DOE/Office of Fossil Energy’s Energy & Water R&D Program

Thomas Feeley

October 27, 2008

DOE/NETL Water-Energy R&D Activities

Power Generation

- Alternative "non-traditional" water sources
- Advanced cooling, recovery/reuse, and treatment technology
- Systems and engineering analysis

Water Availability & Quality Issues

Carbon Capture & Storage

- Geological sequestration
- CO_2 capture technology
- Systems and engineering analysis

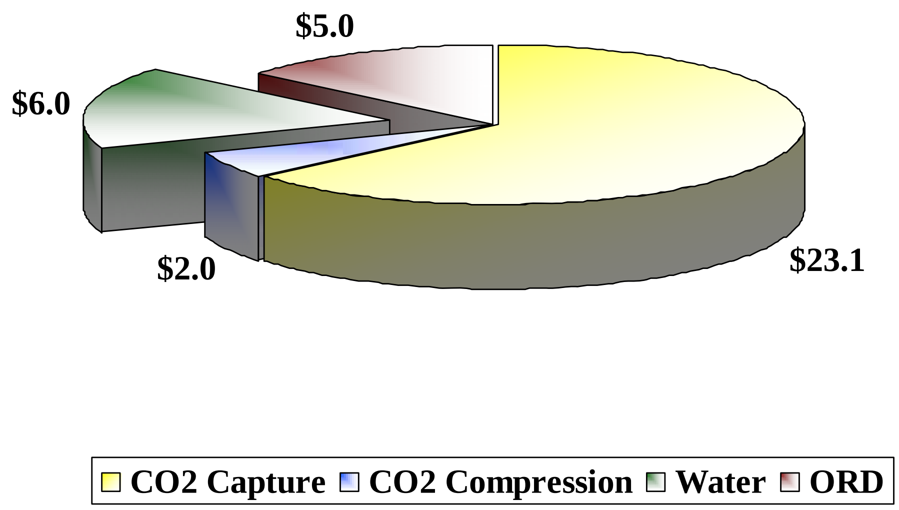
Oil & Gas Exploration

- Water management technology
- Coal bed methane and produced water
- Systems and engineering analysis

IEP Power Plant-Water R&D Program

- **Funded under Innovations for Existing Plants (IEP) Program**
- **Both inhouse and extramural R&D**
- **Research focused on:**
  - Advanced cooling
  - Water recovery & reuse
  - Non-traditional water
  - Advanced water treatment/detection
- **Supporting engineering and system analysis**

IEP Funding	
FY2008	FY2009
$36.1 M	$40 M



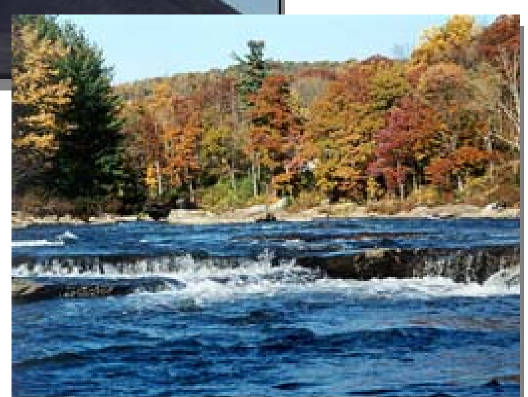
History

- **July 23-24, 2002 "Workshop on Electric Utilities and Water – Emerging Issues and R&D Needs," Pittsburgh, PA**
- **FY 2003 – 1st Competitive solicitation seeking advanced technologies in cooling, water recovery & reuse, non-traditional water, and detection/treatment**
- **FY 2008 – 2nd solicitation (Financial Opportunity Announcement) focused on advanced cooling, water recovery & reuse, and non-traditional water**

Three Things Power Plants Require

1) Access to transmission lines

2) Available fuel, e.g., coal or natural gas

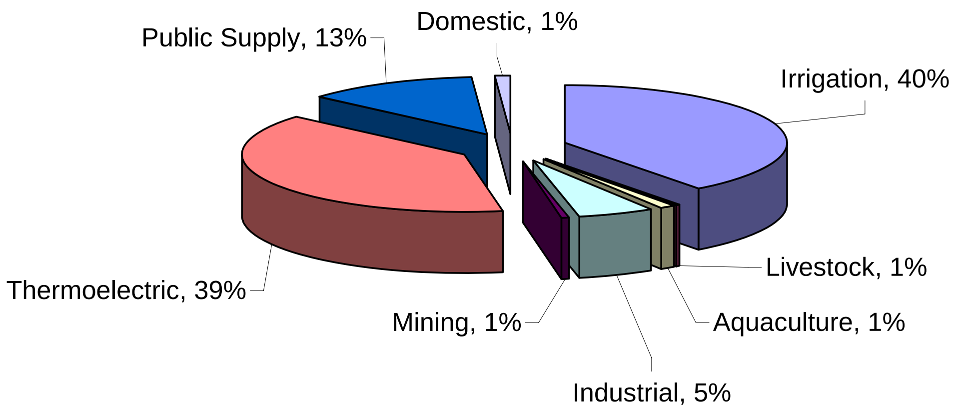


3) Water

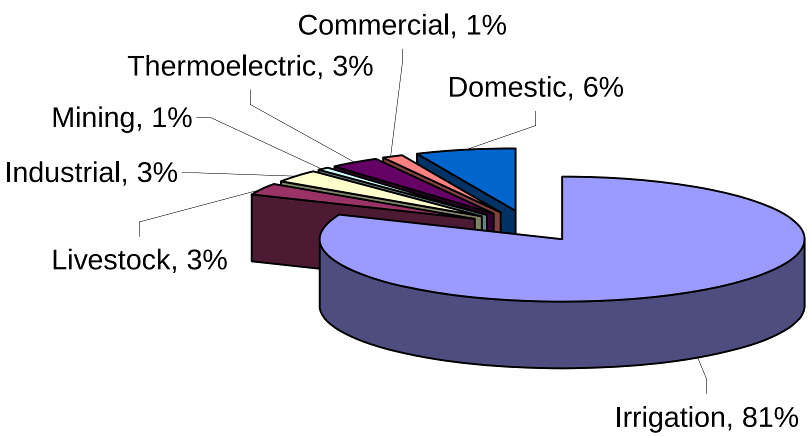
Thermoelectric Generation & Water

- **2000 thermoelectric water requirements:**
  - **Withdrawal: ~ 136 BGD**
  - **Consumption: ~ 4 BGD**

U.S. Freshwater Withdrawal (2000)



U.S. Freshwater Consumption (1995)

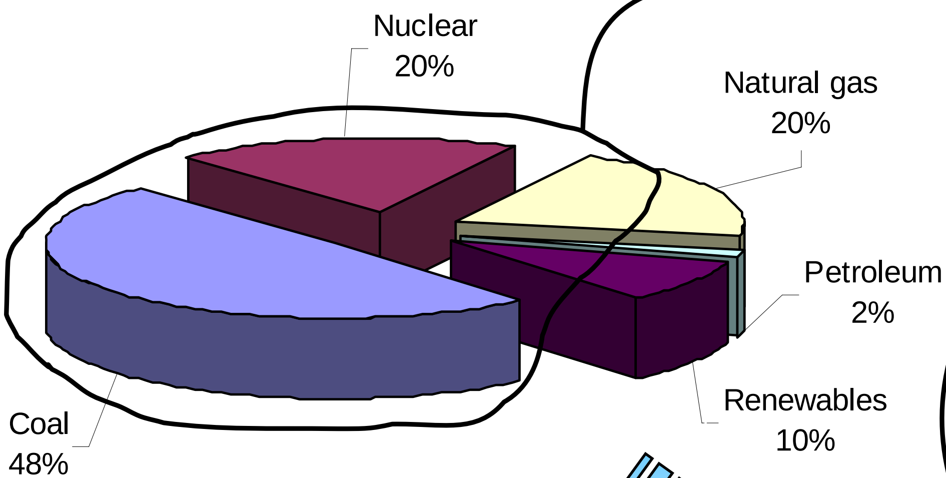


- **Thermoelectric power plants compete with other use sectors.**

Sources: USGS, Estimated Use of Water in the United States in 2000, USGS Circular 1268, March 2004
USGS, Estimated Use of Water in the United States in 1995, USGS Circular 1200, 1998

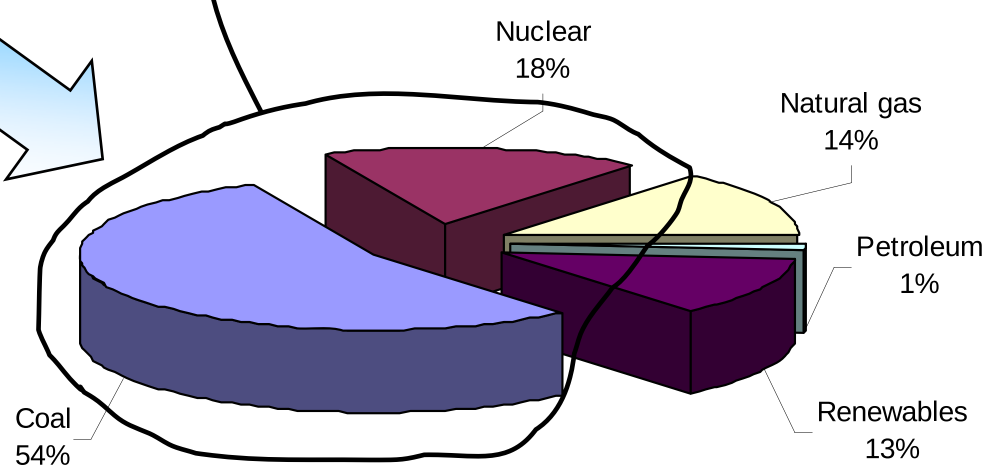
U.S. Electricity Generation by Fuel Type

Base Case 2006



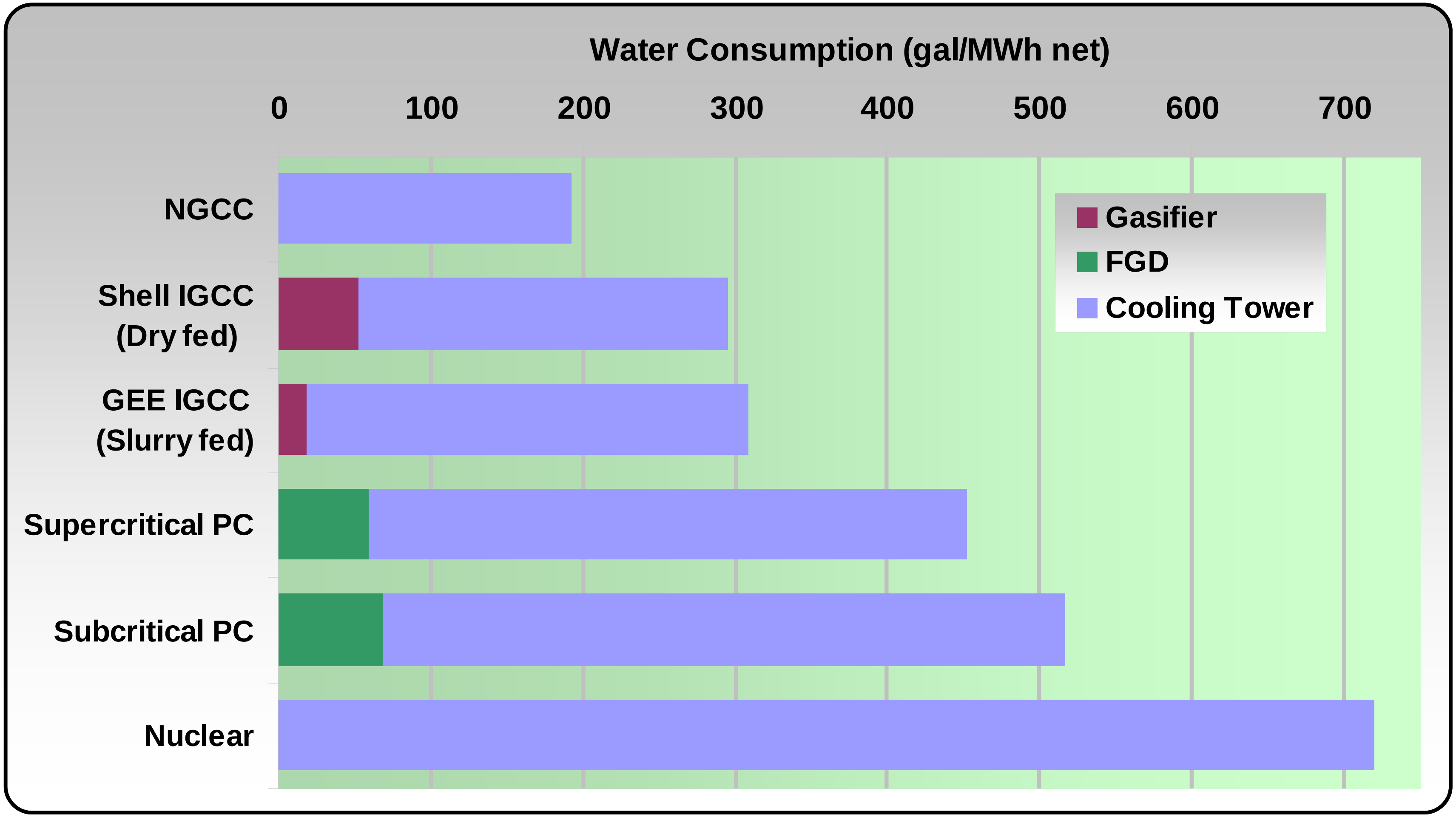
Approx. 90% of current and future electricity generation is thermoelectric

Reference Case 2030



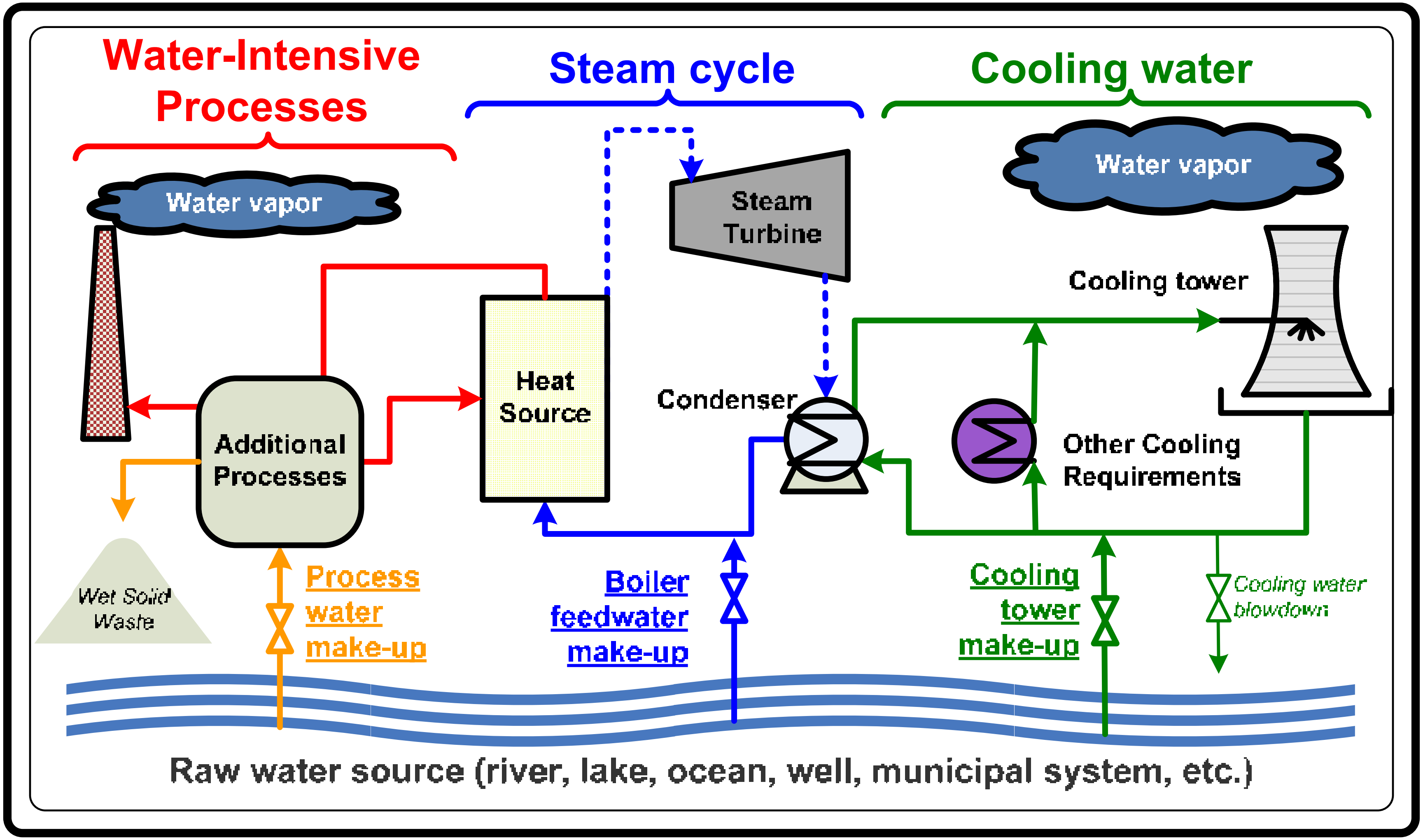
Reference: Energy Information Administration / Annual Energy Outlook 2008 (June 2008 Release)

Thermoelectric Power Plant Water Consumption



Plants equipped with wet re-circulating cooling towers

Water Flow Schematic for Power Plants



Water/Energy-Related Articles

Water is Impacting on Power Plant Siting and Operation

- **Drought Could Force Nuke-Plant Shutdowns**
  –*The Associated Press, January 2008*
- **Sinking Water and Rising Tensions**
  –*EnergyBiz Insider, December 2007*
- **Stricter Standards Apply to Coal Plant, Judge Rules; Activists Want Cooling Towers for Oak Creek**
  –*Milwaukee Journal Sentinel, November 2007*
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  –*The Atlanta Journal-Constitution, October 2007*
- **Maryland County Denies Cooling Water to Proposed power plant**
  –*E-Water News Weekly, October 2007*
- **Water Woes Loom as Thirsty Generators Face Climate Change**
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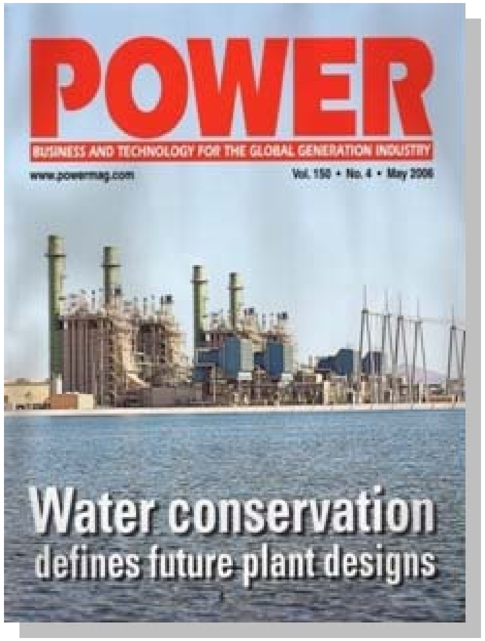
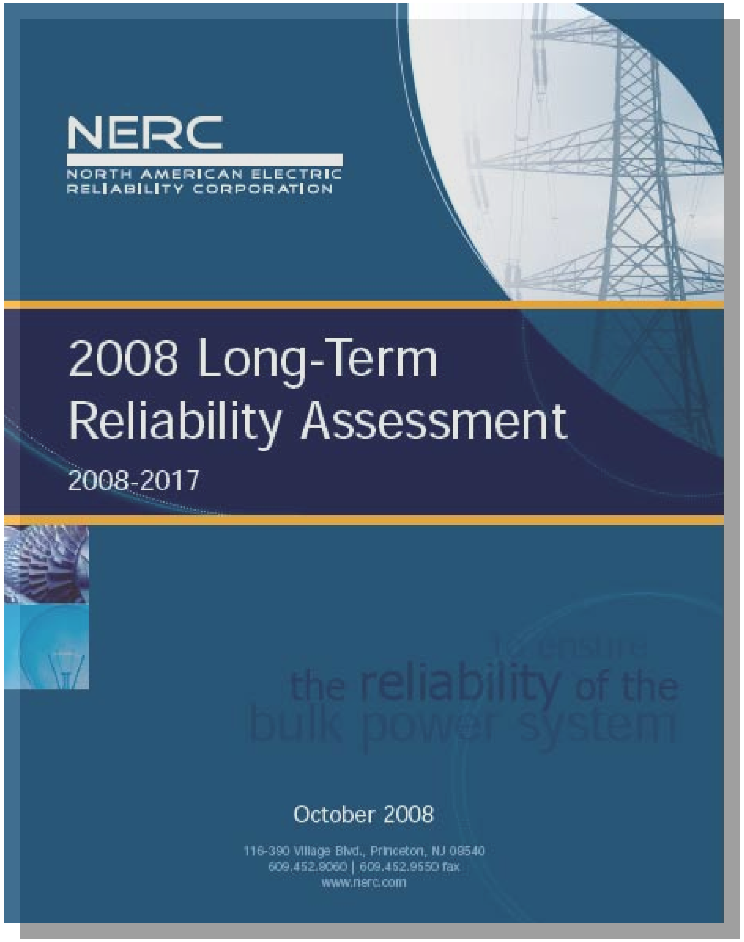


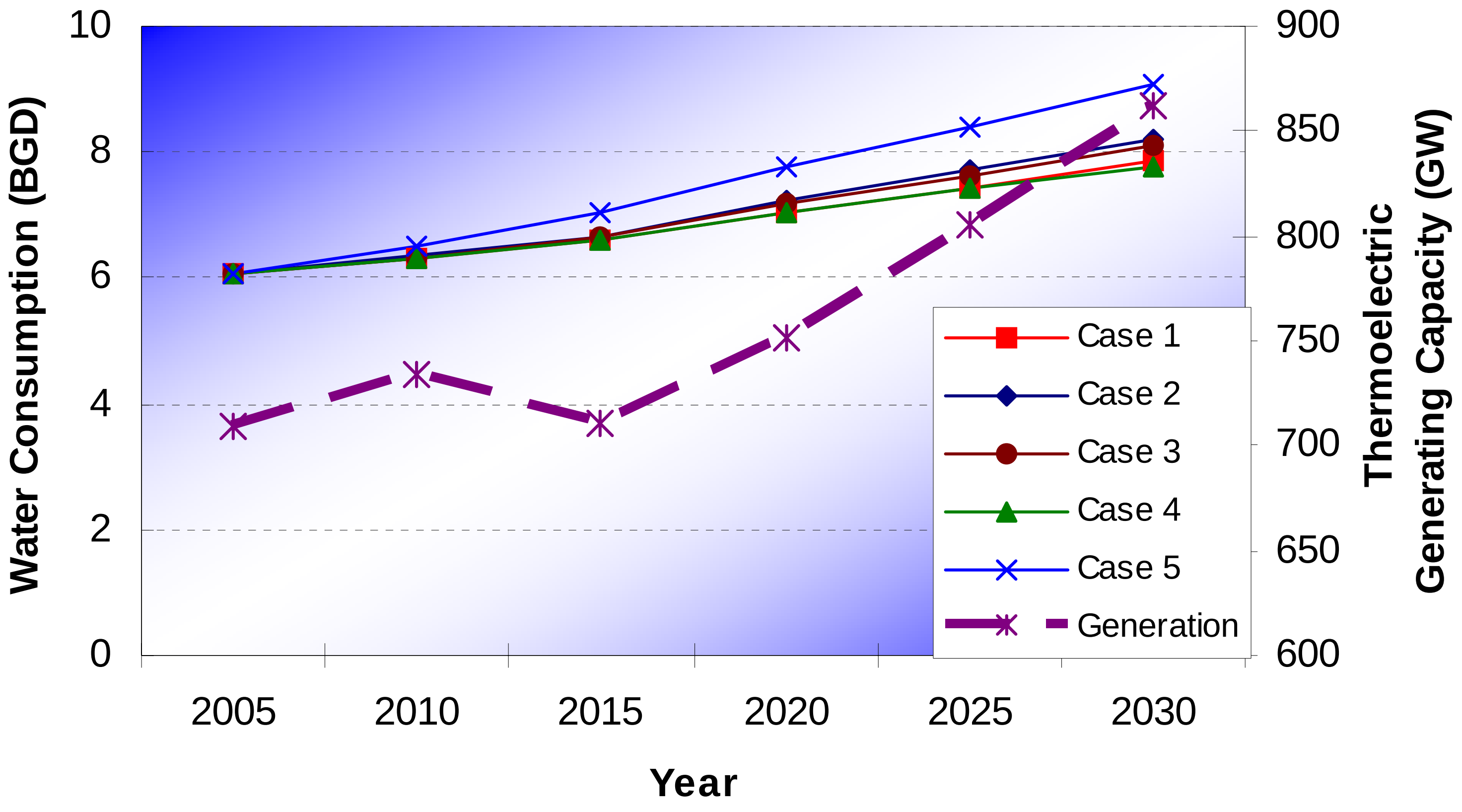
May 2006 Issue of Power Magazine

NERC 2008 Reliability Assessment

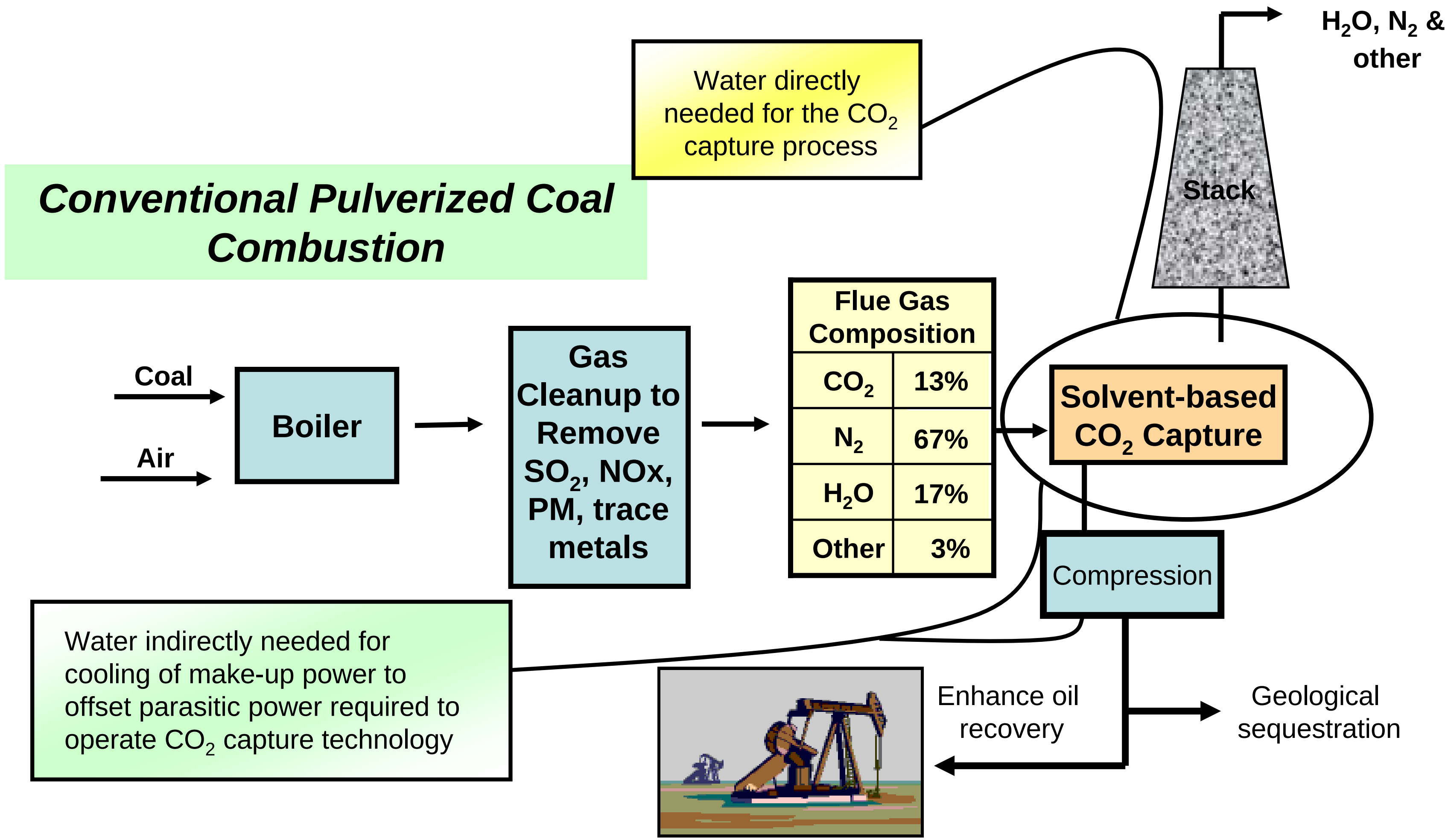
"Demand for water is increasing in North America and it is a vital resource requiring careful management. Thermal power plants require sufficient levels and quantities of water for cooling. Understanding the industry's role in water use and the implications of reduced water availability on bulk power system reliability requires careful study."



Average Daily National Freshwater Consumption for Thermoelectric Power Generation

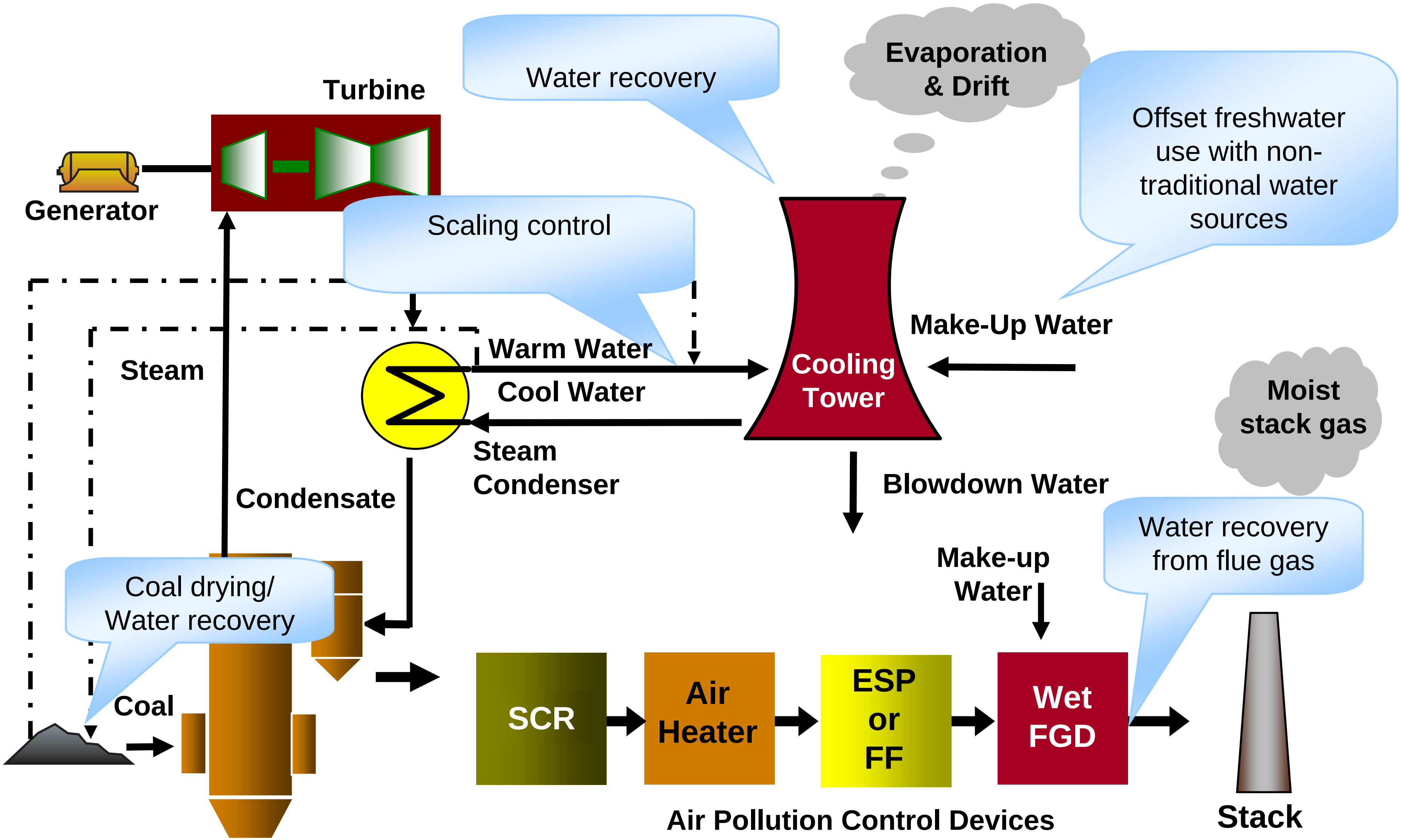


Water and CO_2 Capture



Source: NETL "2007 Pulverized Coal Oxyfuel Combustion Power Plants" August 2007 Final Report.

NETL Water Management R&D



IEP Water-Energy R&D Goals

Short-term goal

- Technologies ready for commercial demonstration by ***2015***
- Reduce freshwater withdrawal and consumption by ***50%*** or greater
- Levelized cost of less than ***$3.90*** per thousand gallons freshwater conserved

Long-term goal

- Technologies ready for commercial demonstration by ***2020***
- Reduce freshwater withdrawal and consumption by ***70%*** or greater
- Levelized cost of less than ***$2.60*** per thousand gallons freshwater conserved

Zebra Mussel Control Technology

- **NETL funded New York State Museum, Cambridge Field Research Laboratory, Cambridge, New York**

- **Tested more than 700 soil and water samples before discovering *Pseudomonas fluorescens*, a naurally occurring bacterium**

- **U.S. Bureau of Reclamation tested bacteria on mussels in 2008 at hydroelectric plant on Colorado River near Laughlin, Nevada -- results said to be promising**

Quagga mussels

- **Bacteria to be commercially available to power industry and water treatment plants in 2009**

Key Takeaways

- **Water and energy interconnected**
  - Water critical to operation of existing thermoelectric power plants and siting/permitting of new plants
  - Deployment of CO_2 capture technology projected to increase thermoelectric water withdrawal and consumption

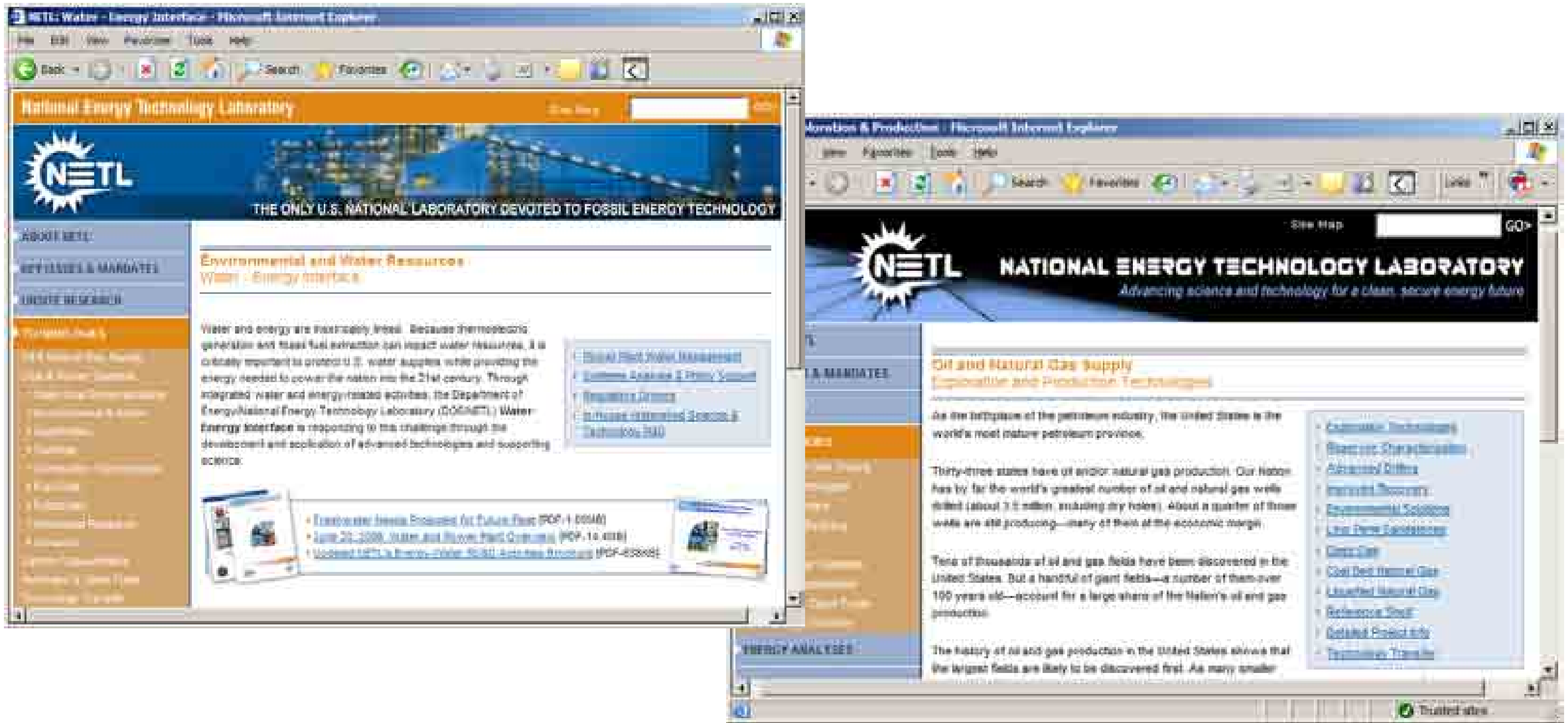
"Whiskey is for drinking; water is for fighting."

– Mark Twain

- **DOE's Office of Fossil Energy actively engaged in energy-water research and supporting systems analysis and data management; but continued RD&D needed to bring advanced water management technologies to state of commercial readiness**

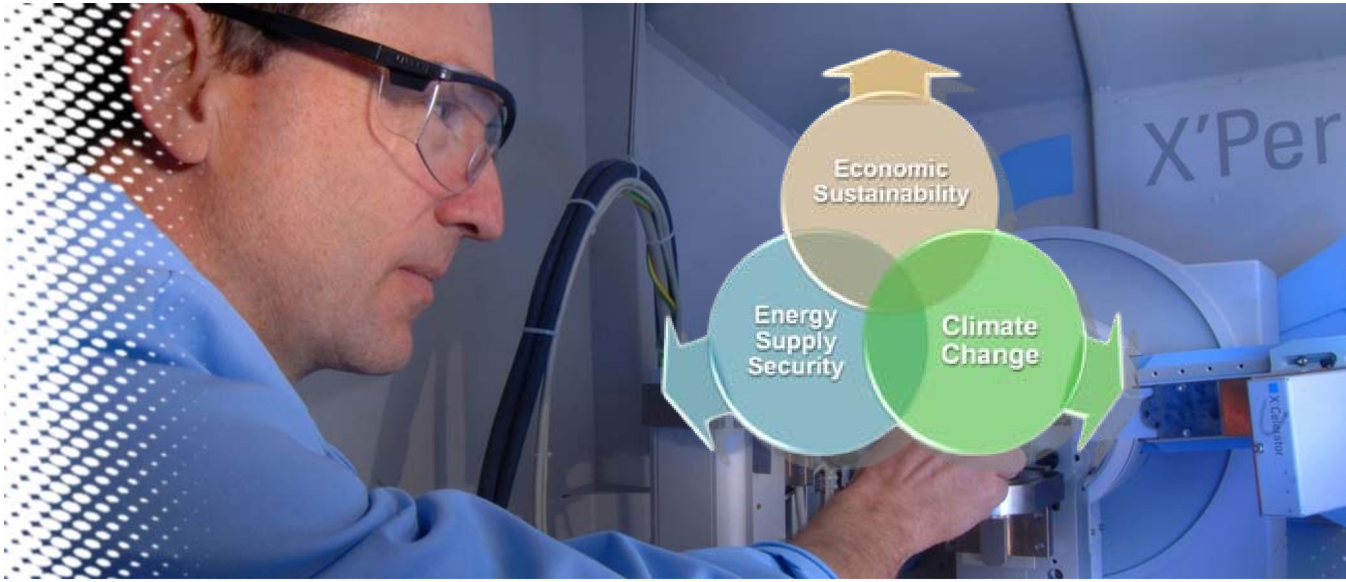
- **Continued collaboration and coordination with other Federal agencies critical to success**

To Find Out More About NETL's Energy-Water R&D



http://www.netl.doe.gov/technologies/coalpower/ewr/water/index.html

http://www.netl.doe.gov/technologies/oil-gas/EP_Technologies/Environmental/Env_Science/water.html



- Water Projections
- 316b Regulatory Impacts on Energy Security

Erik Shuster/Jeff Hoffmann
Office of Systems Analyses and Planning

Water/Energy-Related Articles
Impacts on Power Plant Siting and Operation

- **Drought Could Force Nuke-Plant Shutdowns**
  - *The Associated Press, January 2008*
- **Sinking Water and Rising Tensions**
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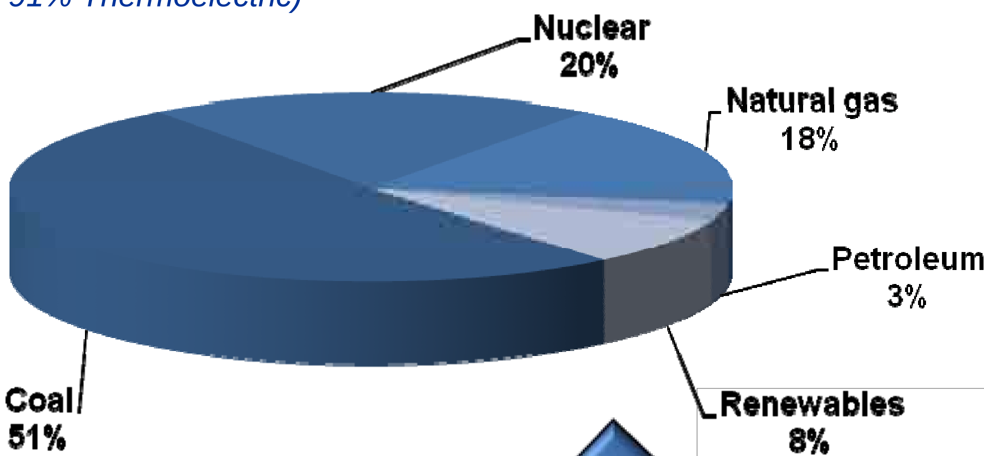
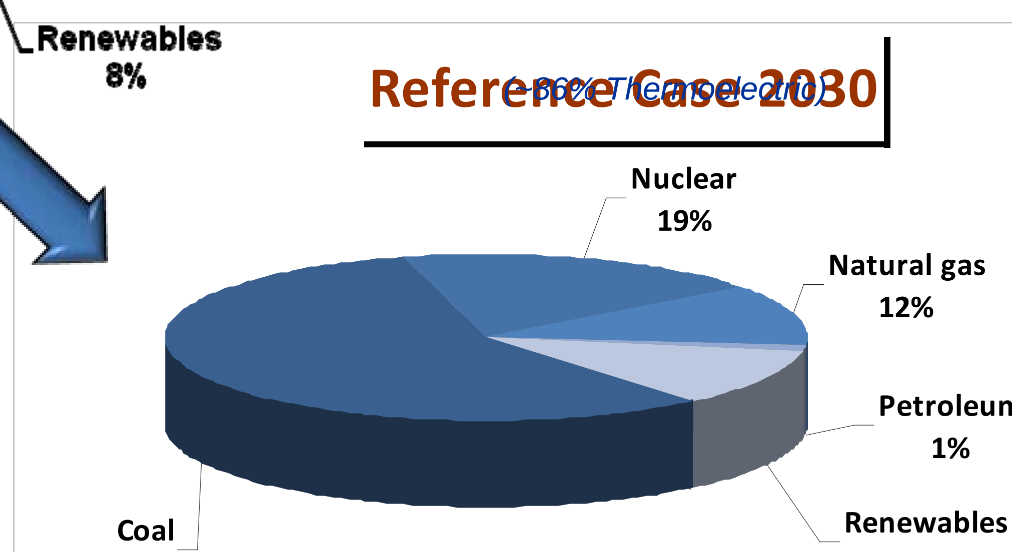
May 2006 Issue of Power Magazine

U.S. Electricity Generation by Fuel Type

Base Case 2005

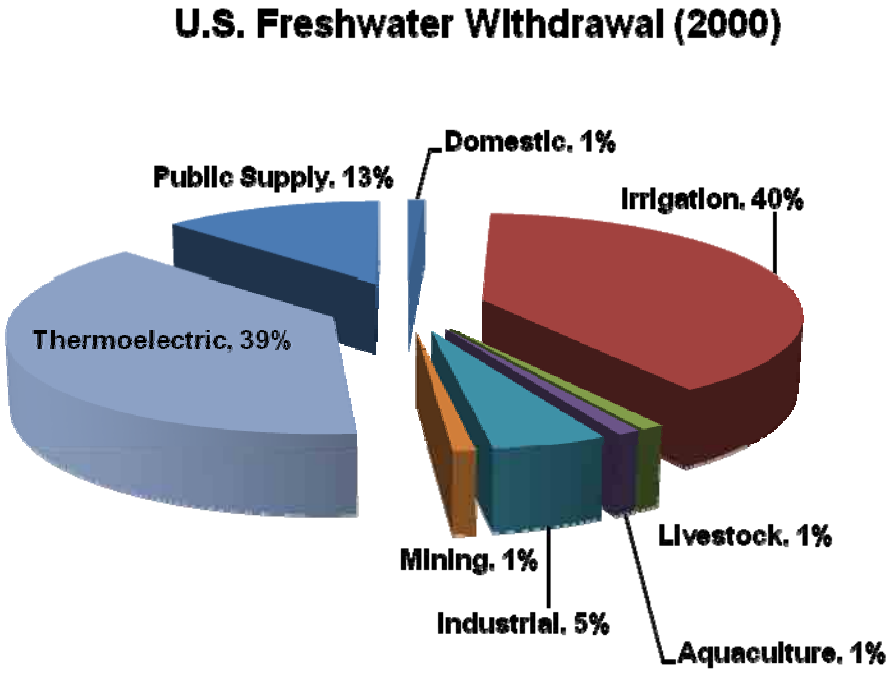
(~91% Thermoelectric)





Reference: Energy Information Administration / Annual Energy Outlook 2008

Competing Water Demands



- *2000 thermoelectric water requirements:*
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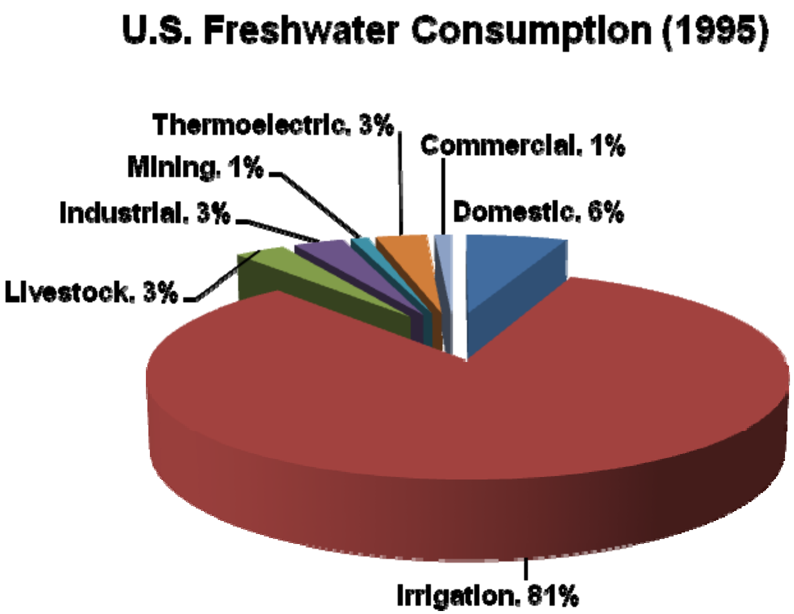
  - *Consumption: ~ 4 BGD*

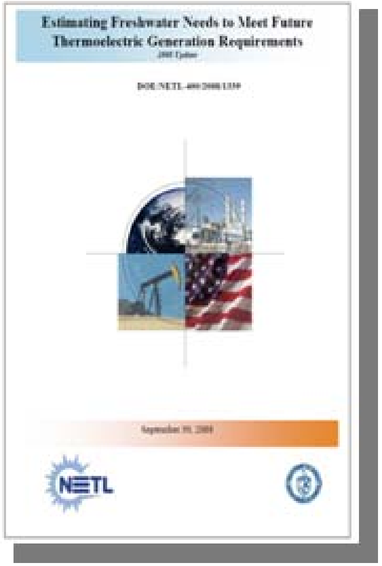


- *Thermoelectric power plants competes with other use sectors.*

Sources: USGS, Estimated Use of Water in the United States in 2000, USGS Circular 1268, March 2004
USGS, Estimated Use of Water in the United States in 1995, USGS Circular 1200, 1998

NETL's Water Needs Report

- ***Thermoelectric Power Generation***
  - *coal steam, combined cycle, other fossil steam, and nuclear*
- ***Projected national and regional freshwater withdrawal and consumption through 2030***
- ***Examine water use of deployed coal-fired power plants with carbon capture technologies***



NETL's Water Needs Report

- **Thermoelectric water use**
  - 5 Cases
    - Cooling systems for new additions
    - Water sources
    - Retrofit of once through systems
  - No Carbon Capture

- **Carbon Capture water use**
  - 4 Scenarios
    - Make-up power for carbon capture retrofits

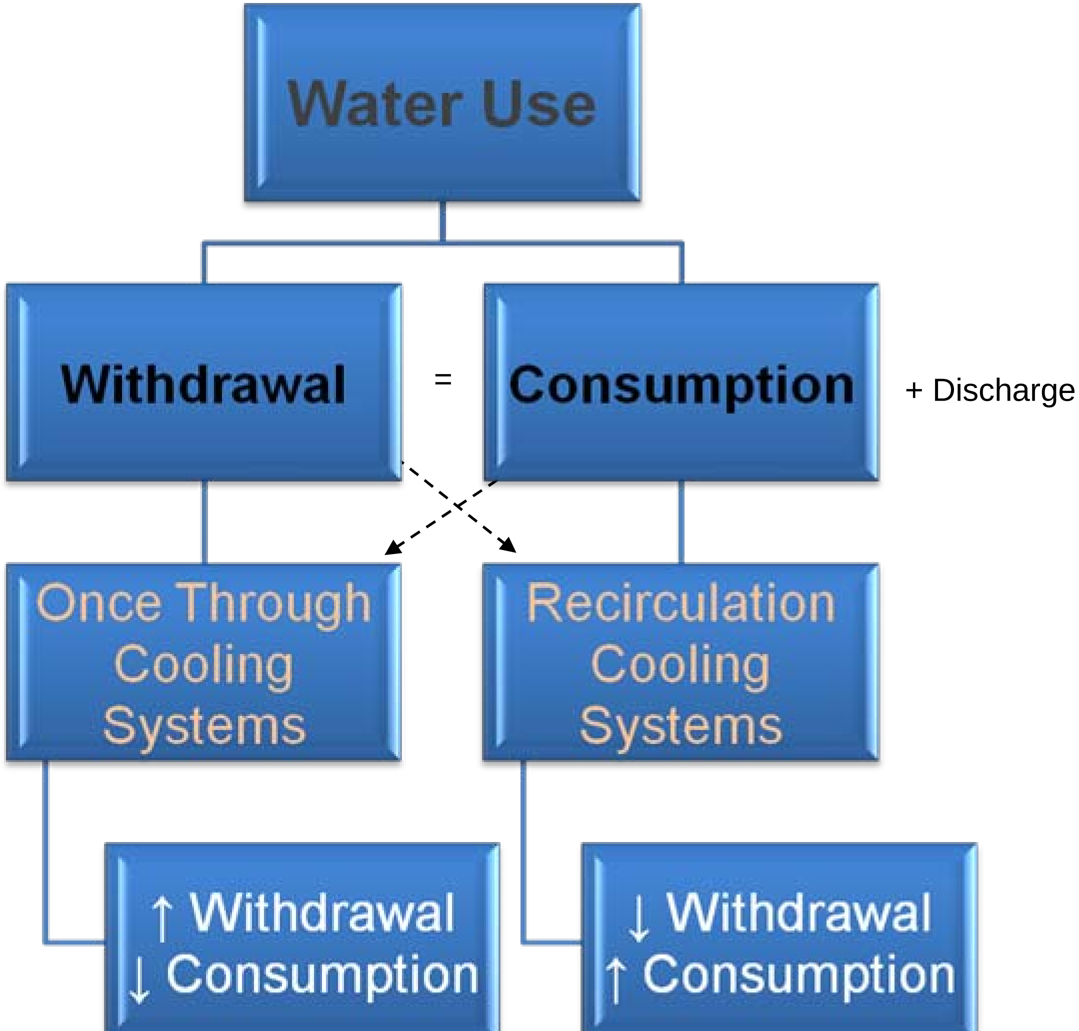
Cooling System Terminology

General:

Specific:

Associated with:

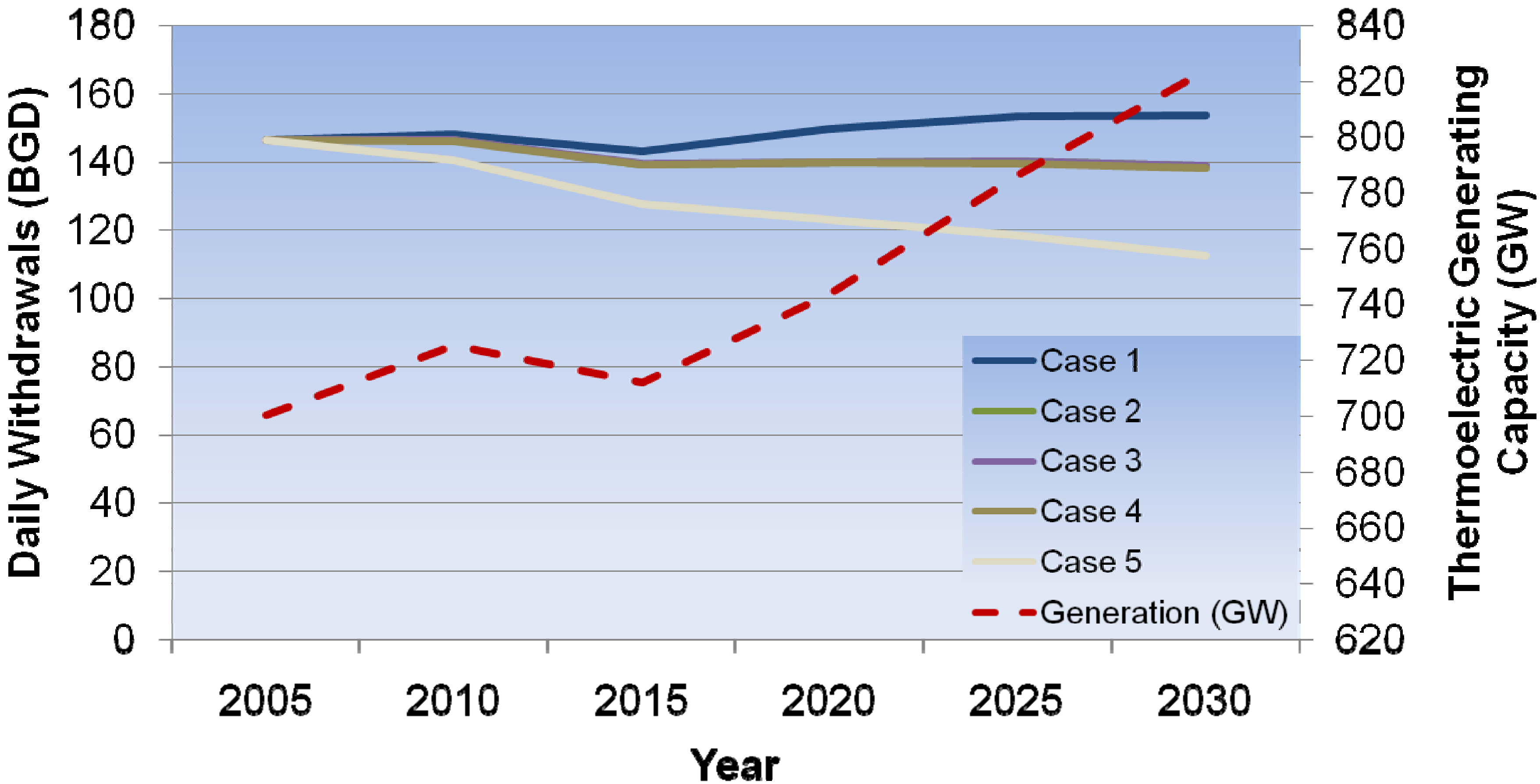
Relative System Characteristics:



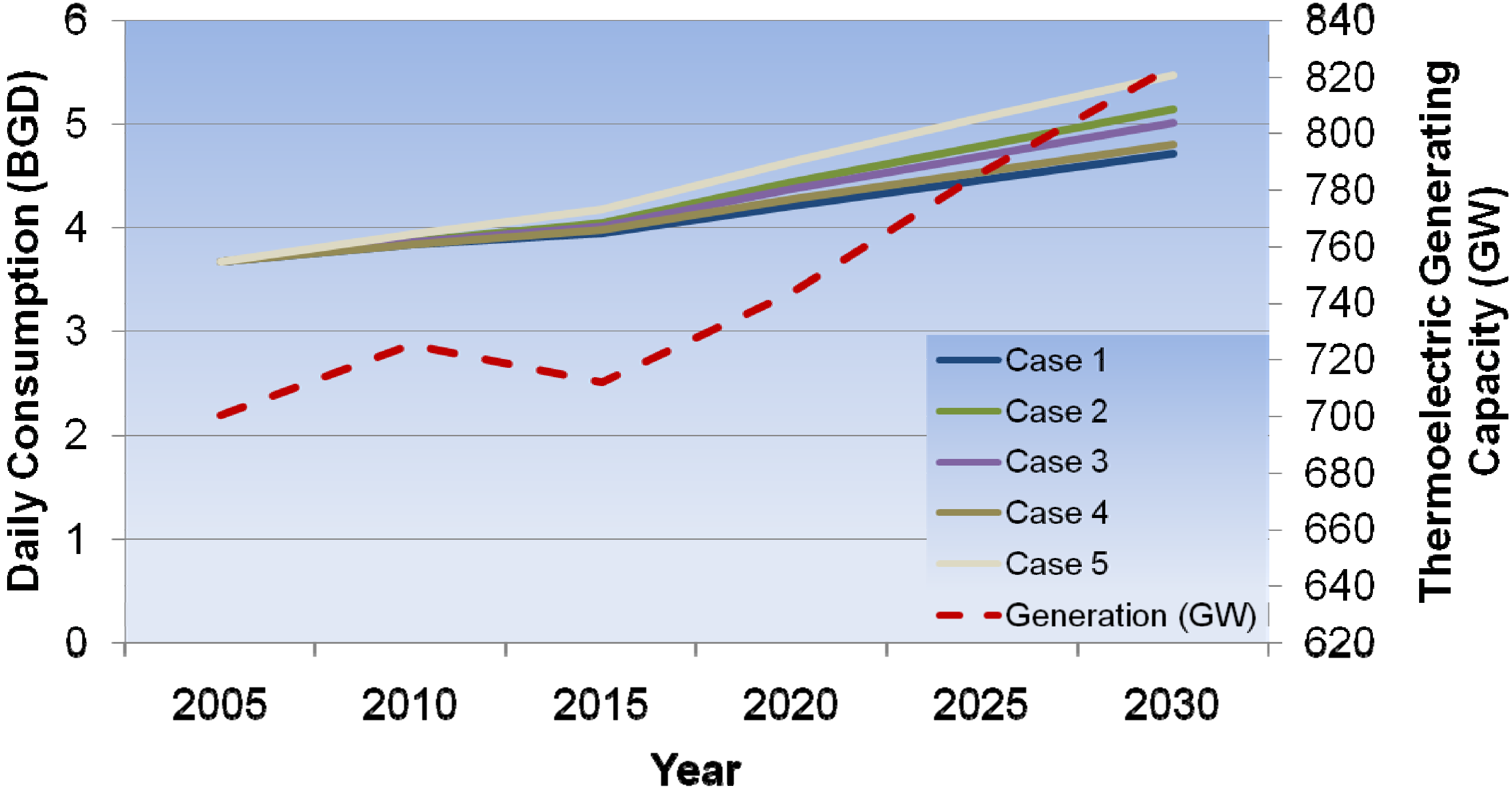
Case Descriptions

Case Description	Rationale
Case 1: Additions and retirements proportional to current water source and type of cooling system.	**Status quo scenario case.** Assumes additions and retirements follow current trends.
Case 2: All additions use freshwater and wet recirculating cooling, while retirements are proportional to current water source and cooling system.	**Regulatory-driven case.** Assumes 316(b) and future regulations dictate the use of recirculating systems for all new capacity. Retirement decisions hinge on age and operational costs rather than water source and type of cooling system.
Case 3: 90% of additions use freshwater and wet recirculating cooling, and 10% of additions use saline water and once-through cooling, while retirements are proportional to current water source and cooling system.	**Regulatory-light case.** New additions favor the use of freshwater recirculating systems, but some saline capacity is permitted. Retirement decisions remain tied to age and operational costs, tracking current source withdrawals.
Case 4: 25% of additions use dry cooling and 75% of additions use freshwater and wet recirculating cooling. Retirements are proportional to current water source and cooling system.	**Dry cooling case.** Regulatory and public pressures result in significant market penetration of dry cooling technology. Retirement decisions remain tied to age and operational costs, tracking current source withdrawals.
Case 5: Additions use freshwater and wet recirculating cooling, while retirements are proportional to current water source and cooling system. 5% of existing freshwater once-through cooling capacity retrofitted with wet recirculating cooling every 5 years starting in 2010.	**Conversion case.** Same as Case 2, except regulatory and public pressures compel state agencies to dictate the conversion of a significant amount of existing freshwater once-through cooling systems to wet recirculating.

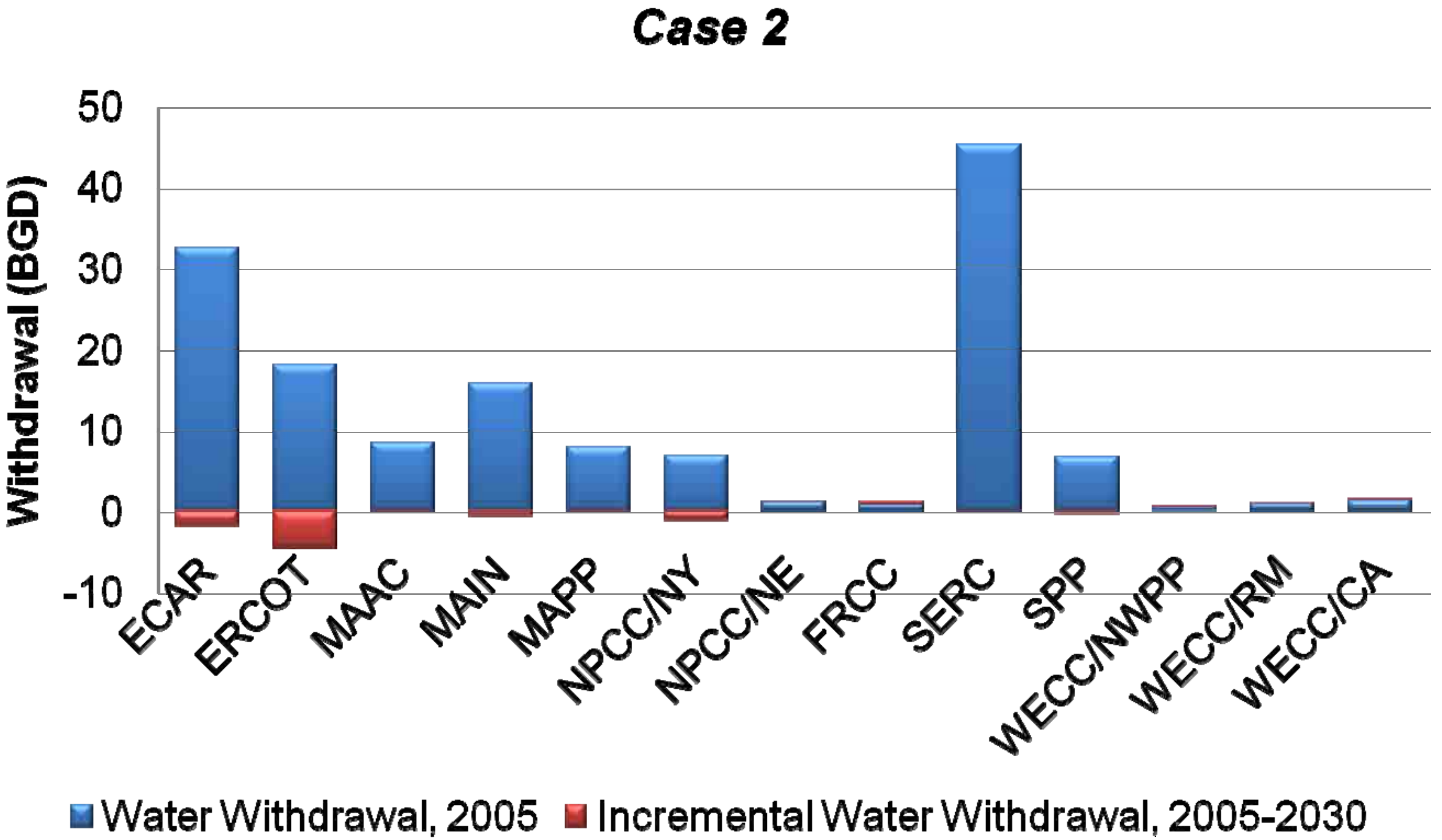
Average Daily National Freshwater Withdrawal for Thermoelectric Power Generation



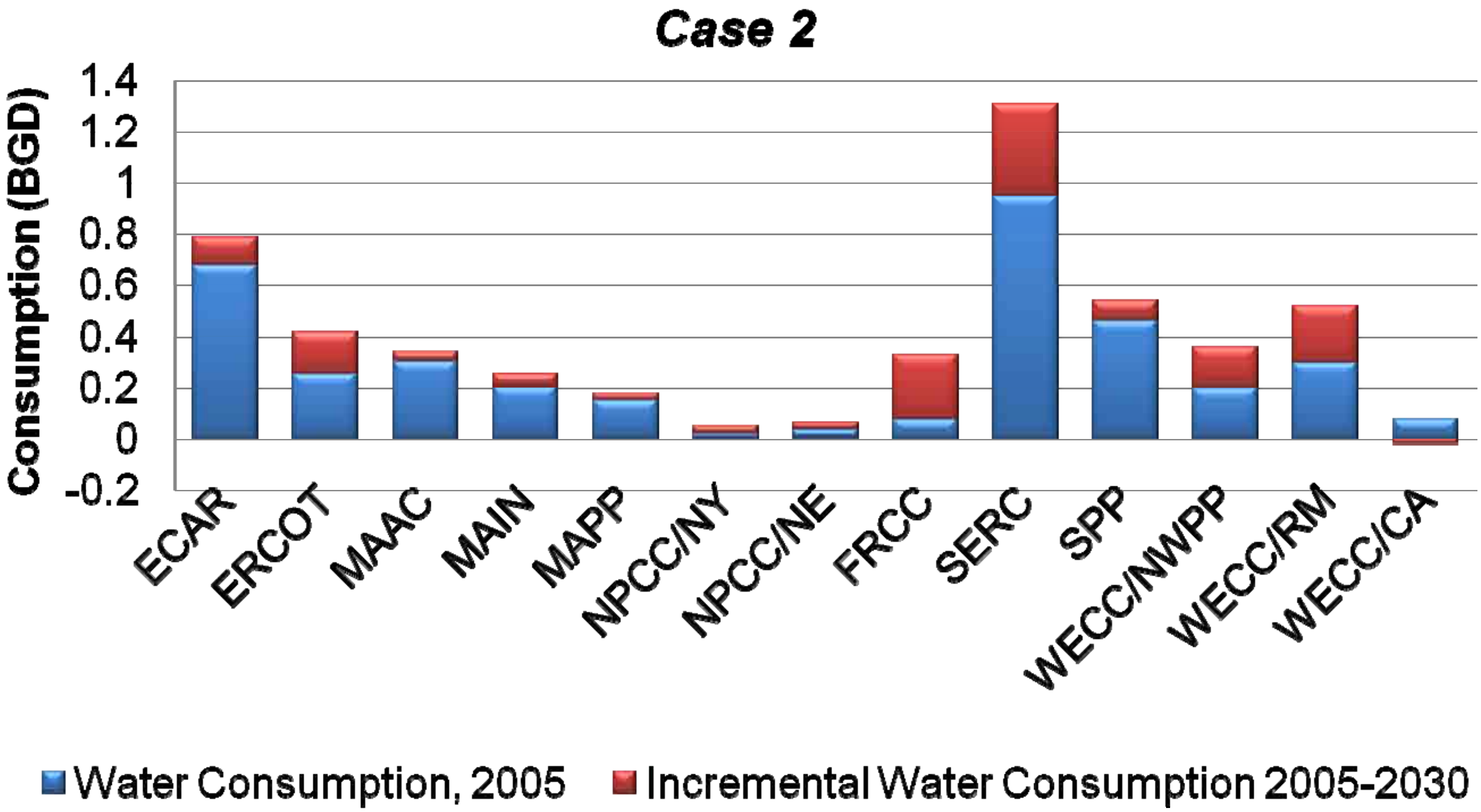
Average Daily National Freshwater Consumption for Thermoelectric Power Generation



Average Daily Regional Freshwater Withdrawal for Thermoelectric Power Generation



Average Daily Regional Freshwater Consumption for Thermoelectric Power Generation



Carbon Capture Water Use Analysis

- **Investigates additional water used for carbon capture technologies**
- **1st order approach**
- **Provides several boundaries or points to make further analysis**

Carbon Capture Assumptions and Scenarios

- **Assumes that carbon mitigation policies will be applied in the year 2020**
- **All new and existing PC plants with scrubbers and IGCC plants would utilize carbon capture technologies by 2030**
  - PC plant w/out scrubbers are not required to capture CO_2
- **All new cooling systems will be recirculating**
- **Carbon capture technologies would remove a nominal 90% of the CO_2 that would be generated from the fuel carbon**
- **Looked at available technologies**
  - Chemical and physical absorption solvents

Develop carbon capture scenarios (boundaries)

Scenario 1	Only accounts for the increased water requirements for the carbon capture technologies used for the retrofits and new builds Do not account for the reduction in capacity due to the retrofits	Reduced capacity will be replaced with some other "non-thermoelectric" generation that doesn't require cooling water
Scenario 2 Builds off of scenario 1	Additional capacity needed to make up for the parasitic loss of the retrofits are supplemented by new IGCC plants with carbon capture	All new IGCC plants required for the makeup power use recirculating cooling and include carbon capture technologies
Scenario 3 Builds off of scenario 1	Additional capacity needed to make up for the parasitic loss of the retrofits are supplemented by new supercritical plants with carbon capture	All new supercritical plants required for the makeup power use recirculating cooling and include carbon capture technologies
Scenario 4 Builds off of scenario 1	Additional capacity needed to make up for the parasitic loss of the retrofits are supplemented by new nuclear plants	All new nuclear plants required for the makeup power use recirculating cooling

Calculate retrofits and parasitic power loss

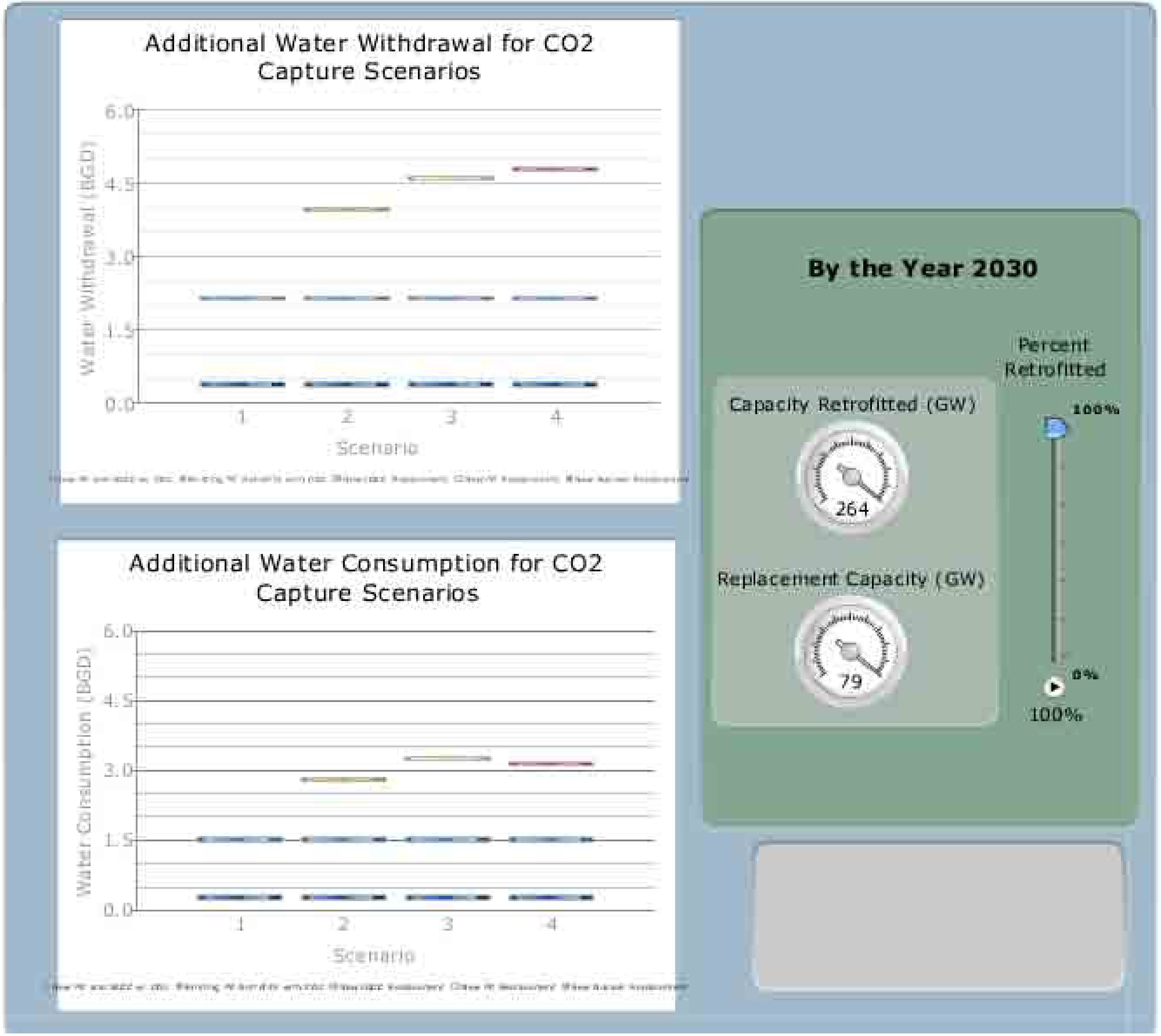
- **Used EIA 2030 forecast**
  - Existing fleet
  - Scrubbed plants
  - New additions (IGCC and PC)
  - Retirements

- **Retrofit will require 30% parasitic load**

- **Retrofits**
  - Existing – Retirements – Unscrubbed = 264 GW

- **Parasitic Power Loss** ***(build new plants to replace, Scenario dependent)***
  - Retrofits * 30% = 79 GW

Additional Water Required for CO_2 Capture

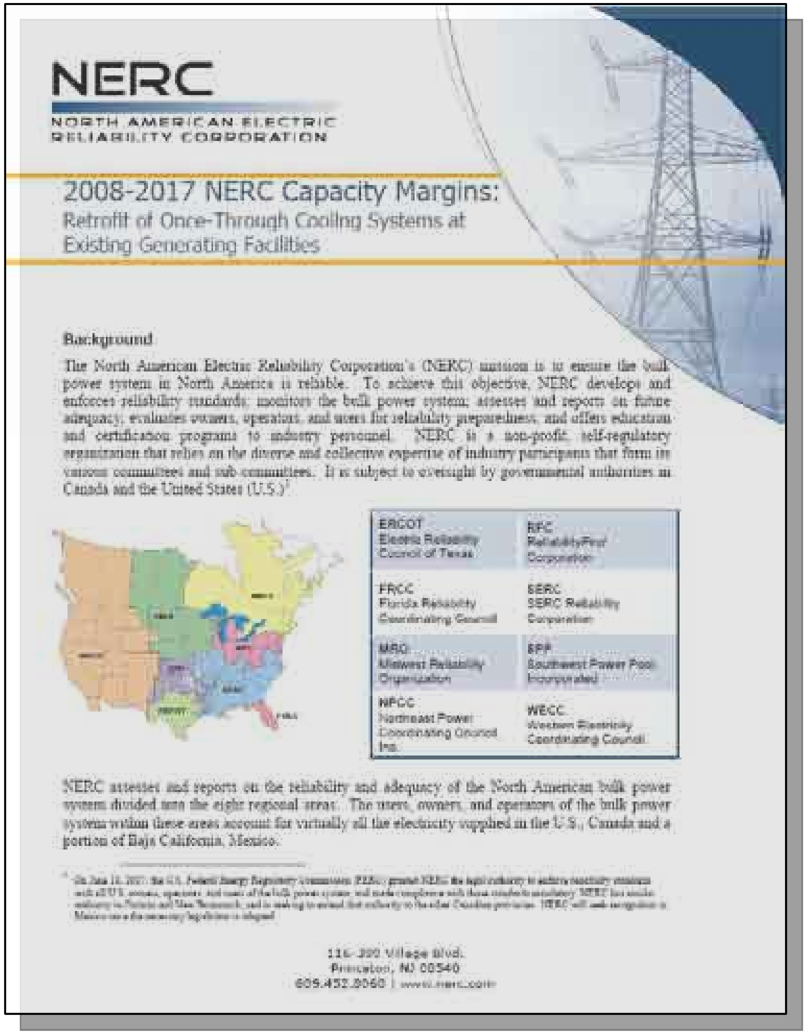


LABORATORY

316(b) Regulatory Impacts on Energy Security

316(b) Scenario Analysis

- **High-level analysis, focus on potential impacts to electricity supply <u>reliability</u>**
- **Collaborative Effort**
  - DOE
  - NERC
- **NETL provided necessary data on regional impacts**
  - Affected facilities
  - Performance impacts



NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

2008-2017 NERC Capacity Margins:
Retrofit of Once-Through Cooling Systems at Existing Generating Facilities

Background

The North American Electric Reliability Corporation's (NERC) mission is to ensure the bulk power system in North America is reliable. To achieve this objective, NERC develops and enforces reliability standards; monitors the bulk power system; assesses and reports on future adequacy; evaluates owners, operators, and users for reliability preparedness; and offers education and certification programs to industry personnel. NERC is a non-profit, self-regulatory organization that relies on the diverse and collective expertise of industry participants that form its various committees and sub-committees. It is subject to oversight by governmental authorities in Canada and the United States (U.S.)[1]

ERCOT Electric Reliability Council of Texas	RFC ReliabilityFirst Corporation
FRCC Florida Reliability Coordinating Council	SERC SERC Reliability Corporation
MRO Midwest Reliability Organization	SPP Southwest Power Pool Incorporated
NPCC Northeast Power Coordinating Council Inc.	WECC Western Electricity Coordinating Council

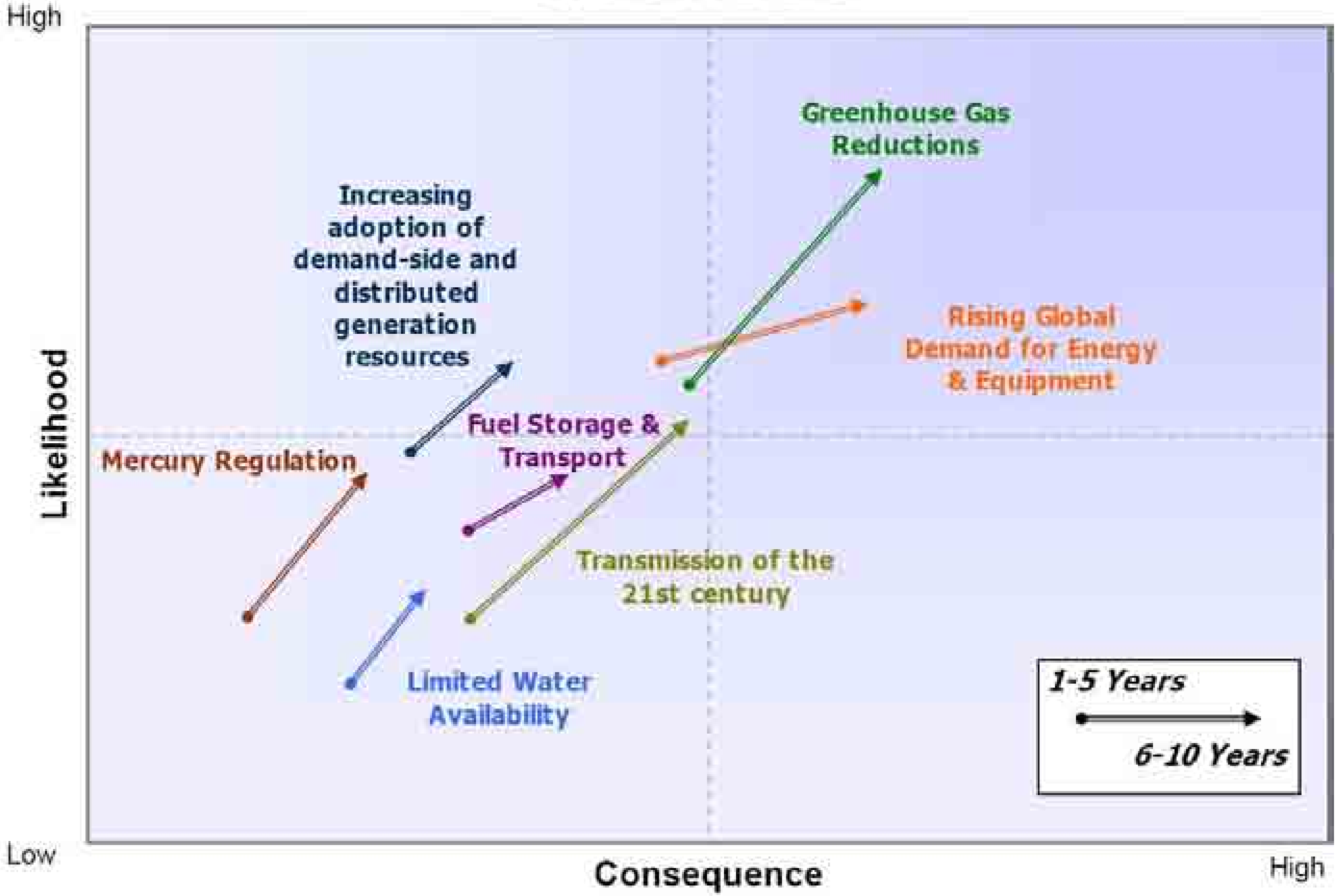
NERC assesses and reports on the reliability and adequacy of the North American bulk power system divided into the eight regional areas. The users, owners, and operators of the bulk power systems within these areas account for virtually all the electricity supplied in the U.S., Canada and a portion of Baja California, Mexico.

