July 29, 2014

Advanced Solid Sorbents and Process Designs for Post-Combustion CO_2 Capture (DE-FE0007707)

RTI International

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Project Overview

Objective

Address the technical hurdles to developing a solid sorbent-based CO_2 capture process by transitioning a promising sorbent chemistry to a low-cost sorbent suitable for use in a fluidized-bed process

This project combines previous technology development efforts: RTI (process) and PSU (sorbent)

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Project Funding: **$3,847,161**

- DOE Share: $2,997,038
- Cost Share: $850,123

Period of Performance:

- 10/1/2011 to 6/30/2015

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- Project management
- Process design
- Fluidized-bed sorbent

PENNSTATE

1855

- PSU's EMS Energy Inst.
- PEI and sorbent improvement

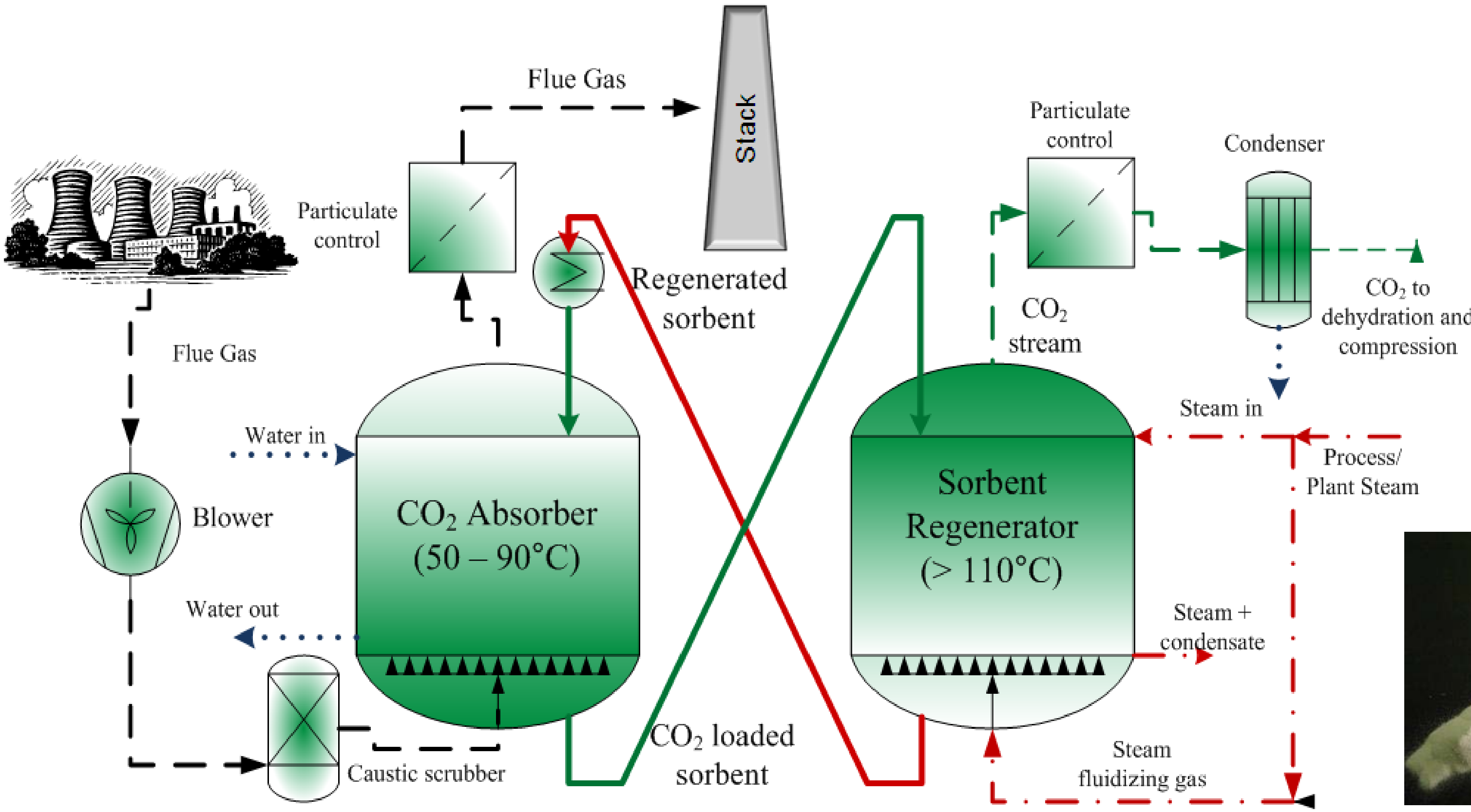
Specific Project Goals

- Improve stability, performance, and fluidizability of novel amine-based (PEI) "Molecular Basket Sorbents"
