RTI's Solid Sorbent-Based CO_2 Capture Process: Technical and Economic Comparison for Application in Coal-fired Power, NGCC, and Cement Plants

4th Post Combustion Capture Conference

Birmingham, AL

Dr. Paul Mobley

Energy Technologies at RTI International

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Energy Technologies at RTI International

RTI develops advanced process technologies in partnership with leaders in energy

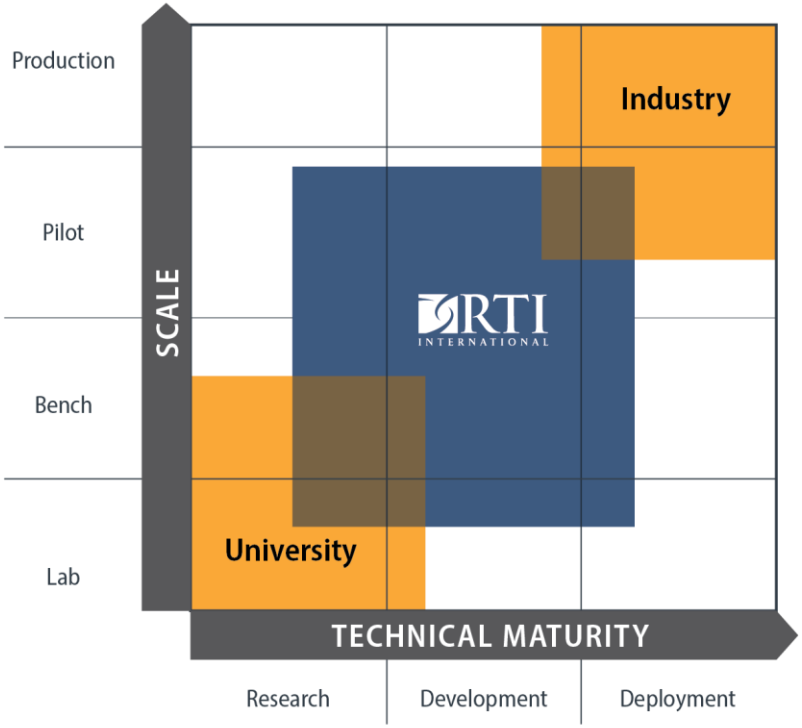
Full alignment with industry objectives

From concept to demonstration

Defined commercialization pathways

Flexible intellectual property arrangements

Potential leveraging of industrial R&D funding with government provided funding



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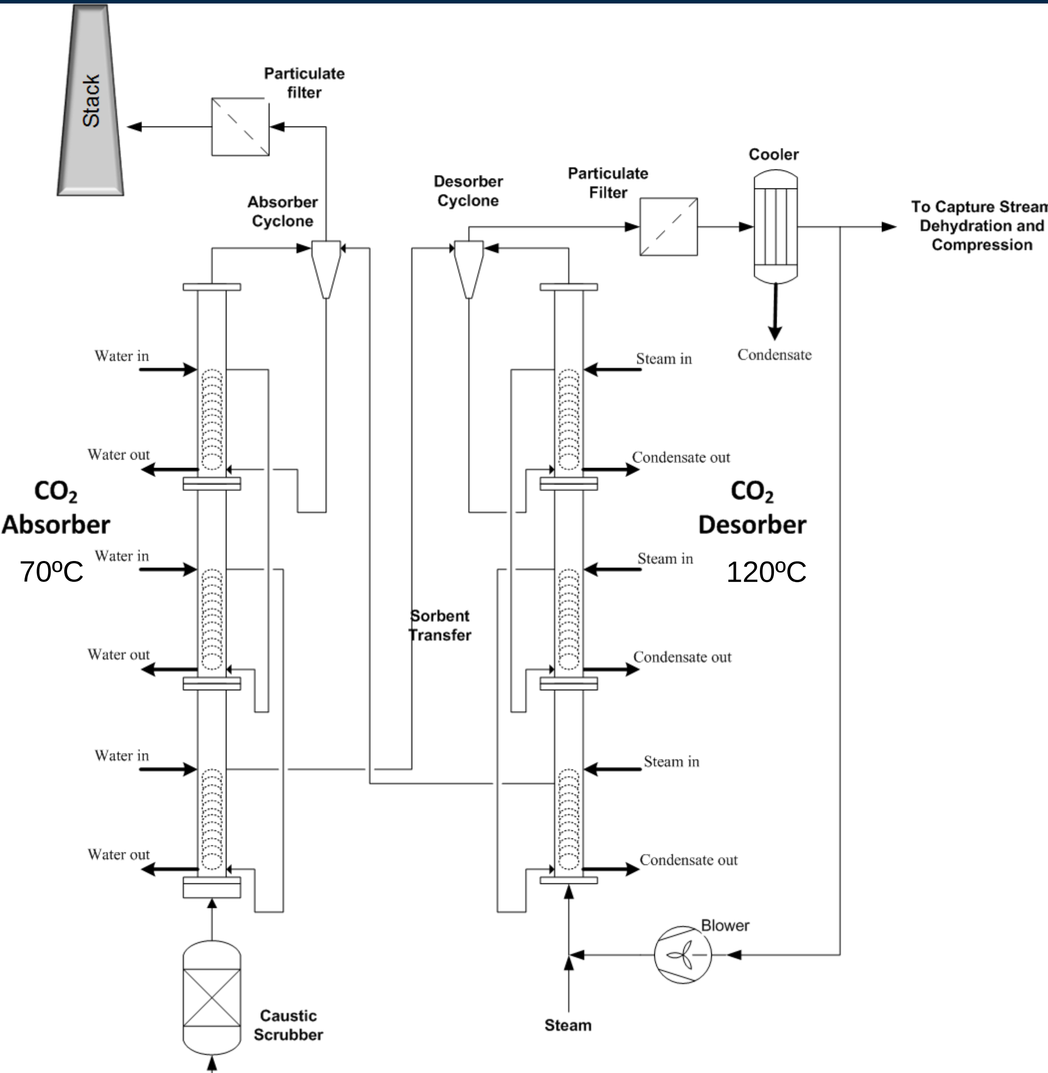
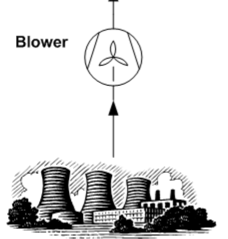
Solid Sorbent CO_2 Capture