116-390 Village Blvd.
Princeton, NJ 08540
609.452.8060 | www.nerc.com

http://www.nerc.com/files/NERC_SRA-Retrofit_of_Once-Through_Generation_090908.pdf

Limited Water Availability – Emerging Reliability Issue

Figure 12: Emerging Issues Risk Evolution:
1-5 Year & 6-10 Years



Source: NERC 2008 Long-Term Reliability Assessment, October 2008

Scenario Results

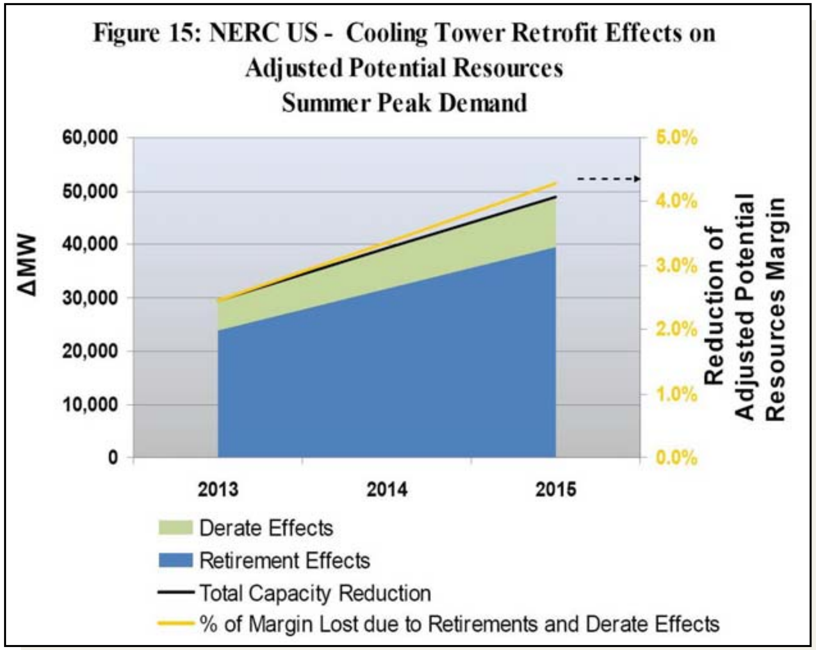


Figure 15: NERC US - Cooling Tower Retrofit Effects on Adjusted Potential Resources Summer Peak Demand

Source: NERC 2008 Long-Term Reliability Assessment, October 2008

Table 1: 2015 US Summer Peak Retrofit/Retirement Effects

	Adjusted Potential Resources (MW)	Reduction due to Retirement (MW)	Derate due to Retrofit (MW)	NERC Reference Margin Level	Adjusted Potential Resources Margin	Margin Reduction	Reduced Margin
United States							
WECC - CA-MX US[1]	72,293	10,137	289	13.2%	12.7%	14.7%	-2.0%
NPCC - New England	31,673	2,827	428	13.0%	10.0%	10.3%	-0.3%
ERCOT	86,436	10,919	542	11.1%	15.9%	12.9%	3.0%
NPCC US	72,750	6,481	990	13.0%	13.3%	[illegible]	3.4%
WECC US[1]	176,944	10,177	314	12.3%	11.1%	5.6%	5.5%
NPCC - New York	41,077	3,654	561	13.0%	15.9%	9.6%	6.3%
SERC - VACAR	78,182	553	1,032	13.0%	11.0%	1.8%	9.2%
WECC - RMPA[1]	15,609	40	0	10.5%	10.2%	0.2%	10.0%
SERC - Central	54,548	0	949	13.0%	12.6%	1.5%	11.0%
SERC - Delta	41,259	4,266	466	13.0%	21.5%	10.2%	11.4%
RFC	230,062	3,336	2,863	12.8%	14.5%	2.4%	12.1%
SERC	269,599	6,054	3,307	13.0%	15.6%	3.0%	12.5%
SERC - Southeastern	66,675	675	357	13.0%	13.9%	1.4%	12.6%
MRO US	55,582	529	612	13.0%	15.1%	1.8%	13.3%
FRCC	63,170	1,267	454	13.0%	18.7%	2.3%	16.4%
WECC - NWPP[1]	51,861	0	25	11.9%	16.9%	0.0%	16.8%
SPP	63,700	817	257	12.0%	24.1%	1.3%	22.8%
SERC - Gateway	28,935	560	502	13.0%	28.8%	2.7%	26.1%
Total-NERC US	**1,018,243**	**39,583**	**9,339**	**13.0%**	**14.7%**	**4.3%**	**10.4%**

Source: 2008-2017 NERC Capacity Margins: Retrofit of Once-Through Cooling Systems at Existing Generating Facilities

Small overall impact…

…however regionally significant!

completing the energy sustainability puzzle

ENERGY and WATER

Emerging Issues and Challenges

NETL Water Projects Review - October 2008

Mike Hightower

Sandia National Laboratories

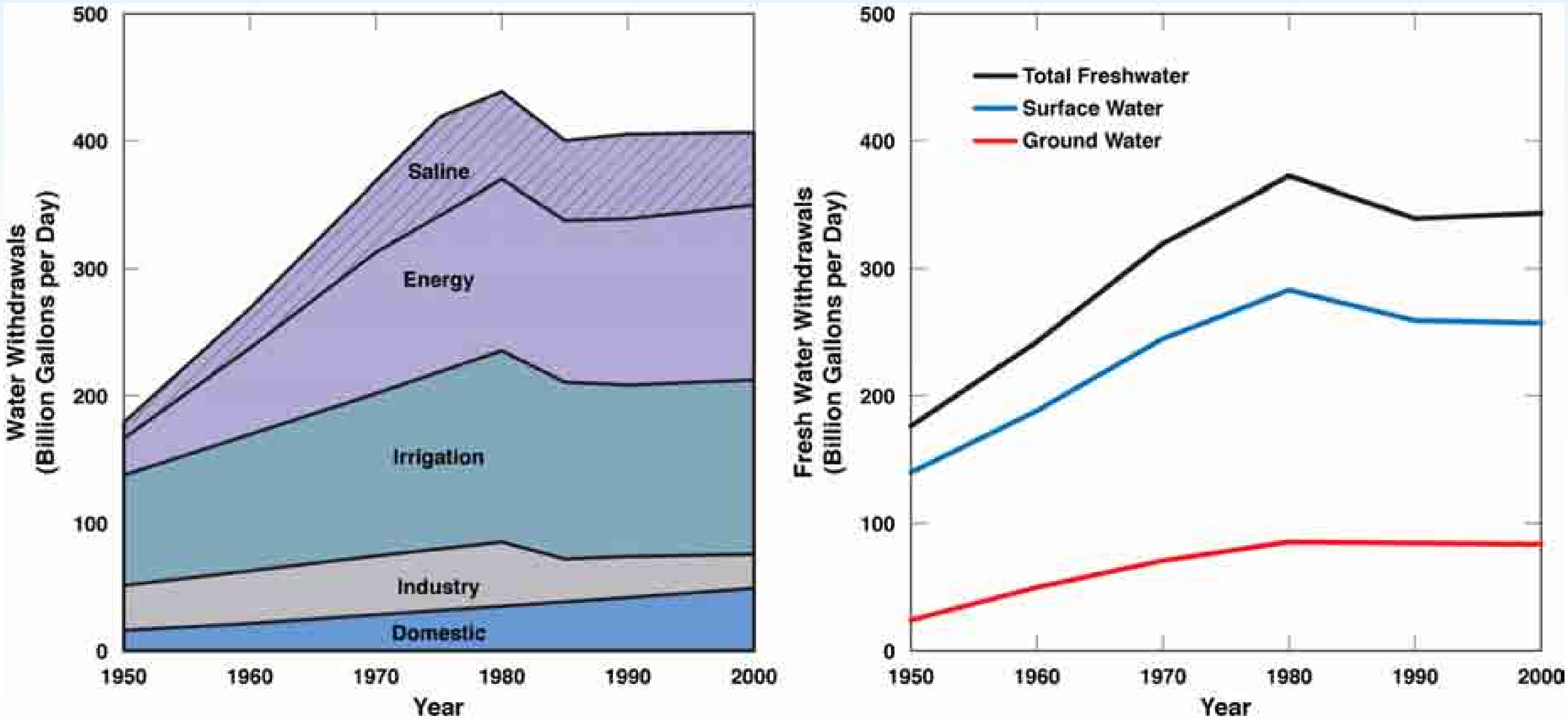
Presentation Overview

- **Energy–Water Connection and Interdependencies**
- **Energy-Water Report to Congress Highlights**
- **Energy–Water Regional Needs Workshops**
  - Regional and national issues and challenges
  - Summary of science and technology needs identified
- **Potential impact of energy development and growth on national and regional water resources**

Background info @ www.sandia.gov/energy-water

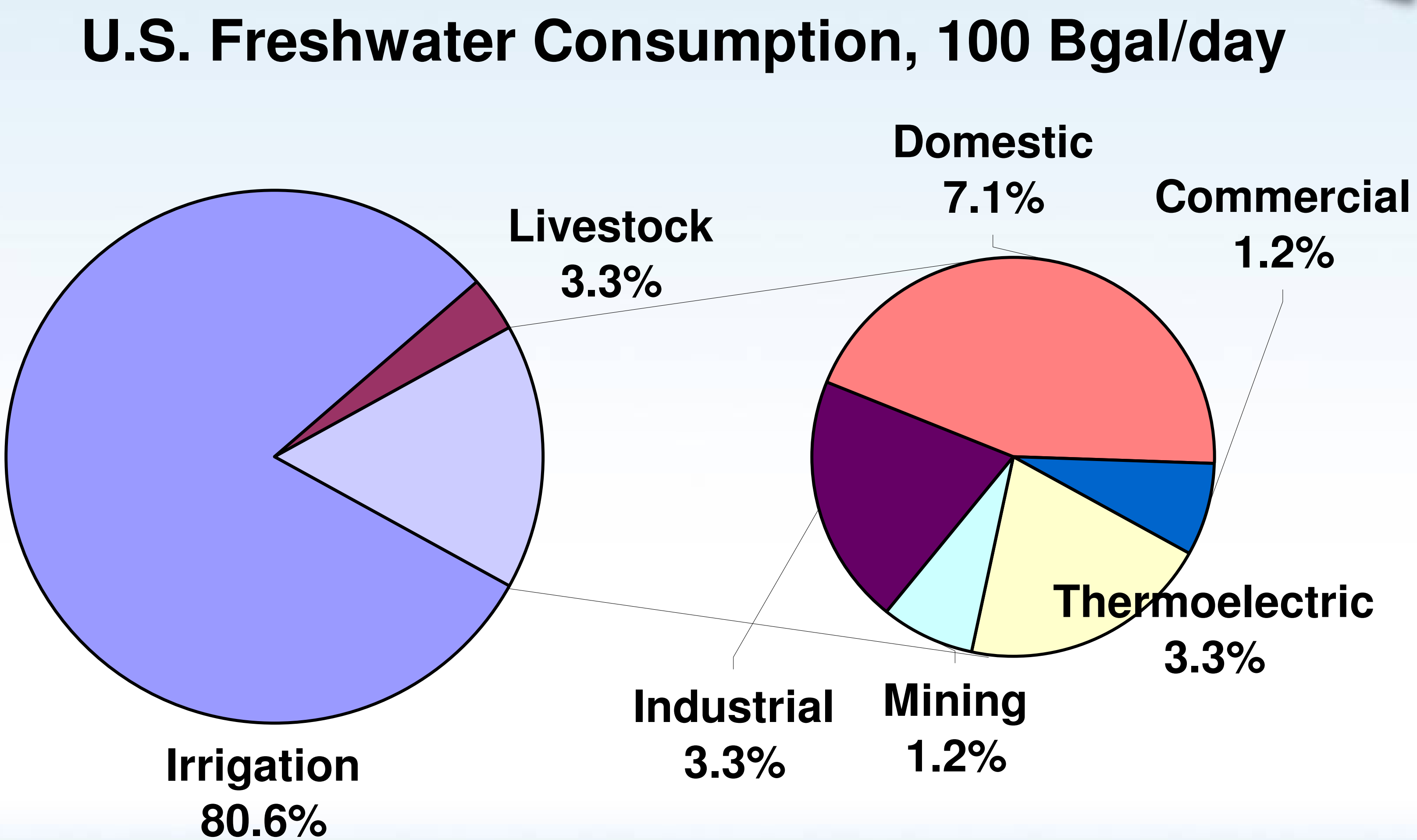
ENERGY and WATER

Water Withdrawal Trends by Sector



[USGS, 2004]

Water Consumption by Sector

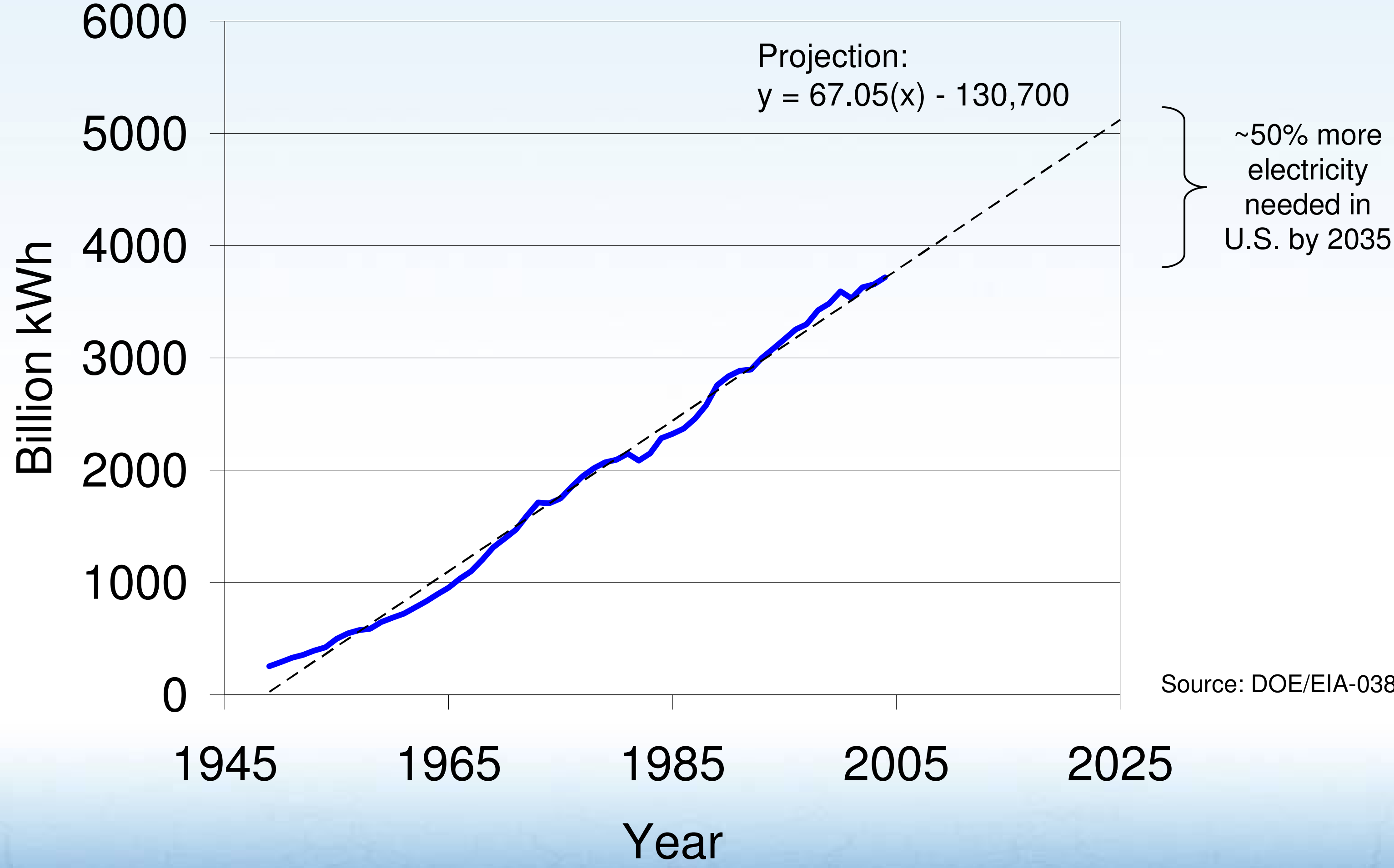


[USGS, 1998]

Energy accounts for 27 percent of non-agricultural fresh water consumption

ENERGY and WATER

The U.S. will need 50% more electricity by 2035

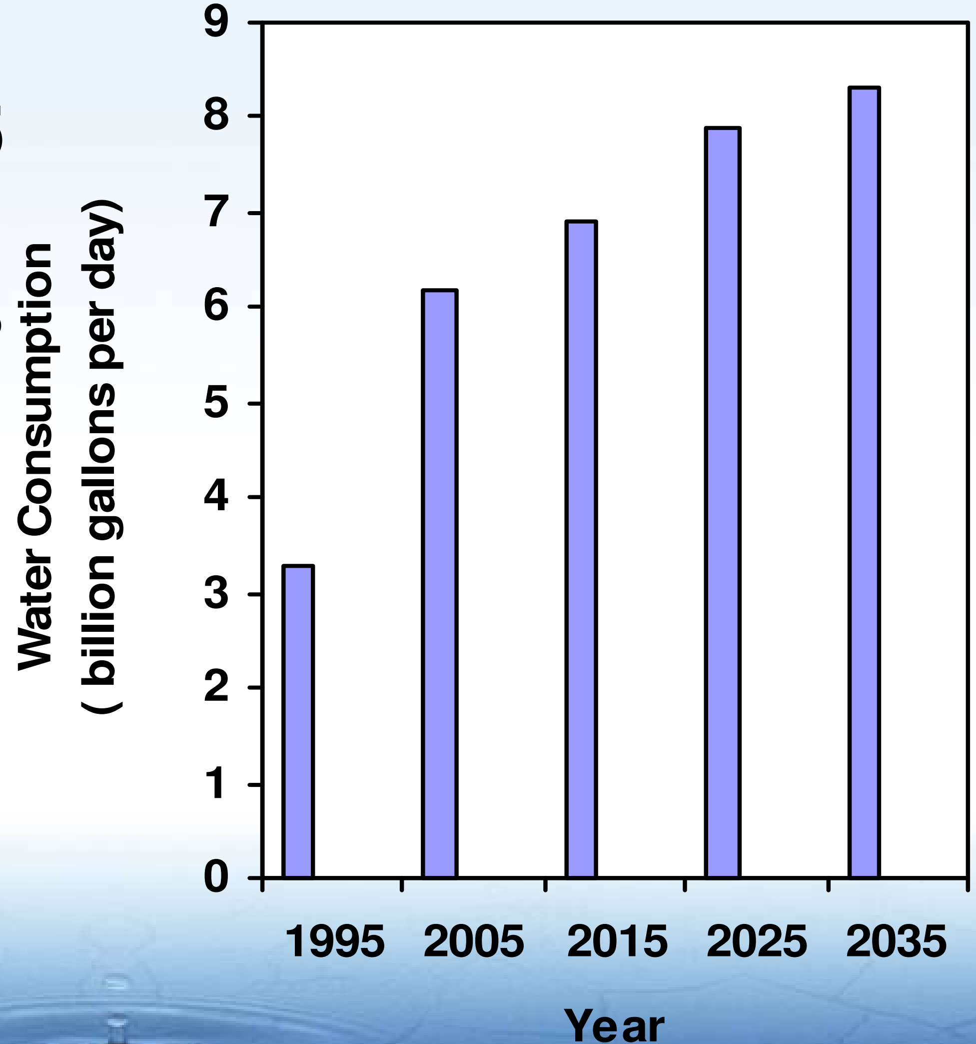


Source: DOE/EIA-0384(2004)

ENERGY and WATER

Water Demands for Future Electric Power Development

- Water demands could almost triple from 1995 consumption for projected mix of plants and cooling
- Carbon emission requirements will increase water consumption by an additional 1-2 Bgal/day

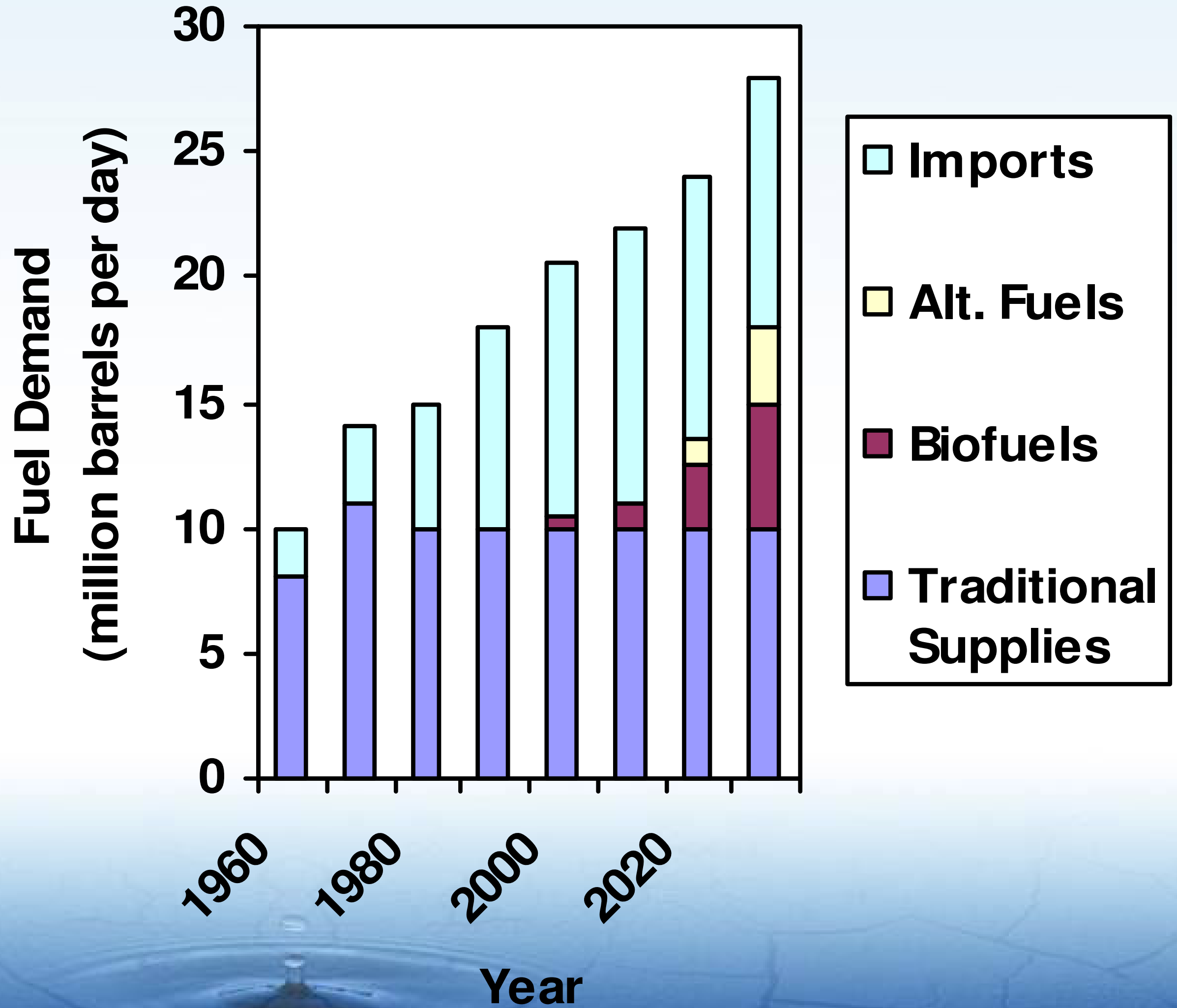


(NETL 2006)

ENERGY and WATER

The U.S. will need 33% more Transportation Fuels by 2030

- Fuel use will increase despite gains in efficiency
- Current initiatives for domestic alternatives like oil shale and biofuels
- Major hydrogen use will be post 2030



ENERGY and WATER

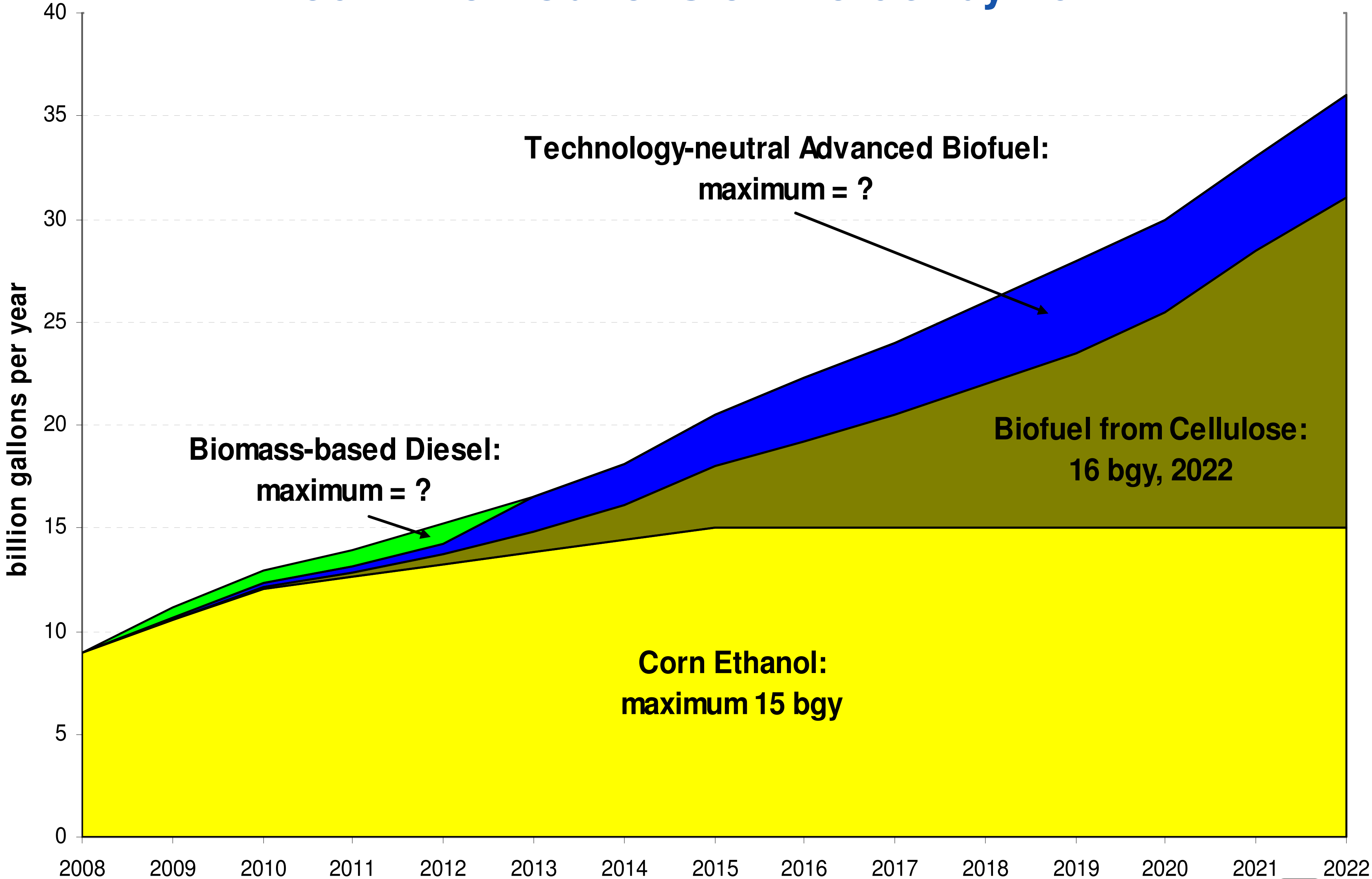
Water Demand/Impact of Transportation Fuels

Fuel Type and Process	Relationship to Water Quantity	Relationship to Water Quality	Water Consumption	
			Water consumed per-unit-energy [gal / MMBTU] †	Average gal water consumed per gal fuel
Conventional Oil & Gas	Water needed to extract and refine; Water produced from extraction	Produced water generated from extraction; Wastewater generated from processing;		
- Oil Refining			7 – 20	~ 1.5
- NG extraction/Processing			2 – 3	~ 1.5
Biofuels	Water needed for growing feedstock and for fuel processing;	Wastewater generated from processing; Agricultural irrigation runoff and infiltration contaminated with fertilizer, herbicide, and pesticide compounds		
- Grain Ethanol Processing			12 - 160	~ 4
- Corn Irrigation for EtOH			2500 - 31600	~ 980*
- Biodiesel Processing			4 – 5	~ 1
- Soy Irrigation for Biodiesel			13800 – 60000	~ 6500*
- Lignocellulosic Ethanol and other synthesized Biomass to Liquid (BTL) fuels	Water for processing; Energy crop impacts on hydrologic flows	Wastewater generated; Water quality benefits of perennial energy crops	24 – 150 ‡§ (ethanol) 14 – 90 ‡§ (diesel)	~ 2 - 6 ‡§ ~ 2 - 6 ‡§
Oil Shale	Water needed to Extract / Refine	Wastewater generated; In-situ impact uncertain; Surface leachate runoff		
- In situ retort			1 – 9 ‡	~ 2 ‡
- Ex situ retort			15 - 40 ‡	~ 3 ‡
Oil Sands	Water needed to Extract / Refine	Wastewater generated; Leachate runoff	20 - 50	~ 4 - 6
Synthetic Fuels	Water needed for synthesis and/or steam reforming of natural gas (NG)			
- Coal to Liquid (CTL)		Wastewater generated from coal mining and CTL processing	35 - 70	~ 4.5- 9.0
- Hydrogen RE Electrolysis			20 – 24 ‡	~ 3 ‡
- Hydrogen (NG Reforming)			40 – 50 ‡	~ 7 ‡

† Ranges of water use per unit energy largely based on data taken from the Energy-Water Report to Congress (DOE, 2007)
* Conservative estimates of water use intensity for irrigated feedstock production based on per-acre crop water demand and fuel yield
‡ Estimates based on unvalidated projections for commercial processing; § Assuming rain-fed biomass feedstock production

EISA 2007 Renewable Fuels Standard

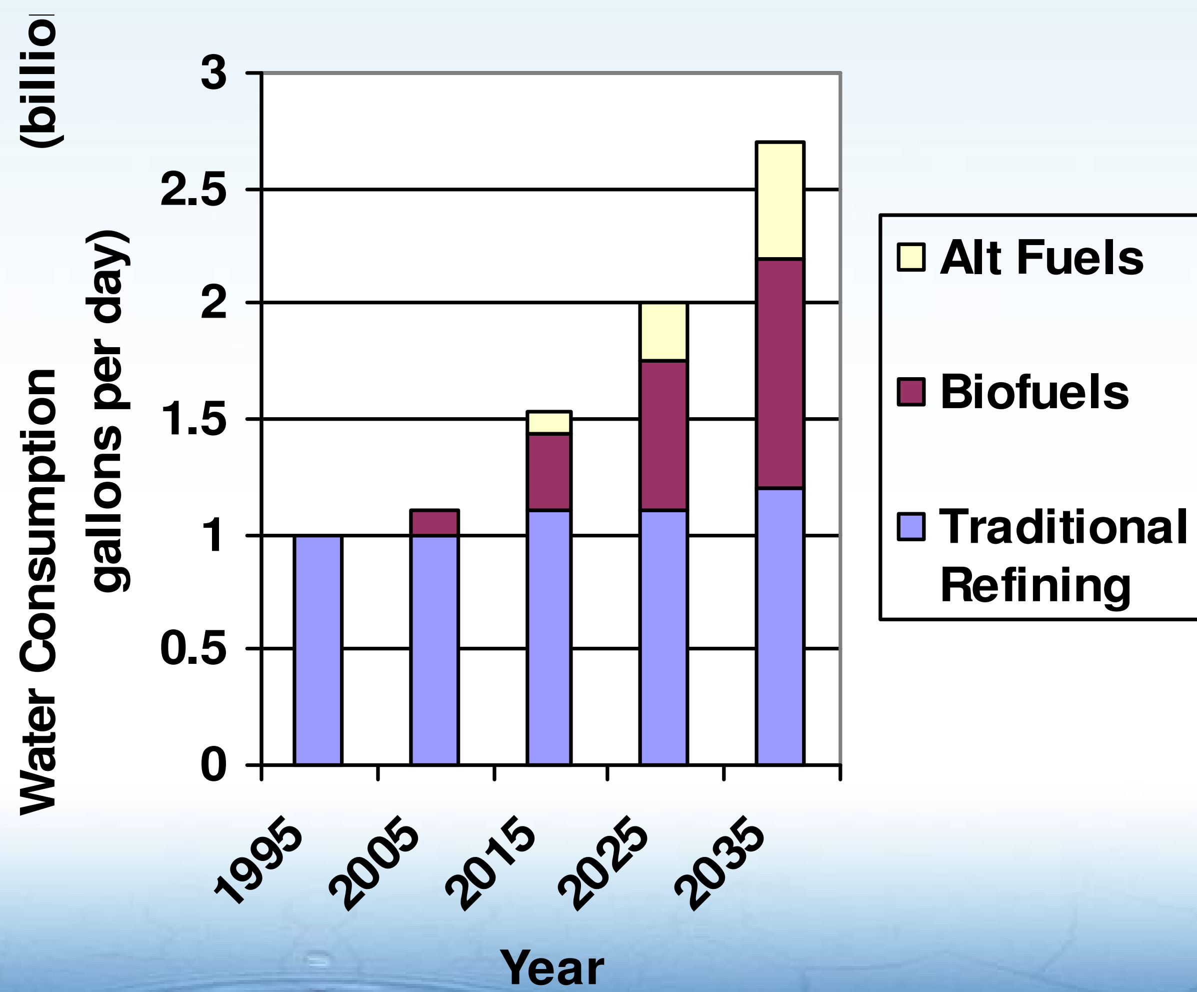
36-Billion Gallons of Biofuel by 2022



Sandia National Laboratories

Emerging Water Demands for Alternative Fuels Development

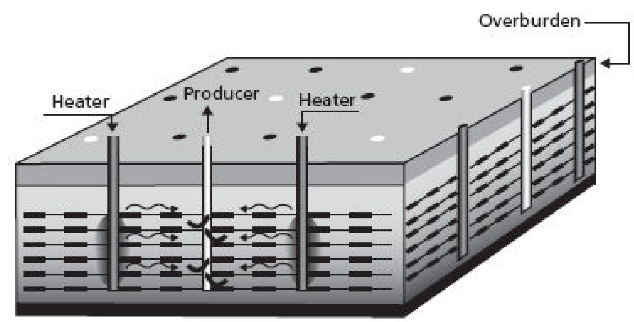
- Irrigation of even small percentage of biofuel acreage will increase water consumption by an additional 5 Bgal/day



Oil Shale development will be regional and impact water availability and quality

- **Reserves are in areas of limited water resources**
- **Water needed for retorting, steam flushing, and cooling up to 3 gallons per gallon of fuel**
- **Concerns over *in situ* migration of retort by-products and impact on ground water quality**

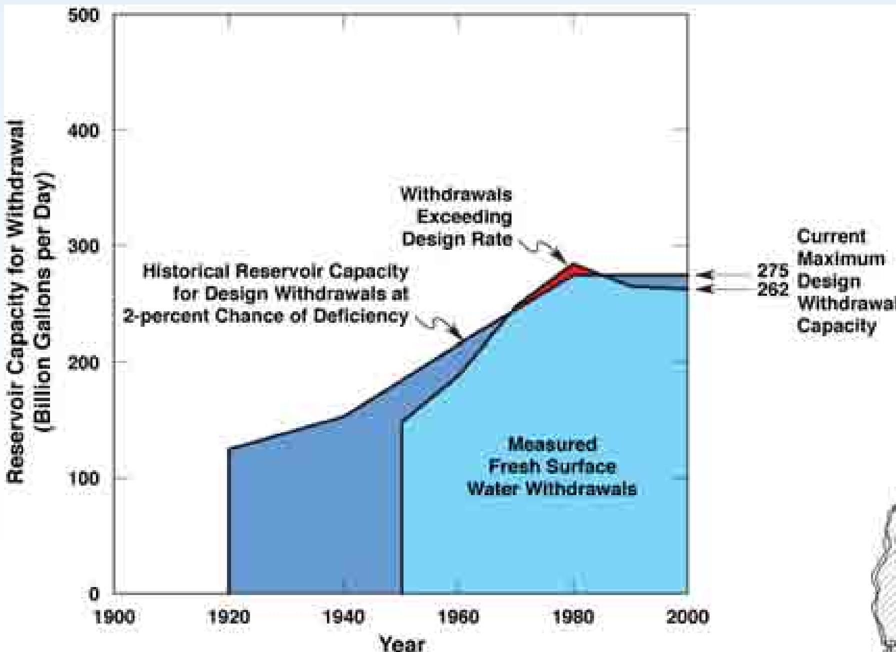
Figure 3.2
The Shell In-Situ Conversion Process



SOURCE: Adapted from material provided by Shell Exploration and Production Company.
RAND MG414-3.2

ENERGY and WATER

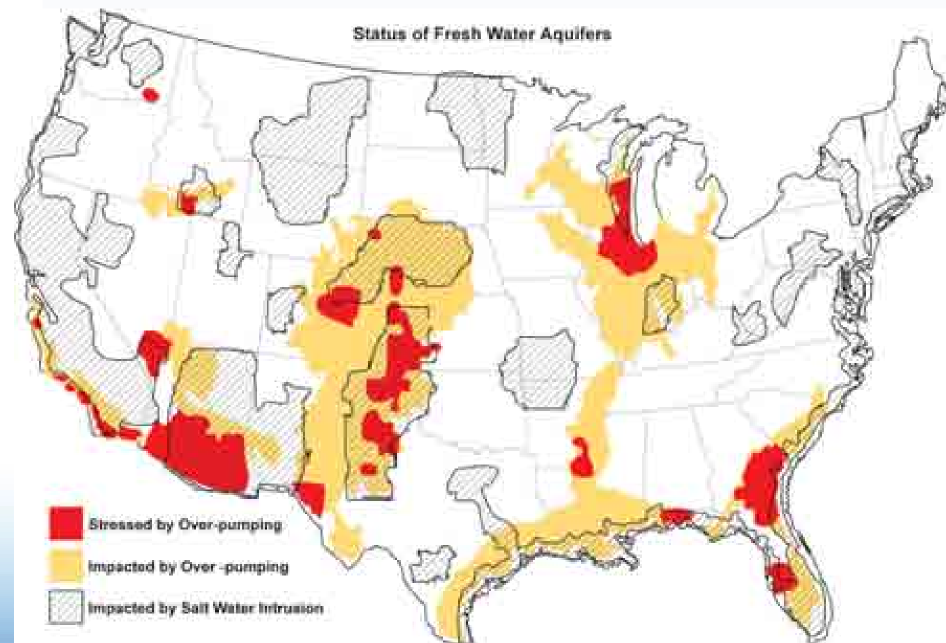
Growing Limitations on Fresh Surface and Ground Water Availability



(Based on USGS WSP-2250 1984 and Alley 2007)

- Little increase in surface water storage capacity since 1980
- Concerns over climate impacts on surface water supplies

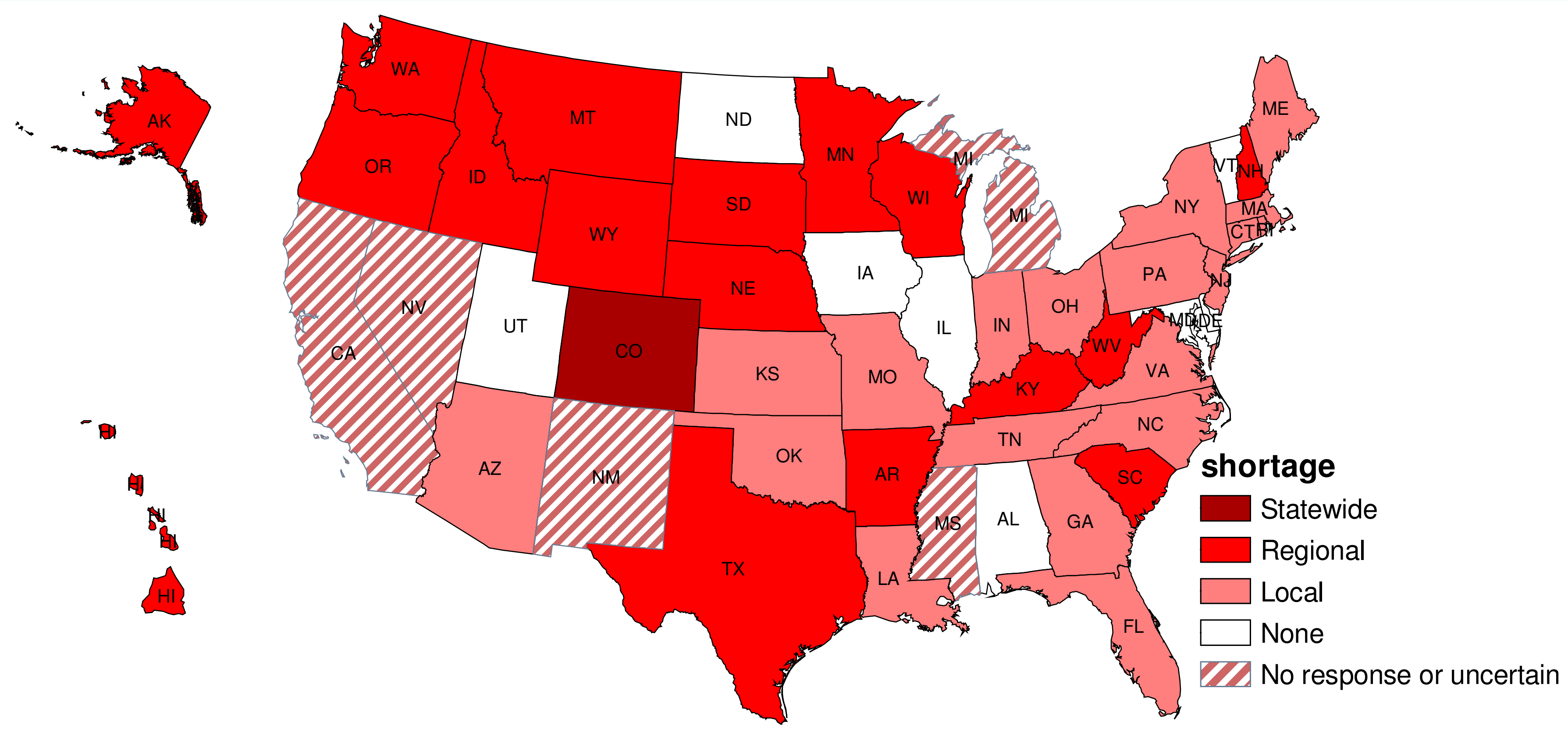
- Many major ground water aquifers seeing reductions in water quality and yield



(Shannon 2007)

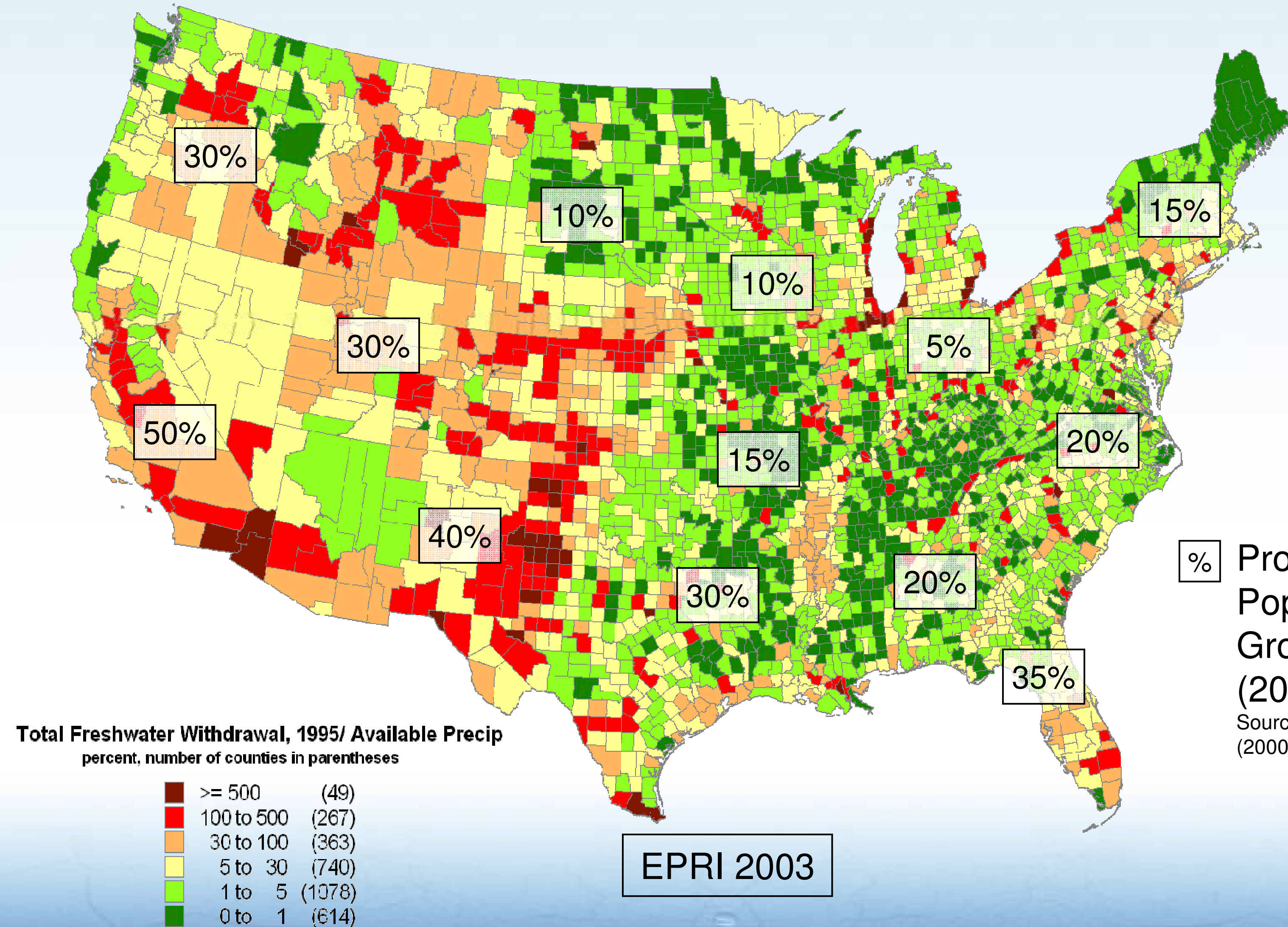
ENERGY and WATER

Most State Water Managers Expect Shortages Over The Next Decade Under Average Conditions



Source: GAO 2003

Water challenges are nationwide



% Projected Population Growth (2000-2020)

Source: Campbell (2000)

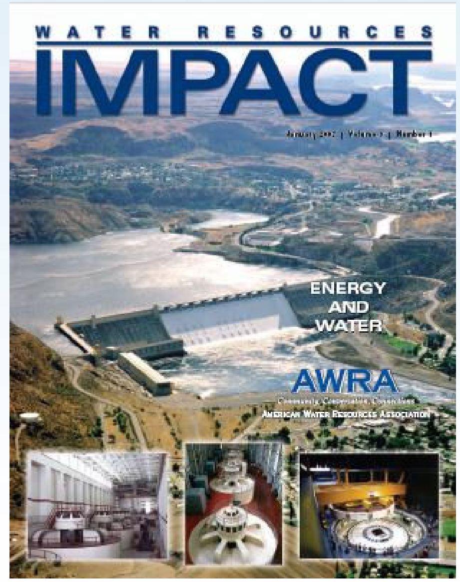
ENERGY *and* WATER

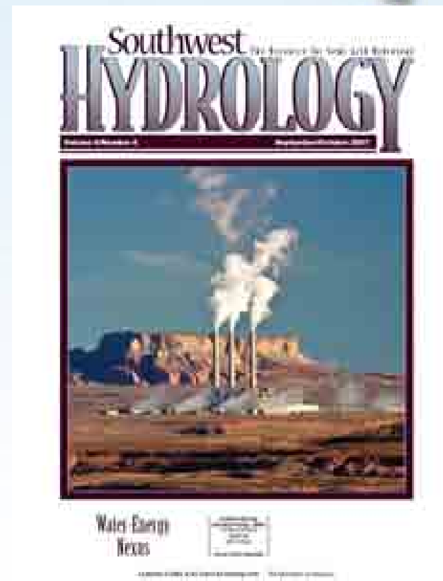
Estimated Capacity Change 1995-2025 (Gw)
AEO Estimates

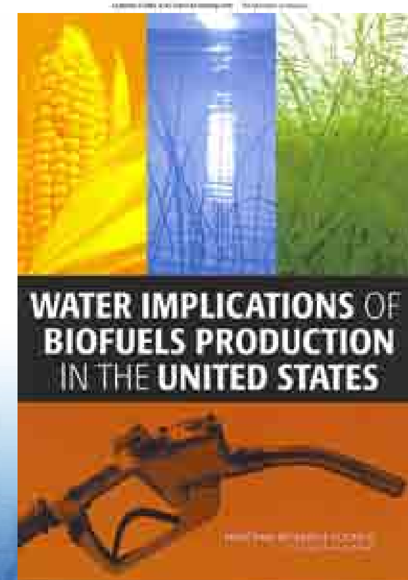
4

Emerging Interest in Energy and Water Issues and Challenges

- State and national water and energy groups
  - 24 invited presentations in FY07 and 08 on energy and water challenges
  - Research and regulatory groups considering future energy and water needs
- Increased media interest
  - NATURE, ECONOMIST
  - Technical magazines
- NSF/NRC interest in energy debate and interdependencies research
- Growing international concerns and challenges
  - Europe, Australia, Asia, Canada





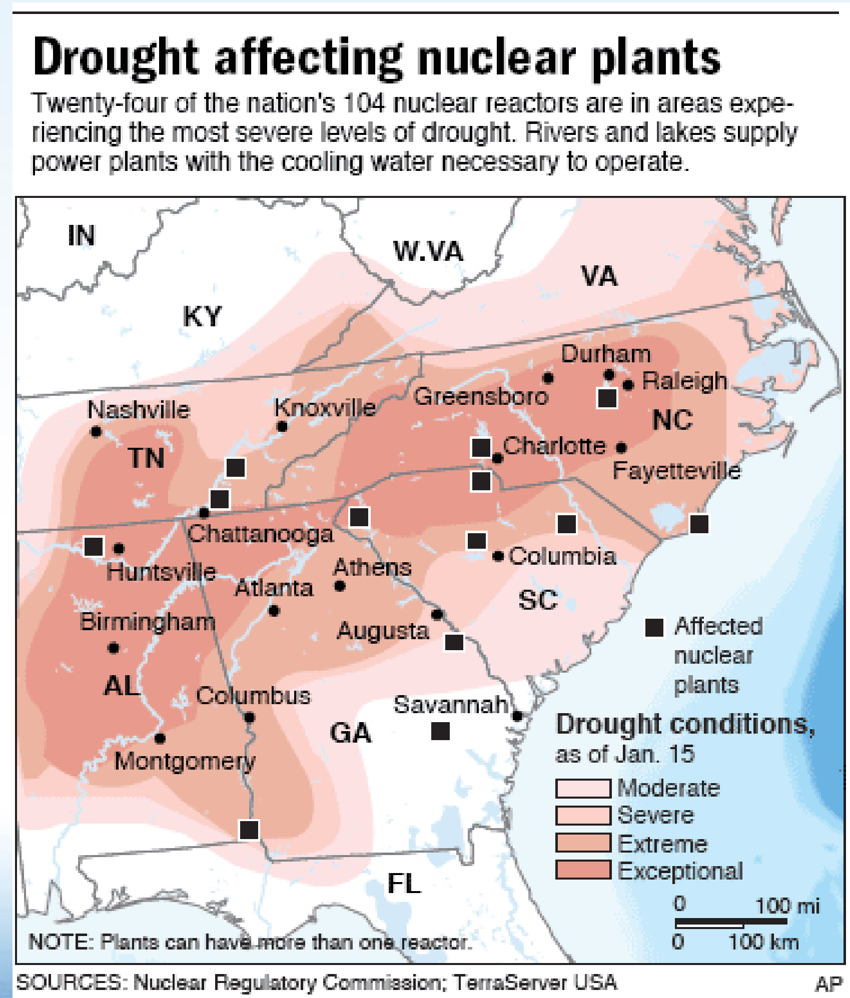


Contemporary Example: Southeast U.S. Drought Impact on Nuclear Power Production

Associated Press

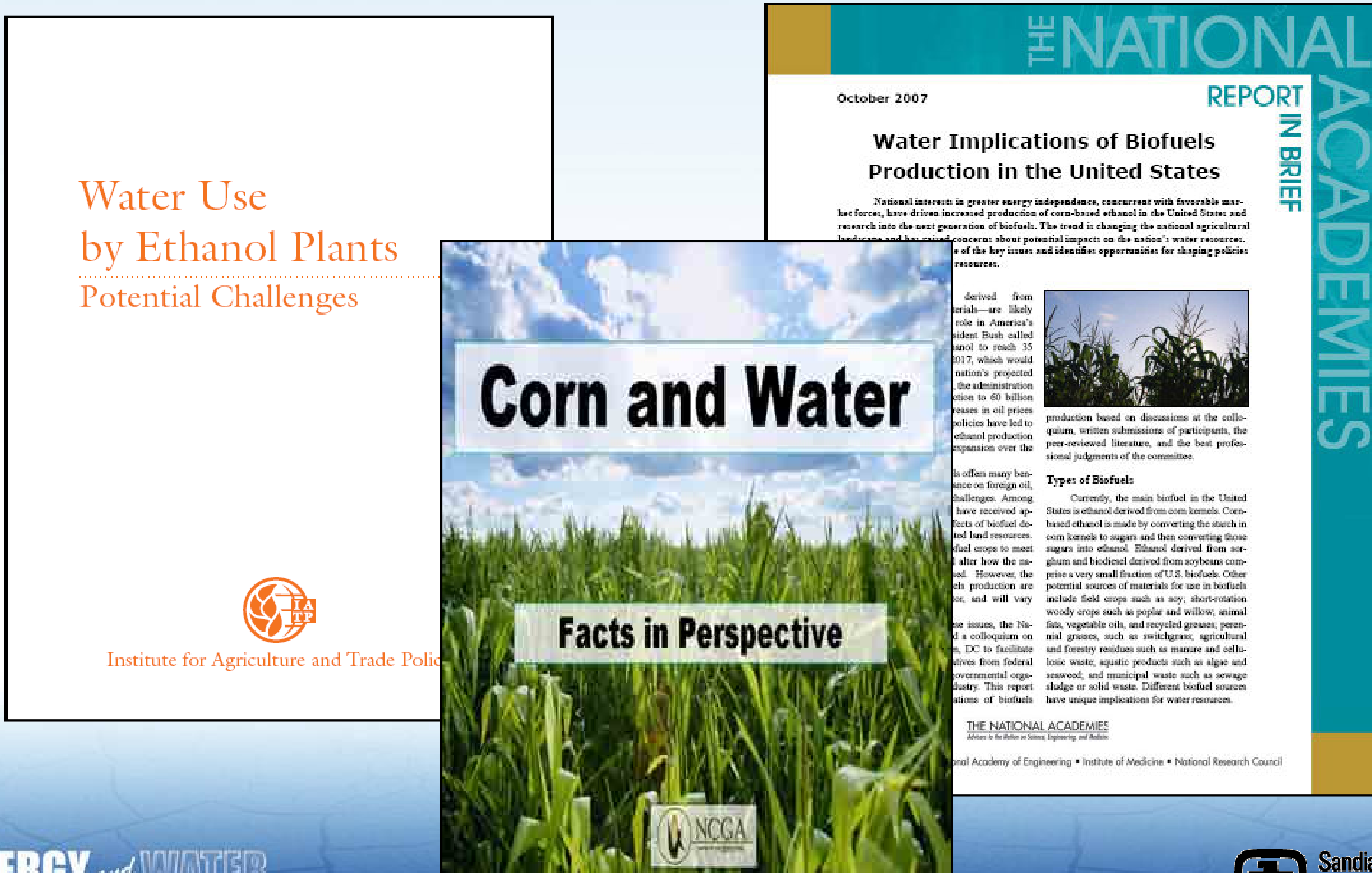
Jan. 23, 2008

"LAKE NORMAN, N.C. - Nuclear reactors across the Southeast could be forced to throttle back or temporarily shut down later this year because drought is drying up the rivers and lakes that supply power plants with the awesome amounts of cooling water they need to operate."



ENERGY and WATER

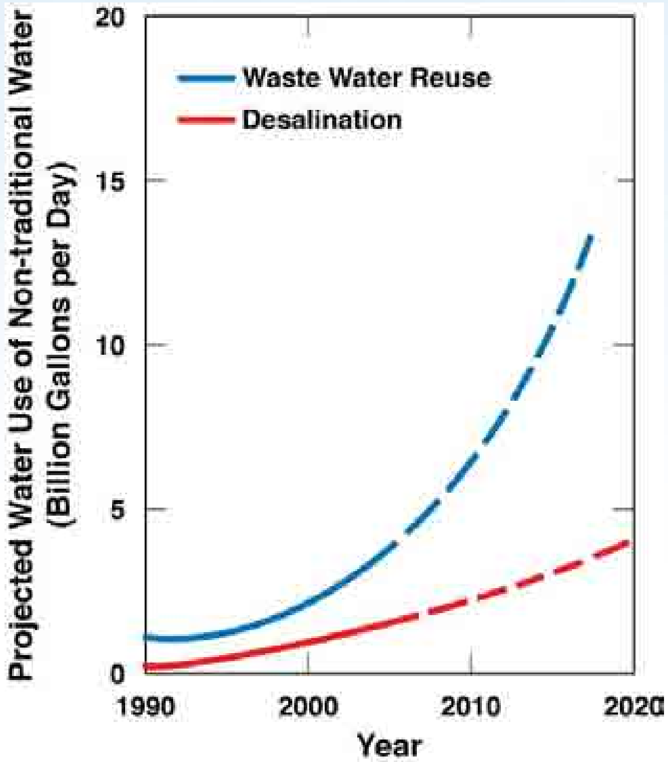
The Biofuel-Water Connection…
Subject of Increasing Discussion



ENERGY and WATER

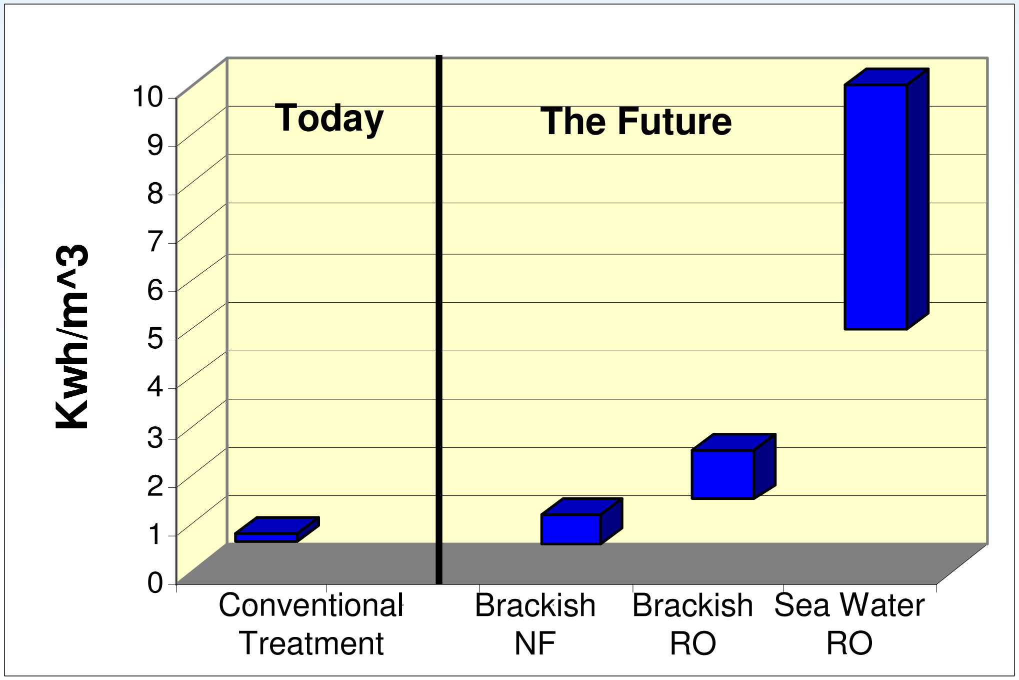
Sandia National Laboratories

Growing Use of Non-traditional Water Resources



(From EPA 2004, Water Reuse 2007, Mickley 2003)

Power Requirements For Treating



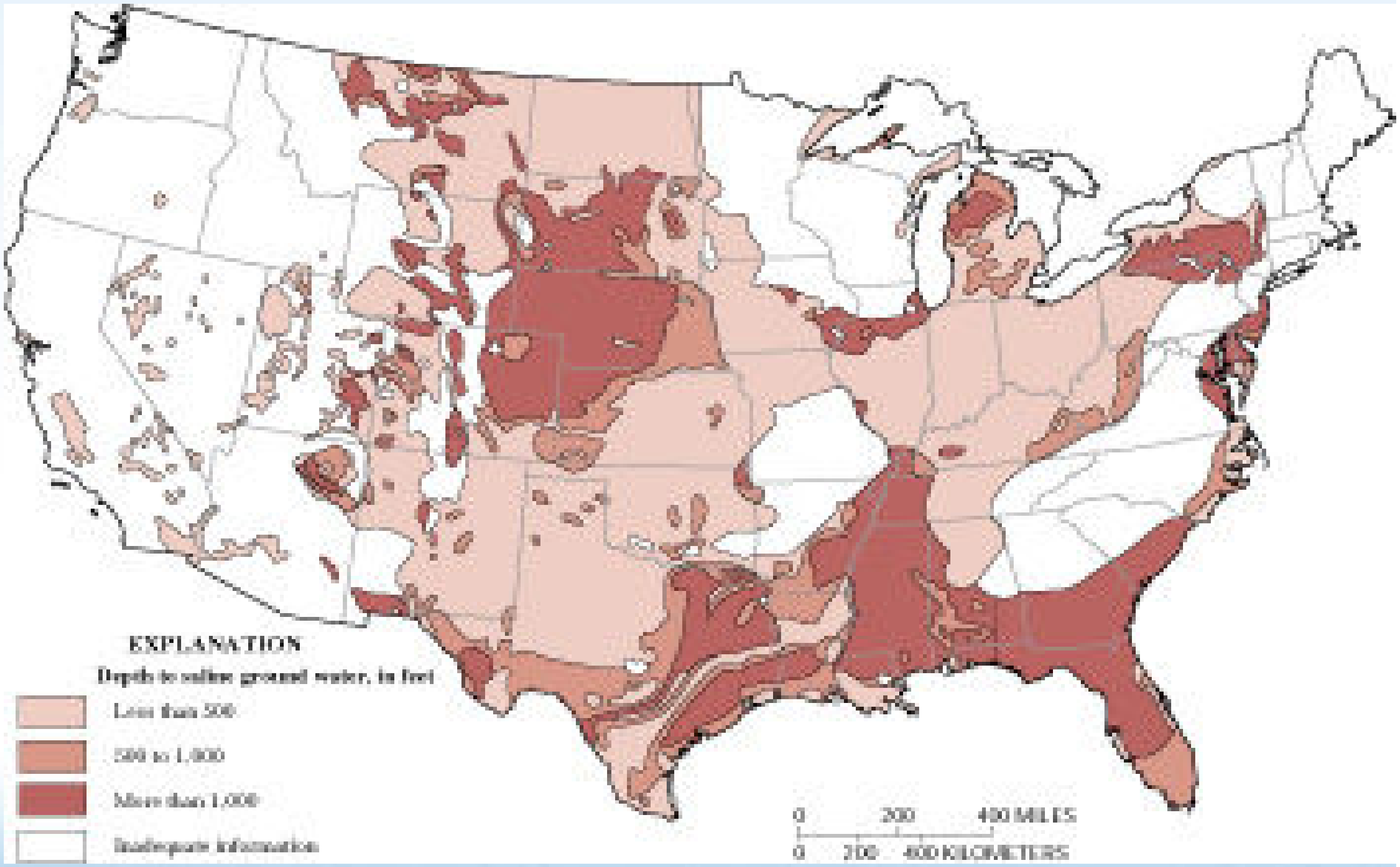
(Einfeld 2007)

- Desal growing at 10% per year, waste water reuse at 15% per year
- Reuse not accounted for in USGS assessments
- Non-traditional water use is energy intensive

ENERGY and WATER

Brackish and Saline Groundwater is a Potential Resource for Algae Production

Saline aquifers in the continental U.S. The brown shading refers to the depth of the aquifer. With appropriate treatment, inland brackish water resources could be an important source of water for thermoelectric power plant cooling and biofuel production. (Data from Feth, 1965)

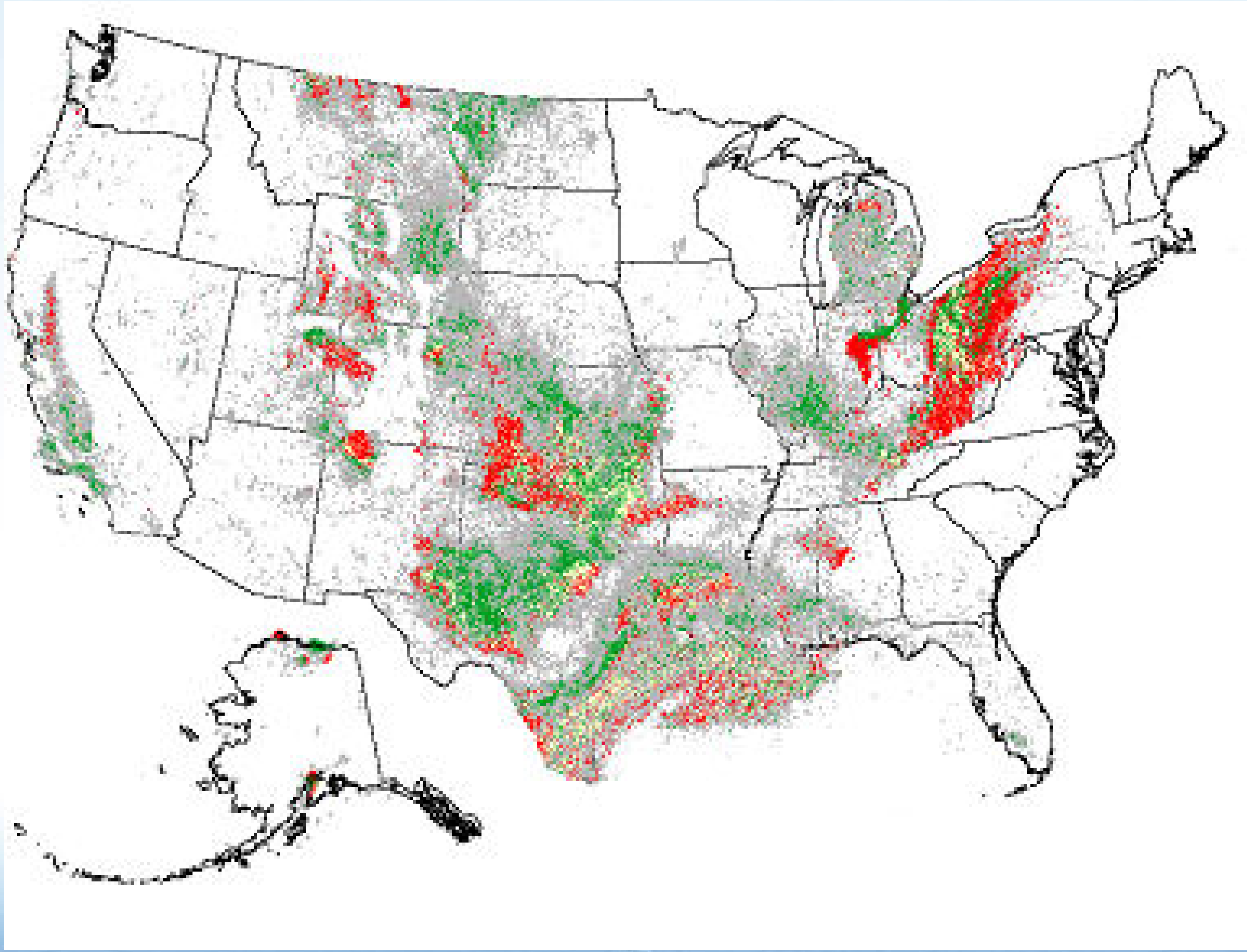


ENERGY and WATER

Sandia National Laboratories

Produced Water from Oil & Gas

Green=oil, Red=gas, Yellow=mixed



ENERGY and WATER

Sandia National Laboratories

Summary of Major National Needs and Issues Identified in Regional Workshops

Better resources planning and management

- Integrated regional energy and water resource planning and decision support tools
- Infrastructure and regulatory and policy considerations for improved energy/water efficiency
- Improved water supply and demand characterization, monitoring, and modeling

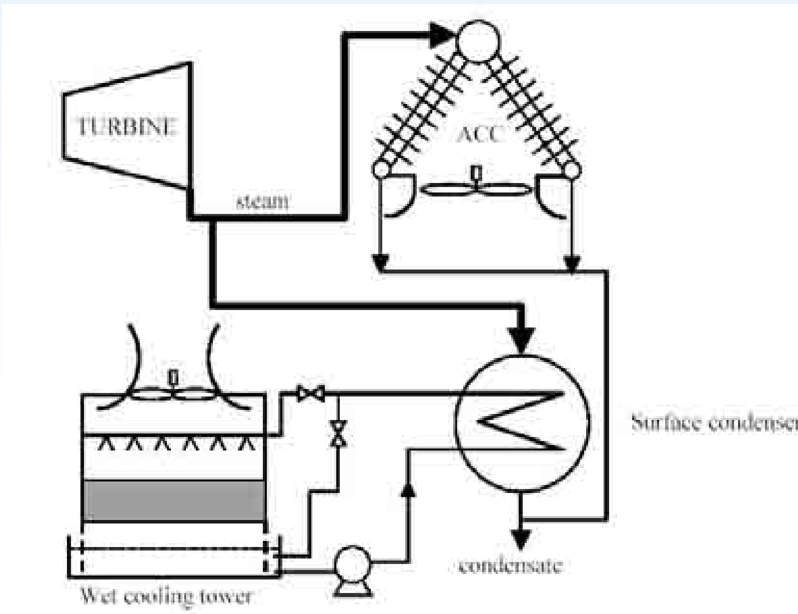
Improved water and energy use efficiency

- Improved water efficiency in thermoelectric power generation
- Improved biofuels/biomass water use efficiency
- Reduced water intensity for emerging energy resources

Development of alternative water resources and supplies

- Non-traditional and oil and gas produced water use and reuse
- Improved energy efficiency for non-traditional water treatment and use

Research Program for Electric Power Sector



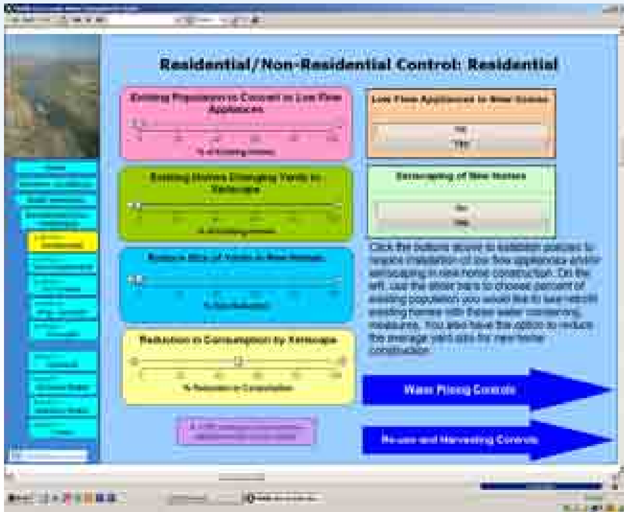
Hybrid Wet-Dry Cooling System

- Improve dry and hybrid cooling system performance
- Improve ecological performance of intake structures for hydro and once-through cooling
- Improve materials and cooling approaches compatible with use of degraded water
- Electric grid infrastructure upgrades to improve low water use renewable technology integration

Research Program for Alternative Fuels Sector

- Reduce water use for cooling in biofuels and alternative fuels production
- Reduce water use in processing
- Develop low fresh water use technologies such as algal biodiesel
- Assess non-traditional water use for fuels applications
- Assess hydrologic impacts of large cellulose biofuels scale up and oil shale

Research and Development Program for Integrated Resources Management



- Accelerate water resources forecasting and management
- Evaluate impacts of climate variability and improve hydrological forecasting
- Improve common decision support tools
- Develop system analysis approaches for: Co-location of energy and water facilities, improved national transmission capabilities to support renewables, distributed generation of biofuels

DOE/NETL's Innovations for Existing Plants Water-Energy R&D Program Goals & Evaluation Methodology

James Murphy, RDS/SAIC

NETL – Existing Plants Water Projects Meeting
October 27-28, 2008
Pittsburgh, PA

Presentation Outline

- **Development of water-energy R&D goal**
- **Proposed methodology to measure progress toward achievement of goal**

Attributes of the Goal Statement

- **Target date**
  - Short term
  - Long term

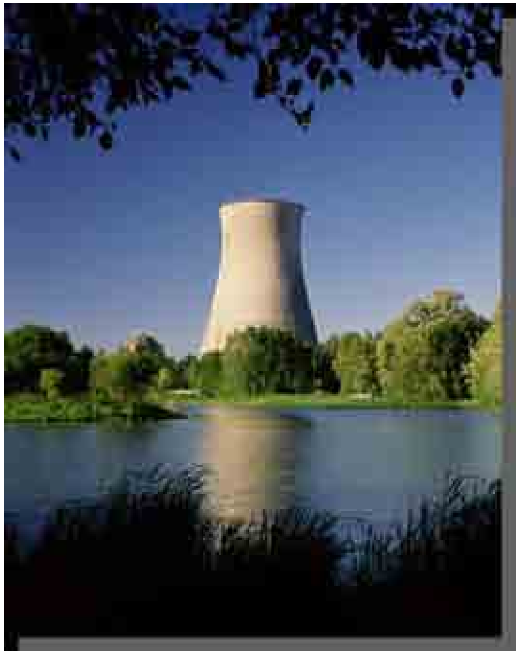
- **Performance targets**
  - Percentage reduction in freshwater use

- **Cost targets**
  - Percentage cost reduction compared to current “state-of-the-art” technology
  - Achieve specific levelized cost
    - Cost per freshwater conservation - $/gallon

IEP Water-Energy R&D Goals

Short-term goal

- Technologies ready for commercial demonstration by ***2015***
- Reduce freshwater withdrawal and consumption by ***50%*** or greater
- Levelized cost of less than ***$3.90*** per thousand gallons freshwater conserved



Long-term goal

- Technologies ready for commercial demonstration by ***2020***
- Reduce freshwater withdrawal and consumption by ***70%*** or greater
- Levelized cost of less than ***$2.60*** per thousand gallons freshwater conserved

IEP Water-Energy R&D Goal Statement

The short-term goal for the IEP water-energy R&D activity is to have technologies ready for commercial demonstration by 2015 that, ***when used alone or in combination***, can reduce freshwater withdrawal and consumption by 50% or greater ***for thermoelectric power plants equipped with wet recirculating cooling technology*** at a levelized cost of less than $3.90 per thousand gallons freshwater conserved.

The long-term goal is to have technologies ready for commercial demonstration by 2020 that, when used in combination, can reduce freshwater withdrawal and consumption by 70% or greater at a levelized cost of less than $2.60 per thousand gallons freshwater conserved.

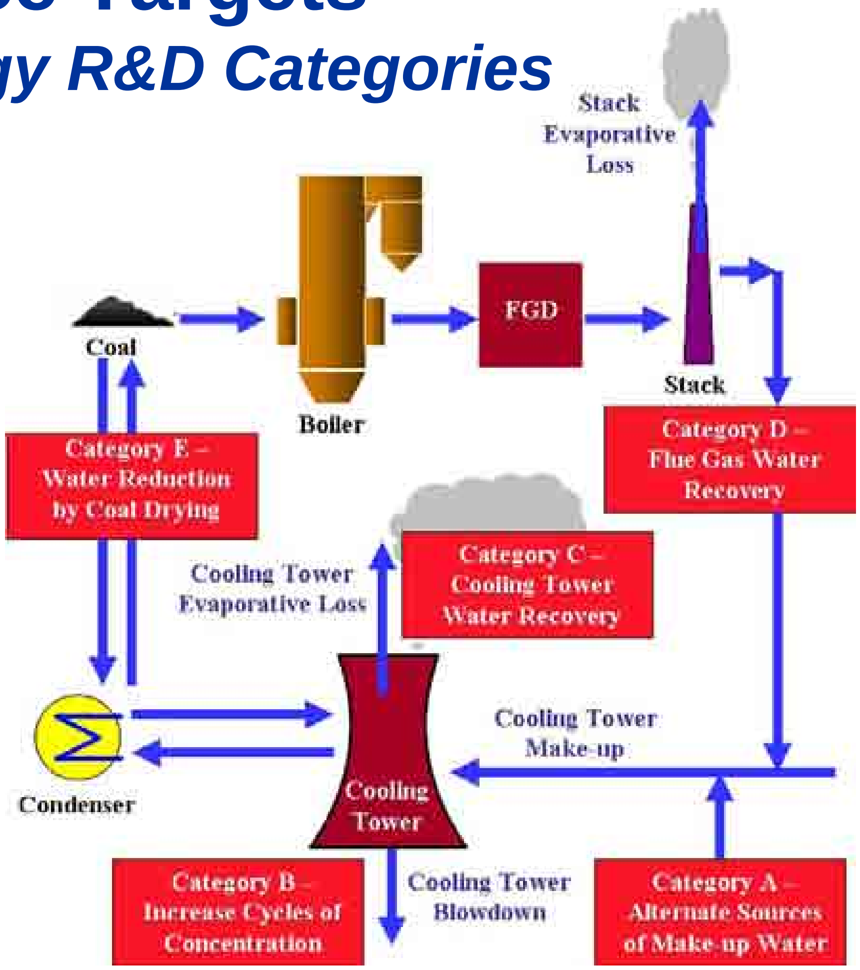
Target Dates

- **Short term goal - *2015***
  - *Maintain current technology development schedule*
- **Long term goal - *2020***
  - *Provide five additional years for technology enhancements*

Performance Targets

Current Water-Energy R&D Categories

- **Category A –** non-traditional water source used to supplement freshwater for cooling water makeup
- **Category B –** increase cycles of concentration (COC) to reduce blowdown, and consequently reduce cooling water makeup
- **Category C –** reduce cooling tower evaporation loss
- **Category D –** reclaim water from combustion flue gas
- **Category E –** utilize waste energy derived from recirculating cooling water to reduce cooling tower evaporative loss



The estimated percentage reduction in freshwater withdrawal and consumption for the five technology categories ranges from 5% to almost 30%. However, by combining technology categories, up to almost 60% reductions are possible for both withdrawal and consumption.

Performance Targets

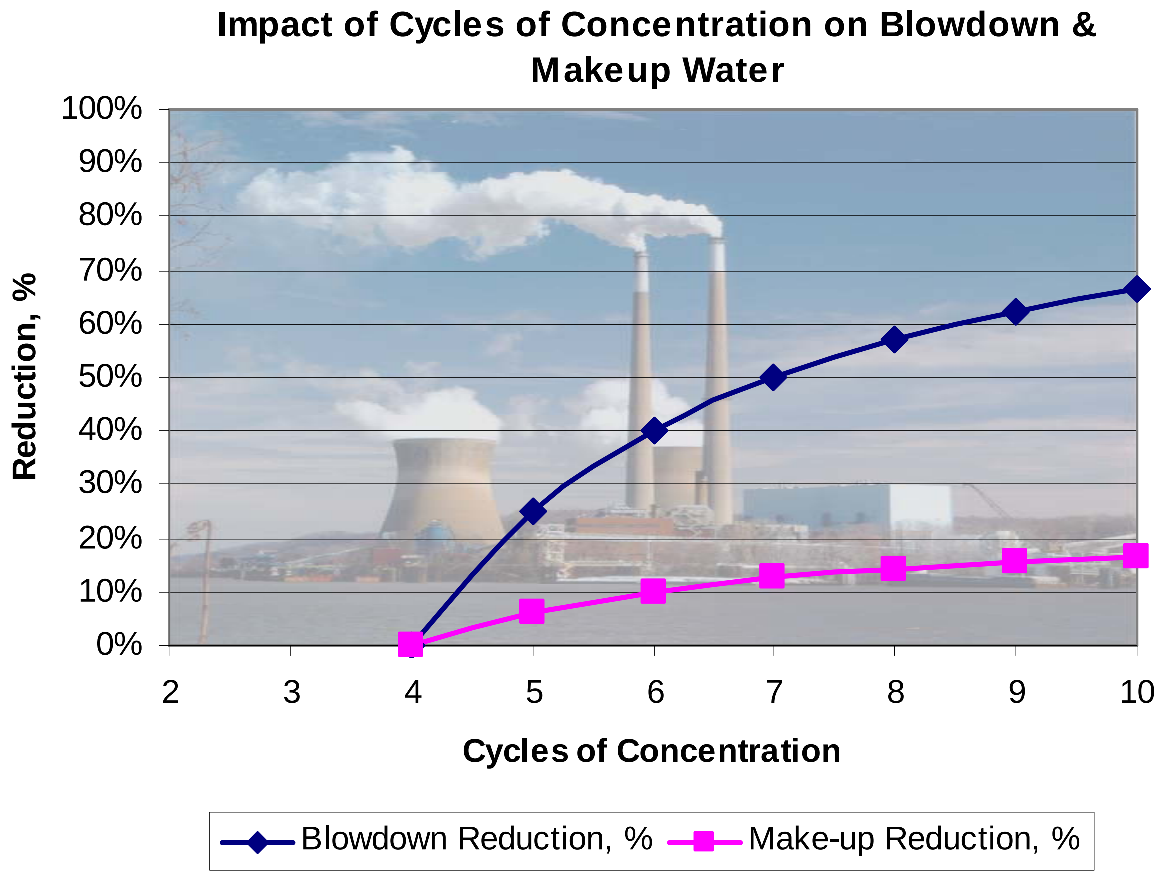
Technology Category - Individual and Combination

Technology Category Combination	Freshwater Withdrawal Reduction, %	Freshwater Consumption Reduction, %
A	27.0%	27.0%
B	11.1%	0.0%
C	20.0%	20.0%
D	3.8%	3.8%
E	5.6%	5.6%
AB	38.1%	30.4%
AC	47.0%	47.0%
BC	28.9%	20.0%
ABC	55.9%	50.4%
ABDE	46.9%	40.3%
ACDE	55.3%	55.3%
BCDE	36.7%	28.8%
ABCDE	63.7%	59.1%

Based on this analysis, it was recommended that the short-term performance goal be stated as a 50% reduction in water withdrawal and consumption and the long-term goal a 70% reduction.

Source: *NETL internal study*, July 2006.

Performance Targets
Cooling Water System Flow Relationships



- **Make-Up = Evaporation + Blowdown + Drift**
- **Blowdown = Evaporation/(COC – 1) – Drift**

  where: COC = cycles of concentration

  assume drift = 0

Cost Targets

Cost Comparison of Wet and Dry Cooling Water Systems for a Reference 500 MW Coal-Fired Power Plant

Cost Component	Wet Cooling (2006$)	Direct Dry Cooling (2006$)	Delta
Equipment Capital Cost			
Capital cost, $/kW	78	168	90
Total capital requirement, Million $	38.8	83.8	45
First year carrying charge, (1,000 $/yr)	6,601	14,251	7,650
Annual Operation & Maintenance Cost (x1,000)			
Maintenance	388	838	450
Water treatment	844	0	-844
Auxiliary power	1,051	2,102	1,051
Lost capacity penalty	0	1,183	1,183
Total annual O&M	2,284	4,124	1,840
Total First Year Costs			
$/yr (x1,000)	8,885	18,375	9,490
COE, mills/kWh	2.54	5.24	2.71
$/1000 gallon water conserved	NA	NA	6.37
Levelized Annual Cost (Constant $)			
$/yr (x1000)	7,332	15,022	7,690
COE, mills/kWh	2.09	4.29	2.19
$/1000 gal water conserved	NA	NA	5.16
Levelized Annual Cost (Current $)			
$/yr (x1000)	8,958	18,328	9,371
COE, mills/kWh	2.56	5.23	2.67
$/1000 gal water conserved	NA	NA	6.29

Step 1: Dry & Wet Cooling Cost
dry @ 4.29 mills/kWh
wet @ 2.09 mills/kWh

Step 2: Dry vs. Wet Δ Cost
4.29 – 2.09 = Δ 2.19 mills/kWh

Step 3: Wet Cooling Water Use
425 gal/MWh

Step 4: Dry Cool Effectiveness
2.19 mills/kWh / 425 gal/MWh
= 5.16 $/kgal conserved

Cost Targets

Cost Effectiveness of Dry Cooling

- **Dry cooling levelized cost @ $5.16 per 1,000 gallons freshwater conserved (2006 constant dollar basis)**
- **Short term goal**
  - Cost effectiveness of R&D technologies equivalent to approx. 75% of dry cooling ($3.90 per 1,000 gallons)
- **Long term goal**
  - Cost effectiveness of R&D technologies equivalent to approx. 50% of dry cooling ($2.60 per 1,000 gallons)

Technology Evaluation Methodology

- ***How to measure progress in achieving DOE/NETL's cost & performance goals?***
  - Calculate levelized cost in terms of dollars per thousand gallons freshwater conserved
  - Compare project cost to NETL cost goal
- ***Need consistent cost methodology for use by all NETL contractors***
- ***Economic assumptions should be equal to those used to establish NETL cost goal***
- ***NETL will provide contractors an economic evaluation guideline and cost estimating spreadsheet model to assure consistency***

Reference Plant Data Sheet

Subcritical PC Boiler Plant Performance Summary @ 100 Percent Load (Table 7-1)	
554.4	Gross power, MW
33.8	Auxilary load, MW
520.6	Net Power, MW
35.4	Net efficiency, % (HHV)
9,638	Net heat rate, Btu/kWh (HHV)
2,335	Condenser cooling duty, 10^6 Btu/h

Reference: DOE/NETL report entitled "Power Plant Water Usage and Loss Study" , Revised May 2007

Reference Plant Data Sheet (cont'd)

Cooling System Assumptions (Table 1-5)	
System type: Closed recirculating system with evaporative mechanical draft cooling towers	
89	Design dry bulb max. ambient temperature, °F
75	Design wet bulb max. ambient temperature, °F
5	Cooling tower approach, °F
25	Cooling tower range, °F
80	Cold circulating water temperature to condenser, °F
105	Hot circulating water temperature from condenser, °F
4	Circulating water cycles of concentration
0.001	Cooling tower drift (% of CW flow rate)

Subcritical PC Boiler Water Balance Around Cooling Water System (Table 7-8)	
3,891	Cooling tower evaporation, gpm
1,297	Cooling tower blowdown, gpm
5,188	Cooling tower make-up, gpm

Circulating Water Flow Rate Calculation (NETL estimate)	
1.0	Specific heat of water, Btu/lb-F
8.33	Density of water, lb/gal
186,875	Circulating water flow rate, gpm

Reference: DOE/NETL report entitled "Power Plant Water Usage and Loss Study“ , Revised May 2007

Input Value Sheet

General Information	
Lead Company	XYZ Company
Principle Investigator	John Doe
NETL Project Manager	Jane Smith
NETL Project #	XXXXXXXX
NETL Water-Energy R&D Category	Category A - Non-Traditional Water
Description of Water Technology	Beta Cooling Technology
Test Site	Alpha Power Company's Beta Power Plant Unit 2
Date Prepared	December 30, 2008

Reference Plant Operating Assumptions	Value	Assumptions/Comments
Plant capacity, MW net	521	From reference plant data sheet.
Net plant heat rate, Btu/kWh	9,638	From reference plant data sheet.
Average plant capacity factor	80%	Assume 80% per NETL Guidelines, Sec.6.3
Cooling tower evaporation, gpm	3,891	From reference plant data sheet.
Cooling tower blowdown, gpm	1,297	From reference plant data sheet.
Cooling tower make-up, gpm	5,188	From reference plant data sheet.
Cycles of concentration	4	From reference plant data sheet.

Input Value Sheet (cont'd)

Water Technology Performance Assumptions & Calculations		All performance values should be based on plant operation at full load.
Reduction in cooling tower freshwater make-up, %	20.0%	Estimate percent reduction in freshwater make-up using water technology for Category A, C, D, E, or F project.
Cycles of concentration	4.0	Estimate COC after application of water technology for Category B project.
Cooling tower freshwater evaporation, gpm	3,113	Calculated value.
Cooling tower freshwater blowdown, gpm	1,038	Calculated value.
Cooling tower freshwater make-up, gpm	4,150	Calculated value.
Reduction in cooling tower freshwater make-up, gpm	1,038	Calculated value.
Reduction in cooling tower freshwater make-up, gallons per year	436,290,048	Calculated value based on average plant capacity factor.
Water Technology Cost Assumptions		
Costs expressed in year dollars	2008	All costs should be escalated to this year dollars for consisteny.
Process capital cost, $	1,000,000	Include costs for all material, equipment, direct and indirect labor, and freight & taxes.
Technology royalty fee, $	0	Estimate fee if necessary.
Special maintenance, $	100,000	Estimate cost of non-routine special maintenance requirements.
Special maintenance frequency, hours	16,000	Estimate operating hours between special maintenance activities.
Primary additive	Additive XX	Identify name and type of additive.
Primary additive cost & feedrate metric	$/lb & lb/hr	Select either $/lb & lb/hr or $/gal & gal/hr.
Primary additive unit cost, $/lb or $/gal	$1.00	Estimate delivered price.
Primary additive feed rate, lb/hr or gal/hr	50	Estimate feed rate at full load. Make sure units are consistent with unit price.
Secondary additive	Additive YY	Identify name and type of additive.
Secondary additive cost & feedrate metric	$/gal & gal/hr	Select either $/lb & lb/hr or $/gal & gal/hr.
Secondary additive unit cost, $/lb or $/gal	$2.00	Estimate delivered price.
Secondary reagent/additive feed rate, lb/hr or gal/hr	10	Estimate feed rate at full load. Make sure units are consistent with unit price.
Increase in flue gas duct pressure drop, in H_2O	0.00	Estimate pressure drop at full load.
Auxiliary electric power consumption, kW	100	Estimate consumption rate at full load.
Process water consumption, gallon/hr	20	Estimate consumption rate at full load.
Process steam consumption, lb/hr	100	Estimate consumption rate at full load.
Service air consumption, cfm	100	Estimate consumption rate at full load.
Waste by-product production, lb/hr	20	Estimate production rate at full load.
No. operators per shift	0.5	Estimate additonal operating personnel per shift. (Fractional entry is acceptable.)

Cost Calculation Sheet

XYZ Company			
Beta Cooling Technology			
Plant Operating Assumptions	**Value**	**Factors**	**Assumptions/Comments**
Plant capacity, MW	521		From input sheet.
Net plant heat rate, Btu/kWh	9,638		From input sheet.
Average plant capacity factor	80%		From input sheet.
Cooling tower water make-up, gpm	5,188		From input sheet.
Reduction in cooling tower freshwater make-up, gpm	1,038		From input sheet.
Costs expressed in year dollars	2008		From input sheet.
Capital Cost			
Process capital cost (PCC)	1,000,000		From input sheet.
Process capital cost w/ retrofit factor	1,000,000	1.00	Retrofit difficulty factor assumed 1.00 per NETL estimate.
Technology royalty fee	0		From input sheet.
General facilities, %	100,000	10%	Assume 10% of PCC per EPRI TAG.
Engineering & construction management fees,%	100,000	10%	Assume 10% of PCC per NETL Guidelines, Sec. 7.1.1.
Process contingency, %	50,000	5%	Assume 5% of PCC per NETL Guidelines Table 6 AACE standards for commercial technology or modifications to commercial technology status.
Project contingency,%	150,000	15%	Assume 15% of PCC per NETL Guidelines Table 7 AACE standards for project control design stage.
Total plant cost (TPC), $	1,400,000		
Total capital requirement, $/kW	2.69		
Total first year capital carrying charge, $/yr	289,800		Calculated using 1st year current $ carrying charge rate from economic factors worksheet.