- Improve design of fluidized, moving-bed reactor; optimize operability and heat integration
- Prove that the technology reduces parasitic energy load and capital and operating costs associated with CO_2 capture (prototype testing & economic analyses)

Masdar
A MUBADALA COMPANY

- Masdar New Ventures
- Masdar Institute
- Techno-economic evaluation of NGCC application

Technology Background



Sorbent Chemistry

- Polyethyleneimine (PEI)

Primary:	$CO_2 + 2RNH_2 \rightleftarrows NH_4^+ + R_2NCOO^-$
Secondary:	$CO_2 + 2R_2NH \rightleftarrows R_2NH_2^+ + R_2NCOO^-$
Tertiary:	$CO_2 + 2R_3N \underset{H_2O}{\rightleftarrows} R_4N^+ + R_2NCOO^-$

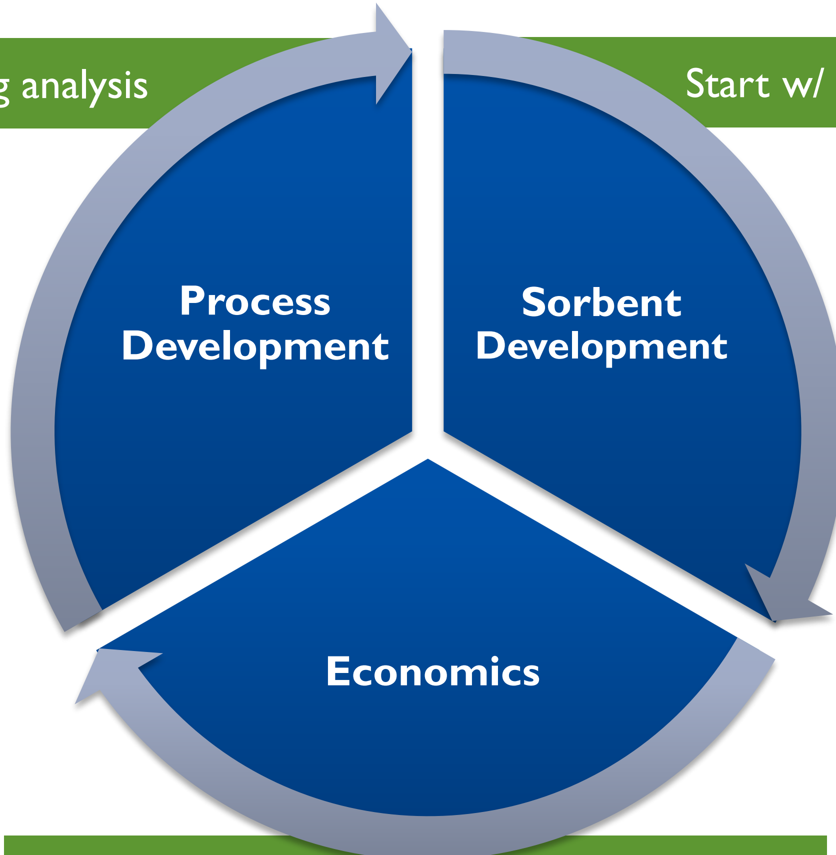
Advantages

- Reduced energy consumption
- Reduced capital cost
- Avoids evaporative emissions
- Density of CO_2 absorbing sites

Challenges

- Heat management
- Solids handling & control
- Physically strong sorbent
- Stability/leaching of PEI

Technical Approach & Scope



Start w/ process engineering analysis

- Concluded that circulating, staged, fluidized-bed design exhibits significant promise.