Sorbent Chemistry (PEI)

Primary: $CO_2 + 2RNH_2 \rightleftarrows NH_4^+ + R_2NCOO^-$

Secondary: $CO_2 + 2R_2NH \rightleftarrows R_2NH_2^+ + R_2NCOO^-$

Tertiary: $CO_2 + 2R_3N \rightleftarrows R_4N^+ + R_2NCOO^-$

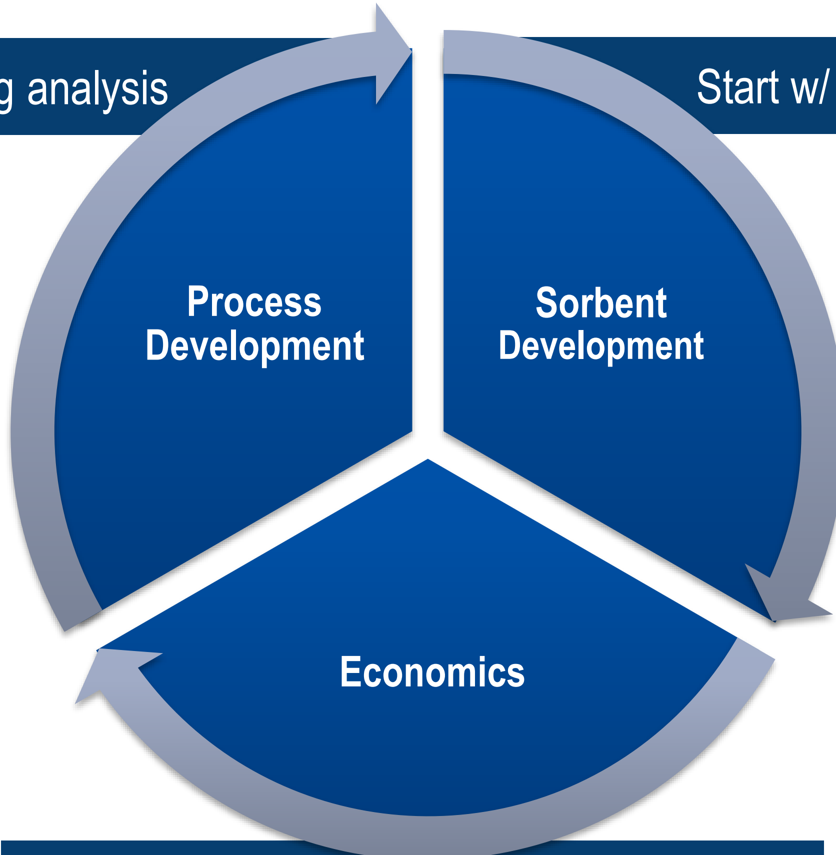
Advantages

- Potential for reduced energy loads and lower capital and operating costs
- High CO_2 loading capacity; higher utilization of CO_2 capture sites
- Relatively low heat of absorption; no heat of vaporization penalty (as with aqueous amines)
- Avoidance of evaporative emissions
- Superior reactor design for optimized gas-solid heat and mass transfer and efficient operation

