Management of Water from CCS:  
*Life Cycle Water Consumption for Carbon Capture and Storage*

Project Number 49607

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Argonne National Laboratory
Benefit to the Program

• Program goals being addressed.
  – Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.

• Project benefits statement.
  – This work supports the development of active reservoir management approaches by identifying cost effective and environmentally benign strategies for managing extracted brines (Tasks 1 + 2).
  – This work will help identify water related constraints on CCS deployment and provide insight into technology choices that can help reduce these constraints (Task 3)
Project Overview: Goals and Objectives

• **Task 1 (FY10/11)** – Analyze geochemical composition of deep saline aquifers, identify viable options for managing extracted water, estimate management costs, and evaluate options for beneficial reuse. *(Completed)*

• **Task 2 (FY11/12)** – Quantify the environmental costs and benefits of a range of viable extracted water management practices to identify those with the potential to manage extracted brines with the lowest cost and environmental impact. *(Final Report pending NETL review)*

• **Task 3 (FY13/14)** – Quantify the life cycle water consumption from coal electricity production with carbon capture and geological carbon sequestration. The analysis will consider a range of scenarios with different capture and sequestration technologies to assess their relative impact on water resources. *(In Progress)*
Task 1 – Key Findings

- Geochemical composition analyzed for 61 deep saline aquifers identified with potential for geological sequestration
- Potential extracted water management practices identified including multiple beneficial use options based upon existing produced water management practices
- Current cost data obtained and analyzed for existing produced water management practices with potential parallel applications for extracted water management

<table>
<thead>
<tr>
<th>Management Practice</th>
<th>Cost Range ($/bbl)*</th>
<th>Cost to CCS ($/ton CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse Osmosis</td>
<td>$1.00-$3.50</td>
<td>$8.80-$31.00</td>
</tr>
<tr>
<td>Thermal Distillation</td>
<td>$6.00-$8.50</td>
<td>$53.00-$75.00</td>
</tr>
<tr>
<td>UIC Injection</td>
<td>$0.05-$4.00</td>
<td>$0.45-$35.00</td>
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<tr>
<td>Evaporation</td>
<td>$0.40-$4.00</td>
<td>$3.50-$35.00</td>
</tr>
</tbody>
</table>

*Quoted costs for produced water management and do not include transportation*
Task 2 – Key Findings

- Hybrid life cycle assessment (LCA) approach used to evaluate potential extracted water management practices for:
  - Energy consumption
  - GHG emissions
  - Net water savings
- Extracted water management practices identified which could manage extracted water while emitting less than 1% of the CO2 injected
- Cost of water management was estimated at $1-3/ton CO2 injected
- Water transportation distance was identified as the primary driver of cost and environmental impact
Task 3 – General Approach

- Project Goal: Quantify the life cycle water consumption from coal electricity production with carbon capture and geological carbon sequestration.

- Approach
  - Define processes to be evaluated
  - Select LCA methodology
  - Define system boundaries
  - Collect data and system parameters
  - Identify and address gaps
    - Addressed through additional data sources, modeling, or assumptions
  - Perform modeling to fill gaps and generate additional parameters
  - Integrate data across the life cycle for each technological pathway
  - Analyze results
    - Assess variability and uncertainty
Task 3 – Processes Evaluated

• Power plants:
  – Subcritical coal with post combustion amine capture
  – Supercritical coal with post combustion amine capture
  – Oxycombustion at subcritical coal plant
  – Oxycombustion at supercritical coal plant
  – IGCC with capture
  – Subcritical coal without capture
  – Supercritical coal without capture
  – IGCC without capture

• Transportation, Storage, and Usage
  – Enhanced Oil Recovery
  – Enhanced Coal Bed Methane
  – Deep Saline Aquifer
  – Assess Impact of Transport Distance
• Hybrid life cycle assessment (LCA) approach used to compare water consumption across multiple CCUS technology pathways for coal power plants

• Hybrid LCA combines process based LCA approach with economic input-output LCA approach (EIOLCA).

• Process approach (used for direct inputs)
  – Ideal for well characterized processes
  – Requires lots of specific data
  – Suffers from cut-off error

• EIOLCA approach (used for capital equipment)
  – Suitable for more general processes
  – Only requires costs
  – Suffers from aggregation error

• Indirect water consumption due to energy consumption and parasitic loads included in analysis
Task 3 – System Boundaries

• Processes Included in Analysis:
  – Coal Mining (Process)
  – Power Plant Operations (Process)
  – Capture System Operations (Process)
  – Power Plant and Capture System Capital (EIOLCA)
  – CO2 Compression and Transport Energy (Process)
  – Pipeline Capital (EIOLCA)
  – Injection Well Construction (Process)
  – Injection Well Operation (Process)

• Processes Excluded:
  – Transportation of fuel
  – Manufacture of chemicals consumed for capture systems and other pollution control processes
  – Decommissioning and waste disposal
Task 3 - Data Sources