Development Needs:

- Optimize reactor design and process arrangement.

Development Approach:

- Detailed fluidized bed reactor modeling.
- Bench-scale evaluation of reactors designs.
- Demonstration of process concept.

Start w/ promising sorbent chemistry

- PSU's Molecular Basket Sorbents offer high CO_2 loading; reasonable heat of absorption (66 kJ/mol).

Development Needs:

- Improve thermal stability.
- Reduce leaching potential.
- Reduce production cost.
- Convert to fluidizable form.

Development Approach:

- Modify support selection.
- Simplify amine tethering.
- Scalable production methods.

Start w/ preliminary economic screening

- Conducted detailed technical and economic evaluations
- ***Basis:*** DOE/NETL's Cost and Performance Baseline for Fossil Energy Plants
- ***Result:*** Total cost of CO_2 captured estimated to be 39.7 \$/T-CO_2 (SOTA Amine Process ~68\$/T-CO2)
- Further reduction needed → reduced power consumption & capital cost

Technical Approach & Scope

Previous Work	Current Project	Future Development		
< 2011	2011-15	2015 - 17	2018-22	> 2022
Proof-of-Concept / Feasibility		Pilot 1 - 5 MW (eq)	Demo ~ 50 MW	Commercial

Laboratory Validation (2011 – 2013)

Economic analysis
- *Milestone:* Favorable technology feasibility study

Sorbent development
- *Milestone:* Improved sorbent stability and production

Process development
- *Milestone:* Working multi-physics, CFD model of FMBR
- *Milestone:* Fabrication-ready design and schedule for bench-scale prototype

Long-Term Performance (2014 – 2015)

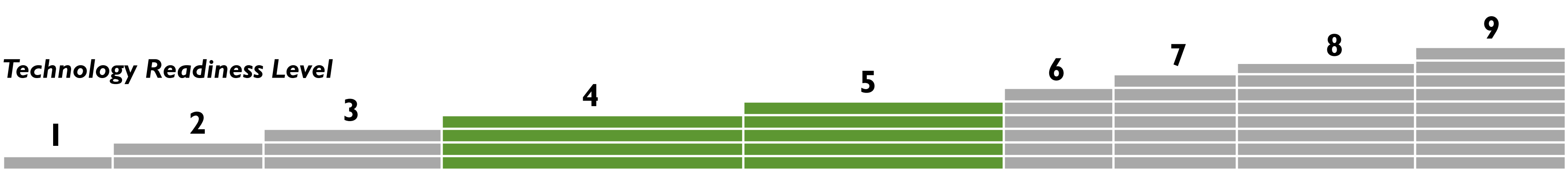
Process Development
- *Milestone:* Fully operational bench-scale with process testing conditions optimized
- *Milestone:* Completion of 1,000 hours of parametric and long-term testing

Updated Economics
- *Milestone:* Favorable technical, economic, environmental study (meets DOE targets)

Prototype Build & Testing (2013 - 2014)

Field Testing of Prototype Unit
- *Milestone:* Operational bench-scale prototype capable of 90% CO_2 capture
- *Milestone:* Successful scale-up of Gen1 sorbent with confirmation of maintained properties and performance compared to lab-scale production

