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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Argonne NATIONAL LABORATORY

Benefit to the Program

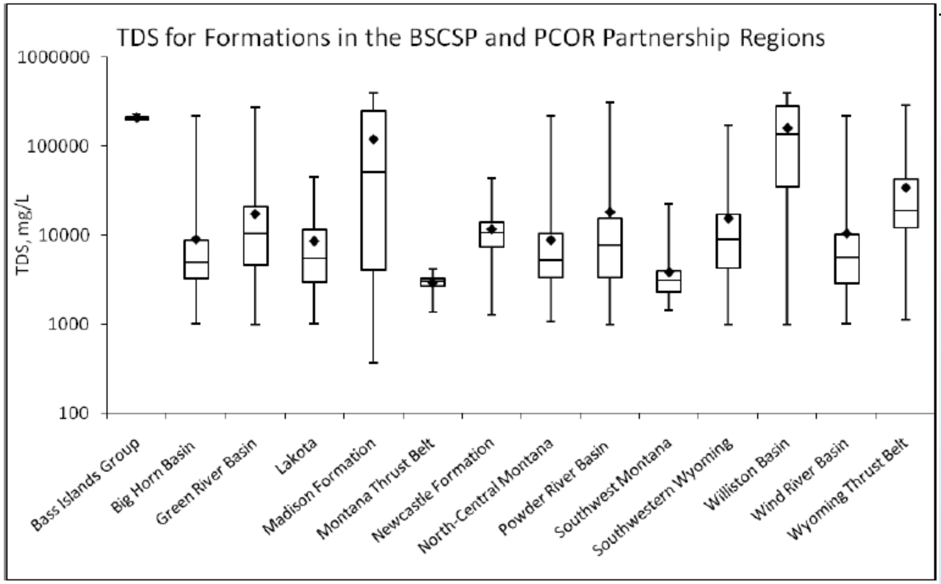
- Program goals being addressed.
  - Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
- Project benefits statement.
  - This work supports the development of active reservoir management approaches by identifying cost effective and environmentally 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. **(Completed)**
- **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. **(Final Report in Draft)**