Cost Calculation Sheet (cont'd)

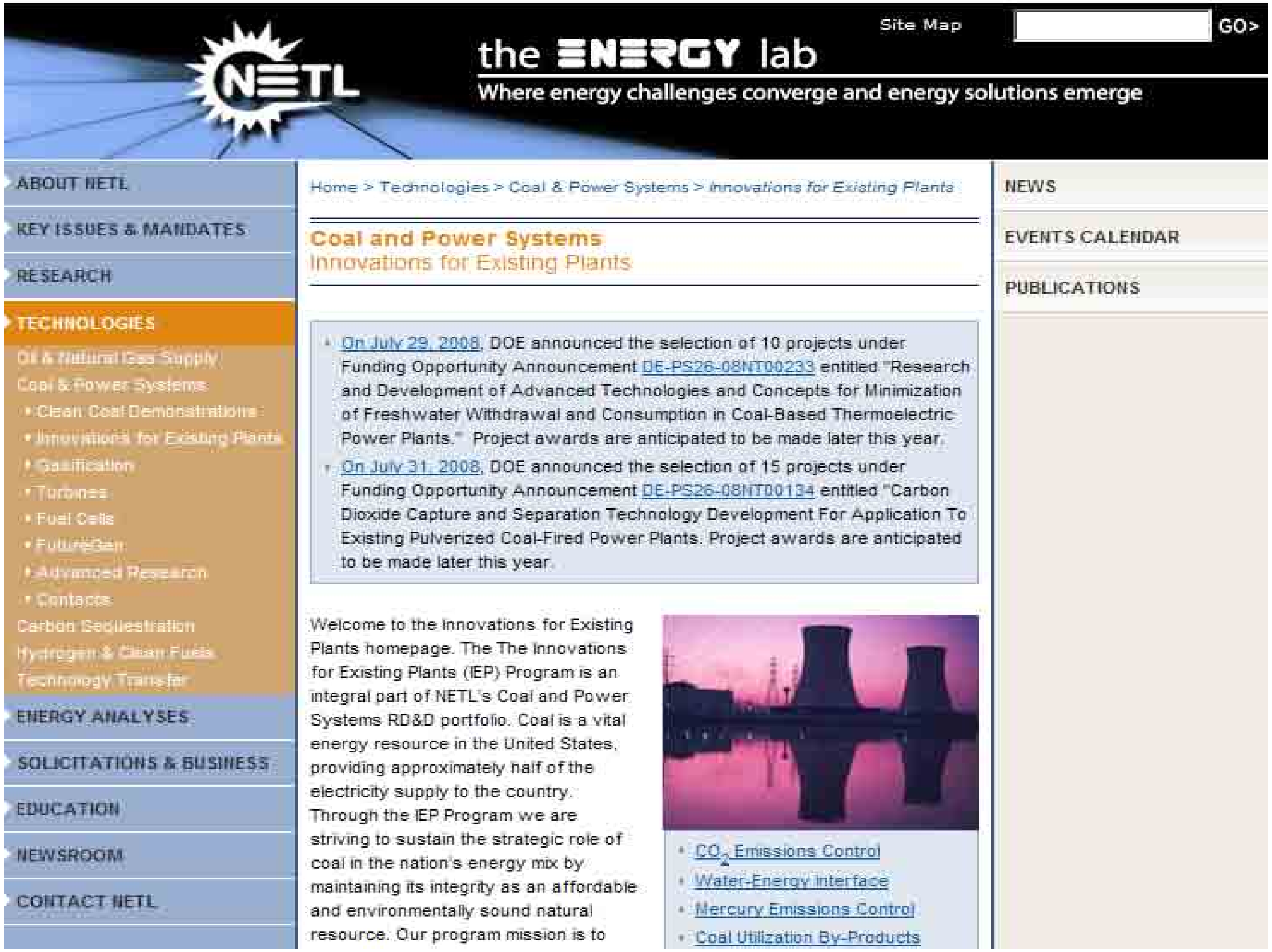
Fixed O&M Cost			
Operating labor, $/yr	219,000		Calculation based on estimated operating labor per shift at $50/man-hr.
Routine maintenance, $/yr	30,800	2.2%	Assume 2.2% of TPC per NETL Guidelines, Sec. 7.2.1.
Special maintenance, $/yr	43,800		Calculation based on special maintenance cost and frequency from input sheet.
Supervisory/clerical, $/yr	69,396		Assume 30% of operating labor and 12% maintenance costs per NETL Guidelines, Sec. 7.2.1.
Total fixed O&M cost, $/yr	362,996		
Total fixed O&M cost, $/kW-yr	0.70		
Variable O&M Cost			Calculate annual variable costs using plant capacity factor.
Primary additive, $/yr	350,400		Calculation based on estimated unit cost and feed rate.
Secondary additive, $/yr	140,160		Calculation based on estimated unit cost and feed rate.
Additional fan power, $/yr	0		Auxiliary power unit cost per calculation on misc. factor worksheet.
Auxiliary power, $/yr	21,024		Auxiliary power unit cost per calculation on misc. factor worksheet.
Process water, $/yr	316		Process water unit cost per calculation on misc. factor worksheet.
Process steam, $/yr	1,939		Steam unit cost per calculation on misc. factor worksheet.
Service air, $/yr	3,268		Service air unit cost per calculation on misc. factor worksheet.
Waste disposal, $/yr	1,402		Waste disposal unit cost per calculation on misc. factor worksheet.
Total Variable O&M Cost, $/yr	518,509		
Total Variable O&M Cost, mills/kWh	0.14		

Cost Calculation Sheet (cont'd)

Total First Year Costs	
$/year	1,171,305
Increase COE, mill/kWh	0.32
$/kgal freshwater make-up conserved	2.68
Levelized Annual Cost (Constant $)	
$/year	1,063,505
Increase COE, mill/kWh	0.29
$/kgal freshwater make-up conserved	2.44
Levelized Annual Cost (Current $)	
$/year	1,324,061
Increase COE, mill/kWh	0.36
$/kgal freshwater make-up conserved	3.03

Questions?

To Find Out More About NETL's Water-Energy R&D:



http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

EXTRA SLIDES

Cost Targets

Economic Assumptions

Economic Assumptions	Reference: NETL Guidelines, Sec. 7.3	
Year dollars	2006	Per study requirements
Project life, yrs	20	
Book life, yrs	20	
Tax life, yrs	20	
Federal and state income tax rate, %	38%	
Tax depreciation method	ACRS	Accelerated cost recovery system - 150% DB
Investment tax credit	0.0%	
Construction interest rate	11.2%	Not used in calculations.
Inflation rate, %	3.0%	
Non-fuel escalation rate, %	0.0%	Not used in calculations.

Financial Structure	Reference: NETL Guidelines, Table 9 - low risk projects				
Type of Security	% of Total	Current $ Cost, %	Current $ Return, %	Constant $ Cost, %	Constant $ Return, %
Debt	80.0%	9.0%	7.2%	5.8%	4.7%
Preferred stock	0.0%	3.0%	0.0%	0.0%	0.0%
Common stock	20.0%	20.0%	4.0%	16.5%	3.3%
Discount rate			11.2%		8.0%

Levelization Factors:	Current $	Constant $
Levelization factor for O&M	1.253	1.000
1st year carrying charge factor	20.7%	17.0%
20-yr levelized factor for capital	15.7%	13.0%

Cost Targets

Cost and Performance Assumptions

Cost & Performance Assumptions:	Value	Reference
Annual escalation rate, %	3.0%	
Plant capacity, MW	500	
Capacity factor, %	80%	
Wet tower capital cost, $/kW (2002$)	69	(1)
Capital cost adder for dry tower	90	(3)
Fixed maintenance as % capital cost, %	1.0%	(1)
Water treatment, $/kW-yr (2002$)	1.5	(1)
Aux. power as % plant capacity (Wet)	1.0%	(2)
Aux. power as % plant capacity (Dry)	2.0%	(2)
Lost capacity penalty, % (Dry)	1.0%	(2)
Energy cost, $/kWh	0.030	(1)
Water evaporation @ full load, gal/MWh	425	(4)

References:

(1) "An Investigation of Site-Specific Considerations for Retrofitting Recirculating Cooling Towers at Existing Power Plants - A Four-Site Case Study", May 2002, Parsons report for DOE/NETL

(2) EPRI August 2004 report #1005358 titled "Comparison of Alternate Cooling Technologies for U.S. Power Plants: Economic, Environmental, and Other Tradeoffs"

(3) Capital cost adder for dry cooling system based on average dry vs. wet delta capital cost from two references:

Burns & McDonnell evaluation for Sempra Energy, November 2002 - 76 $/kW adder (dry @ 172 $/kW vs. wet @ 96 $/kW)

EPRI August 2004 (see reference 2) - 99 $/kW adder (dry @ 135 $/kW vs. wet @ 36 $/kW)

(4) "Power Plant Water Usage and Loss Study", May 2007, Parsons report for DOE/NETL. Average of 449 gal/MWh for subcritical PC and 402 gal/MWh for supercritical PC plant.

Application of pulsed electrical fields for advanced cooling in coal-fired power plant

"Advanced Technologies and Concepts
to Minimize Freshwater Use in Coal-Based Thermoelectric Power Plants"

Topic 2: Advanced Cooling Technology

U.S. DEPARTMENT OF ENERGY
National Energy Technology Laboratory

Drexel University
Y. Cho, A. Fridman, and A. Gutsol

Oct. 28, 2008

Background

Thermoelectric generation accounted for 39% (136 billion gallons per day) of all freshwater withdrawals in 2000.

→ Why so high?

High concentration of mineral ions in the circulating cooling water due to evaporation of pure water evaporates

→Mineral fouling problem, reducing condenser capacity

To maintain a desired calcium level in the cooling water,

→ cycle of concentration, COC = 3.5

→ continuously blowdown with fresh makeup water

Three reactions leading to mineral fouling

Reaction 1: dissociation of bicarbonate ions into hydroxyl ions and carbon dioxide

$$HCO_3^- (aq) \leftrightarrow + OH^- (aq) + CO_2(g)\uparrow$$

Reaction 2: hydroxyl ions produced further react with existing bicarbonate ions, producing carbonate ions and water

$$HCO_3^- (aq) + OH^- (aq) \leftrightarrow CO_3^{2-} (aq) + H_20 (l)$$

Reaction 3: reaction between calcium and carbonate ions, resulting in the precipitation and crystallization of calcium carbonate particles

$$Ca^{2+} (aq) + CO_3^{2-} (aq) \leftrightarrow CaCO_3 (s)\downarrow$$

Goal of the Project

To develop a scale prevention technology based on integrated system of physical water treatment (PWT) and a novel filtration method.

To significantly reduce water blowdown, which accounts approximately 30% of water loss in a cooling tower.

Specific Target

To increase COC from 3-4 to a higher COC (8-10)

How?

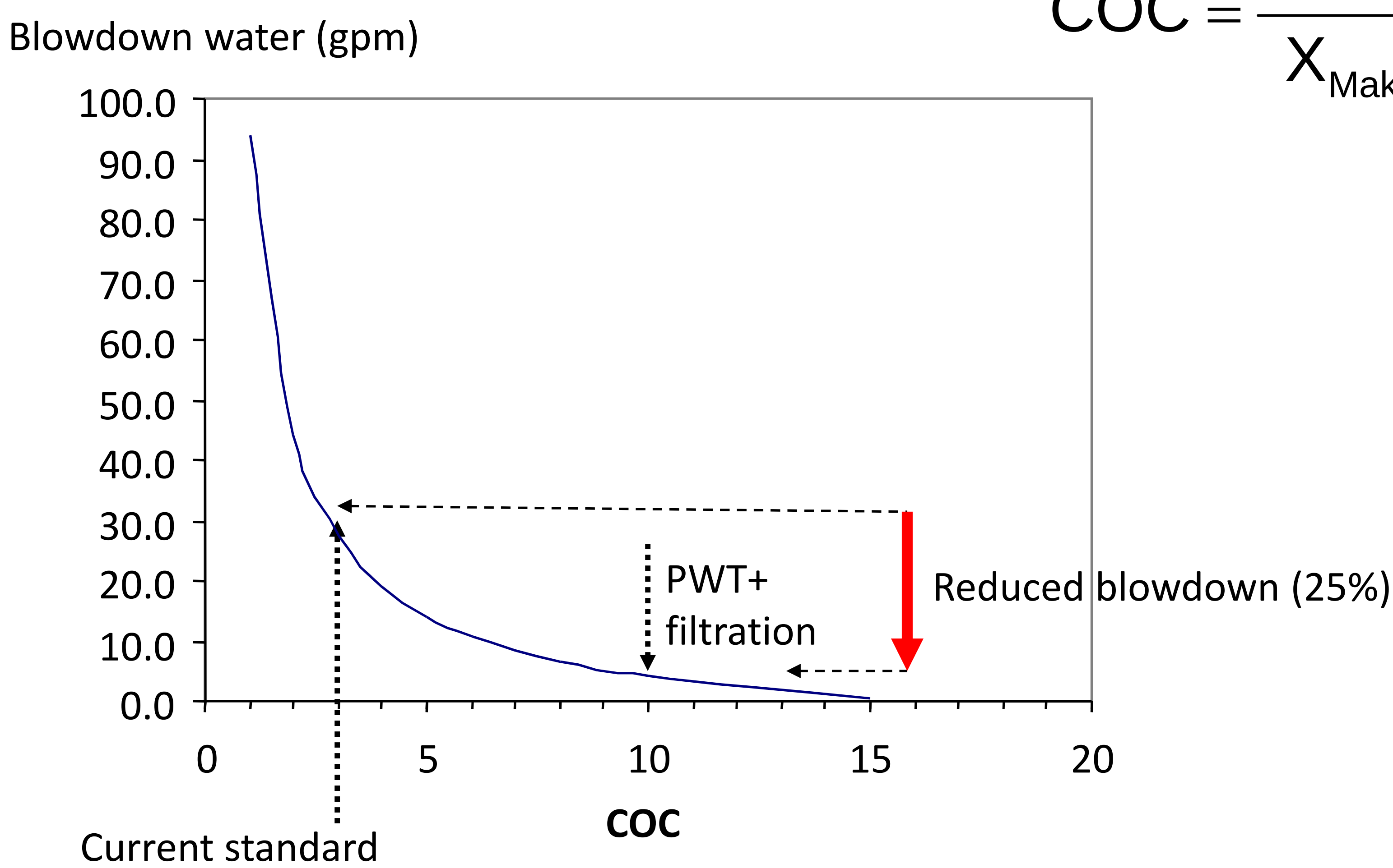
To continuously convert dissolved calcium ions in water to calcium particles (PWT technology) and

To continuously remove them

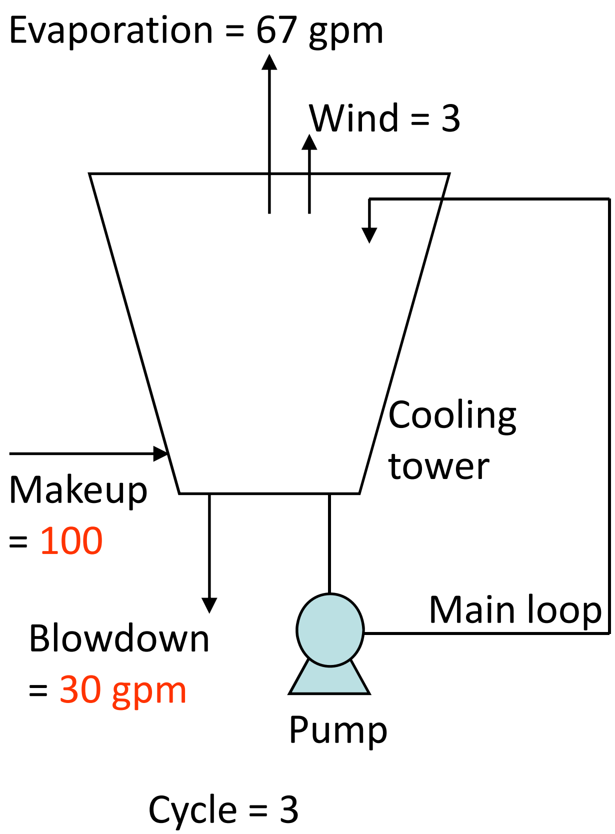
Reduced Blowdown by Increasing COC

If Makeup water is 100 gpm,

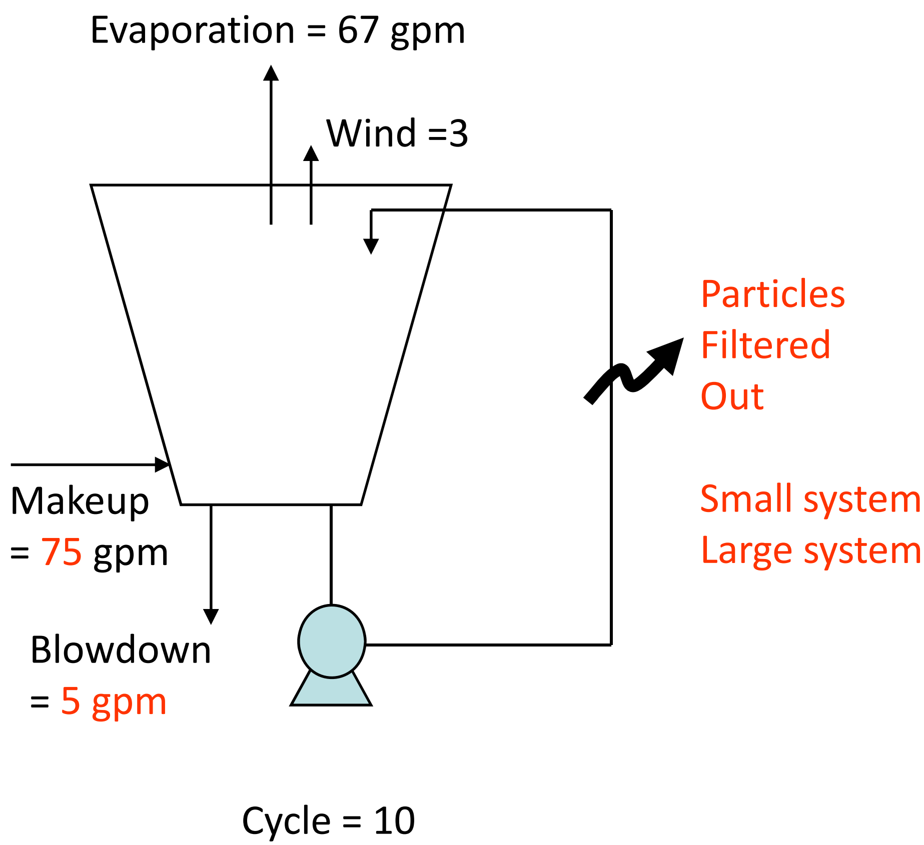
$$COC = \frac{X_{Circulating\ water}}{X_{Make\text{-}up\ water}}$$



Continuous Removal of $CaCO_3$ Particles



(A) Conventional technology



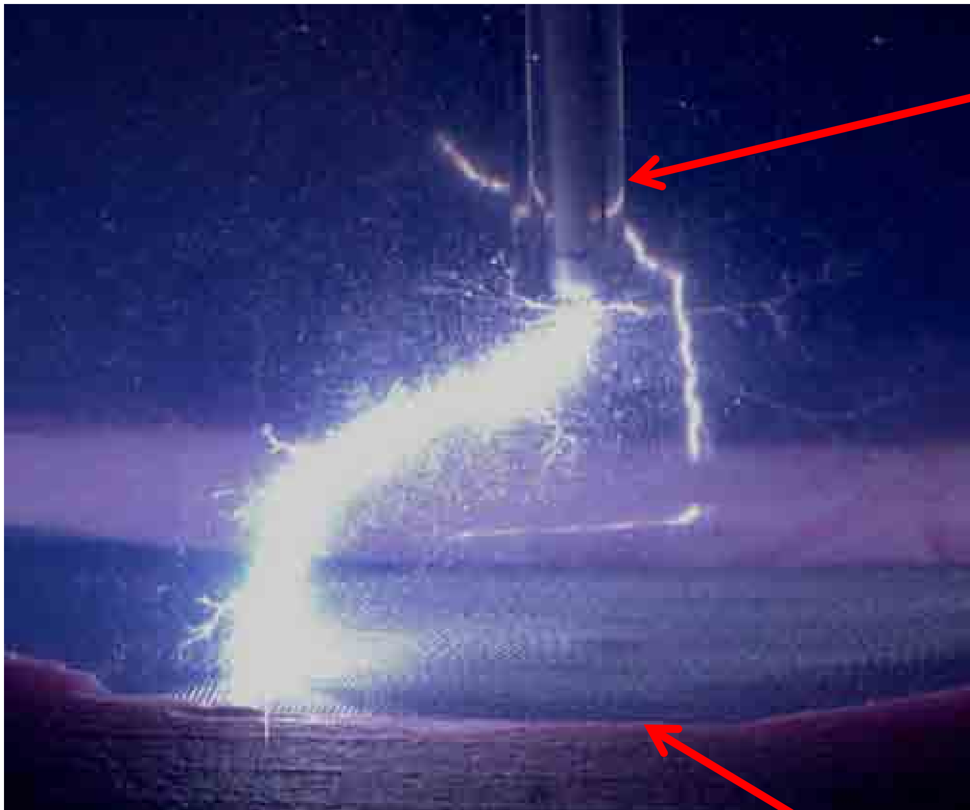
(B) Present technology
(Maintain high COC)

TASKS

Task 1
Development of a self-cleaning filtration system

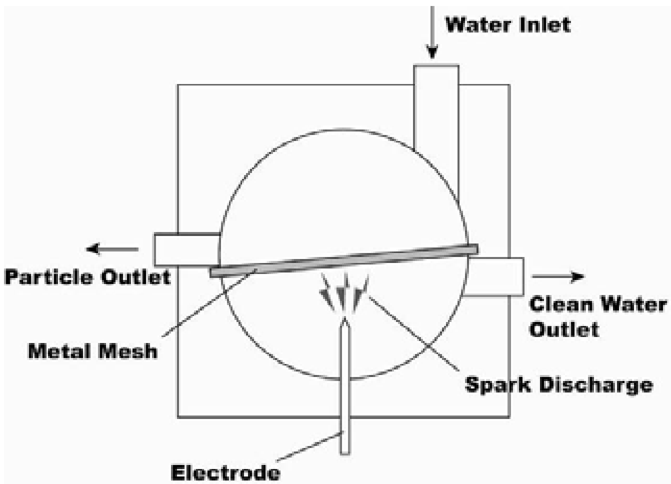
Task 2
Validation test of a self-cleaning filter system to prevent mineral fouling and biofouling

Use of Wire-Plate Electrode Configurations to Produce Plasma Discharge in Water



A Self-Cleaning Filtration System with Spark Discharge in Water

b



a

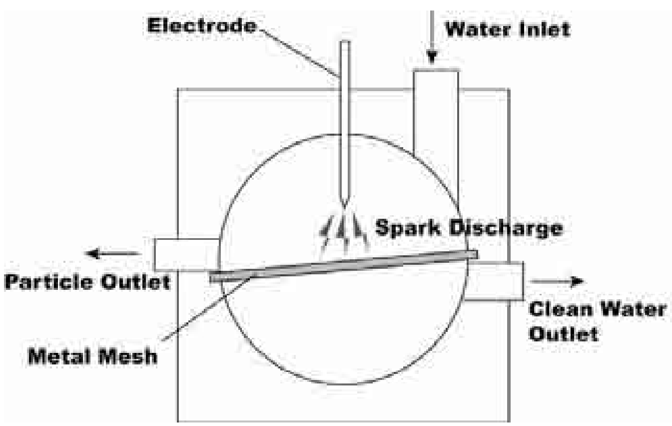
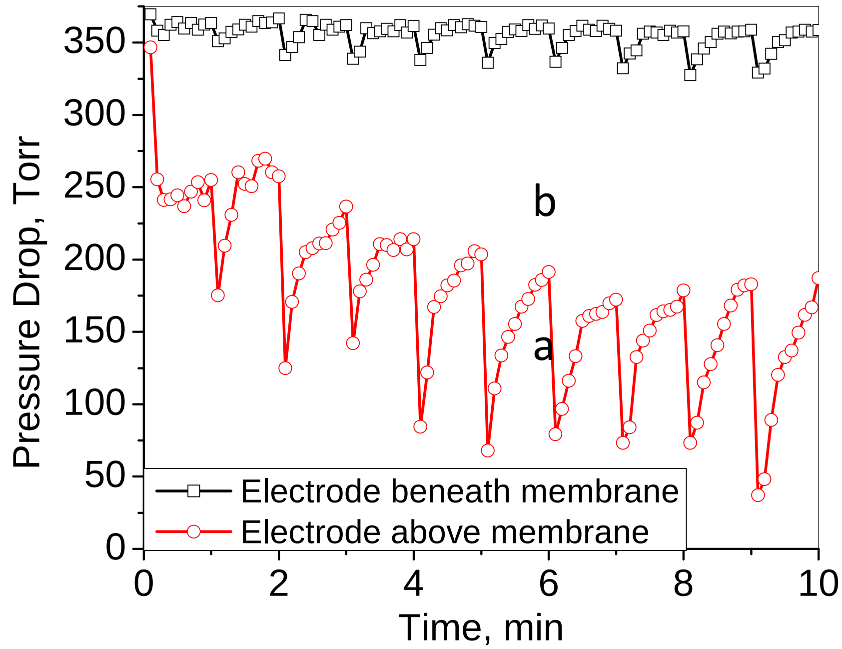
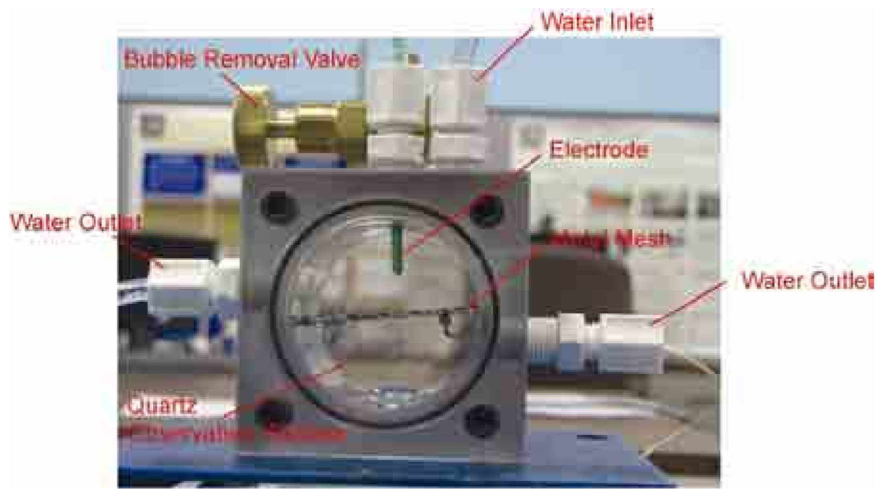


Fig 1. Schematic diagrams of a self-cleaning filter using spark discharges in water: (a) electrode on top; (b) electrode at bottom of the filter surface.





Scanning Electron Microscopy Photographs of Deposited Particles on Filter Membrane

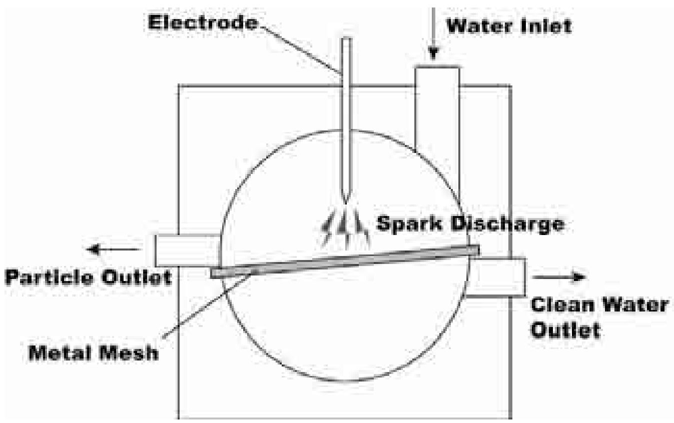
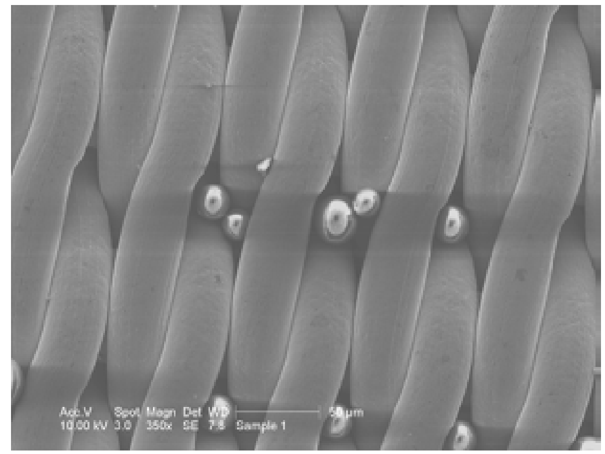
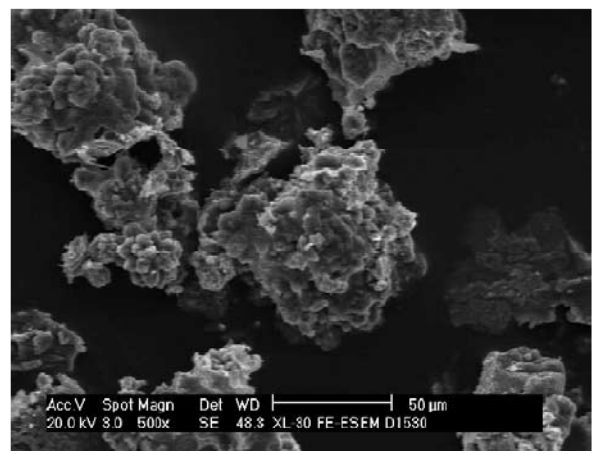


Fig 1. Schematic diagrams of a self-cleaning filter using spark discharges in water:

spark discharge

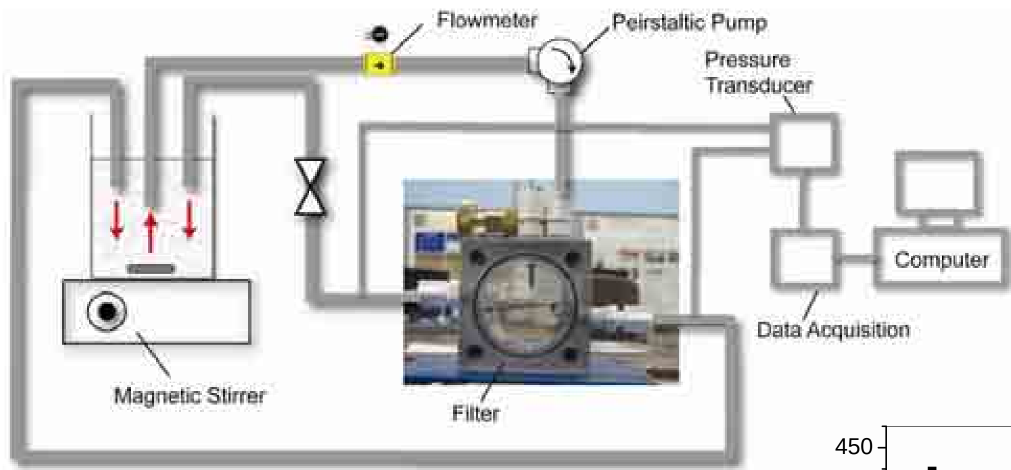


(a) glass spheres



(b) calcium carbonate particles

A Self-Cleaning Filtration System with Spark Discharge (Cooling Tower Water)



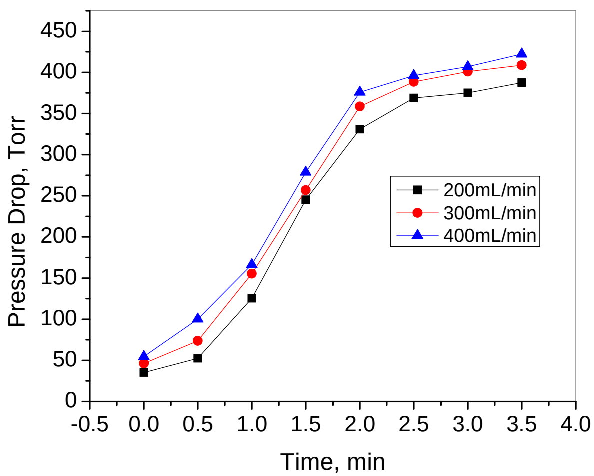


Fig. 4. Change of pressure drop under different flow rates using calcium carbonate particles produced by simulated cooling tower

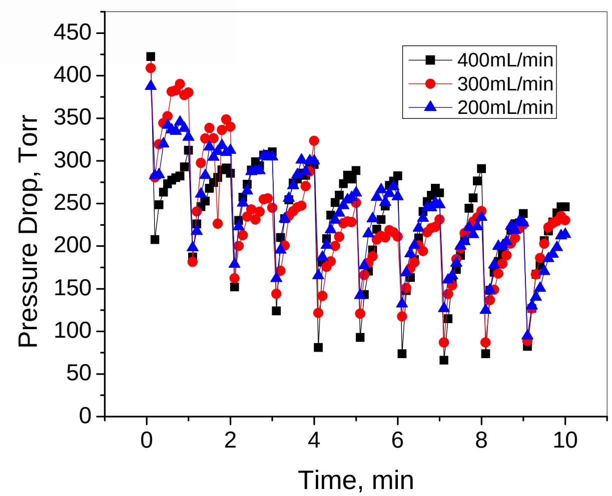
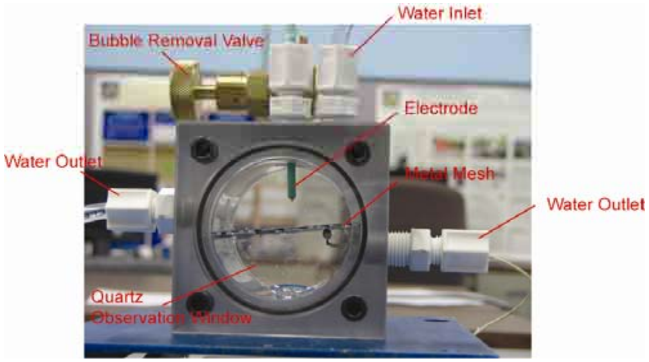
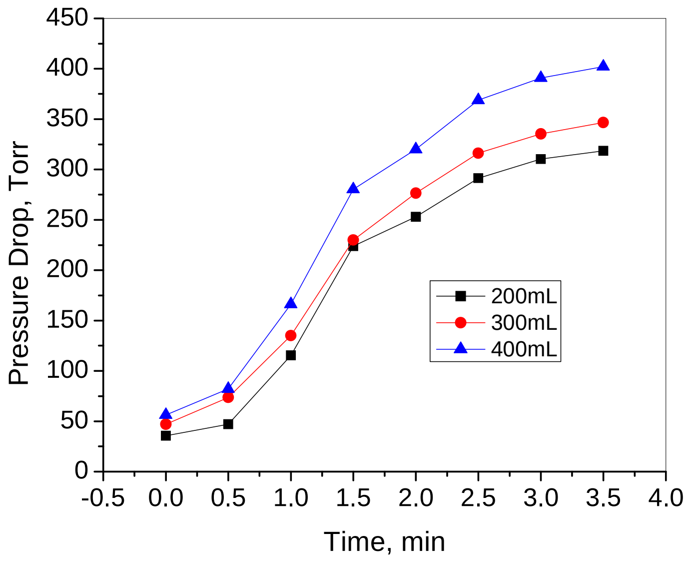


Fig. 5 Change of pressure drop under repeated pulsed spark discharges using $CaCO_3$ produced by simulated cooling tower

A Self-Cleaning Filtration System with Spark Discharge (Artificially Hardened Water)

An artificially hardened water with hardness of 1,000 mg/L of $CaCO_3$ from a mixture of calcium chloride ($CaCl_2$) and sodium carbonate (Na_2CO_3)





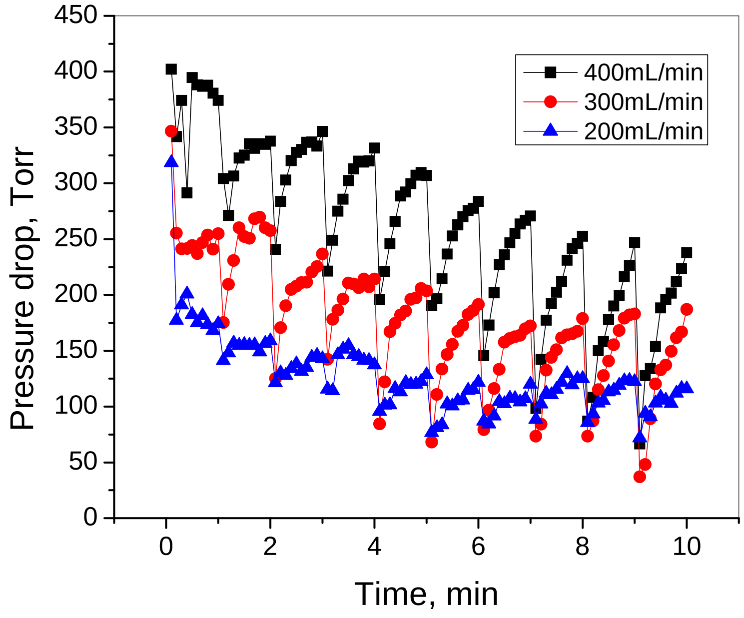
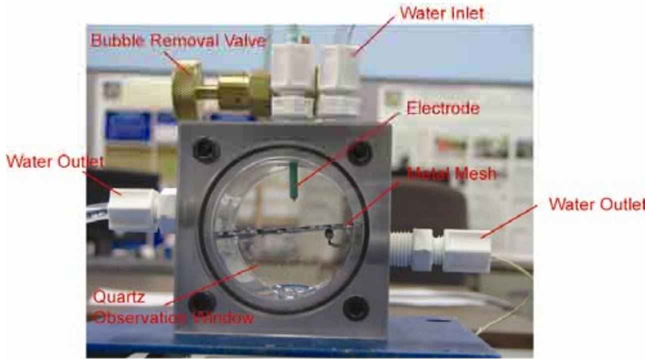
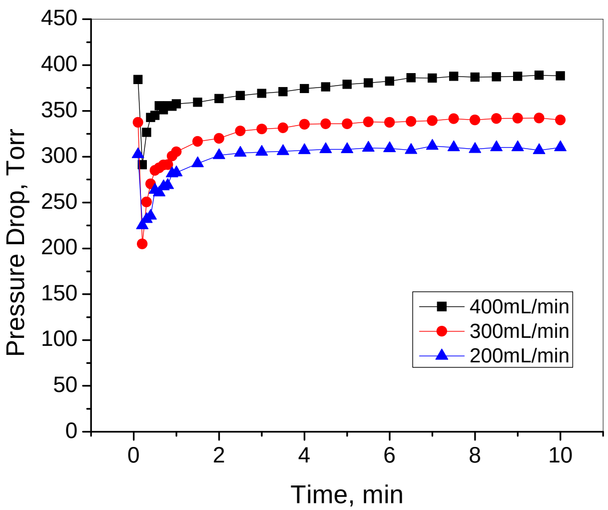


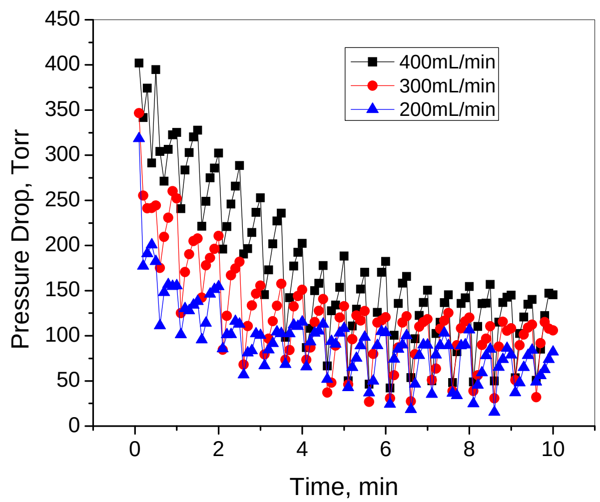
Fig. 7 Changes in pressure drop under repeated pulsed spark discharges with an artificially hardened water.

A Self-Cleaning Filtration System with Spark Discharge (Artificially Hardened Water)

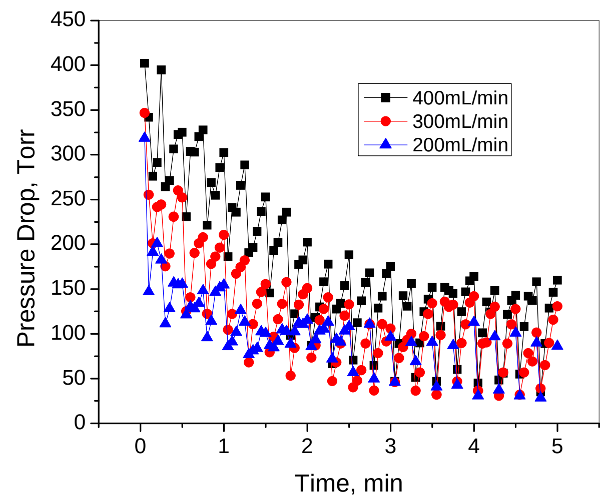




One single pulse only



2 pulses/min



4 pulses/min

Fig. 10 Changes in pressure drop under repeated pulsed spark discharges with different frequencies with an artificially hardened water.

Design Optimization of a Self-Cleaning Filter via CFD Modeling

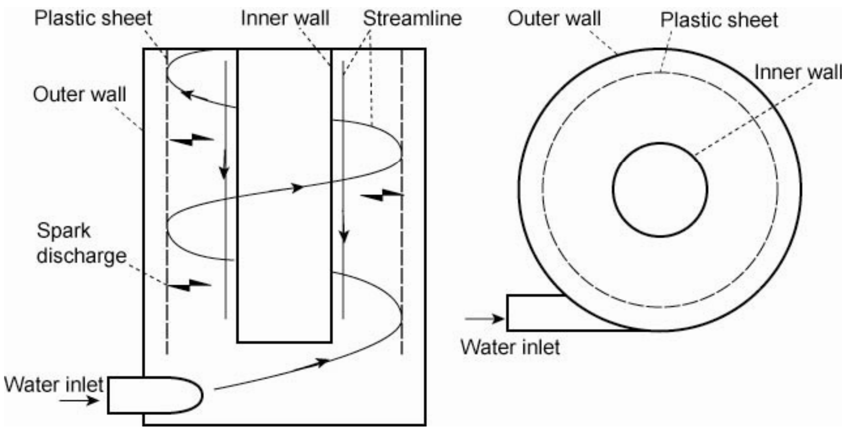
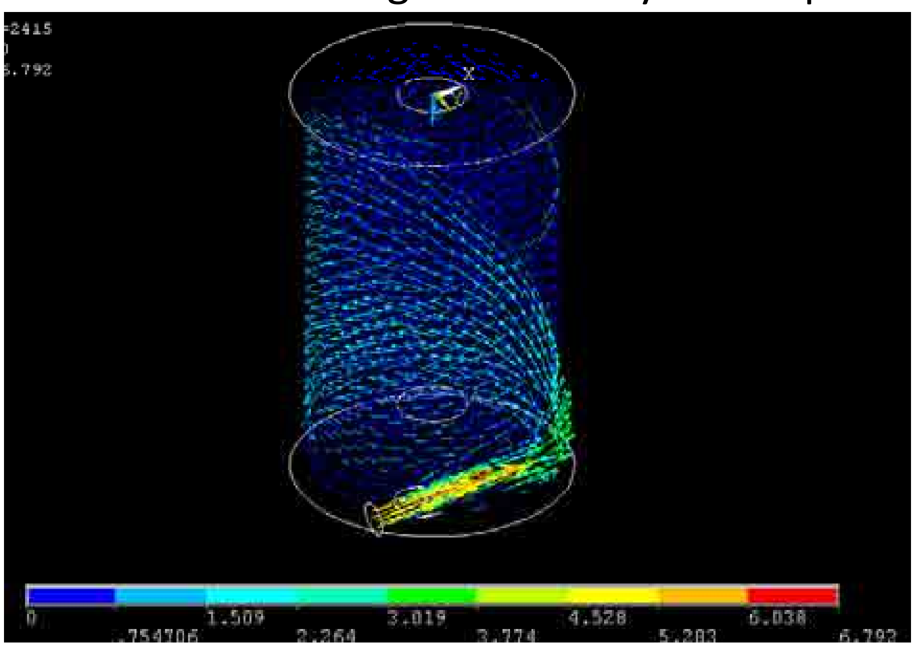
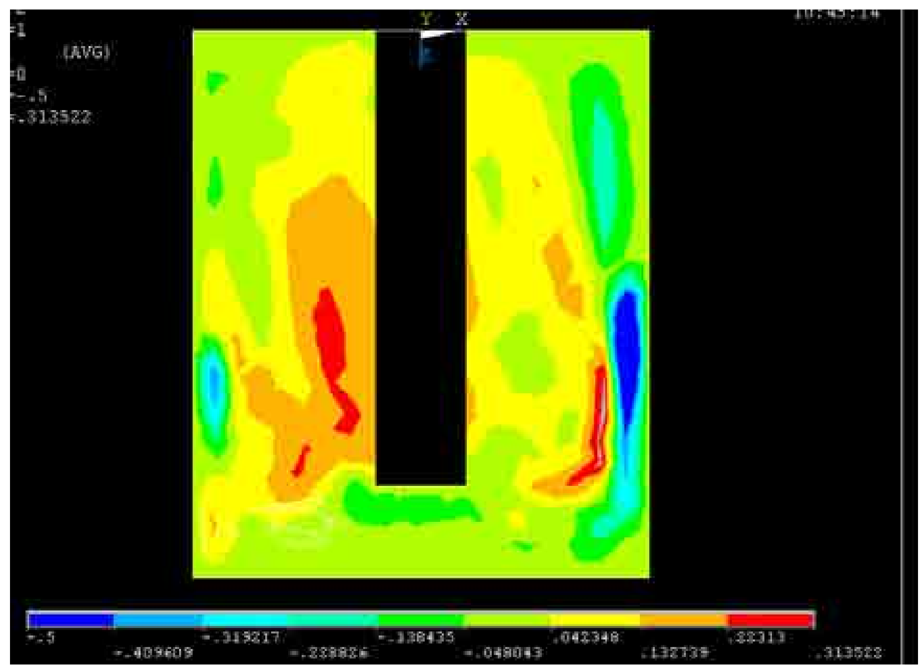


Fig. 7. Schematic diagram of new self-clean filter

Figure 11 Velocity contour plot

Fig. 10. Velocity vector plot





Construction of a Self-Cleaning Filter and a Mini Cooling Tower

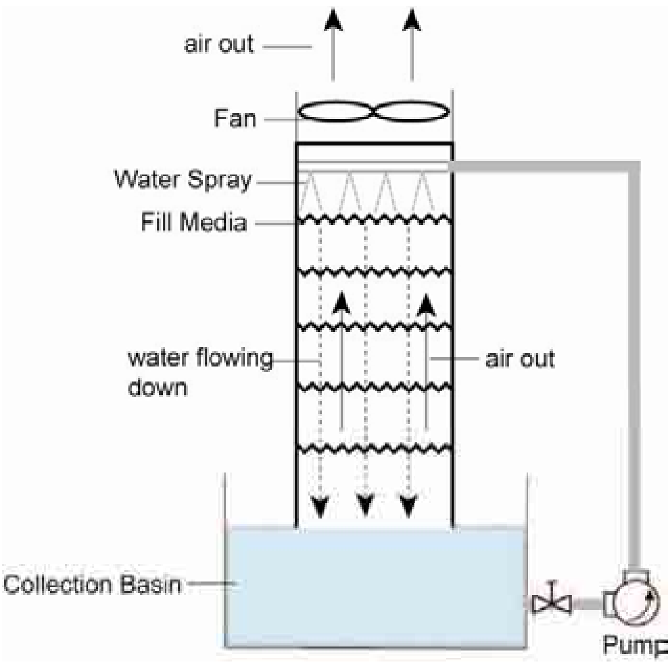


Fig. 4 Schematic diagram of the mini water cooling tower

Fig. 3 Close up picture of the filter and pressure transducer

Construction of a Self-Cleaning Filter using Pulse Spark Discharge in Water

Fig. 5 Picture of a filter system with plasma generator

Fig. 6 Left: cartridge housing (side view). See a drain outlet at the bottom for the removal of debris; Right: cartridge housing and 10"-long cartridge (top view)

Validation Test with a Self-Cleaning Filter

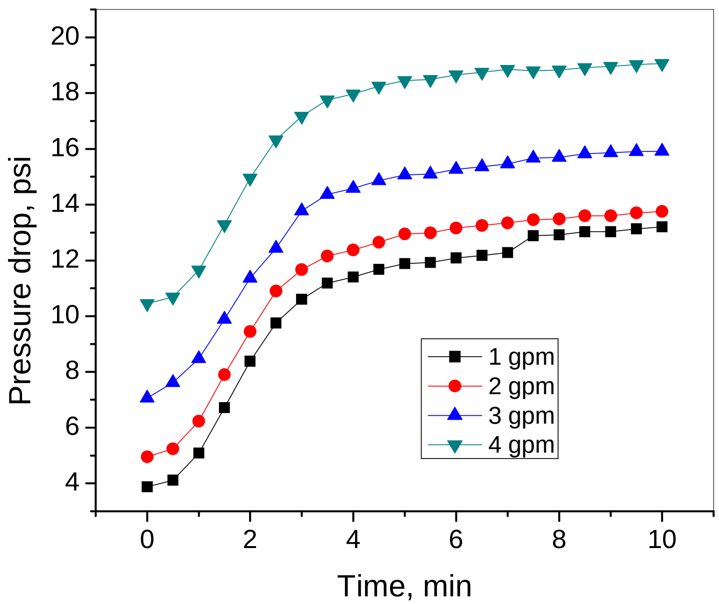


Fig. 3 Changes of pressure drop under various flow rates

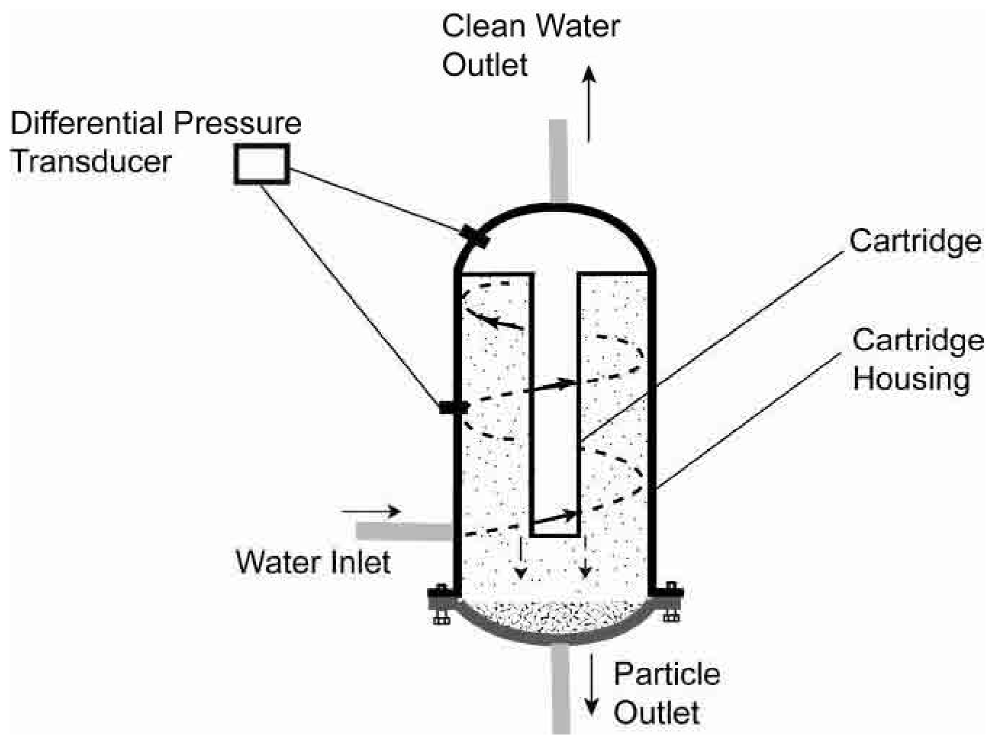


Fig. 7 Schematic diagram of the cartridge housing

Validation Test with a Self-Cleaning Filter with Pulse Spark Discharge in Water

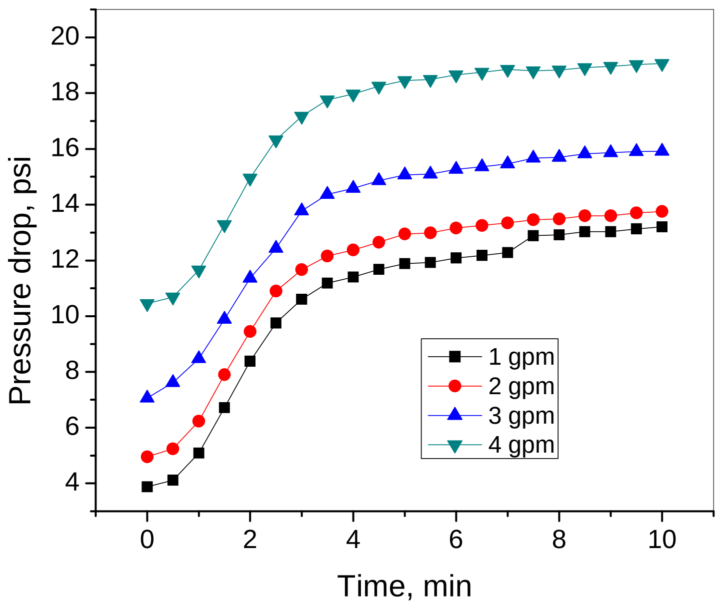
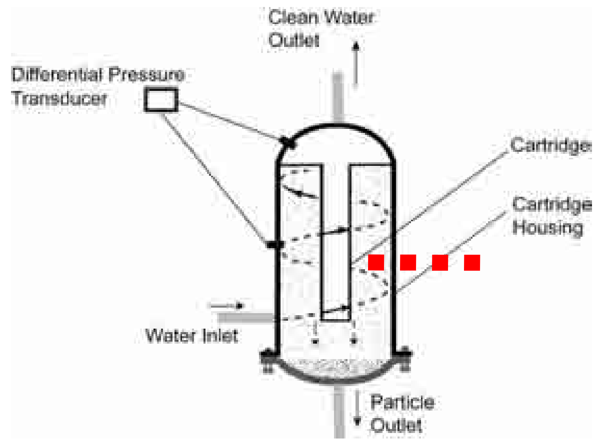


Fig. 3 Changes of pressure drop under various flow rates



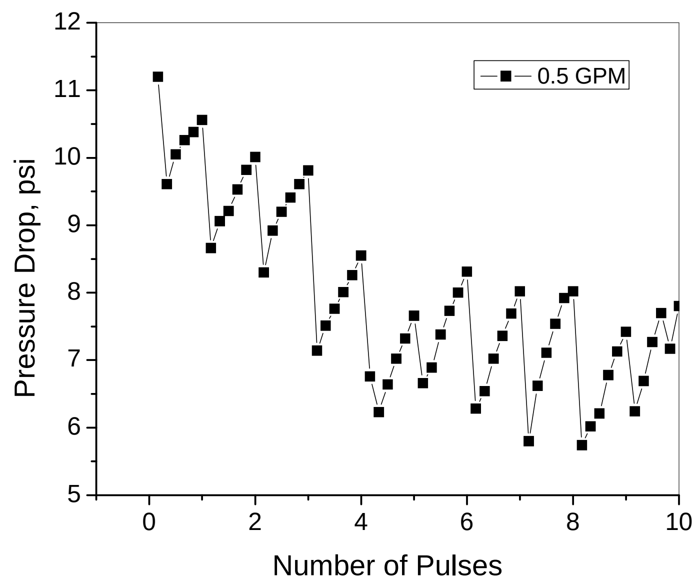
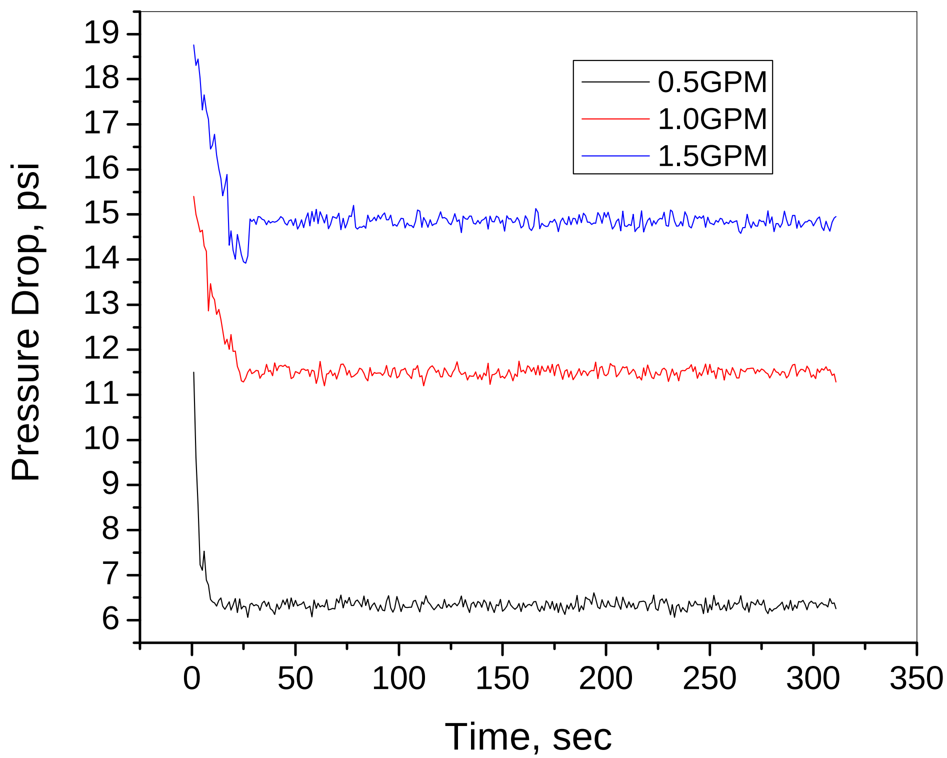


Fig. 7 Changes of pressure drop with spark discharge

Use of Spark Discharges to Maintain Constant Pressure Drop across Filter



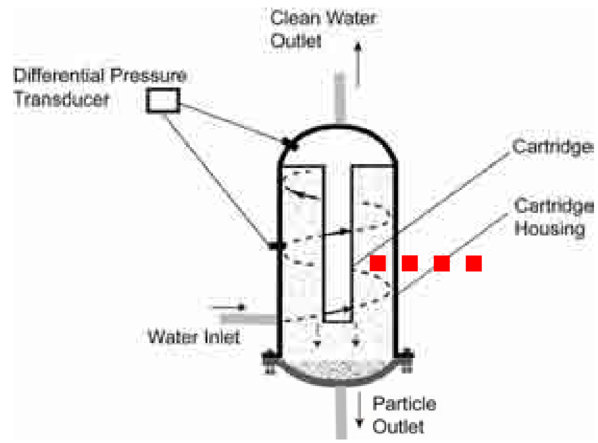


Fig. 9 Changes of pressure drop with spark discharge over an extended time period at different flow rates

Validation Test Using Spark Discharge to Prevent Bio-fouling in Cooling Water

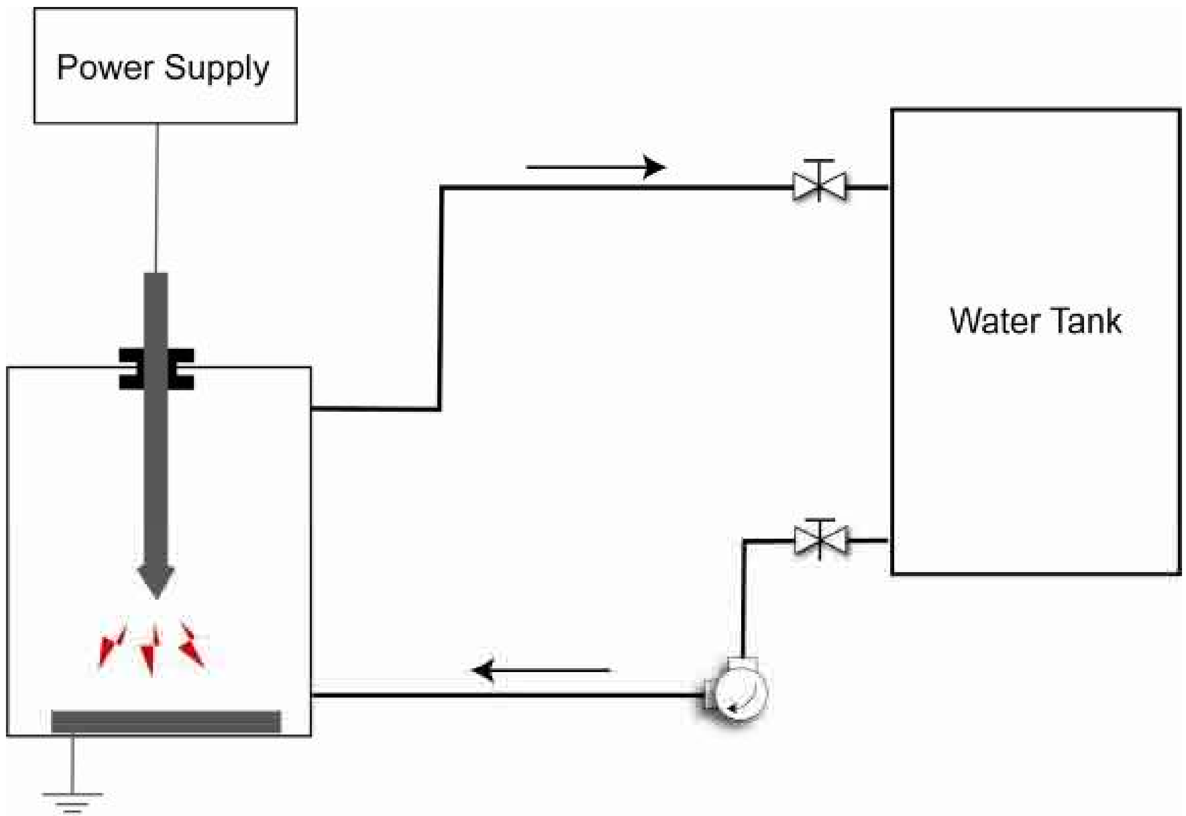


Fig. 10 Schematic diagram of the bio-fouling prevention system by spark discharge

Theoretical Modeling (Breakdown Mechanism)

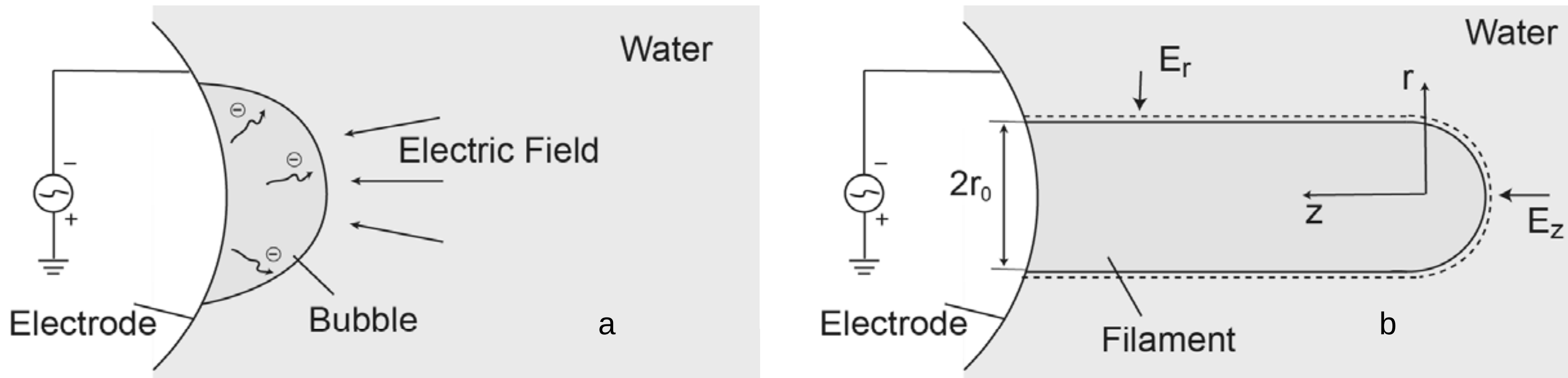


Fig. 1. (a) – initial bubble form at the moment of high voltage application; (b) – bubble elongation and gaseous plasma filament formation due to interaction of electrical forces with surface tension and external pressure forces.

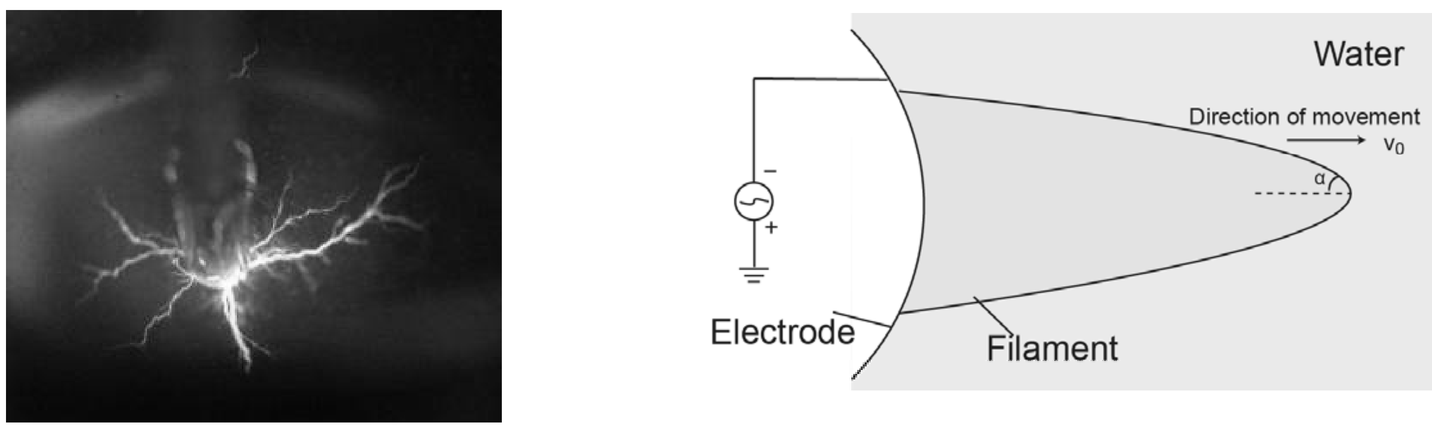
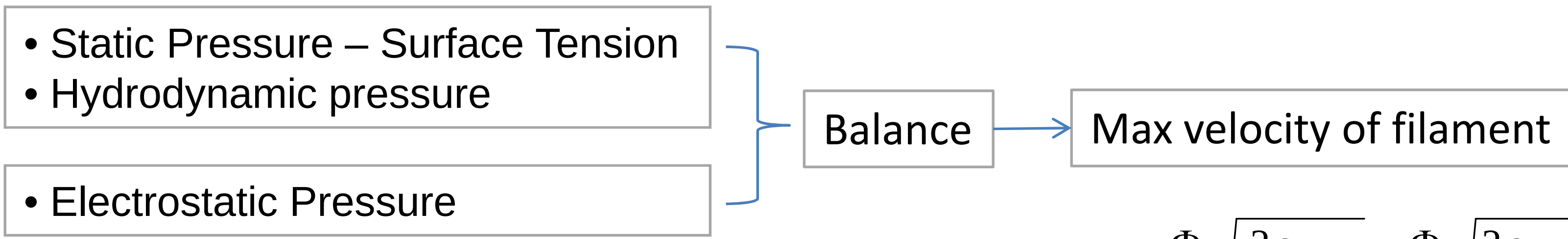
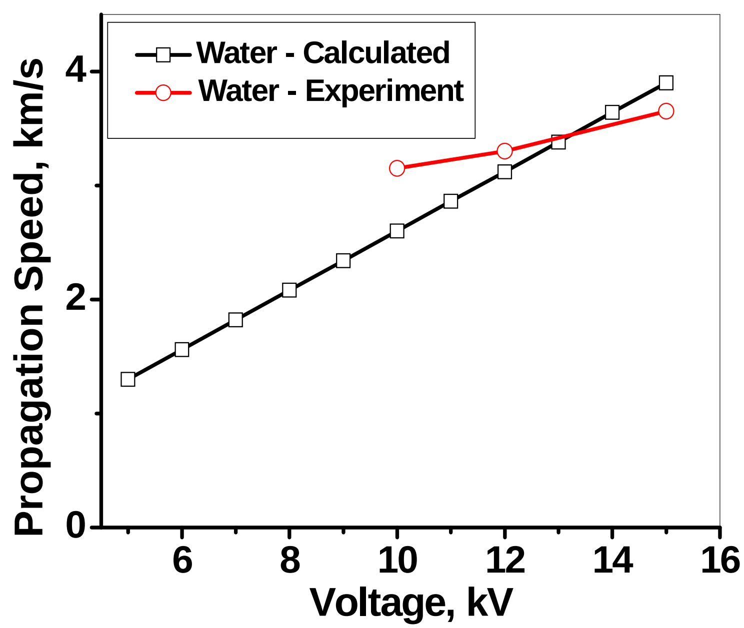


Fig. 2. (a) Photo of corona discharge in water; (b) schematic diagram of needle shape filament

Theoretical Modeling (Breakdown Mechanism)



$$v_0 = \frac{\Phi}{r_0}\sqrt{\frac{2\varepsilon_{water}}{\rho \tan\alpha}} \approx \frac{\Phi}{r_0}\sqrt{\frac{2\varepsilon_{water} L}{\rho r_0}}$$



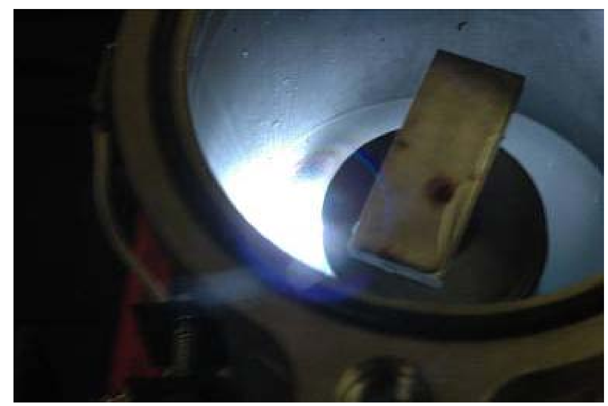


Fig. 3. Comparison of calculated and measured propagation speed of filament during breakdown of water

Theoretical Modeling (Breakdown Mechanism)

Stability Analysis

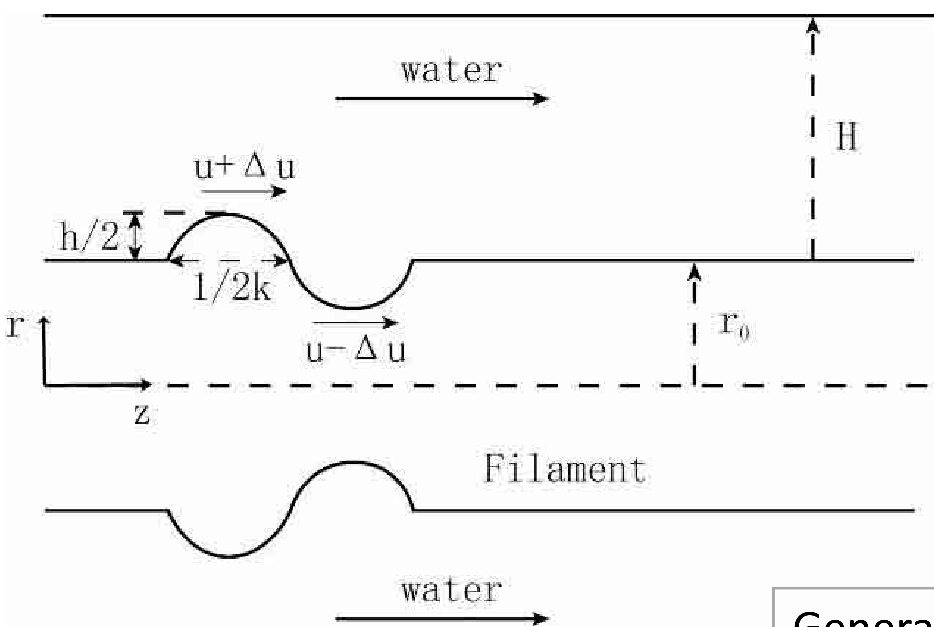


Fig. 4. Schematic diagram of disturbance at the surface of filament

Surface of the perturbation

$$r = r_0 + \frac{h}{2}\exp(ikz + iwt)$$

- Electrostatic Pressure
- Static Pressure – Surface Tension
- Hydrodynamic pressure

Generally, the surface tension tends to minimize the surface area and subsequently stabilize the disturbance, while the electrostatic force tends to push the disturbance to grow.

MILESTONE LOG

	Year 1	93006	31-Dec	3/31/2007	Year 2				Year 3			
Task Development of an integrated PWT and filtration system	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q
Task 1: Development of self-cleaning membrane filter												
Task 1.1: Review on self-cleaning filter technology	******											
Task 1.1a: Prepare a report on self-cleaning filter technology	*											
Kick-off meeting with DOE staffs		*										
Task 1.2: Theoretical modeling of dielectrophoresis		***********										
Task 1.3a: Design of conductive filter (both lab visualization and field uses)			**********									
Task 1.3b: Design of pulse power supply			*****									
Task 1.3: Construction of complete filter system with pulse power system				*******								
Project review - Annual contractor review meeting				*								
Technical report - for the first year effort				*								
Task 1.4: Visualization of particle adhesion on filter medium with microscope					************							
Task 1.5: Visualization of particle dislodge from filter medium with microscope						*******						
Project review - semiannual						*						
Task 1.6: Optimization of filter design based on Tasks 1.4 ad 1.5							***********					
Task 1.7: Construction of self-cleaning filters for fouling tests								**********				
Project review - Annual contractor review meeting								*				
Technical report - for the second year effort								*				
Task 2: Validation test of an integrated PWT and self-cleaning filter system												
Task 2.1: Conduct baseline fouling tests - mineral fouling									***			
Task 2.2: Conduct baseline fouling tests - biofouling fouling										****		
Project review - semiannual										*		
Task 2.3: Conduct baseline test - combined mineral and biofouoling											******	
Task 2.4: Conduct test with integrated PWT - mineral fouling									*****			
Task 2.4: Conduct test with integrated PWT - biofouling										*****		
Task 2.4: Conduct test with integrated PWT - mineral and biofouling											*****	
Preparation of final report - draft												*****
Submission of the final report												*
Project review - Annual contractor review meeting (last)												*

Conclusions

The present project has developed a novel filtration method using pulse spark discharge in cooling water.

$CaCO_3$ particles are continuously produced and removed.

The present technology can significantly reduce water blowdown, which accounts approximately 30% of water loss in a cooling tower.

A2A Water Conservation

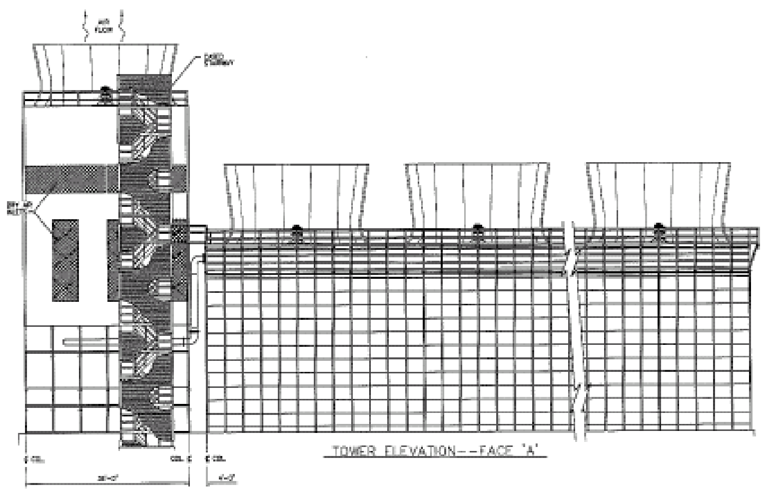
October 27, 2008

Sponsored by
National Energy Technology Laboratory,
Department of Energy

GLOBAL INFRASTRUCTURE X PROCESS EQUIPMENT X DIAGNOSTIC TOOLS

SPX
WHERE IDEAS MEET INDUSTRY

"Use of Air2Air™ *Cooling Tower Technology* to Recover Fresh Water at Thermoelectric Power Plants"



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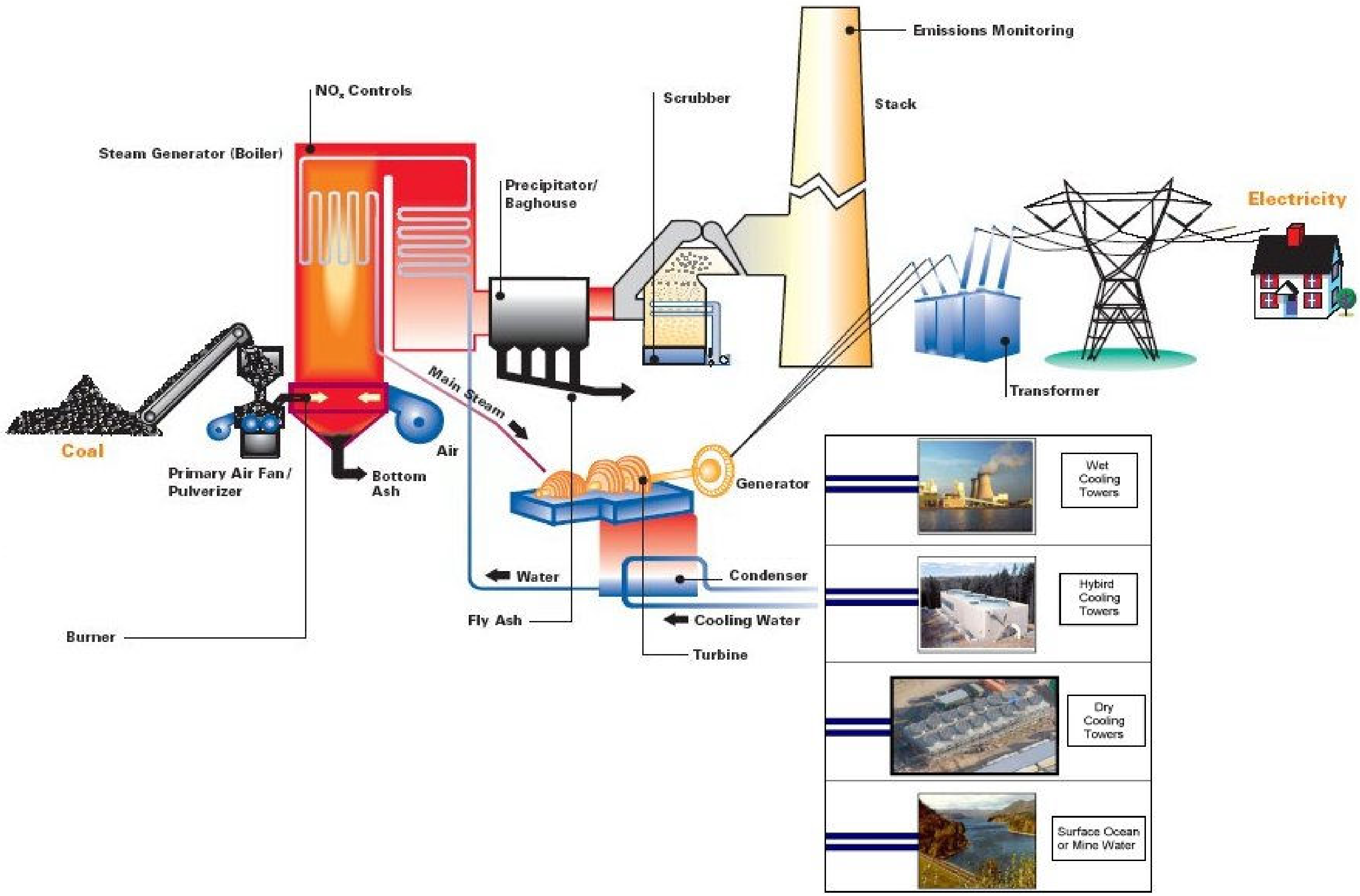
National Energy Technology Laboratory,

Department of Energy

Water at Power Plants

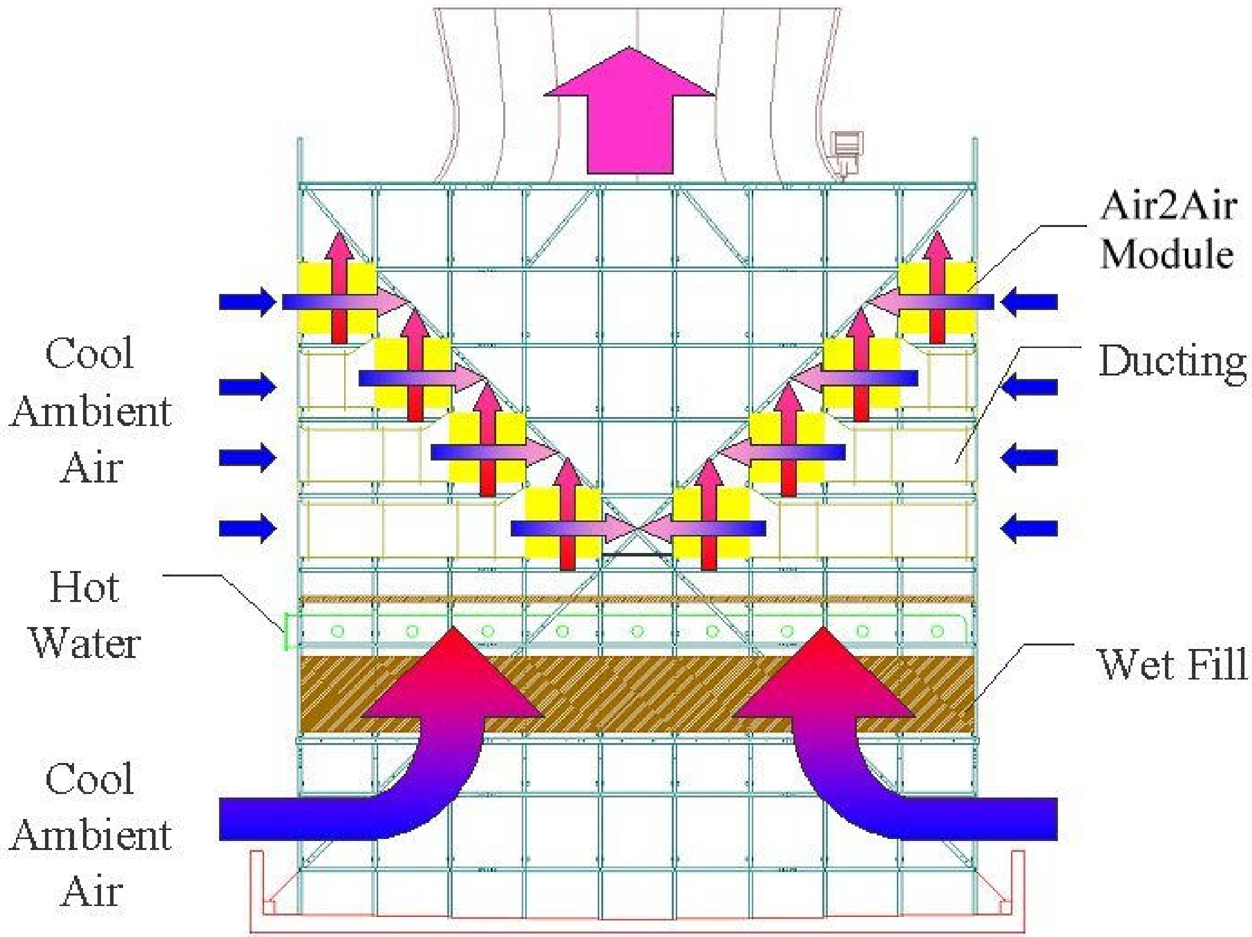


Adapted from http://www.eei.org/industry_issues/environment/air/New_Source_Review/coal1.pdf

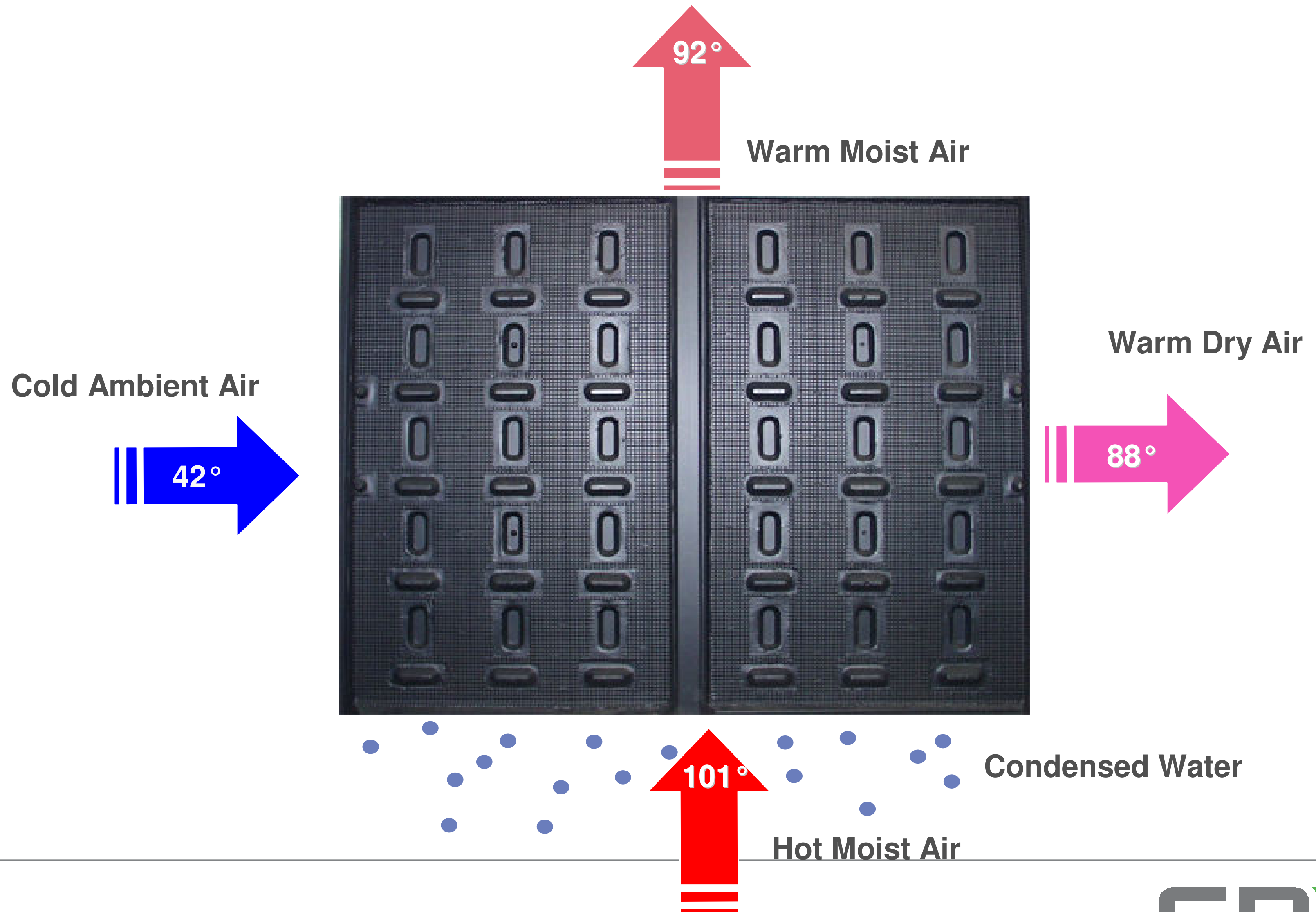
The Air2Air

Water Conservation Cooling Tower

Air2Air Technology



Condensing Module



Water Recovery Potential at Example Site with A2A:

2.82M GPD

3157Acre-Ft./yr.

