CO$_2$ Capture from IGCC Gas Streams Using the AC-ABC Process

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Project Overview

• **Project Participants:**
  - SRI International.
  - Bechtel Hydrocarbon Technology Solutions, Inc.
  - ElG, Inc.
  - National Carbon Capture Center
  - U.S. Department of Energy (National Energy Technology Laboratory)

• **Funding:**
  - U.S. Department of Energy: $4,508,355
  - Cost Share (SRI and BHTS): $1,167,654
  - Total: $5,676,009

• **Performance Dates:**
  - October 2009 through September 2015.
Project Objectives

• Overall objective:
  – To develop an innovative, low-cost CO₂ capture technology based on absorption on a high-capacity and low-cost aqueous ammoniated solution with high pressure absorber and stripper.

• Specific objectives and project status:
  – Test the concept on a bench scale batch reactor (completed)
  – Determine the preliminary optimum operating conditions (completed)
  – Design and build a small pilot-scale reactor capable of continuous integrated operation (completed)
  – Perform tests to evaluate the process in a coal gasifier environment (scheduled in Sept 2015)
  – Perform a technical and economic evaluation on the technology
Process Fundamentals

- Uses well-known reaction between carbon dioxide and aqueous ammonia:
  \[ \text{NH}_4\text{OH} + \text{CO}_2 \leftrightarrow \text{NH}_4\text{HCO}_3 \]
  \[ (\text{NH}_4)_2\text{CO}_3 + \text{CO}_2 + \text{H}_2\text{O} \leftrightarrow 2\text{NH}_4\text{HCO}_3 \]
  \[ \text{NH}_4(\text{NH}_2\text{CO}_2) + \text{CO}_2 + 2\text{H}_2\text{O} \leftrightarrow 2\text{NH}_4\text{HCO}_3 \]

- Reactions are reversible
  - Absorption reactions at lower temperature
  - Desorption reactions at higher temperature

- High pressure operation enhances absorption of CO\(_2\).

- A similar set of reactions occur between H\(_2\)S and ammoniated solution.

- H\(_2\)S from the regenerated gas is converted to elemental sulfur at high pressure.
Process Block Flow Diagram

**Water Gas Shift**
30 to 60 bar
230 – 285°C

**Syngas Cooling**
30 to 60 bar
40 to 60°C

**AC-ABC CO₂ and H₂S Absorption**

**H₂(g)**
30 to 50 bar

**CO₂(g)**
30 to 50 bar

**Sulfur Recovery**
30 to 50 bar

**Solvent Regeneration CO₂ and H₂S Release**

Rich Solvent
Temperature 130 to 200°C
Lean Solvent
Process Highlights

• Concentrated ammoniated solution is used to capture both CO₂ and H₂S from syngas at high pressure.
• Absorber operation at 40°-60° C temperature; No refrigeration is needed.
• CO₂ is released at high pressure (30 bar) at <200°C:
  – The size of CO₂ stripper, the number of stages of CO₂ compression, and the electric power for compression of CO₂ to the pipeline pressure are reduced.
• High net CO₂ loading, up to 20% by weight.
• The stripper off-gas stream, containing primarily CO₂ and H₂S, is treated using a high pressure Claus process, invented by Bechtel, to form elemental sulfur.
  – CO₂ is retained at high pressures.
Process Advantages

• Low cost and readily available reagent (aqueous ammonia).
• Reagent is chemically stable under the operating conditions.
  – Ammonia does not decompose under the operating conditions.
• High efficiency for CO₂ capture
  – Reduces water-gas shift requirements - Reduced steam consumption.
• No loss of CO₂ during sulfur recovery
  – High pressure conversion; No tail gas treatment
• Low heat consumption for CO₂ stripping (<600 Btu/lb CO₂).
• Extremely low solubility of H₂, CO and CH₄ in absorber solution: Minimizes loss of fuel species.
• Absorber and regenerator can operate at similar pressure.
  – No need to pump solution cross pressure boundaries. Low energy consumption for pumping.
CO₂ Capture Efficiency vs Solution Composition

CO₂ Capture Efficiency Exceeds 90%

- Run 17 (4 M, 50 C)
- Run 16 (4 M, 33 C)
- Run 18 (4 M, 45 C)
- Run 19 (4 M, 60 C)
- Run 20 (4 M, 43 C)
- Run 21 (8 M, 55 C)

Inlet CO₂ Partial Pressure 450 kPa

Reactor Volume = 0.0045 m³
Reactor Pressure = 265 psia
Inlet CO₂ Partial Pressure 450 kPa

Capture Efficiency (%)