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

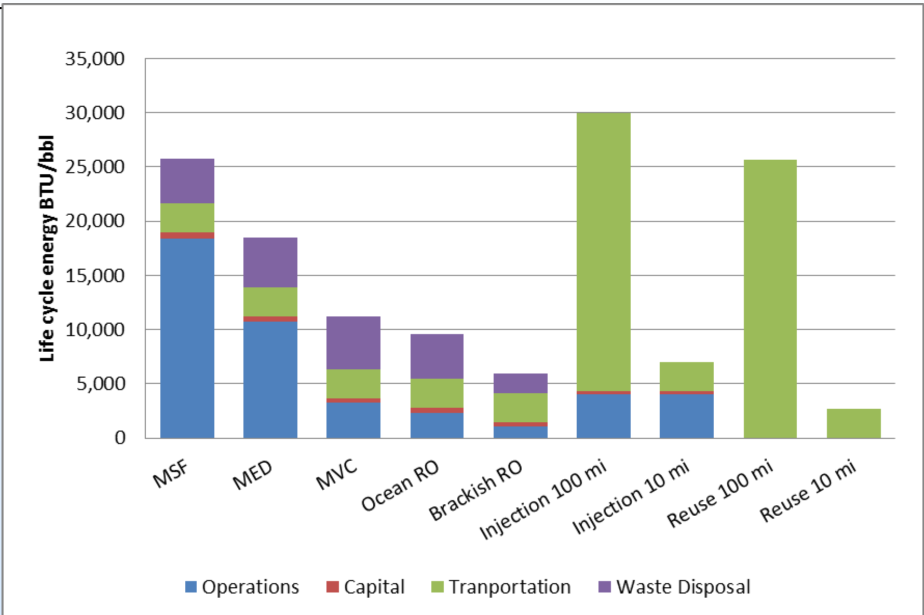


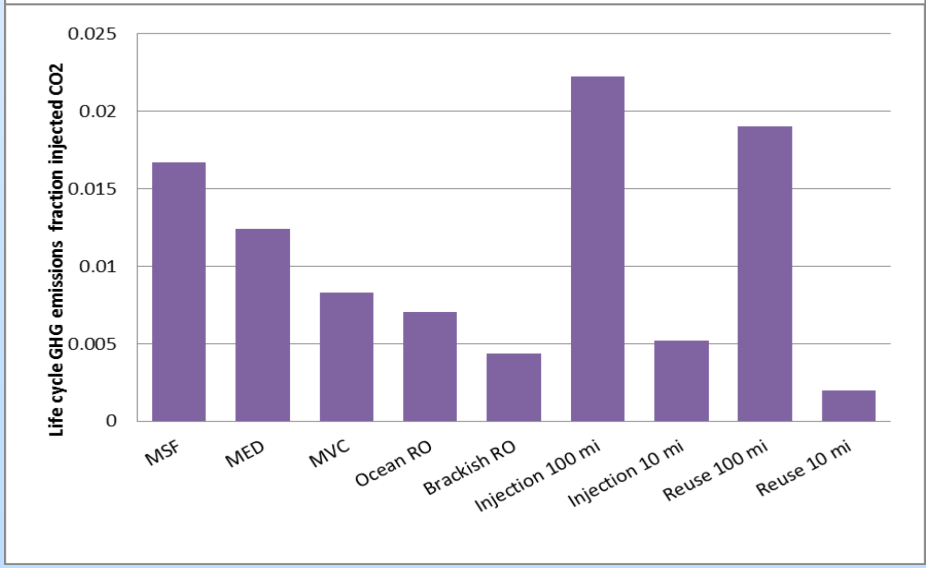
Management Practice	Cost Range ($/bbl)*	Cost to CCS ($/ton CO_2)
Reverse Osmosis	$1.00-$3.50	$8.80-$31.00
Thermal Distillation	$6.00-$8.50	$53.00-$75.00
UIC Injection	$0.05-$4.00	$0.45-$35.00
Evaporation	$0.40-$4.00	$3.50-$35.00

**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 - 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 cost data
  - Suffers from aggregation error
- Indirect water consumption due to energy consumption and parasitic loads included in analysis

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
  - IGCC with capture
  - Subcritical coal without capture
  - Supercritical coal without capture
  - IGCC without capture
- Transportation, Storage, and Usage
  - Deep saline aquifer
  - Enhanced oil recovery
  - Distance of CO_2 transport to storage

Task 3 - System Boundaries

- Processes Included in Analysis:
  - Coal Mining (Process)
  - Power Plant Operations (Process)
  - Capture System Operations (Process)
  - Power Plant and Capture System Construction (EIOLCA)
  - CO_2 Compression and Transport Energy (Process)
  - Pipeline Construction (EIOLCA)
  - Injection Well Construction and Operations (EIOLCA)
- Processes Excluded:
  - Transportation of fuel
  - Manufacture of chemicals consumed for capture systems and other pollution control processes
  - Decommissioning and waste disposal

Task 3 - Scenario Parameters

Plant type	**SubPC no CCS**	**SubPC Amine**	**SuperPC no CCS**	**SuperPC Amine**	**IGCC no capture**	**IGCC w/ capture**	**Oxyfuel**
Source	Doctor 2012	Doctor 2012	NETL 2010	NETL 2010	NETL 2010	NETL 2010	Doctor 2012
Gross Power Output (MW)	483	483	580	663	748	734	483
Net Output (MW)	450	290	550	550	622	543	296
Capacity Factor	0.85	0.85	0.85	0.85	0.8	0.8	0.85
Capture %	0	90%	0%	90%	0	90%	98%
Coal Consumption (tonnes/hr)	186	186	186	257	212	221	186
Coal Type	Illinois #6	Illinois #6	Illinois #6	Illinois #6	Illinois #6	Illinois #6	Illinois #6
CO2 Pipeline Flow (tonnes/hr)	0	359	0	549	0	458	393
Plant lifetime	40	40	40	40	40	40	40
Power Plant Total Capital ($/kWnet)	1,216	2,268	1,647	2,913	1,987	2,711	2,411
Storage cost ($/tonne)	10.1	10.1	10.1	10.1	10.1	10.1	10.1
Pipeline cost ($/tonne)	3.7	3.7	3.7	3.7	3.7	3.7	3.7

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,* July.