- 561,000GPM @ 106.6/83.5/66degF
- GPM_{evap} = GPM_{fl} X Range degF X 0.0008
- GPM_{ws}= 20% X GPM_{evap}

SPX

1. ***Coal-fired power generation station in New Mexico***
2. ***Complete rebuild of single counter-flow cell***
3. ***Milestones, as follows:***

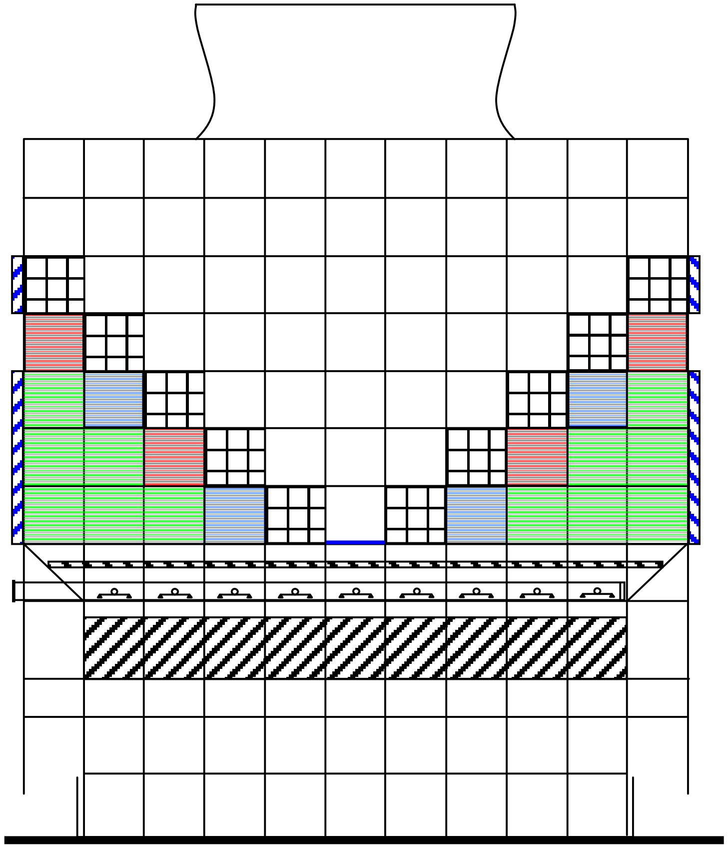
Milestone Description	Year	Dates
1. Finalize Host Site Agreement with Power Company 2. Design & Procure Materials of Construction for the Air2Air Test Cell	1	6/30/06 COMPLETE 12/31/06 COMPLETE
1. Construction of the Air2Air Test Cell	2	8/31/07 COMPLETE
1. Testing of Winter, Spring, Summer Operation 2. Final Report drafted	3	3/31/09 IN PROCESS 6/30/09

Construction

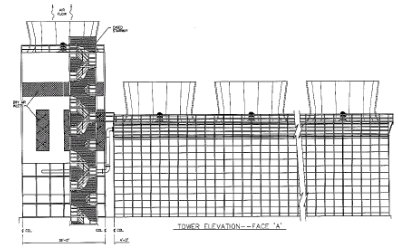
Full Scale Validation - Operation

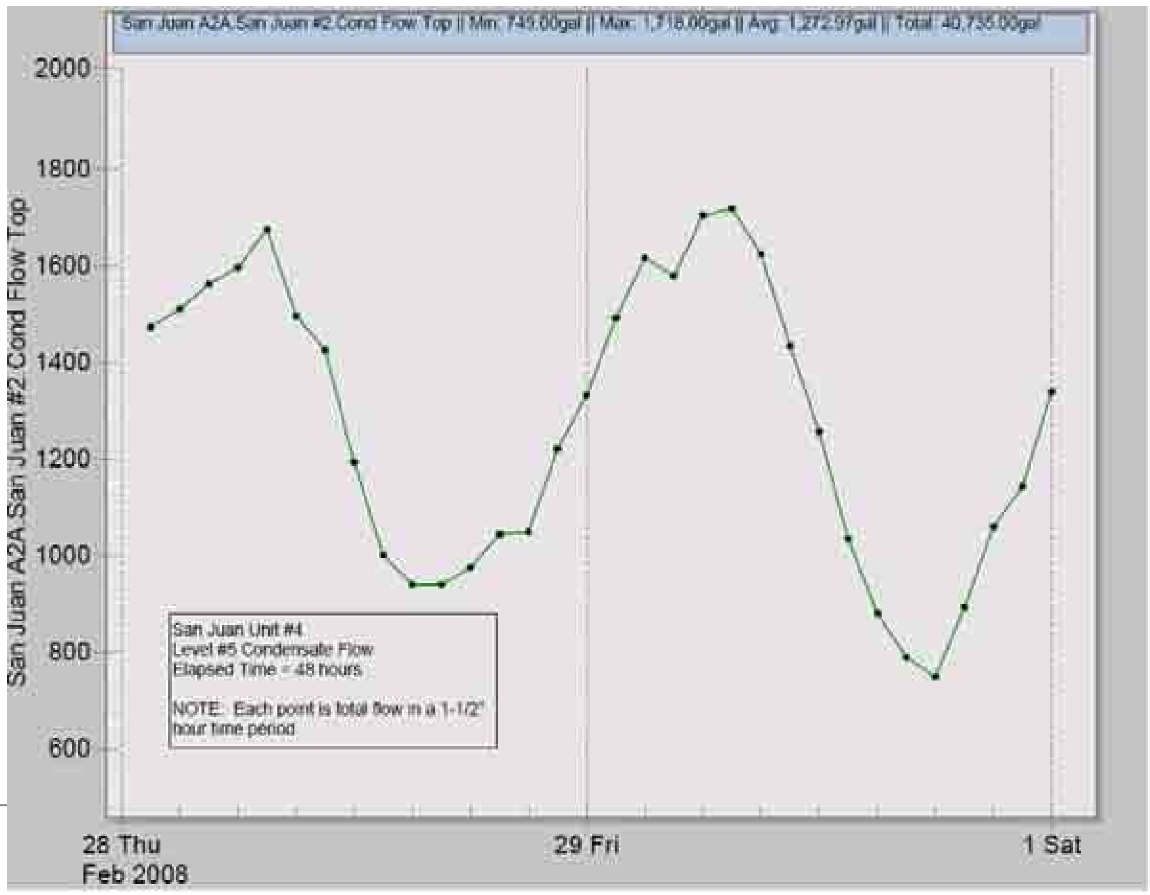
Full Scale Validation - Operation

Air2Air Technology

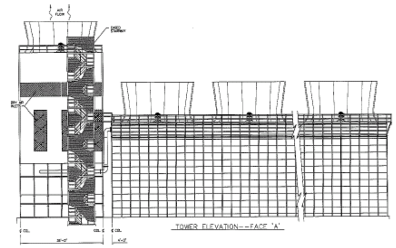


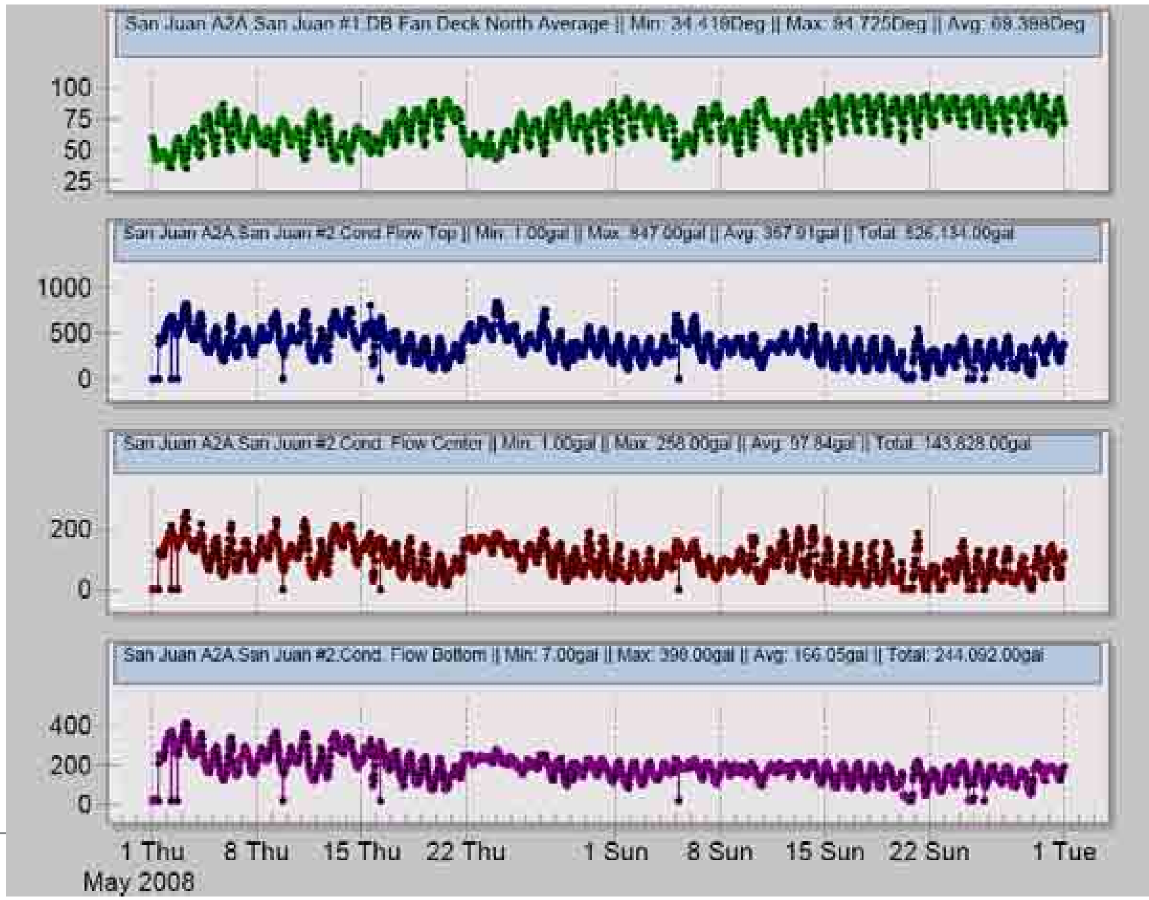
> Results – 48 Hours, Feb. 28 - March 1, 40,735 Gallons collected and averaging 14.1 GPM for that period, Level 5 only

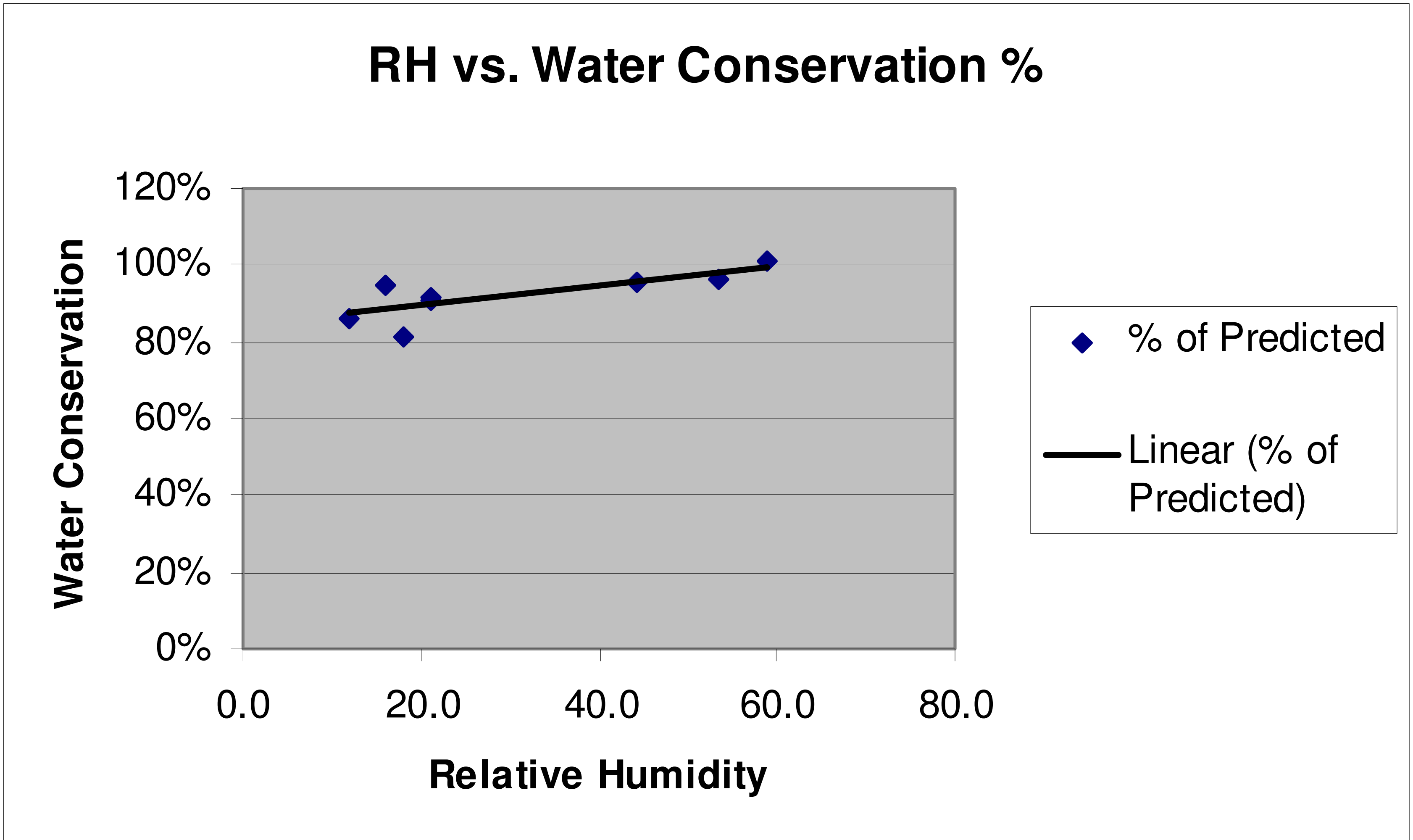


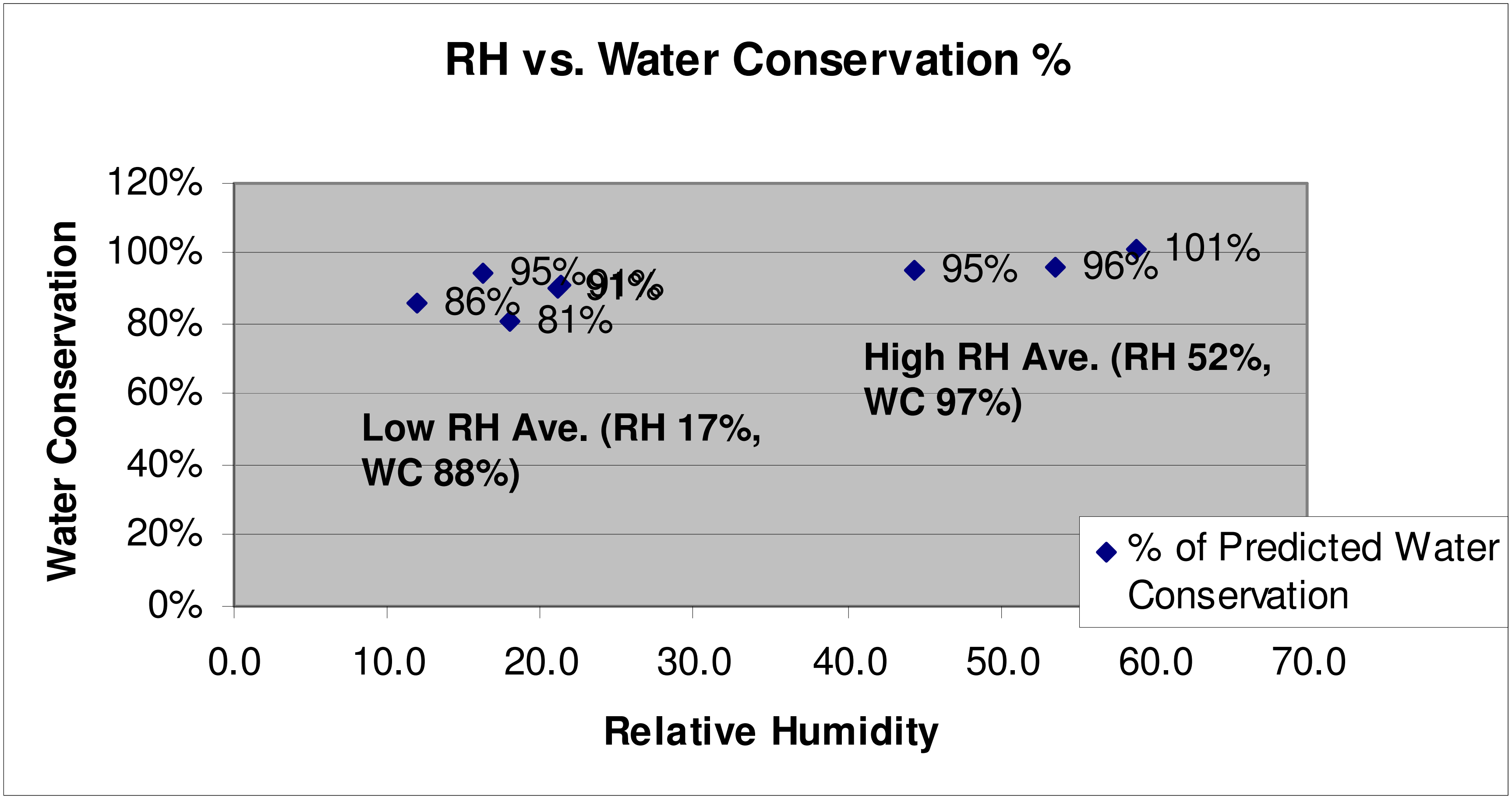


- Results – Total for May = 914,054 Gallons collected, averaging 20.47 GPM for the period

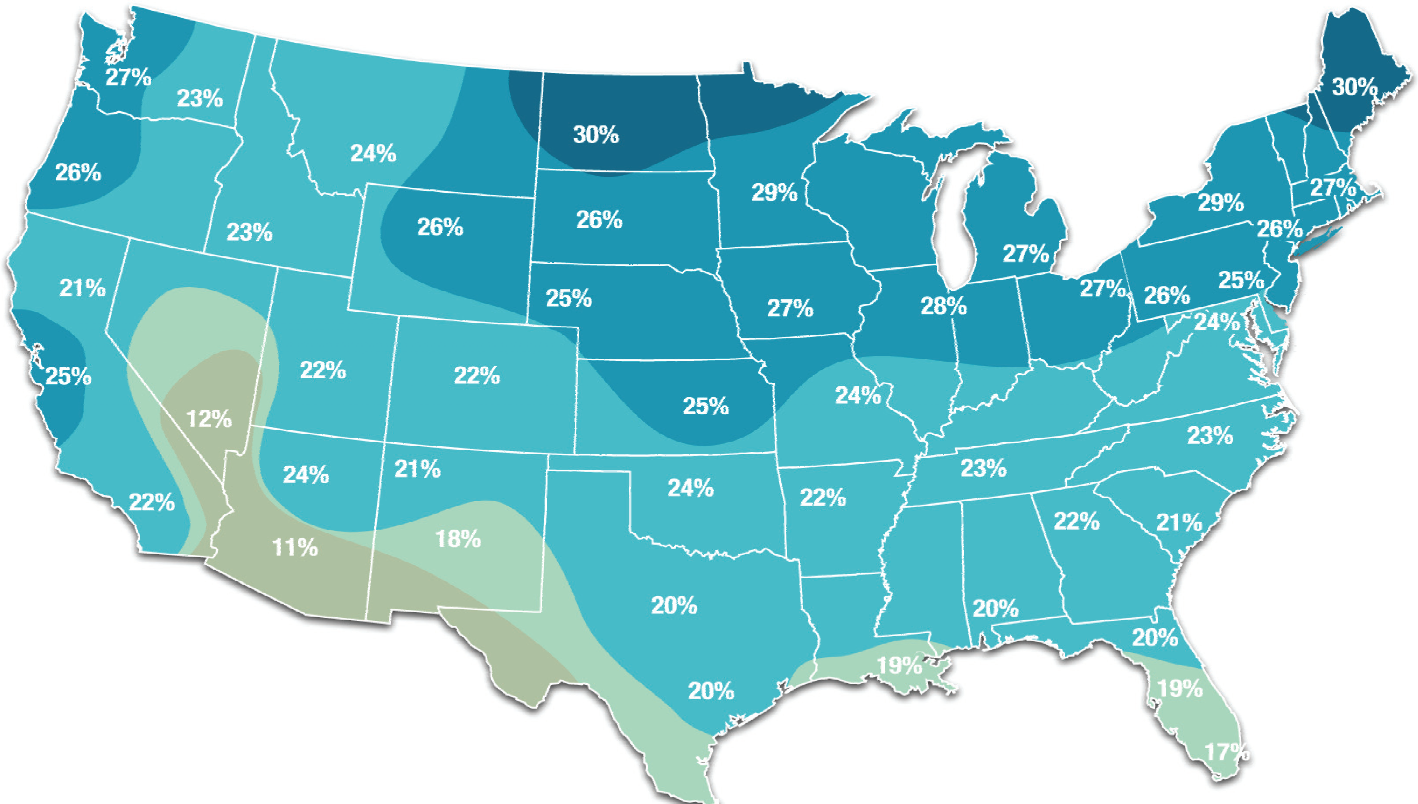





RH vs. Water Conservation %
Water Conservation
120%
100%
80%
60%
40%
20%
0%
0.0
20.0
40.0
60.0
80.0
Relative Humidity
% of Predicted
Linear (% of Predicted)

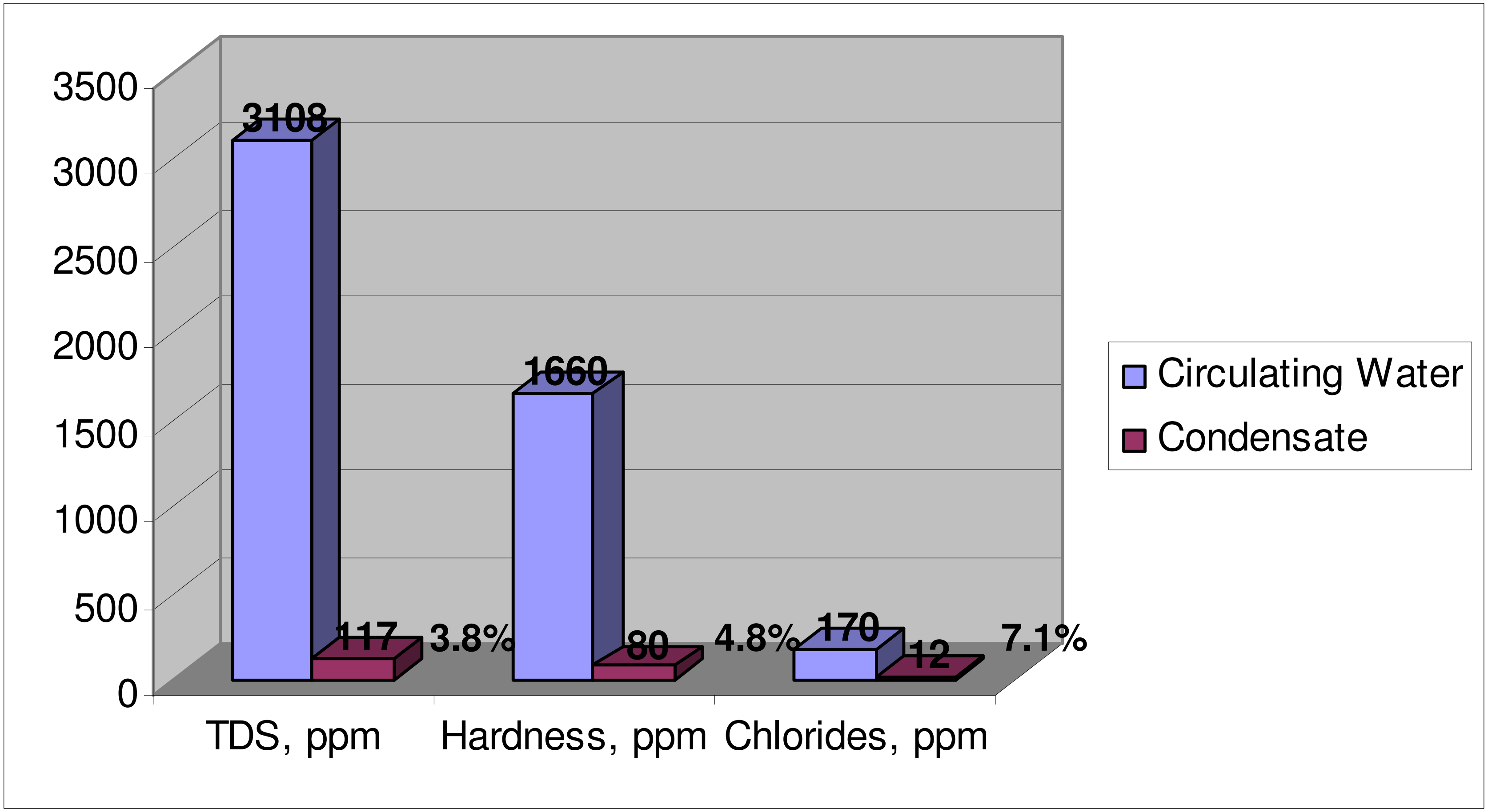

RH vs. Water Conservation %
Water Conservation
120%
100%
80%
60%
40%
20%
0%
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
Relative Humidity
86%
95%
81%
91%
95%
96%
101%
Low RH Ave. (RH 17%, WC 88%)
High RH Ave. (RH 52%, WC 97%)
% of Predicted Water Conservation

Water Savings/Generation–Gallons/Day



A typical 500 MW combined cycle power plant			
	12%	18%	21%
	345,000	515,000	600,000
	24%	27%	30%
	685,000	770,000	865,000

High Quality Condensed Water



Water Conservation

- Less make-up
- Less blow-down
- Less chemical treatment

Compared to ACC

- Colder Water
- Less Parasitic Power
- Lower Capital Cost

Reduced Plume -

- Lowers the Actual Grains of Moisture Exiting the Tower
- No Change Pump-Head
- No Water to A2A Heat-Exchanger [***No Icing, No Fouling***]

Possible Collection/Use - High Quality Condensate

Many Thanks to the NETL/Department of Energy for this Opportunity…

Water Conserving Steam-Ammonia Power Cycle

Donald C. Erickson

Energy Concepts Co.

DOE SBIR Phase II Project

DE-FG02-05ER84201

NETL Existing Plants Water Projects Meeting

October 27, 2008

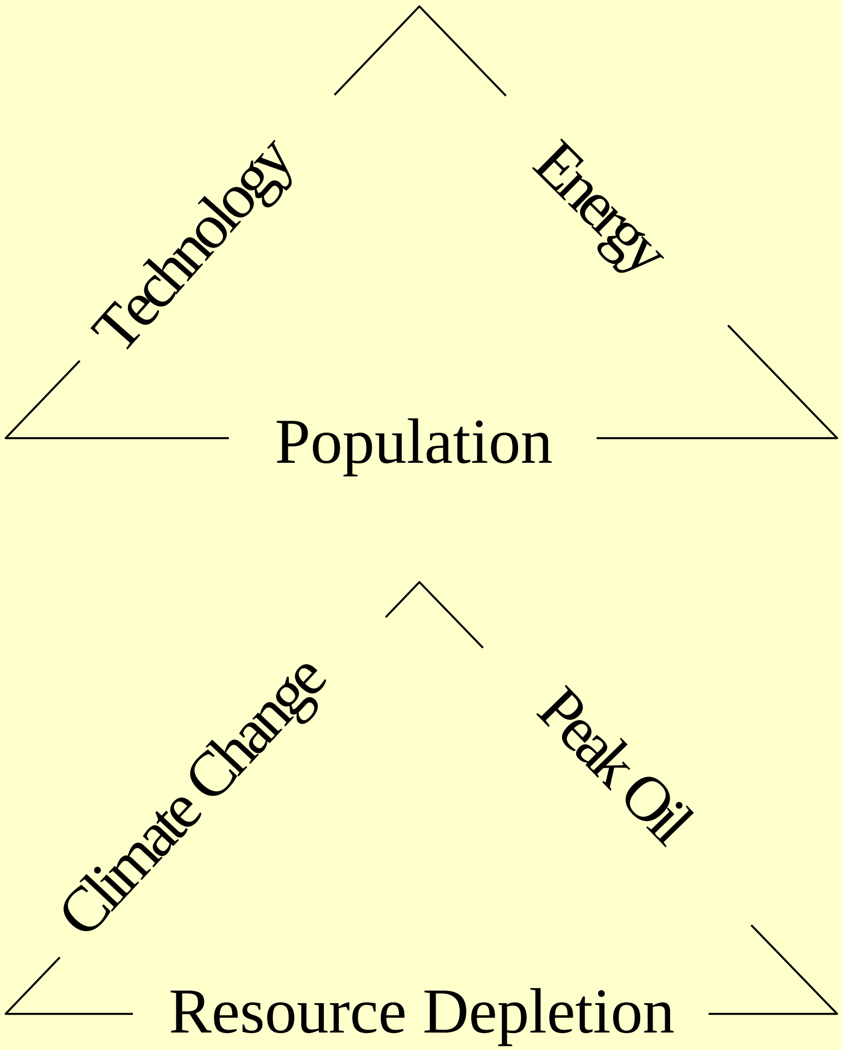
OUTLINE

- Nexus of Water, Energy, and Climate
- Higher Efficiency, Lower Temperature Cycles Conserve Water <u>and</u> Energy
- Steam-Ammonia Absorption Power Cycle
- Demonstration Project in Kotzebue, Alaska
- Water Conserving Aspects

The Triple Alliance

Encounters

The Triple Crisis



CONTEXT

- Ultimate question - carrying capacity
- Current ecological footprint - 1.5 planets
- Two/thirds of global population have unacceptably low living standard
- “Economic growth” paradigm exacerbates the crisis
- Sustainable paradigm - economic stability plus rapidly shrinking ecological/carbon footprint

Objectives

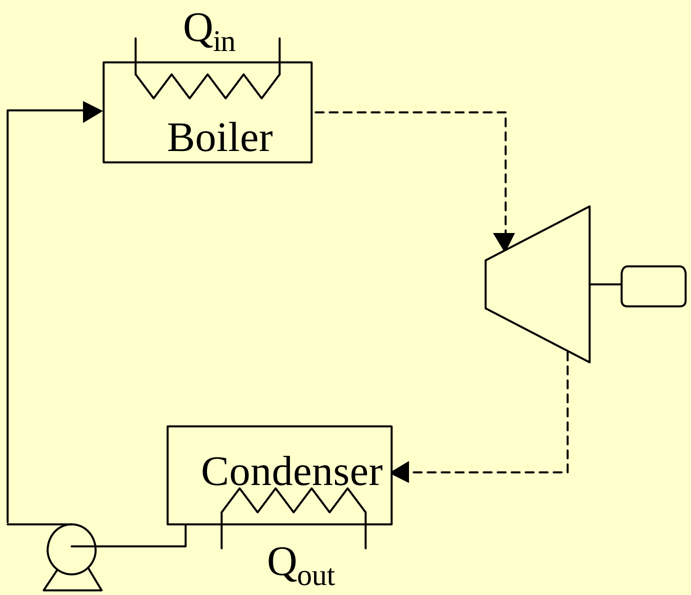
- Conserve Water and Energy
  - Higher efficiency saves energy
  - Reduced heat rejection saves water
  - Higher efficiency reduces CO_2
  - Saved energy can be used to reclaim waste water
- Concentrate on low temperature waste heat
  - Between 160°F and 300°F (>90°F above ambient)
  - Exceedingly large and under-utilized resource

APPROACH
Steam Ammonia Absorption Power Cycle

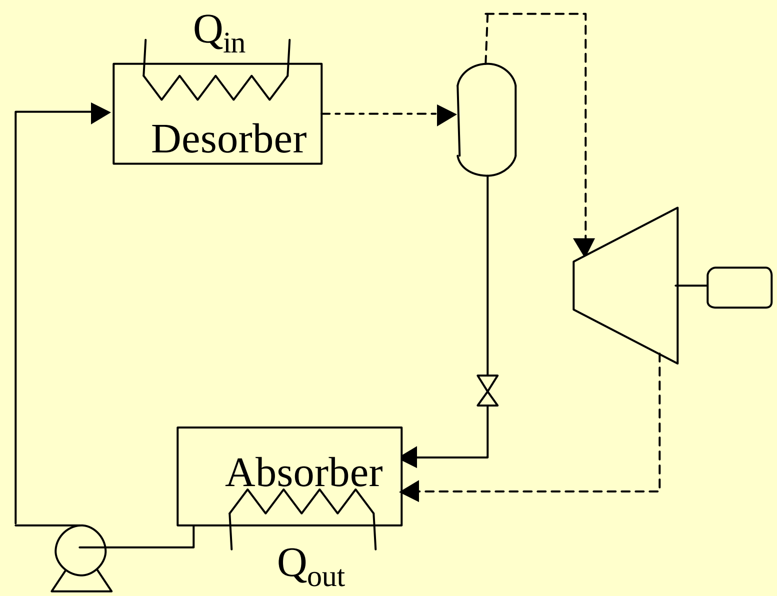
- Why the Absorption Power Cycle is Preferred
  - vs Organic Rankine Cycle
    - glide match for higher efficiency
    - smaller, lower cost turbine
    - smaller, lower cost heat exchangers
  - vs the Kalina Cycle
    - avoids total condensation (corrosion problem)
    - higher performing components
    - no need for "DCSS"

Power Cycle Comparison

Rankine



Absorption



APPROACH

Steam-Ammonia Absorption Power Cycle

- Why aqueous ammonia is the preferred working fluid
  - superior transport properties
  - optimal pressures
  - non-corrosive to low cost materials
  - high latent heat
  - less than half the heat transfer surface

Working Fluid Properties
Condensing at 35°C (95°F)

		H_2O	NH_3	Propylene	R134a
Pressure	[bar]	0.06	13.5	14.7	8.9
	[psia]	0.82	196	214	129
Latent Heat	[J/g]	2418	1122	314	168
	[Btu/lb]	1039	483	135	72
Density [kg/m^3]	Liquid	994	588	486	1168
	Vapor	0.04	10.5	31.5	43.4
Liquid Thermal Conductivity [W/m-K]		0.611	0.457	0.107	0.078
Liquid Heat Capacity [J/g-K]		4.183	4.873	2.775	1.466
Liquid Viscosity [10^{-6}, kg/m-s]		720	120	83	172
Condensation-side Coefficient [W/m^2-K]		3021	2417	587	517
Water-side Coefficient [W/m^2-K]		5000	5000	5000	5000
Overall Coefficient [W/m^2-K]		1883	1629	526	468

$$h_{condensation} = 0.729\left[\frac{g\rho_l(\rho_l-\rho_v)k_l^3\left(h_{fg}+0.68c_{p,l}\left(T_{sat}-T_{surface}\right)\right)}{N\mu_l\left(T_{sat}-T_{surface}\right)D}\right]^{1/4}$$

where, $T_{sat}-T_{surface}$ = 10 K

N = 100

D = 1 [inch]

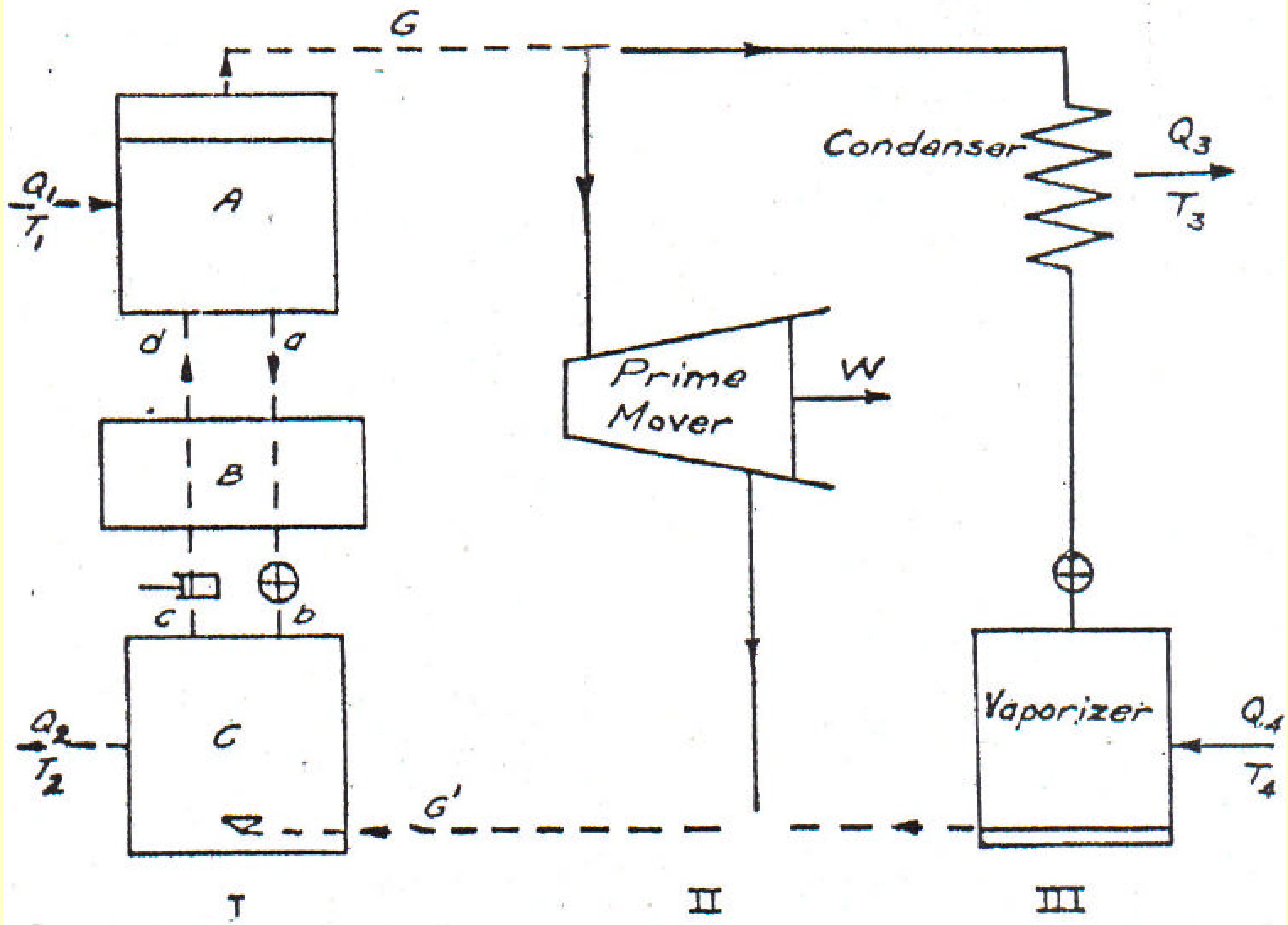


Fig. 2. Elementary Solution Cycle.
I.—Basic Solution Thermo-Compression Process; II.—Power Process; III.—Refrigeration Process.

THE HONIGMANN FIRELESS LOCOMOTIVE ENGINE.

see U 340

Fig. 6.

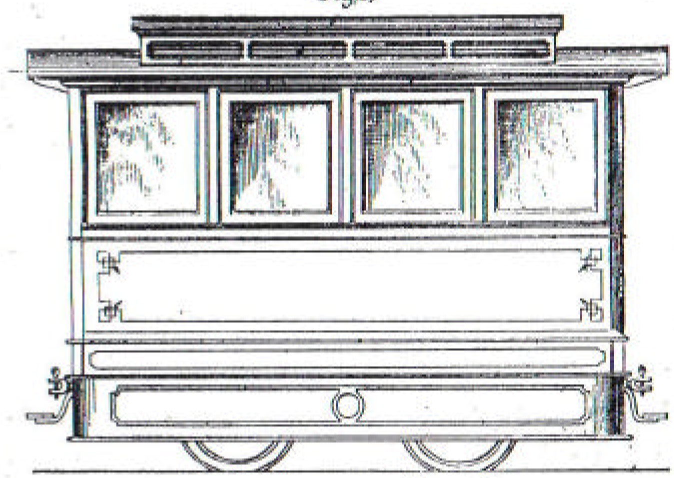


Fig. 5.

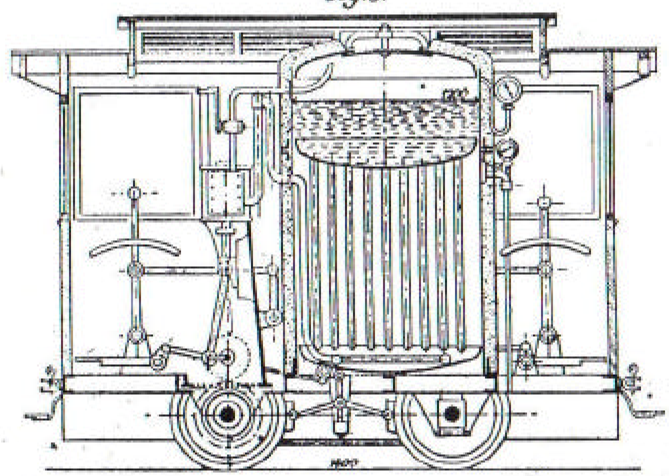


Fig. 1

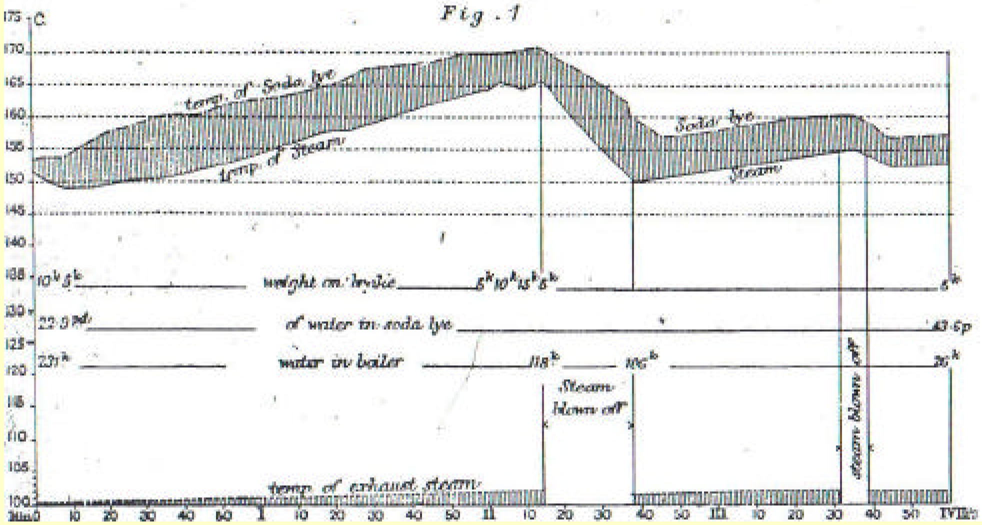
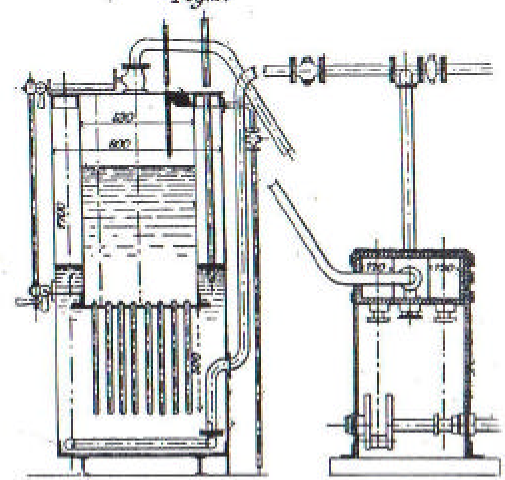


Fig. 2.



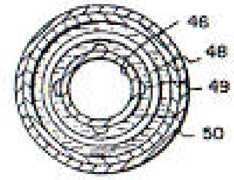


Fig. 2

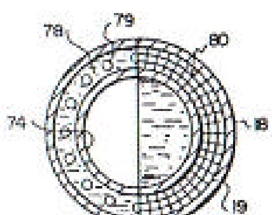


Fig. 3

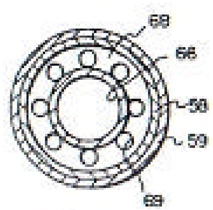


Fig. 4

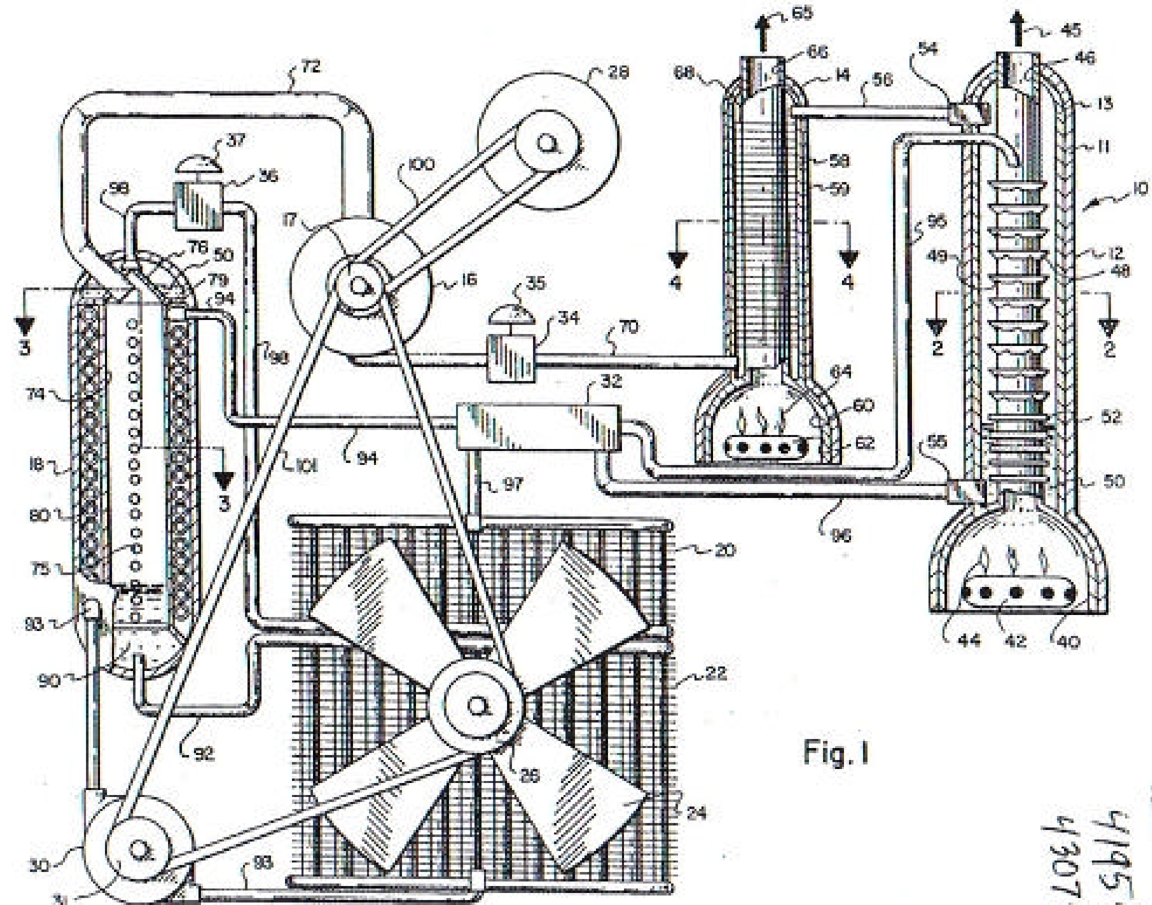


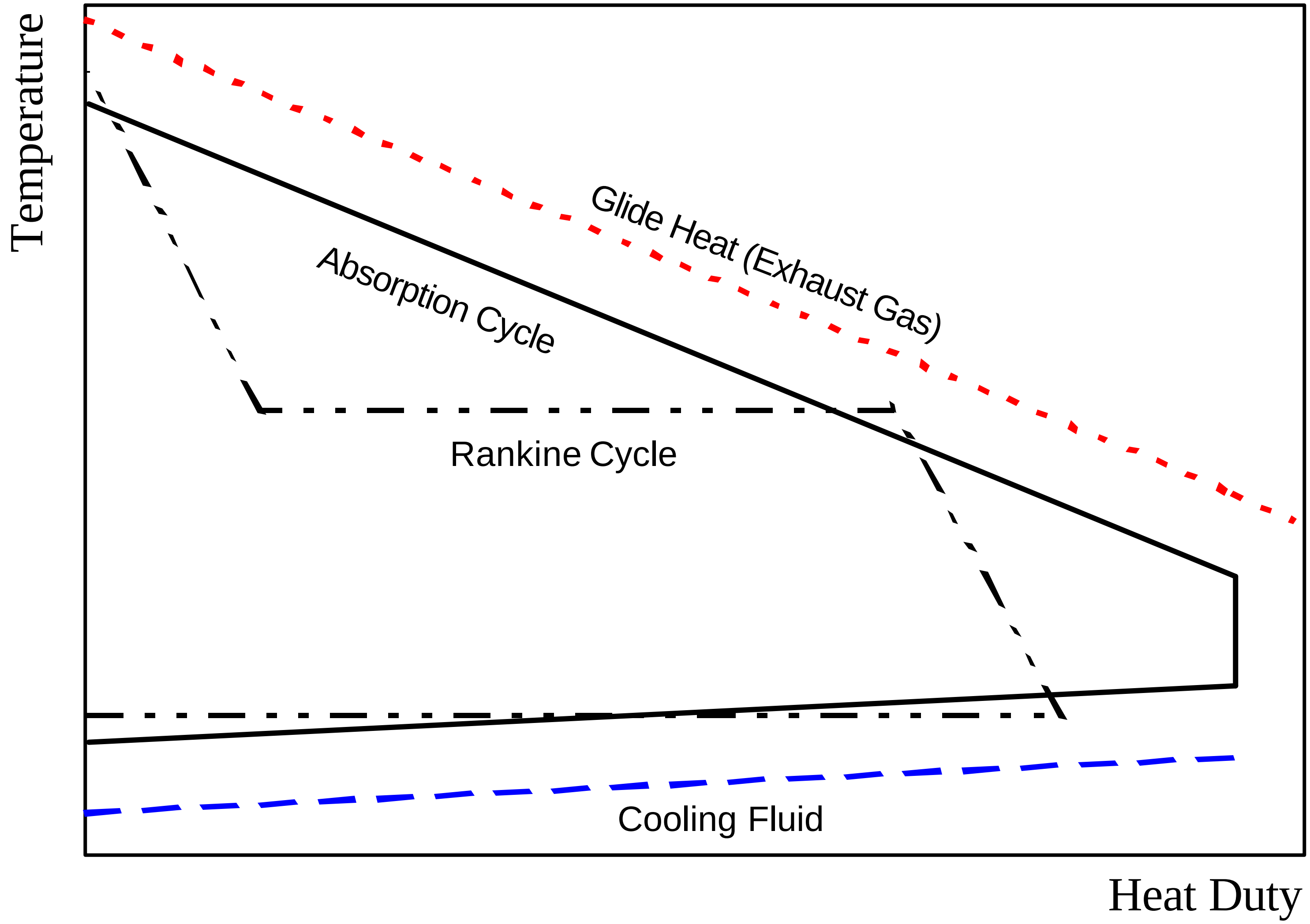
Fig. 1

add
4195485
4307572

Absorption Power Cycle

- Optimal pressures - compact, economical equipment
- Glide-matching heat input
- Glide-matching heat rejection - more efficient, and conserves water
- Uses more of the glide heat (system efficiency vs cycle efficiency)

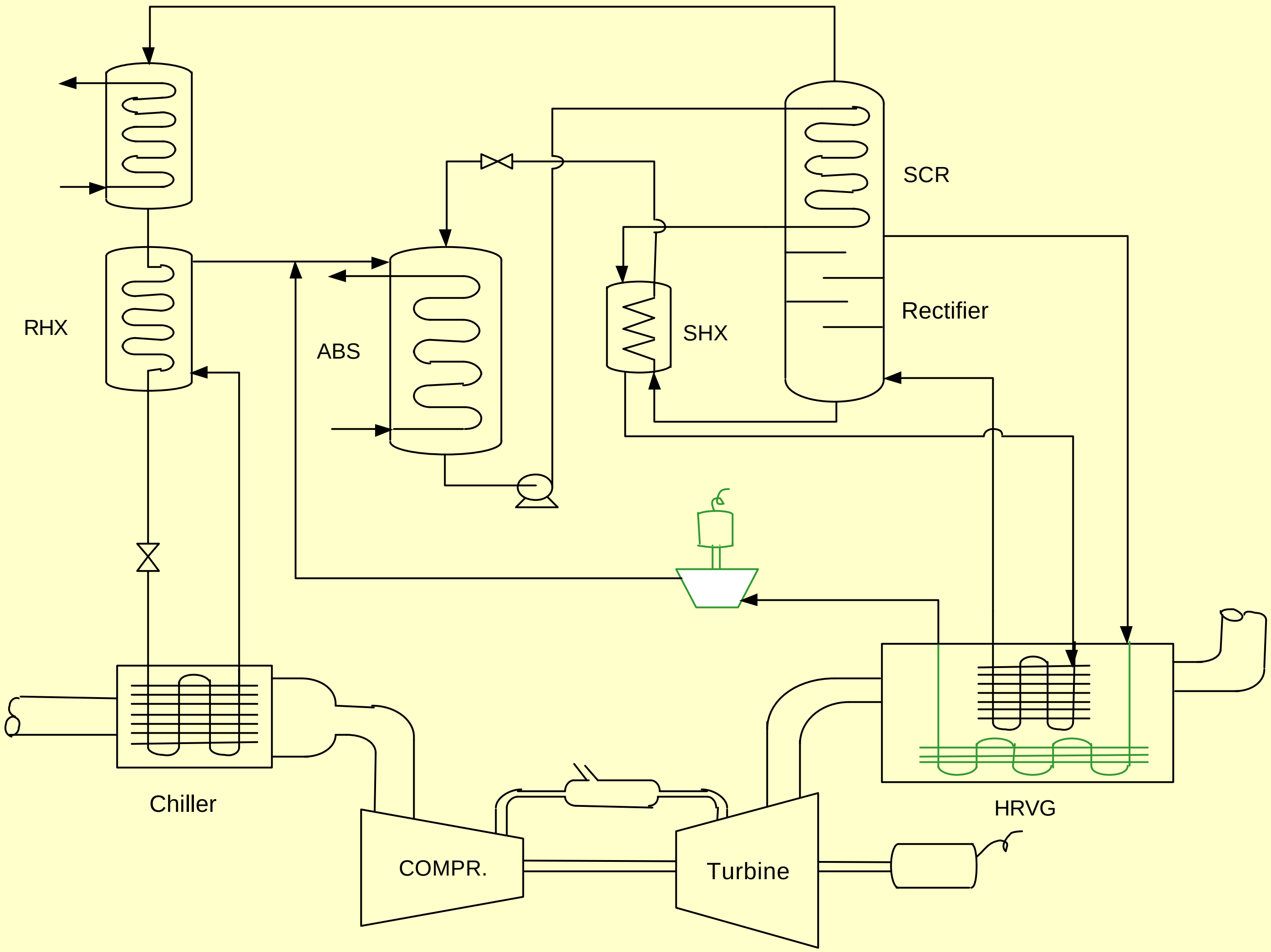
Qualitative Power Cycle Comparison



(WASTE) HEAT SOURCES FOR ABSORPTION POWER CYCLES

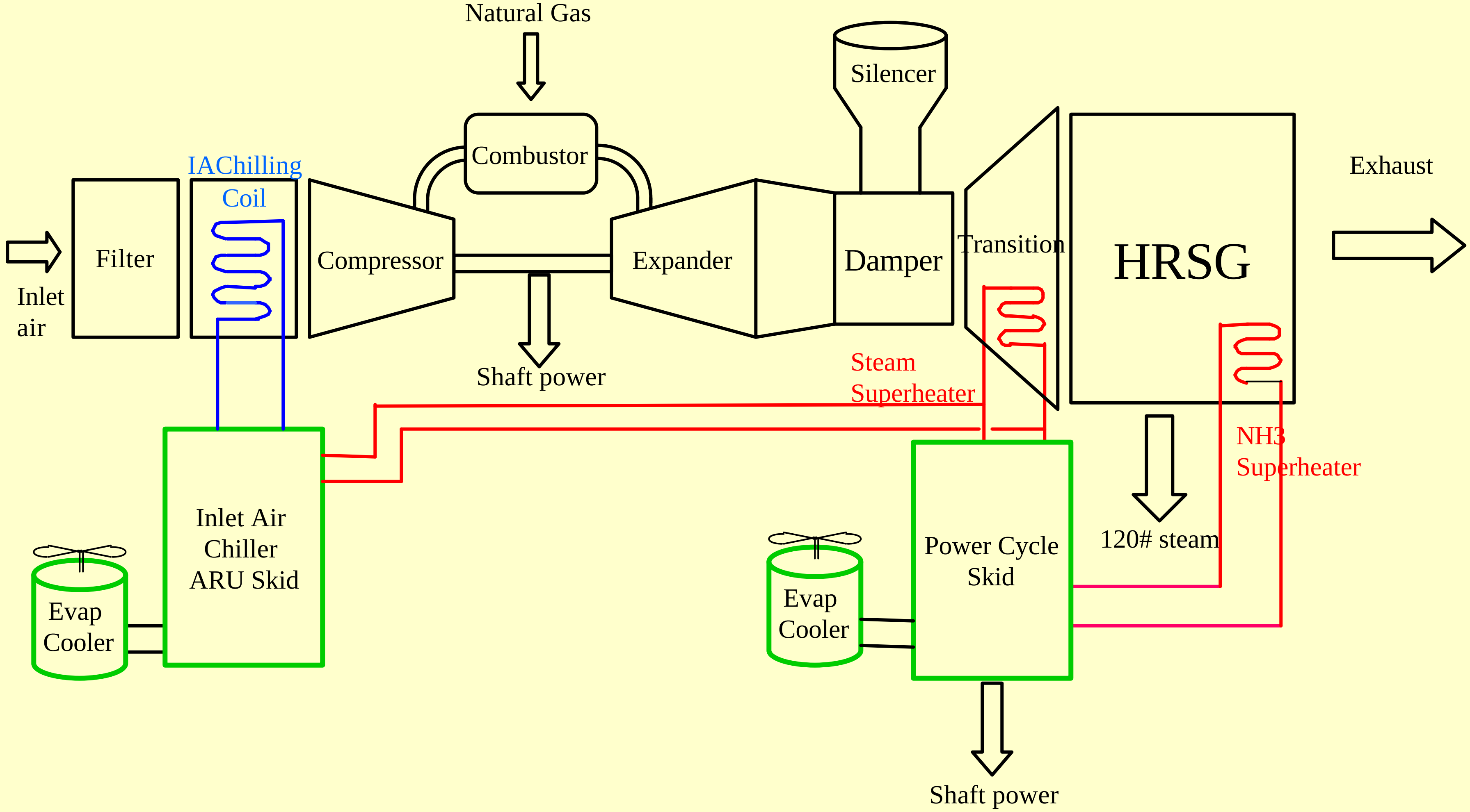
- Prime mover exhaust
- Boiler/furnace/kiln exhaust
- Process fluids
- Geothermal heat
- Solar thermal heat

Dual Function Absorption Cycle



Avenal Power Plant: Modified System

5/4/2007

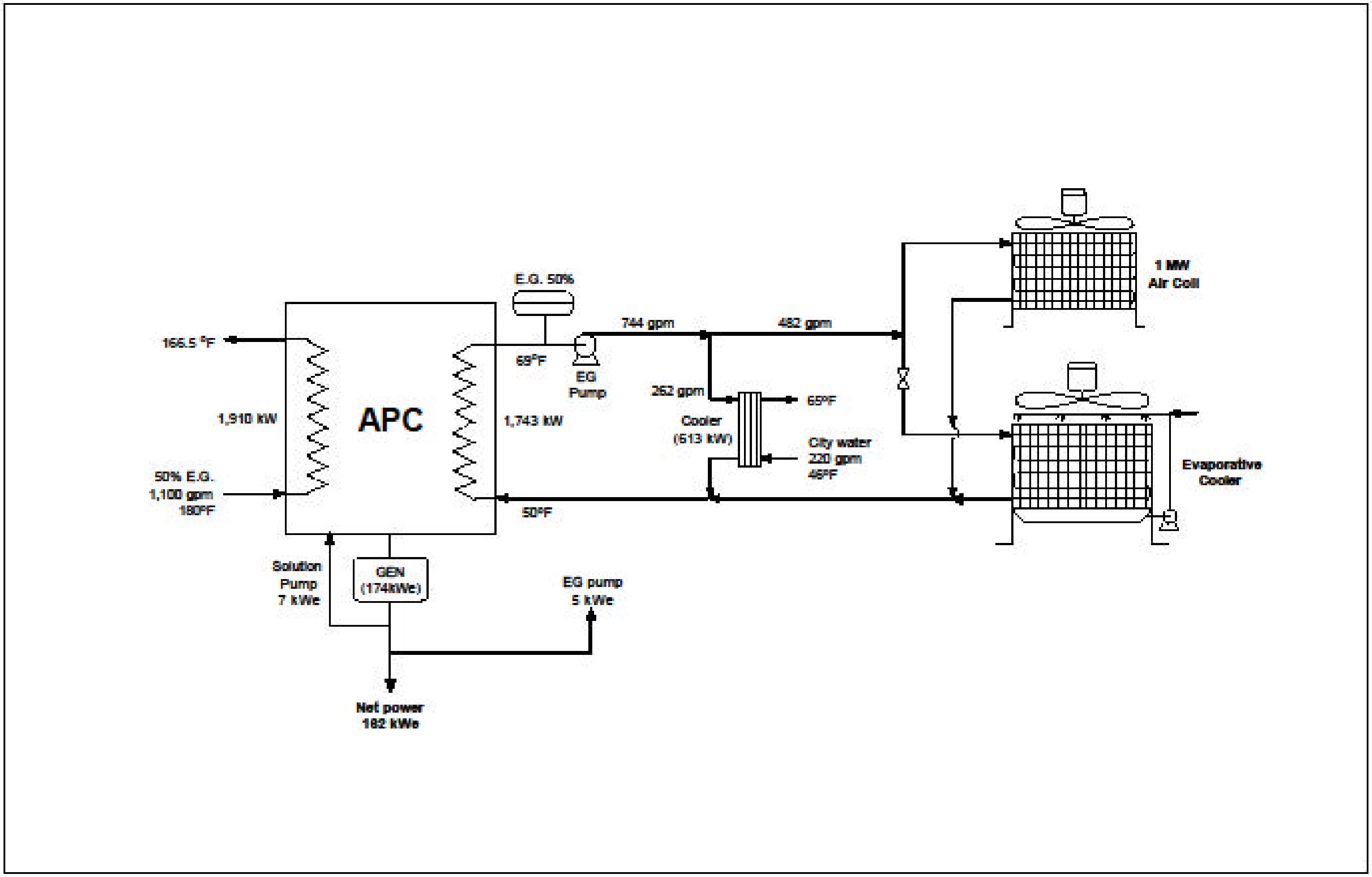


DEMONSTRATION PLAN

- Design, build, and test 25 kW laboratory prototype APC
  - validate performance of single rotor helical screw expander
- Field demonstrate 150 kW APC at Kotzebue Electric Association
  - 180°F jacket water heat source
  - generic application useful at many other sites
  - Alaska Energy Authority interest
  - KEA is an early adopter - has implemented numerous other advanced energy efficiency and renewable energy projects

Kotzebue-APC

10/6/08



Air Flow Required for Power Cycle Heat Rejection - Dry Cooling vs Wet Cooling

- Six times more for same condensing pressure
- Three times more for max power production
- Coolant glide doubles (40 vs. 20 ? F)
- ~ 3% penalty on heat rate

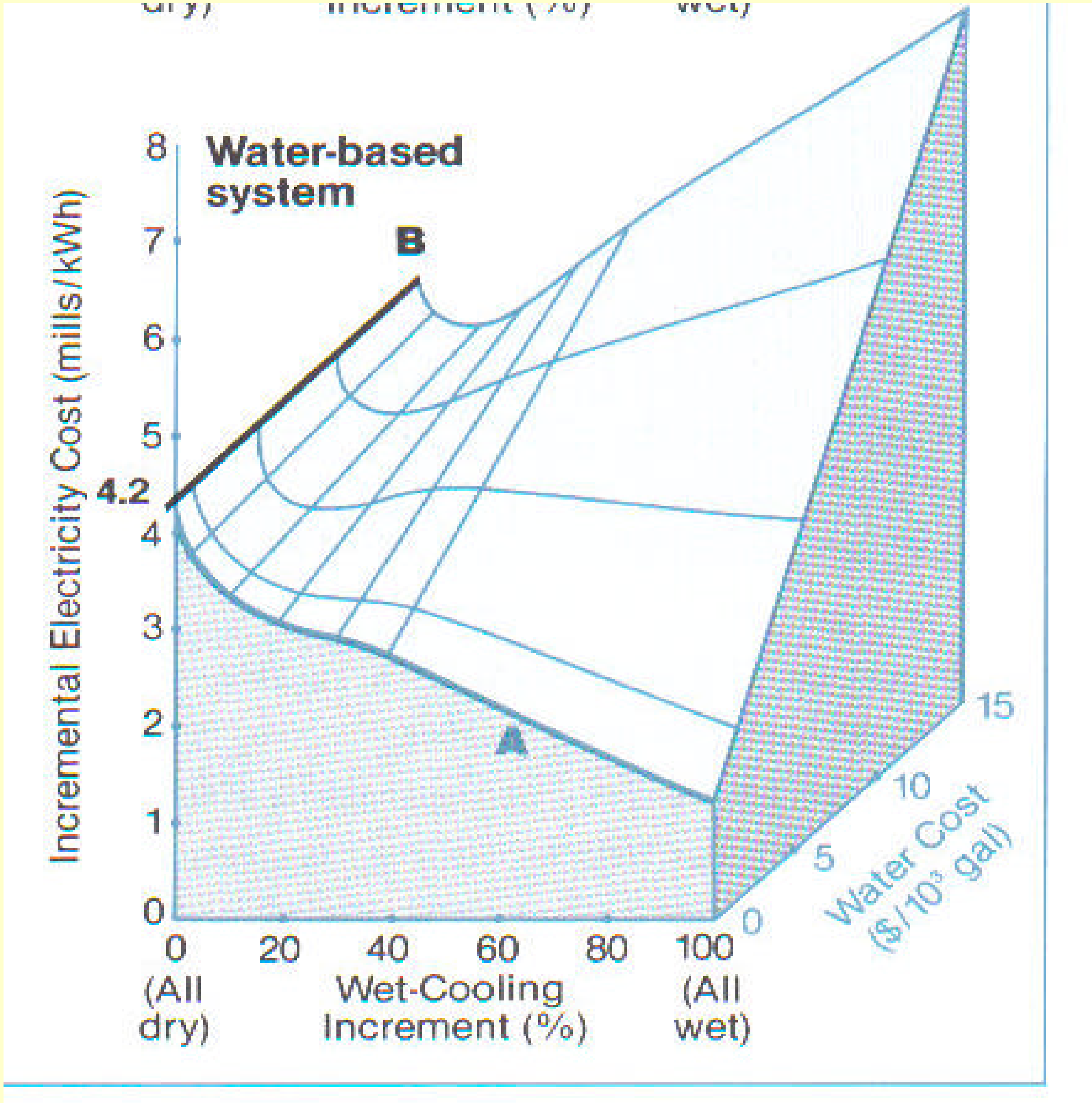
WATER CONSERVATION ASPECTS

- Opportunity cooling
  - one third of heat rejection to city water
  - reduces energy used by city residents to make hot water
- Damp cooling
  - dry radiator cooling most of year
  - wet cooling tower cooling only on hottest days of summer

CONCLUSIONS

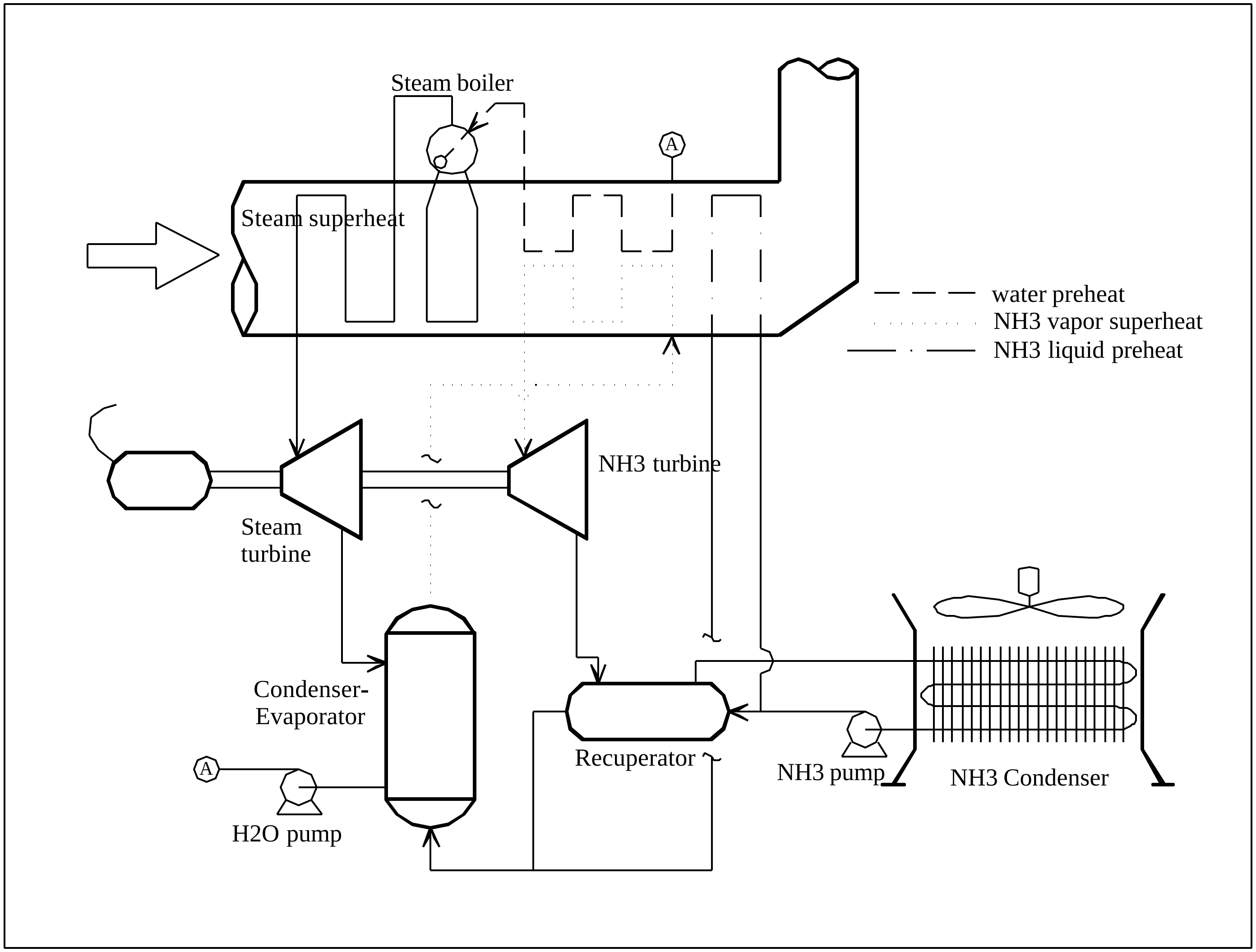
- The century-old absorption power cycle is being re-constituted
- The APC excels at converting low temperature waste heat to power
- The planned 150 kW demonstration at Kotzebue Electric Association will convert 180°F jacket heat to power at 9% efficiency
- Water will be conserved by opportunity cooling and by damp cooling

Effect of Damp Cooling



Steam-Ammonia Power Cycle

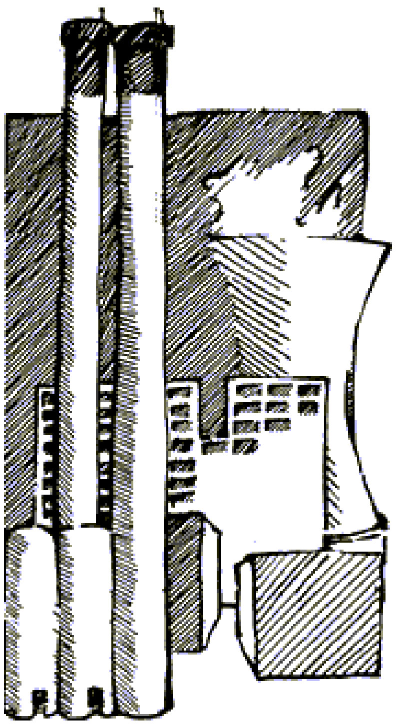
- Two Rankine cycles with two interconnections
- Adds superheater and economizer
- Major system efficiency gain due to glide matching
- Each working fluid stays within its optimum range
- Patented


Steam boiler
A
Steam superheat
water preheat
NH3 vapor superheat
NH3 liquid preheat
NH3 turbine
Steam
turbine
Condenser-
Evaporator
Recuperator
NH3 pump
NH3 Condenser
A
H2O pump

Limitations of Steam Power Plants with Low Temperature Glide Heat

- Deep vacuum - large and costly components
- Boiling temperature selection - Hobson's choice
- Condensing temperature - similar tradeoff

RECOVERY OF WATER FROM BOILER FLUE GAS



Project DE-FC26-06NT42727

Dr. Edward Levy
Dr. Harun Bilirgen
Energy Research Center
Lehigh University

DOE-NETL Water Meeting
Pittsburgh, Pa
October 27, 2008

ACKNOWLEDGEMENTS

Funding also provided by:

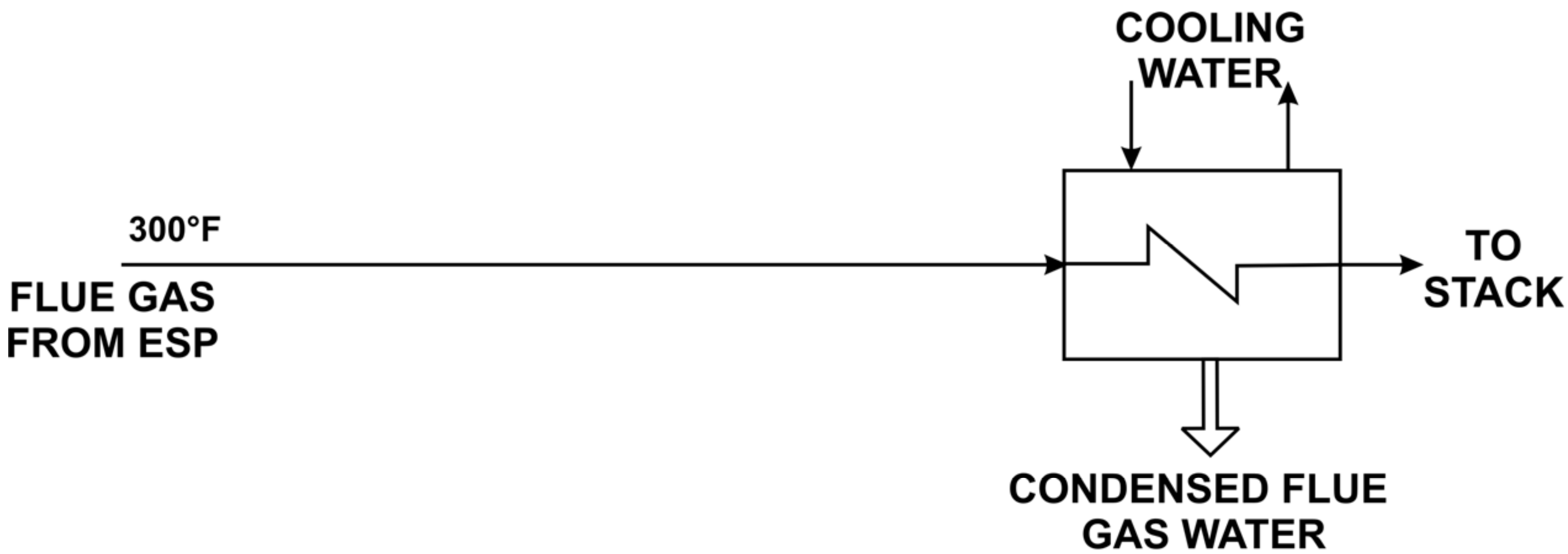
> Alstom Power Company

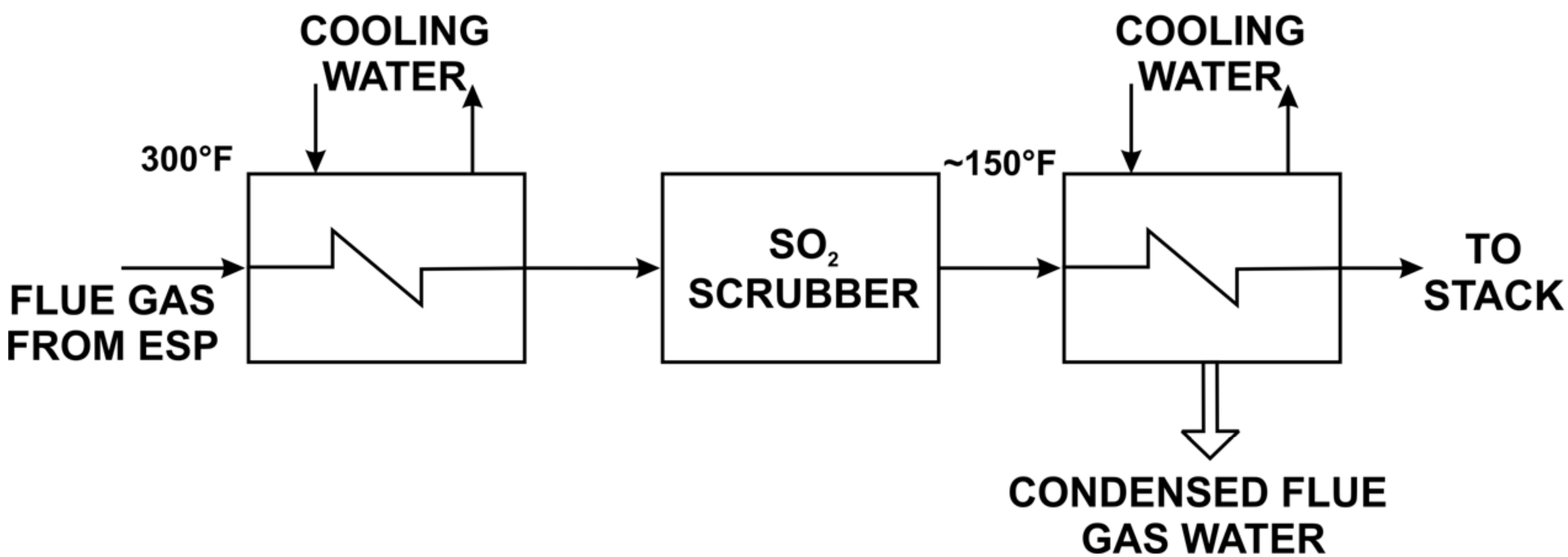
> Pennsylvania Infrastructure Technology Alliance,

> Lehigh University

BACKGROUND

- **Concentrations and Dew Points**
  - **> Water vapor**
    6 to 15 vol % …….95 to 130 F
  - **> Sulfuric acid**
    0 to 40 PPM ……..220 to 310 F
- **Flue Gas Inlet Temperature…….300 F**
- **Cooling Water Inlet Temp……50 to 110 F**


COOLING
WATER
300°F
FLUE GAS
FROM ESP
TO
STACK
CONDENSED FLUE
GAS WATER


COOLING
WATER
300°F
FLUE GAS
FROM ESP
SO_2
SCRUBBER
~150°F
COOLING
WATER
TO
STACK
CONDENSED FLUE
GAS WATER

QUESTIONS

- **How much flue gas moisture can be recovered?**

- **Heat rate Impacts…How large?….Will depend on how much sensible and latent heat can be captured.**

- **Can we control the region over which acid condenses?**

- **Acid corrosion……What heat exchanger designs and tubing materials will be needed to avoid serious acid corrosion problems?**

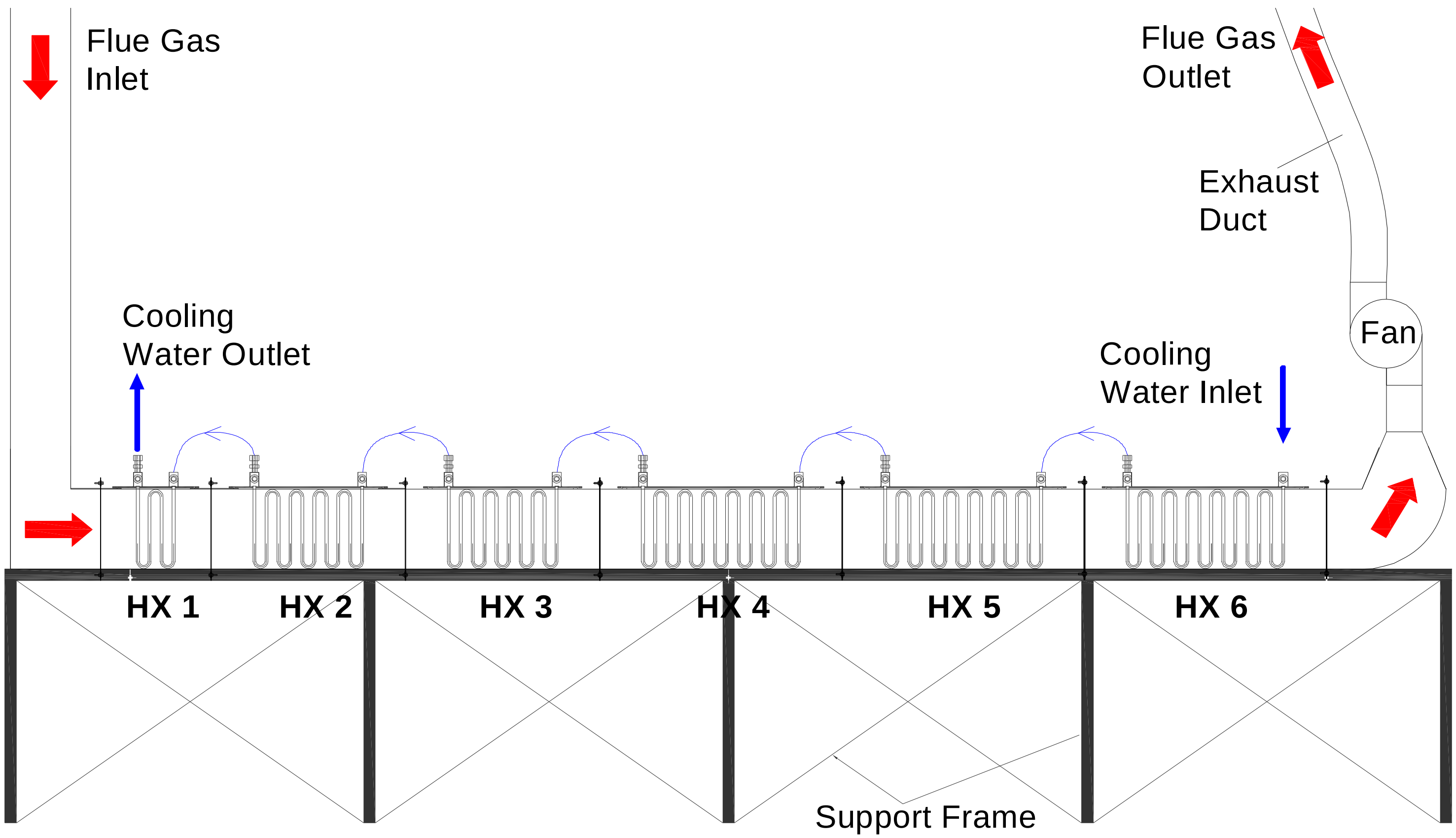
- **What will be impact on Hg emissions?**

PROJECT OBJECTIVES

- **Explore technical issues involved in using heat exchangers to condense H_20 from boiler flue gas**
- **Develop new designs for condensing heat exchangers**
- **Perform pilot scale tests and measure acid and water condensation patterns**
- **Determine maximum recoverable water from flue gas**
- **Determine potential heat rate benefits**

HEAT EXCHANGER SYSTEM DESIGN PHILOSOPHY

- > Cool flue gas and condense acids and water in stages
- > Condense sulfuric acid in high temperature heat exchangers
- > Condense water vapor and other acids in low temperature heat exchangers

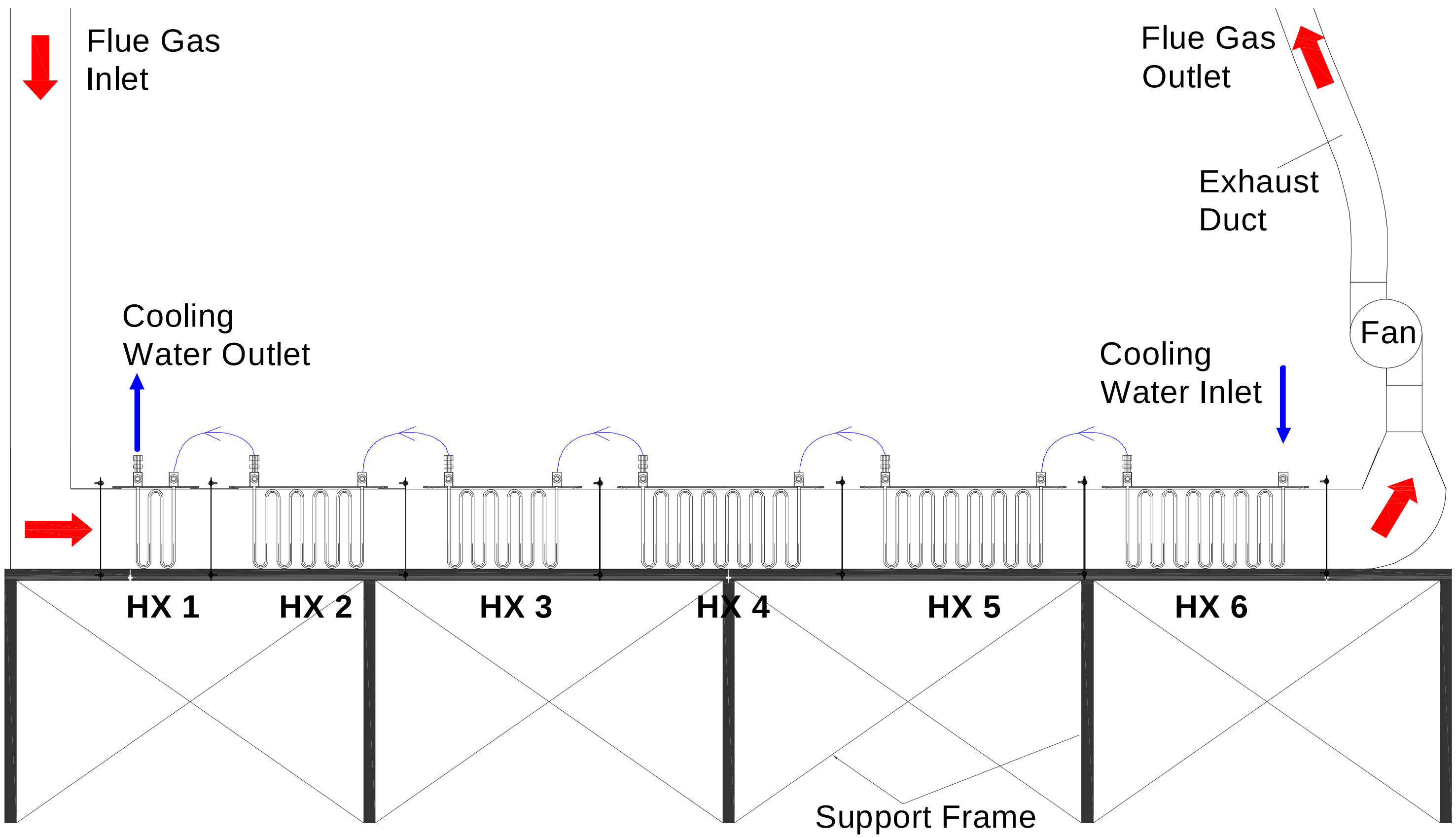

Flue Gas
Inlet
Flue Gas
Outlet
Exhaust
Duct
Fan
Cooling
Water Outlet
Cooling
Water Inlet
HX 1
HX 2
HX 3
HX 4
HX 5
HX 6
Support Frame

PILOT-SCALE TESTS

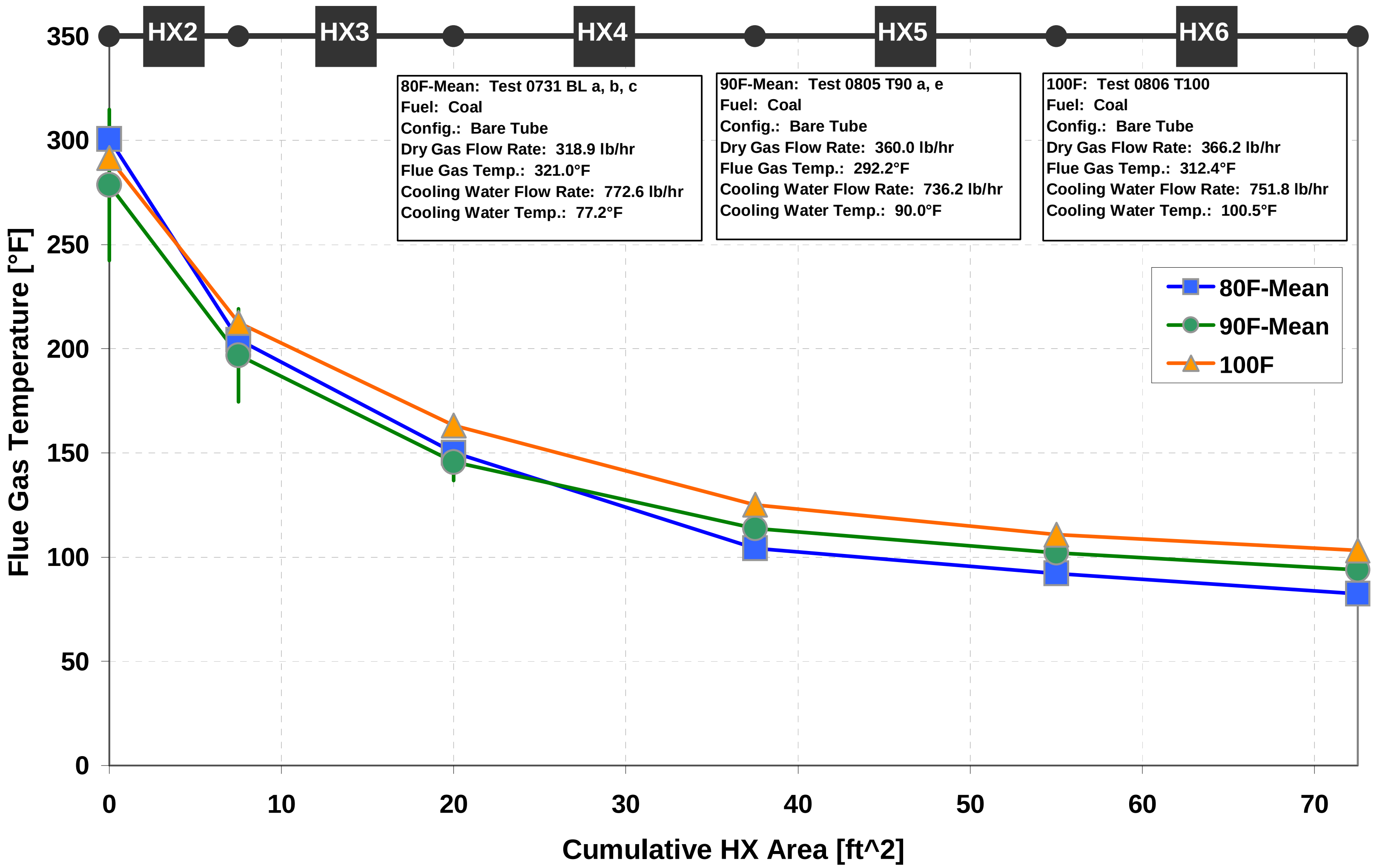
- Lehigh University Boiler
  - > #6 fuel oil and natural gas
  - > flue gas slip stream after economizer

