Cryogenic Carbon Capture Development
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CCC Value Proposition

- Energy efficient CO$_2$ capture (about $\frac{1}{2}$ amine)
- Cost effective CO$_2$ capture (about $\frac{1}{2}$ amine)
- Grid-scale, efficient, rapid, inexpensive energy storage
- Bolt-on technology (retrofit or greenfield)
- Widely deployable (NG, biomass, coal, waste)
- Multipollutant process (Hg, SO$_x$, HC, NO$_2$, PM$_{2.5}$, ...)
- Water conservation
Cryogenic Carbon Capture

• General separation technology applicable to
  – Post-combustion systems (this presentation)
  – Pre-combustion systems (active development)
  – Natural gas processing (active development)
  – LNG production

• Retrofit or greenfield process

• Described in over 80 patent applications
**Simplified Flow Diagram (ECL)**

- Flue Gas
- Water
- Heat Exchanger And Dryer
- Heat Recovery
- SO₂, NO₂, Hg, HCl
- Solid Separation
- Solid Compression
- Heat Recovery
- Compression
- Ambient Heat Exchange
- Expansion
- Refrigeration Loop
- Pressurized, Liquid CO₂
- Pump
- N₂-rich Light Gas
Energy Penalty

CCC nearly eliminates emissions while consuming half the energy of alternatives.
CCC nearly eliminates emissions while increasing the cost of electricity by 2-3 ¢/kWh
Completed Skid-scale Demonstrations

- **Fuels**
  - Coals (subbituminous and bituminous)
  - Natural gas
  - Biomass
  - Municipal waste, tires

- **Technologies**
  - Utility power plants
  - Industrial heat plants
  - Cement plant kilns
  - Large pilot-scale reactor

- **Pre-combustion/NG Processing (lab scale)**
Utility Power Plant

4-unit, 817 MWₑ power plant in Wyoming

Slip stream on unit 4, which has a baghouse and a wet scrubber (on subbituminous coal).
Utility Power Plant Skid Test
ECL Skid Photos
Utility Power plant

Steady-state, continuous CO₂ removal

CO₂ Capture %

Hours

0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Objective

• Improve reliability and efficiency of unit operations based on field test experience.
• Implement improvements in skid system.
• Retest skid system (budget period 2) in field on power plant flue gas over 3-month period with minimum continuous operation of 500 hours.
• Project Partners: SES, Tri-state, Pacificorp, EPRI
Tasks

1. Management
2. Flue gas drying
3. CO$_2$ in contact liquid
4. Solid-liquid separations
5. Desublimating heat exchanger
6. Instrumentation and controls
7. Light gas dispersal
8. Multipollutant capture
9. Techno-economic analysis
Task 2. Drying

- Moist Flue Gas Input
- Direct Contact Heat Exchanger
- Heat Recovery Heat Exchanger
- Warm Liquid
- Cold liquid
- Water Out
- FU From Treatment
- Water Mole Fraction
- Temperature (°C)
- Ice Barrier
- System 3
- System 4
Task 5. Heat Exchanger Testing

Major Activities
Spray Tower
• Initial droplet size testing done for spray nozzles and parallel spray device
• Designed new skid-scale hybrid spray tower HX
• Design incorporates the latest knowledge of slurry handling, desublimating heat exchangers, and maximizing heat exchange, from thousands of hours of experimental work
• Spray tower constructed in Q3 and testing began
Task 6. Instrumentation and Controls

Major Activities

- New instrumentation includes thermocouples, pressure transducers, level transmitters, flowmeters, and control valves
- I/O channels will increase by 23% (i.e., 104 to 128)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Existing</th>
<th>New or modified</th>
<th>Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog outputs</td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Analog inputs</td>
<td>33</td>
<td>32</td>
<td>40</td>
</tr>
<tr>
<td>Discrete outputs</td>
<td>19</td>
<td>9</td>
<td>22</td>
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<tr>
<td>Discrete inputs</td>
<td>4</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Thermocouples</td>
<td>36</td>
<td>26</td>
<td>39</td>
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<tr>
<td>Total</td>
<td>104</td>
<td>90</td>
<td>128</td>
</tr>
</tbody>
</table>

- Of the existing channels, 63% (i.e., 66) will be modified in some way, such as by repurposing for a different instrument, re-routing to a new process location, or rebranding tag
- All changes require some programming time
Task 8. Pollutant Removal

- NO - Captured at very high rates, likely reacted to NO₂
Task 8. Particulate Capture

Relative particle concentration

PM$_{2.5}$  PM$_{4}$  PM$_{7}$  PM$_{10}$
Task 8. Mercury Testing

• Field test at utility power plant
• Inlet 735 ppt, or 5.77 µg/m³ (after wet scrubber)
• Outlet below detection limit, which is 1 ppt, or 0.01 µg/m³ for 99.9%+ capture.
• Actual concentrations predicted to be far below atmospheric levels (1-2 ng/m³).
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