Skid-scale Cryogenic Carbon Capture™ Demonstration

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CCC Value Proposition

- Energy Efficient CO₂ Capture (about ½ amine)
- Cost Effective CO₂ Capture (about ½ amine)
- Bolt-on Technology (ideal retrofit or greenfield)
- Widely deployable (NG, refineries, coal …)
- Multipollutant process (Hg, SOₓ, HC, PM₂.5, …)
- Enables adoption of renewables through rapidly responding, large-scale energy storage
Sustainable Energy Solutions

Founded in 2008

Support from:

- Brigham Young University
- DONG Energy
- Advanced Conversion Technologies Task Force (Wyoming)
- US Department of Energy (ARPA-E)
- CCEMC (Canada)
- GE Global Research
- American Air Liquide
Cryogenic Carbon Capture (CCC)
Process Block Diagram

Coal, NG, Cement, or Industrial Flue Gas

Gas Conditioning → Cooling → Solids Separation → Warming

Heat Integration

CO₂(l) → Light Gases
Simplified Flow Diagram (CFG)

- Flue Gas
- Condensing Heat Exchanger
- Dry Gas
- Compressor
- Heat Exchanger
- Moisture
- SO₂, NO₂, Hg, HCl
- Solid CO₂ Bypass
- Solid CO₂ Stream
- N₂-rich Steam
- Pressurized Liquid CO₂ Stream
- Liquid Pump
- Make-up Refrigeration
- Gaseous N₂-rich Stream
- Expansion
- Separator
- Separator
- Pressurizer
Simplified Flow Diagram (ECL)

Unit Operations

• Heat exchange above the frost point
  – Commercial equipment and processes
• Desublimating heat exchangers
  – New (patented) equipment
• Solid-liquid separation
  – Adapted commercial equipment and processes
• Staged compressor and other major equipment
  – Commercial equipment
Bubbling Heat Exchanger
Major Process Setpoints

- Flue gas pressure
  - Sufficient to overcome pressure drop
- Flue gas minimum temperature
  - -120 °C (90% capture) to -132 °C (99% capture)
- Product conditions (all nominally ambient temperature)
  - CO₂ – 150 bar liquid 99+% purity
  - Other gases – ambient pressure
Energy Penalty

Energy Consumption by Technology

- Amine (NETL case 12)
- CCC-ECL
- CCC CFG
- CCC-CFG Integrated

CCC nearly eliminates emissions while consuming half the energy of alternatives

SUSTAINABLE ENERGY SOLUTIONS
CCC Greenfield Incremental Cost

Increase in Cost of Electricity (COE)

CCC nearly eliminates emissions while increasing the cost of electricity by 2-3 ¢/kWh
99% atmospheric Hg Capture
100% Coal Hg Capture
100% Coal CO2 Capture
CCC exceeds current EPA standards for SOX, NO2, Mercury, CO2

Pollutant levels at 90% capture in parts per million

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>ppm</th>
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<tbody>
<tr>
<td>SO2</td>
<td>32.73</td>
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<tr>
<td>SO3</td>
<td>0.002</td>
</tr>
<tr>
<td>NO2</td>
<td>0.007</td>
</tr>
<tr>
<td>Hg</td>
<td>4.83E-10</td>
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<tr>
<td>As</td>
<td>7.31E-37</td>
</tr>
<tr>
<td>CO2</td>
<td>17882</td>
</tr>
<tr>
<td>HCl</td>
<td>101386</td>
</tr>
</tbody>
</table>

CCC exceeds current EPA standards for SOX, NO2, Mercury, CO2
Energy Storage

• Grid-scale energy storage
  – Intermittent renewable sources
  – Load leveling
  – High efficiency (95%)
  – Low cost
## CCC ECL Energy Consumption by Source

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flue Gas Blower</td>
<td>11.6%</td>
</tr>
<tr>
<td>Refrigerant Compression</td>
<td>83.0%</td>
</tr>
<tr>
<td>Separations Compression</td>
<td>2.1%</td>
</tr>
<tr>
<td>Condensed-phase Pumping</td>
<td>3.3%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>
Previous Demonstrations
Wyoming Skid Testing
Wyoming Skid Construction
Wyoming Skid Photos

1 tonne/day CO$_2$ capture
Conditioning and Controls
Cold Boxes and Separations
In Place
Pollutant Capture Data

- % CO2 Removed
- % SO2 Removed

Minutes: 0, 15, 30, 45, 60, 75, 90, 105, 120

% CO2 Removed and % SO2 Removed over time.
Accomplishments

• CCC demonstrated at skid scale (up to 125 scfm flue gas – 1 ton/day CO₂).

• Economic and energy analyses refined (about ½ of DOE estimates for sorbent-based systems).

• Energy storage and pilot-scale demonstrations being pursued.

• Climate change mitigation for 2-3 ¢/kWh.
Pilot Facility

100 tonne/day, 5 MW\textsubscript{e} pilot system
Acknowledgements

• Wyoming Advanced Conversion Technologies Task Force funding, DOE/Arpa-E, CCEMC, GE, Air Liquide, Dong Energy, and BYU.

• Chris Bence was engineering manager. Substantial contributions from all SES team members.

• BYU hosting field test. Other tests field tests are scheduled.