Cryogenic carbon capture

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Cryogenic Carbon Capture

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Outline

• Cryogenic Carbon Capture™ (CCC) Overview
• Status and Highlights of Recent Tests
• CCC Enabling Low-CO₂ Fossil Systems, Renewables, Energy Storage, and Grid Stability
An Optimistic Message

Cryogenic Carbon Capture™ (CCC) represents a promising pathway for global CO₂ reduction with minimal cost and energy consumption. CCC addresses the largest issues in both fossil and renewable energy. CCC reduces fossil CO₂ emissions and reliably stores renewable energy. It is a realistic pathway to achieving a 2 °C global temperature rise.
CCC Value Proposition

- Energy efficient CO\(_2\) capture (about ½ amine)
- Cost effective CO\(_2\) capture (about ½ amine)
- Enables adoption of renewables through rapidly responding, large-scale energy storage
- Bolt-on technology (ideal retrofit or greenfield)
- Widely deployable (NG, refineries, coal ...)
- Multipollutant process (Hg, SO\(_x\), HC, PM\(_{2.5}\), ...)
- Consumes no additional water
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)**
Simplified Flow Diagram (ECL)
ASU Comparisons

ASU
- Energy Demand: Small
- Heat Exchange
- LP Distillation
- HP Distillation
- Utilization
- Compression

CCC
- Energy Demand: Smaller
- Utilization
- Heat Exchange
- LP Distillation
- HP Distillation
- None
- Compression

Very Small
Basic Principles

$\Delta T_1$ suffices to drive a process that produces a product near its initial temperature – far less cooling than a traditional refrigeration cycle requires.

$\Delta T_2$ corresponds to traditional refrigeration
Energy Demand at High Capture

- 100% coal-derived CO2 capture
- 1% CO2 in flue gas
Actual Gas Temperature Profiles

Flow Direction

Temperature, K

Flue Gas Cooling, Desublimating

Separate N2, CO2 Streams Warming
Utility Power Plant Skid Test
Wyoming Skid Photos

1 tonne/day CO$_2$ capture
Utility Power plant

Steady-state, continuous CO$_2$ removal

CO$_2$ Capture %

Hours
Pollutant Removal

- NO - Captured at very high rates, likely reacted to NO₂
Pollutant Capture Data

Graph showing SO₂ Capture Percent over time (in minutes) and the percentage of CO₂ and SO₂ removed. The graph indicates fluctuations in removal percentages over time, with a trend line for CO₂ and SO₂ removal.
Particulate Capture

Relative particle concentration

- \( \text{PM}_{2.5} \)
- \( \text{PM}_{4} \)
- \( \text{PM}_{7} \)
- \( \text{PM}_{10} \)
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).
CCC nearly eliminates emissions while consuming half the energy of alternatives.
<table>
<thead>
<tr>
<th></th>
<th>No Capture</th>
<th>Amine</th>
<th>CCC</th>
<th>Integrated CCC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Net Power (GJ/tonne CO₂)</strong></td>
<td>0</td>
<td>1.38</td>
<td>0.714</td>
<td>0.555</td>
</tr>
<tr>
<td><strong>Net HHV Heat Rate (BTU/kWh)</strong></td>
<td>8687</td>
<td>12002</td>
<td>10144</td>
<td>9776</td>
</tr>
<tr>
<td><strong>Parasitic Load</strong></td>
<td>0.00%</td>
<td>27.6%</td>
<td>14.4%</td>
<td>11.1%</td>
</tr>
</tbody>
</table>
Cost of Electricity

![Cost of Electricity Diagram](image)

- **NETL Case 12 (Amine)**
- **CCC CFG**
- **CFG Integrated**
- **CCC ECL**
- **ECL Integration**

Legend:
- Capital
- Fuel
- Fixed O&M
- Variable O&M
- TS&M
Retrofit Costs
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>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>
Diverse Power Sources

Graph showing power generation from various sources over time.

- Coal power (MW)
- Total power (MW)
- Total electricity demand (MW)
- Wind power (MW)
- Gas power (MW)
- Power from natural gas combined cycle (MW)
- Residential demand (MW)
Actual Supply Curve

Power supply curve
NERC region: Southeastern Electric Reliability Council
Year: 2010

Source: Deloitte Center for Energy Solutions & Deloitte MarketPoint, Made in America: The economic impact of LNG exports from the United States, Jan. 25, 2013
Results

• An $800 \text{ MW}_e$ power plant with CCC stabilized +/- $400 \text{ MW}_e$ grid surges associated with periodic demand cycles and intermittent renewable availability with no need for spinning reserves or other supplementary power.

• Power demand cycles, wind availability, and general costs taken from actual grid data (southern California).

• $250 \text{ MW}_e$ surge in wind power that occurs in the evening, as power demand generally is in rapid decrease, was effective absorbed by CCC and delivered the next day during peak power.

• Similar load following with coal being constant is possible, but requires larger storage tank and NG replacement rate.
Integrated System
Pilot Facility

100 tonne/day, 5 MWₑ pilot system
Acknowledgements

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• Dave Frankman and Kyler Stitt are engineering managers. Substantial contributions from all SES team members

• Power plants, cement plants, and other host facilities

• Details at www.sesinnovation.com