120° C Regeneration, ambient pressure
  - Initial target application: coal-fired power plants with wet flue gas desulfurization
- **Key project features:**
  - Built on past research: DOE Project # DE-FC26-00NT40923
  - Emphasis on coupled process and sorbent technology development
  - Project R&D focused on scale-up to pre-pilot (1 ton/day) CO_2 capture prototype

Technology Background

RTI's Dry Carbonate Process



RTI's Dry Carbonate Process

Reaction Chemistry

CO_2 Adsorption (Carbonation)

$$Na_2CO_3(s) + CO_2(g) + H_2O(g) \leftrightarrow 2NaHCO_3(s)$$

Exothermic ΔH_r° = -1325 Btu/lb CO_2

Operating temperature: < 80° C

Sorbent Regeneration

$$2NaHCO_3(s) \leftrightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$$

Endothermic ΔH_r° = 1325 Btu/lb CO_2

Operating temperature: ~120° C

Contaminants

$$Na_2CO_3(s) + SO_2(g) + \tfrac{1}{2}O_2(g) \rightarrow Na_2SO_4(s) + CO_2(g)$$
$$Na_2CO_3(s) + 2HCl(g) \rightarrow 2NaCl(s) + CO_2(g) + H_2O(g)$$

No observed effects by O_2, Hg, and NO_x

Advantages of a Na_2CO_3-based CO_2 Capture Process
(Compared to conventional amine technology)

- Sorbent Advantages
  - Readily available and inexpensive sorbent (raw material)
  - Non-hazardous and non-toxic sorbent
  - No hazardous emissions or waste generated
  - Tolerance to contaminants in flue gas (e.g., H_2O, O_2, SO_2, HCl)
    - Near-zero emissions from power plant
- Process Advantages
  - Lower total regeneration energy requirement
  - Lower CO_2 removal cost
    - capital savings; operating costs; sorbent make-up savings
  - No flue gas pretreatment
    - No heating, No cooling, No guard beds

Challenges of CO_2 Capture with a Na_2CO_3-based Process

- Sorbent Challenges
  - Na_2CO_3 reacts irreversibly with SO_2 and HCl at process conditions
    - Solution: *Continuous sorbent make-up*
  - Raw Na_2CO_3 is not physically strong
    - Solution: *Engineered sorbent (binders / support materials)*
- Process Challenges
  - Large solids handling/circulation requirements
    - Best-case scenario → $Na_2CO_3 : CO_2 = 2.4 : 1$ (mass ratio)
    - Solution: *High capacity sorbents; utilize best available solids handling technologies*
  - Exothermic CO_2 capture affects reaction equilibrium
    - CO_2 capture is heat transfer limited
    - Solution: *Reactor design is critical; target designs with highly effective heat transfer*
  - Water management in process
    - Solution: *Engineered sorbent; operate system above flue gas dew point*

Project History

Project History

Development Timeline (*Focus*: Process and Sorbent Development)

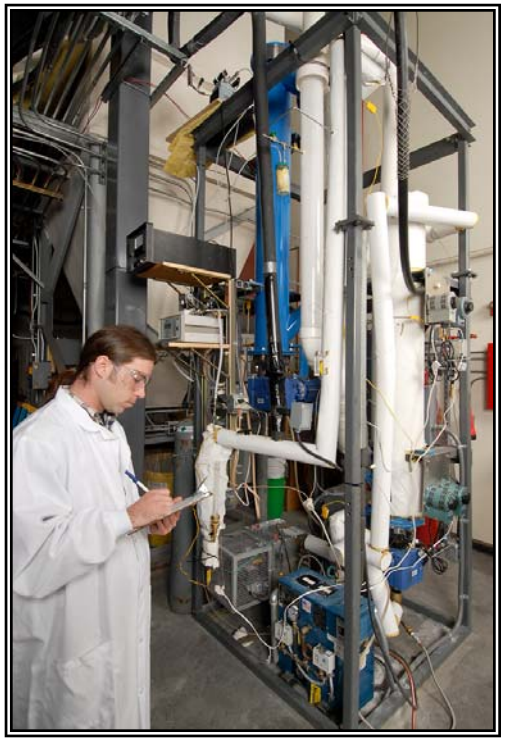
- Early proof-of-concept testing: Thermogravimetric Analysis
- 2005 – 2006: Sorbent and reactor screening
- 2007 – 2008: Field Testing at U.S. EPA's coal combustion facility