- **Literature Review**
  - Previous Water Studies
    - Often focused on a minimal number of system designs
    - Often only include capture, not complete LCA
  - Previous LCA Studies
    - Most don’t include water
    - Can provide energy requirements and important system parameters
  - Technoeconomic Analyses
    - Can provide EIO-LCA inputs and important system parameters
  - Reports on demonstration projects and pilot studies
    - Can provide system parameters and well and pipeline designs
- **Modeling**
  - Aspen Modeling
  - Argonne Well Analysis Tool
Task 3 – Literature Review

• Initial Literature review completed
• Key system parameters collected and aggregated into a database by life cycle stage
• Review of the data and parameters in progress
• Additional literature will be included as necessary as data gaps are identified
Task 3 – Power Plant Stage Data

Coal Power Plant Water Consumption by Plant Design

- Supercritical No Capture
- Subcritical No Capture
- IGCC No Capture
- Supercritical Post Combustion
- Subcritical Post Combustion
- IGCC w/Capture
- Oxyfuel
## Task 3 – Aspen Modeling

- Previously developed Aspen models were utilized to evaluate the water footprint of Amine and Oxyfuel capture systems
- Based upon a new 450 MW PC power plant
- Aspen models originally developed for: Doctor, R., 2012, *Future of CCS adoption at existing PC plants: economic comparison of CO₂ capture and sequestration from amines and oxyfuels*, ANL/ESD/12-9

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>Non Cooling Water Consumption (gal/Mwhnet)</th>
<th>Consumptive Cooling Water (gal/Mwhnet)</th>
<th>Non Cooling Water Consumption (gal/Mwhnet)</th>
<th>Consumptive Cooling Water (gal/Mwhnet)</th>
<th>Non Cooling Water Consumption (gal/Mwhnet)</th>
<th>Consumptive Cooling Water (gal/Mwhnet)</th>
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<tbody>
<tr>
<td>Boiler/Steam/SCR/Baghouse 450 MW</td>
<td>11.0</td>
<td>500.0</td>
<td>17.0</td>
<td>773.9</td>
<td>16.7</td>
<td>759.5</td>
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<td>Greenfield</td>
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<td>LSFO - Limestone -Forced Oxidation 450 MW</td>
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<td>83.3</td>
<td>N/A</td>
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<td>Oxyfuel - Air Separation Unit 450 MW</td>
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<td>2.2</td>
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<td>Flue Gas Compression 450 MW</td>
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<td>Dual Alkali 450 MW</td>
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<td>Amine CCS 450 MW</td>
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<td>CO₂ Liquefaction and Pumping 450 MW</td>
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<td>39.3</td>
<td>(26.1)</td>
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<td>Sub Total</td>
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<td>500.0</td>
<td>133.1</td>
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<td>1394</td>
<td>888</td>
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Task 3 - Argonne Well Analysis Tool

- Argonne has previously developed an LCA analysis tool for wells drilled for geothermal and oil and gas development.
- This model will be updated to include carbon storage wells including:
  - Deep Saline Aquifers
  - EOR Wells
  - Enhanced Coal Bed Methane Wells
  - Monitoring Wells
- Tool calculates total water, energy, and materials required to drill a well based upon reference well designs and user defined well depth
Task 3 – Current Project Status

- Define processes to be evaluated (Complete)
- Select LCA methodology (Complete)
- Define system boundaries (Complete)
- Collect data and system parameters (Complete*)
- Identify and address gaps (In Progress)
- Perform modeling to fill gaps and generate additional parameters (In Progress)
- Integrate data across the life cycle for each technological pathway (FY14Q1)
- Analyze results (FY14Q1)
Accomplishments to Date

– A wide range of extracted water management practices have been evaluated both qualitatively and quantitatively
– Multiple extracted water management practices have been identified as likely to be both economically and environmentally viable
  • Reverse Osmosis
  • Mechanical Vapor Compression
  • Direct Reuse
  • Injection for Disposal or Hydrological Purposes
– Initial data collection and modeling has been performed for the evaluation of the life cycle water consumption from carbon capture, utilization, and storage
Summary

– Key Findings
  • Reverse osmosis, mechanical vapor compression, direct reuse, and injection for disposal were all identified as likely environmentally and economically viable technologies for managing extracted water
  • *(PRELIMINARY)* Carbon Capture adds anywhere from 50-100% to the water footprint of coal electricity generation
    – IGCC appears to be the most water efficient capture system design

– Future Plans
  • Complete CCUS water LCA study
  • Evaluate the role that water extraction can play in mitigating the larger water footprint of electricity production with carbon capture and storage
Appendix
Organization Chart

• PI:
  – Christopher Harto

• Other Researchers
  – John Veil, *Retired* (Task 1 only)
  – Richard Doctor, *Retired* (Task 3 only)
  – David Murphy (Task 3 only)
  – Robert Horner (Task 3 only)
  – Ellen White (Task 3 only)
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<tr>
<th>Task</th>
<th>Milestone Description</th>
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<th>FY11</th>
<th>FY12</th>
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<td>Q3</td>
<td>Q4</td>
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<td>Task 1 - Extracted Water from CCS</td>
<td>Qualitative assessment of options for managing extracted water based upon produced water management practices</td>
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<td>Quantification of the life cycle environmental costs and benefits of different extracted water management scenarios.</td>
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Bibliography

– Technical Reports

– Conference Papers

– Conference Presentations