- Coal-Fired Power Plant
  - > high moisture coal
  - > flue gas slipstream after ESP

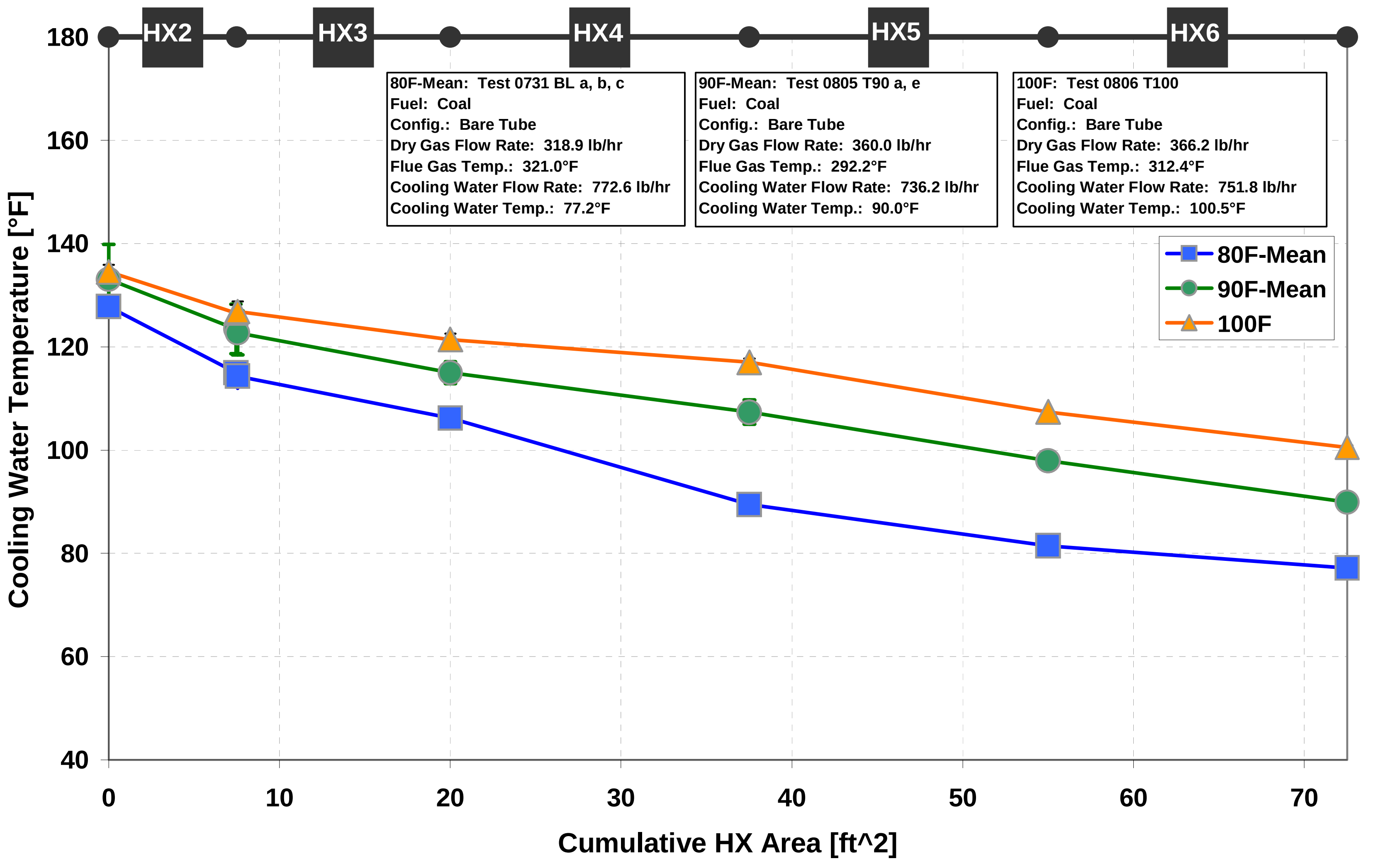

CAE
AI


Flue Gas
Inlet
Flue Gas
Outlet
Exhaust
Duct
Cooling
Water Outlet
Fan
Cooling
Water Inlet
HX 1
HX 2
HX 3
HX 4
HX 5
HX 6
Support Frame

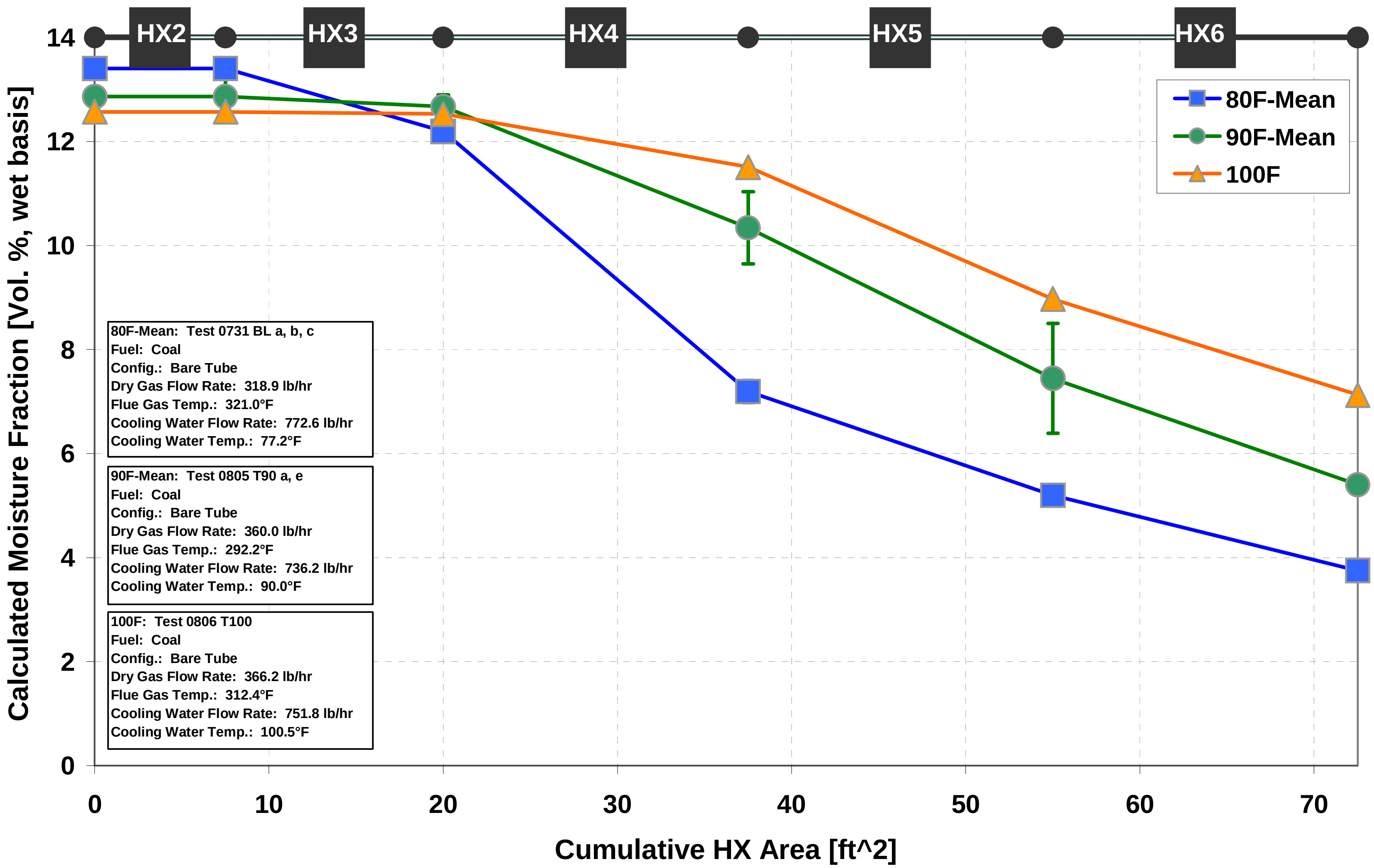
AXIAL VARIATIONS OF FLUE GAS TEMPERATURE



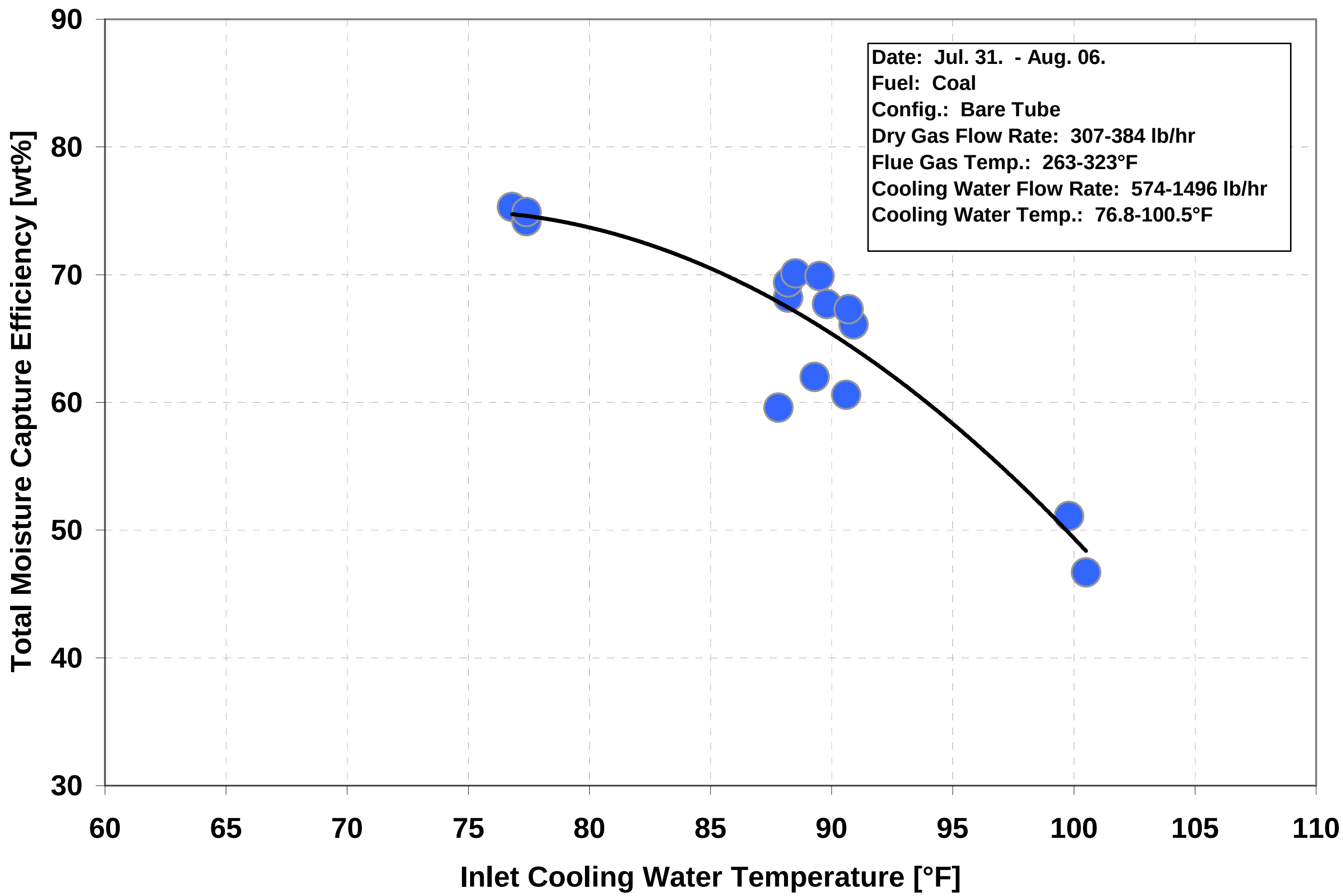
AXIAL VARIATION OF COOLING WATER TEMPERATURE



AXIAL VARIATIONS OF FLUE GAS MOISTURE CONCENTRATION



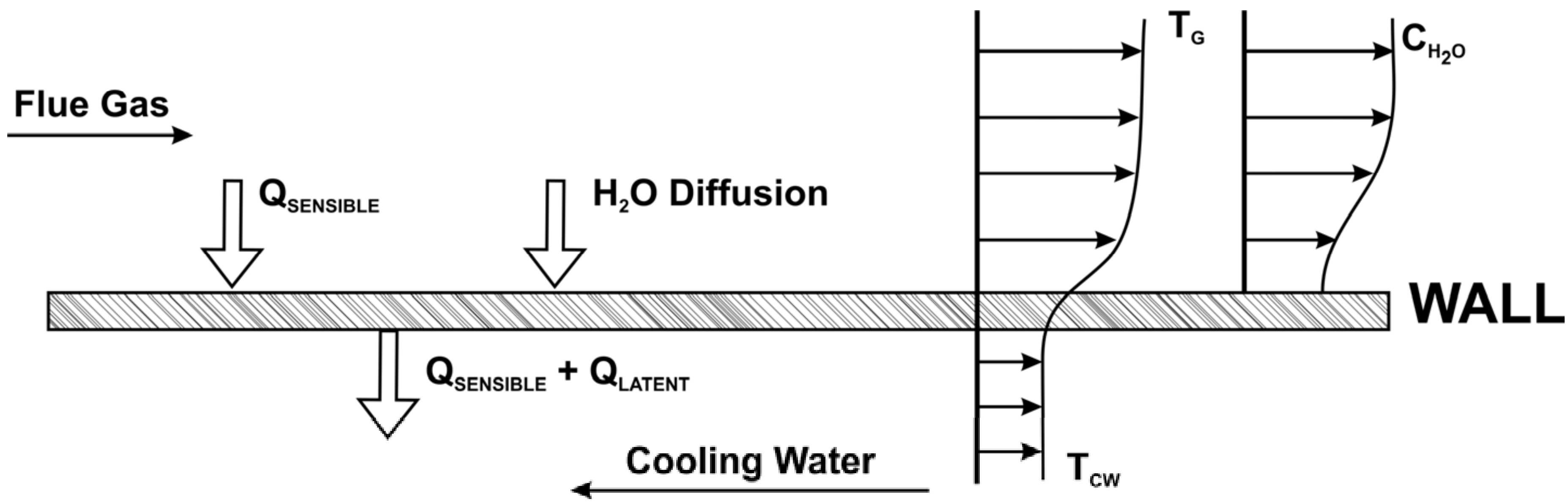
MOISTURE CAPTURE EFFICIENCY VS INLET COOLING WATER TEMPERATURE



COMPARISONS BETWEEN

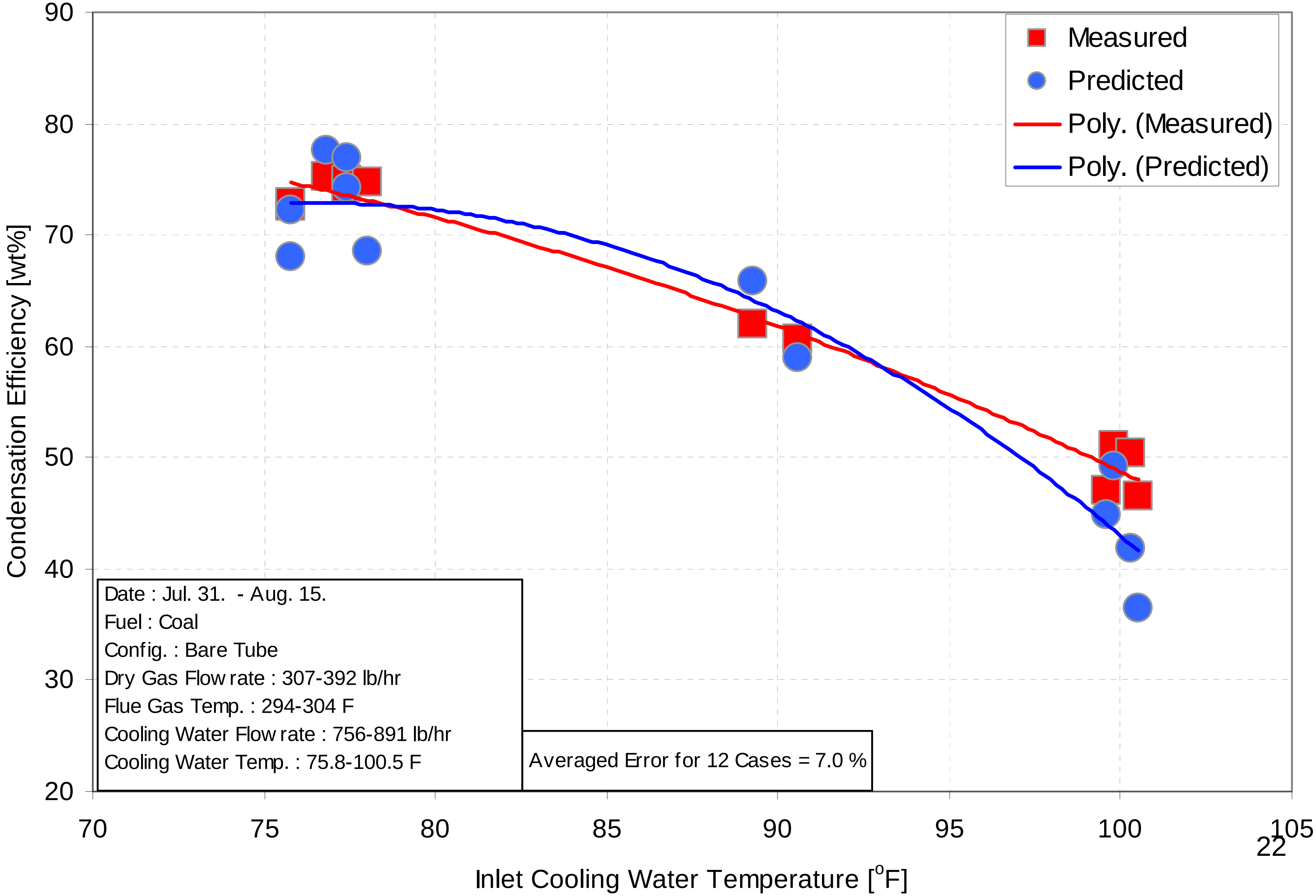
PILOT- SCALE WATER CONDENSATION DATA

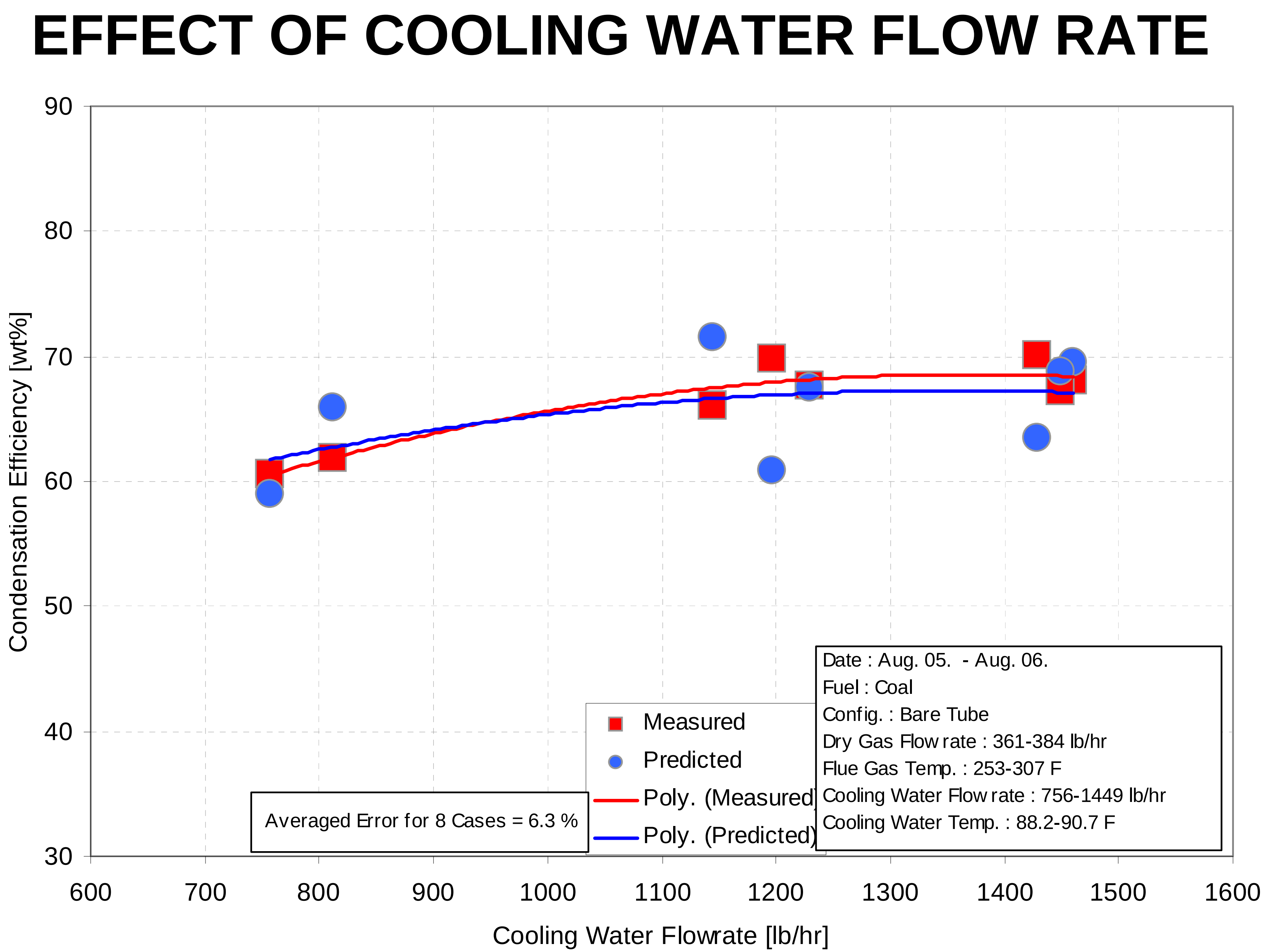
AND HEAT AND MASS TRANSFER MODEL



Flue Gas
Q SENSIBLE
H2O Diffusion
T G
C H2O
WALL
Q SENSIBLE + Q LATENT
Cooling Water
T CW

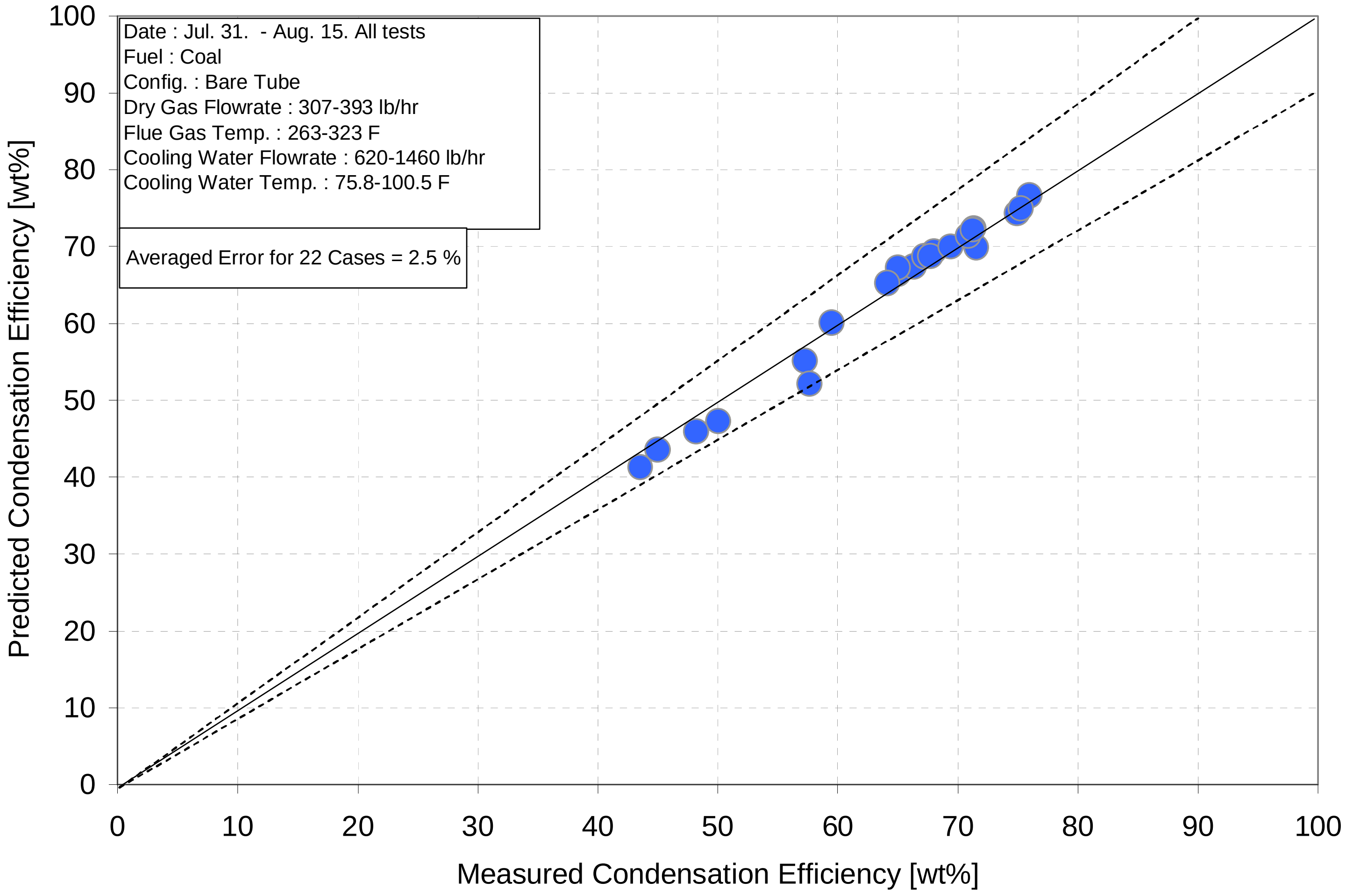
EFFECT OF INLET COOLING WATER TEMPERATURE





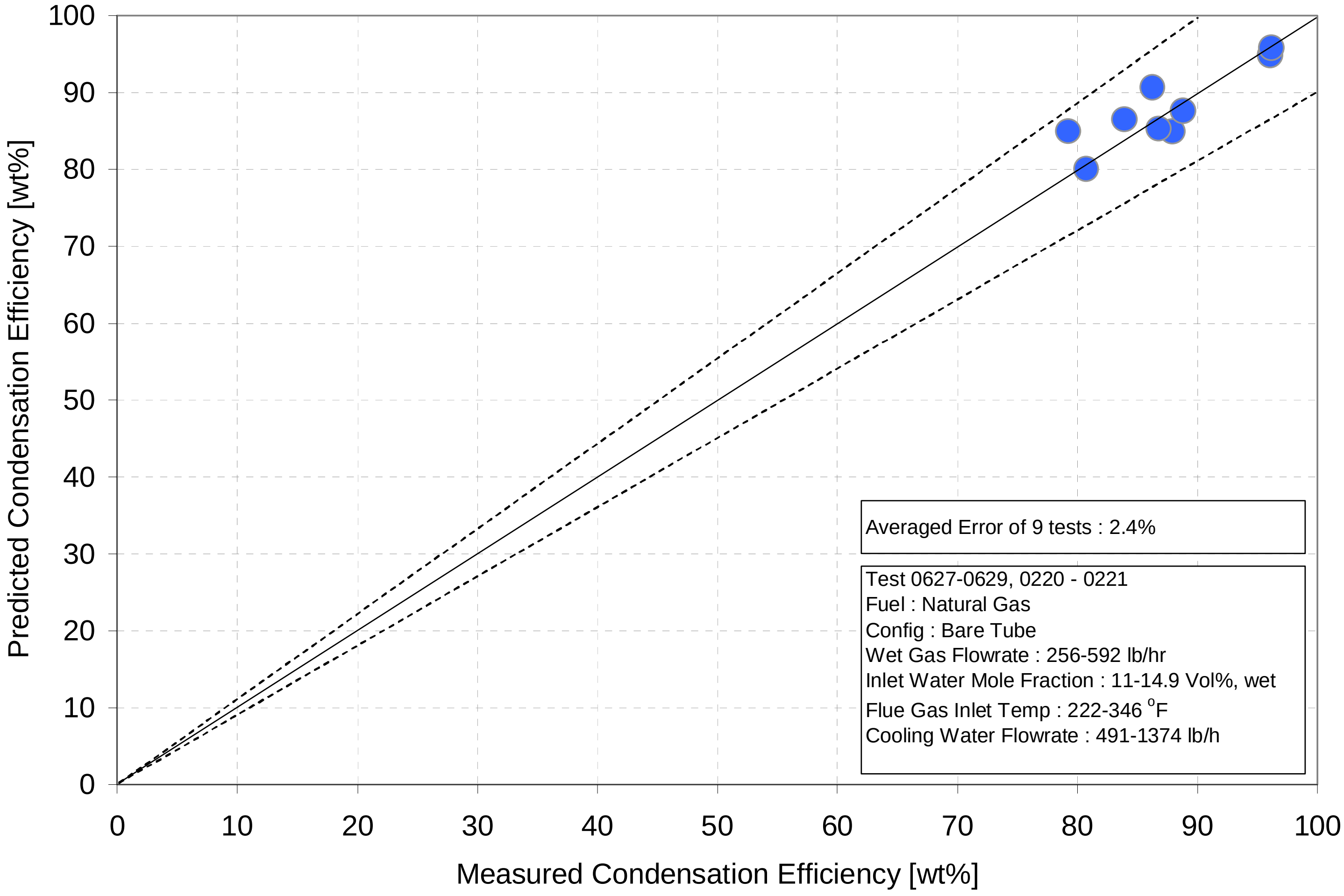
EFFECT OF COOLING WATER FLOW RATE
90
80
70
60
50
40
30
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Condensation Efficiency [wt%]
Cooling Water Flowrate [lb/hr]
Measured
Predicted
Poly. (Measured)
Poly. (Predicted)
Averaged Error for 8 Cases = 6.3 %
Date : Aug. 05. - Aug. 06.
Fuel : Coal
Config. : Bare Tube
Dry Gas Flow rate : 361-384 lb/hr
Flue Gas Temp. : 253-307 F
Cooling Water Flow rate : 756-1449 lb/hr
Cooling Water Temp. : 88.2-90.7 F

COAL DATA



Date : Jul. 31. - Aug. 15. All tests
Fuel : Coal
Config. : Bare Tube
Dry Gas Flowrate : 307-393 lb/hr
Flue Gas Temp. : 263-323 F
Cooling Water Flowrate : 620-1460 lb/hr
Cooling Water Temp. : 75.8-100.5 F
Averaged Error for 22 Cases = 2.5 %
Predicted Condensation Efficiency [wt%]
Measured Condensation Efficiency [wt%]
0
10
20
30
40
50
60
70
80
90
100

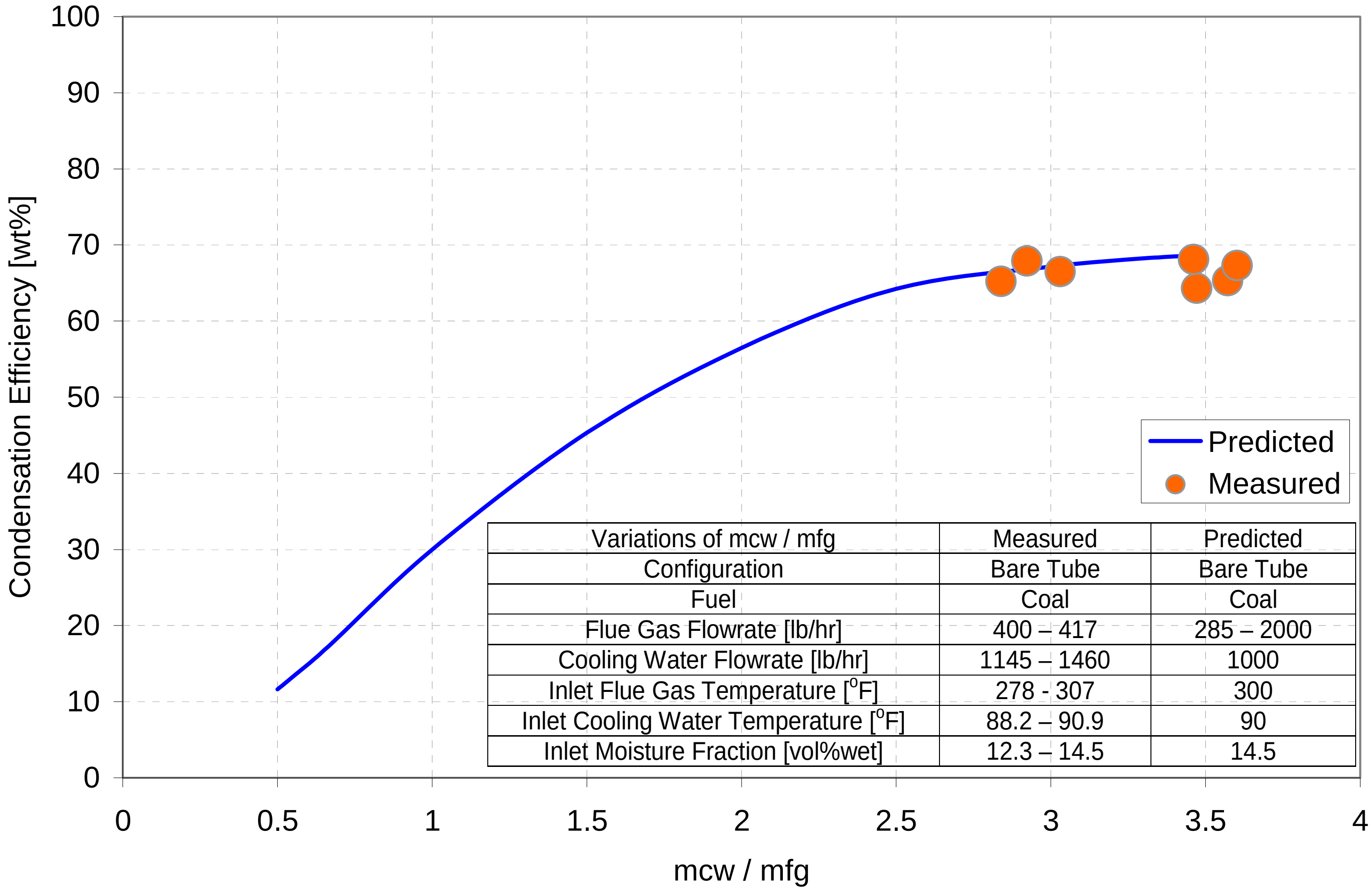
NATURAL GAS DATA



WATER CAPTURE EFFICIENCY

- **Results suggest that water capture efficiencies greater than 70 percent will be possible for some process conditions.**
- **However, for other combinations of process conditions, much lower water capture efficiencies are to be expected.**

EFFECT OF LOW COOLANT FLOW RATE ON CAPTURE EFFICIENCY

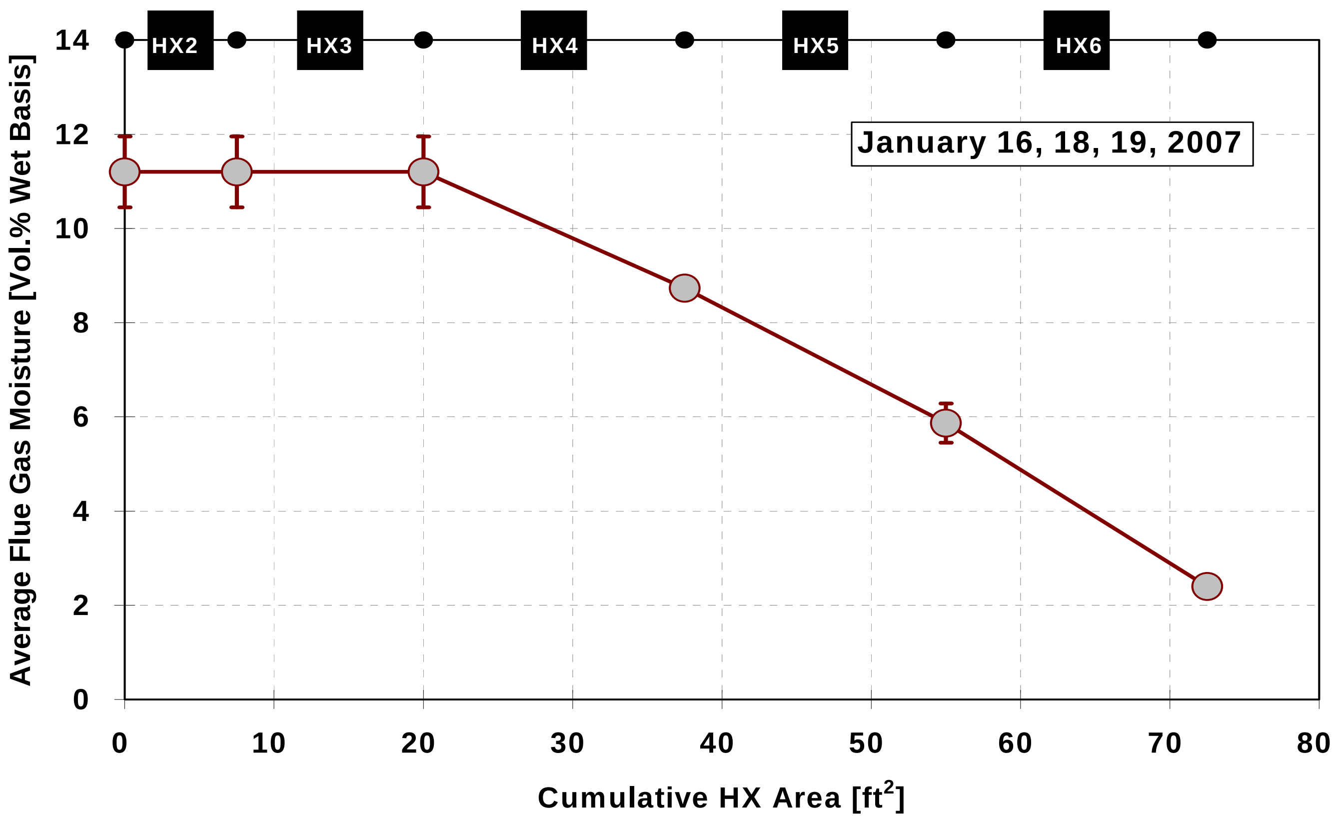


Variations of mcw / mfg	Measured	Predicted
Configuration	Bare Tube	Bare Tube
Fuel	Coal	Coal
Flue Gas Flowrate [lb/hr]	400 – 417	285 – 2000
Cooling Water Flowrate [lb/hr]	1145 – 1460	1000
Inlet Flue Gas Temperature [^oF]	278 - 307	300
Inlet Cooling Water Temperature [^oF]	88.2 – 90.9	90
Inlet Moisture Fraction [vol%wet]	12.3 – 14.5	14.5

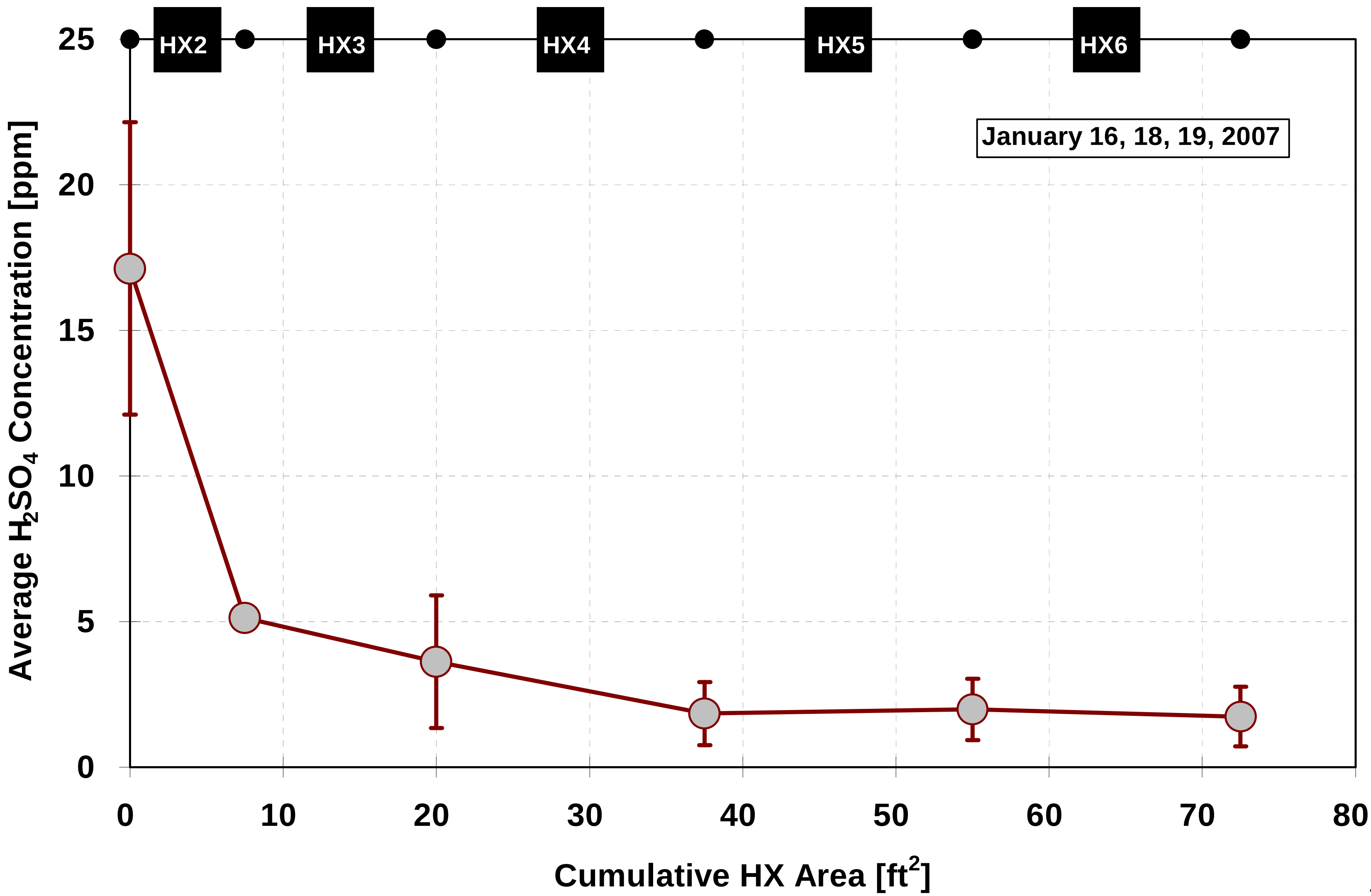
SULFURIC ACID MEASUREMENTS

- **Flue gas--Controlled Condensation Method**
- **Condensed water-- Laboratory analysis of acid concentrations**

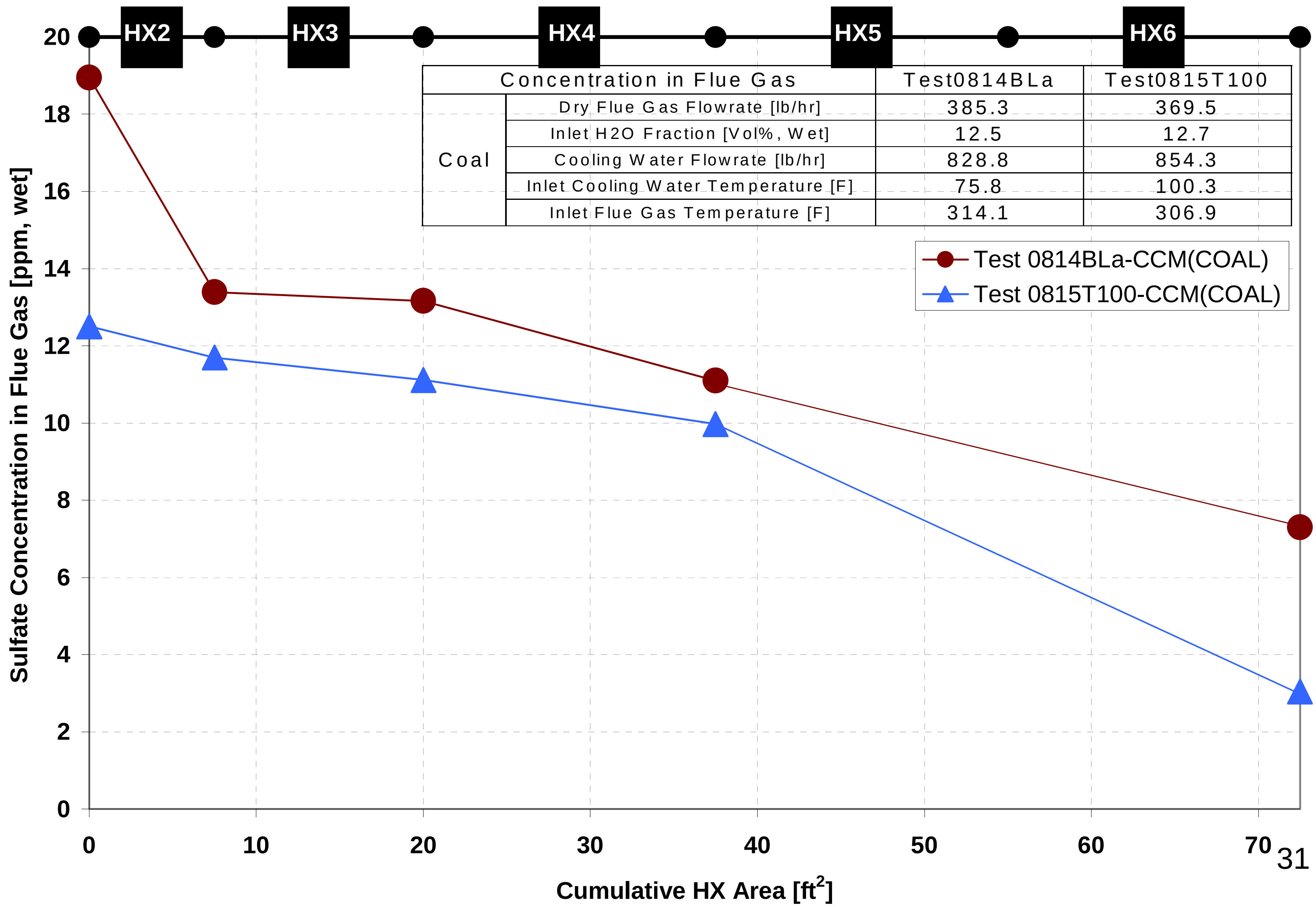
OIL DATA….WATER VAPOR CONDENSATION PATTERN



OIL DATA…H2SO4 CONDENSATION PATTERN



COAL DATA…H2SO4 CONDENSATION PATTERN



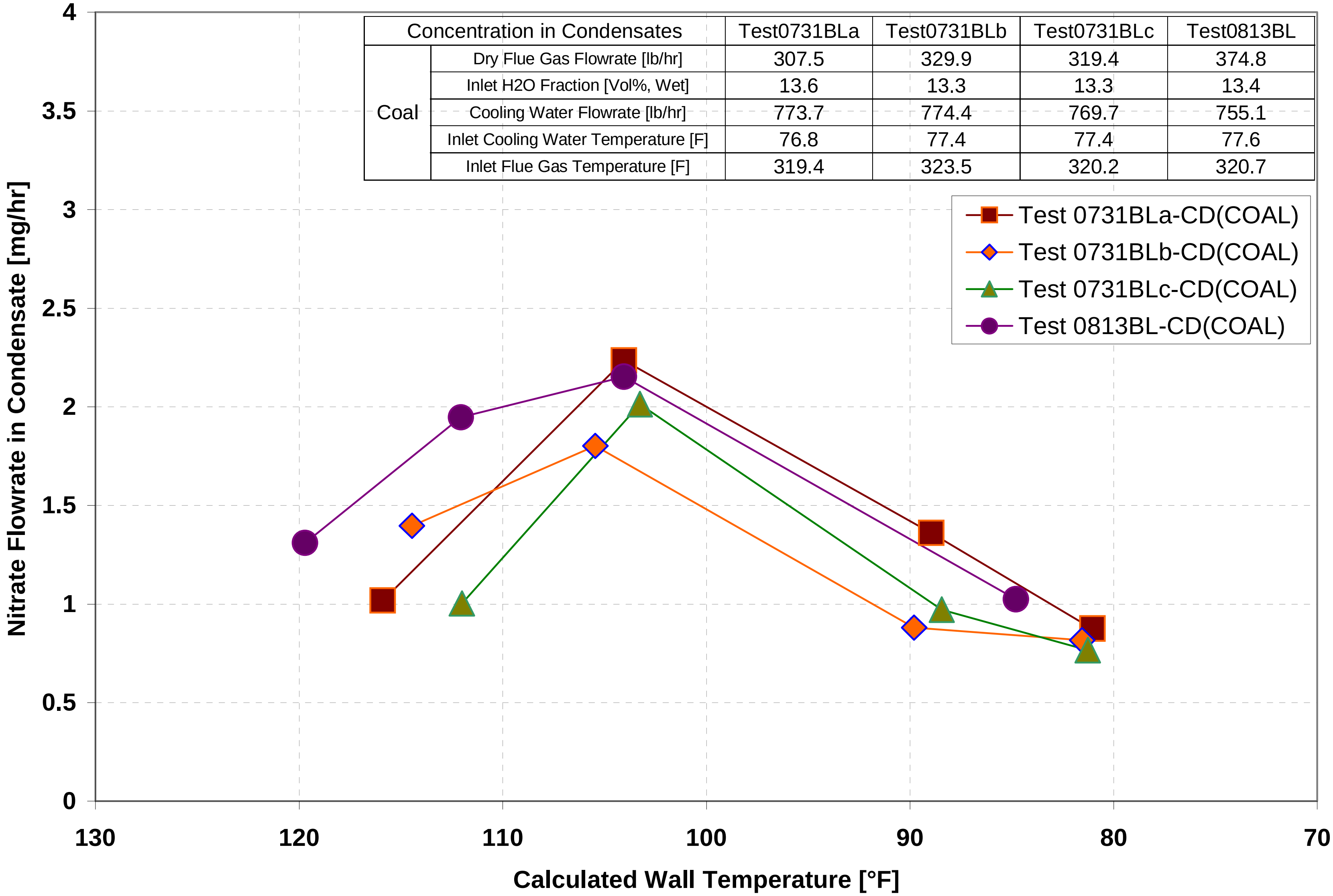
Concentration in Flue Gas		Test0814BLa	Test0815T100
Coal	Dry Flue Gas Flowrate [lb/hr]	385.3	369.5
	Inlet H2O Fraction [Vol%, Wet]	12.5	12.7
	Cooling Water Flowrate [lb/hr]	828.8	854.3
	Inlet Cooling Water Temperature [F]	75.8	100.3
	Inlet Flue Gas Temperature [F]	314.1	306.9

Flue gas from coal and oil had:

- Similar inlet vapor H_2SO_4 concentrations
- Similar H_2SO_4 concentrations in condensed water
- Radically different flue gas H_2SO_4 profiles
- The reasons for these differences are under investigation.

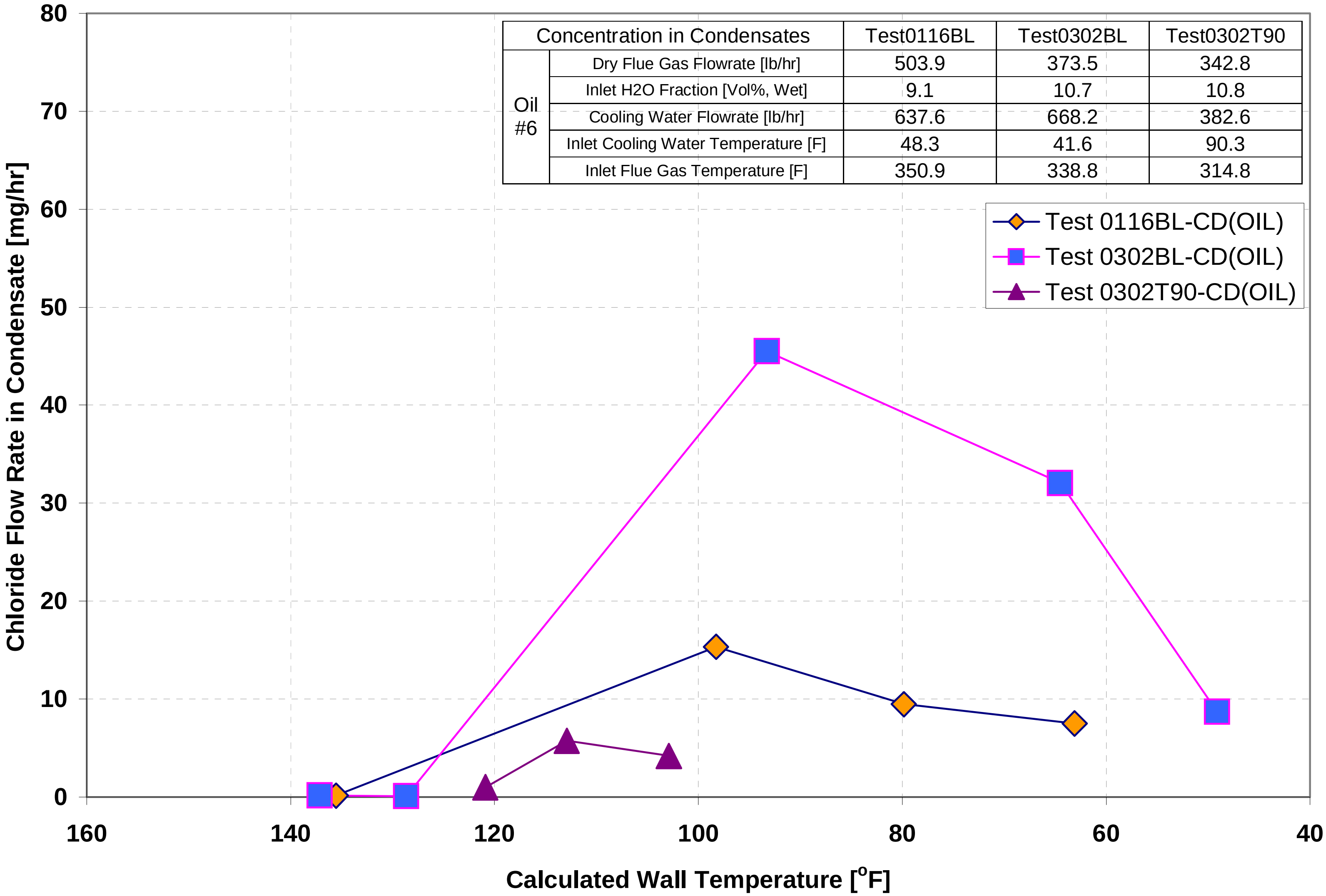
Hydrochloric and nitric acids condense in same temperature range as water vapor

NITRIC ACID



Concentration in Condensates		Test0731BLa	Test0731BLb	Test0731BLc	Test0813BL
Coal	Dry Flue Gas Flowrate [lb/hr]	307.5	329.9	319.4	374.8
	Inlet H2O Fraction [Vol%, Wet]	13.6	13.3	13.3	13.4
	Cooling Water Flowrate [lb/hr]	773.7	774.4	769.7	755.1
	Inlet Cooling Water Temperature [F]	76.8	77.4	77.4	77.6
	Inlet Flue Gas Temperature [F]	319.4	323.5	320.2	320.7

HYDROCHLORIC ACID



Concentration in Condensates		Test0116BL	Test0302BL	Test0302T90
Oil #6	Dry Flue Gas Flowrate [lb/hr]	503.9	373.5	342.8
	Inlet H2O Fraction [Vol%, Wet]	9.1	10.7	10.8
	Cooling Water Flowrate [lb/hr]	637.6	668.2	382.6
	Inlet Cooling Water Temperature [F]	48.3	41.6	90.3
	Inlet Flue Gas Temperature [F]	350.9	338.8	314.8

FLUE GAS MERCURY MEASUREMENTS

Used sorbent traps at flue gas inlet and at exit of condensing heat exchanger system.

Vapor phase mercury was reduced by 60 percent.

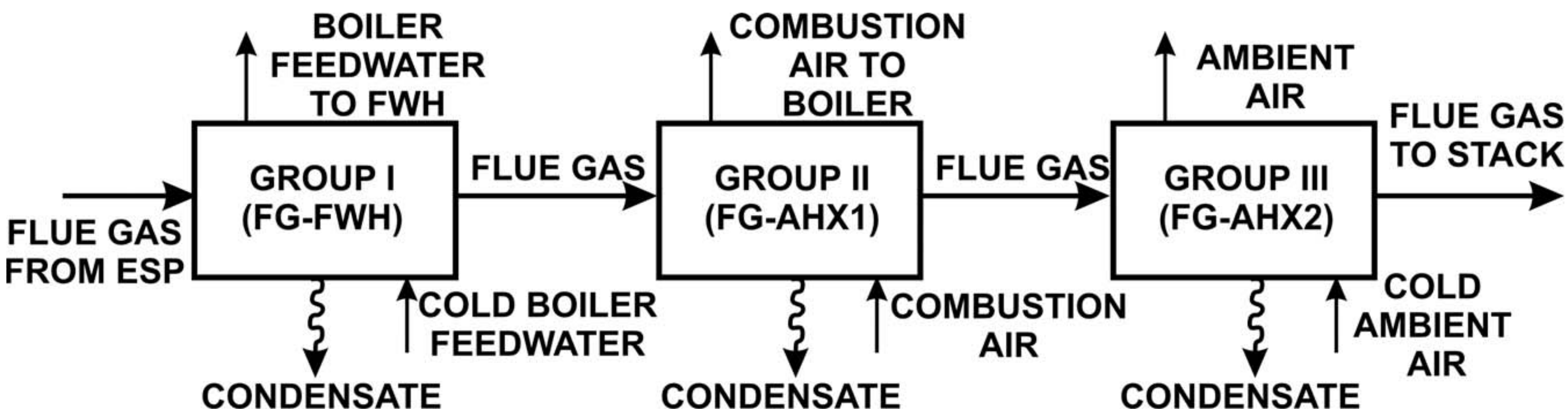
ENHANCING WATER CAPTURE EFFICIENCY AND UNIT HEAT RATE

Analyses performed to determine:

> Maximum recoverable flue gas water vapor

> Maximum unit heat rate improvement

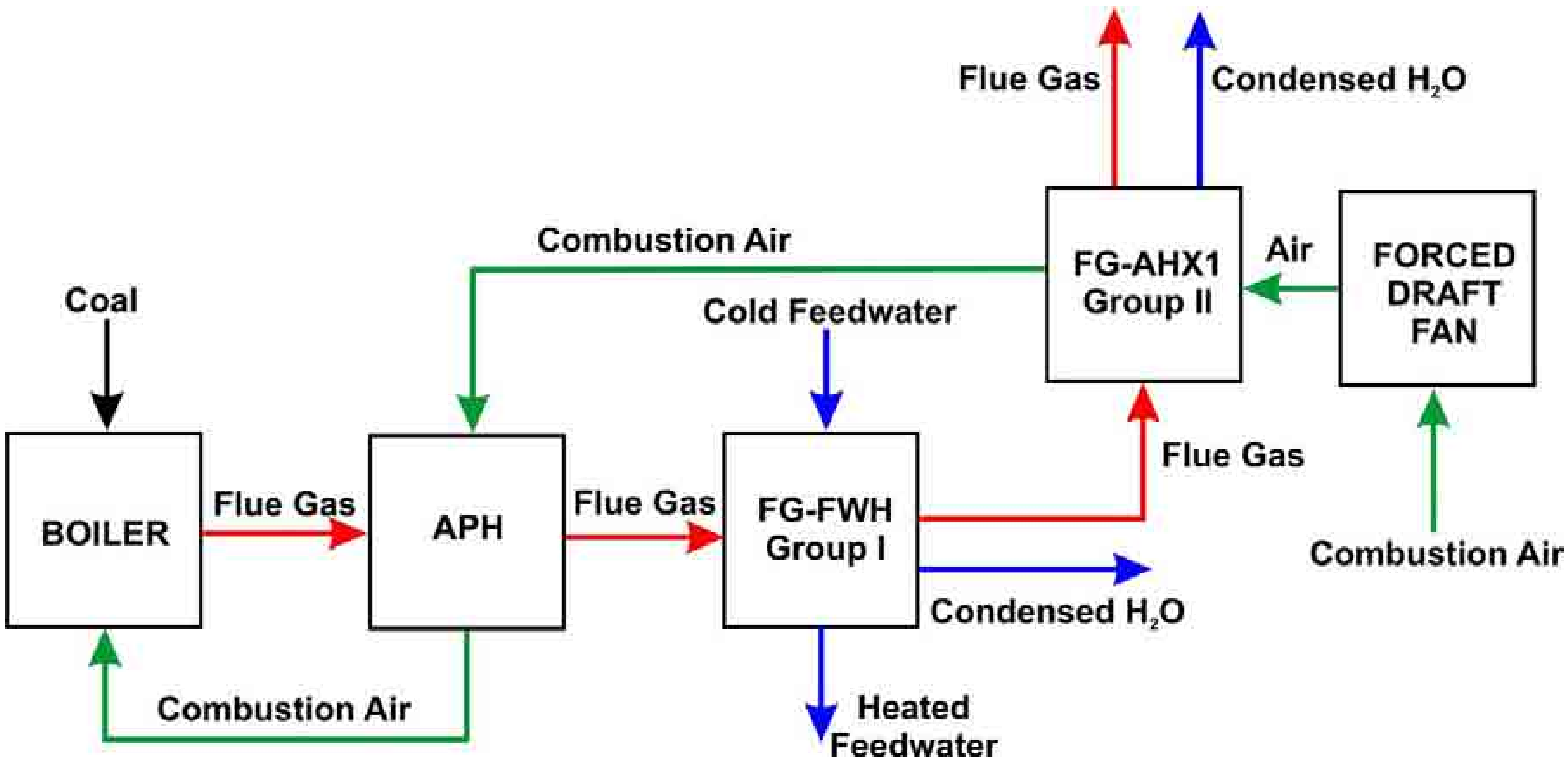
SEPARATE HEAT EXCHANGERS INTO THREE GROUPS

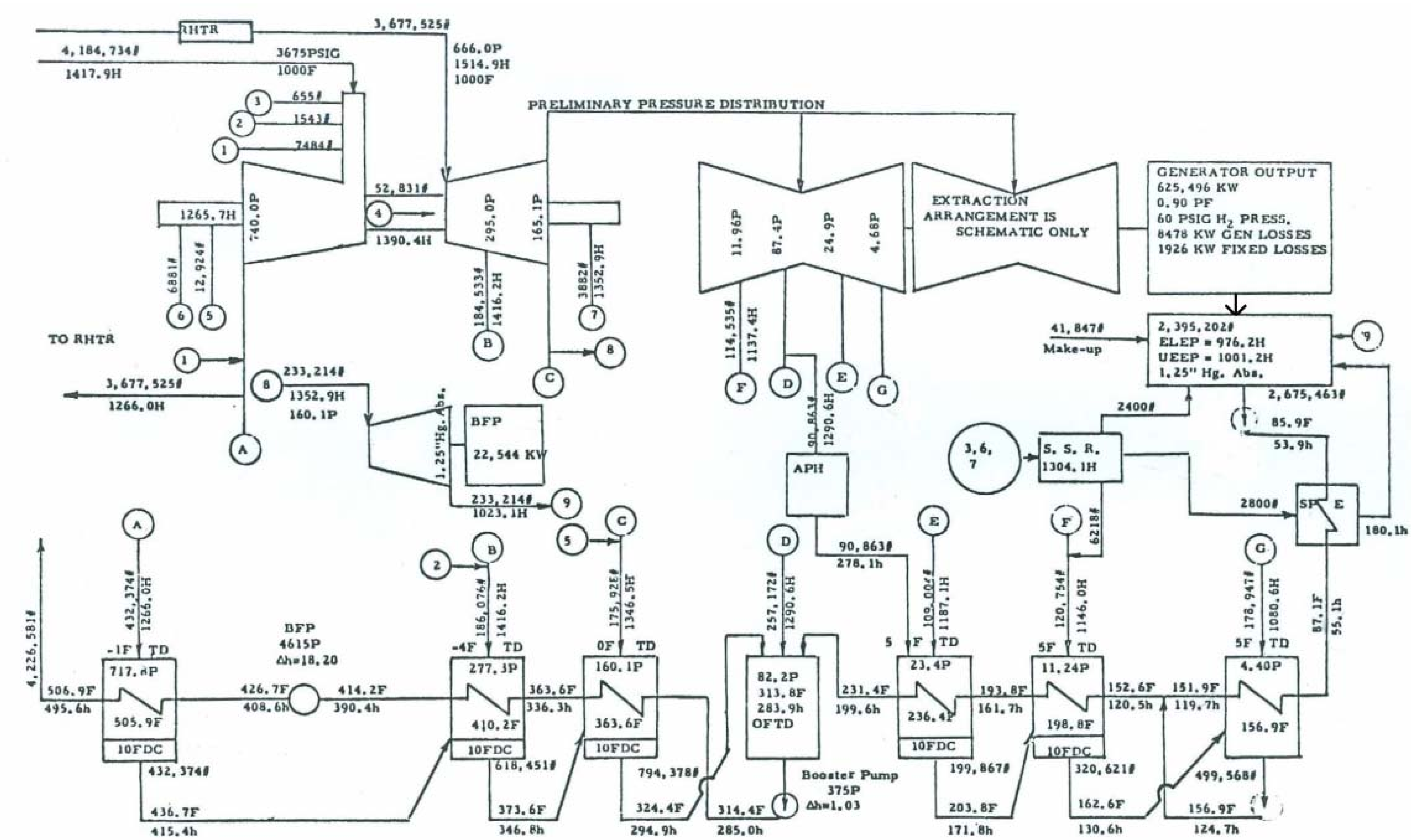


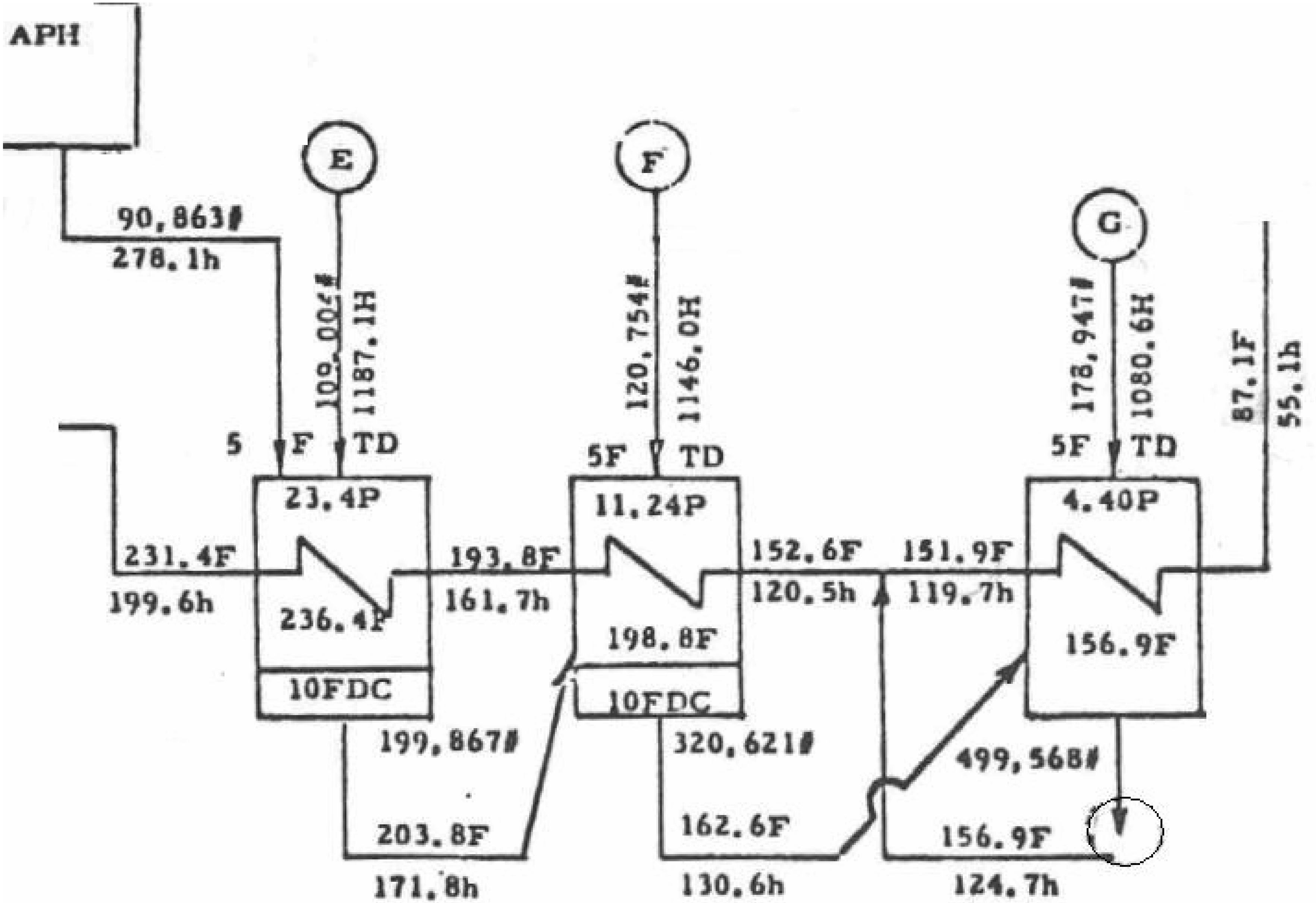
Descriptions of HX Groups

Group	Heat Sink	Water Capture	Heat Rate Decrease
I	Boiler Feedwater	Yes	Yes
II	Combustion Air	Yes	Yes
III	Ambient Air	Yes	No

COMBINED ANALYSES OF BOILER & TURBINE CYCLE

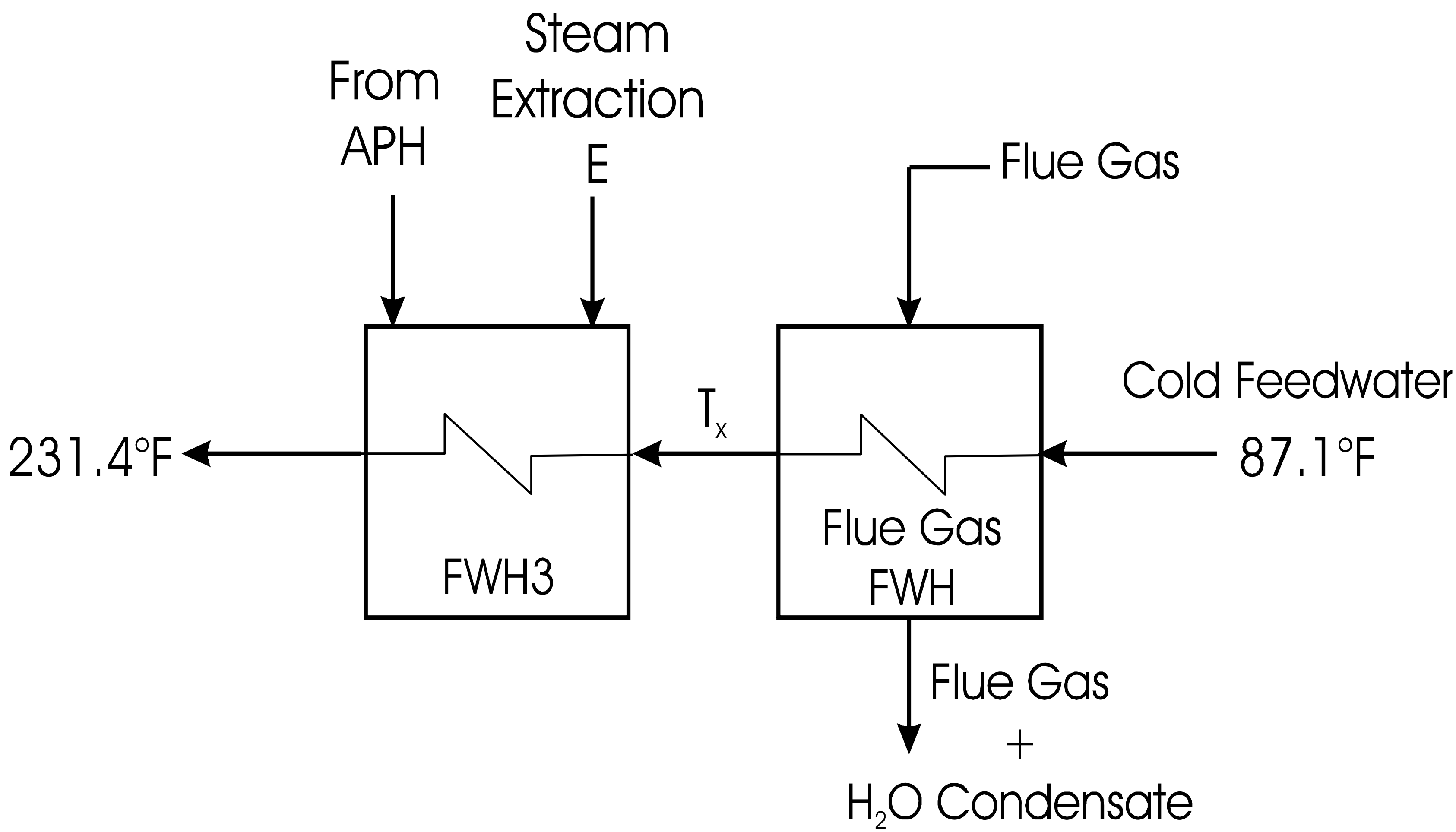



RHTR
3,677,525#
4,184,734#
1417.9H
3675PSIG
1000F
666.0P
1514.9H
1000F
655#
1543#
7484#
PRELIMINARY PRESSURE DISTRIBUTION
52,831#
1390.4H
1265.7H
740.0P
295.0P
165.1P
6881#
12,924#
184,533#
1416.2H
3882#
1352.9H
11.96P
87.4P
24.9P
4.66P
EXTRACTION ARRANGEMENT IS SCHEMATIC ONLY
GENERATOR OUTPUT
625,496 KW
0.90 PF
60 PSIG H_2 PRESS.
8478 KW GEN LOSSES
1926 KW FIXED LOSSES
114,535#
1137.4H
90,863#
1290.6H
TO RHTR
3,677,525#
1266.0H
233,214#
1352.9H
160.1P
1.25"Hg. Abs.
BFP
22,544 KW
233,214#
1023.1H
APH
41,847#
Make-up
2,395,202#
ELEP = 976.2H
UEEP = 1001.2H
1.25" Hg. Abs.
2400#
2,675,463#
85.9F
53.9h
S. S. R.
1304.1H
2800#
SPE
180.1h
6218#
90,863#
278.1h
4,226,581#
432,374#
1266.0H
506.9F
495.6h
-1F
TD
717.8P
505.9F
10FDC
432,374#
436.7F
415.4h
BFP
4615P
Δh=18.20
426.7F
408.6h
414.2F
390.4h
186,076#
1416.2H
-4F
TD
277.3P
410.2F
10FDC
618,451#
373.6F
346.8h
363.6F
336.3h
175,925#
1346.5H
0F
TD
160.1P
363.6F
10FDC
794,378#
324.4F
294.9h
314.4F
285.0h
257,172#
1290.6H
82.2P
313.8F
283.9h
OFTD
Booster Pump
375P
Δh=1.03
109,004#
1187.1H
5F
TD
231.4F
199.6h
23.4P
236.4F
10FDC
199,867#
203.8F
171.8h
193.8F
161.7h
120,754#
1146.0H
5F
TD
11.24P
198.8F
10FDC
320,621#
162.6F
130.6h
152.6F
120.5h
151.9F
119.7h
178,947#
1080.6H
5F
TD
4.40P
156.9F
499,568#
156.9F
124.7h
87.1F
55.1h



APH
E
F
G
90,863#
278.1h
109,004#
1187.1H
120,754#
1146.0H
178,947#
1080.6H
87.1F
55.1h
5 F TD
5F TD
5F TD
23.4P
11.24P
4.40P
231.4F
199.6h
193.8F
161.7h
152.6F
120.5h
151.9F
119.7h
236.4F
198.8F
156.9F
10FDC
10FDC
199,867#
320,621#
499,568#
203.8F
171.8h
162.6F
130.6h
156.9F
124.7h

Captured Sensible and Latent Heat Preheat Cycle Feedwater



- **Use captured sensible and latent heat to preheat cycle feedwater**
- **CHX reduces need for steam turbine extractions, increases MW output, and improves heat rate**
- **Preheating combustion air improves boiler efficiency**

GROUP I & II RESULTS

- **Flue gas water capture efficiency and heat rate depend on coal moisture content, inlet feedwater temperature, HX effectiveness, and ambient air temperature**
- **Heat rate reduction:**

  2.6 to 3.8 % (winter)

  1.8 to 3.1 % (summer)

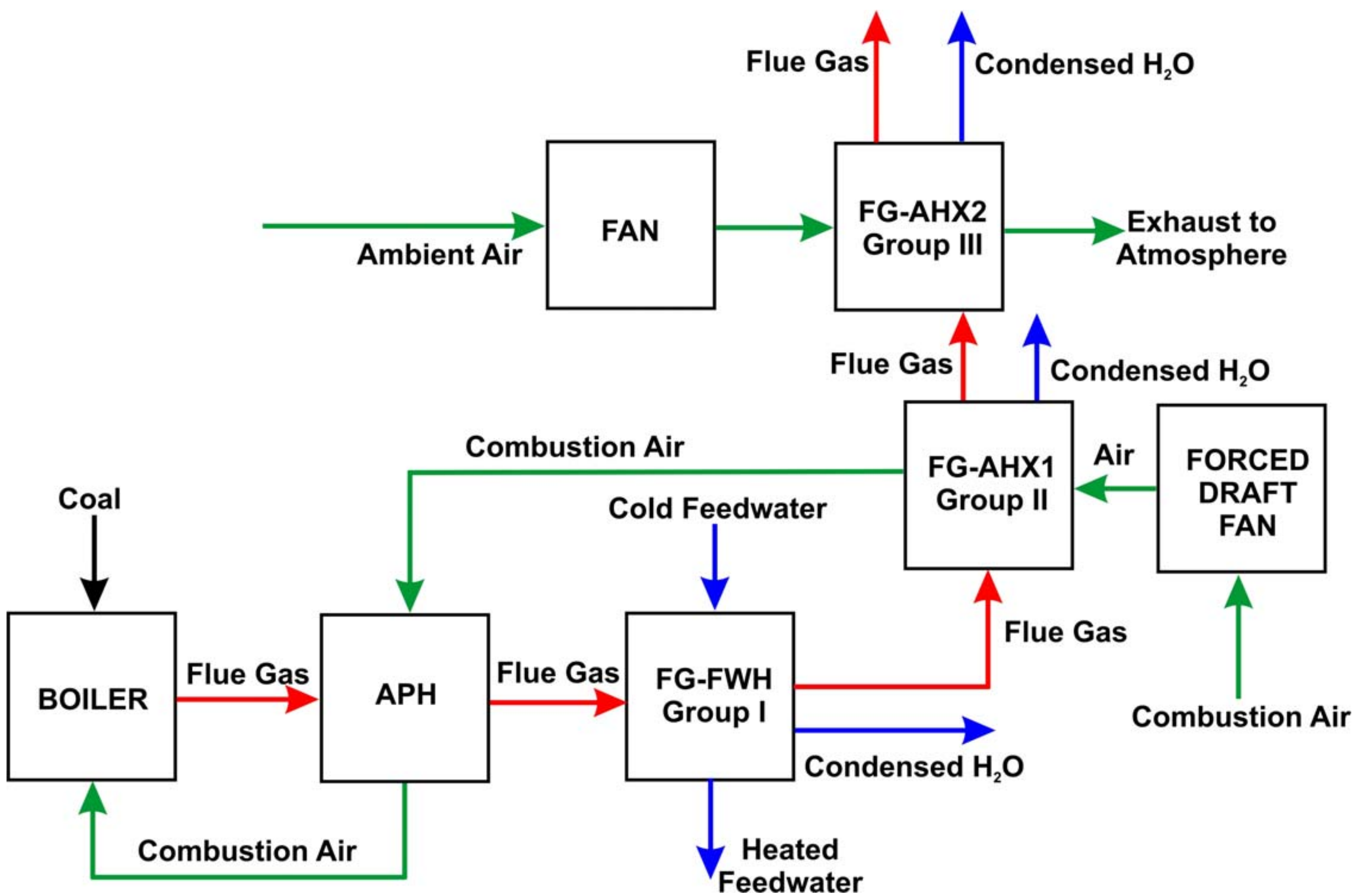
GROUP I & II RESULTS (continued)

- **Water capture efficiency:**

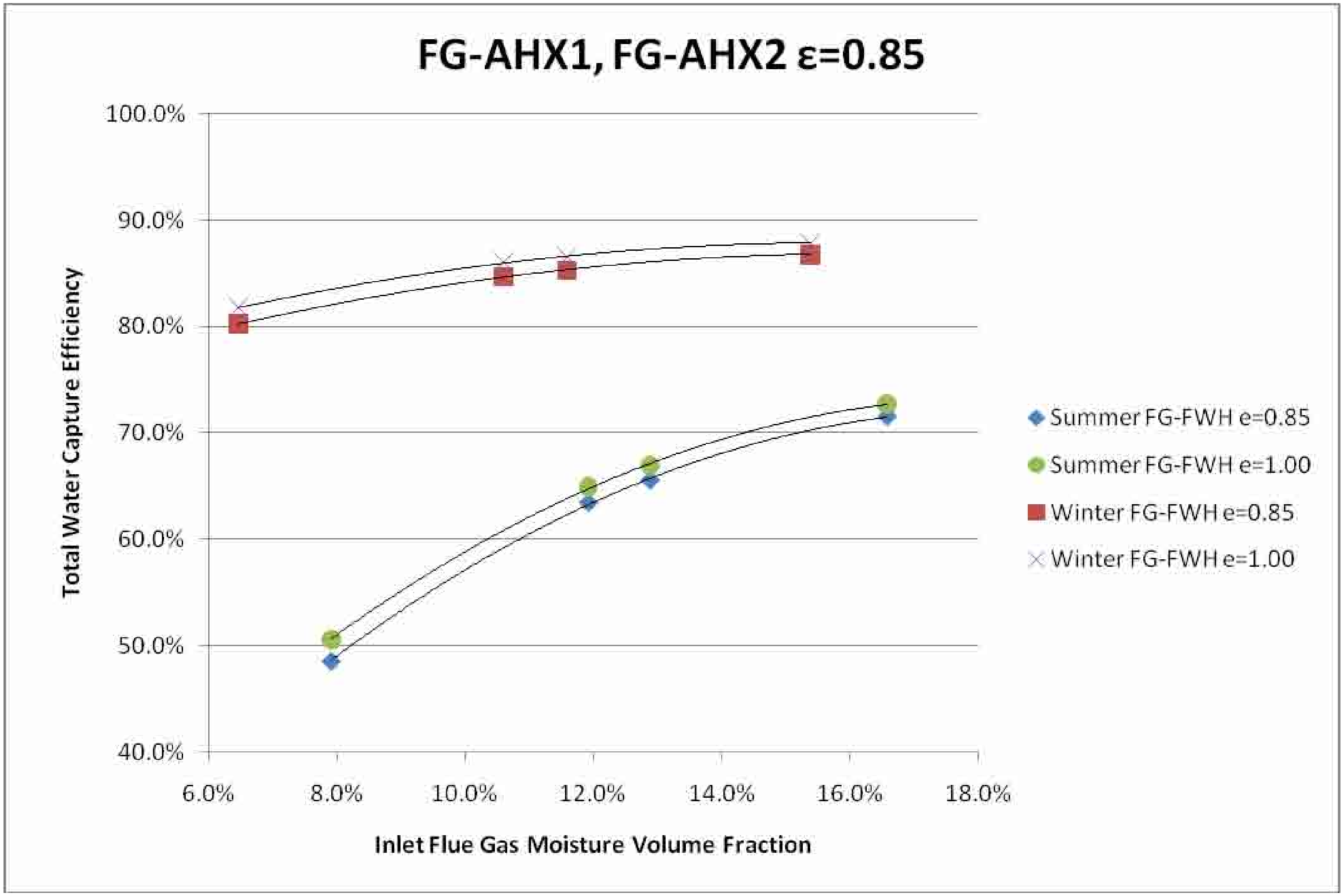
  21 to 34 % (winter)

  10 to 26 % (summer)

COMBINED ANALYSIS OF GROUPS I, II, & III



TOTAL WATER CAPTURE EFFICIENCY



INTERPRETATION OF RESULTS

- **Flue gas water capture efficiency increases greatly with addition of Group III HX, and it is strong function of coal moisture content and ambient air temperature.**
- **Water capture efficiency:**

  50 to 72 % in summer (77 F air)

  81 to 88 % in winter (33 F air)

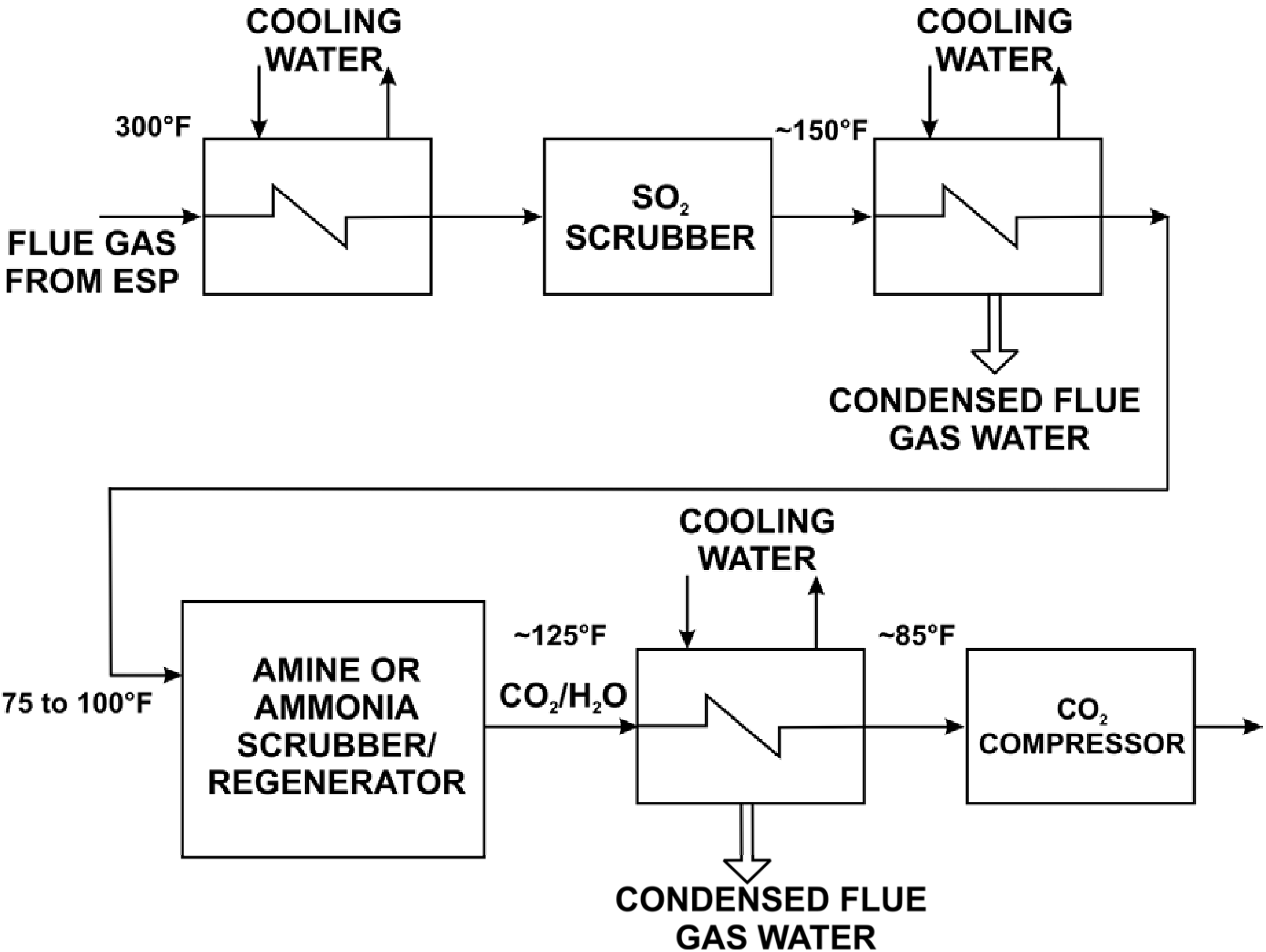
TOTAL MOISTURE RECOVERY AS PERCENT OF COOLING TOWER MAKEUP WATER

	Percent
Low Moisture Bituminous	6.4 to 8.5
PRB	14.1 to 16.5
High Moisture Lignite	22.2 to 24.8

POTENTIAL APPLICATIONS IN CARBON CAPTURE SYSTEMS

- **Reduce flue gas temperature, moisture content and acid concentrations ahead of amine or ammonia scrubbers**

- **Reduce moisture content of CO_2/H_2O mixture entering CO_2 compressor**


COOLING WATER
300°F
FLUE GAS FROM ESP
SO2 SCRUBBER
~150°F
COOLING WATER
CONDENSED FLUE GAS WATER
COOLING WATER
~125°F
~85°F
75 to 100°F
AMINE OR AMMONIA SCRUBBER/ REGENERATOR
CO2/H2O
CO2 COMPRESSOR
CONDENSED FLUE GAS WATER

WHAT'S NEXT?