Challenges

- Heat management / temperature control
- Solids handling / solids circulation control
- Physically strong / attrition-resistant sorbent
- Stability of sorbent performance

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

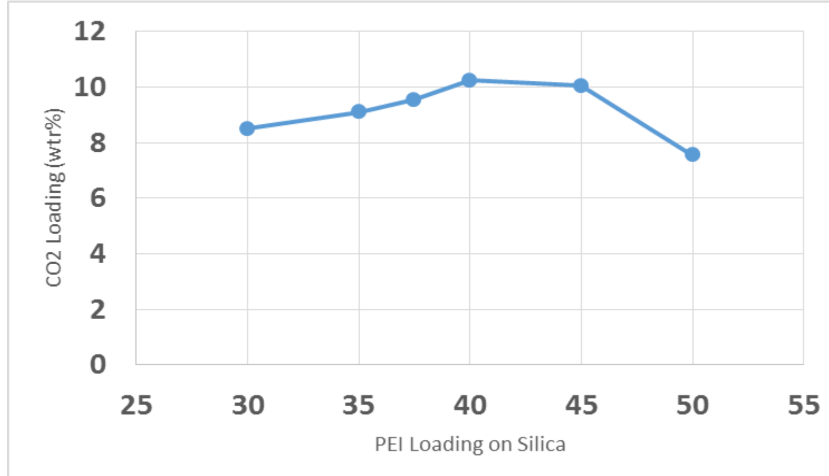
- Conducted detailed technical and economic evaluations
- ***Basis:*** DOE/NETL's Cost and Performance Baseline for Fossil Energy Plants
- Further reduction needed → reduced power consumption & capital cost

Lab-Scale Sorbent Development

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

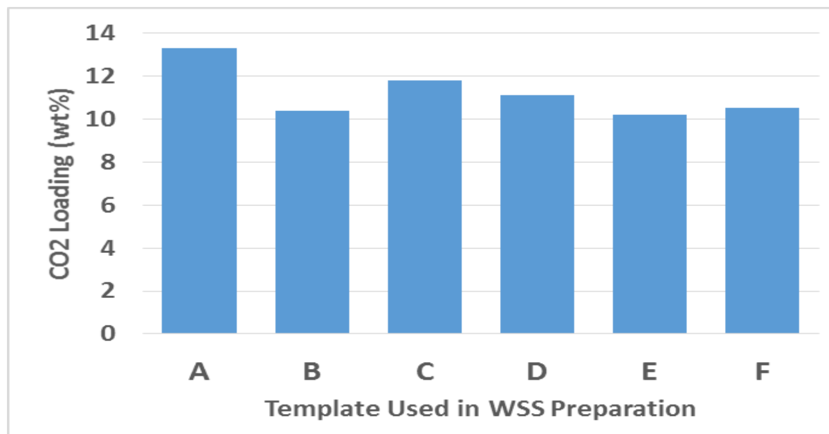
PEI-impregnated Silica ("Gen1")

- Stability improvements through addition of moisture and PEI / support modifications.
- Suitable low-cost, commercial supports identified (1000x cost reduction).
- Converted sorbent to a fluidizable form.
- Optimized Gen1 sorbent through: solvent selection; drying procedure; PEI loading %; regeneration method; support selection; etc.

