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

Project Number 49607

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Developing the Technologies and Infrastructure for CCS
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Benefit to the Program

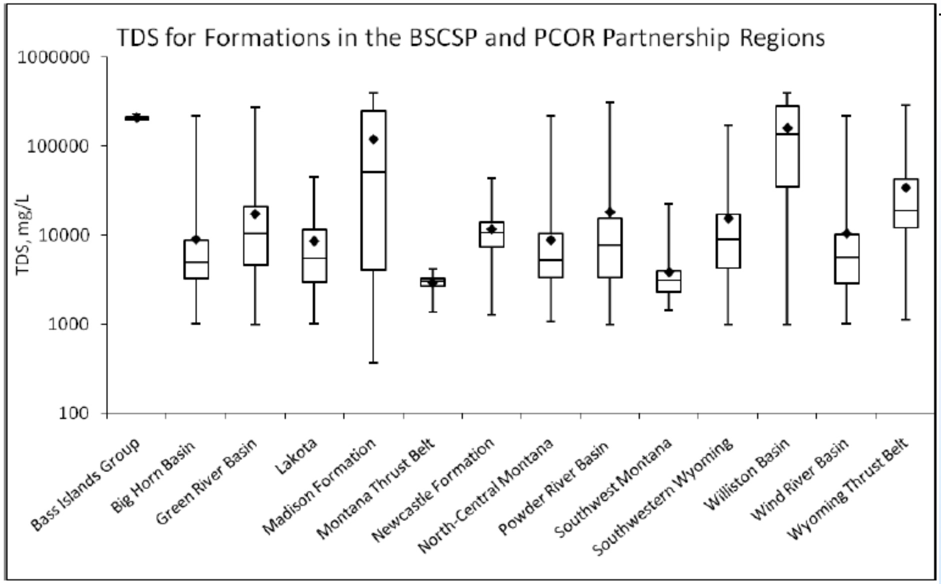
- Program goals being addressed.
  – Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
- Project benefits statement.
  – This work supports the development of active reservoir management approaches by identifying cost effective and environmentally 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