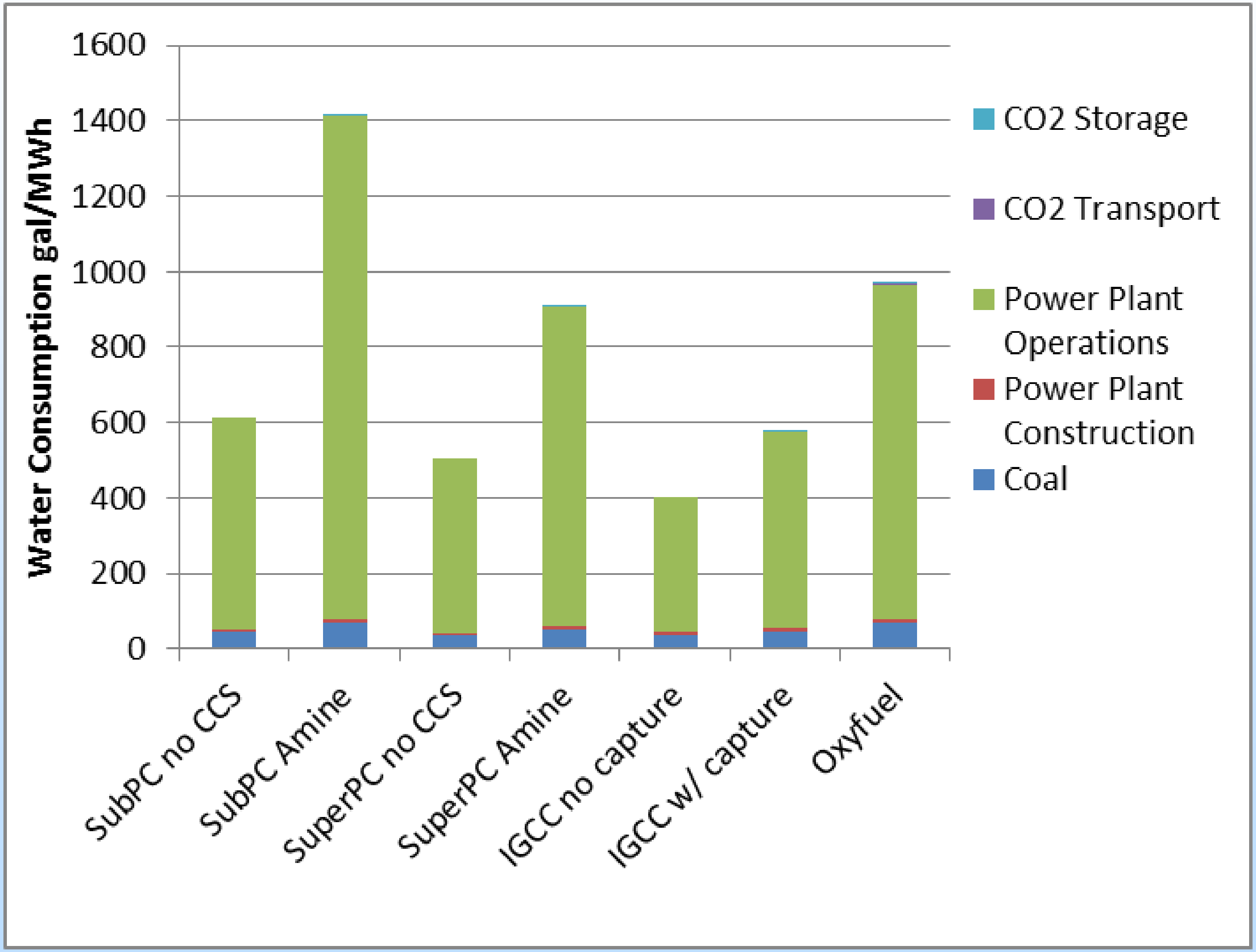
NETL, 2010, *Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity,* Revision 2, DOE/NETL-2010/1397, November.