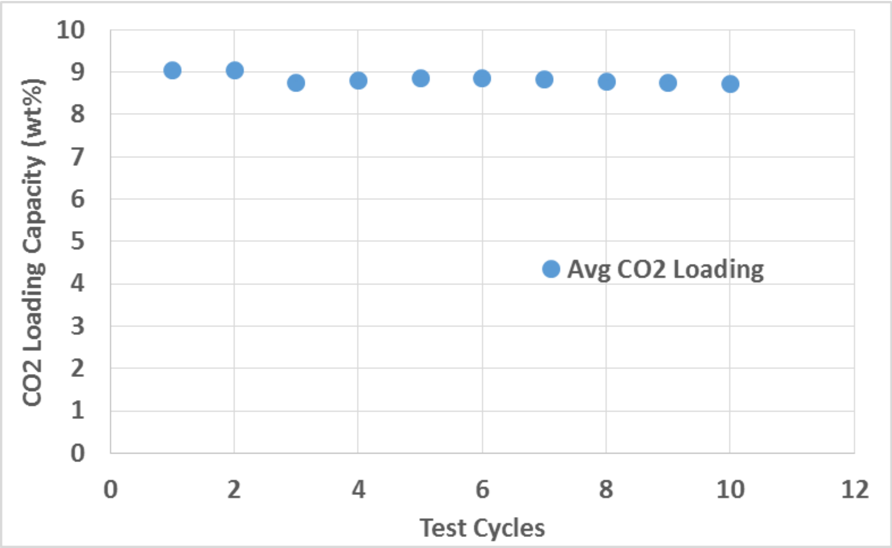


Co-Precip Amine/Silica ("Gen2")

- Extremely stable sorbent, high CO_2 loadings (10 - 14 wt%).
- *Key benefits*: stability in liquid water, high CO_2 loadings, tailoring potential, diverse applications
- *Challenges*: density, physical strength, cost
- Mixed results with most promise identified in the use of blended amines and templates



Sorbent Scale-up



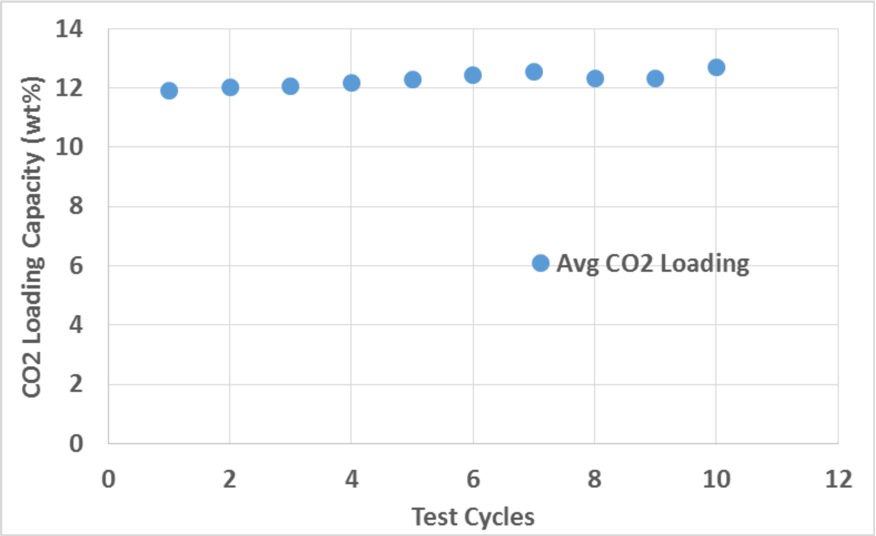
Initial Scale-up (150 kg)

- 30 wt% PEI on commercially-available silica
- Scaled-up sorbent matches performance and properties of lab sorbent
- 6 months of bench-scale testing exhibited little to no degradation

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

Sorbent Batch for Norcem Demonstration (100 kg)

- Improved silica selection, optimized PEI loadings
- Improved commercial preparation
- Sorbent exhibits improved CO_2 capture performance