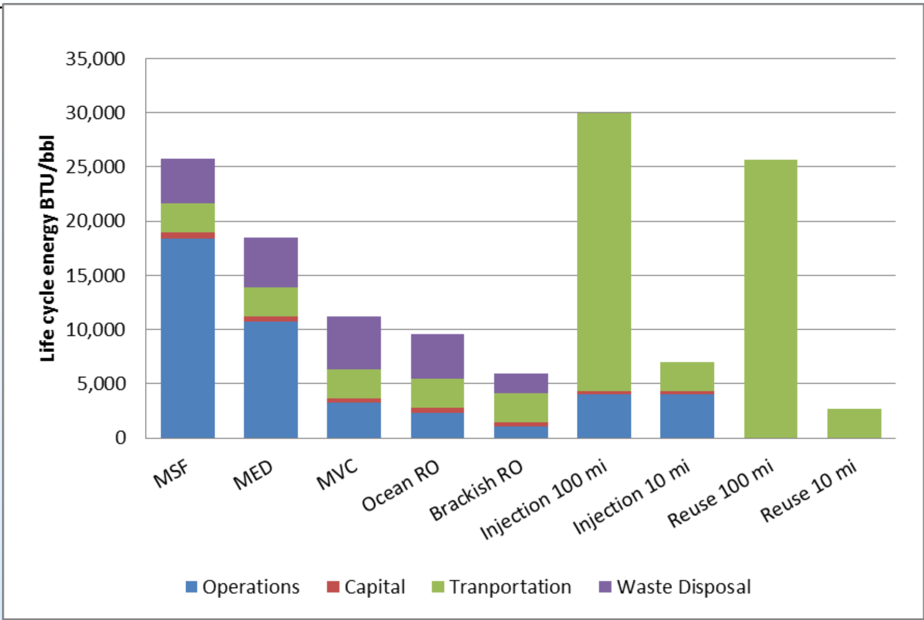


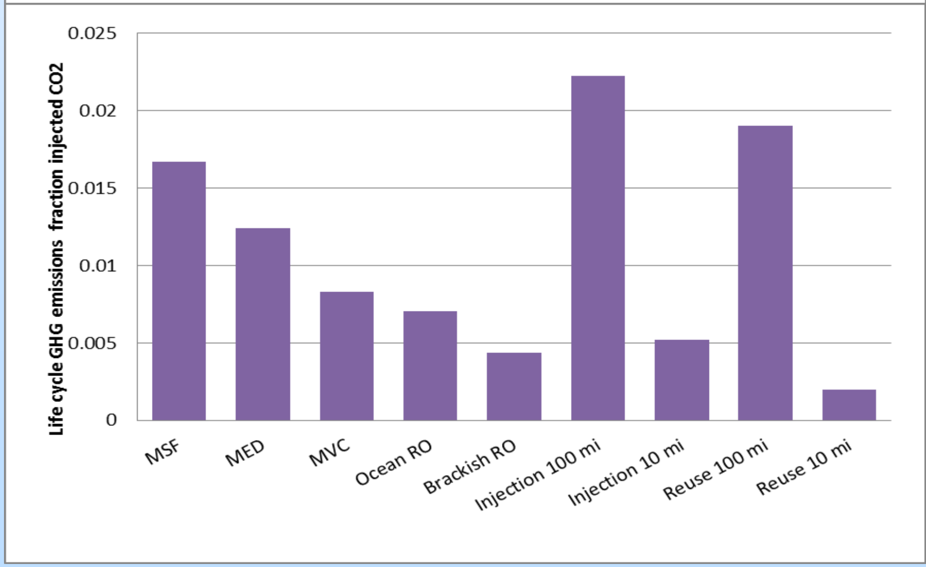
Management Practice	Cost Range ($/bbl)*	Cost to CCS ($/ton CO_2)
Reverse Osmosis	$1.00-$3.50	$8.80-$31.00
Thermal Distillation	$6.00-$8.50	$53.00-$75.00
UIC Injection	$0.05-$4.00	$0.45-$35.00
Evaporation	$0.40-$4.00	$3.50-$35.00

**Quoted costs for produced water management and do not include transportation*

Task 2 – Key Findings

- Hybrid life cycle assessment (LCA) approach used 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

Task 3 – LCA Methodology

- 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)
  - CO_2 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

