Cryogenic Carbon Capture Development
Progress and Field Test Data
August 26, 2019
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DE-FE0028697; $3.7M DOE/$4.7M total;
10/01/2016 – 06/30/2019
CCC-Dev Project Timeline

**Phase 1**
De-Risking Individual Unit Operations

Oct 2016 – Sept 2017

**Phase 2**
Field Test Skid Modification

Oct 2017 – Dec 2018

Field Test at Hunter Power Plant

Jan 2019 - Jun 2019
Overview

- High-level review of CCC technology
- Full-scale techno-economic discussion
- Detailed discussion process and subsystems
- Testing data from field tests
## Current Carbon Capture Technology Challenges

| Expensive | $70/tonne CO₂ (more for existing plants)  
<table>
<thead>
<tr>
<th></th>
<th>25%-30% Parasitic Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difficult to retrofit</td>
<td>Require an entirely new plant in some cases or significant modifications/integration with the steam cycle and turbine in others</td>
</tr>
<tr>
<td>Produce CO₂ gas</td>
<td>Requires additional compression and purification for transportation and many uses</td>
</tr>
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</table>
## CCC Provides the Solutions

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
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<tbody>
<tr>
<td>Half the cost and energy</td>
<td>Even greater advantages in retrofit scenarios</td>
</tr>
<tr>
<td>Easily retrofits to any stationary emissions source</td>
<td>Applicable to NG and coal power plants, cement plants, NG burners, etc. without plant modifications</td>
</tr>
<tr>
<td>Produces CO₂ ready for use</td>
<td>Produces high-purity (&gt;99.9%), high pressure CO₂ ready for transportation and sale</td>
</tr>
</tbody>
</table>
CCC has Additional Unique Advantages

Robustly handles SO\(_x\) and NO\(_x\) With development may be able to replace SOX, NOX, and mercury treatments

Option of Grid-Scale Energy Storage* Integrates with intermittent renewables on the grid, allows for 80% reduction in parasitic load during peak demand

*See appendix for more details
The CCC process (1) cools a dirty exhaust gas stream to the point that the CO$_2$ freezes using mostly heat recuperation, (2) separates solid CO$_2$ as it freezes from the clean gas, (3) melts the CO$_2$ through heat recuperation and pressurizes it to form a pure liquid, and (4) warms up the clean, harmless gas releasing it to the atmosphere. See appendix slides for more detailed flow diagrams.
Independent Validation

Of all these processes [CCS technologies], I regard the CCC process to have the greatest potential by a significant margin.

-Howard Herzog, MIT Energy Initiative
Process Simulation and Modeling

- Robust in-house process simulation software developed specifically for CCC
- Capable of simulating various sizes and applications ranging from our skid-scale system to full-scale
- Thermodynamically rigorous calculations
- Results comparable to Aspen simulations
- Vetted and checked by various project partners and third-party contractors
Retrofit Costs

![Graph showing Retrofit Costs](image)
Cost and Energy with Composition

CAPEX numbers is the total equipment cost, not depreciated over any timeframe, and it does not include operating costs. These numbers assume large installations on the order of a power plant.
Cost and Energy with Plant Size

CAPEX numbers is the total equipment cost, not depreciated over any timeframe, and it does not include operating costs. These numbers assume a CO₂ composition of approximately 16% on a dry basis.
PROCESS PFD AND SUBSYSTEMS WALKTHROUGH
External Cooling Loop (ECL)
Simplified Process Flow Diagram
Light Gas Path through System
CO$_2$ Path through System
Direct Contact
Desublimating HX

Multiple heat exchangers developed
• Spray tower (skid selected HX)
  • Easiest to scale
  • Similar to commercial processes
  • Most tested
• Multi-stage bubbler
• Fluidized bed
• Combined spray and bubbler systems
Contact Liquid Cooler
Solid-Liquid Separations
Distillation Column
Distillation Column

Skid Scale

- Sulzer assisted with design
- Built by SES
- Packed bed with 7 theoretical stages
- Operated for 8+ months at Hunter power plant
- 99.99% CO2 design spec exceeded in actual operation
- Sized for 1 tonne/day CO2

Pilot/Full Scale

- Direct scale up from skid-scale
- >99.99% CO2 design spec
- Condenser cooling provided by heat of melting CO2—no additional utility required
- Reboiler utility can be provided by low pressure steam, natural gas burner, or electric heater
- Alternative designs with no/reduced reboiler load
1 TPD SKID-SCALE OPERATION
Objectives of Skid System

• Objectives
  – Proof of concept of the CCC process
  – Develop and test most innovative unit operations
  – Improve reliability, efficiency, and scalability of overall process
  – Extended tests with real flue gas

• Not intended to
  – Achieve representative energy and cost numbers
  – Use same equipment design as full scale
## Selected Skid Instrumentation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Instrument</th>
<th>Purpose</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Flue Gas Composition</td>
<td>Fourier transform infrared spectroscopy (FTIR), Nondispersive infrared (NDIR)</td>
<td>Measuring the concentrations of CO2 and other pollutants</td>
<td>(2)</td>
</tr>
<tr>
<td>Flue Gas Temperature</td>
<td>Thermocouples (TC)</td>
<td>Validating thermodynamic models</td>
<td>(1)(2)</td>
</tr>
<tr>
<td>Cooling Load</td>
<td>TC’s, Coriolis Meter</td>
<td>Measure the cooling obtained from the Stirling Coolers</td>
<td>LN2 Tank, CL Cooler</td>
</tr>
<tr>
<td>Clean Gas Composition</td>
<td>FTIR, NDIR</td>
<td>Determine capture rate</td>
<td>(6)</td>
</tr>
<tr>
<td>Slurry Composition</td>
<td>Coriolis Meter</td>
<td>Monitor thickness of slurry</td>
<td>(4)</td>
</tr>
<tr>
<td>Melter Liquid Composition</td>
<td>Coriolis Meter</td>
<td>Monitor efficiency of screw press system</td>
<td>(5)</td>
</tr>
<tr>
<td>Spray Tower Recirculation Rate</td>
<td>Coriolis Meter, Turbine Meter</td>
<td>Monitor flow into spray tower</td>
<td>(3)</td>
</tr>
<tr>
<td>Liquid CO₂ Composition</td>
<td>FTIR</td>
<td>Monitor liquid CO₂ purity</td>
<td>Clean CO₂ Out</td>
</tr>
</tbody>
</table>
OVERALL TEST RESULTS
High Capture and Purity
Hunter Plant Test Results

• Testing was delayed due to delays with equipment construction and unexpected equipment failures
• Over 450 cumulative hours of testing
• Typical test results
  – 90-98% CO₂ capture
  – Tests reached 1 tonne/day, but overall capacity and test duration missed targets
Test Run (1-3 June 2019)

98% avg. CO₂ capture

−135 °C avg refrigerant T
Acknowledgements

• DOE/NETL Project No. DE-FE0028697
  – $3.7M DOE/$4.7M total
  – 10/01/2016 – 03/31/2019

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