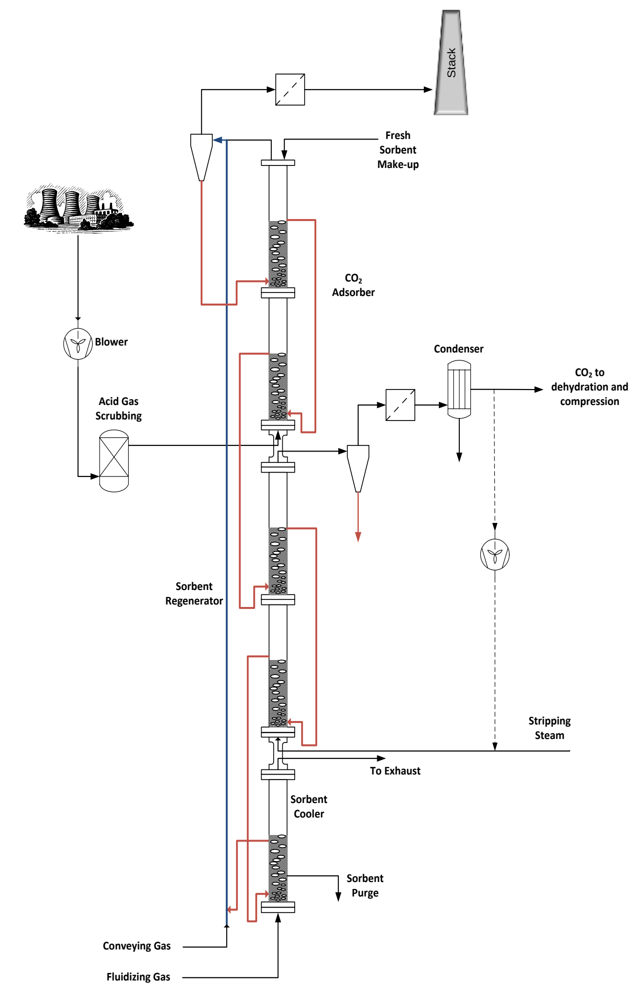
Test Equipment

RTI's Bench-scale Solid Sorbent CO_2 Capture Prototype System

Flue gas throughput: 300 and 900 SLPM

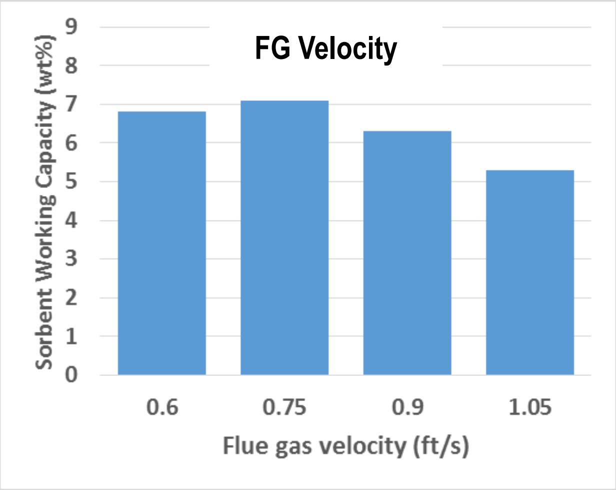
Solids circulation rate: 75 to 450 kg/h

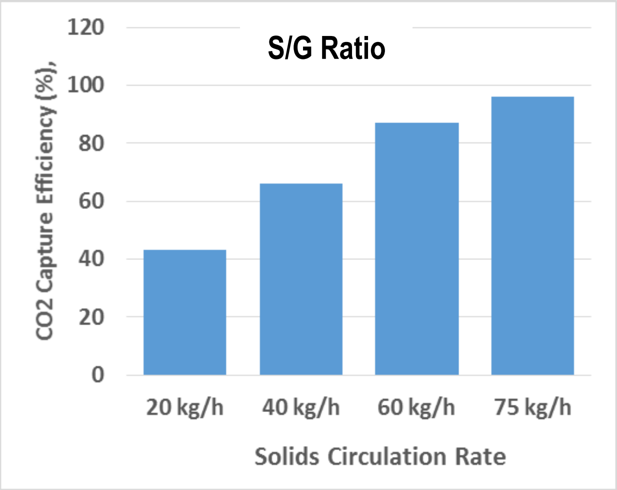
Sorbent inventory: ~75 kg of sorbent

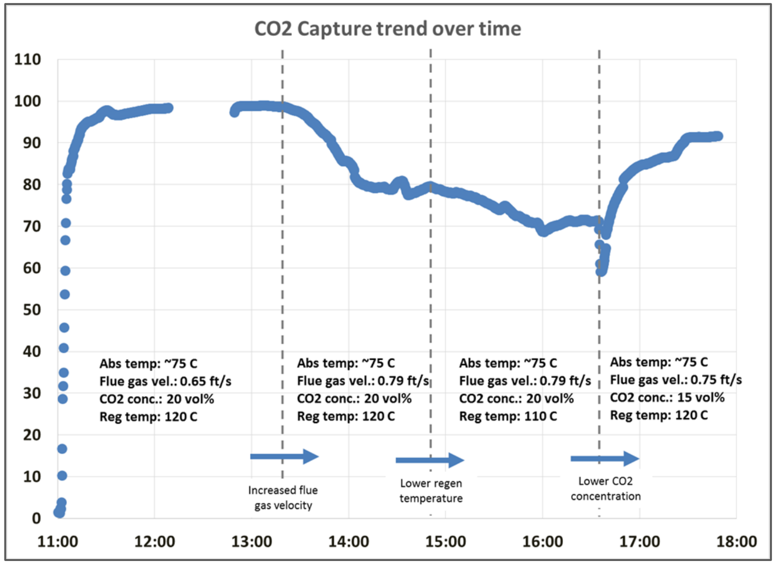


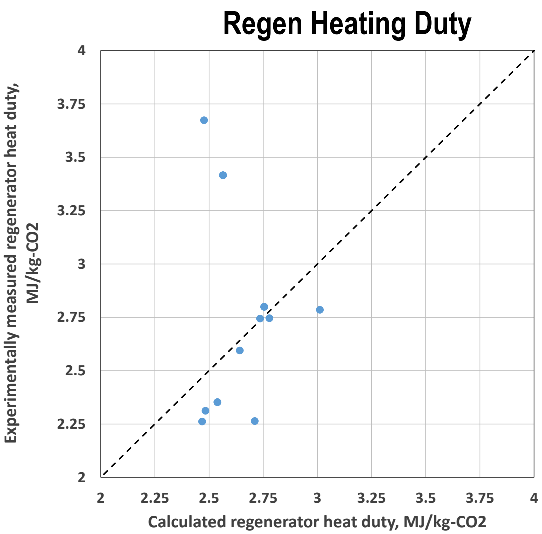
Bench-scale Prototype Testing

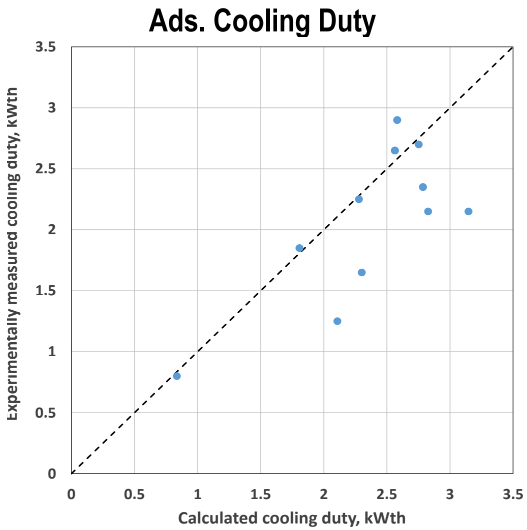
- Cumulative testing: 1,000+ circulation hours; 420+ CO_2 capture hours.
- The sorbent is capable of rapid removal of CO_2 from the simulated flue gas
- Sustained 90% capture of CO_2 in simulated flue gas stream is easily achieved
- Collected performance data, performed parametric testing, and proved reliability of bench-scale testing