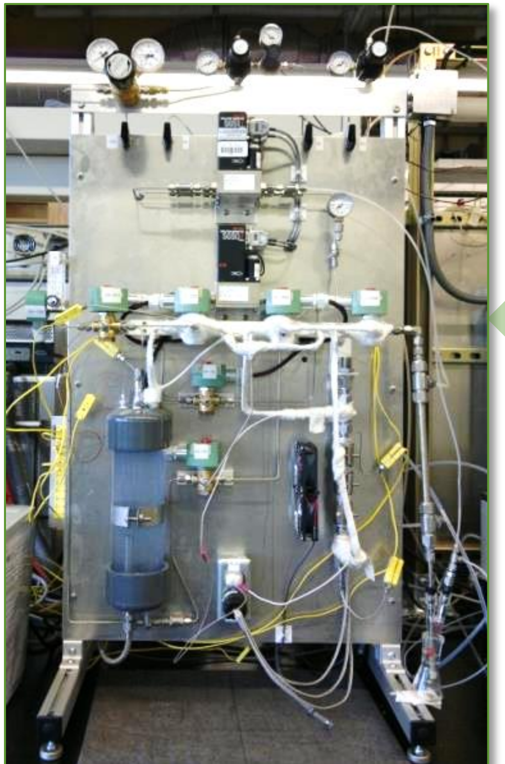
Technology Readiness Level

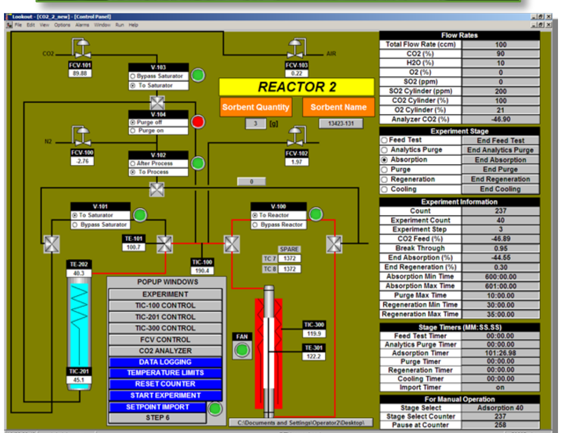


Project Status

- Test Equipment
- Process Development Progress
- Bench-scale System Design and Build
- Sorbent Development Progress
- Sorbent Scale-up
- Next Steps

Test Equipment – PBR and vFBR





Packed-bed Reactor

- Fully-automated operation and data analysis; multi-cycle absorption-regeneration
- Rapid sorbent screening experiments
- Measure dynamic CO_2 loading & rate
- Test long-term effect of contaminants

“visual” Fluidized-bed Reactor

- Verify (visually) the fluidizability of PEI-supported CO_2 capture sorbents
- Operate with realistic process conditions
- Measure ΔP and temperature gradients
- Test optimal fluidization conditions

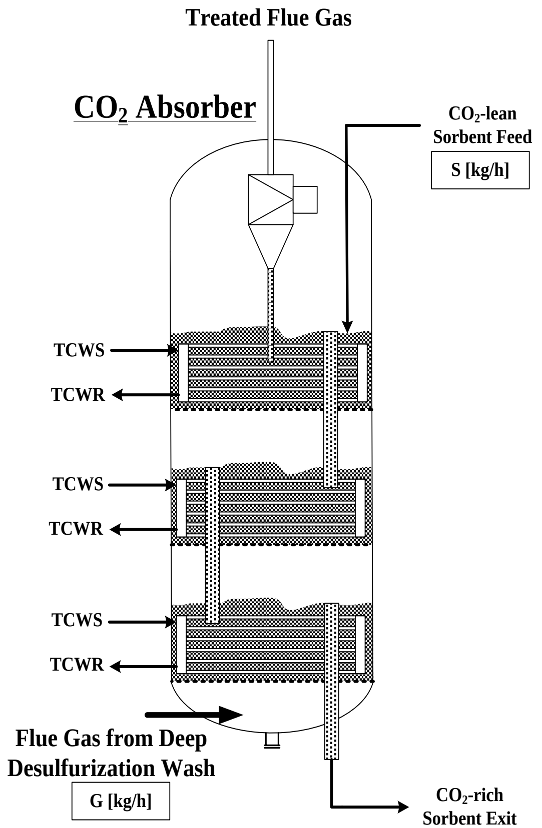
Process Development Progress

Objective

Design, build, and test a bench-scale system to evaluate optimal fluidized-bed reactor design and demonstrate long-term performance stability of PEI-based CO_2 sorbents.