- Project DE-NT0005648
- Recovery of Water from Boiler Flue Gas Using Condensing Heat Exchangers
- Funds also provided by Southern Company and Lehigh University

TASKS

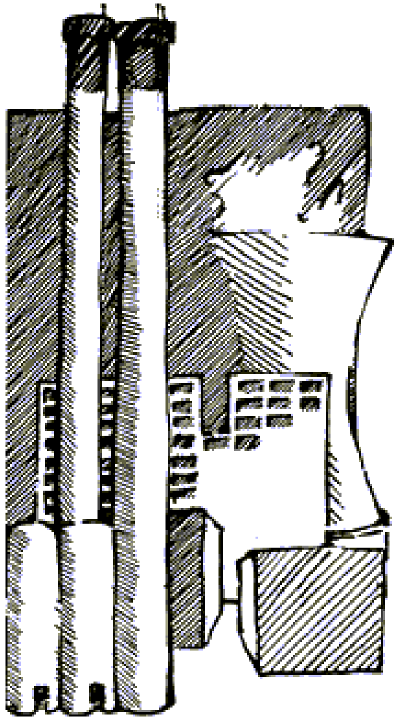
- **Develop techniques to enhance H_2SO_4 capture at high temperature end of CHX**
- **Perform additional field tests for H_2O, H_2SO_4 , HCl, HNO_3 and mercury capture.**
  - **> Unit with high sulfur coal and FGD**
  - **> Unscrubbed unit firing PRB**
- **Determine corrosion resistance of available corrosion resistant materials**
  - **> Laboratory corrosion tests**

WHAT'S NEXT (cont.)

- **Scale up heat exchanger design for commercial-size units**
- **Estimate capital costs**
- **Determine condensed water treatment needs**

POTENTIAL BENEFITS

- Water recovery
- Heat rate improvement
- Acid capture
- Hg removal
- Technology useful in CO_2 capture systems



THANK YOU!!!

QUESTIONS?

A Synergistic Combination of Advanced Separation and Chemical Scale Inhibitor Technologies for Efficient Use of Impaired Water as Cooling Water in Coal-Based Power Plants

Jasbir S.Gill

Nalco company

YuPo Lin and Seth Snyder

ANL

Nalco Company and Argonne National Laboratory

NETL Water and Power Plants Program 2008 Review Meeting

October 27, 2008, Pittsburgh, PA

Outline

- Introduction
- Technical Approaches
- Task Plan
- Progresses to Date
- Next Steps

Nalco Company Overview

- Nalco Company is a leader in water treatment with more than 70,000 customers worldwide
- Three business units
  - Industrial and Institutional
  - Paper
  - Energy
- Nalco produces & supplies chemicals, equipment and service for a wide range of customers including power plants

Project Overview

- Participants
  - Nalco Company, LEAD
  - Argonne National Laboratory, via CRADA (Nalco-Argonne CRADA #C0600501)
- Duration
  - 41 months (March 31, 2006 to August 30, 2009)
- Goal
  - To minimize fresh water use by using impaired water for cooling
- Technology needs
  - Scale control technologies for impaired water in recirculating cooling water systems at high cycles of concentrations
- Approach
  - Synergistic combination of physical and chemical technologies
    - Separation processes to reduce the scaling potential
    - Scale inhibitors to extend the safe operating range

Task Plan

- Phase 1: Technical Targets and Proof of Concept (Years 1 & 2)
  - Task 1: Identify Limiting Factors for High Cycles and Quantify Technical Targets (Months 1-12)
  - Task 2: Develop High Stress Calcite and Silica Scale Control Chemistries (Months 1-18)
  - Task 3: Develop Advanced Membrane Separation Technologies and Processes (Months 2-18)
- Phase 2: Technology Development and Integration (Years 2 and 3)
  - Task 4: Develop Additional Novel Scale Control Chemistries (Months 19-30)
  - Task 5: Develop and Integrate Separation Processes (Months 19-30)

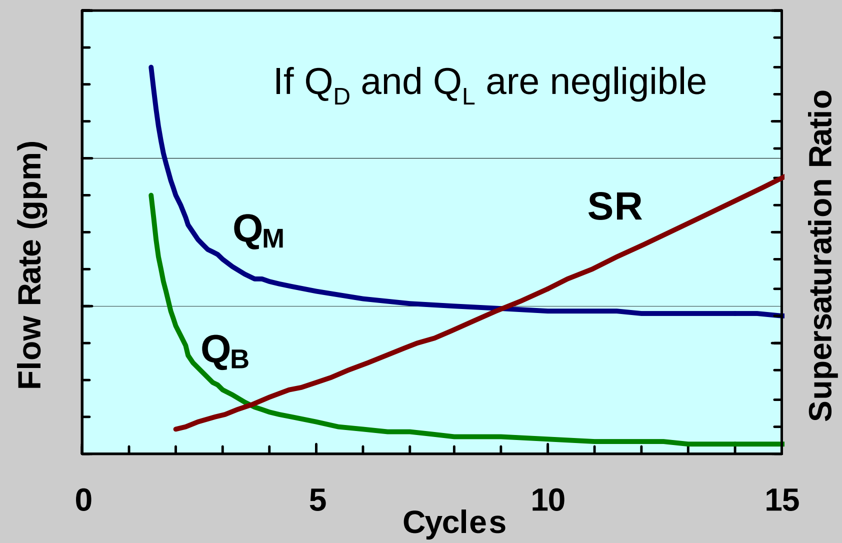
Task Plan (cont'd)

- Phase Three: Technology Validation (Years 3 and 4)
  - Task 6: Pilot Technology Demonstration (Months 30-41)
  - Task 7: Prepare Final Report (Months 40-41)

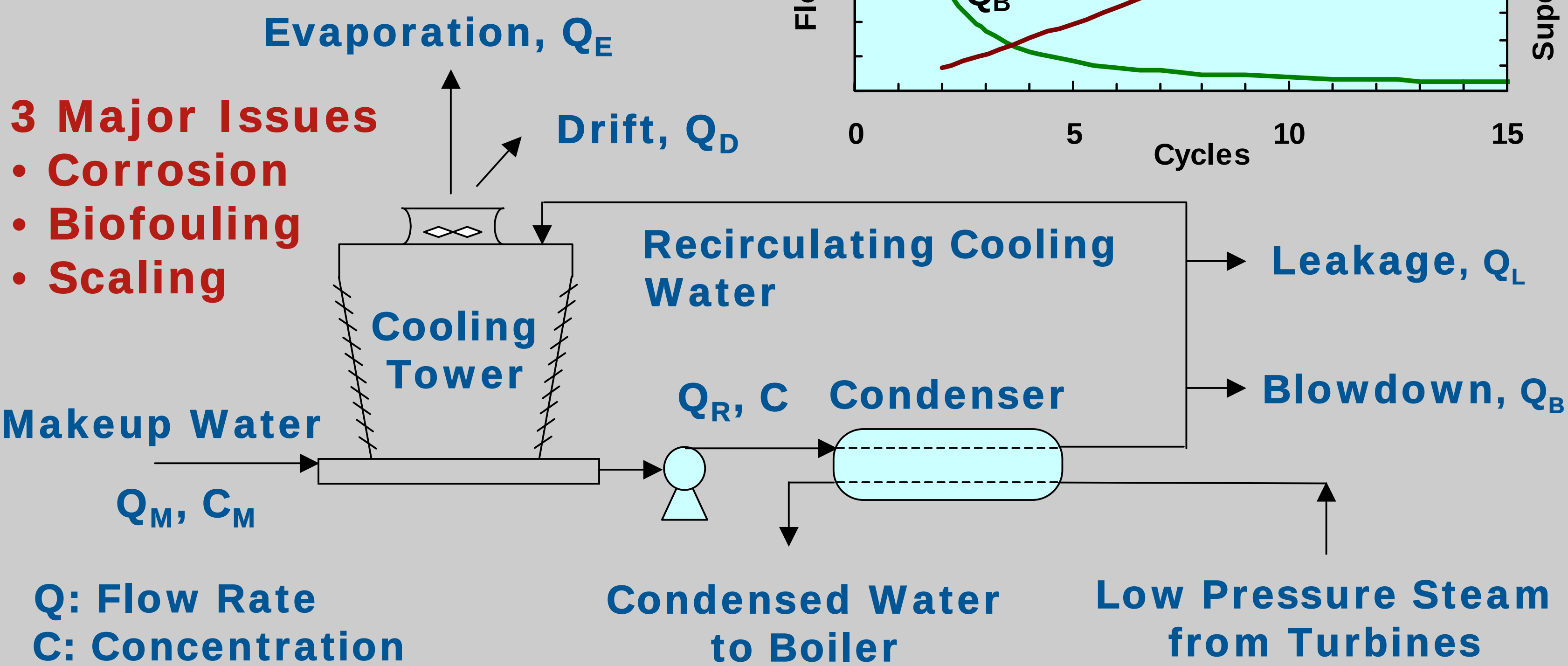
Open Re-circulating Cooling Water System

Cycles of concentration
$$= 1 + Q_E / (Q_B + Q_D + Q_L)$$

Scaling potential exists, if supersaturation ratio > 1



3 Major Issues
- Corrosion
- Biofouling
- Scaling

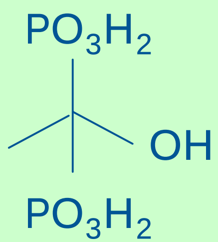


Q: Flow Rate
C: Concentration

Scale Inhibitors

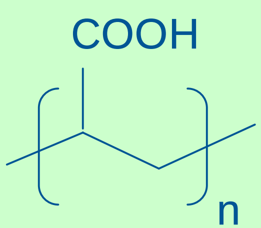
Chemistry

- Phosphonates



HEDP

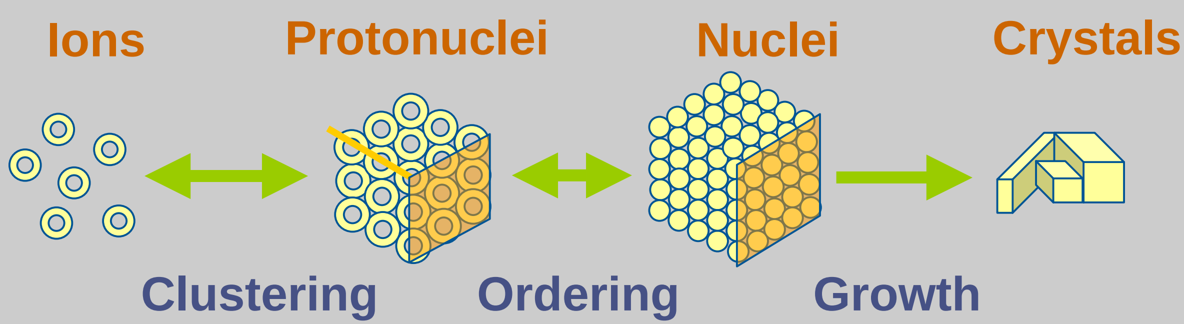
- Polymers



Polyacrylic Acid

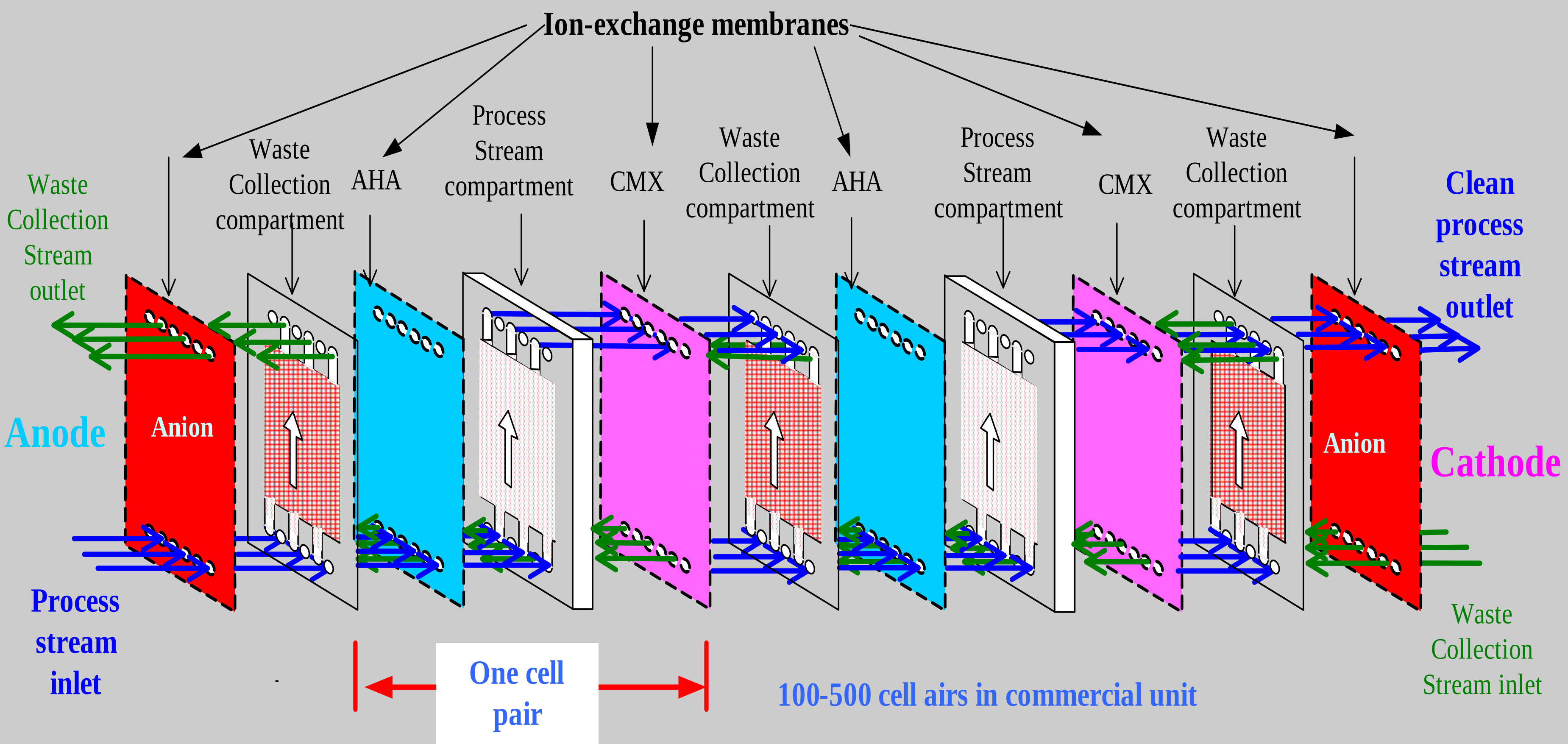
Mechanisms

- Threshold Inhibitors
  - Delay the ordering process
- Crystal Modifiers
  - Form irregular crystals that are less adhering
- Dispersants
  - Keep crystals suspended in water



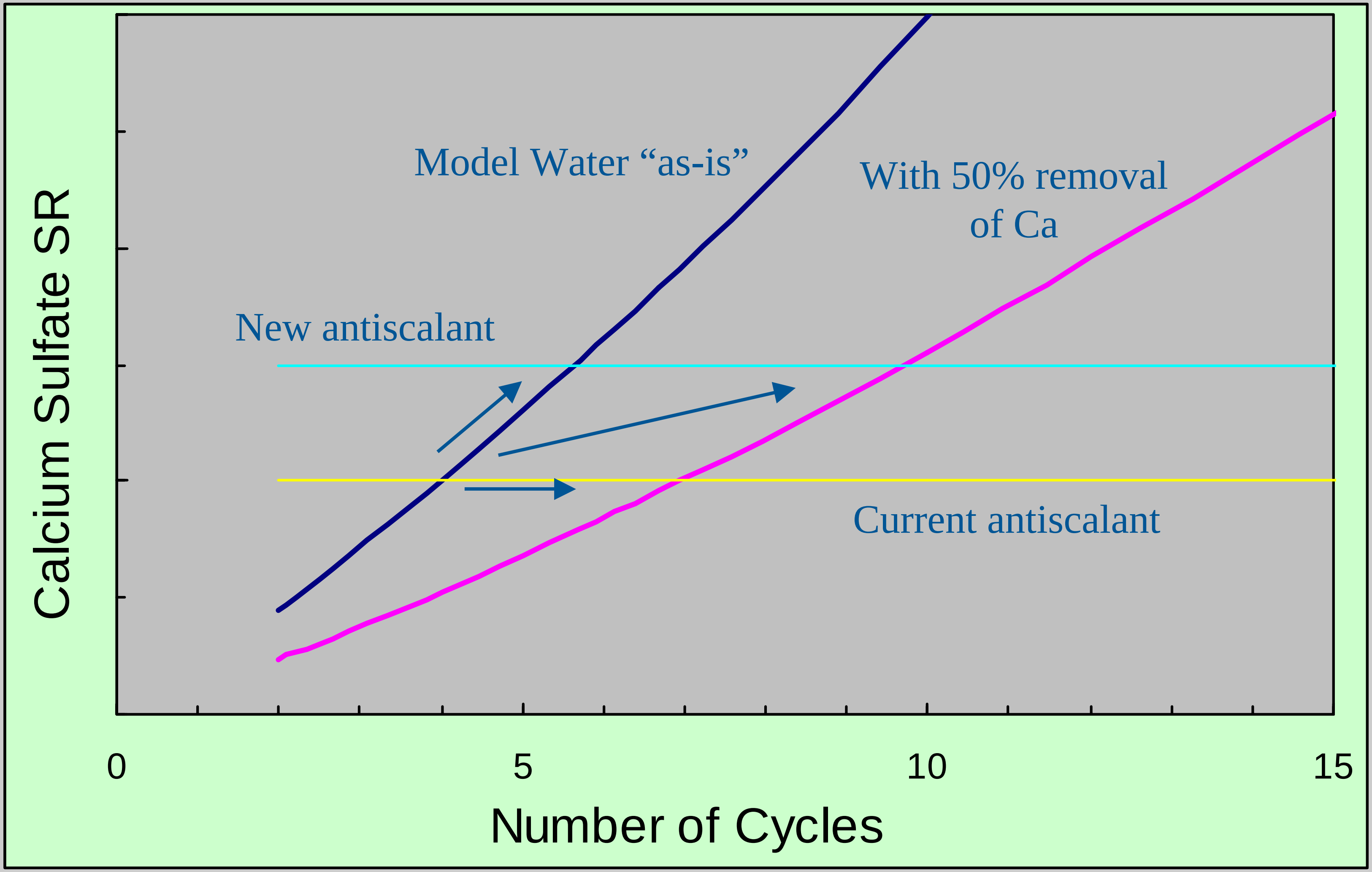
Stages of Crystallization

ED and RW-EDI Technologies



Synergy of Separations and Scale Inhibitors

Model Water: Agricultural Drainage Water in California (EPRI and CEC, 2003)



Task 1 Progress Update

- Reviewed Literature and existing Nalco data on characteristics of impaired waters.
  - Produced water
  - Municipal secondary effluent
- Additional target impaired waters were identified and samples collected for analysis
- Calculated of scaling limitations of impaired.

Typical Produced Water Characteristics

Reference	Tsai (1995)		Nalco	EPRI & CEC (2003)	EPRI (2004)	
Location	Site B	Site C	Gillette, WY	Central Valley, CA	McGrath, NM	Fairway, NM
Type		CBM	CBM	Oil Well	Mixed	CBM
pH	7.6	7.2	8.1	7.9	7.1	8.0
TDS, mg/L	8,000	14,700	4,000	3,879	12,714	12,236
Na, mg/L	2,640	6,200	870	982	4,149	3,620
Ca, mg/L	18.9	22.1	44	40	143	31.0
Ba, mg/L	10.1	27.2	1.5		3.1	25.1
Fe, mg/L	3.87	3.16	0.6		41	4.87
Cl, mg/L	18.9	1,920	25	920	6,298	2,018
SO4, mg/L	6.9	10.6	0	110	544	4.3
HCO3, mg/L	1,976	11,700	2,684	1,100	765	6,381
SiO2, mg/L			15	120	18.5	21.4

Typical Municipal Secondary Effluent Characteristics

Reference	Nalco			EPRI & CEC (2003)
Location	OCWD, CA	DDSD, CA	Naperville, IL	Bay Area, CA
pH	7.8	8.0	7.9	7.0
TDS, mg/L	940	1190	555	869
Na, mg/L	230	248.3	88.0	76
Ca, mg/L	82.0	52.1	64.0	76
Fe, mg/L	0.55	0.19	0.08	
Al, mg/L		0.4		
Cl, mg/L		290.5	120	102
SO4, mg/L		220.8	60	68
PO4, mg/L	2.5	0.6	2.0	6.0
HCO3, mg/L		305	171	1100
SiO2, mg/L	26.0		8.3	17

Scaling Limitations

- Common cycle-limiting species
  - Calcium carbonate
  - Silica/silicate
    - With co-presence of high silica
  - Calcium sulfate
    - Often due to sulfuric acid for pH control
  - Calcium phosphate (municipal effluent)
  - Iron and aluminum
- Challenges vary for each impaired water and power plant

Proposed Technical Strategy

Universal methodology to develop case-specific solutions

- Recognize and address interdependence of scaling/corrosion/biofouling
- Use model to select and control operating conditions, such as pH and cycles of concentration
- Address scale control and blowdown management simultaneously
- Use combination of different technologies for scale control, including scale inhibitors, separation technologies and cooling tower operations
  - Need a well-equipped technology tool box

Task 2 Progress Update

- Scale control chemistries for high stress calcite and silica control
- Silica/silicate
  - Laboratory screening of candidate chemistries completed
  - Selected promising candidate
  - Completed two field trials at Coal fired PP using the selected molecule
- Calcite/Calcium sulfate control
  - Candidate chemistries identified
  - Laboratory screening completed
  - Field trial completed at ZLD

Established the Limits of Chemical Treatment

Silica Scale

- Silica is often the limiting factor in impaired waters
- It is often encountered in both hot surfaces and cold surfaces
- Silica scales are tenacious, insulating, and difficult to remove.

- Silica deposition is caused by:
  - polymerization
  - precipitation with multi-valent ions
  - co-precipitation with other minerals
  - biological activity

Silica deposition processes occur simultaneously, and all must be controlled.

Calcium Carbonate

Different polymorphs are formed depending on the temperature, salinity and presence of multivalent ions in the brine

- Less soluble at higher temperature and higher pH

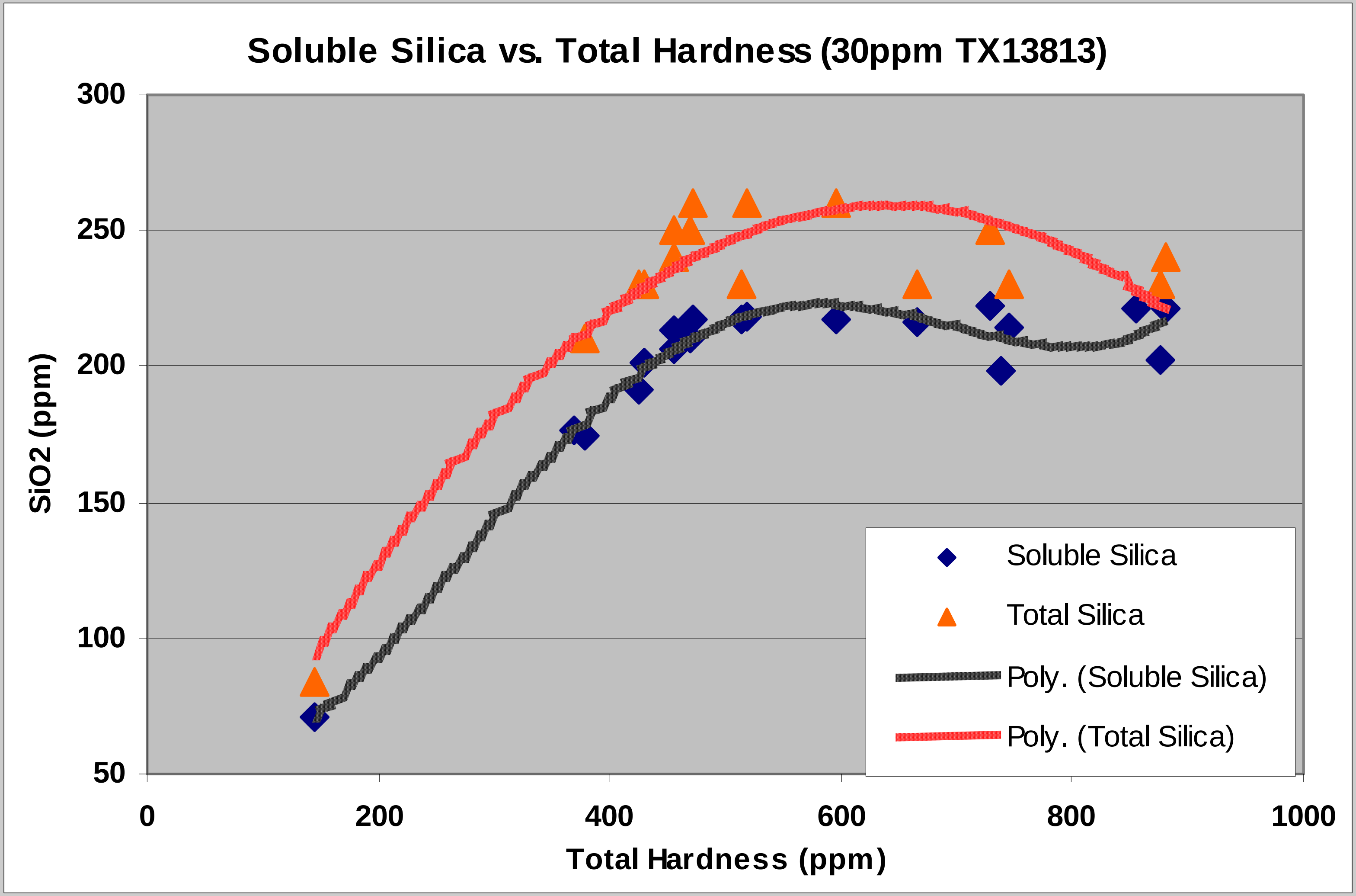
Can be controlled by either acid or scale inhibitor

Laboratory Study

Beaker Study

Time (minutes)	Silica SiO_2 PPM: No Inhibitor	Silica SiO_2 PPM: 20PPM Inhibitor
0	300	300
10	230	300
20	180	300
30	160	290
45	150	280

Laboratory Study



Phase 2 &3 Progress

Field Study

1. Coal Fired Western PP with ZLD
2. South Western Power Plant limited by Silica

Case Study 1

- Coal Fired with Total of >500 Megawatts electric output.
- There are multiple units each> 100MW generating capacity.
- The cooling towers operate at 7-8 cycles and is a ZLD facility with on site evaporative pond.
- The source of make up water (30-35 PPM as SiO_2) is a blend of River water and well water stored in Ponds.
- The towers have PVC Splash fill.

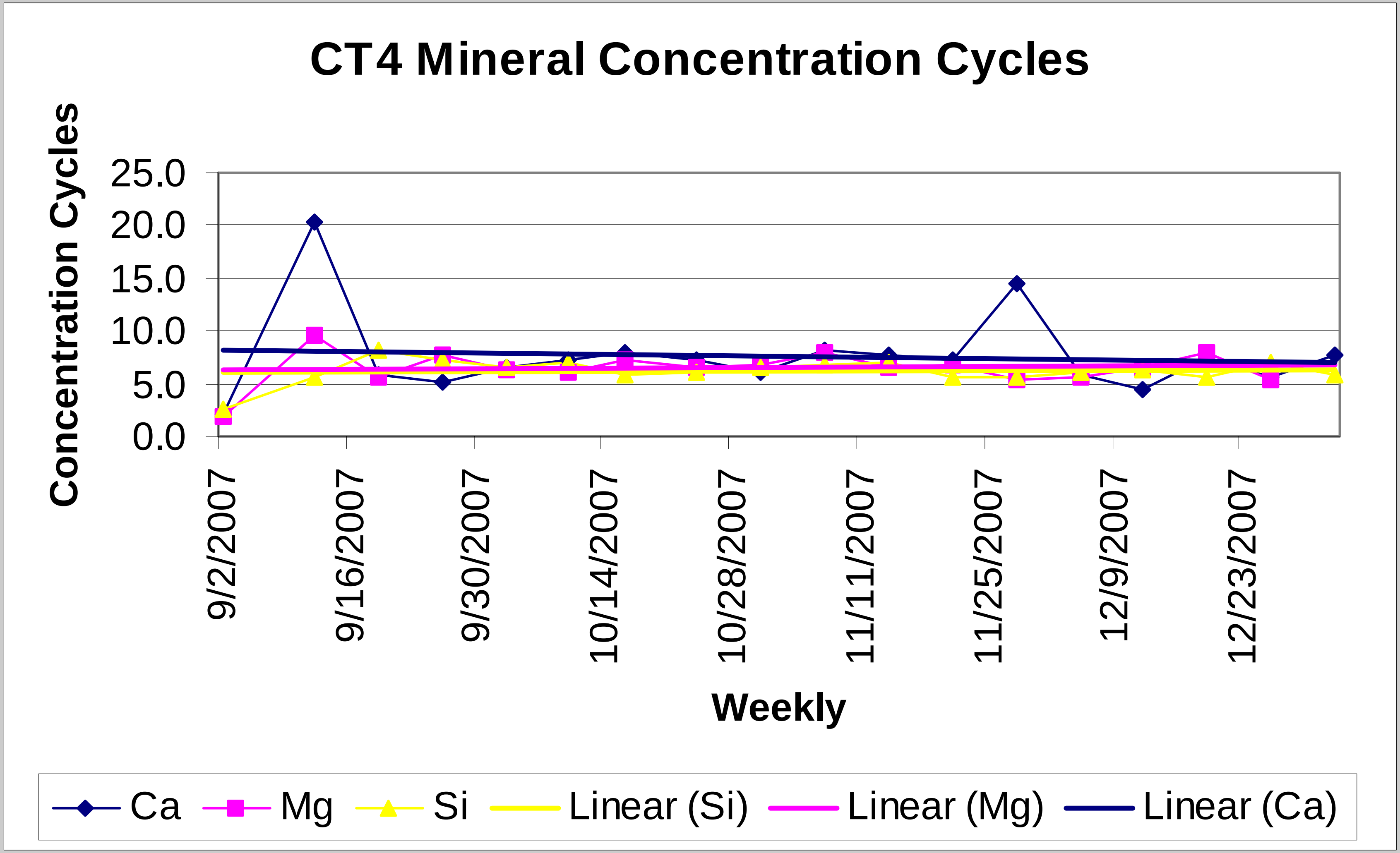
Chemical Treatment

3DT195	40 PPM (Tag control)
3DT199	5 PPM (slaved)
TX138813 (silica inhibitor)	20 PPM (Slaved)
Bleach	0.43 ppm FRH (ORP control)

Tower Chemistry

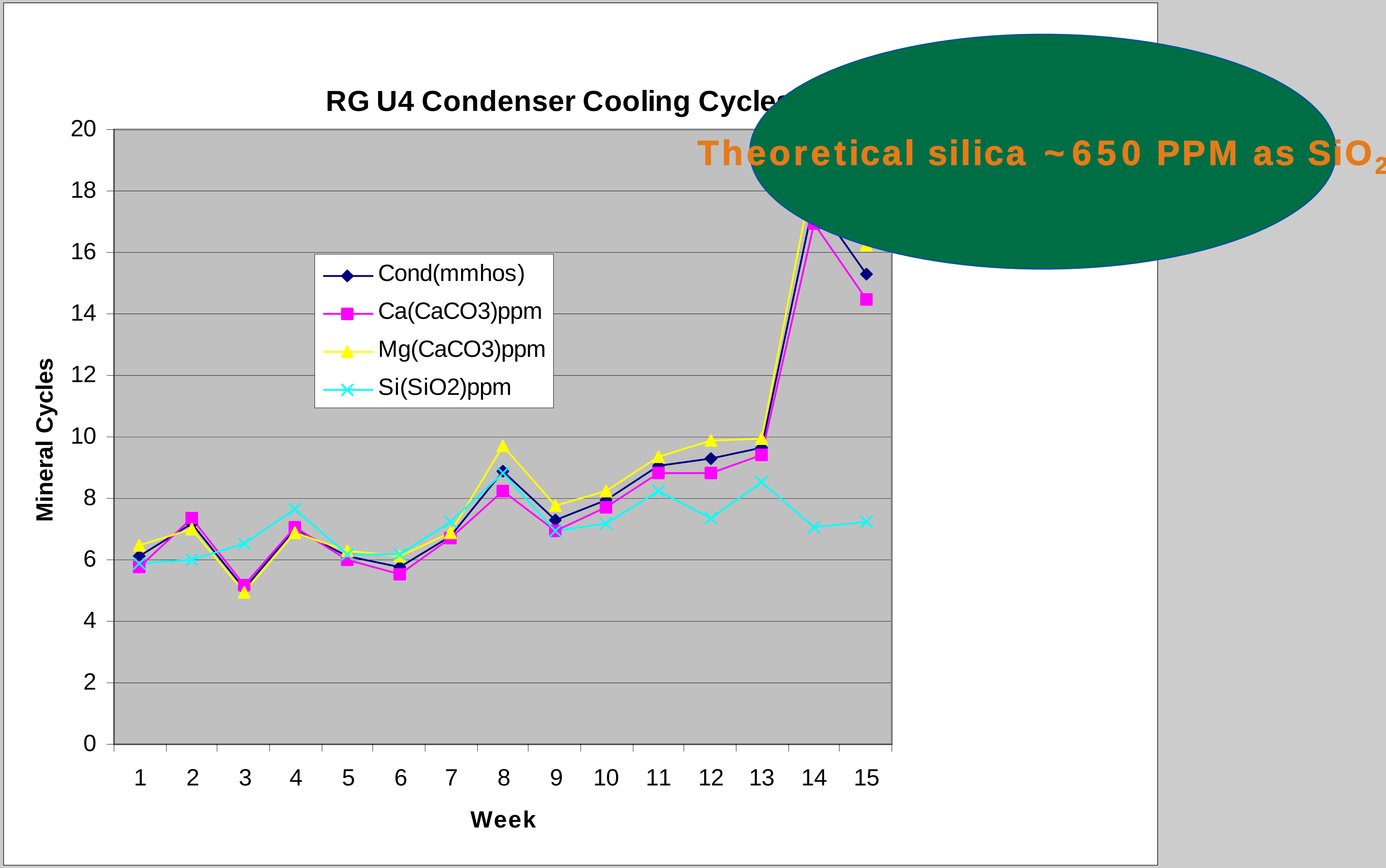
Tower Chemistry	Value	Unit
pH	7.6	Unitless
Calcium	378	ppm as Ca
M Alkalinity	71	ppm as $CaCO_3$
Conductivity	6,860	µS/cm
Aluminum	0.0	ppm Al
Ammonia	0.0	ppm NH_3
Chloride	494	ppm Cl
Iron	0.0	ppm as Fe
Magnesium	182	ppm Mg
Manganese	0.0	ppm Mn
Silica	224	ppm SiO_2
Sulfate	2,544	ppm SO_4
Turbidity	35	NTU

Unit 4 Cycles of Concentration



Upset Conditions(BD)

(Conductivity from 6200 to 18590 US/Cm)



Heat Exchanger After the Upset

Performance of LL99B0
(Calcium carbonate Control)

Comparison of Inhibition at 300X Calcite Supersaturation, pH 9.0, Temperature 55 °C

Inhibitor	Active Dose PPM	% Inhibition
AMP	25	41
HMDTMP	25	55
PBTCA	25	57
HEDP-AMP-AA/AMPS Copolymer	23.4	60
LL99B0	25	100
PMA	25	56
AEC	25	62

Performance of LL99B0

Mixed calcium carbonate and calcium sulfate inhibition with LL99B0, pH 7.5 250 °C; SO4 1500 PPM

Inhibitor	Dose PPM	% Inhibition at various Calcium PPM			
		50	100	500	1000
PAA	5	100	100	60	0
	10	100	100	60	0
PMA	5	100	80	70	0
	10	100	80	60	0
LL99B0 & Polymer	5	100	100	100	72
	10	100	100	100	89

Western Coal Fired PP ZLD

>400 MW Net Coal Fired Power Generation station

Water Recirculating Rate varied between 100,000-200,000 GPM

Make up water source is river water

Automated Blow down based on conductivity and Calcium level at a rate of 280-312 GPM (average)

HTI ~ 168 hours; 11-12 cycles of concentration

High Efficiency Fill

Typical Tower Water Chemistry

Ion/parameter	PPM	Ion/parameter	PPM
pH	7.6-8.0	Sulfate	3600-4200
Conductivity (uS/Cm)	6300-6500	Sodium	650-725
Calcium	1600-1700	Silica	65-110
Magnesium	1000-1200	Total Phosphate	8.1-8.9
Alkalinity	70-90	O-Phosphate	5.1-5.7
Chloride	375-425	Turbidity (ntu)	2.1-2.3

Task 3 Progress Update

- Feasibility of membrane separation technologies
  - Electrodialysis and electrodeionization (Argonne lead)

- Task started when CRADA with Argonne was signed

- Key technical issues
  - Selectivity
  - Energy consumption
  - Flux
  - Scale control

Tasks 5.2 and 5.3 Membrane Separation Technology Feasibility Evaluation

1. Evaluation electrodialysis (ED) membrane separation to remove hardness from impaired water
   - Screen ion-exchange membrane
   - Evaluate energy cost for processing stream

2. Evaluation of Resin Wafer ElectroDeionIzation (RW-EDI) membrane separation to remove alkalinity and in-situ pH control for impaired water
   - Screen and optimize resin wafer
   - Optimize EDI stack configuration for pH-control and maximum alkalinity removal

3. Integration evaluation of EDI and heat-exchanger system

Compositions of Simulated Waters

Feed Compositions

Water #	1A	1B	2A	2B	3A	3B	
Water simulated	High Hardness Water	High Hardness Water	Produced Water (Gilette, WY)	Produced Water (Gilette, WY)	Produced Water (Fairway, NM)	Produced Water (Fairway, NM)	
Stream simulated	Make-up	Side Stream at 10 cycles with 50% Removal of Calcium and Magnesium at pH 7.5	Make-up	Side Stream at 10 cycles and pH 8.0	Make-up	Side Stream at 10 cycles and pH 8.0	Molecular Weight, g/mole
Application #	1	1	2	2	2	2	
Analyses							
Calcium, mg/L as Ca	70.0	350.0	0.0	0.0	0.0	0.0	40
Magnesium, mg/L as Mg	19.0	95.0	0.0	0.0	0.0	0.0	24.3
Sodium, mg/L as Na	275.0	2750.0	1045.0	1345.0	3800.0	15500.0	23.0
Chloride, mg/L as Cl	390.0	3045.0	50.0	500.0	2000.0	20000.0	35.5
Sulfate, mg/L as SO4	192.0	2739.0	0.0	0.0	0.0	0.0	96
Bicarbonate, mg/L as HCO3	121.5	121.7	2655.0	2662.9	6405.3	6395.2	61
Carbonate, mg/L as CO3	0.3	0.5	22.5	24.2	82.9	168.4	60
Carbon dioxide, mg/L as CO2	4.7	3.6	30.5	29.8	61.5	44.7	44
Total dissolved solids, mg/L	1079.0	9099.0	3785.1	4505.1	12285.1	42065.1	
pH	7.5	7.5	8.0	8.0	8.0	8.0	
Temperature (oC)	25.0	25.0	25.0	25.0	25.0	25.0	

Applications
#1: Preferential removal of calcium over sodium using ED
#2: Removal of alkalinity without acid using WSED or EDI

Cations (mN)	17.02	144.88	45.43	58.48	165.22	673.91
Anions (mN)	16.99	144.85	45.68	58.55	164.11	673.83
NaCl equivalent (mg/l)	995	8475	2665	3423	9633	39422

Results of Feasibility Evaluation

Hardness Removal from 10X blowdown and makeup water

Hardness is preferentially removed compared to mono-valent ions

Process Range Salt content (inlet - effluent)	Salt Removal (%)	Power consumption (kWh/100 gal water)
9000 ppm to <10 ppm	> 99%	3.0
1000 ppm to < 15 ppm	>98%	0.45

NALCO

Results of Feasibility Evaluation

Alkalinity Removal & pH Adjust

Process Range	Salt Removal	Power consumption	effluent pH
Salt content (inlet - effluent)	(%)	(kWh/100 gal water)	
4000 ppm to <40 ppm	> 99%	3-5	5 5-7.0.
500 ppm to < 40 ppm	>94%	1-2	5.5-7.0

Assessment of Pre- and Post-Treatment of Water Reused for Heat-Exchanger

Impaired Water gal/day	**100,000**	
	Blow-down water	Make-up water
Process Concentration (inlet - effluent)	5000 - 500 ppm	500 - 50 ppm
Power consumption wkh/100gal	5.00	1.00
Effluent pH	6.0-7.0	5.5-6.5
Estimated Capital cost	$ 150,000	$ 500,000
Electricity KW	300	60

REUSE OF INTERNAL OR EXTERNAL WASTEWATERS IN THE COOLING SYSTEMS OF COAL-BASED THERMOELECTRIC POWER PLANTS

Radisav Vidic
University of Pittsburgh

David Dzombak
Carnegie Mellon University

October 27, 2008

OVERVIEW

- Project goal
- Background and regulatory information
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  - Pilot-scale studies
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PROJECT GOAL

- Assess potential of three different impaired waters for use in recirculating cooling water systems
  - secondary-treated municipal wastewater
  - passively-treated coal mine drainage
  - ash pond effluent

NONTRADITIONAL SOURCES OF COOLING WATER: TREATED MUNICIPAL WASTEWATER

- 11.4 trillion gallons of municipal wastewater collected and treated annually in U.S.
- Experience with use of treated municipal water for power plant cooling in arid west; e.g., Burbank, Las Vegas, Phoenix
- Significant additional treatment beyond secondary treatment (e.g., clarification, filtration, N and P removal)

NONTRADITIONAL SOURCES OF COOLING WATER: PASSIVELY-TREATED AMD

- Significant flows of abandoned mine drainage (AMD) in coal mining regions
- NETL has confirmed magnitude and reliability of AMD as source of cooling water
- Adequate treatment (to raise pH, remove dissolved solids and metals) prior to use is largest concern
- Passive treatment systems offer potential for inexpensive source of cooling water

NONTRADITIONAL SOURCES OF COOLING WATER: ASH POND EFFLUENT

- Water-ash slurry systems used commonly to remove bottom ash and fly ash
- Slurry is directed to ponds where settling of ash particles occurs
- Slurry water is often discharged
- Potential to reuse the slurry water in the slurry system and as cooling system makeup water

PROBLEMS WITH USE OF IMPAIRED WATERS

- Precipitation and scaling
- Accelerated corrosion
- Biomass growth

Review of Regulations Relevant to Reuse of Impaired Waters

- The basis of reusing water.
- Cooling tower blowdown discharge.
- Air emissions when using impaired waters.
- Transporting wastewater across boundaries (interstate or intrastate).

Franklin Township Municipal Sanity Authority, Murrysville, PA.

Basis for Water Reuse

- None of the current regulations directly prohibit the use of reclaimed water as power plant cooling water.

In the “Guidelines of U.S. Water Reuse” (2004), USEPA suggested the treatment requirements and standards for reclaimed water reutilized as cooling water in thermoelectric systems.

Cooling Tower Blowdown Discharge

- Clean Water Act (CWA) §402, EPA establishes the National Pollutant Discharge Elimination System (NPDES), which requires that all point source discharges of pollutants to surface waters must be authorized by NPDES discharge permits. Limits in NPDES permits can be technology-based or water quality based.

Depending on technologies adapted in cooling tower design, the concentrations of available chlorine, chromium, and zinc are likely to be confining factors.

Control of Air Emissions

- Aerosols are the major concern for cooling tower emissions
- In National Ambient Air Quality Standards (NAAQS) and Regional Haze Regulations," (EPA, 2005), cooling towers are categorized as potential point sources of pollutants emission with volatile organic compounds, PM10, PM2.5, and NH_3
- Possible issues with emissions of concentrated metal and chemicals

Transporting Wastewater Across Boundaries

- One potential approach that may alleviate severe water shortages in drought areas, such as Arizona, Texas, and Florida, is to transfer natural or treated water from other regions where it may be available in larger quantities

- Most transfer events between states were evaluated on a case-by-case basis and records indicate few prohibitions against water transfer

SUMMARY – Task 1

- Existing regulations do not prohibit the use of impaired waters for cooling purposes. Regular monitoring and evaluation is required to meet the discharge and air emission regulations.

- Cases of interbasin transfer showed that most transfer events were evaluated on a case-by-case basis without explicit prohibition.

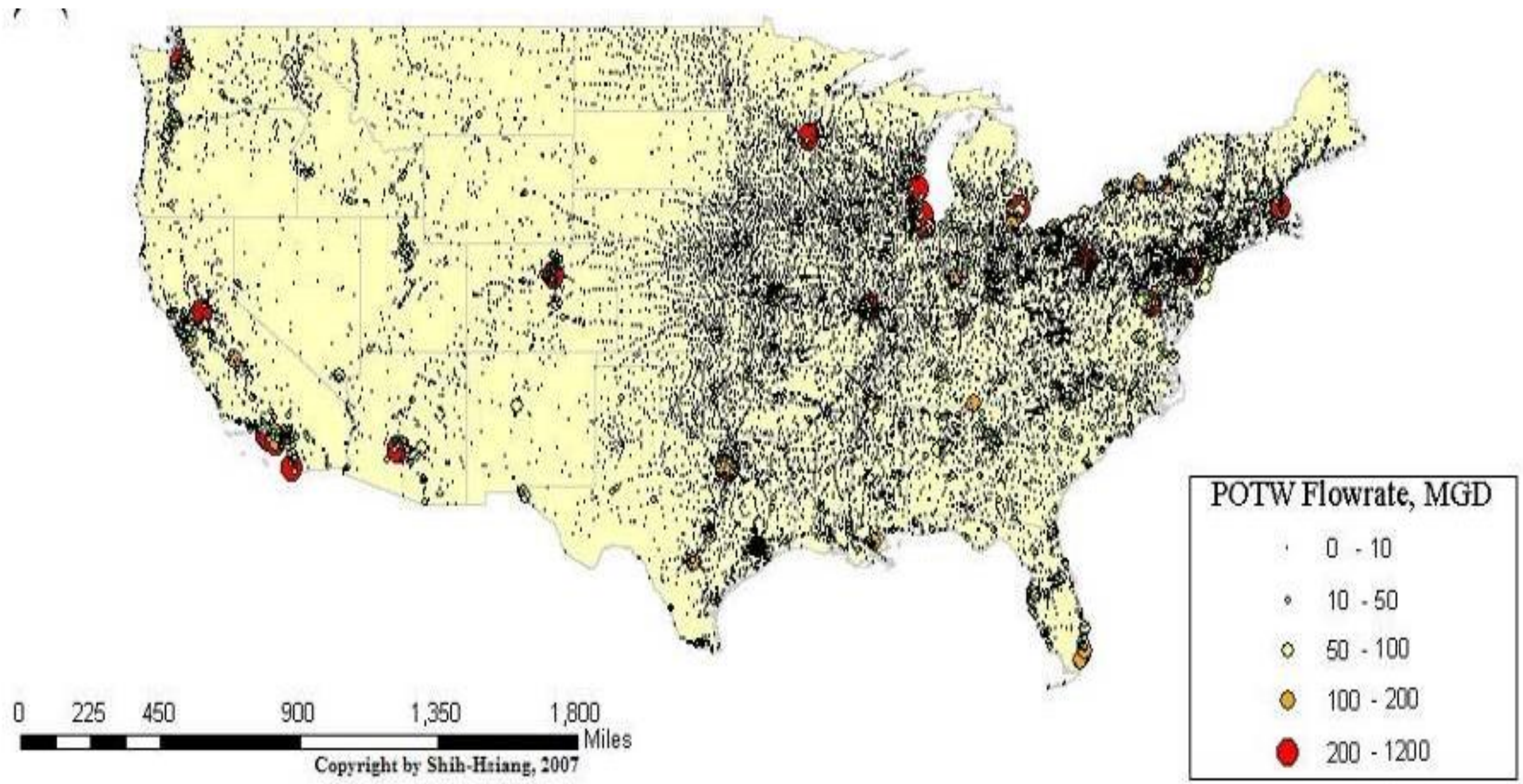
Feasibility Analysis of Using Wastewater in Cooling Towers

Assess availability of impaired waters (quantity and proximity) to meet cooling needs of coal-based thermoelectric power plants:

- Build a scenario of water supply: Construct a map of publicly owned treatment plants on GIS.
- Build a scenario of water demand: Develop an equation to estimate the water demand for a proposed power plant.
- Spatial analysis: Use the GIS map to evaluate the potential wastewater flowrate within a specific range of each proposed power plant.
- Compare available wastewater flowrate and estimated water needed for proposed power plants.

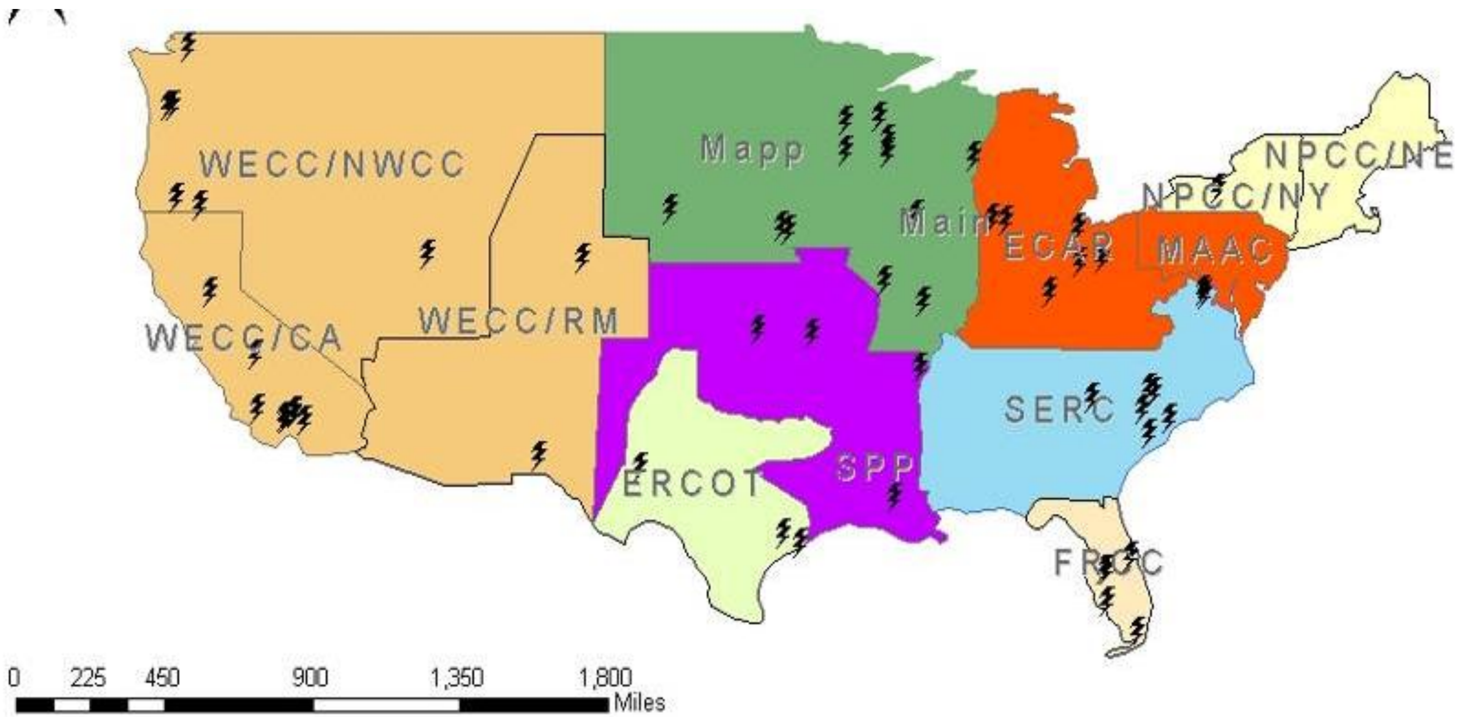
Inventory of Available Wastewater

A GIS-based tool is developed to assess the availability of secondary effluent from publicly owned treatment works in the continental U.S. Digital geographic map containing 17864 publicly owned treatment works in the lower 48 states is developed as potential water supply.



Inventory of Water Needs

- The 110 proposed power plants are from EIA annual report 2007.
- U.S. is divided into 8 major NERC regions (shown in color) and 13 minor regions.



Estimation of Water Needs

Project a list of proposed power plants as water demander layer on the same GIS map

→ Build an equation to estimate the cooling water need based on generating capacity

- A total of 110 power plants proposed in 2007 was used to assess water demand.
- Water needed for power generation is 1.2 gallon per kWh.
- The equation for estimating cooling water need:

Water needed =

Capacity (kW)*1.2 (gal/kWh)* 24 (hr)*0.75 (Load factor)

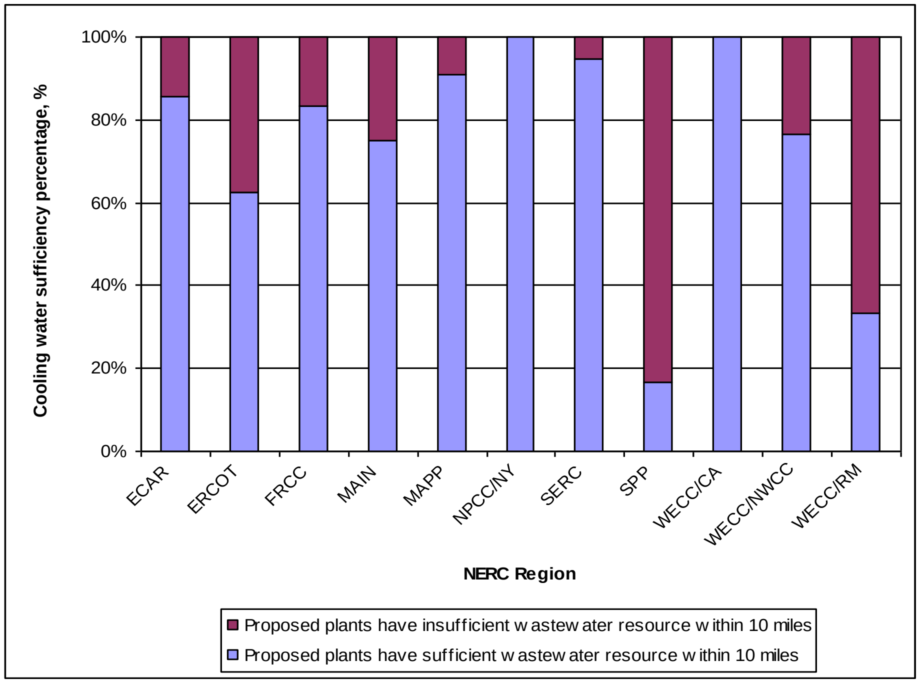
Supply vs. Demand

Region	Total Daily Cooling Water Need, MGD	Total Daily Wastewater Flow rate, MGD	Percentage of Available Wastewater needed for cooling, %
ECAR	27.5	4873	0.56
ERCOT	15.0	1993	0.76
FRCC	42.9	1374	3.12
MAIN	1.6	3318	0.05
MAPP	25.7	1167	2.20
NPCC/NY	0.1	1112	0.01
SERC	28.2	3915	0.72
SPP	17.5	2077	0.84
WECC/CA	22.5	3636	0.62
WECC/NWCC	44.9	1910	2.35
WECC/RM	9.3	1061	0.88

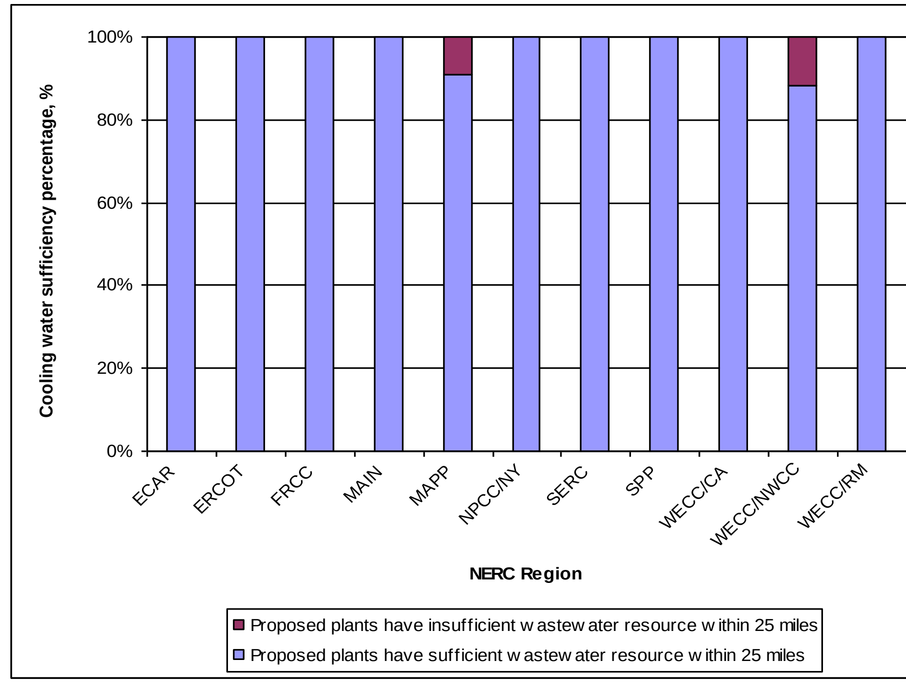
How many POTWs are needed to satisfy the cooling water demand?

Region	Proposed power plants that have sufficient wastewater within 10 mi to satisfy their cooling water needs, %	Average number of POTWs within a 10 mile radius of a proposed power plant	POTWs needed to satisfy cooling water needs within a 10 mile radius
ECAR	86	2.9	1.1
ERCOT	63	3.0	1.2
FRCC	83	4.6	1.4
MAIN	75	7.0	1.0
MAPP	91	3.1	1.0
NPCC/NY	100	4.0	1.0
SERC	95	2.1	1.0
SPP	17	2.0	2.0
WECC/CA	100	4.9	1.0
WECC/NWCC	76	2.8	1.0
WECC/RM	33	2.0	1.0

How many POTWs are needed to satisfy the cooling water demand?



Percentage of proposed plants which have sufficient wastewater within 10 mi



Percentage of proposed plants which have sufficient wastewater within 25 mi

Summary – Task 2

- POTWs located within 10 and 25 mile radius from the proposed power plants can satisfy 81% and 97% of power plant cooling water needs, respectively.
- On average, one fairly large POTW can completely satisfy the cooling water demand for each of these power plants.

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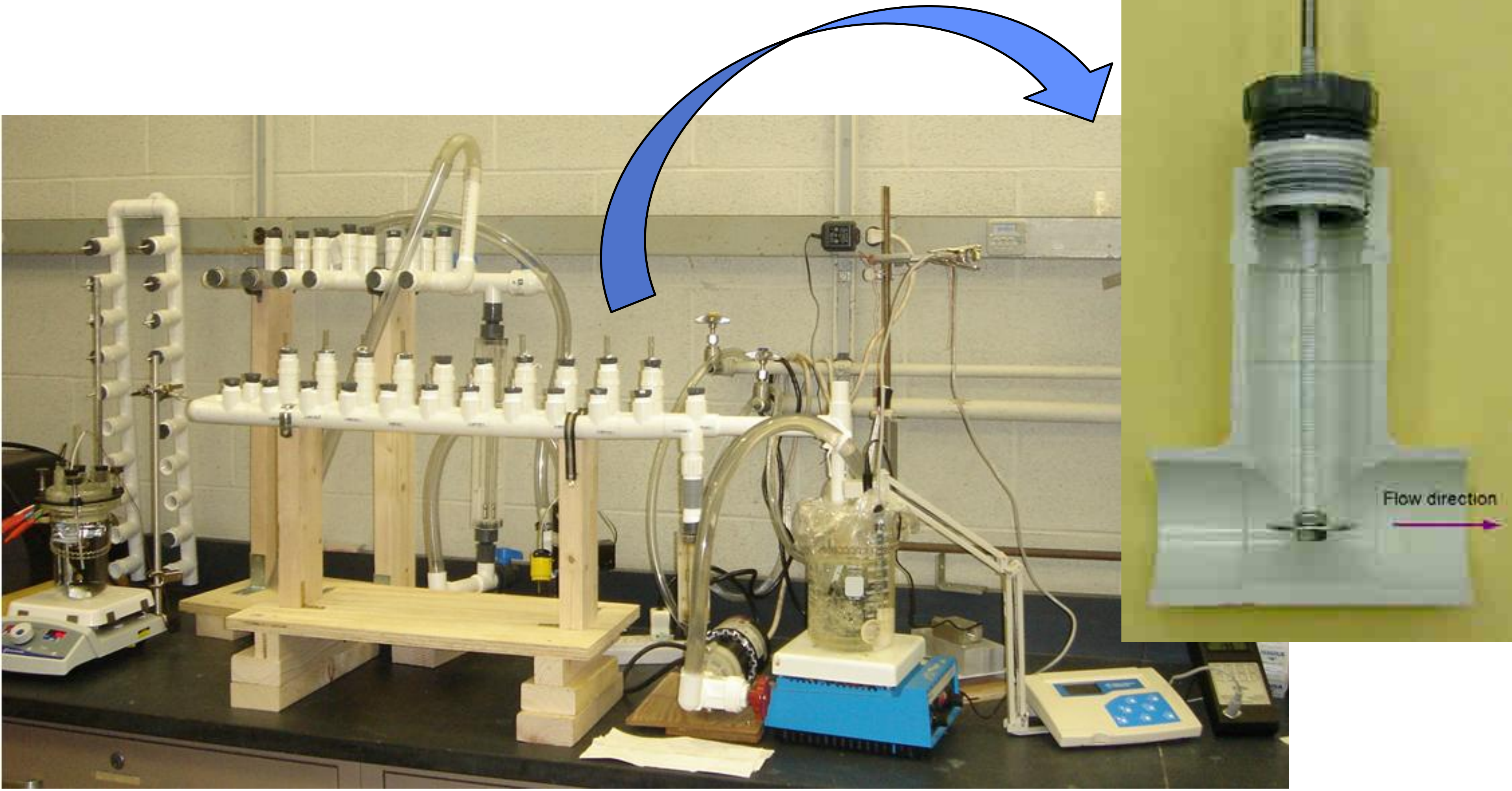
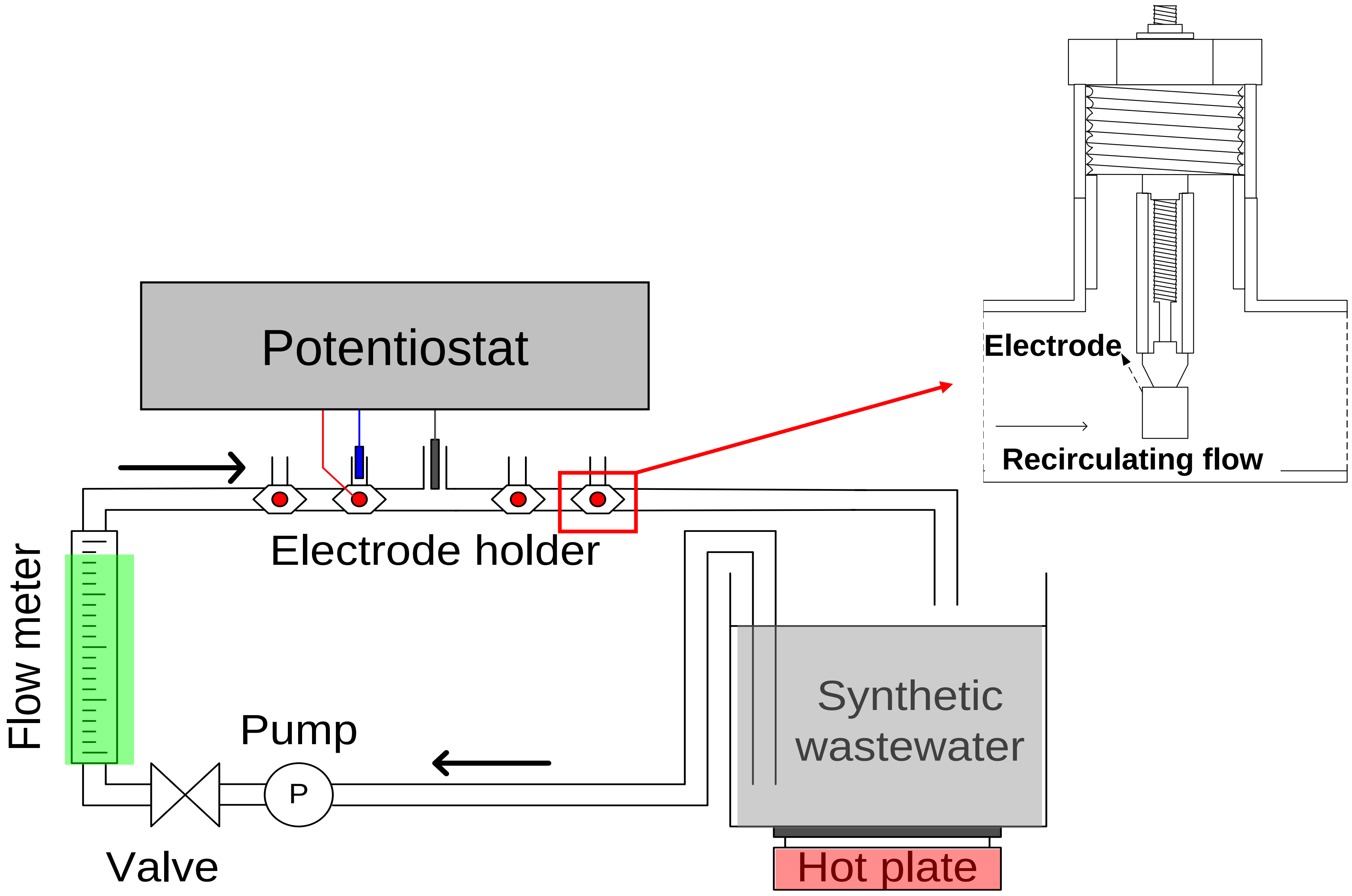
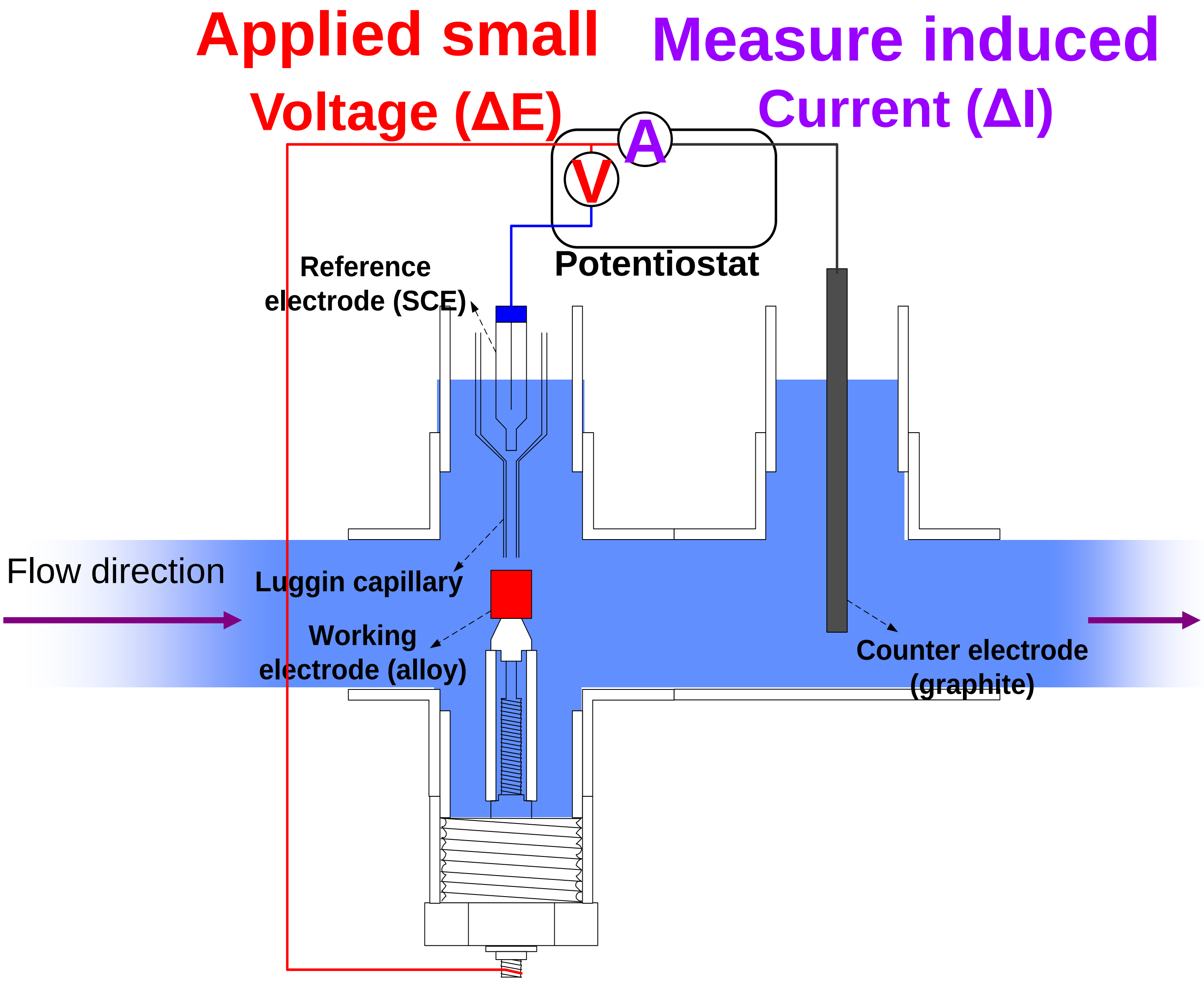
Bench-scale Water Recirculating System: Scaling Kinetics



Bench-scale Water Recirculating System: Corrosion Studies

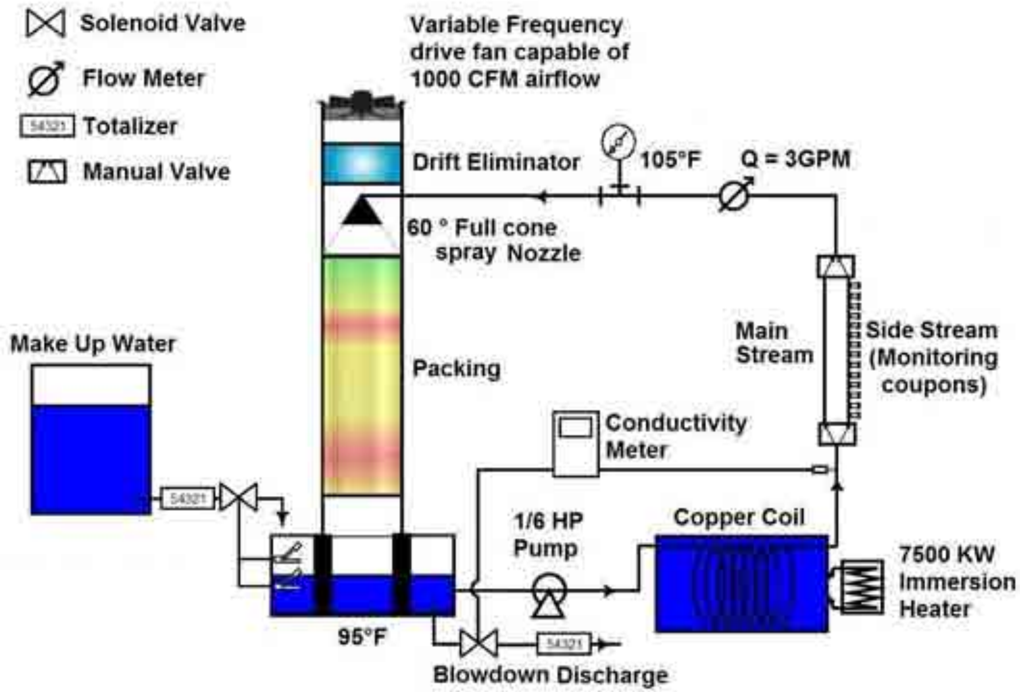


Design of T-section for Electrochemical Study

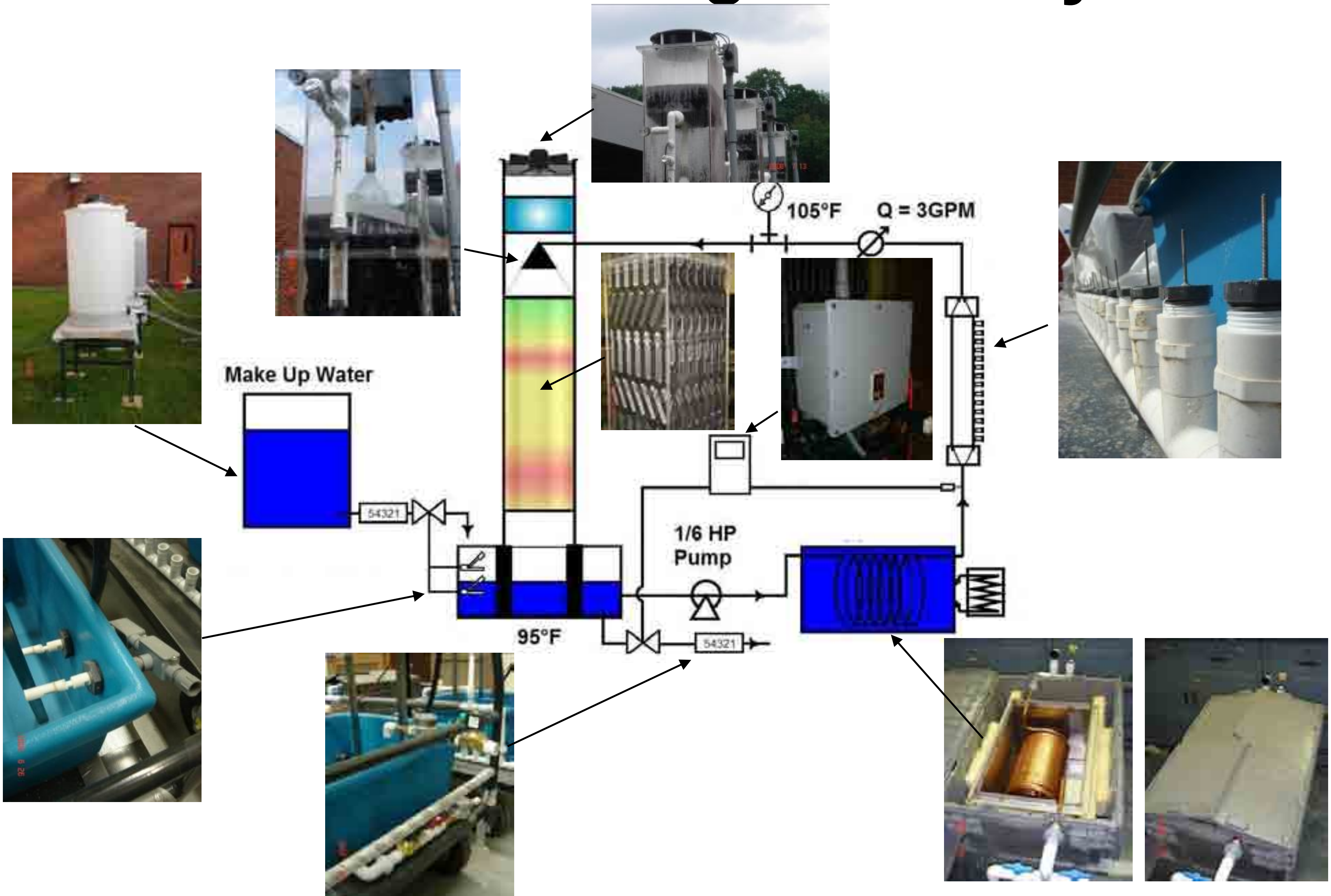


Pilot Scale Cooling Tower System Design

Design Criteria	
Flowrate	3GPM
Water Temperature	105ºF
Cooling capacity	10ºF
Airflow rate	150 CFM
Cycle of Concentration	4 COC
Blowdown Control	Conductivity of water



Pilot Scale Cooling Tower System



Pilot Scale Cooling Tower System

Pilot Scale Cooling Tower System

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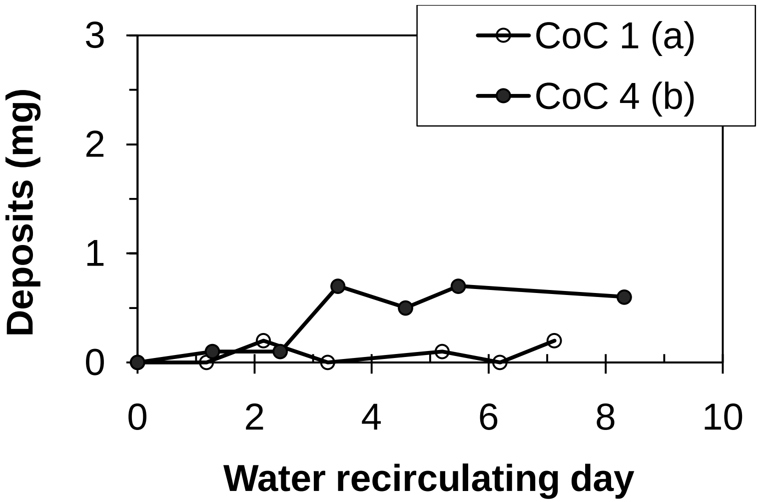
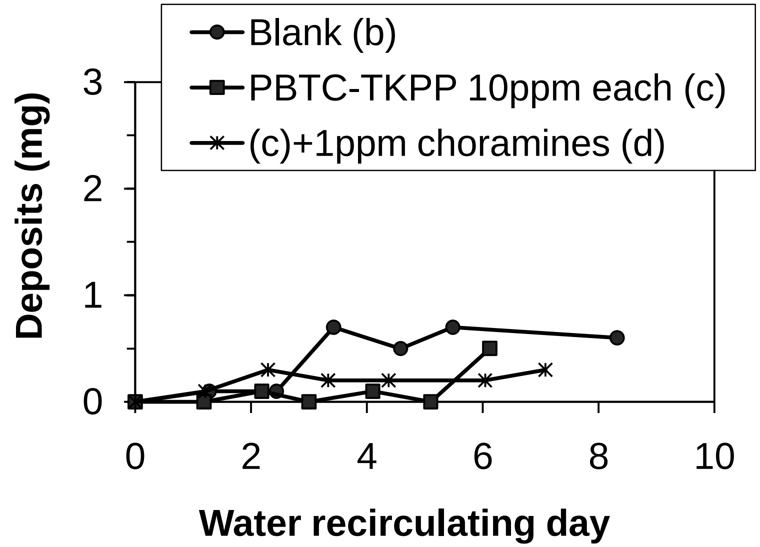
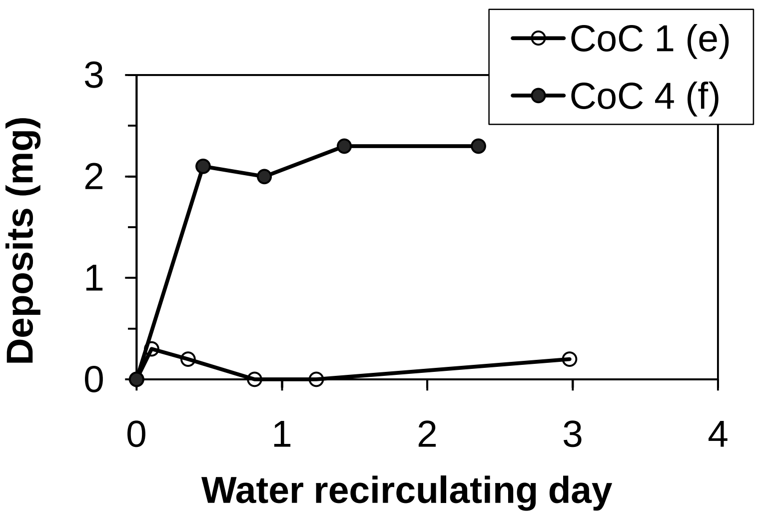
Experimental Matrix for Scaling Study with Secondary Wastewater

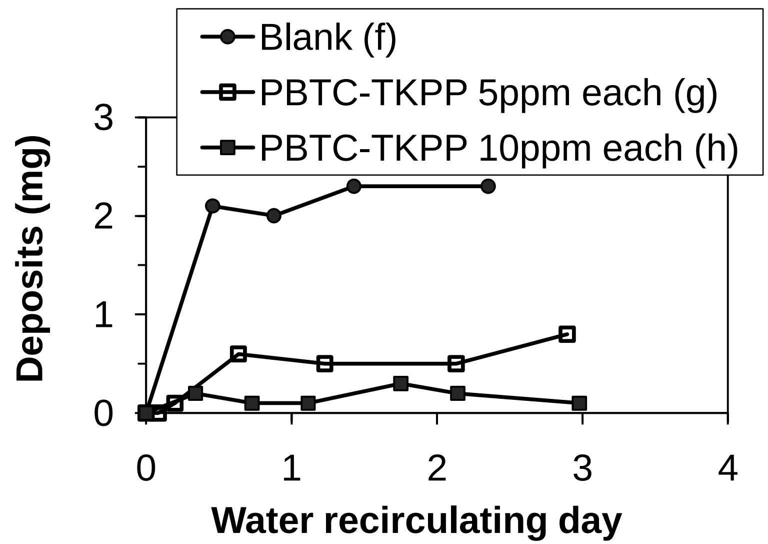
	Source Water				Concentration of antiscalant (mg/L)		
Exp. #	Actual	Synthetic	CoC	Chlorine addition [α]	PMA	PBTC	TKPP
a	√		1	-	-	-	-
b	√		4	-	-	-	-
c	√		4	-	-	10	10
d	√		4	1ppm chloramines	-	10	10
e		√	1	-	-	-	-
f		√	4	-	-	-	-
g		√	4	-	-	5	5
h		√	4	-	-	10	10
i		√	4	1ppm chlorine [β]	-	10	10
j		√	4	1ppm chloramines	-	10	10
k		√	4	1ppm chloramines	10	5	-
l		√	4	1ppm chloramines	20	10	-
m		√	4	w/o ammonia	-	10	10
n		√	4	w/o phosphate	-	10	10

Scaling behavior of secondary wastewater: actual vs. synthetic

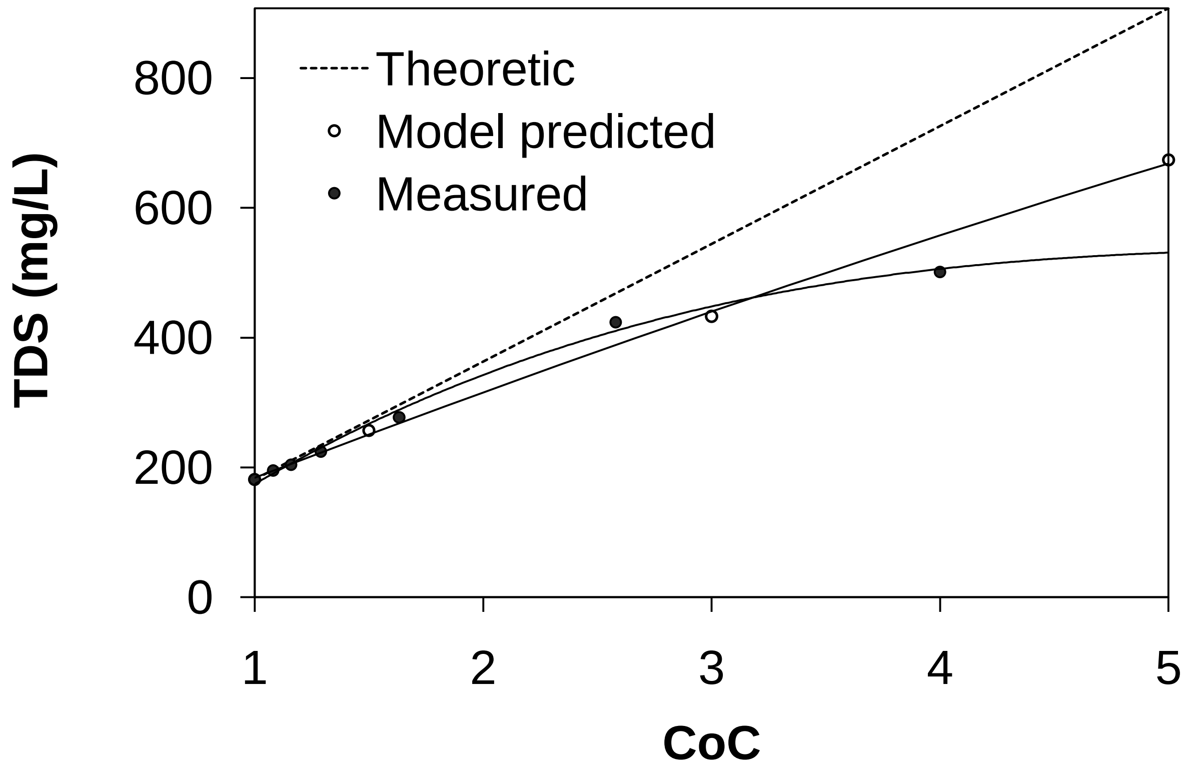




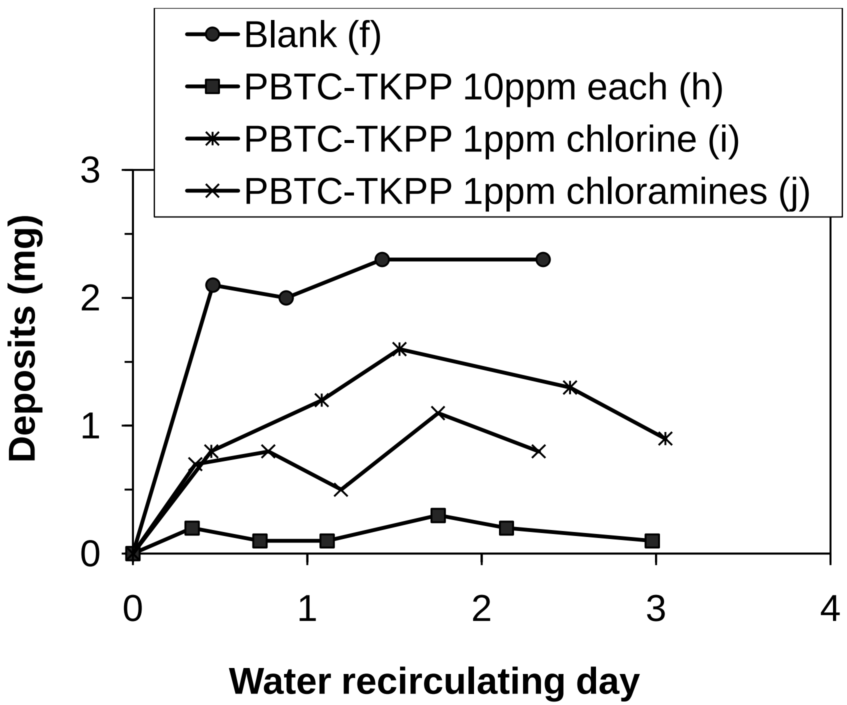


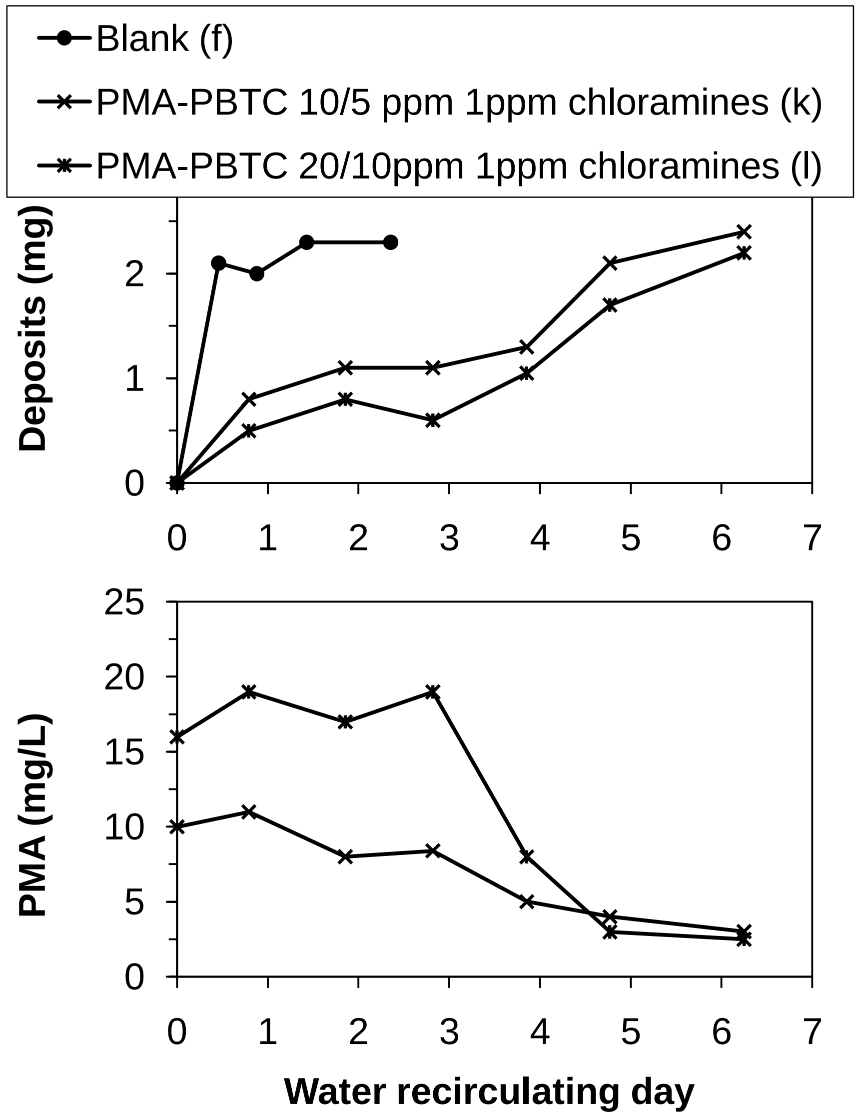


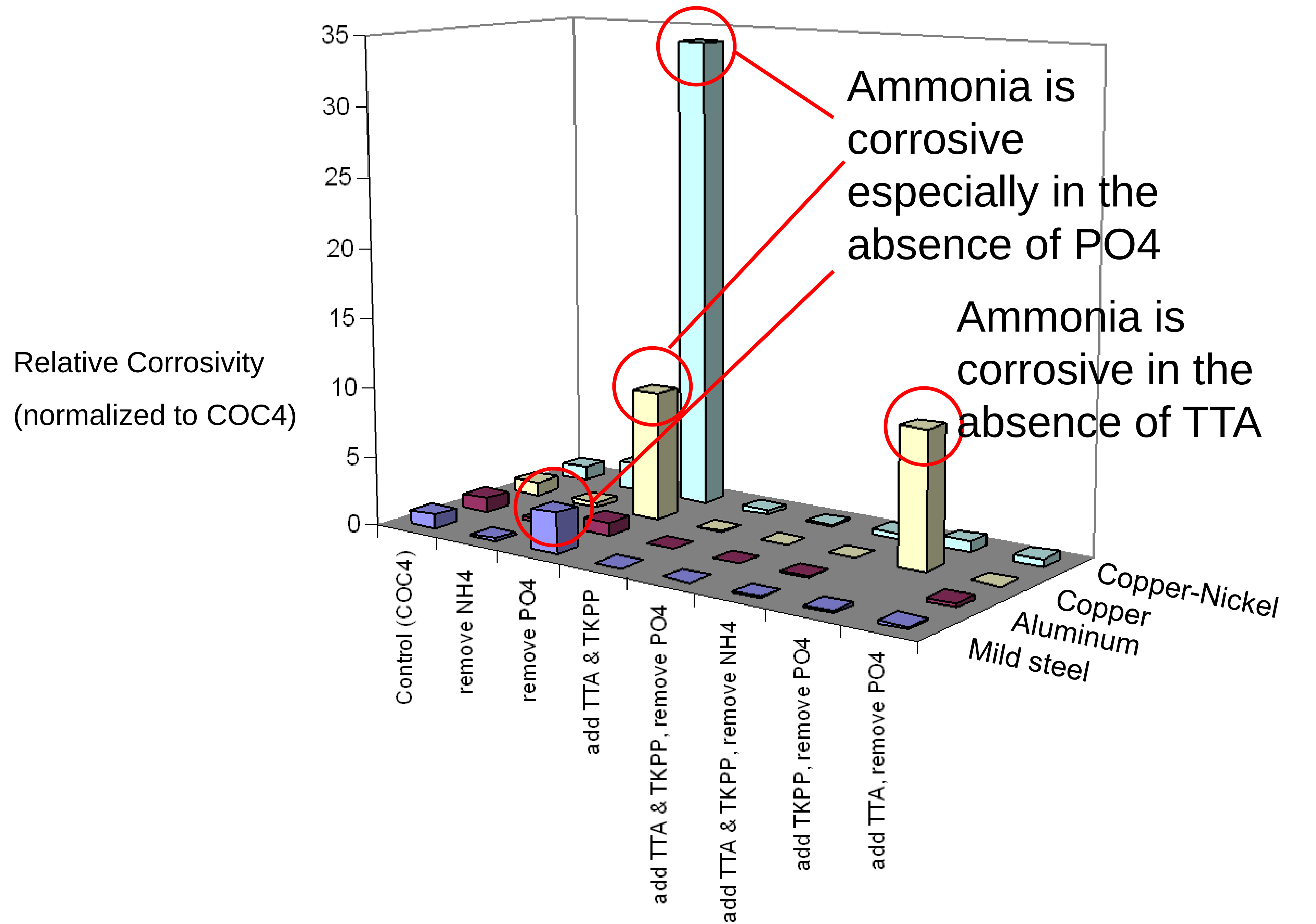
Actual waters concentrated by evaporation are not suitable for scaling studies because a significant amount of dissolved solids precipitates during the evaporation process

