Development of a Novel Gas Pressurized Stripping (GPS)-Based Technology for CO$_2$ Capture from Post-Combustion Flue Gases

DE-FE0007567

Carbon Capture Scientific, LLC.
CONSOL Energy Inc.
Nexant Inc.
Western Kentucky University

Presented by Shiaoguo (Scott) Chen

DOE Carbon Capture Technology Meeting, July 10, 2012, Pittsburgh, PA
About Carbon Capture Scientific, LLC

- Early stage company located in Pittsburgh, PA
- Two patent pending CO$_2$ capture technologies
- Bench-scale development funded by the Department of Energy / National Energy Technology Laboratory
- Chemical Engineers/Scientists with strong expertise in process design, simulation and optimization
- Technology development based on transition from thermodynamic analysis, to process simulation, to bench scale prototyping
## Project Budget

<table>
<thead>
<tr>
<th></th>
<th>Budget, $</th>
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<tbody>
<tr>
<td><strong>DOE</strong></td>
<td>2,999,756</td>
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<tr>
<td><strong>CCS</strong></td>
<td>751,178*</td>
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<tr>
<td><strong>Total</strong></td>
<td>3,750,934</td>
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</table>

*including cost share from CONSOL Energy and Western Kentucky University

(Cost share is ~20%)

DOE funding and cost share on a yearly basis
Project Team and Focus

**DOE/NETL**
- Timothy Fout, NETL project manager

**Carbon Capture Scientific, LLC**
- Computer simulation to optimize GPS based process for existing power plants
- Bench-scale experiments to obtain process design data for GPS based process

**CONSOL Energy Inc.**
- Work with CCS to acquire phase equilibrium and related process design data

**Nexant Inc.**
- Conduct techno-economic analyses for the GPS based technology

**Western Kentucky University (WKU)**
- Consult on thermal and oxidative properties; Corrosion effects and physical property measurements
Project Objectives

- Conduct computer simulations to maximize the benefit of the GPS technology for existing power plants
- Perform bench-scale tests of individual process units to obtain necessary process design data for the pilot scale
- Carry out experimental investigation of selected solvents to minimize the economic risk of the GPS technology
- Conduct techno-economic analyses for GPS based process to identify improvement potentials
An Integrated Process for CO\textsubscript{2} Capture and Compression

CO\textsubscript{2} Capture/Regeneration:

\[ M + CO_2 \Leftrightarrow N - \Delta H \]

\[ K = \left( \frac{\gamma_N x_N}{\gamma_M x_M} \right) \frac{1}{P_{CO_2}} \]

\[ \text{van't Hoff Equation:} \]

\[ \frac{d\ln K}{dT} \approx - \frac{d\ln P_{CO_2}}{dT} = - \frac{\Delta H}{RT^2} \]

Ignore all the driving force for heat and mass transfer
Thermodynamics of the Integrated CO$_2$ Capture Process

\[ \ln(P_2) - \ln(P_1) = \frac{\Delta H}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right) \]

\[ \Delta H = \text{kJ/mol} \]

Required pressure ratio

P$_2$/P$_1$

P$_3$

P$_2$

P$_3$

T$_2$ °C (T$_1$=40 °C)

Required pressure ratio

P$_2$

P$_3$

MEA Theoretical

MEA Actual

\[ \text{MEA Actual} \]

\[ \text{MEA Theoretical} \]
Issues with Conventional Strippers

- Water vapor is used as stripping gas, thus operating pressure is limited by the vapor pressure of the lean solution at the reboiler temperature.

- Water vapor is also used as a heat carrier which leads to a temperature gradient along the column.

- Low operating pressure results in a high ratio of $P_{H_2O}/P_{CO_2}$ at the top of the stripper.

**Consequences:**
- Low thermal efficiency
- High compression work
The Novel Gas Pressurized Stripping (GPS) Column

- Adding a high pressure stripping gas stream into the column
  - Eliminating water as stripping gas
  - Enables high operating pressure

- Adding side heaters to provide heat
  - Eliminates the necessity of using water vapor as heat carrier
  - Reduces temperature gradient in the stripper

- Product gas is a mixture of stripping gas and CO$_2$ along with water vapor
  - Increased CO$_2$ partial pressure
  - Requires a separation unit
GPS Column Based Process---One Solvent GPS Process
Advantages of the GPS Based Processes

- Uses commercial off-the-shelf technology
  - All major equipment are common with conventional absorption/stripping processes
  - suitable for large scale applications such as power plants

- High operating pressure
  - Low stripping heat

- Minimal or no need for mechanical CO₂ compression
  - Uses thermal compression
  - High thermal efficiency (low exergy loss)

- Flexible
  - Many common units with the conventional absorption/stripping processes
  - Can be repeatedly used depending on the needs

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Task Duration</th>
<th>Task Focus</th>
<th>Performer</th>
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<tbody>
<tr>
<td></td>
<td>1-12 BP1</td>
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<tr>
<td></td>
<td>13-24 BP2</td>
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<td></td>
<td>24-36 BP3</td>
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<td>Task 1. Project planning &amp; management</td>
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<tr>
<td>Task 2. GPS column study and its optimization</td>
<td>Process</td>
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<td>Task 3. Optimization of GPS process for existing plant</td>
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<td>Task 4. Optimization of flashers</td>
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<td>Task 5. Phase equilibrium data measurement</td>
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<td>Task 6. First absorption column testing</td>
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<td>Task 7. GPS column design/fabrication and testing</td>
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<td>Task 8. Second absorption column testing</td>
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<td>Task 9. Stability of solvent at high loading and high T</td>
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<td>Task 10. Corrosion test at high loading and high T</td>
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<td>Task 11. Physical properties measurement</td>
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<td>Task 12. Survey of EH&amp;S of GPS process</td>
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<td>Task 13. Preliminary technological-economic analysis</td>
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<td>Task 14. Revision of technological-economic analysis</td>
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<td>Task 15. Updated technological-economic analysis</td>
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# Project Milestones and Success Criteria