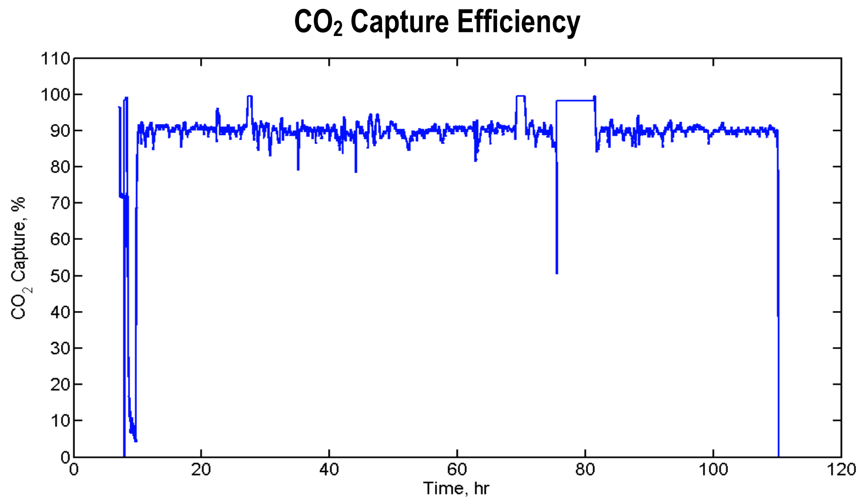








Long-term Performance Testing

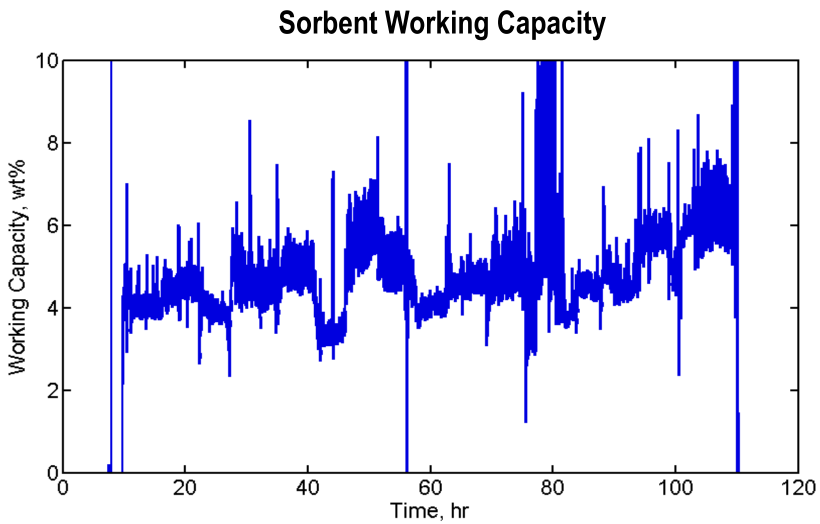


Other Observations / Lessons

- SO_x, NO_x, and other acid gases should be targeted for 99% removal
  - As a means of overall cost reduction, RTI may be able to use spent PEI-based sorbent, from the CO_2 capture unit, in a simple reactor environment to remove similar acid gases – essentially a replacement for the caustic scrubber.
- The need for reactor staging in both the Adsorber and the Regenerator has been confirmed through this pilot system testing
- A 2-stage Adsorber and 2-stage Regenerator approach are sufficient for good CO_2 capture performance, but a 3-stage Regenerator may be required for optimal operation

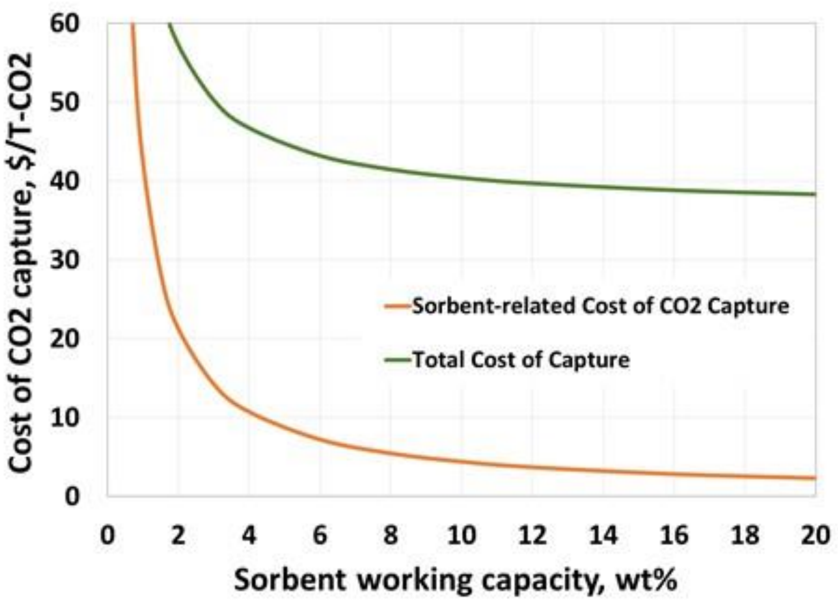
Long-term testing

- 100+ hr continuous testing, maintaining the performance target of 90% CO_2 capture by varying sorbent circulation rate
- Sorbent maintained CO_2 working capacity between 4 and 7 wt.%
- A 50% improvement in sorbent CO_2 working capacity is observed when the pilot system regeneration temperature is raised from 110˚C to 120˚C
- Attrition-resistance of sorbent is evident from similar PSD for used sorbent, fines collection rate, and no sorbent make-up
- Sorbent maintains excellent hydrodynamic / fluidization properties



Updated Technoeconomic Analysis for Coal-Fired Power

	Revised Assumption	Increase in cost of CO_2 capture, $/T-$CO_2$
Sorbent cost, $/kg	11	+ 2.7
Capture stream CO_2 concentration, vol%	60	+ 1.0
Working capacity, wt.%	10	+ 0.6
Regeneration temperature, °C	120	+ 0.4
Acid gas scrubbing strategy	Use spent sorbent	- 1.7



Summary

- Total cost of CO_2 captured ~ **$43.3/T-$CO_2$**
- **> 25% reduction** in cost of CO_2 capture, with > 40% reduction possible with advances in sorbent stability and reactor design
- **~ 40% reduction** in energy penalty; significant reduction in total capture plant cost (compared to SOTA)

