Advanced Solid Sorbents and Process Designs for Post-Combustion CO₂ Capture (DE-FE0007707)

RTI International

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Address the technical hurdles to developing a solid sorbent-based CO₂ 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)

Project Funding: $3,847,161
- DOE Share: $2,997,038
- Cost Share: $850,123

Period of Performance:
- 10/1/2011 to 6/30/2015

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 CO₂ capture (prototype testing & economic analyses)

- Project management
- Process design
- Fluidized-bed sorbent

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

PSU’s EMS Energy Inst.
PEI and sorbent improvement
Sorbent Chemistry

- Polyethylenimine (PEI)
  
  **Primary:** \( \text{CO}_2 + 2RNH_2 \rightleftharpoons NH_4^+ + R_2NCOO^- \)
  
  **Secondary:** \( \text{CO}_2 + 2R_2NH \rightleftharpoons R_2NH_2^+ + R_2NCOO^- \)
  
  **Tertiary:** \( \text{CO}_2 + 2R_3N \rightleftharpoons R_4N^+ + R_2NCOO^- \)

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/ 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 CO₂ captured estimated to be 39.7 $/T-CO₂ (SOTA Amine Process ~68$/T-CO₂)
- Further reduction needed → reduced power consumption & capital cost

Start w/ promising sorbent chemistry

- PSU's Molecular Basket Sorbents offer high CO₂ 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.

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.
Technical Approach & Scope

### Previous Work

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<thead>
<tr>
<th>Proof-of-Concept / Feasibility</th>
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#### 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)

### Current Project

<table>
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<tr>
<th>2011-15</th>
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### Future Development

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<th>2015 - 17</th>
<th>2018-22</th>
<th>&gt; 2022</th>
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#### Pilot

- 1 - 5 MW (eq)

#### Demo

- ~ 50 MW

#### Commercial

### Technology Readiness Level

1 2 3 4 5 6 7 8 9

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**Prototype Build & Testing (2013 - 2014)**

- **Field Testing of Prototype Unit**
  - *Milestone:* Operational bench-scale prototype capable of 90% CO₂ capture
  - *Milestone:* Successful scale-up of Gen1 sorbent with confirmation of maintained properties and performance compared to lab-scale production
Project Status

- Test Equipment
- Process Development Progress
- Bench-scale System Design and Build
- Sorbent Development Progress
- Sorbent Scale-up
- Next Steps
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 $\Delta P$ and temperature gradients
- Test optimal fluidization conditions
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.
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 CO₂ sorbent
  - Cold flow demonstration of stable and controllable flow of sorbent and circulation between stages and columns
  - CO₂ capture experiments
    - Demonstrate ability to achieve 90% CO₂ capture
    - Demonstrate effective heat management in Absorber/Regenerator
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 CO₂ 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

<table>
<thead>
<tr>
<th>Silica</th>
<th>Support</th>
<th>Amount</th>
<th>PEI loading</th>
<th>CO₂ Capacity</th>
<th>FBR test</th>
<th>Density</th>
<th>PSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab Sorbent</td>
<td>Silica A</td>
<td>100+ g</td>
<td>30 %</td>
<td>8.5 wt%</td>
<td>Pass</td>
<td>0.6 g/cc</td>
<td>75 – 250 um</td>
</tr>
<tr>
<td>Scaled-up Sorbent</td>
<td>Silica A</td>
<td>150 kg</td>
<td>30 %</td>
<td>8.9 wt%</td>
<td>Pass</td>
<td>0.6 g/cc</td>
<td>80 – 250 um</td>
</tr>
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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 CO₂

- 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
Objective: Demonstrate RTI’s advanced, solid sorbent CO₂ capture process in an operating cement plant and evaluate economic feasibility

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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