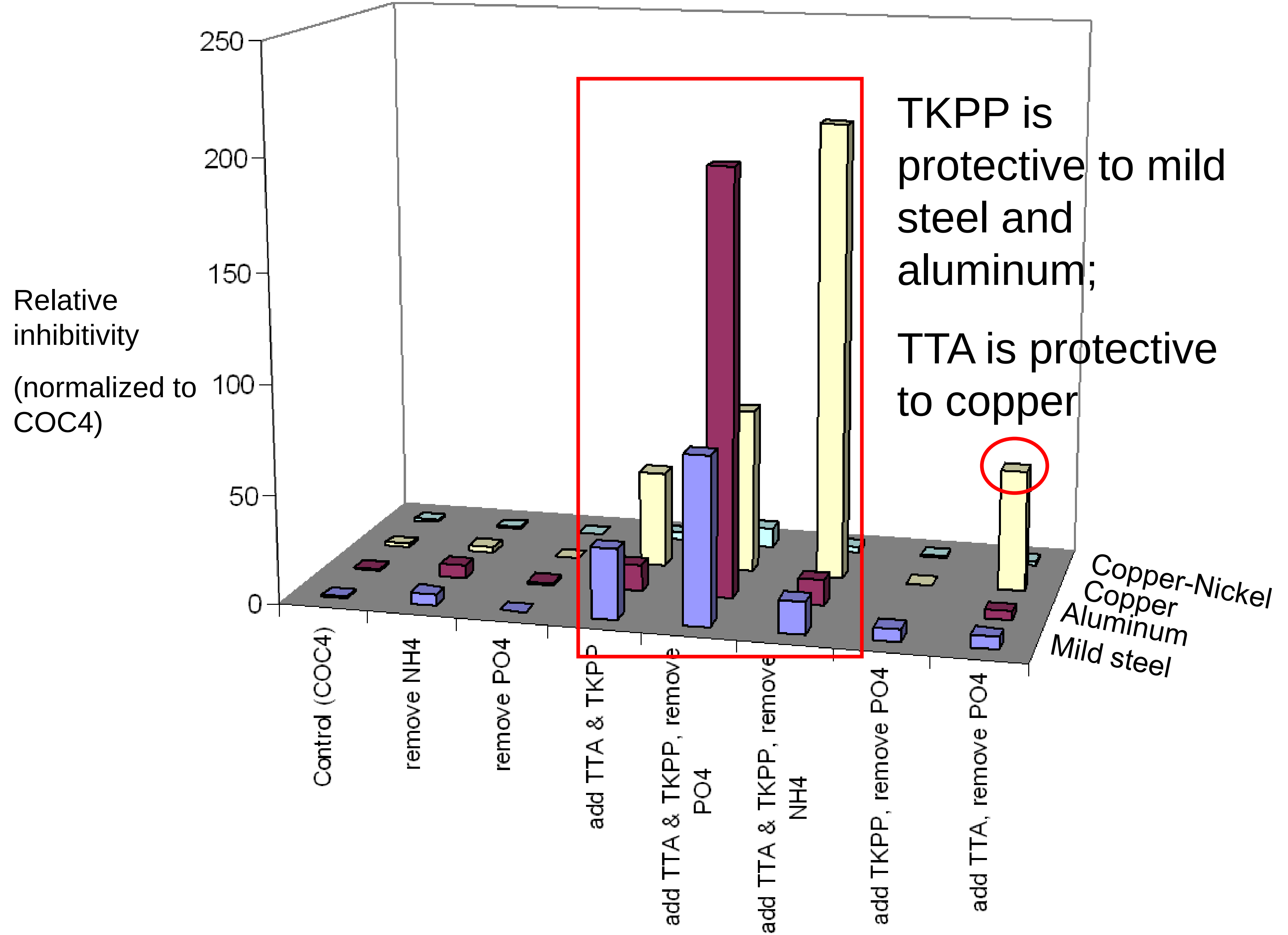


Impact of disinfection by chlorine and chloramines on scaling control effectiveness






Relative Corrosivity
(normalized to COC4)
35
30
25
20
15
10
5
0
Control (COC4)
remove NH4
remove PO4
add TTA & TKPP
add TTA & TKPP, remove PO4
add TTA & TKPP, remove NH4
add TKPP, remove PO4
add TTA, remove PO4
Copper-Nickel
Copper
Aluminum
Mild steel
Ammonia is corrosive especially in the absence of PO4
Ammonia is corrosive in the absence of TTA



TKPP is protective to mild steel and aluminum;

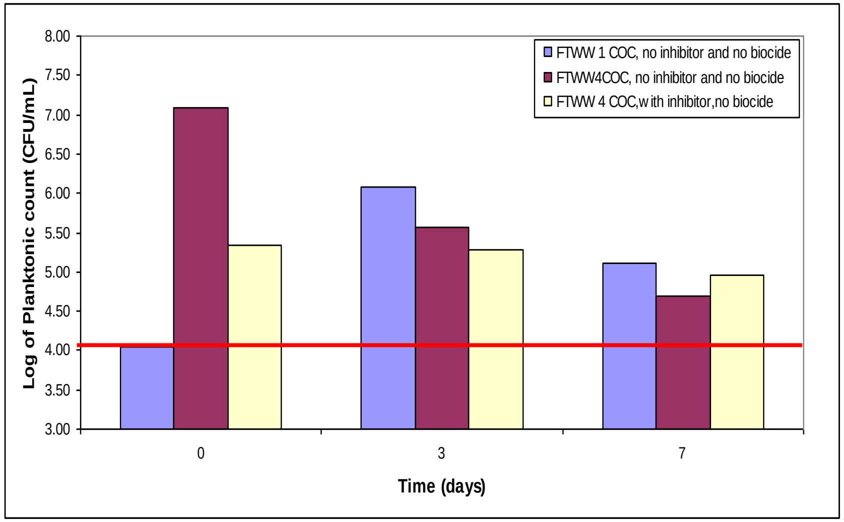
TTA is protective to copper

Influence of Key Parameters on Corrosion

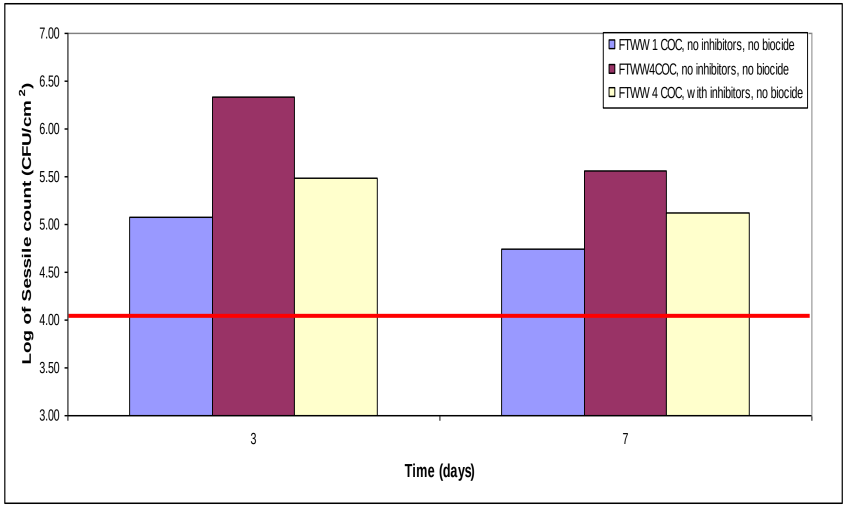
	Mild steel	Aluminum	Copper	Copper-nickel
Ammonia (100 ppm)	-Very aggressive (esp. w/o PO_4) -Negligible w/ TKPP (10ppm)	-Very aggressive -Negligible w/ TKPP (10ppm)	-Very aggressive (esp. w/o PO_4) -Negligible w/ TTA (2-4ppm)	-Very aggressive (esp. w/o PO_4) -Negligible w/ TTA (2-4ppm)
Free Cl2 (1ppm)	Aggressive	NC	Very aggressive	Very aggressive
Monochloramine (1ppm)	Aggressive	Aggressive	Not aggressive in the presence of TTA (2-4ppm)	Some aggressive in the presence of TTA (2-4ppm)
Phosphate (20ppm)	Some protective	Aggressive	NC	NC
TKPP (10ppm)	Very protective (esp. w/o PO_4 because of co-precipitation)	Very protective (esp. w/o PO_4 because of co-precipitation)	NC	NC
TTA (2-4ppm)	NC	NC	Very protective even w/ NH_3	Protective only w/ NH_3

Biofouling potential of Secondary Treated Municipal Wastewater in Bench-Scale Experiments

- Heterotrophic bacteria count in both COC1 and COC4 exceeded the target criteria of 10^4 CFU / ml (CTI, 2006)
- As the cycles of concentration increase, wastewater may be more susceptible to biofouling, due to increase in organic loading and nutrients



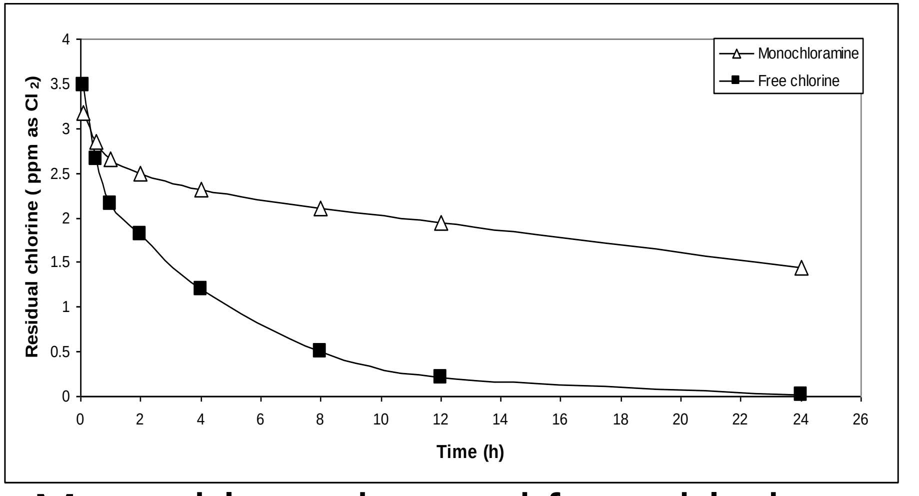
Planktonic HPC



Sessile HPC

Comparison of Chlorine Dose Requirements for Free Chlorine and Chloramine

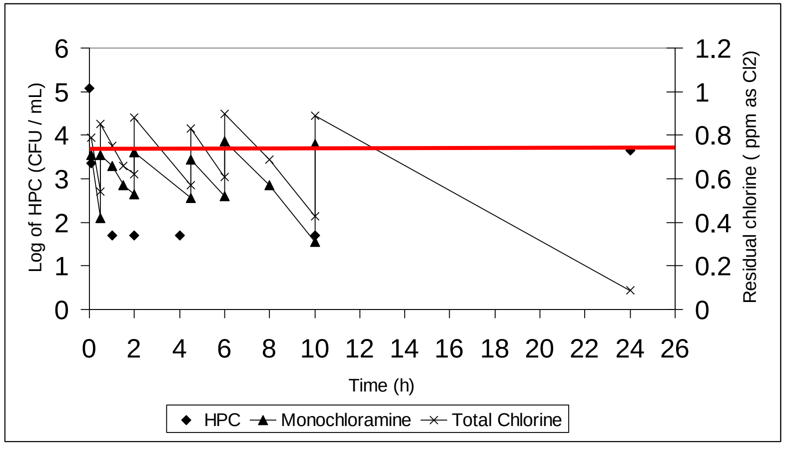
- The decay rate of monochloramine is much slower than that of free chlorine.
- Chlorine dose required to maintain certain monochloramine level may be much lower than for maintaining free chlorine.
- Chloramination may reduce chlorine requirements and be more cost-effective.



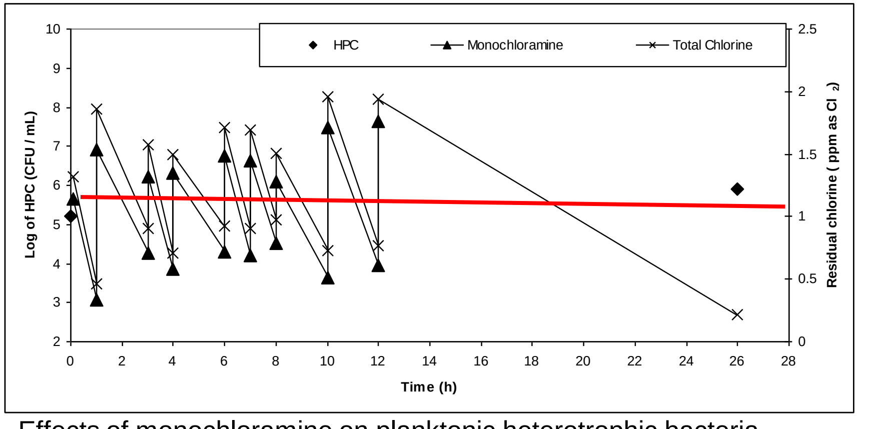
Monochloramine and free chlorine decomposition at 4 COC and pH 8

Bench-Scale Experiments for Biofouling Control by Chloramination

- In FTWW 4 COC, the planktonic HPC was 1.2 x 10^5 CFU / mL before adding chloramine.
- For both dosage, 0.5 -1 ppm as Cl_2 and 1-2 ppm as Cl_2, monochloramine seems very effective and can keep plantonic HPC under detection limit for 10 hours.



Effects of monochloramine on planktonic heterotrophic bacteria maintaining total chlorine between 0.5-1 ppm as Cl2 at initial 100 ppm NH_3-N in FTWW 4 COC in bench-scale circulating system



Effects of monochloramine on planktonic heterotrophic bacteria maintaining total chlorine between 1-2 ppm as Cl2 in FTWW 4 COC in bench scale circulating system

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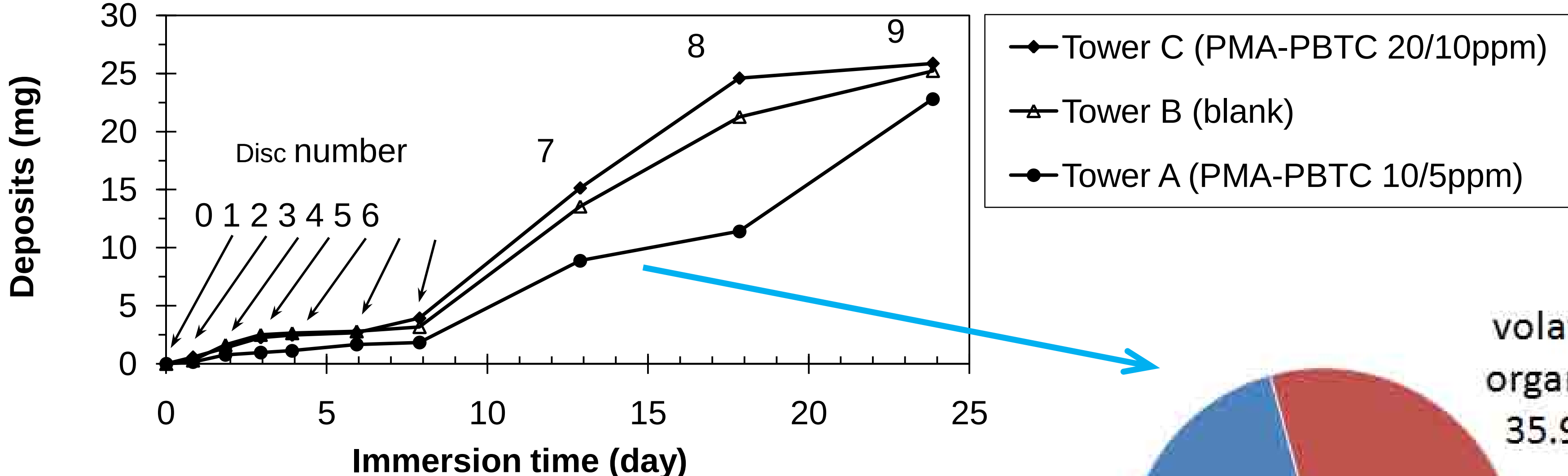
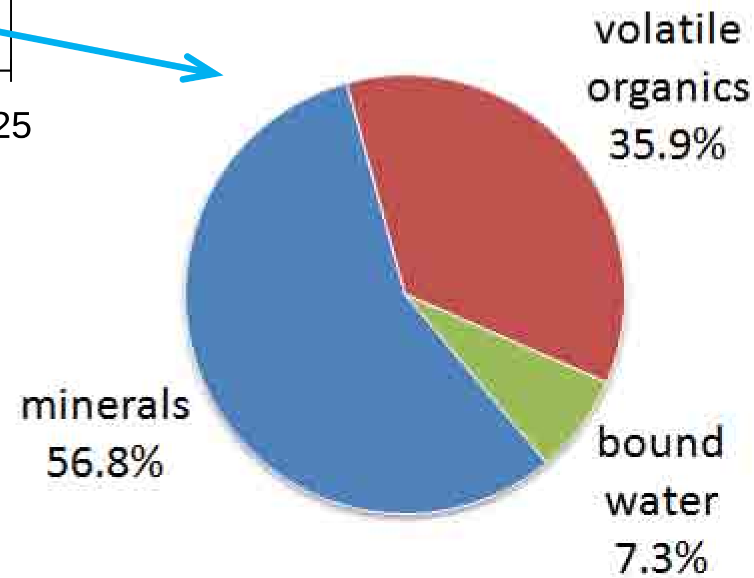
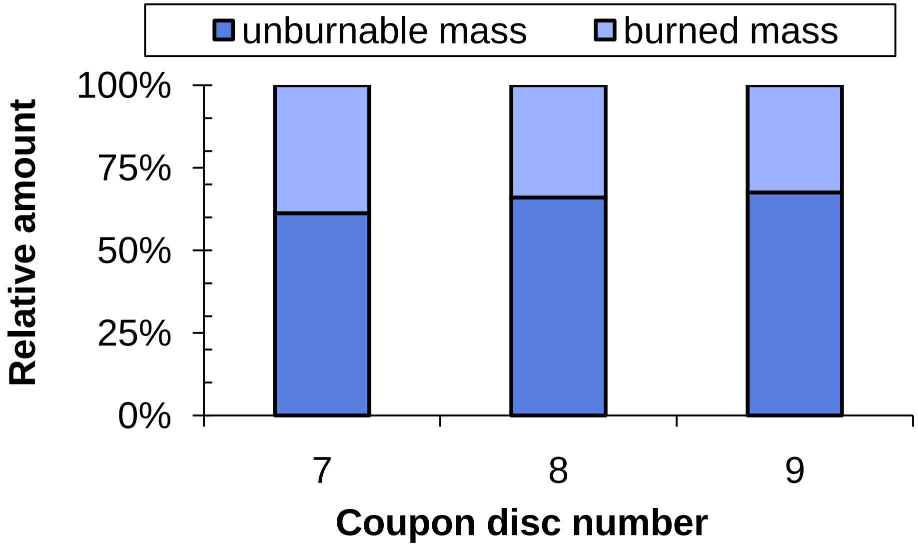
- Summary

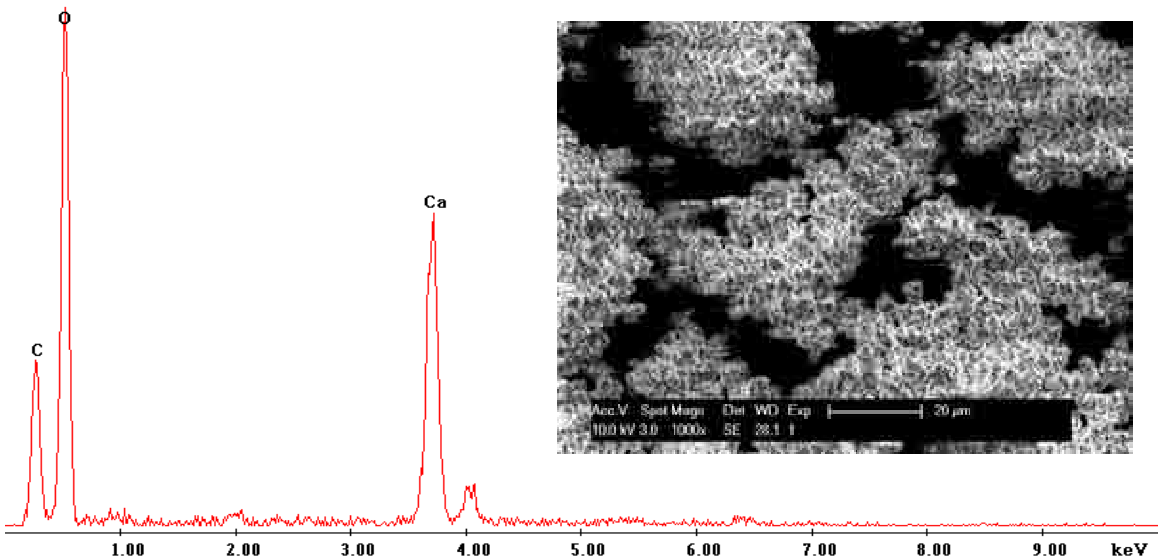
Cooling water scaling when using secondary treated MWW at Franklin Township



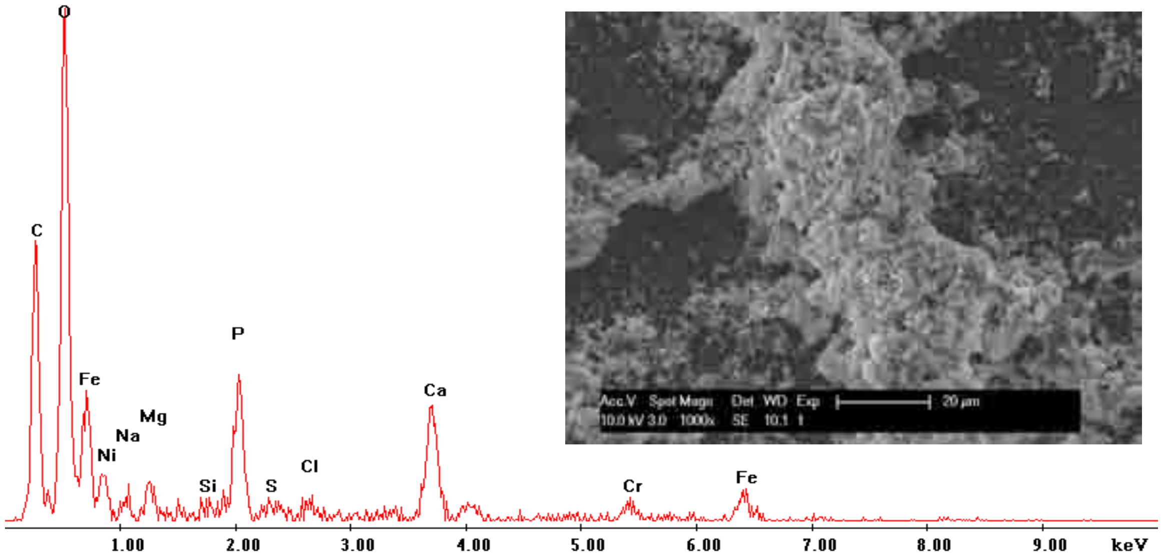




SEM-EDS examination of solids collected from coupon discs

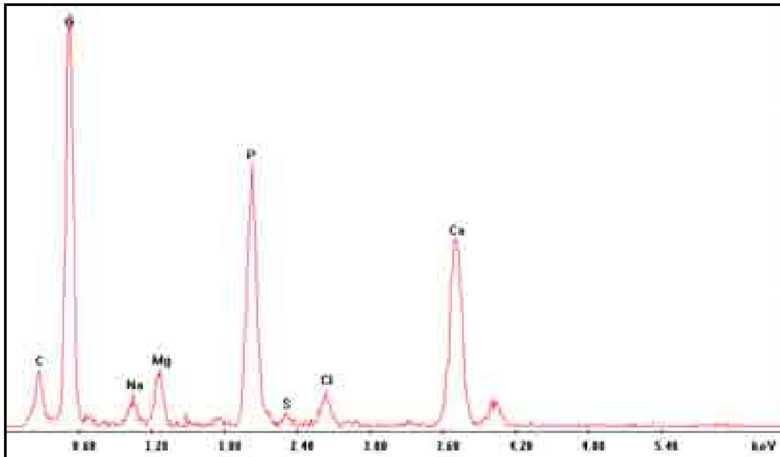


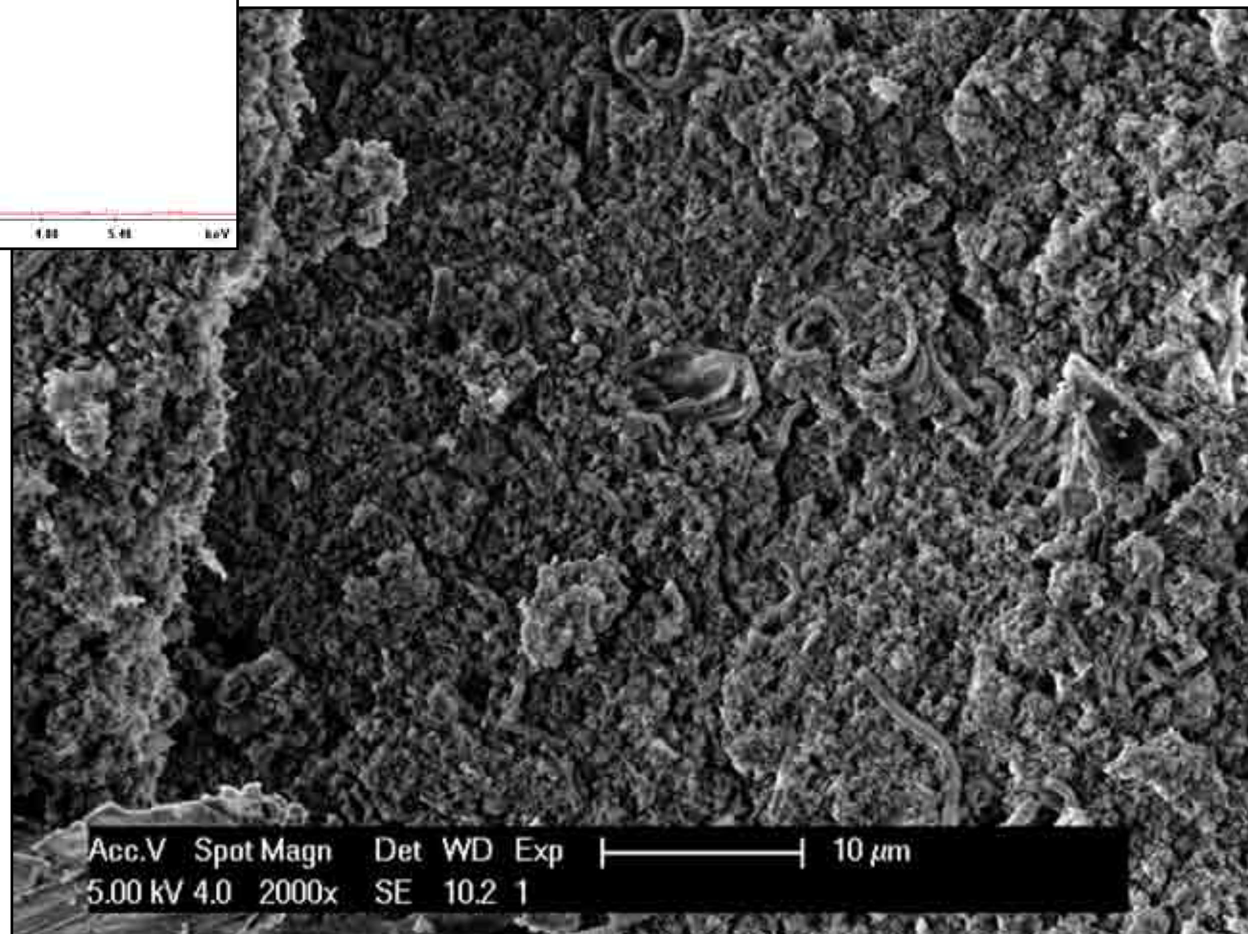
Coupon disc for synthetic wastewater



Coupon disc for actual wastewater

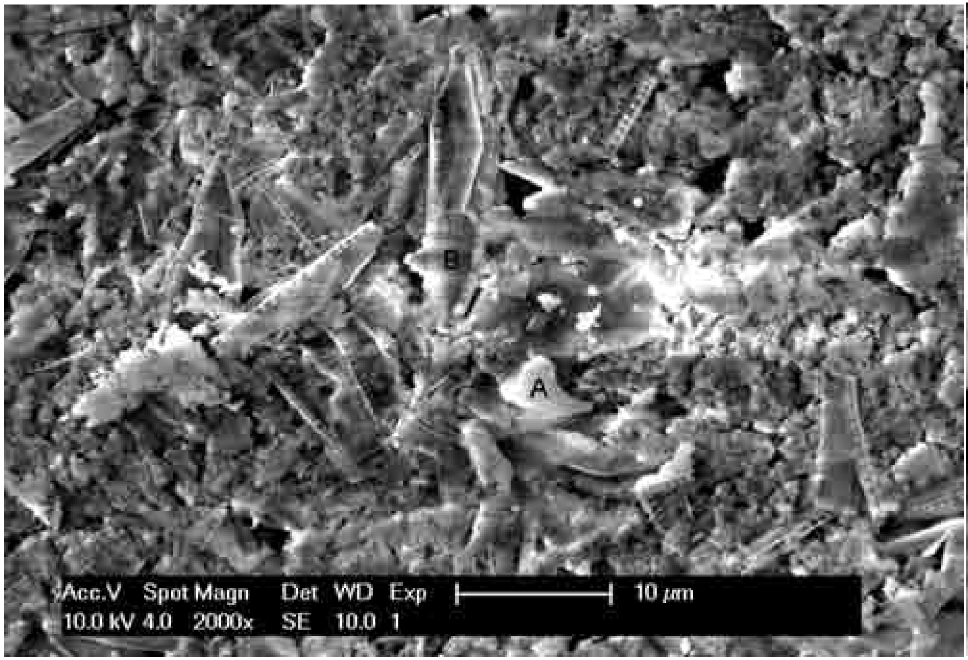
Bio-growth in the deposited solids of disc coupons

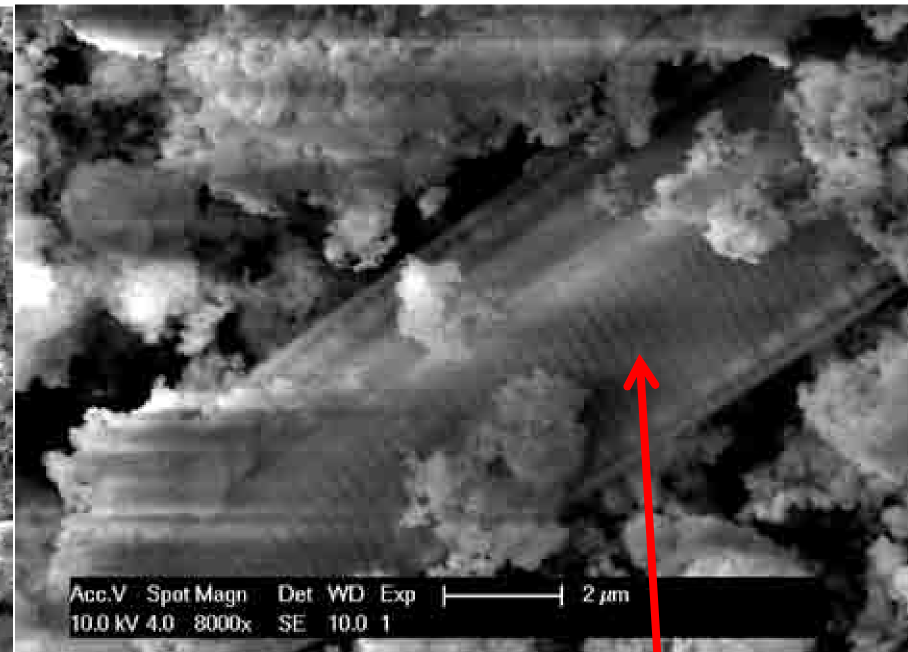


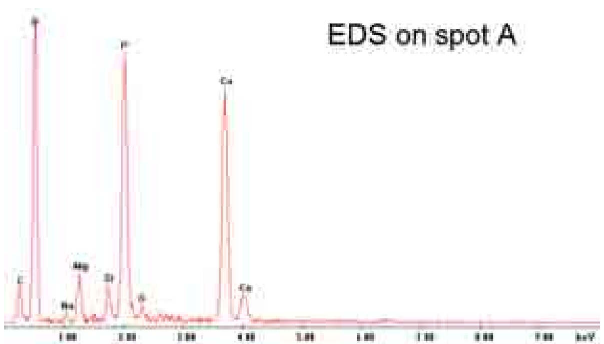


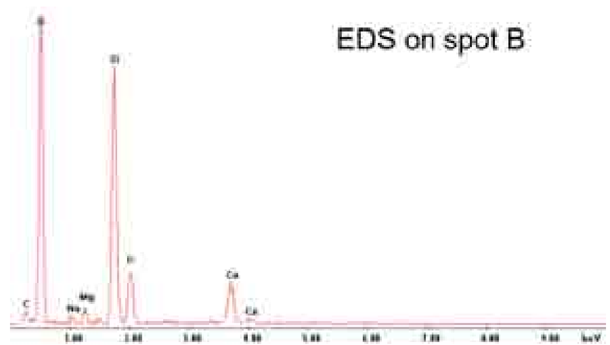
Settled solids at the bottom of recirculating water basin

Algal cells found inside the in-line flowmeter





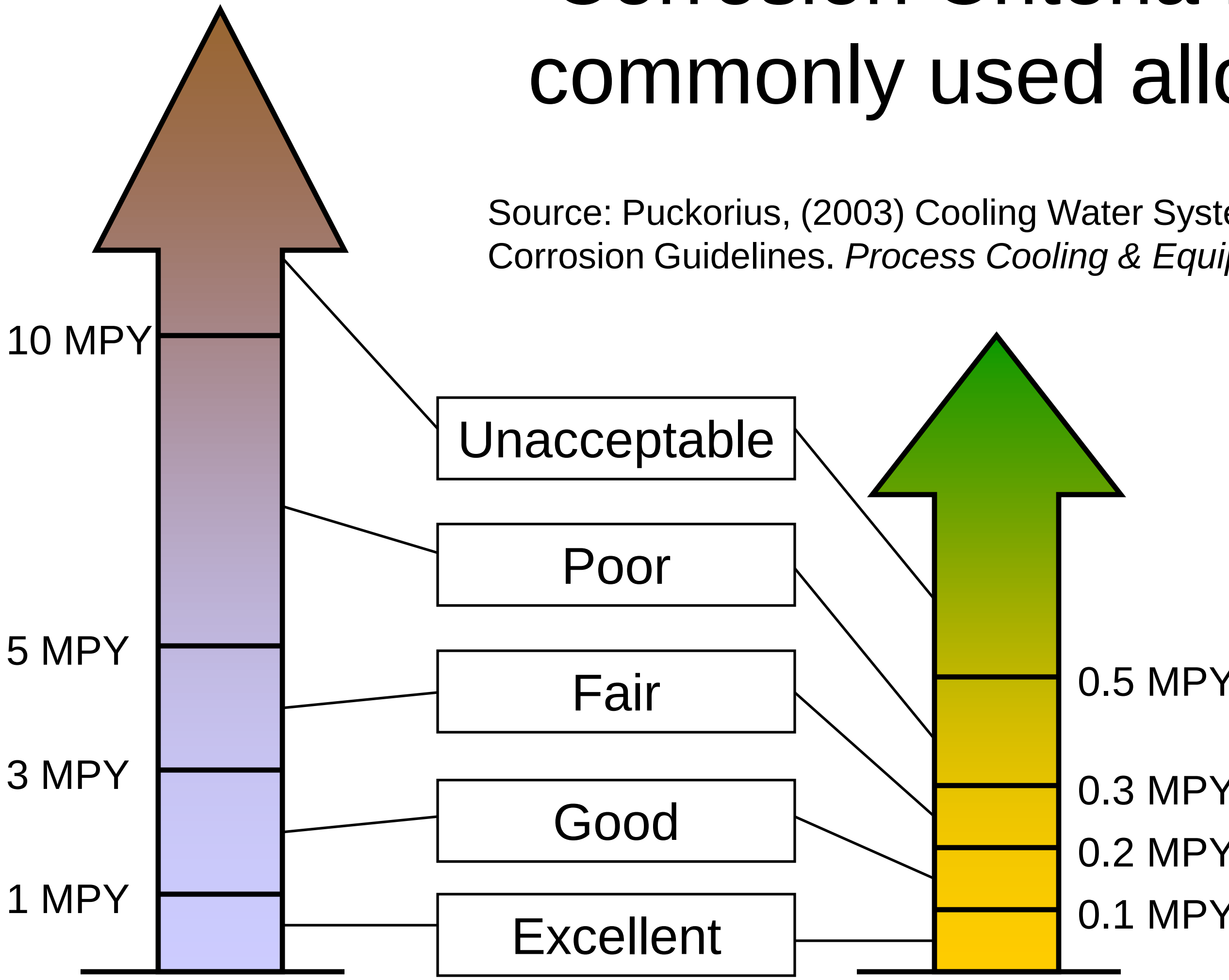




Nitzschia palea

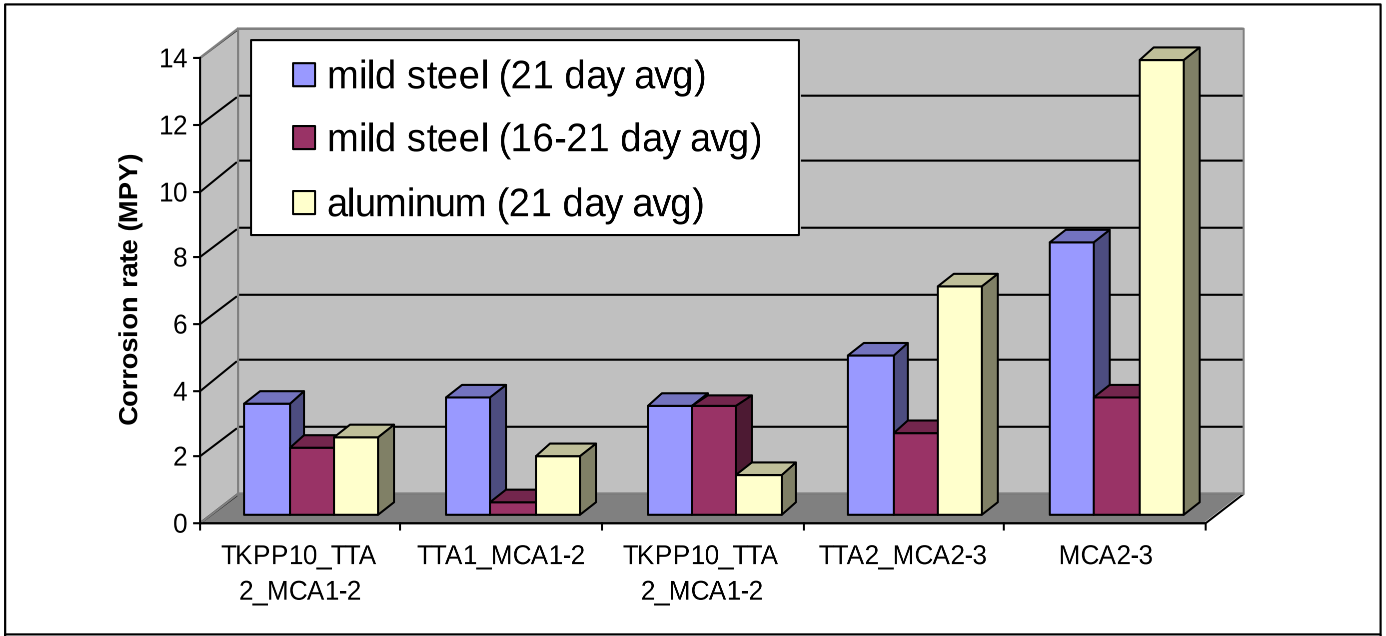
Corrosion Criteria for commonly used alloys

Source: Puckorius, (2003) Cooling Water System Corrosion Guidelines. *Process Cooling & Equipment*.

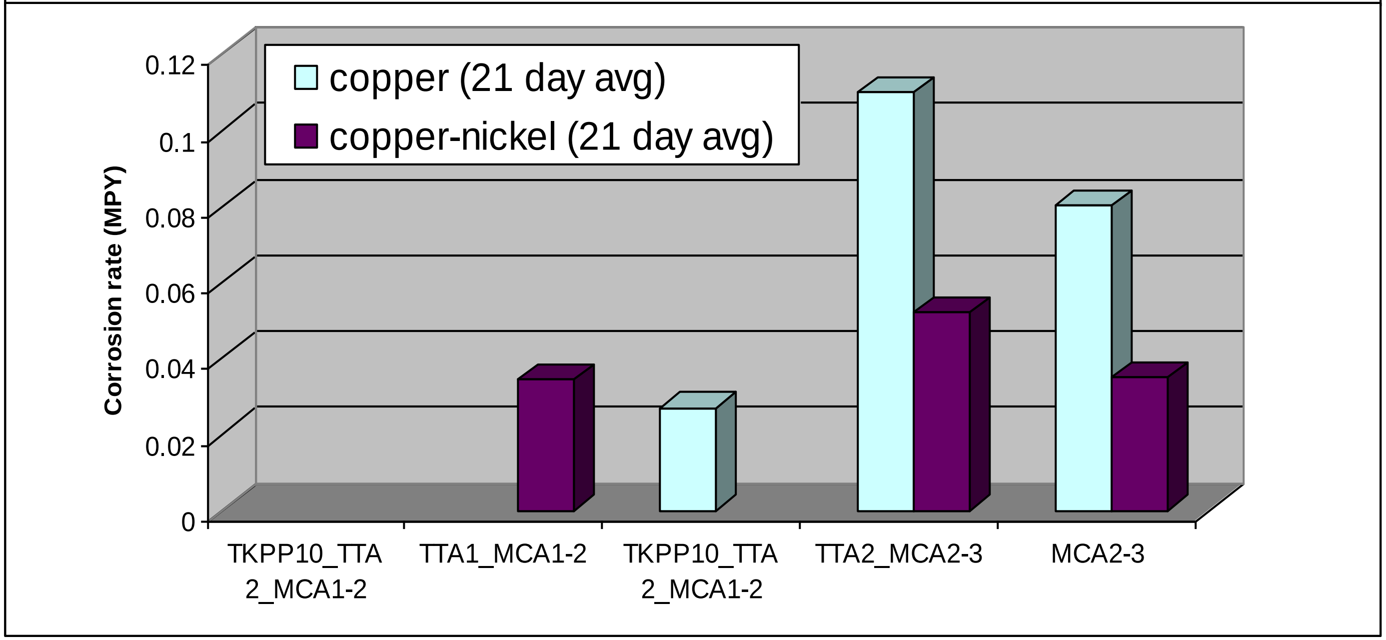


Mild steel piping

Copper and copper alloys



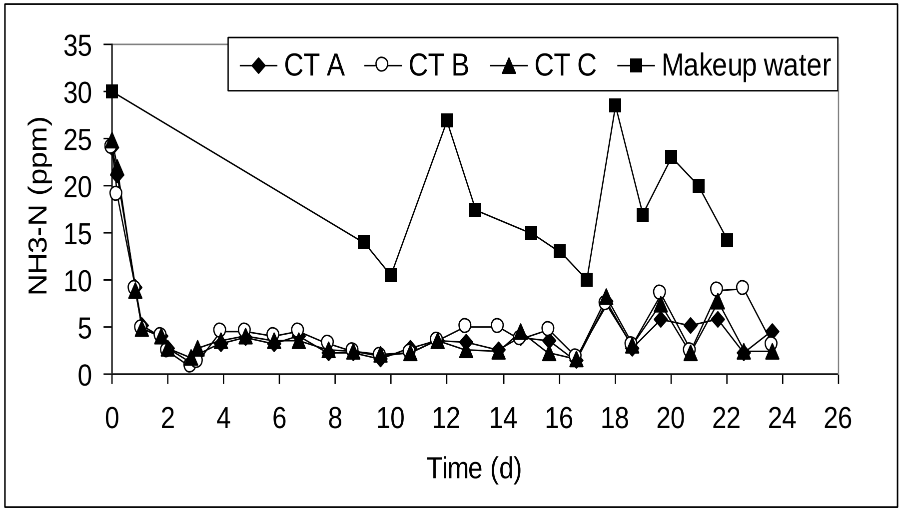
mild steel (21 day avg)
mild steel (16-21 day avg)
aluminum (21 day avg)
Corrosion rate (MPY)
14
12
10
8
6
4
2
0
TKPP10_TTA 2_MCA1-2
TTA1_MCA1-2
TKPP10_TTA 2_MCA1-2
TTA2_MCA2-3
MCA2-3



copper (21 day avg)
copper-nickel (21 day avg)
Corrosion rate (MPY)
0.12
0.1
0.08
0.06
0.04
0.02
0
TKPP10_TTA 2_MCA1-2
TTA1_MCA1-2
TKPP10_TTA 2_MCA1-2
TTA2_MCA2-3
MCA2-3

Ammonia Concentration in Pilot-Scale Cooling Towers

- All towers were dosed with sodium hypochlorite solution at rates intended to achieve 0.5-1.0 ppm as Cl2 monochloramine in the circulating water.
- The monochloramine was formed in situ through reaction with the ammonia present in the wastewater.
- Average ammonia concentration in the raw makeup water was 18.4±6.8 ppm NH_3-N but all towers have relatively low ammonia concentration.



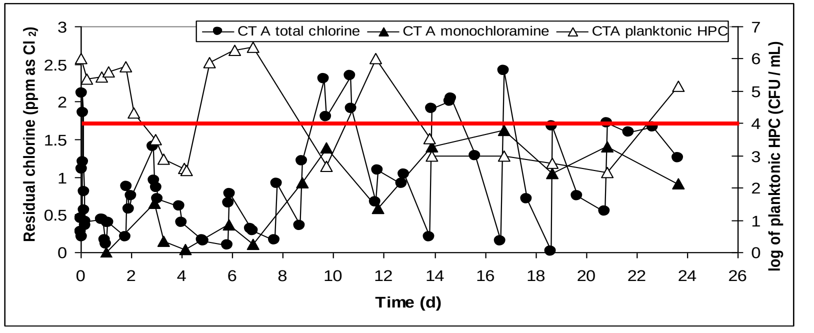
Ammonia concentration in makeup water and in three cooling towers in pilot scale tests at Franklin Township Municipal Sanitary Authority, Murrysville, PA, July-August, 2008

Results of Pilot-Scale Experiments for Biofouling Control by Chloramination

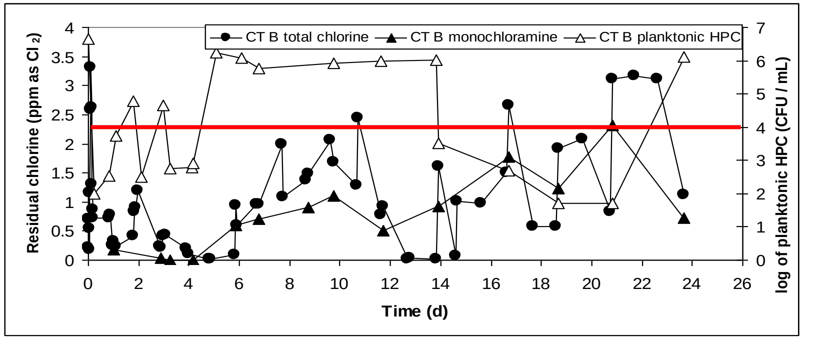
- Once the total chlorine and monochloramine were above 1 ppm as Cl_2, HPC were reduced below the target criteria of 10^4 CFU / ml (CTI, 2006)

- It appears that when total chlorine and mono-chloramine levels drop to non-detectable levels, biogrowth is established and it takes time to reverse.

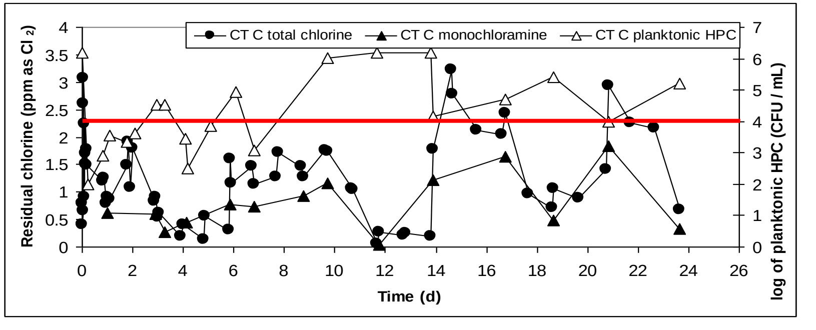
(A)



(B)



(C)



SUMMARY: Scaling (1)

- Water pre-concentrated by evaporation is not representative of higher COCs.
- Several scale inhibitors were effective in the absence of disinfectants.
- Addition of chlorine impaired the effectiveness of the antiscalants.
- Phosphate, either present in the makeup water or added as corrosion inhibitor, worsened scaling.
- Ammonia helped mitigate scaling.

SUMMARY: Scaling (3)

- Biomass significantly contributed to scaling; therefore, control of biogrowth in both the makeup tank and the recirculating system is required.
- Addition of phosphate-containing chemicals should be avoided or minimized.
- Less aggressive disinfectants, such as chloramines, worked better with scale control chemicals.
- The beneficial effect of ammonia observed in bench-scale studies could not be relied on as the ammonia was effectively stripped out in the pilot-scaling cooling towers.

SUMMARY: Corrosion (1)

- Methodology of instantaneous corrosion rate (ICR) is established.
- In terms of corrosion, feasibility of using impaired waters in cooling systems can be evaluated through ICR measurement
- From lab experiment, key parameters to corrosion have been identified:
  - Protective: phosphate, TKPP, TTA
  - Aggressive: ammonia, free Cl2 and monochloramine
  - Aggressivity of ammonia overcome by TKPP and TTA

SUMMARY: Corrosion (2)

- TKPP failed to reduce corrosion since it co-precipitated with PO_4
- MCA 2-3 was more corrosive than MCA 1-2 to all alloys, especially to copper.
- All alloys were covered by deposition, and thus were protected. The deposition also made TTA less effective.
- In general, except for aluminum (pitting in all situations), corrosion rate of alloys were within acceptable range

SUMMARY: Biofouling (1)

- Increase in cycles of concentration can increase the susceptibility of biofouling for secondary treated municipal wastewater
- Bench-scale recirculating system results show that chloramination can be an effective oxidizing biocide option for secondary treated municipal wastewater.

SUMMARY: Biofouling (2)

- Relatively high organic load in secondary treated municipal wastewater makes biofouling control a challenging task
- Ammonia stripping can significantly affect biocidal efficacy of monochloramine formed by adding chlorine directly into the wastewater
- Continuous supply of biocide may be required to control biogrowth in cooling tower using secondary treated municipal wastewater as makeup

USE OF TREATED MUNICIPAL WASTEWATER AS POWER PLANT COOLING SYSTEM MAKEUP WATER:

TERTIARY TREATMENT VS. EXPANDED CHEMICAL REGIMEN FOR RECIRCULATING WATER QUALITY MANAGEMENT

David Dzombak
Carnegie Mellon University

Radisav Vidic
University of Pittsburgh

October 27, 2008

Carnegie Mellon
ENGINEERING

UNIVERSITY OF PITTSBURGH
VERITAS VIRTUS 1787

OVERVIEW

- Project goal
- Background
- Specific objectives
- Project tasks
- Project schedule
- Summary

PROJECT GOAL

- Evaluate benefits and costs of implementing tertiary treatment for secondary-treated municipal wastewater prior to use in cooling systems vs. expanded chemical management of cooling water chemistry

BACKGROUND

- Treated municipal wastewater is a common, abundant and widespread source of impaired water
- ~ 80% of US power plants have sufficient cooling water supply from 1-2 POTWs within 10 miles
- ~ 97% from 1-2 POTWs within 25 miles

PROBLEMS WITH USE OF IMPAIRED WATERS

- Precipitation and scaling
- Accelerated corrosion
- Biomass growth

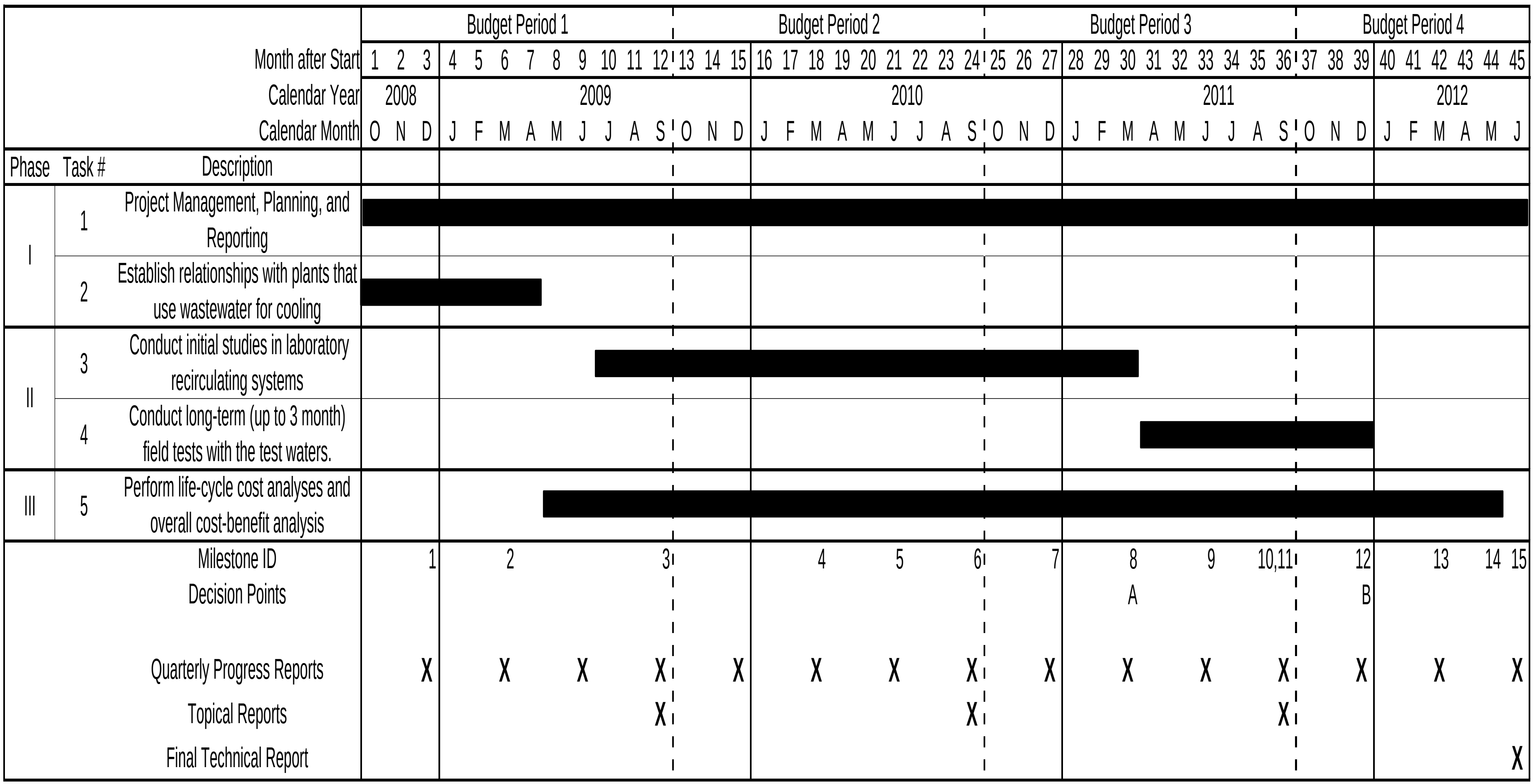
SPECIFIC OBJECTIVES

- Determine benefits and costs of different levels of additional treatment
- Determine different chemical treatment regimens required for waters with different levels of tertiary treatment
- Perform comparative life-cycle analyses
- Determine critical economic, technical and social factors

RESEARCH TASKS

- Task 1: Project management
- Task 2: Establish relationships with power plants that use treated ww as cooling makeup
- Task 3: Conduct initial lab studies
- Task 4: Conduct long-term field tests
- Task 5: Perform comparative life-cycle cost analyses and overall cost-benefit analysis

PROJECT SCHEDULE



SUMMARY

- Collaborative project: Carnegie Mellon and University of Pittsburgh
- Goal: evaluate benefits and costs of tertiary treatment for municipal wastewater prior to use in cooling systems vs. expanded cooling water chemical management
- Methods: Lab tests, field tests, economic analyses
- 45-month schedule

Development and Demonstration of a Modeling Framework for Assessing the Efficacy of Using Mine Pool Water for Thermoelectric Generation

Prepared for: USDOE
National Energy Technology Laboratory
Water and Power Plants Review Meeting
October 27, 2008

Bruce Leavitt
Paul Ziemkiewicz
WV Water Research Institute Project *WRI-232*

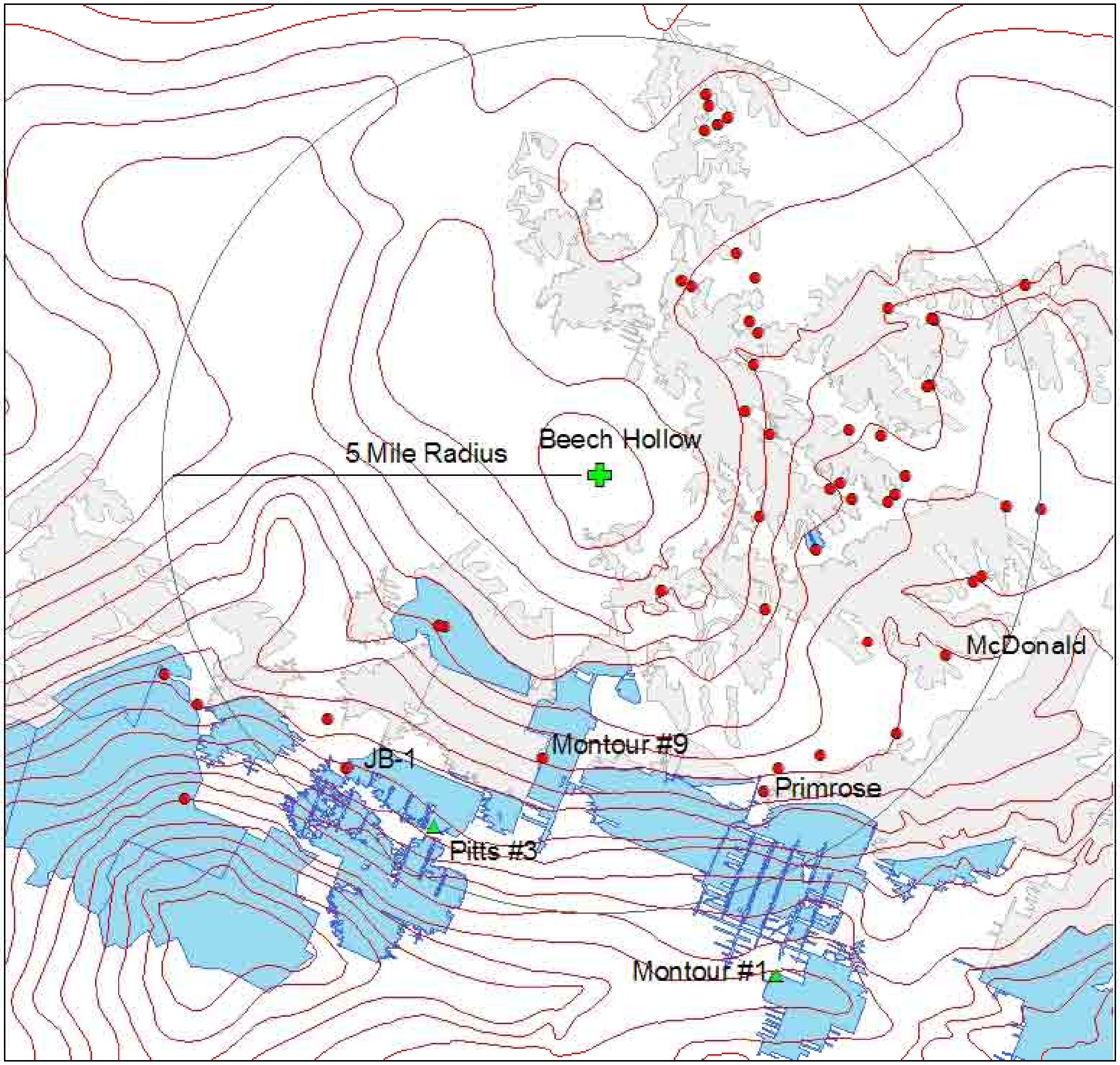
Objective

- Develop and demonstrate a computer based design aid around the Beech Hollow Power Plant that can be used by developers in evaluating the hydrologic, chemical, engineering, environmental benefits and costs of using mine pool water as an alternative to traditional supply

Task 1.1 – Identify Mine Water Sources

- WVU mine discharge mapping was combined with location data obtained from Operation Scar Lift reports, and field reconnaissance to locate discharges within five miles of the proposed power.
- Both above drainage and below drainage mines were identified.
- Two wells were drilled to intercept below drainage mines.

Mine Discharge Locations Near Beech Hollow



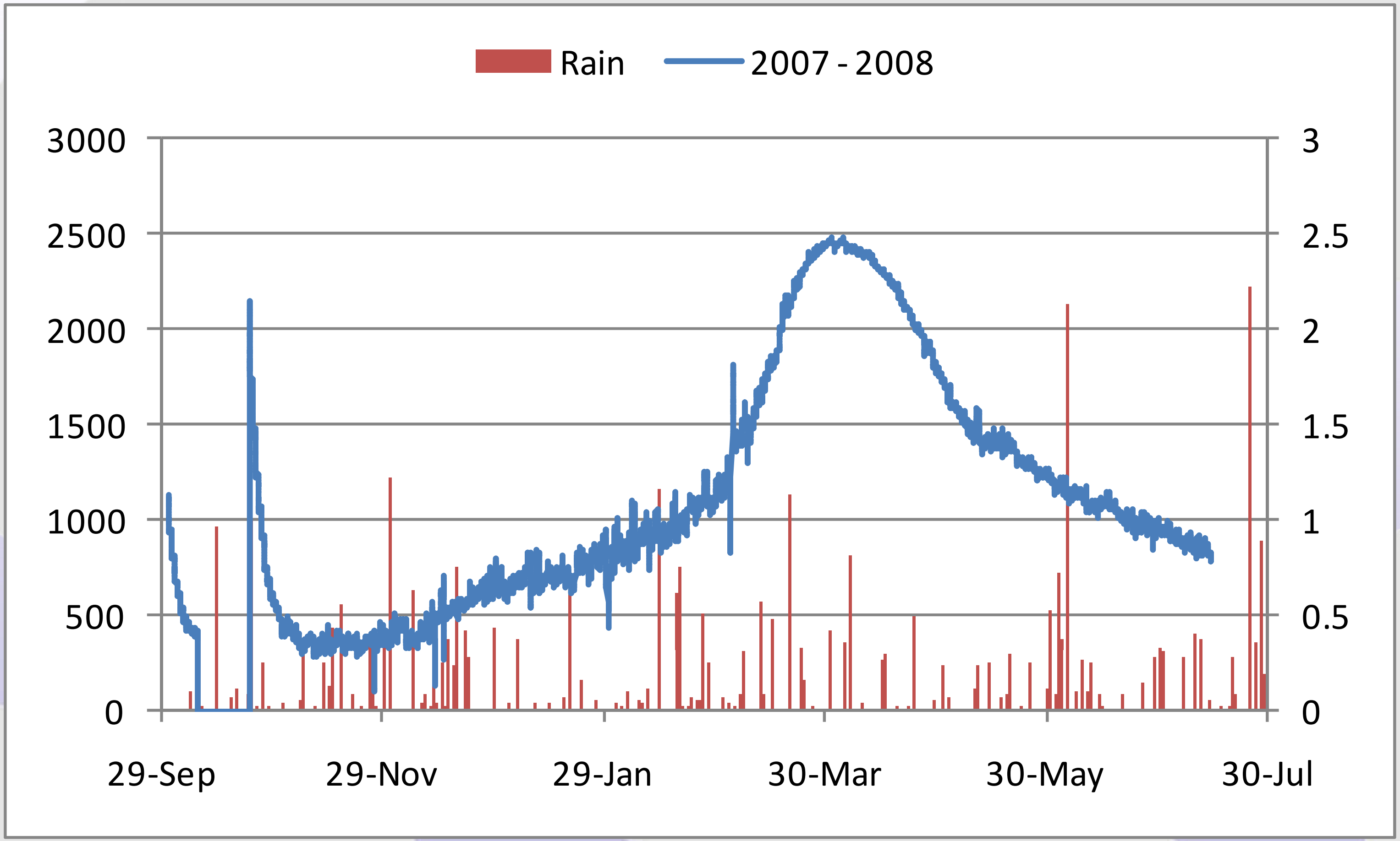
Task 1.2 – Quantify Water Volume and Water Quality

- JB-1, Primrose, Hopper, and a discharge on the North Branch of Robinson Run were equipped with H-Flumes and pressure transducers. Data were also obtained from a pressure transducer operated by PADEP.
- Monthly water quality was measured from all primary sites.
- A pressure transducer was installed in both wells.

JB-1 with H-Flume

pH 5.3, Fe 47 mg/L , Flow 1066 gpm

JB-1 Discharge

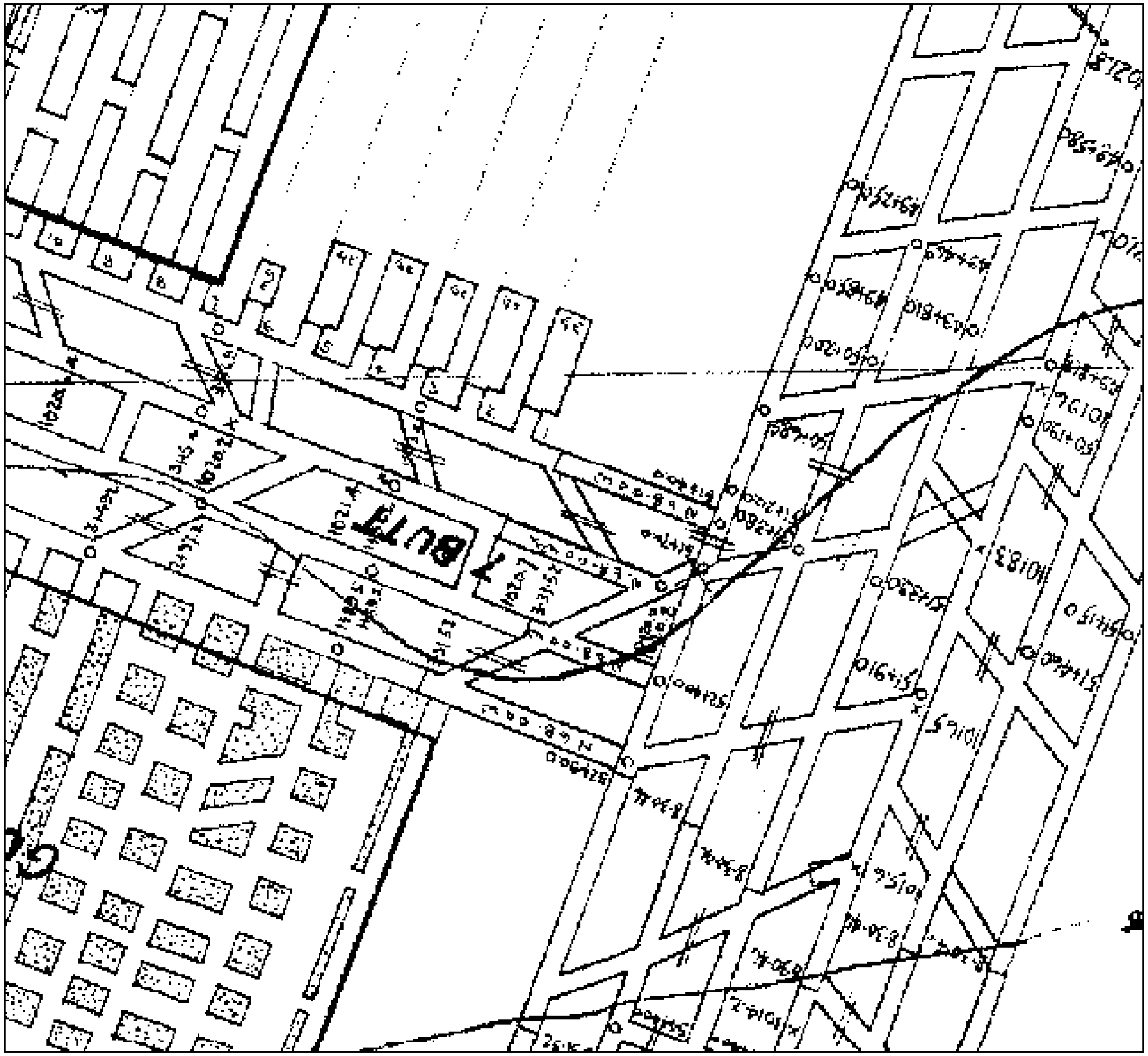


Task 1.3 – GIS Mapping

- 1:1,200 scale mine maps were obtained from the Hillman Library and the PADEP map repositories.
- These maps were composited and geo-referenced in Arc Map format. The extent of underground mining and any identified surface mining was digitized.
- Water level data from wells and mine discharges were used to identify the extent of mine flooding.

Montour #9
Mine Map

1 inch =
100 ft.



Task 1.4 - Mine Discharge Selection

- Precipitation data were combined with mine discharge data and stream recharge records to generate a mine recharge equation that allows the estimation of the water availability from under historic rainfall conditions.

$$Q = \frac{IA}{12}\left(\sum_{Oct-May} P - P_{sat}\right)$$

Task 1.4 - Mine Discharge Selection Continued

Mine	Acreage	Observed	Mean Flow	10th Percentile	90th Percentile
JB-1	3,060	941.3	649.2	495.8	834.6
Primrose	887	210	230.5	176.0	296.3
Montour #9	675	111.4	196.4	148.4	250.3
McDonald	1,678 est.	495.7	498.5	380.6	640.8
Montour #1	2,085	N/A	442.4	337.8	568.8
Bulger	1,009	N/A	237.5	179.4	302.7
Total	9,394	1,758	2,254	1,718	2,893

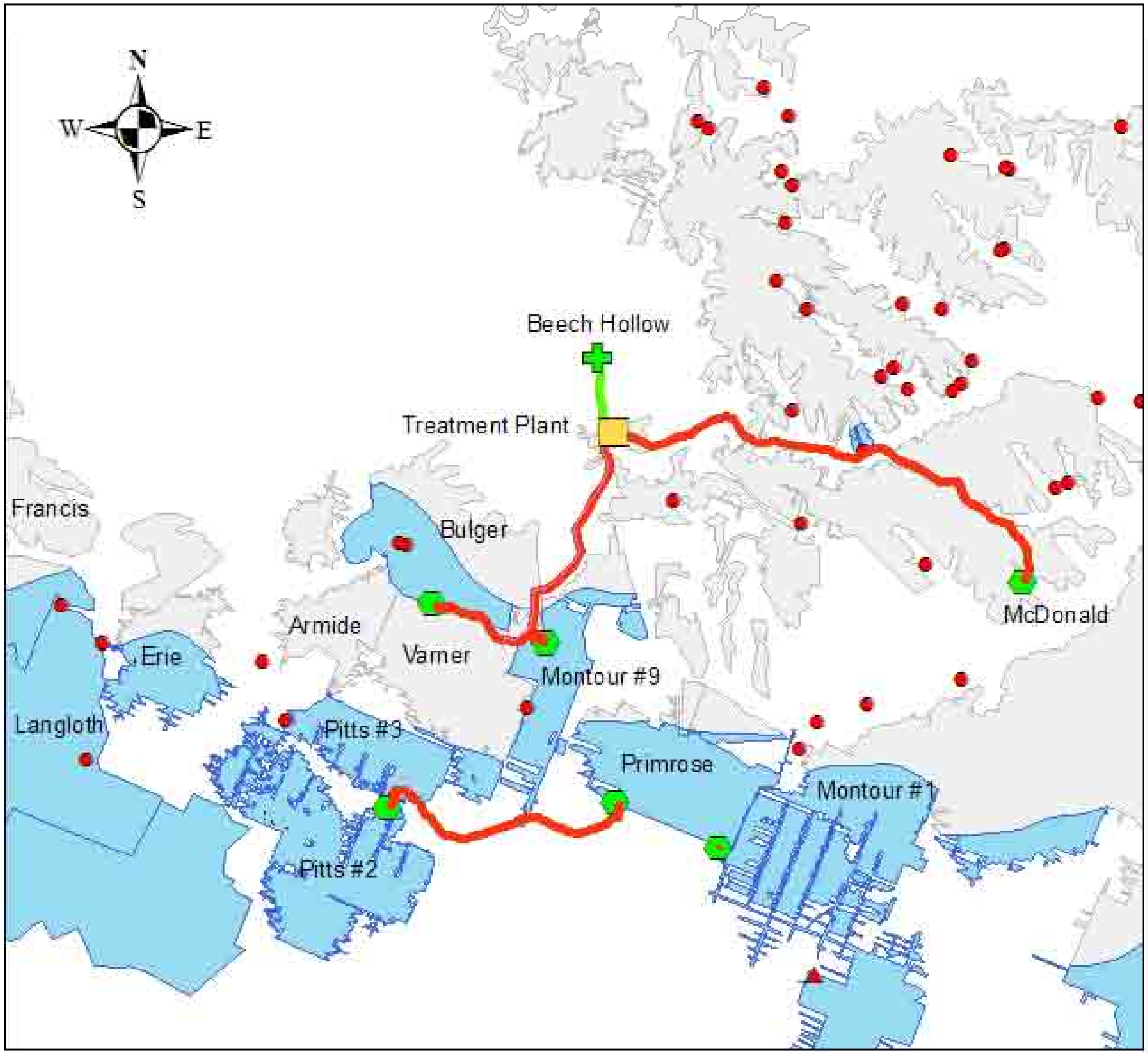
Task 1.5 – Collection and Treatment System design

- Working with the Beech Hollow design team a collection system will be designed to pipe the mine water to the power plant.
- Based on power plant requirements, a treatment system will be designed using initial hydrated lime treatment.
- Anticipated capital and operating costs will be generated.

Task 1.5 – Collection and Treatment System design continued

- Due to the number and location of mines supplying water to the Beach Hollow facility a transfer system was designed using mine to mine transfers to reduce the amount of overland piping.
- The mine water treatment plant is based on hydrated lime, with the potential to add soda ash softening if desired .

Water Transfer System



Task 2.1 - General Information Module

- Module will query the user for:
  - Site information.
  - Owner information.
  - Anticipated construction date.
  - If the mine water will provide: makeup water or both makeup water and heat rejection.
- User will specify the inflation rate.
- Design program will consist of a Microsoft Excel spreadsheet with Visual Basic for Applications (VBA) modules.

Task 2.2 - Water Source Module

- Module will query for:
  - Mine discharge flow rate.
  - Water quality.
  - Distance from the source to the treatment plant.
  - Elevation of mine water.
  - Elevation of mine water pump.
  - Elevation of treatment plant.
  - Maximum elevation of the pipeline.

Task 2.2 - Water Source Module

- Module will recommend:
  - Three different pipeline diameters.
  - Estimated installed cost for each option.
- Module will calculate:
  - Low flow discharge rate for above drainage mines.
  - Sustainable yield for below drainage mines.
- Module will accept multiple water source inputs.

Task 2.3 - Water Treatment Module

- User will have the option of forcing the module to minimize mine water temperature.
- Module will size the treatment plant equipment based upon:
  - Water treatment volume.
  - Raw water chemistry.
- Module's calculations will assume that:
  - Hydrated lime will be the neutralization regent.
  - Either air or hydrogen peroxide will be oxidant.

Task 2.4 - Cost Module

- The use of mine water can result in cooler summer makeup water temperatures. This will result in an increase in power plant output compared to surface water sources.
- If the user elects to use mine makeup water, the module will calculate overall operational cost savings.
  - The method described by Thomas Hamilton, 2000, using heat rate curves, has been incorporated into the module.

Effect of Cold Water Temperature on Turbine-Generator Output.

After Hamilton 2000

EFFECT OF COLD WATER TEMPERATURE ON TURBINE-GENERATOR OUTPUT

BASIS: TURBINE-GENERATOR OUTPUT: 511,000 KW AT 1.0 IN. HG. ABS.

CONDENSER DESIGN: 4.0" HG. BACK PRESSURE WITH
92°F. COLD WATER - 116°F. HOT WATER
210,000 GPM

COOLING TOWER: 210,000 GPM (116-92-80) 24°F. RANGE

BACK PRESSURE IN. HG	CONDENSING TEMPERATURE °F.	TURBINE-GENERATOR KW LOSS	COLD WATER °F.
1.50	91.7	0	54.8
1.75	96.7	0	61.0
2.00	101.1	153	66.2
2.25	105.0	511	70.5
2.50	108.7	1,122	74.45
2.75	112.0	2,044	77.95
3.00	115.1	2,997	81.22
3.25	117.9	4,156	84.17
3.50	120.6	5,560	87.0
3.75	123.1	7,055	89.6
4.00	125.4	8,690	92.0
4.25	127.7	10,510	94.37
4.50	129.8	12,317	96.53
4.75	131.8	14,401	98.58

Task 2.5 - Module Integration

- VBA modules will be integrated into a design aid.
- Calculations and the user interface of the design aid will be extensively tested.
- Design aid will incorporate a user's manual that will explain the application of design aid and basic cost data employed.

Design Aid Requirements

- Using the design Aid will require:
  - 90 MHz Pentium Computer.
  - Microsoft Windows 2000 or XP.
  - 48 MB RAM.
  - Microsoft Office 2000.
- Design aid and user's manual will be available via the WV Water Research WWW site.

Evaluating Saline Aquifers for Combined Carbon Sequestration and Power Plant Cooling Water Needs:

Phase I Efforts and Phase II Goals

Contributing Authors:

Peter H. Kobos, Malynda Cappelle, Jim Krumhansl, Tom Dewers, Andrea McNemar, David J. Borns, Michael Hightower

Location:
October 27 – 28, 2008, NETL
Pittsburgh, PA Site Meeting

Acknowledgements: This work is developing under the funding and support of the National Energy Technology Laboratory.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.
Working Results, SAND2008-7023P.

National Nuclear Security Administration

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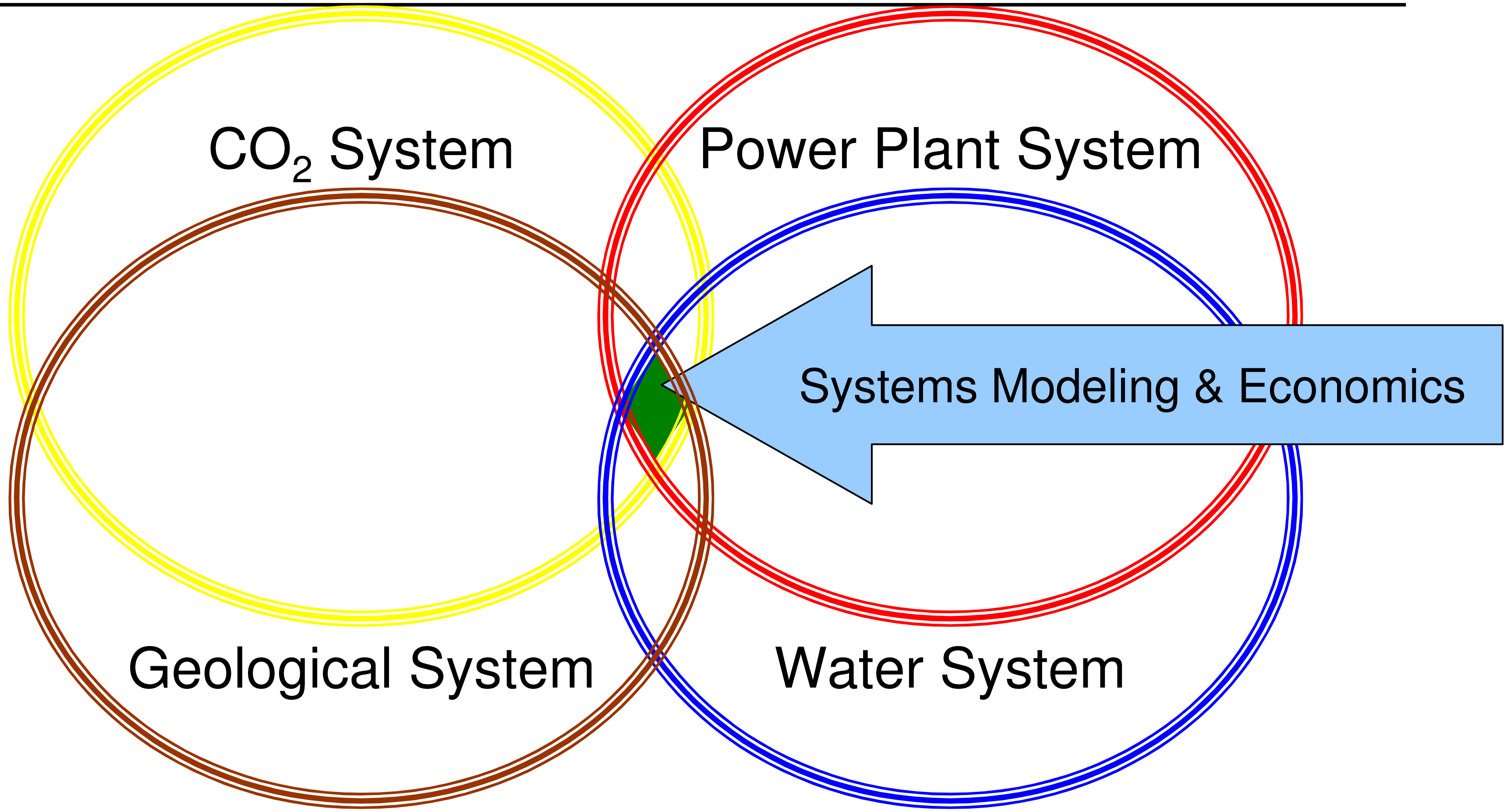
Energy-Economic Modeling: Conceptual Layout of the Project



Can a power plant sequester Carbon Dioxide in a geological saline formation, while also utilizing treated water for cooling or other uses?