R' (Molar Ratio, CO₂/NH₃)
Rapid Rate of Reactions Approaching Equilibrium

Absorber Operating Pressure = 1800 kPa (265 psia)
4 M and 8M Ammonia, 0.88 acfm CO2 flow rate (25 %v/v)

CO2 Partial Pressure at the Exit (psia)

- Run 17 (4 M, 50 C)
- Run 16 (4 M, 33 C)
- Run 13 (4 M, 45 C)
- Run 11 (4 M, 45 C)
- Run 18 (4 M, 45 C)
- Run 19 (4 M, 60 C)
- Run 20 (4 M, 43 C)
- Run 21 (8 M, 55 C)
- Equilibrium Line (10 M, 55 C)

R', Molar Ratio CO2/NH3
High Efficiency of $\text{H}_2\text{S}$ Capture

Target $< 1$ ppm $\text{H}_2\text{S}$
Measured CO$_2$ Attainable Pressure Function of Temperature

![Graph showing the relationship between total pressure (psi) and temperature (°C) for different runs labeled AC-ABC. The graph includes data points for Run 1, Run 2, Run 3, Run 4, and Run 5, with a focus on the vapor pressure of water.](image-url)
AC-ABC Process Schematic
Slip Stream Test Set up
Absorber, Stripper, Water Wash Columns
Syngas Compressor and Gas Inlet Manifold
Process Skids
Bechtel Pressure Swing Claus (BPSC) Process
AC-ABC and BPSC Process Changes to IGCC Reference Case
## Plant Performance Summary

<table>
<thead>
<tr>
<th>Plant Performance</th>
<th>Units</th>
<th>IGCC with SRI AC-ABC and BPSC</th>
<th>Reference Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Turbine Power</td>
<td>MWe</td>
<td>464.0</td>
<td>464.0</td>
</tr>
<tr>
<td>Syngas Expander Power</td>
<td>MWe</td>
<td>5.7</td>
<td>6.5</td>
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<tr>
<td>Steam Turbine Power</td>
<td>MWe</td>
<td>246.2</td>
<td>263.5</td>
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<tr>
<td>Auxiliary Load</td>
<td>MWe</td>
<td>150.0</td>
<td>190.8</td>
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<tr>
<td>Net Plant Power</td>
<td>MWe</td>
<td>565.9</td>
<td>543.3</td>
</tr>
<tr>
<td>Net Plant Efficiency (HHV)</td>
<td>-</td>
<td>33.7%</td>
<td>32.6%</td>
</tr>
<tr>
<td>Net Plant Heat Rate (HHV)</td>
<td>kJ/kWh</td>
<td>10,679</td>
<td>11,034</td>
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<tr>
<td></td>
<td>Btu/kWh</td>
<td>10,122</td>
<td>10,458</td>
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</table>
## Economic Analysis

<table>
<thead>
<tr>
<th>Economic Analysis (June 2011$)</th>
<th>IGCC with SRI AC-ABC and BPSC</th>
<th>Reference Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Plant Cost, before Owner's Costs, million</td>
<td>$1,676</td>
<td>$1,785</td>
</tr>
<tr>
<td>Total Plant Cost, before Owner's Costs</td>
<td>$2,962/kW</td>
<td>$3,286/kW</td>
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<tr>
<td>Initial Chemical Fill Cost, million</td>
<td>$4.3</td>
<td>$15.9</td>
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<tr>
<td>Annual Fixed O&amp;M Cost, million</td>
<td>$64.5</td>
<td>$68.0</td>
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<tr>
<td>Annual Variable O&amp;M Cost, million</td>
<td>$42.4</td>
<td>$45.9</td>
</tr>
<tr>
<td>Total Annual O&amp;M Cost, million</td>
<td>$106.9</td>
<td>$113.9</td>
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<tr>
<td>FY COE* without TS&amp;M**</td>
<td>$108.28</td>
<td>$118.85</td>
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<tr>
<td>FY COE with TS&amp;M</td>
<td>$113.33</td>
<td>$124.04</td>
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</tbody>
</table>

*FY COE = First Year Cost of Electricity

**TS&M = Transport, Storage, and Monitoring
Anticipated Benefits, if Successful

• We estimate a 22.7 MW improvement in Net Plant Power and a 1.1 percentage point increase in Net Plant Efficiency (HHV basis) than a reference plant (GE gasifier with Selexol AGR and conventional Claus).

• Capital cost is ~6% less expensive than the reference plant on an absolute basis and 9% less on a normalized basis.

• The COE is 9% lower for the SRI AC-ABC and BPSC plant relative to the reference case.

• The process configuration is economically viable per this analysis.

• The process will be tested in this Budget Period at the National Carbon Capture Center.
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