Cost Reduction Pathway

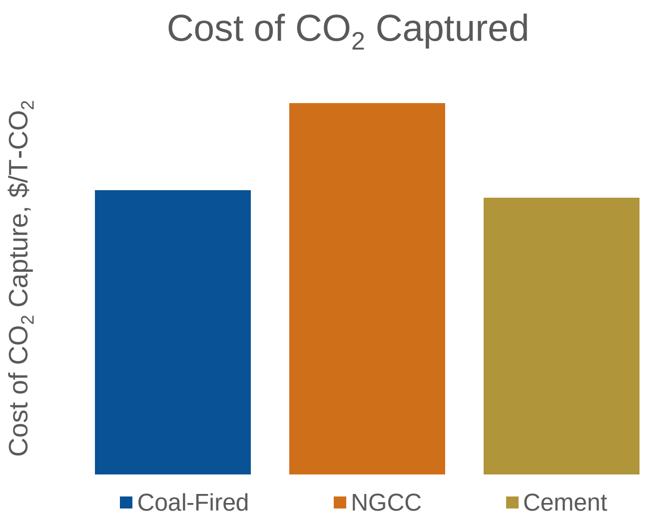
Sorbent

- Improve CO_2 capacity
- Improve long-term stability; minimize losses
- Reduce production costs

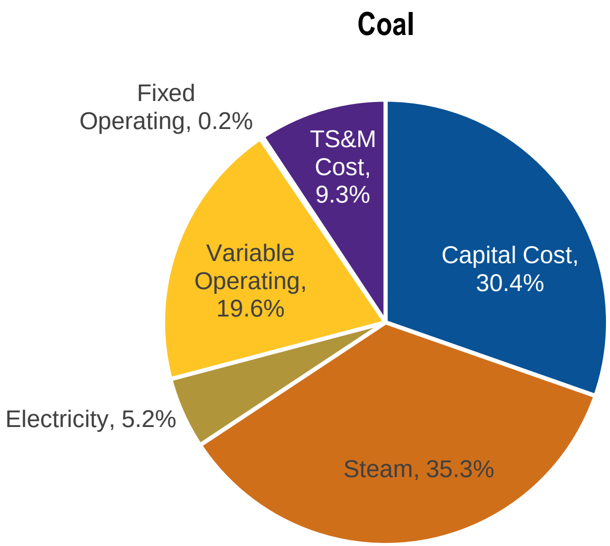
Process

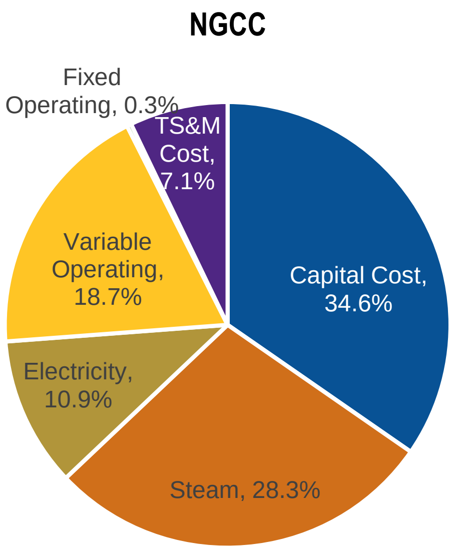
- Heat recovery from absorber / compression train and integration into process
- Recycle attrited sorbent particles for removal of acid gases
- Explore lower cost MOCs and compatibility

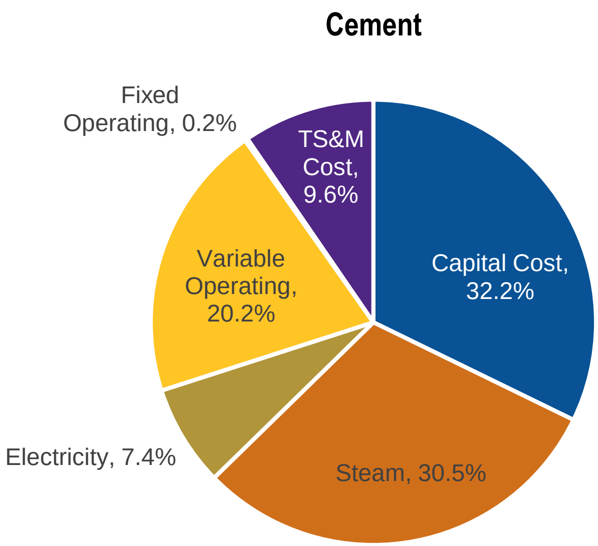
Cost Comparison of Coal-Fired Power, NGCC, and Cement Plants



- Relative to Coal-Fired Power:
  - NGCC plants process higher flue gas flow rates with lower CO_2 concentrations, increasing the size and cost of equipment, and blower costs
  - Cement plants can utilize waste heat to reduce the steam usage, but additional heat exchangers increase the capital costs
    - Slight reduction in total cost of CO_2 capture compared to coal







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