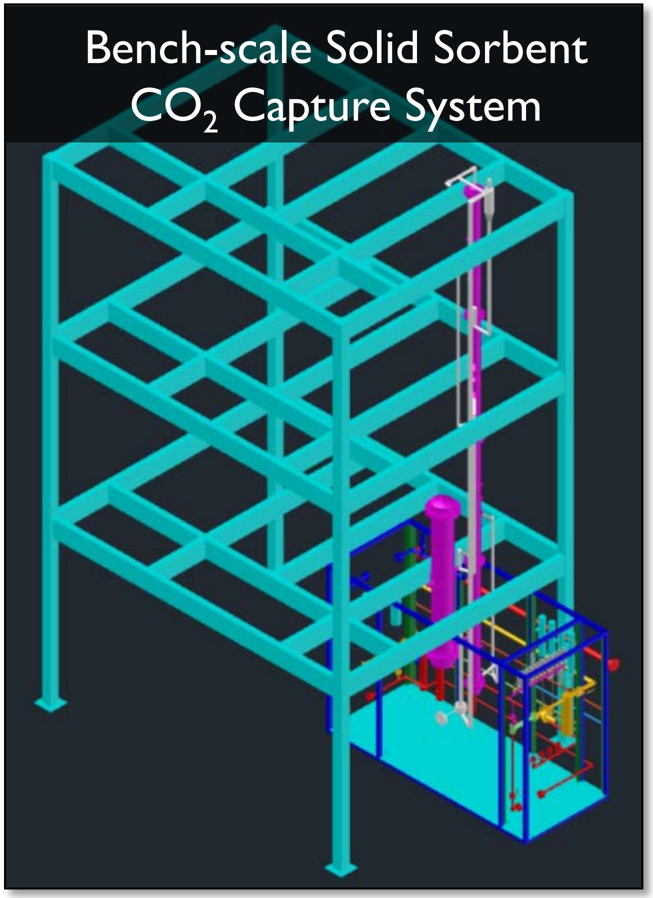
Previous Work

- *Process design screening:* initial process design screening, heat transfer tests, and engineering evaluation, concluding that fluidized moving-bed design exhibits significant promise.
- *Fluidized-bed reactor model:* developed a FB reactor model to simulate the performance of conceptual fluidized-bed reactor configurations.
- *Bench-scale system design:* developed a detailed engineering design package of a bench-scale contactor evaluation unit (BsCEU). Designed to evaluate effectiveness of proposed reactor designs for CO_2 removal from flue gas.



Test Site & BsCEU Design

- ETDF is dedicated to hosting bench- and pilot-scale systems
- 60' x 50' x 45' tall enclosed structure
- ETDF is equipped with:
    - Simulated flue gas generation
    - closed-circuit chilled water loop
    - steam generator
    - air compressor
    - electrical supply for multiple systems



- BsCEU specifications:
    - *Flue gas throughput:* 300 and 900 SLPM
    - *Solids circulation rate:* 75 to 450 kg/h
    - *Sorbent inventory:* ~75 kg of sorbent