Task 3 - ASPEN Modeling

- Previously developed Aspen models were utilized to evaluate the water footprint of Subcritical PC with and without Amine and Oxyfuel capture systems
- Based upon a new 450 MW Subcricital 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**	17.0	**774**	16.7	**760**
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	**335**		
CO2 Liquefaction and Pumping 450 MW			(26.6)	39.3	(26.1)	42.1
Sub Total	**64.8**	**500**	**133**	**1,202**	**73**	**815**
Total	**565**		**1335**		**888**	

LCA Results


Water Consumption gal/MWh
1600
1400
1200
1000
800
600
400
200
0
SubPC no CCS
SubPC Amine
SuperPC no CCS
SuperPC Amine
IGCC no capture
IGCC w/ capture
Oxyfuel
CO2 Storage
CO2 Transport
Power Plant Operations
Power Plant Construction
Coal

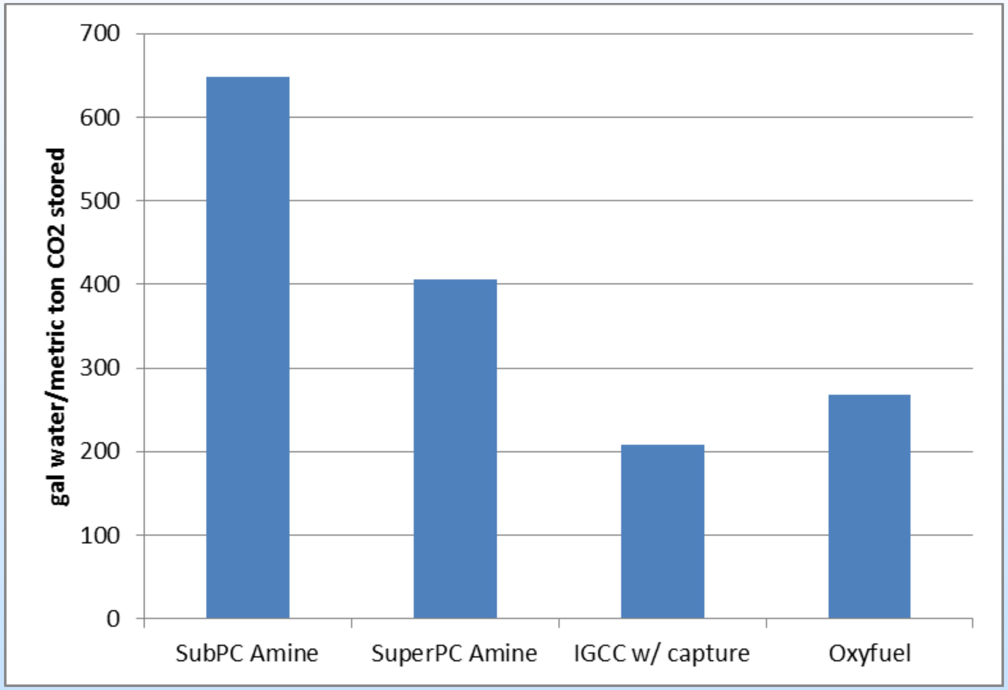
Sensitivity Analysis

Coal Type				
Coal Type	SubPC Amine	SuperPC Amine	IGCC w/ capture	Oxyfuel
Illinois #6	*71*	*51*	*45*	*69*
Wyodak-Anderson	11	8	7	11
Pocahontas #3	52	38	33	51
Pipeline Length				
Pipeline Length	SubPC Amine	SuperPC Amine	IGCC w/ capture	Oxyfuel
100km	*1.2*	*0.9*	*0.8*	*1.2*
500km	9.0	6.3	4.7	8.4
1000km	17.9	12.5	9.4	16.9
Storage Site				
Storage Site	SubPC Amine	SuperPC Amine	IGCC w/ capture	Oxyfuel
Baseline	*3.4*	*2.7*	*2.3*	*3.6*
Low	1.9	1.5	1.3	2.0
High	5.9	4.8	4.0	6.4
EOR	0.0	0.0	0.0	0.0

All values in gal/MWh, italics indicate baseline assumption for analysis

Water Consumption per Ton CO_2 Stored

- The incremental water consumption for CO_2 capture and storage was calculated (gal/ton)
- Water consumption for same power plant without capture subtracted from water consumption for power plant with capture divided by the volume of CO_2 stored
- Technology choice can play a significant role in reducing the water impact of carbon emissions reductions
- This metric provides a direct quantification of the tradeoff between emissions reduction and water consumption



Can Water Extraction Offset Increased Water Demand?