## Milestones

| A | GPS column study and optimization to achieve thermal efficiency of 60% or greater |
| B | Solvent loss due to degradation of solvent is less than 3 kg/ton CO$_2$ |
| C | Overall energy performance column and solvent less than or equal to 0.22 kWh/kg CO$_2$ |
| D | GPS column efficiency experimental measured at 50% or greater |
| E | Overall energy performance of system less than or equal to 0.20 kWh/kgCO$_2$ |
| F | Increase in capital equipment costs of less than or equal to 20% over existing process |

## Success Criteria

<table>
<thead>
<tr>
<th>Category</th>
<th>Risk</th>
<th>Target</th>
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<tr>
<td>Solvent Loss</td>
<td>High operating T leads to solvent loss</td>
<td>Loss of &lt; 3 kg / ton CO$_2$</td>
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<tr>
<td>Equipment Capital Cost</td>
<td>High operating P and T result in large increase in capital cost</td>
<td>Increase of &lt; 20% relative to conventional process</td>
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<tr>
<td>Energy Consumption</td>
<td>Still require significant amount of mechanical compression of CO$_2$</td>
<td>Consumption of &lt; 0.22 kWh/kgCO$_2$</td>
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# Tasks for BP 1: *Simulation & Experiments*

<table>
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<tr>
<th>Task #</th>
<th>Description</th>
<th>Simulation / Experiment</th>
<th>Comments</th>
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<tr>
<td>2</td>
<td>GPS column study and its optimization</td>
<td>Simulation</td>
<td>In process / on schedule / meet milestone</td>
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<tr>
<td>5</td>
<td>Phase equilibrium data measurement</td>
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<tr>
<td>6</td>
<td>First absorption column testing</td>
<td>Experiment</td>
<td>In process / on schedule</td>
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<tr>
<td>9</td>
<td>Stability of solvent at high loading and high T</td>
<td>Experiment</td>
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<tr>
<td>13</td>
<td>Preliminary techno-economic analysis</td>
<td>Simulation</td>
<td>In process / on schedule / design document generated</td>
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Task 2. GPS Column Study and Optimization

A report entitled:

“Preliminary Simulation of GPS Based Process: Used as Input for Preliminary Techno-economic Analysis”

Has been submitted to Nexant

<table>
<thead>
<tr>
<th>Items</th>
<th>Conventional MEA</th>
<th>GPS Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction Heat KJ/kgCO₂</td>
<td>1870</td>
<td>1472</td>
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<tr>
<td>Stripping Heat KJ/kgCO₂</td>
<td>690</td>
<td>156</td>
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<tr>
<td>Stripping Column Total Heat KJ/kgCO₂</td>
<td>2560</td>
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<tr>
<td>Minimum Heat Required KJ/kgCO₂</td>
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<td>Stripping Column Efficiency (%)</td>
<td>39</td>
<td>78**</td>
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</table>

** Milestone is 60% efficiency for GPS column
Task 5: Phase equilibrium data measurement

Solvent A

$\text{PCO}_2$ (kPa)

$\text{CO}_2$ Loading (mol/mol amine)

Lab, 30C
Lab, 40C
Lab, 50C
Lab, 60C
Lab, 70C
Lab, 80C
Lab, 90C
Lab, 100C
Lab, 110C
Lab, 120C
Lab, 130C
Task 6: First Absorption Column Testing

Column CO$_2$ Capture Performance

- Lean Loading (by % weight)
- 14.5L/min
- 31.4L/min
- 47.6L/min
- 58.9L/min

CO2 Removal Rate

Lean Loading (by % weight)
Task 9: Stability of solvent at high loading and high T

Thermal Degradation at 140°C

- **Loading=40%**
- **Loading=60%**

Cooking time, Day

Solvent Loss kg/ton CO2

- **L=40%, 140°C**
- **L=60%, 120°C**

Residence Time (Min.)

Milestone 3 kg/ton CO2
Task 13. Preliminary techno-economic analysis

- “Gas Pressurized Stripping for CO$_2$ Capture from Post-Combustion Flue Gas – Preliminary Technology Feasibility Study Basis” has been finalized
- Techno-economic analyses are in progress
Summary of Progress to Date

- Company infrastructure in place, personnel hired and performing tasks
- All experimental testing for BP1 underway and proceeding as planned
- Two milestones for Budget Period 1 have been achieved
  - GPS column Efficiency of 60%: actual 85%
  - Solvent loss 3kg/tonCO$_2$: actual <1kg/tonCO$_2$
- Financial expenses are all within budget
Future Work

Perform Tasks in BP2

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Simulation / Experiment</th>
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<tr>
<td>3</td>
<td>Optimization of GPS process for existing plant</td>
<td>Simulation</td>
</tr>
<tr>
<td>7</td>
<td>GPS column design/ fabrication and testing</td>
<td>Experiment</td>
</tr>
<tr>
<td>10</td>
<td>Corrosion test at high loading and high T</td>
<td>Experiment</td>
</tr>
<tr>
<td>14</td>
<td>Revision of techno-economic analysis</td>
<td>Simulation</td>
</tr>
</tbody>
</table>

Prepare for Pilot Scale Tests

- Process design data for GPS based technology

Looking for EOR Opportunities

- GPS technology uses off-the-shelf equipment
- Interested in partnering opportunities
Acknowledgements

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