EPA Testing

- Facility: 1.2 MW_t multi-fuel fired facility (330 lbs/hr coal)
- RTI worked with ARCADIS to install and operate Dry Carbonate unit
- Process: Bench-scale entrained-bed based reactor
- Sorbent: Sodium carbonate on support material

Highlights of Coal-fired, EPA Testing

- Able to operate with continuous adsorption and regeneration
- Hundreds of hours of combustion flue gas testing
- > 90% CO_2 capture exhibited with both coal and natural gas
- Heat control in adsorber is critical for CO_2 capture rate – reactor design must be optimized
- Sorbent CO_2 working capacity is not economically viable

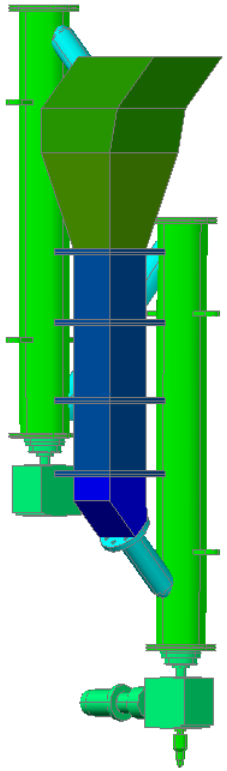


Current Research & Development

Dry Carbonate Process

- RTI has selected an isothermal, fluidized moving-bed design for further scale-up
- Most commercially- and technologically-feasible embodiment of the Dry Carbonate Process
- Design specifically addresses key process challenges

Heat Transfer	• Achieves maximum heat transfer rates • Dedicated heating/cooling service systems • Commercial: Coal dryers, Circulating fluidized-bed combustors
Reaction Rate	• Maximizes thermodynamic and concentration driving forces • Maximizes gas-solid contacting • Permits counter-current gas-solids contacting
Solids Handling	• Permits gravity feeding through reactor • Simple gas-solid separation • Commercial: Used in mining, cement plants, power plants



- Focus on scale-up: Dry Carbonate pre-pilot capable of 1 ton/day CO_2 capture

RTI's Development Approach

RTI's ongoing R&D effort to prepare for 1 TPD CO_2 capture unit

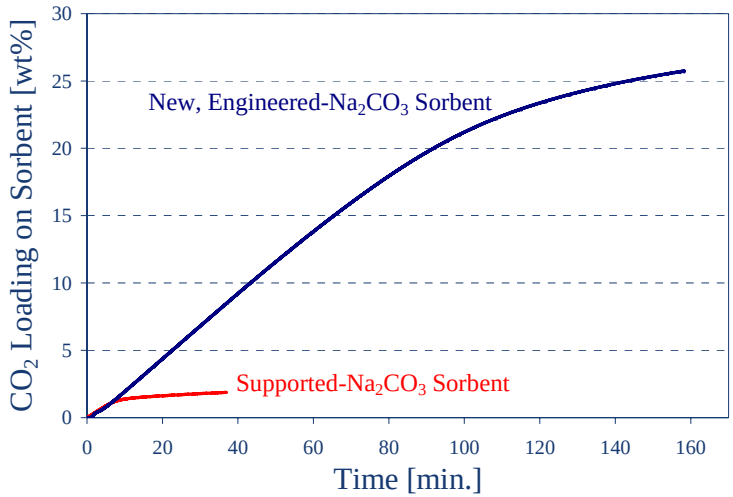
Development Areas	Approach
Improve Sorbent CO_2 Capacity	• Modify sorbent recipe and production procedure • Screen candidates in lab-scale CO_2 adsorber
Evaluate Fluidized, Moving-bed Heat Transfer	• Measure overall heat transfer coefficients on bench-scale • CFD Modeling to accelerate development
Operate in Moving-bed Mode	• Bench-scale evaluation of moving-bed contactor
Evaluate Solids Handling / Control	• Consult with solids/fluidization experts • Bench-scale evaluation of conveyors and control valves
Develop Process Design & Sizing	• Detailed engineering and design for 1 ton/day pre-pilot unit