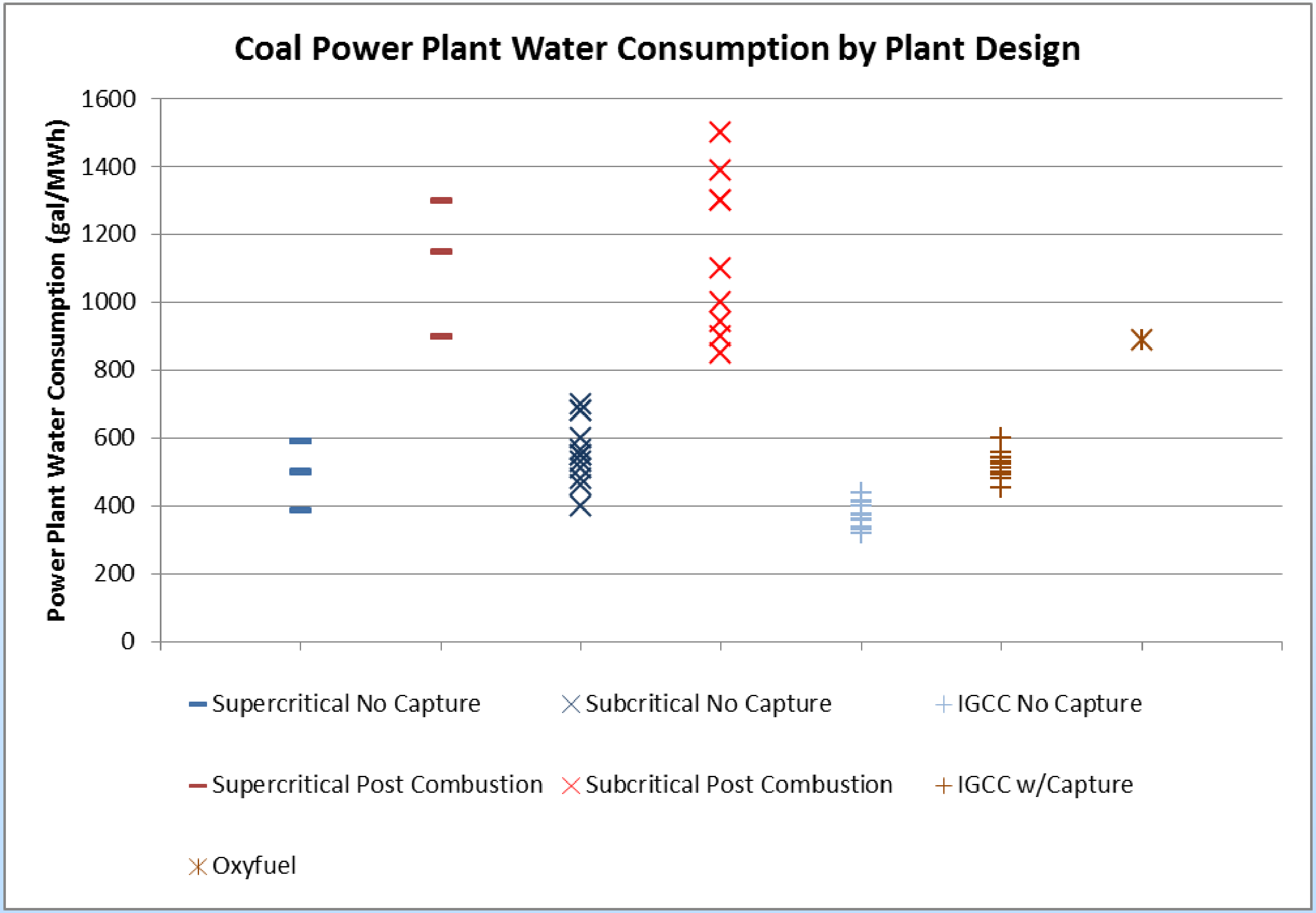
Task 3 - Data Sources

- 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 EIOLCA 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



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 CO_2 capture and sequestration from amines and oxyfuels, ANL/ESD/12-9*

SYSTEM	Greenfield PC Boiler 450 MW		Greenfield Amine CCS 291 MW net		Greenfield Oxyfuel CCS 296 MW net	
	Non Cooling Water Consumption (gal/Mwhnet)	Consumptive Cooling Water (gal/Mwhnet)	Non Cooling Water Consumption (gal/Mwhnet)	Consumptive Cooling Water (gal/Mwhnet)	Non Cooling Water Consumption (gal/Mwhnet)	Consumptive Cooling Water (gal/Mwhnet)
Boiler/Steam/SCR/Baghouse 450 MW *Greenfield*	11.0	**500.0**	17.0	**773.9**	16.7	**759.5**
LSFO - Limestone -Forced Oxidation 450 MW	53.8	N/A	83.3	N/A	81.8	N/A
Oxyfuel - Air Separation Unit 450 MW						2.2
Flue Gas Compression 450 MW			N/A	53.6	N/A	10.7
Dual Alkali 450 MW			0.8	N/A	0.8	N/A
Amine CCS 450 MW			58.6	**393.9**		
CO2 Liquefaction and Pumping 450 MW			(26.6)	39.3	(26.1)	42.1
Sub Total	**64.8**	**500.0**	**133.1**	**1,260.6**	**73**	**815**
Total	**565**		**1394**		**888**	

Task 3 - Argonne Well Analysis Tool

- Argonne has previous 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)

Gantt Chart

Task	Milestone Description	FY10				FY11				FY12				FY13				FY14	
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Task 1 - Extracted Water from CCS	Qualitative assessment of options for managing extracted water based upon produced water mangament practices		⟷	⟷	⟷	⟷	⟷	⟷											
Task 2 - Extracted Water from CCS: Environmental Cost/Benefit Analysis	Quantification of the life cycle envirionmental costs and benefits of different extracted water management scenarios.						⟷	⟷	⟷	⟷	⟷	⟷	⟷						
Task 3 - Extracted Water from CCS: Water LCA	Quantification of the life cycle water consumption for electricity production from coal generation with carbon sequestration												⟷	⟷	⟷	⟷	⟷	⟷	⟷

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  - Harto, C.B., 2012, "Life Cycle Assessment of Water Management Options used for Managing Brines Extracted from Deep Saline Aquifers used for Carbon Storage," DRAFT.
- Conference Papers
  - Veil, J.A., Harto, C.B., and A.T. McNemar, 2011, "Management of Water Extracted From Carbon Sequestration Projects: Parallels to Produced Water Management," SPE 140994, Presented at SPE Americas E&P Health, Safety, Security and Environmental Conference, Houston, Texas, 21–23 March 2011.
- Conference Presentations
  - Harto, C.B., 2011, "Environmental Costs of Managing Geological Brines Produced or Extracted During Energy Development," presented at the International Petroleum and Biofuels Environmental Conference, Houston, TX, November 8-10.
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  - Harto, C.B., Veil, J.A., and McNemar, A., 2011, "Extracting Water from Carbon Sequestration Projects: Quantities, Costs, and Environmental Considerations", presented at the 10th Annual Conference on Carbon Capture & Sequestration, Pittsburgh, PA, May 2-5.
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