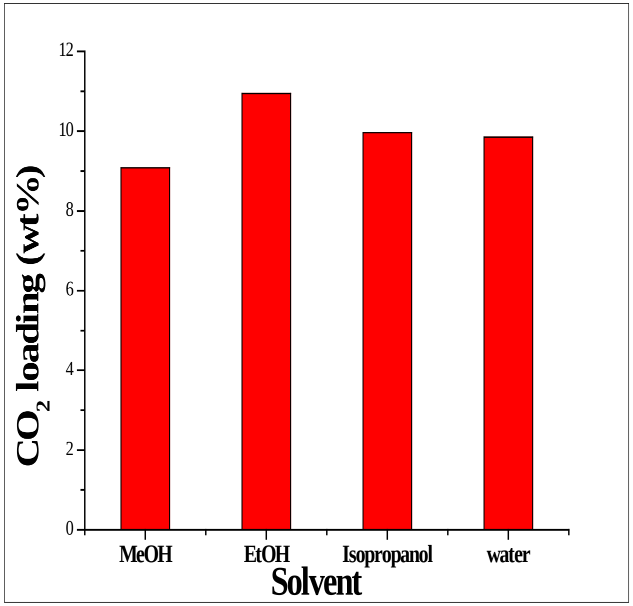
BsCEU Testing Status

- ✓ Pressure & leak testing in parallel with mechanical completion
- ✓ Electrical completion and testing
- ✓ Field verification of system instrumentation and the data acquisition and control system
- ✓ Cold and hot gas flow verification
  - Heated gas flow, differential pressure validation
  - Verification of gas composition control
- ✓ Fluidization characterization with "commissioning material"
  - Demonstration of stable/controllable solids flow and circulation between Absorber and Regenerator
  - Calibration of valves and other control mechanisms
  - Verification of cooling/heating within Absorber and Regenerator
- System operation and testing with CO_2 sorbent
  - Cold flow demonstration of stable and controllable flow of sorbent and circulation between stages and columns
  - CO_2 capture experiments
    - Demonstrate ability to achieve 90% CO_2 capture
    - Demonstrate effective heat management in Absorber/Regenerator

Sorbent Development Progress

Objective

Improve the thermal and performance stability and production cost of PEI-based sorbents while transitioning fixed-bed MBS materials into a fluidizable form.



Previous Work

- Stability improvements through addition of moisture – reducing formation of urea.
- Stability improvements through PEI / support modifications.
- Suitable low-cost, commercial supports identified (1000x cost reduction).
- Converted sorbent to a fluidizable, strong particle.

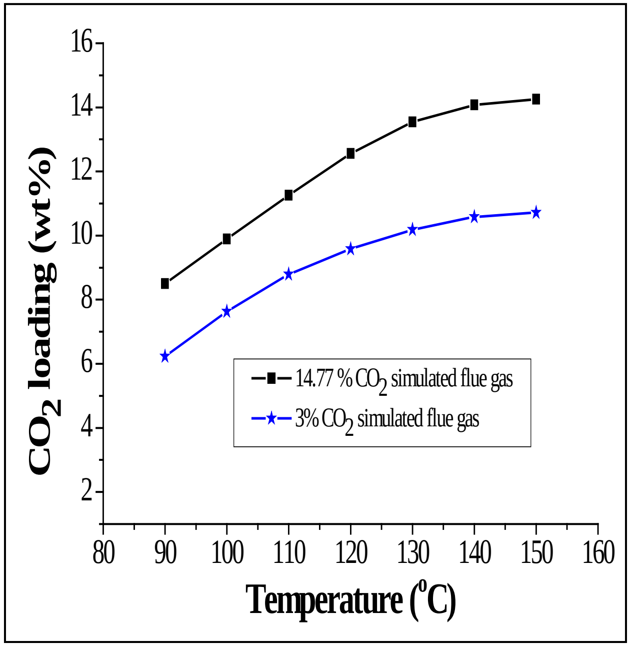
Current Work

Gen1 Sorbent (chosen for scale-up)

- PEI on a fluidizable, commercially-produced silica support.
- Optimized Gen1 sorbent through: solvent selection; drying procedure; PEI loading %; regeneration method; gas composition; support selection; support pretreatment, etc.

Gen2 Sorbent (promising next step)

- Extremely stable sorbent with high CO_2 loadings (11 wt%).
- Provisional patent application filed.



Sorbent Scale-Up

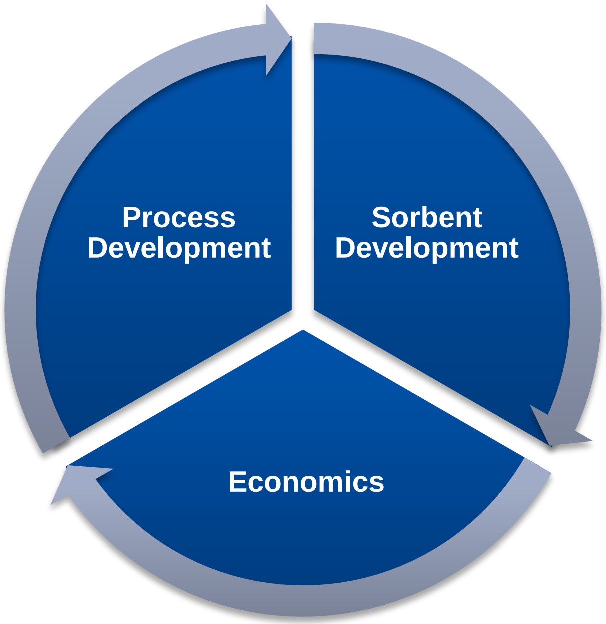
- 150 kg prepared by commercial manufacturer
- No agglomeration or PEI leaching in all conditions tested in vFBR system