Sorbent Optimization Program

- R&D Scope of Work
  - Construct sorbent test station → Complete
  - Improve sorbent CO_2 loading capacity → Complete
  - Improve sorbent CO_2 capture rate → In Progress
  - Maintain target physical properties → In Progress
  - Scalable manufacturing procedure → In Progress

Status

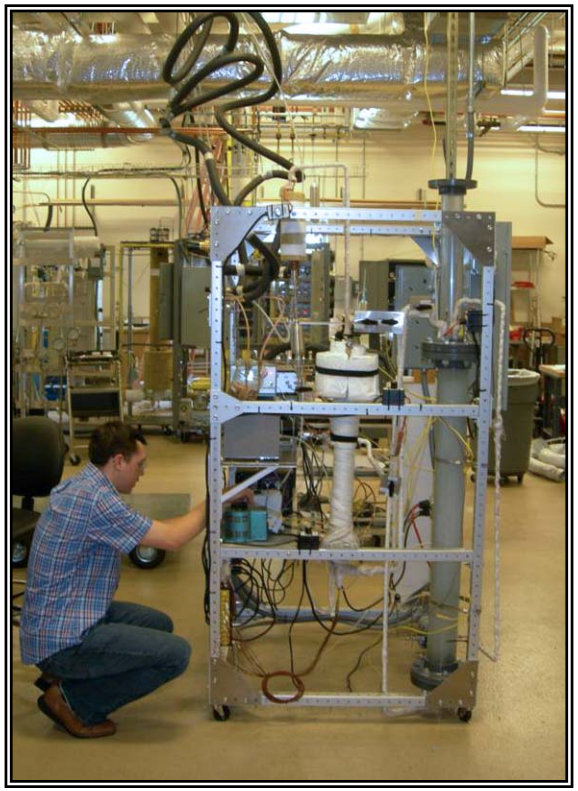
- Expected Results
  - Na_2CO_3-based sorbent having a minimum dynamic CO_2 capacity of 10 wt%
  - Sorbent with an optimized CO_2 capture rate
  - Attrition resistance consistent with commercial materials used in fluidized-bed applications
  - Production of several thousand pounds of optimized sorbent by Süd-Chemie, Inc.



- >10x improvement in CO_2 loading capacity
- Maintained high rate of capture

Sorbent Development Program

Bench-scale CO_2 Sorbent Test Station



Status of R&D Effort

Sorbent	Density [g/cm³]	Attrition Ratio[1]	CO_2 Capacity [wt%]
Supported -Na_2CO_3	0.96	0.75	2.2
Sorbent A	0.67	1.8	13.3
Sorbent B	0.57	1.4	16.3
Sorbent C	0.65	2.0	24.3
Sorbent D	0.73	1.2	30.0

Continuous Improvement

[1]Attrition ratio is a relative measure of a material's physical strength.

- Continuous, directed sorbent improvement
- Commercially-relevant production procedures
- Scale-up at Süd-Chemie manufacturing plant

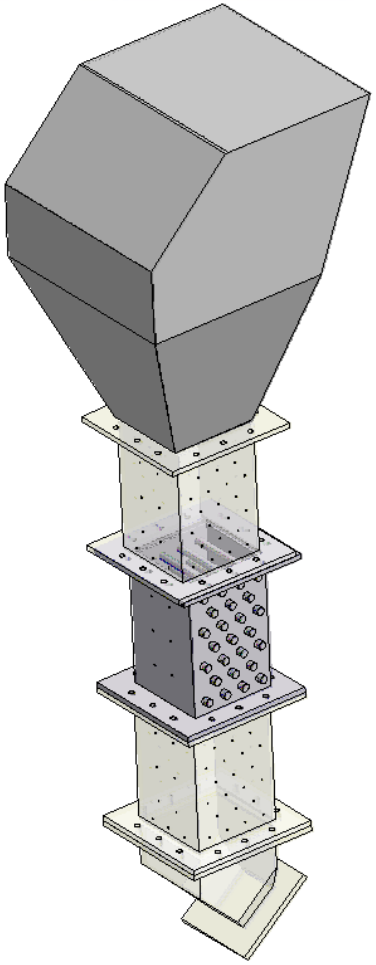
Heat Transfer Evaluations

- R&D Scope of Work
  - Design heat transfer evaluation system
  - Construct heat transfer evaluation system
  - Test heat transfer evaluation system