- Extraction of water from deep saline aquifers has been proposed as a means to provide operational benefits to CO_2 storage operations
  - increased storage capacity, higher injectivity, improved reservoir control, lower CO2 leakage risk, and reduced area of review
- It may also present an opportunity to help offset the increased water demand of CCUS
- Challenges:
  - Treatment Cost ($1-3/ton CO2 stored)
  - Transportation Distance

	SubPC Amine	SuperPC Amine	IGCC w/ capture	Oxyfuel
Total Water Demand For Power (gal/MWh)	1420	910	580	970
Incremental Water Demand of CCUS (gal/MWh)	800	410	175	360
Potential water extracted 1:1 ratio (gal/MWh)	**460**	**370**	**310**	**490**
Fraction of total water demand	0.32	0.41	0.53	0.51
Fraction of incremental water demand	0.58	0.90	1.77	1.36

Task 3 - Conclusions

- This analysis shows that technology choice for CCUS can play a significant role in the amount of water consumed by future clean coal generation
- IGCC was found to be by far the most water-efficient CCUS technology
- Overall the power plant and capture system operations account for the vast majority of water consumption in all scenarios (~90%)
- Water extraction has the potential to offset a significant fraction of the incremental water demand for CCUS for most technology pathways.

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
- The water impact of a wide range of CCUS pathways have been evaluated and the potential to mitigate that impact through water extraction has been examined

Summary

– Key Findings
  - Water extraction and management is likely to be possible with manageable CO_2 emissions, parasitic energy loads.
  - CCUS adds significantly to the water consumption of coal electricity production, however technology choice can significantly reduce that burden
  - Water extraction and re-use for cooling has the potential to more than offset the incremental water demand for capture for some system configurations

– Future Plans
  - The existing funded tasks have been completed
  - Proposal submitted to more closely examine the economics of water extraction and management

Appendix

– These slides will not be discussed during the presentation, but are mandatory

Organization Chart

- PI:
  - Christopher Harto
- Other Researchers
  - John Veil, *Retired* (Task 1 only)
  - Richard Doctor, *Retired* (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																		

Bibliography

- Technical Reports
  - Harto, C.B, 2014, “Quantitative Assessment of Options for Managing Brines Extracted from Deep Saline Aquifers Used for Carbon Storage” Prepared for the US DOE National Energy Technologies Program by Argonne National Laboratory, ANL/EVS/TM-14/1, February.
  - Harto, C.B., and J.A. Veil, 2011, “Management of Water Extracted from Carbon Sequestration Projects,” Prepared for the US DOE National Energy Technology Laboratory Carbon Sequestration Program by Argonne National Laboratory, ANL/EVS/R-11/1, January.
- Conference Papers
  - Harto, C., E. White, R. Horner, and J. Schroeder, 2014, “Technology Choice and Water Consumption for Carbon Capture and Storage,” Proceedings of the ASME 2014 Power Conference, Baltimore, MD, July 28-31.
  - 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., E. White, R. Horner, and J. Schroeder, 2014, “Life Cycle Water Consumption for Carbon Capture and Storage: The Impact of Technology Choice,” presented at the 13th Annual Conference on Carbon Capture & Sequestration, Pittsburgh, PA, April 28-May 1.
  - Harto, C.B., 2012, “Quantifying the Environmental Costs of Managing Brines Extracted from Deep Saline Aquifers Used for Carbon Storage,” presented at the 11th Annual Conference on Carbon Capture & Sequestration, Pittsburgh, PA, April 30 - May 3.
  - 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.
  - Harto, C.B., 2011, “Environmental Costs of Managing Geological Brines Produced or Extracted During Energy Development,” presented at the Groundwater Protection Council Annual Forum, Atlanta, GA, September 25-28.