Silica	Support	Amount	PEI loading	CO_2 Capacity	FBR test	Density	PSD
Lab Sorbent	Silica A	100+ g	30 %	8.5 wt%	Pass	0.6 g/cc	75 – 250 um
Scaled-up Sorbent	Silica A	150 kg	30 %	8.9 wt%	Pass	0.6 g/cc	80 – 250 um

Next Steps

Bench-scale contactor and prototype system testing

- Demonstrate long-term stability of the sorbent and process equipment
- Demonstrate continuous operation of process under high-fidelity flue gas conditions
- Testing at RTI's Energy Technology Development Facility
- Parametric and long-term testing (1,000+ hours)
- Collect critical process data to perform detailed T&E assessment



Sorbent optimization and scale-up

- Further optimization and commercial production of Gen1 sorbent
- Integrate Gen2 sorbent advancements with fluidizable particle production
- Produce extra sorbent inventory for prototype testing (~ 150 kg)

Detailed technical and economic assessment

- Update economic analyses using bench- and prototype testing data
- Continue to show ability to achieve DOE/NETL programmatic goals

Application to other industrial sources of CO_2

- Currently demonstrating technology at cement plant in Norway – Norcem (part of HeidelbergCement) – Phase II approved in July 2014.
- Continue evaluating economic factors of NGCC application - Masdar

Demonstration in Norway - Cement

NORCEM
HEIDELBERGCEMENT Group

Objective: Demonstrate RTI's advanced, solid sorbent CO_2 capture process in an operating cement plant and evaluate economic feasibility

Photo Source: Norcem

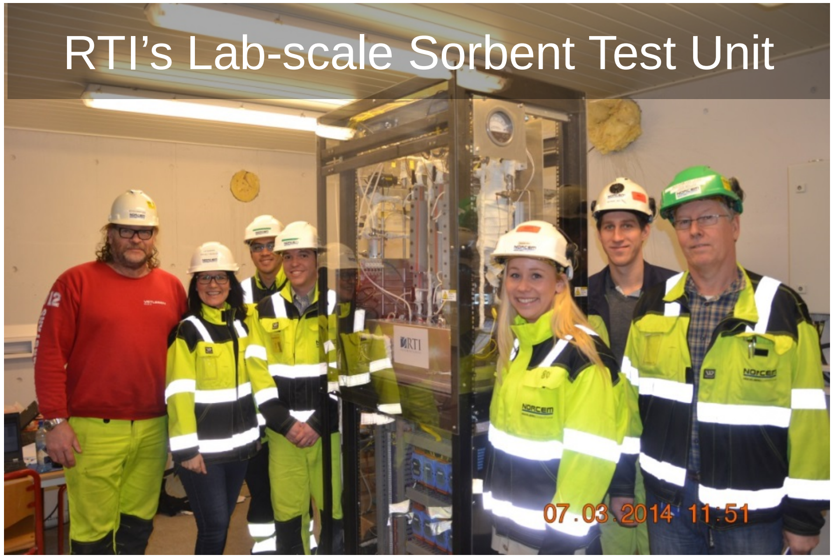


Photo Source: Norcem

Phase I – *Complete*

- Performed sorbent exposure testing with real cement flue gas using lab-scale test unit
- Performed techno-economic study

Phase II – *Awarded* (July '14 to June '16)

- Pilot field testing of RTI's technology at Norcem's Brevik cement plant

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Acknowledgements

Funding provided by:

- The U.S. DOE/National Energy Technology Laboratory
  - Bruce Lani (NETL Project Manager)
- Masdar (Abu Dhabi Future Energy Company)

RTI Team

- DeVaughn Body
- Chris Bonino
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Masdar Team

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- Dang Viet Quang
- Amaka Nwobi

BsCEU Build

- AC Corporation
- C&H Insulation
- Dewberry Engineers
- Guy M Turner
- Harris Brothers
- PSRI
- Unitel Technologies
- Wesa Automation