Status
→ Complete
→ In Progress
→ May 2009

- Expected Results
  - Strong understanding of hydrodynamics and heat transfer
  - Obtain "real" overall heat transfer coefficients
  - Identify effective reactor designs
  - Effectively design pre-pilot CO_2 Capture and Regeneration reactors

Approach	Description
Flexible / Modular design	• Design and build multiple gas-solid contactors • Utilize various heat transfer internal patterns (pitch ratio, layout, orientation) • Well instrumented • Utilize existing screw conveyors for sorbent delivery
Evaluate bed hydrodynamics	• Measure bed densities, pressure drop, fluidization • Define regions of operability for gas and solids flow
Evaluate heat transfer	• Measure overall heat transfer coefficients • Determine heat transfer efficiency throughout bed



Solids Handling and Control

Status

→ In Progress

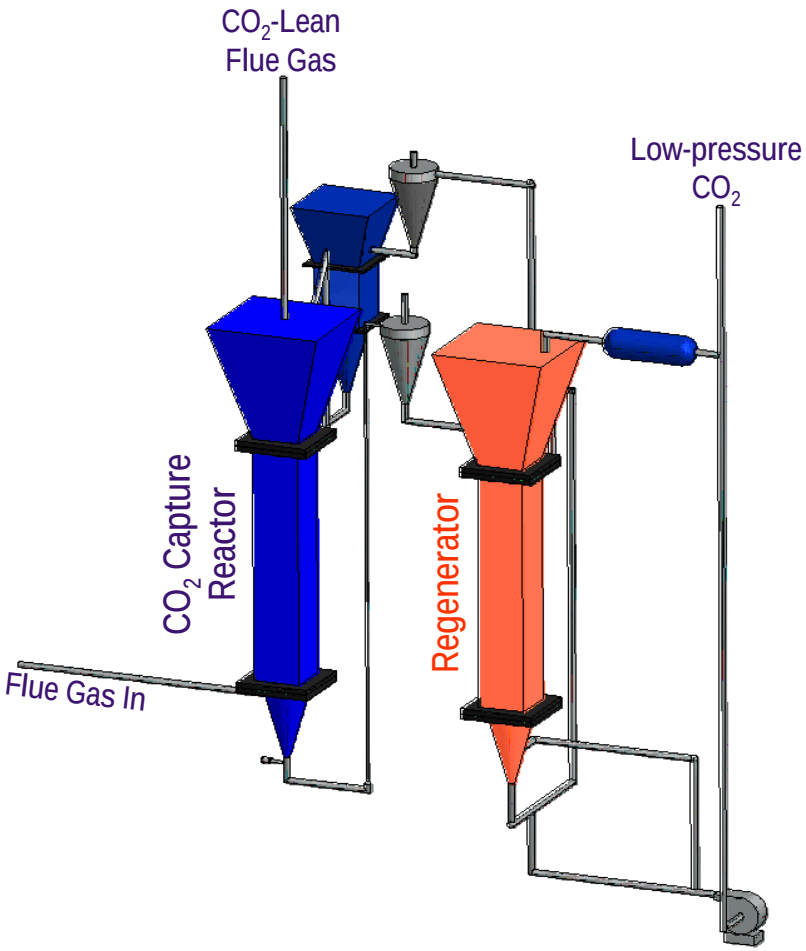
- R&D Scope of Work
  - Evaluate solids control valves
  - Demonstrate pneumatic conveying of carbonate sorbent
  - Evaluate gas-solids separation and filtering
- Expected Results
  - Effective solids flow control techniques for 1 TPD
  - Operating ranges for pneumatic conveyor
  - Effective gas-solids separation techniques
- Approach
  - Utilize solids flow equipment developed under DOE-funded project DE-FG36-04GO14312
  - Parametric testing of control valves, seals, conveying, and separation techniques (i.e., cyclone design, bag-filter, etc.)

Design of 1 TPD CO_2 Capture Unit

- Scale: 1 ton per day CO_2 Capture Unit
- Current work: generating PFDs and P&IDs, sizing, reviewing fabrication needs, process control
- Sizing:

CO_2 Captured (90%)	2000 lbs/day, 84 lbs/hr
Flue Gas Flowrate (wet)	8,730 SCFH
Initial Sorbent Loading	1,500 lbs
Sorbent Circulation	500 – 1500 lb/hr
Sizing of Test Unit	12' tall - 4' X 4' footprint
Cooling Load (water)	10 gpm
Heating Load (steam)	140 lb/hr

- Modular and easily scalable design



Path Forward

EPA Field Testing of Pilot Dry Carbonate Process

Objectives:

- 2,500 hours online
- Utilize 10-20% slipstream of flue gas
- Evaluate multiple coals and conditions: bituminous, sub-bit., lignite

Expected Outcomes:

- Long-term reliability proven
- True measure of:
  - sorbent attrition
  - sorbent degradation
  - regeneration gas purity
- Parametric/sensitivity studies exhibit optimal conditions for Dry Carbonate Process

Detailed Technical and Economic Analyses

- Comprehensive technical and economic analysis of RTI's Dry Carbonate Process by EPRI and Nexant (complete by end of BP2)
  - Basis: DOE's "Bituminous Coal" Report (2007)
  - Baseline: Fluor's Econamine FG+ CO_2 capture process
  - Utilize data from pilot-scale testing
  - Expected outcomes: CAPEX, OPEX, Power Performance, novel heat integration schemes, novel compression schemes
- Other Activities:
  - Retrofit impact analyses
  - Analyses of CO_2 capture for other industrial sources (cement, refining, natural gas…)

Path to Commercialization

Development timeline for RTI's Dry Carbonate Process

2001
Laboratory and "proof of concept" studies

2003
Novel CO_2 capture sorbent developed based on supported sodium carbonate

2005
RTI field testing proves feasibility of dispersed gas-solid reactor design

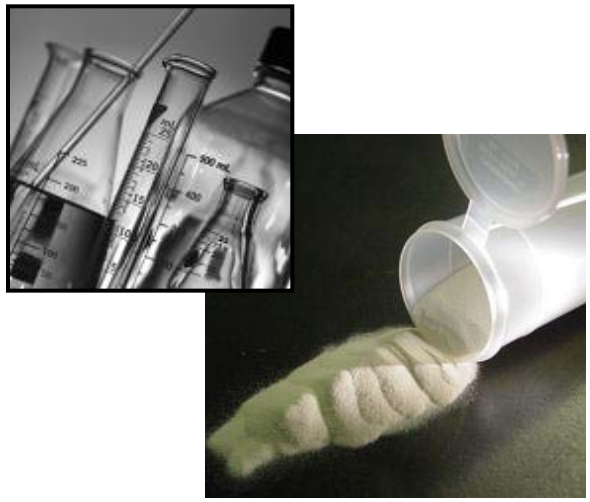
2007
Bench-scale system successfully tested at coal-fired research facility

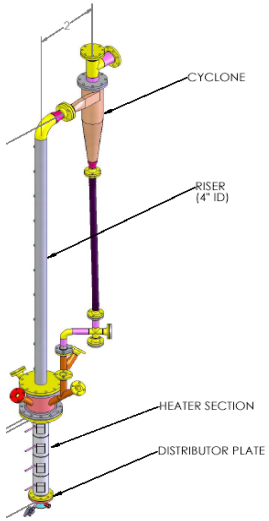
→

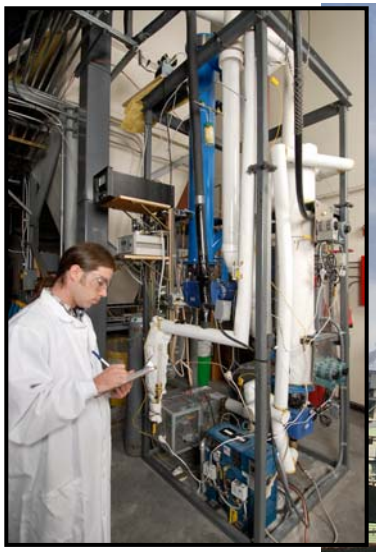
2010
Pilot-scale demonstration of technology – up to 1 ton CO_2 captured per day

2012
Large-scale demonstration at utility company site – 100 ton CO_2 captured per day

>2015
Commercial Technology







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