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Progress of the Modeling Efforts

Timeline	
2008	• **Completed Phase I:**
	– Developed a Test Case Model
	• Formation Assessment, CO_2 and Water
	• San Juan Power Plant
	• Desalination (Reverse Osmosis)
	– Initial results indicate there may be several hundred years worth of CO_2 storage capacity in saline formations
	– Potential to displace and produce these waters, with treatment, could supplement the additional water requirements (parasitic loads due to CCS and producing and treating the water)
Summer	
	• **Ongoing:**
	– Additional Geosystems Analysis
	• Detailed TOUGH 2 modeling of the Morrison Formation
Fall	• Additional Potential Formation / Locations
	– Collaborative Paper Presentation at the USAEE / IAEE conference (New Orleans, 12/08).
	• **Where we are going:**
	– Studying the expansion to additional aquifers
2009 +	– Looking to develop a portfolio of power plant systems (e.g., supercritical coal) models for comparison
	– Final Product
	• Framework for Analysis -- coupled sequestration and water treatment system assessment for new candidate sites

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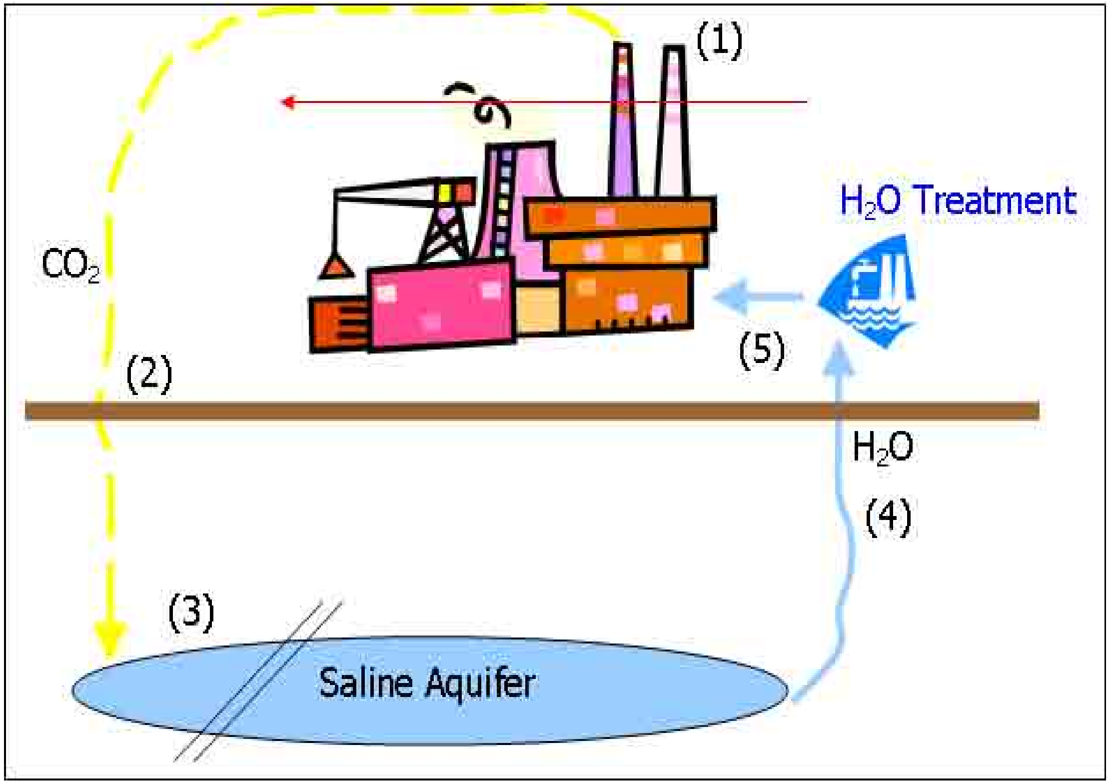
The Model
Building the Assessment Framework



Briefly describe steps.

- **(1) CO_2 power plant emissions**
- **(2) CCS Potential**
- **(3) Saline Aquifer CO_2 sequestration potential**
- **(4) Pump Saline Aquifer for use at the power plant**
- **(5) Desalinate water for use at the power plant**

Note: Carbon Capture and Sequestration (CCS)

Key Metrics of Interest

- **Costs**
  - $/kWh
  - Carbon Capture and Sequestration
  - Treated Water Costs

- **Water**
  - <u>Volumes</u> associated with Formations, flow rates
  - <u>Length of time</u> water may last

- **Carbon Dioxide**
  - <u>Volumes</u> of CO_2 potentially sequestered, flow rates
  - <u>Length of time</u> geological sink may last
  - Financial ($/kWh), Energy (parasitic energy for systems) and Water (additional water for additional/parasitic systems) costs

Developing the Test Case Model Assessment Framework

- **Developing a Test Case to build the Framework**
  - Looking to scale up the assessment to the Regional & National scale
- **Power Plant: San Juan Generating Station**
  - 1,848MW Subcritical, Coal, Steam power plant
  - Annual Water Consumption: 22,400 acre-ft/year
    (7.3 billion gallons/yr) with the cooling towers representing 90% of consumption
  - Annual CO_2 Emissions: 14.5 million ton/yr
- **Saline Formation: Morrison Formation**
  - 3,000+ million metric tonnes CO_2 sequestration capacity

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Formation CO_2 REACT 'box model' studies

- Several Aquifers were studied in these formations:
  - Mesa Verde / Point Lookout
  - Dakota
  - Hermosa / Paradox
  - Morrison
- Insights:
  - Morrison may have the more favorable geochemical/geospatial conditions for CCS & water treatment and use
  - Morrison has a broad regional occurrence
  - Assess Formation's long term ability to retain sequestered CO_2

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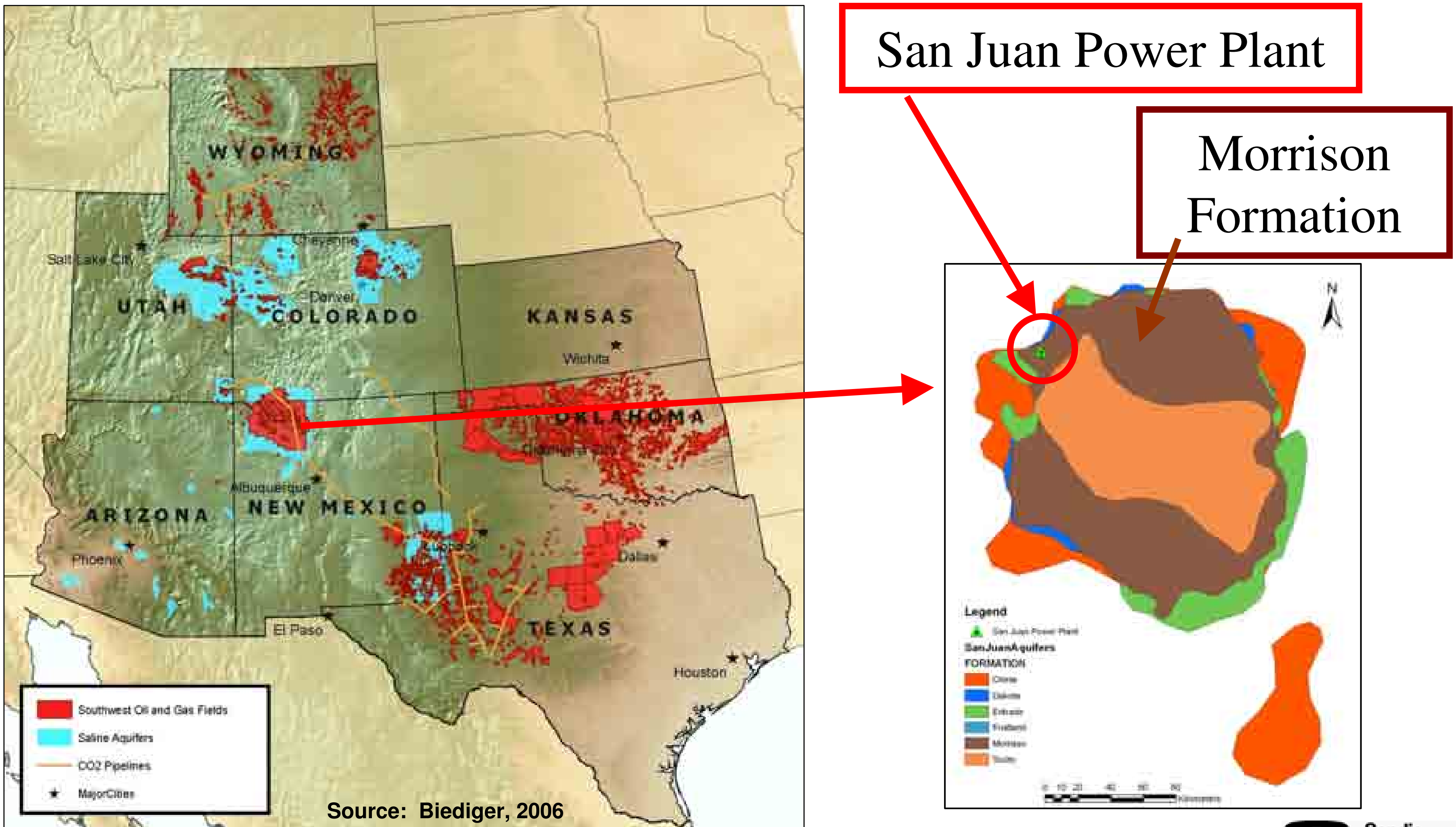
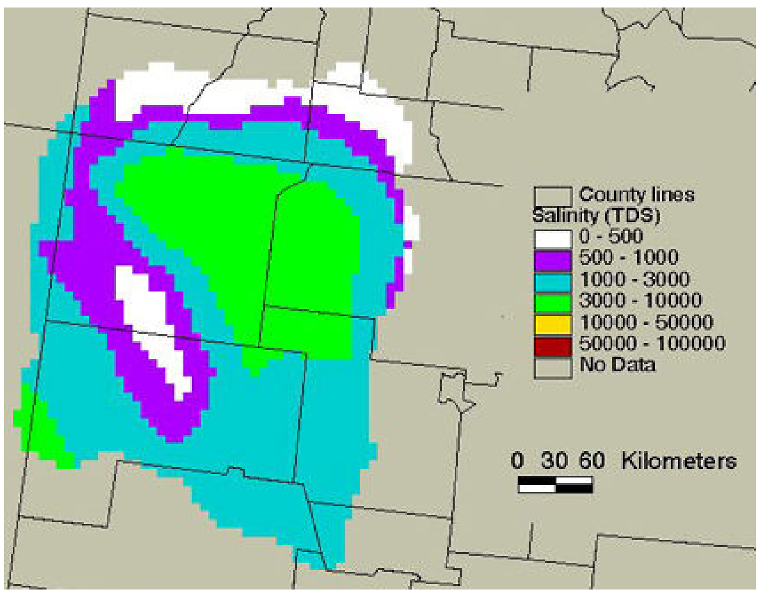
The San Juan Power Plant and Morrison Formation



Source: Biediger, 2006

Salinity Profile for the Morrison Formation

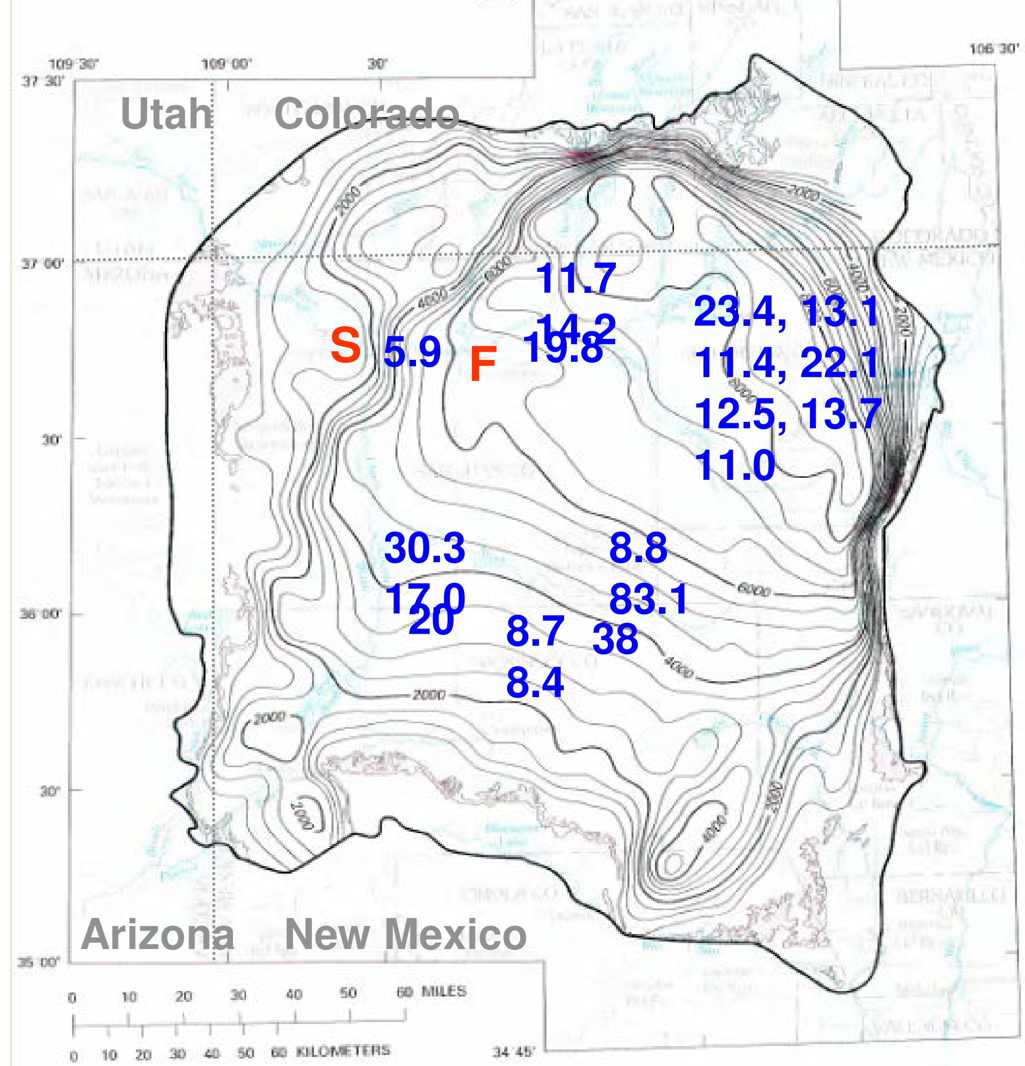
- Has been recognized for it's CO_2 sequestration potential
- Meets some of the assessment's criteria by having __a low salinity throughout__



(Source: Hovorka et al., 2000, Sequestration of Greenhouse Gases in Brine Formations; Texas Bureau of Economic Geology)

(Proposed EPA, UCI Water Rule on TDS)

- TDS (g/kg) for NATCARB-listed Morrison wells in the San Juan Basin



Rock-Water-CO_2 Interactions in the Morrison

- CO_2 injection will lower formation water pH initially to ~3.5
  - But, reactions w/formation minerals will bring the pH back to ~4.9 in less than a century.

- Changes in brine chemistry relevant to desalinization are elevated levels of iron and silica.

- Unlikely the CO_2-charged fluids will mobilize deeply buried uranium
  - Deposits (just one log in 21examined exhibited a significant ‘hit’)

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Modeling CO_2 Injection in San Juan Basin:

Developing the Earth Model

Hydrostratigraphy

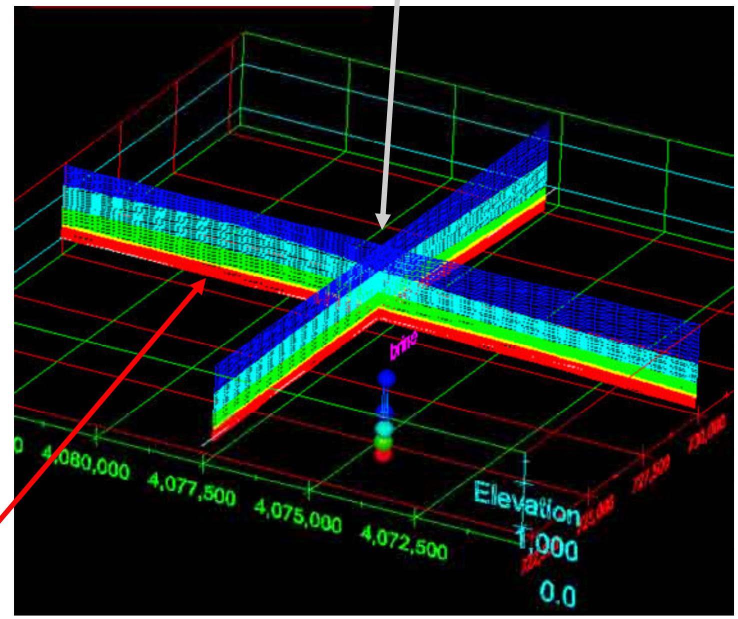
Table 2. Absolute permeabilities used for Morrison "layer-cake" TOUGH2 model

Hydro-stratigraphic Unit	**Conductivity (ft/s)**		**Permeability (m^2)[5]**	
	Horizontal	Vertical	Horizontal	Vertical
Lower Mancos Confining Unit	1.00E-08	1.00E-12	7.46E-16	7.46E-20
Dakota Aquifer	4.40E-06	3.90E-10	3.28E-13	2.91E-17
Brushy Basin Confining Unit	1.00E-07	9.50E-11	7.46E-15	7.09E-18
Morrison Aquifer	5.44E-06	3.90E-10	4.06E-13	2.91E-17
Wanaka Confining Unit	1.00E-07	4.20E-10	7.46E-15	3.13E-17

Notes:
[1]Frenzel, 1983
[2]Thomas, 1989
[3]Kernodle, 1996
[4]Estimated for similar rock type
[5]assumes temperature of 30°C and brine density of 1100 kg/m^3

Earth Model

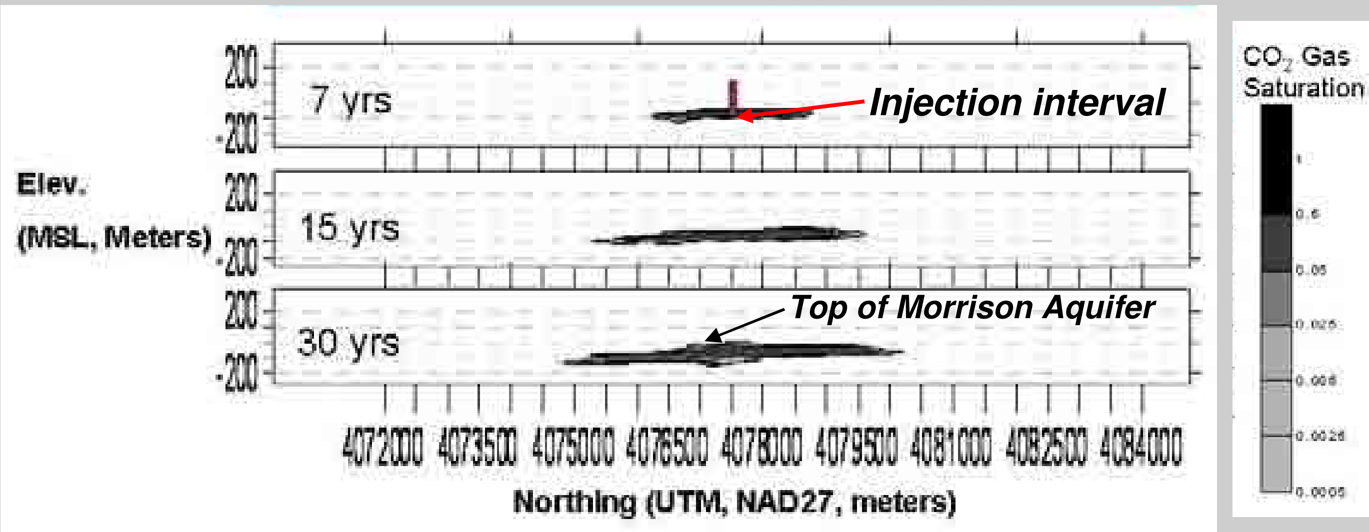
SJGS directly above



Morrison Aquifer (~ 200 m saturated thickness) is injection target

Modeling CO_2 Injection in San Juan Basin:

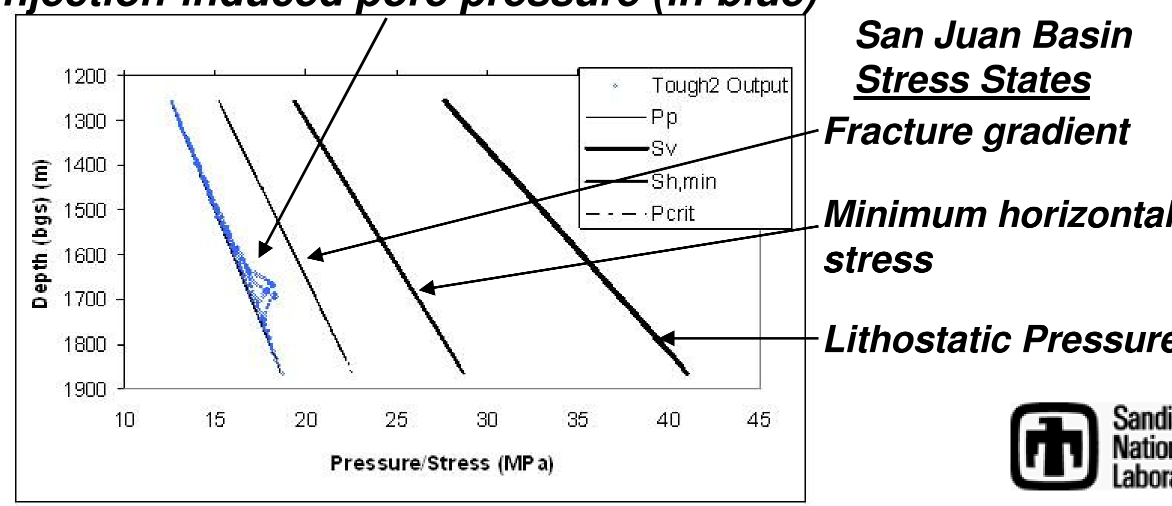
Calculating Manageable CO_2 Injection Rates



TOUGH2 (Pruess, 1999) simulations of CO_2 injection into Morrison Fm.

- **Injection rate of *2,500 metric tons/day* can be achieved without near-wellbore damage**

Injection-induced pore pressure (in blue)



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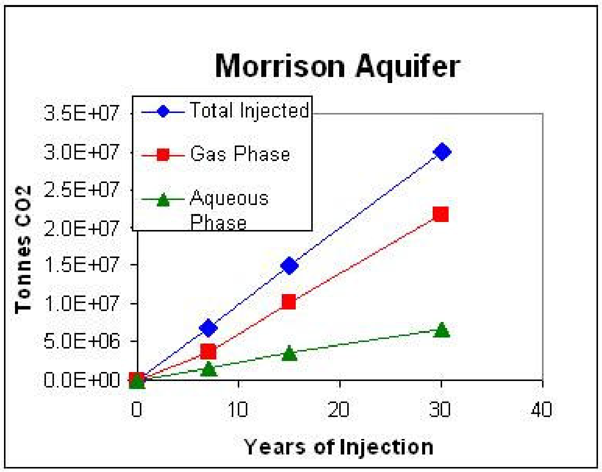
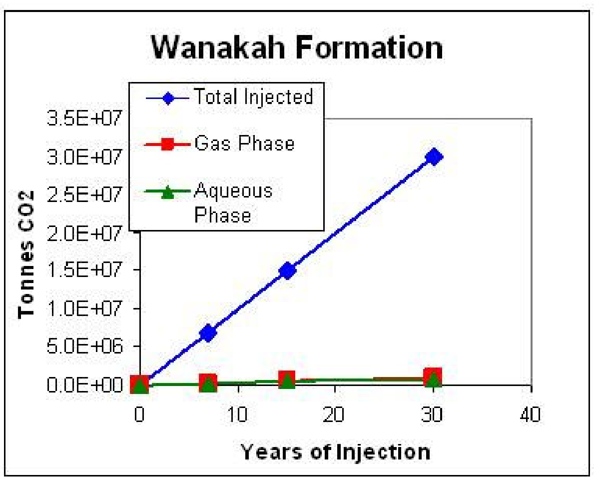
Modeling CO_2 Injection in San Juan Basin:

Calculating Storage Capacity (Morrison, ~3,300 million metric tonnes)

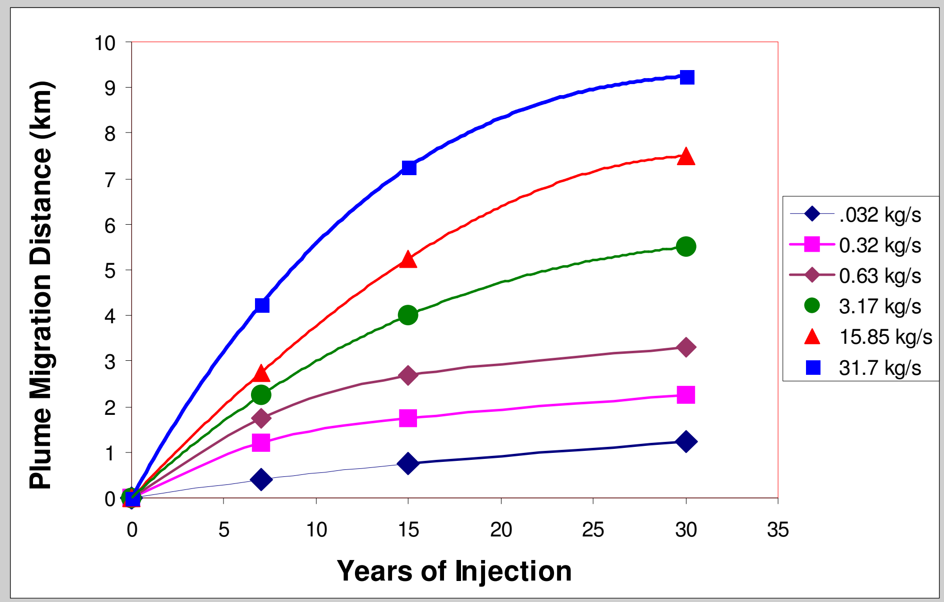
CO_2 Mass Storage





TOUGH2 simulations constrain the amount of storage capacity in Morrison Fm and the CO_2 plume migration distance

Plume Migration, fxn of injection rate



References: Pruess et al., 1999, LBNL-43134; Pruess, 2005, LBNL-57952

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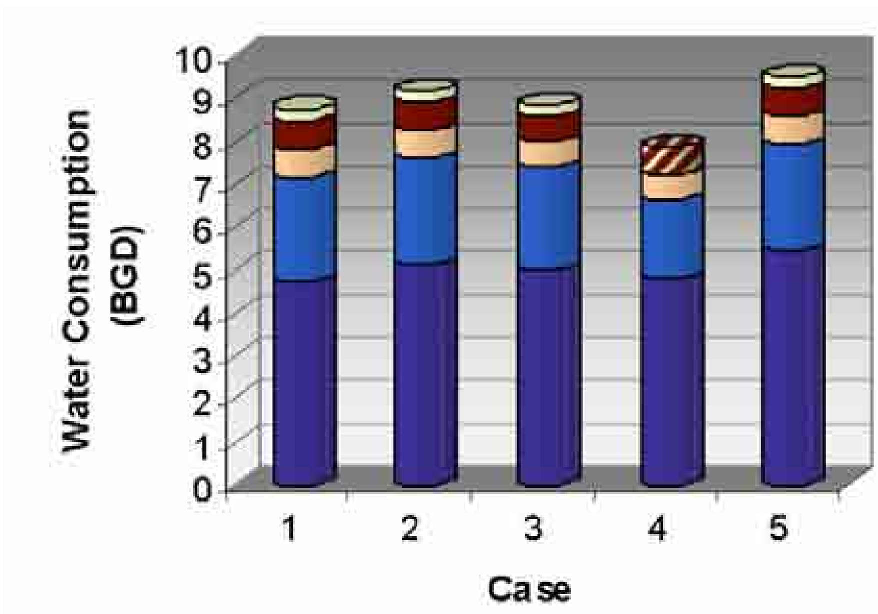
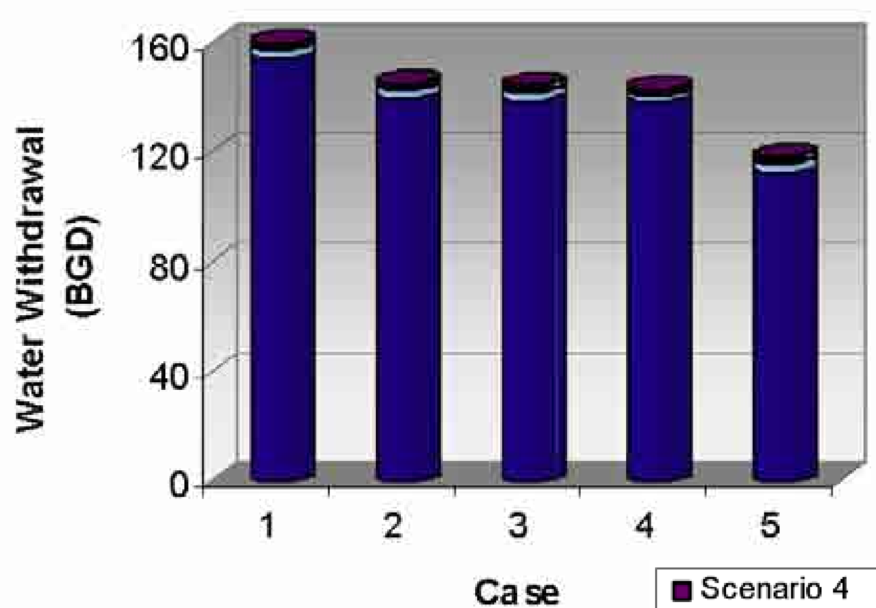
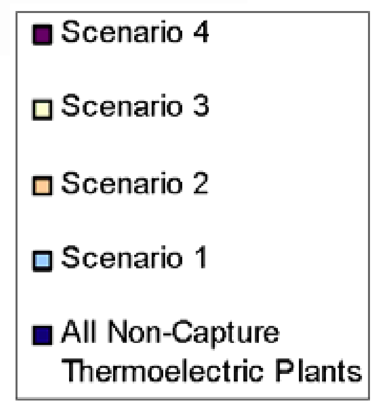
Carbon Sequestration:
Water Consumption & Water Withdrawal







- Carbon Capture and Sequestration ↑ water consumption
- However, Water Consumption is small relative to Water Withdrawal
- Point: Experts Point out overall water withdrawal may only change slightly

Source: DOE/NETL-400/2008/1339, Figures ES-5 & ES-6.

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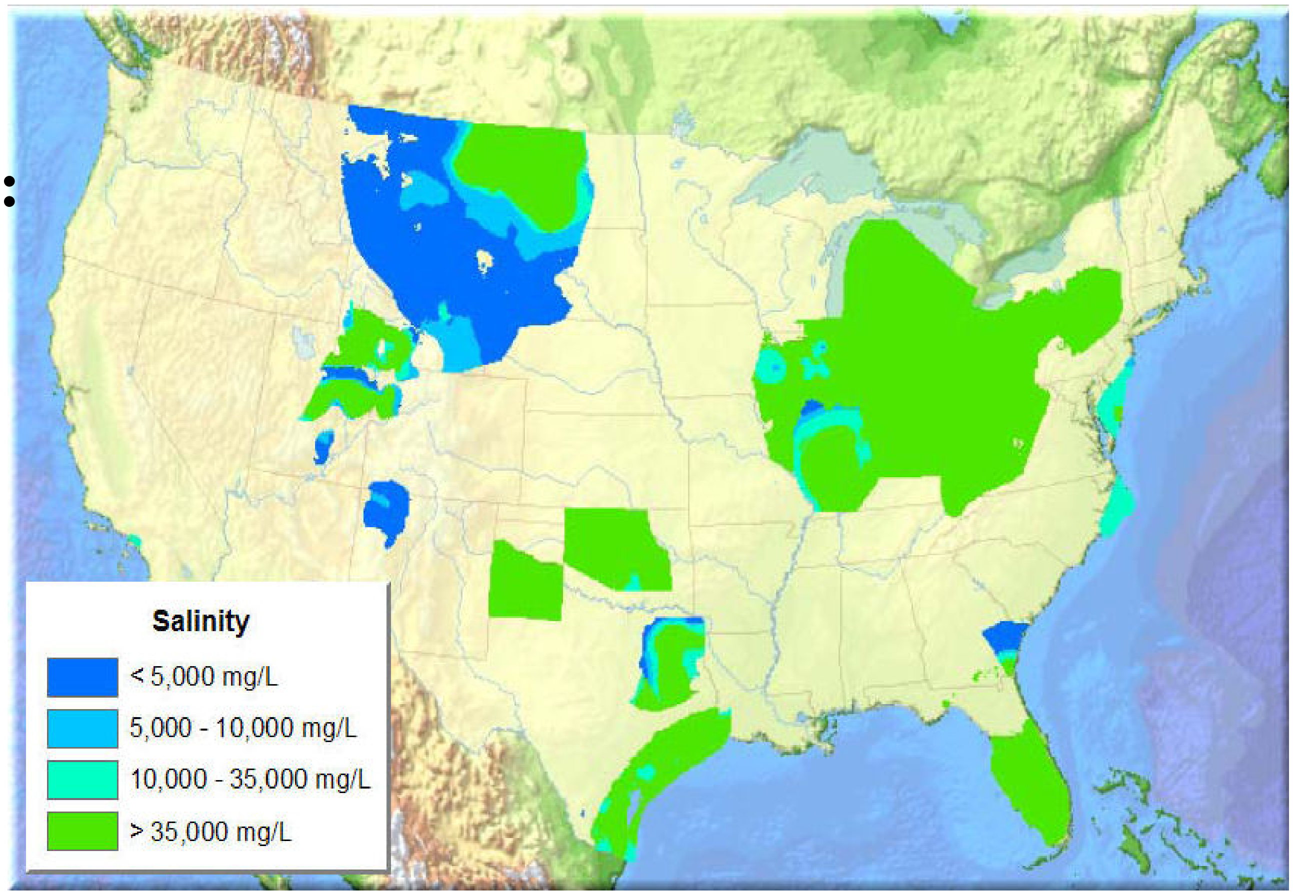
Deep Saline Formations: Potential Limited CO_2 Sequestration Volume

If aquifers are used:

• CO_2 injection wells likely to be restricted to those sites with TDS > 10,000 mg/L



Source: Davidson et al. 2008 (Batelle)

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Water Treatment Options

Order of Magnitude Technology Cost Options

Total Cost - includes equipment & O&M for desalination and concentrate disposal (e.g. ponds)		Option A BWRO-**no conc disposal** $/1000 gal		Option B BWRO-**evap ponds** $/1000 gal		Option C BWRO-**injection well** $/1000 gal		Option D HERO + **BC retrofit** $/1000 gal
Annualized Total Capital	$	2.90	$	5.04	$	3.24	$	2.59
Annual O&M	$	2.31	$	2.35	$	2.32	$	2.73
Electrical	$	0.42	$	0.42	$	0.42		
Membrane Replacement	$	0.00	$	0.00	$	0.00		
Other	$	0.54	$	0.54	$	0.54		
Total Cost (O&M+cap)	**$**	**5.21**	**$**	**7.39**	**$**	**5.56**	**$**	**5.31**

Cost of Desalination only - includes only equipment & O&M for desalination (i.e. no ponds, no GW pumping)		Option A BWRO-no conc disposal $/1000 gal		Option B BWRO-evap ponds $/1000 gal		Option C BWRO-injection well $/1000 gal		Option D HERO+BC retrofit $/1000 gal
Annualized Total Capital	$	1.59	$	1.59	$	1.59	$	1.28
Annual O&M	$	1.34	$	1.34	$	1.34	$	1.43
Electrical	$	0.42	$	0.42	$	0.42	$	0.86
Membrane Replacement	$	0.08	$	0.08	$	0.08	$	-
Other	$	0.59	$	0.62	$	0.59	$	0.64
Total Cost (O&M+cap)	**$**	**2.93**	**$**	**2.93**	**$**	**2.93**	**$**	**2.72**

Note: Brine Water Reverse Osmosis (BWRO); High Efficiency Reverse Osmosis + Brine Concentrator (HERO+BC); Ground Water (GW); Operations and Maintenance (O&M). Source: Bureau of Rec. Handbook.

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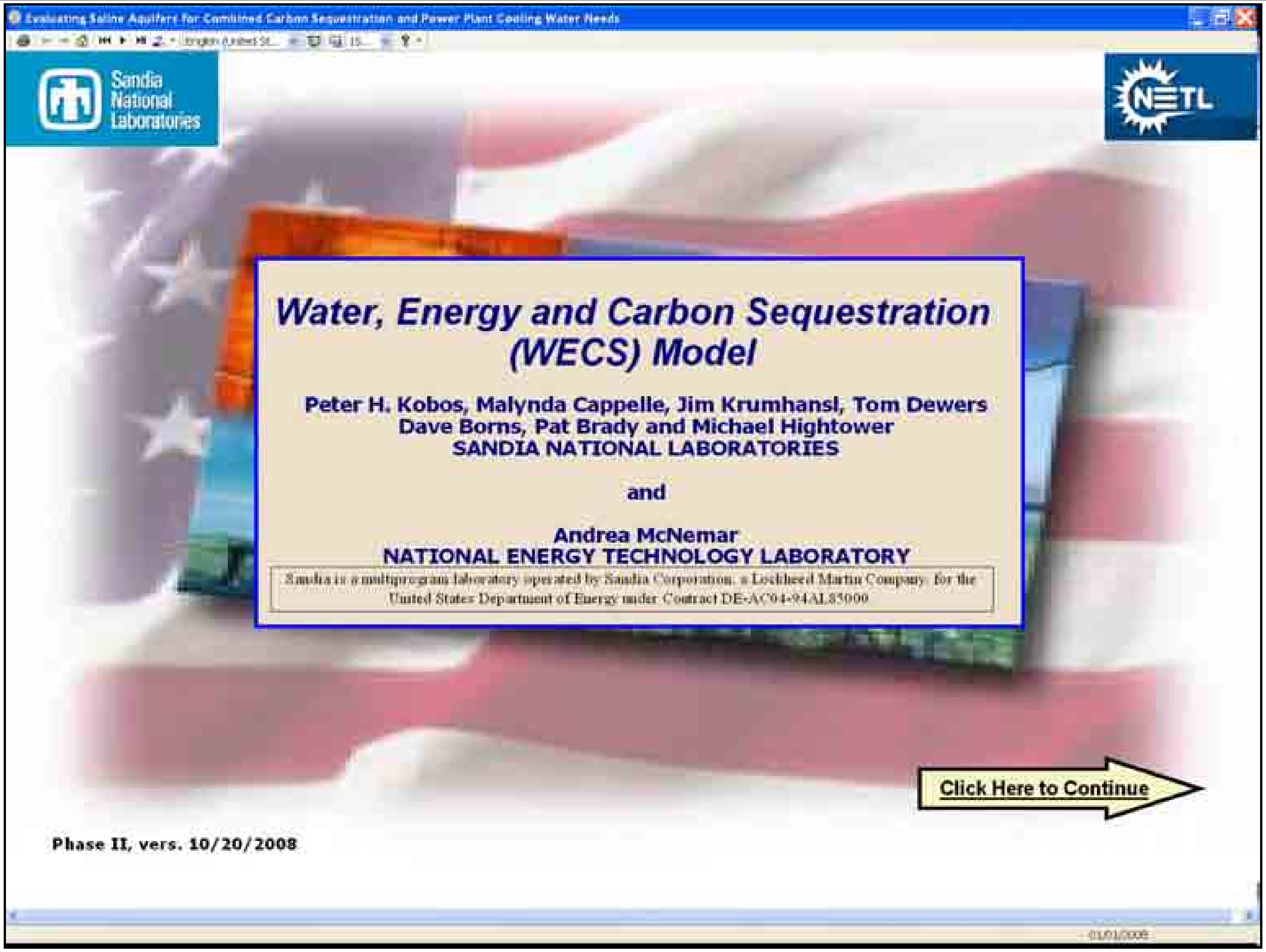
Evaluating Combined Carbon Sequestration and Power Plant Cooling Water Needs: *Using the Integrated Systems Framework*



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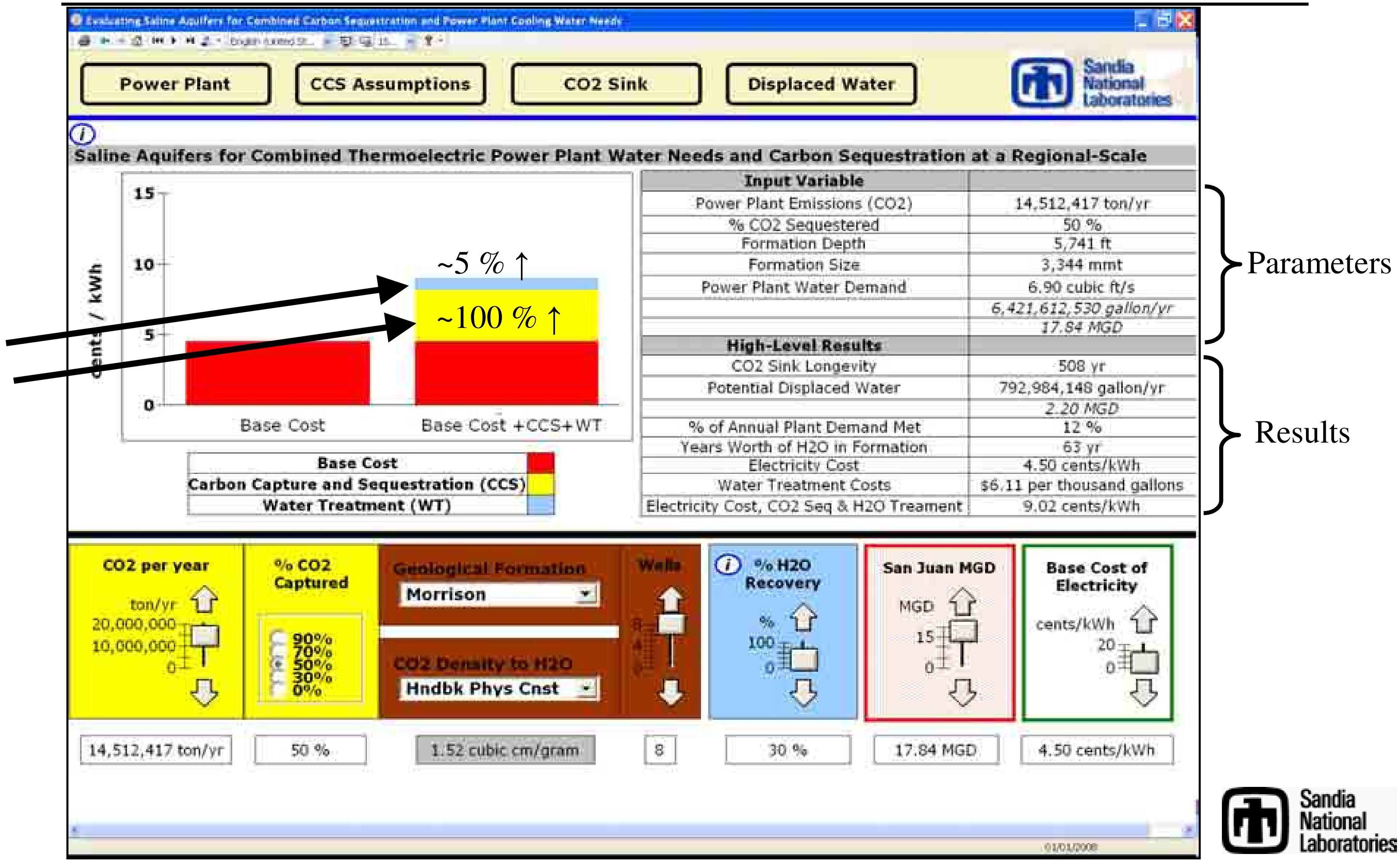
Working Interface:

Using the Interactive Systems Model to Evaluate Scenarios



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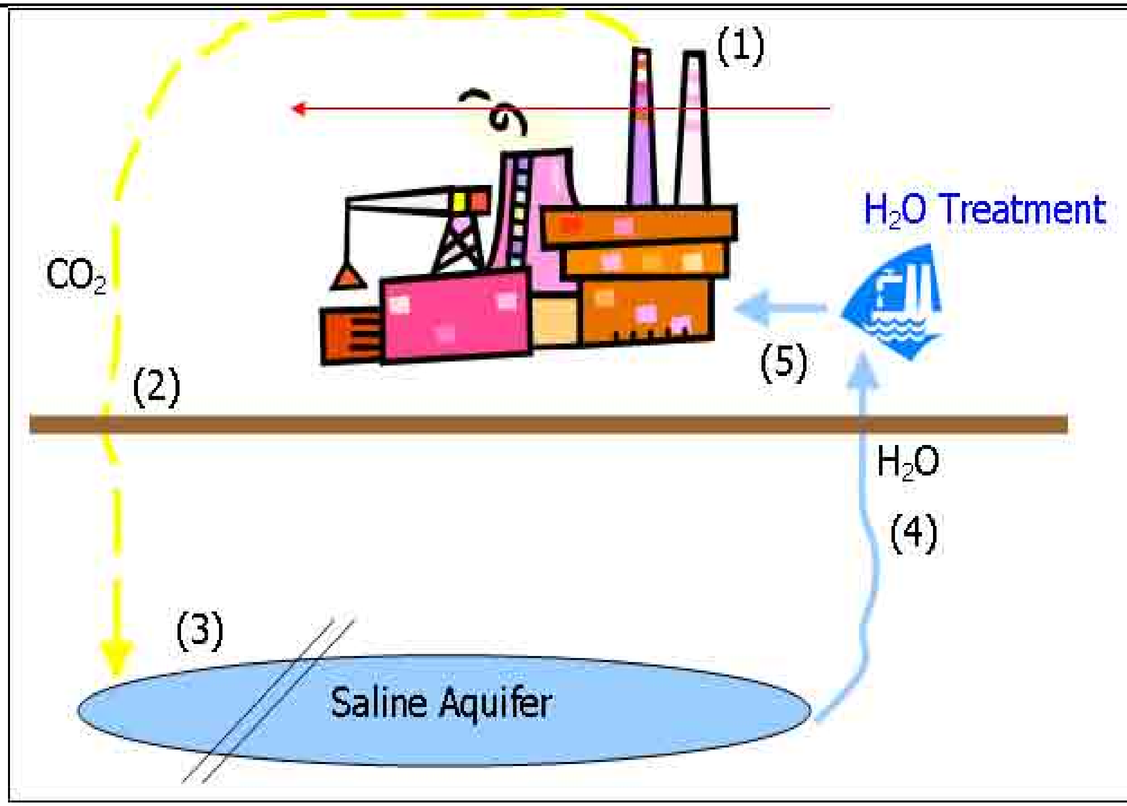
(1) Carbon Capture and Sequestration (CCS),
20%+ Energy Penalty, ↑ costs ~100%, ↑H_2O demands

(2) CCS, 50% capture and sequestration, ~7 mmt/yr



(5) Produced Water Treatment, ↑ costs ~5%, meet potentially a portion of Power Plant's annual H_2O demand

(3) Morrison Formation, 3,000+ mmt, 100s yrs. worth of CO_2 sequestration capacity

(4) <1 - 4 Million Gallons per Day for ~50-100s yrs., Assuming 30% recoverable produced water potential

Assumptions with the Framework: *Caveats*

- Can we sequester CO_2 at these flow rates?
- Can we produce water at these flow rates for what period of time?
- Will there be sufficient communication between the CO_2 and the H_2O in the formation without complications?
- Others…

Evaluating Saline Aquifers for Combined Carbon Sequestration and Power Plant Cooling Water Needs:

Phase I Efforts and Phase II Goals

Thank You

Acknowledgements: This work is developing under the funding and support of the National Energy Technology Laboratory.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

EERC Technology... Putting Research into Practice

Optimization of Cooling-Water Resources for Power Generation

NETL Water Projects Meeting

Pittsburgh, Pennsylvania

October 28, 2008

Northern Great Plains Water Consortium

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National Energy Technology Laboratory

Spiritwood Industrial Park

- $350+ million project
- Located in Jamestown, North Dakota
- 100-million-gallon ethanol plant
- Cargill malting facility expansion
- Spirtwood Station (Great River Energy)
  - 99MW coal-fired electricity
  - 200,000 lb/hr steam

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Bismarck Tribune June 16, 2008

- Headline: **Ethanol plant on hold near Jamestown**
  - "The State Water Commission says the *aquifer in the Spiritwood area does not have enough capacity to provide water* for the ethanol plant and for the Cargill malting plant, which has expanded."

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Mankato Power Plant

- 365-MW natural gas-fired combined-cycle plant located in Mankato, Minnesota.
- Calpine Corporation 12-MGD wastewater reclamation facility:
  - 25% used as cooling-tower makeup
  - 75% discharged directly to the Minnesota River
- Project conserves drinking water resources and improves discharge water quality.

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Introduction

- Adequate supplies of quality water are critical to the existing and future power generation needs of the nation.
- Thermoelectric power generation faces significant societal, political, technical, and legal challenges in addressing water needs.

Justification

- A decision support system (DSS) would be a useful tool for power generation utilities to rapidly assess critical water issues, including the availability of adequate supplies of suitable water for new generation or the assessment of supplemental supplies at existing power plants.

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DSS Project Objectives

- Initiate the development of a regional Web-based DSS to provide power utilities with an interactive assessment tool to address water supply issues when planning new, or modifying existing, generation facilities.

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Northern Great Plains Water Consortium

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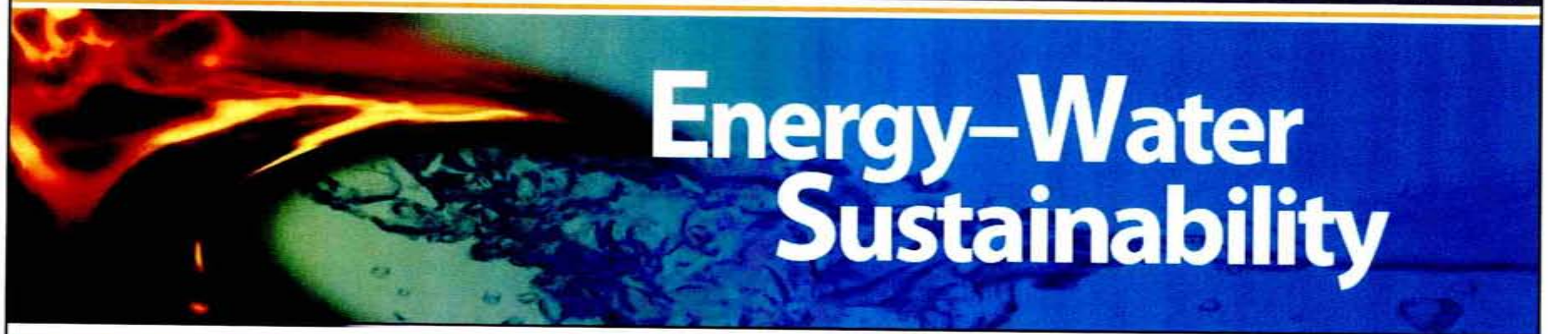

Water Law

Water Resource

DSS – Desision Support System

Treatment Technology Desription

draft

Featured Tool

This area will be used to highlight a tool on the DSS site.

NGPWC News Today

The Demand for Water

Water is the most critical limiting resource throughout the world. Sustainable economic growth requires a reliable supply of water for energy, agriculture, and a growing population. Water is necessary for urban development, power production, growing and processing high-value crops, oil and gas development and processing, and industrial manufacturing. Satisfying all of these competing needs requires a better **understanding of water**

DSS Region Selection

- Minnesota, North Dakota, South Dakota:
  - Politically diverse region
  - U.S. Environmental Protection Agency (EPA) Region 5 (MN), EPA Region 8 (ND, SD)
  - Eastern vs. western water law doctrine
  - Watershed districts vs. county water boards
- The EERC has a history of dealing with local- and state-level jurisdictions in Minnesota and North Dakota on numerous water projects.

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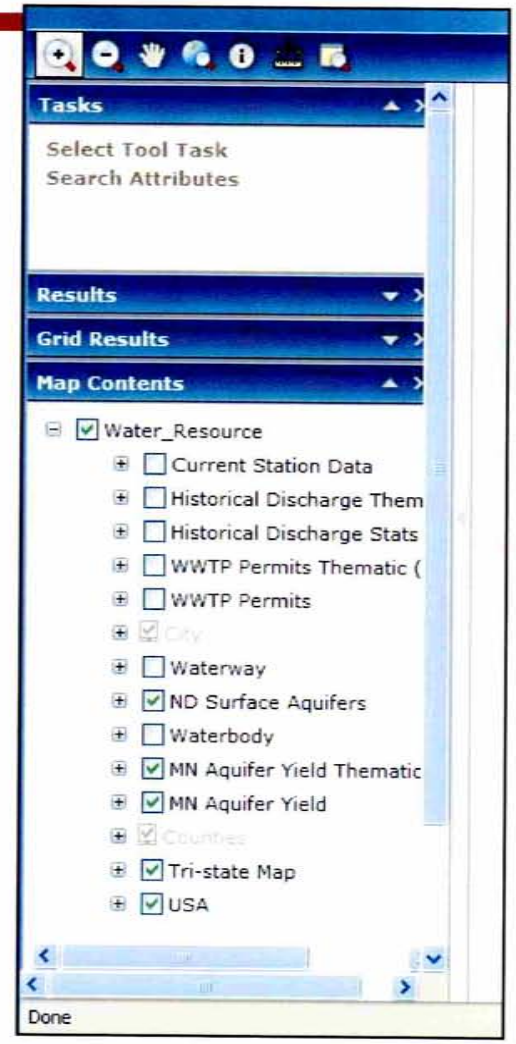
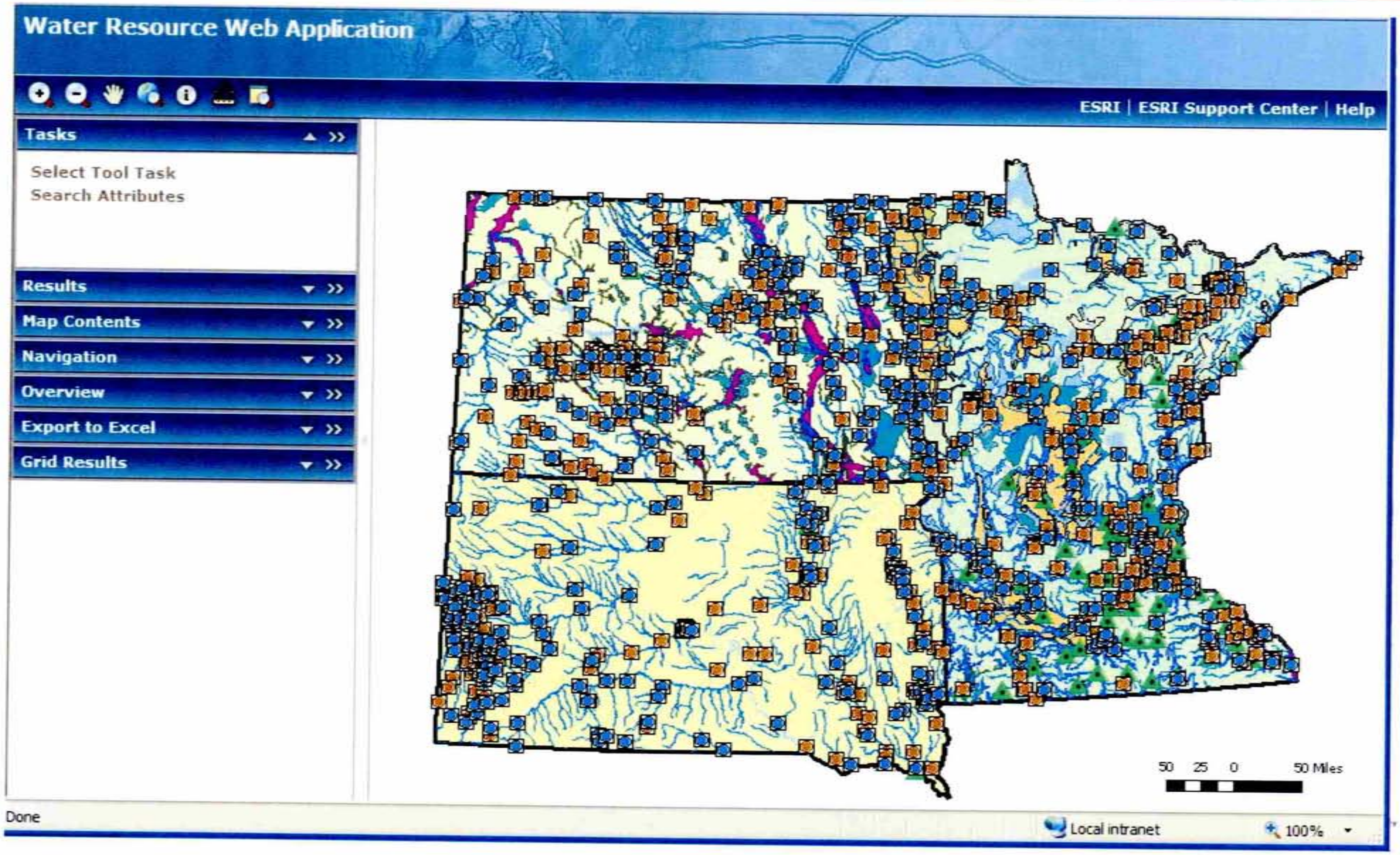
Water Resource DSS Components

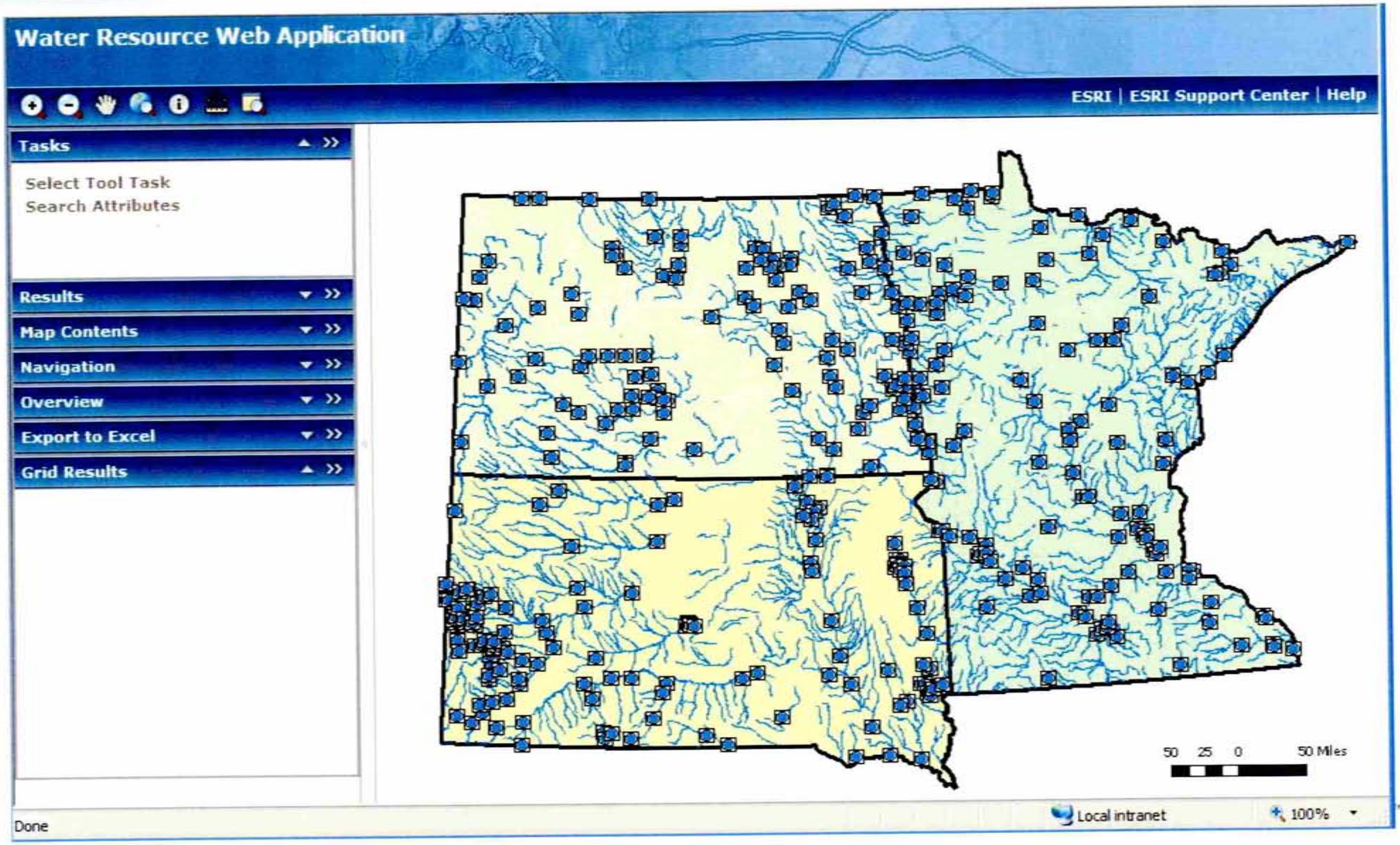
- Geographic information system (GIS)-based
  - Surface waters (U.S. Geological Survey [USGS])
  - Groundwater (states)
  - Nontraditional resources (USGS, states, ?)
  - Water quantity (USGS, states)
  - Water quality (EPA STORET)
- Text-based
  - Water treatment/minimization issues
  - Water quality
  - Legal Issues



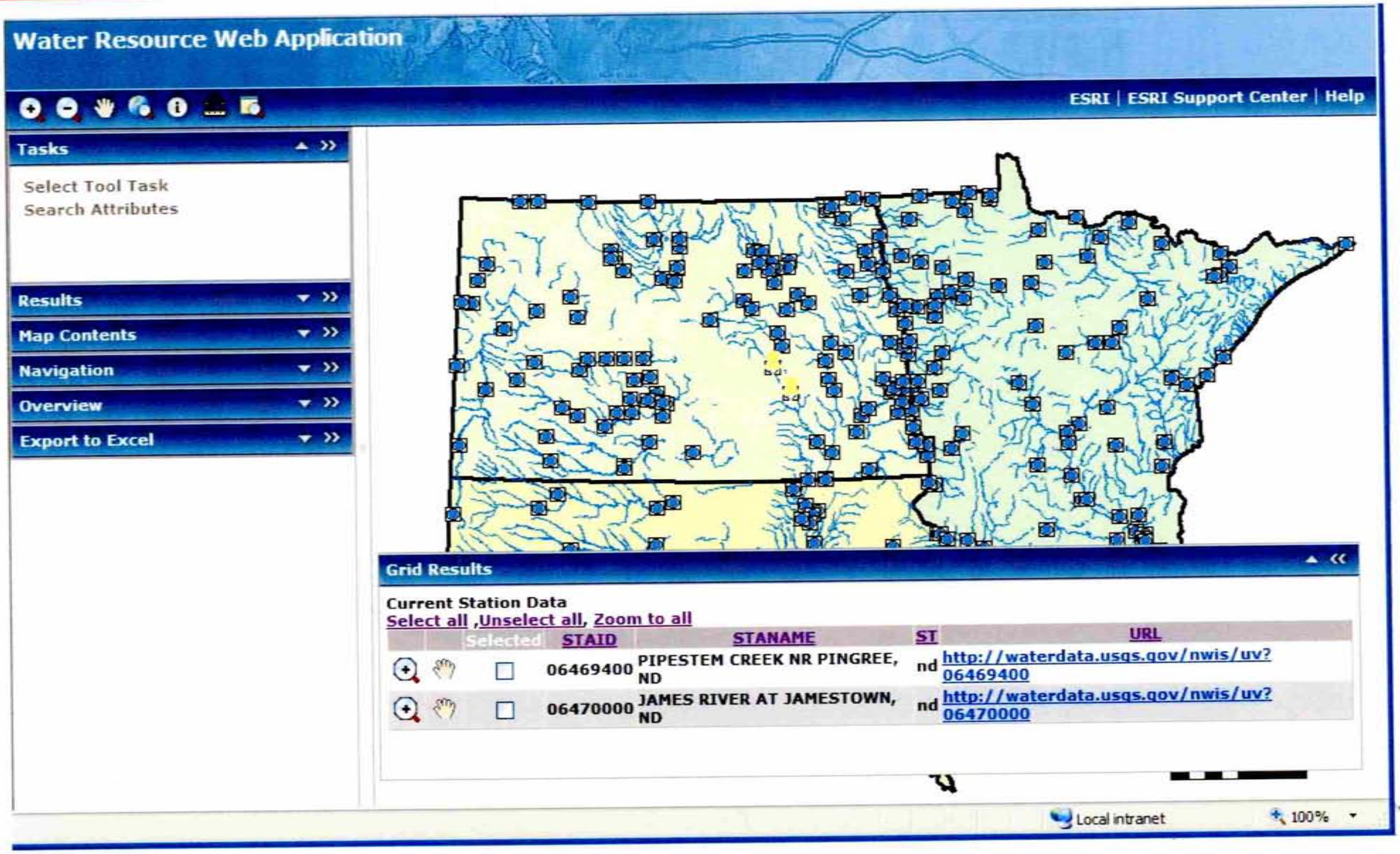
Current Data Distribution



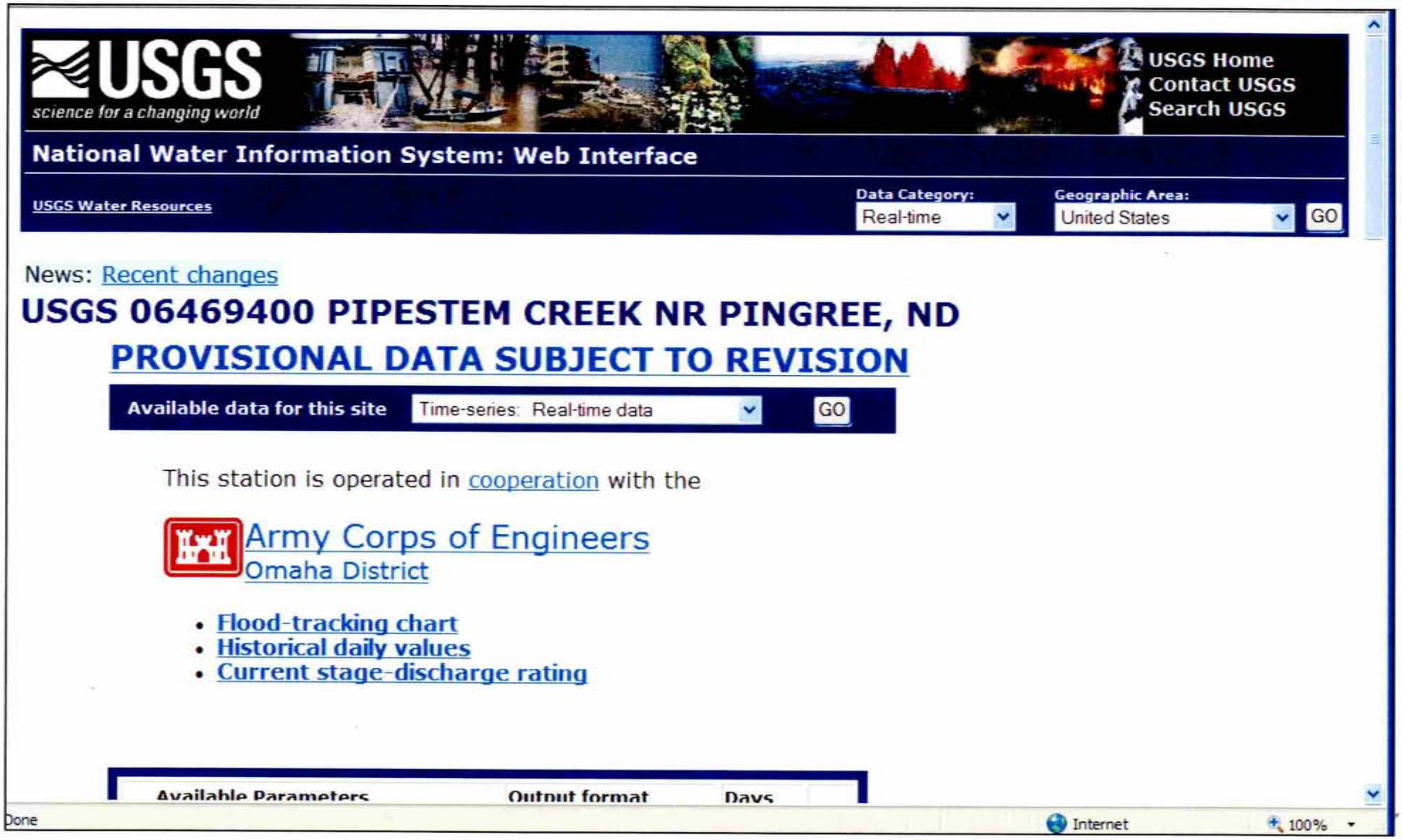
Real-Time Water Flow



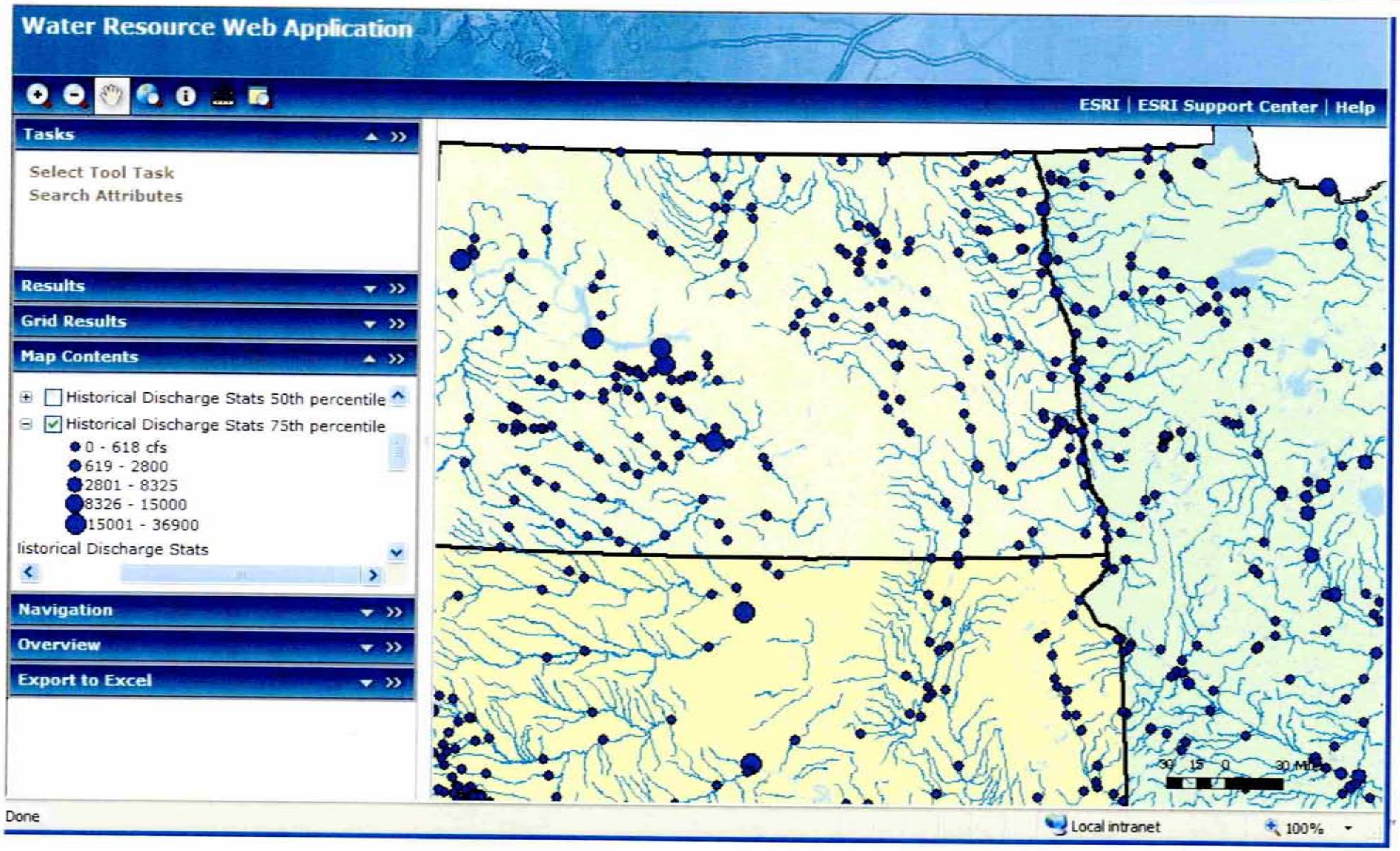
Live Link to USGS Gaging Station Data



Live Link to USGS Gaging Station Data

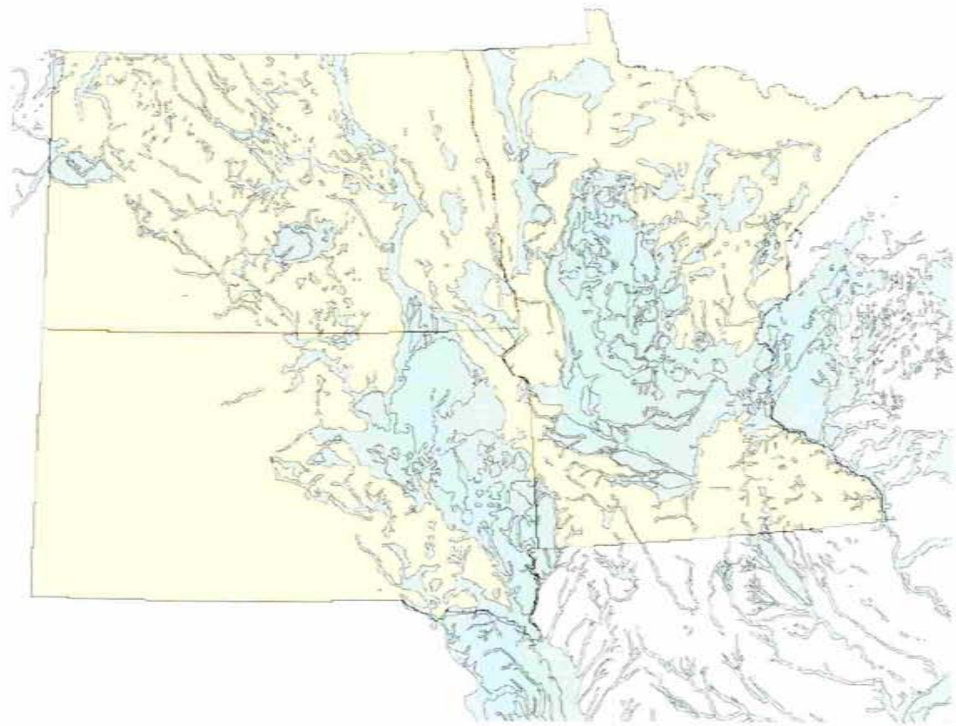


Historical Stream Flow Data



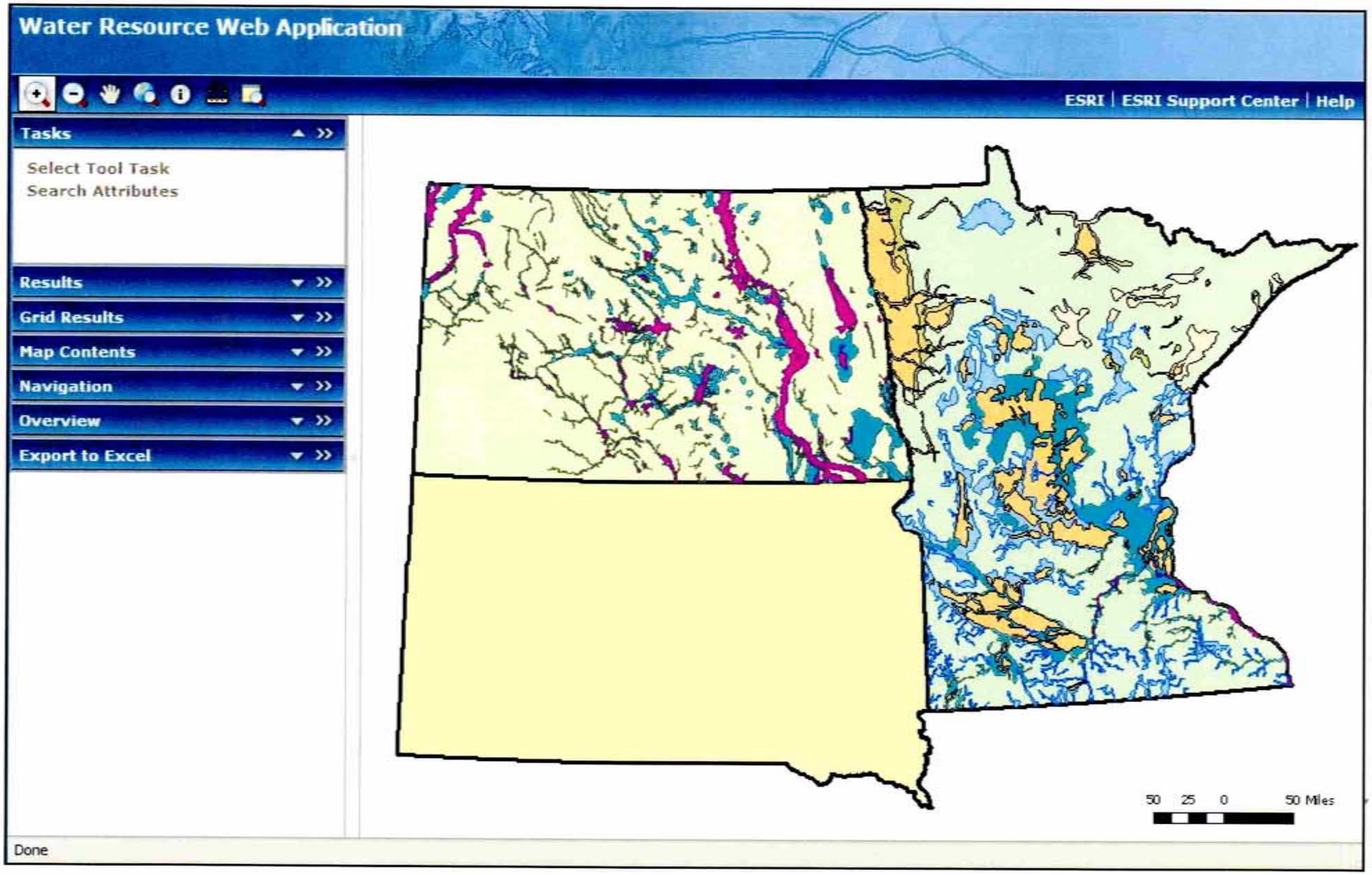
The Hunt for Informative Aquifer Data

- Although there is an understanding of the distribution of aquifer-bearing material, there is much less known with regard to the yield potential.

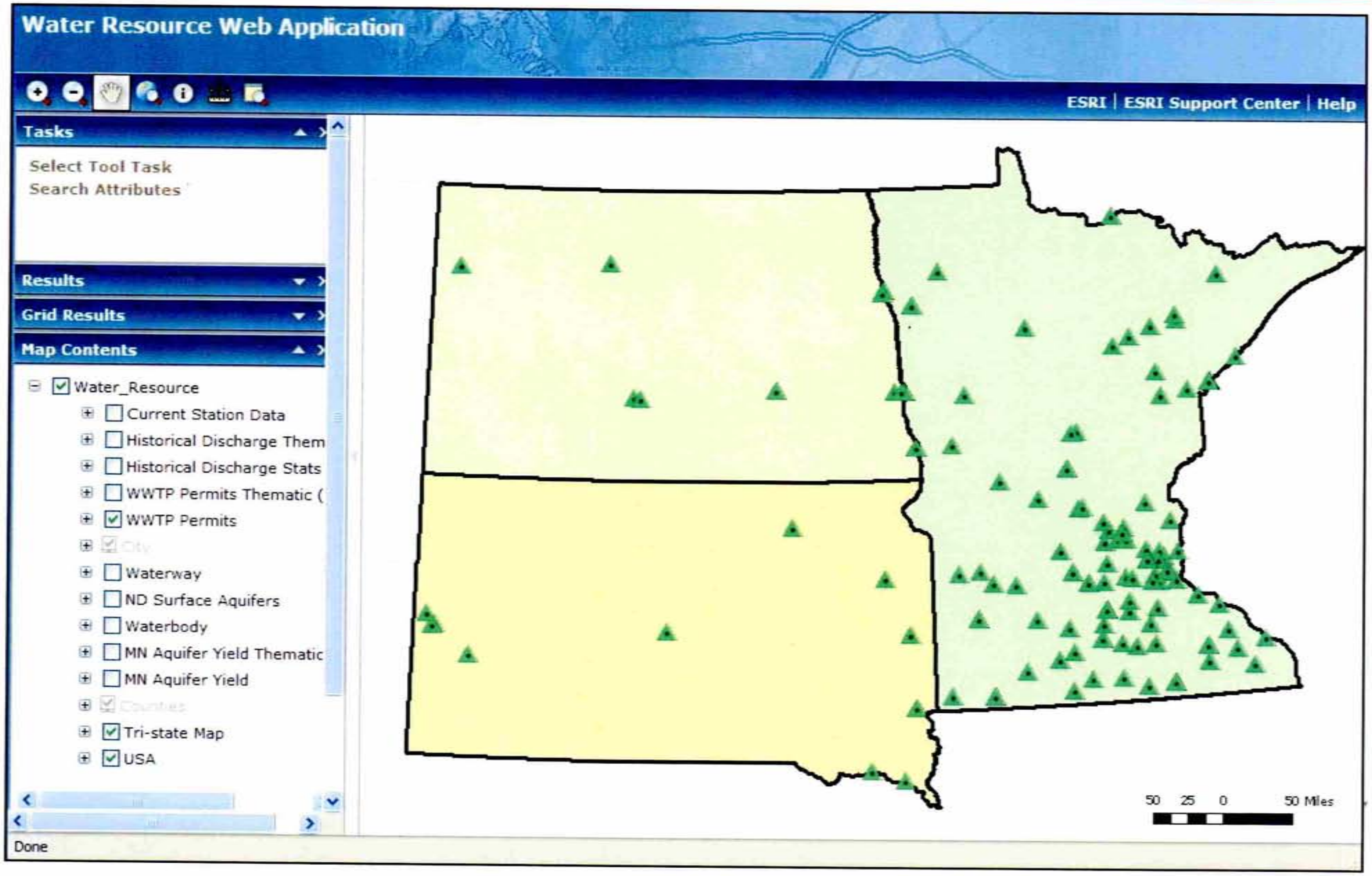


Distribution of Glacial Aquifer Material in the Tristate Area

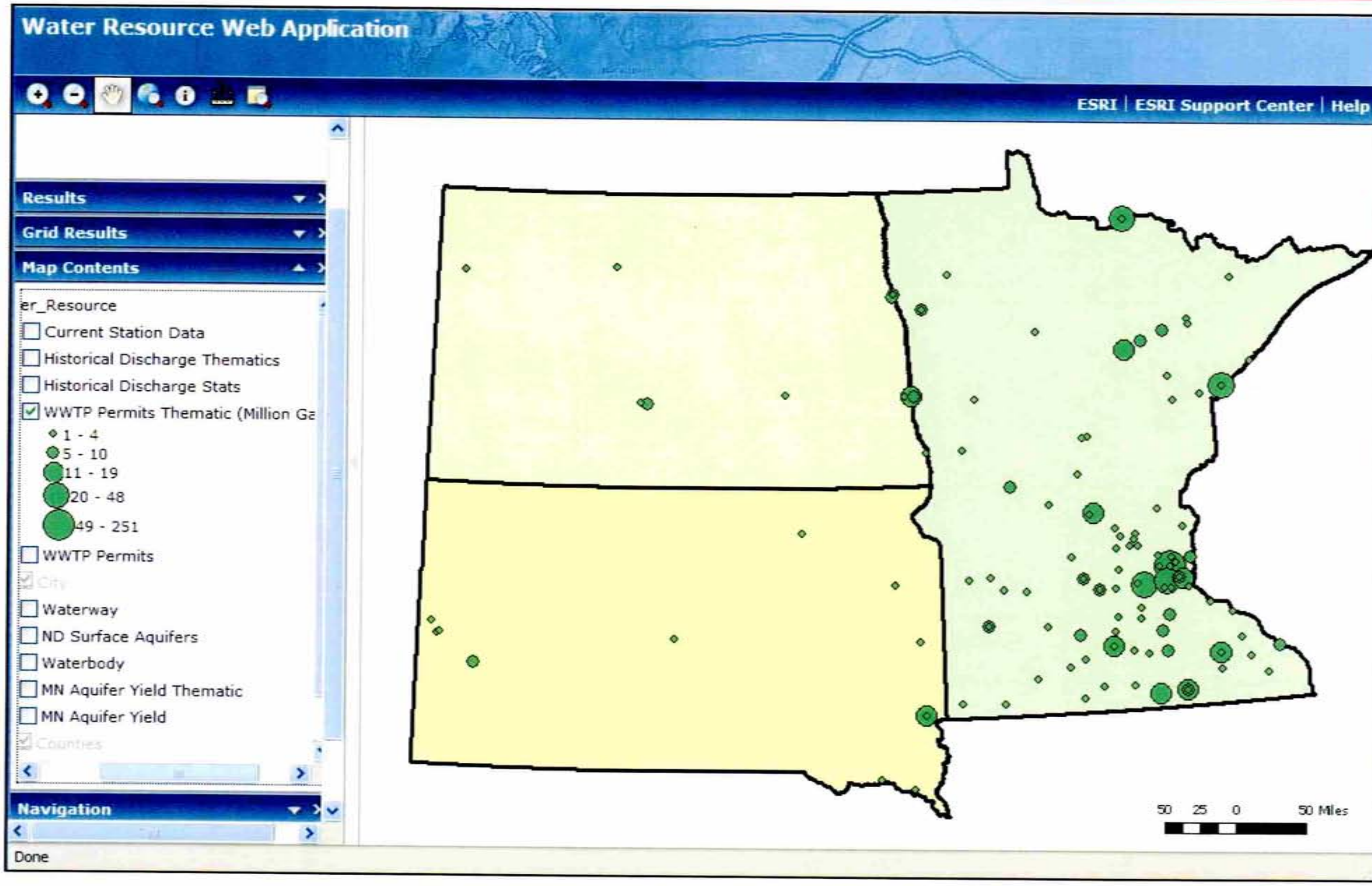
Aquifer Yield Data



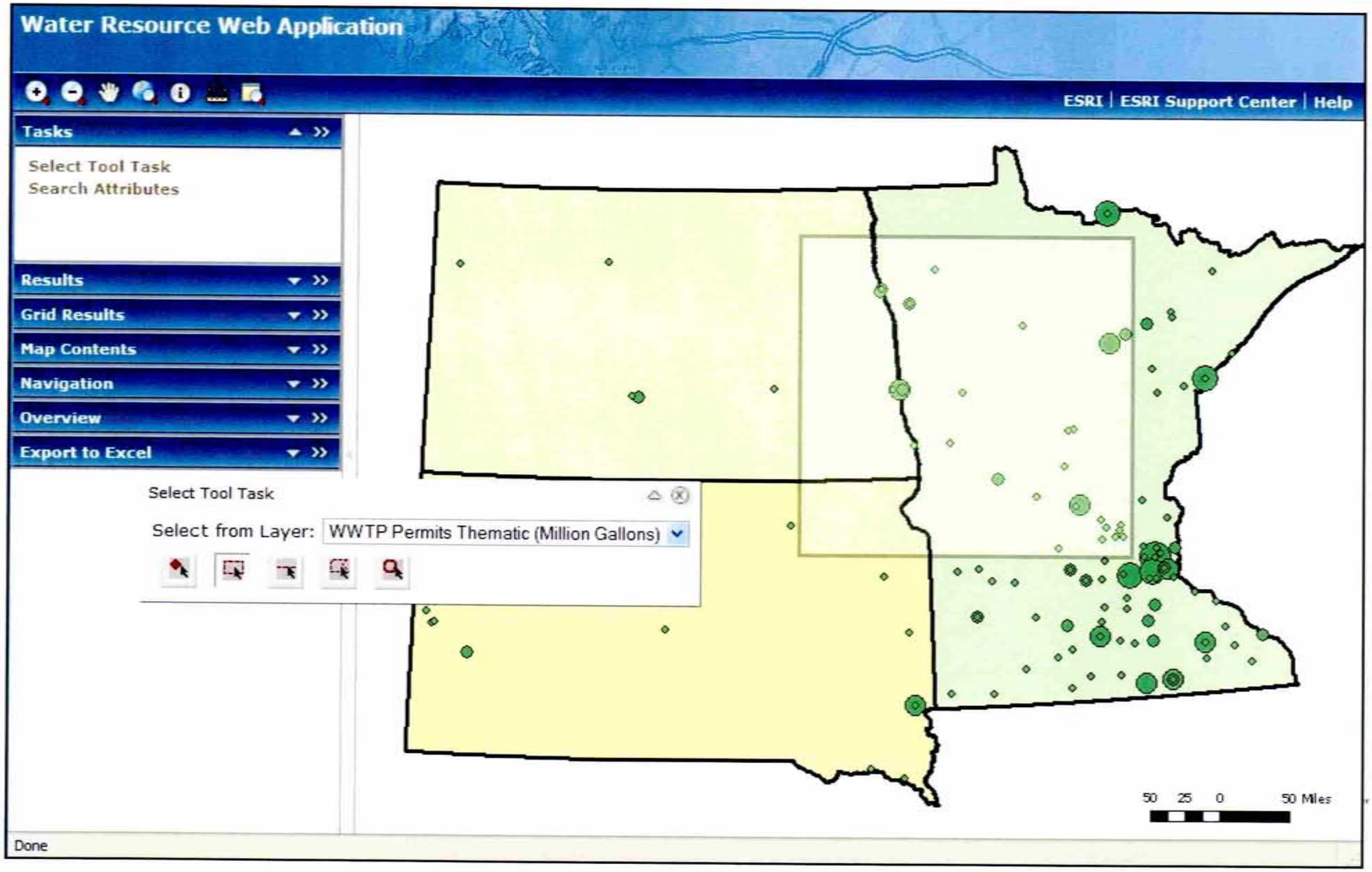
Distribution of Wastewater Treatment Discharge Points



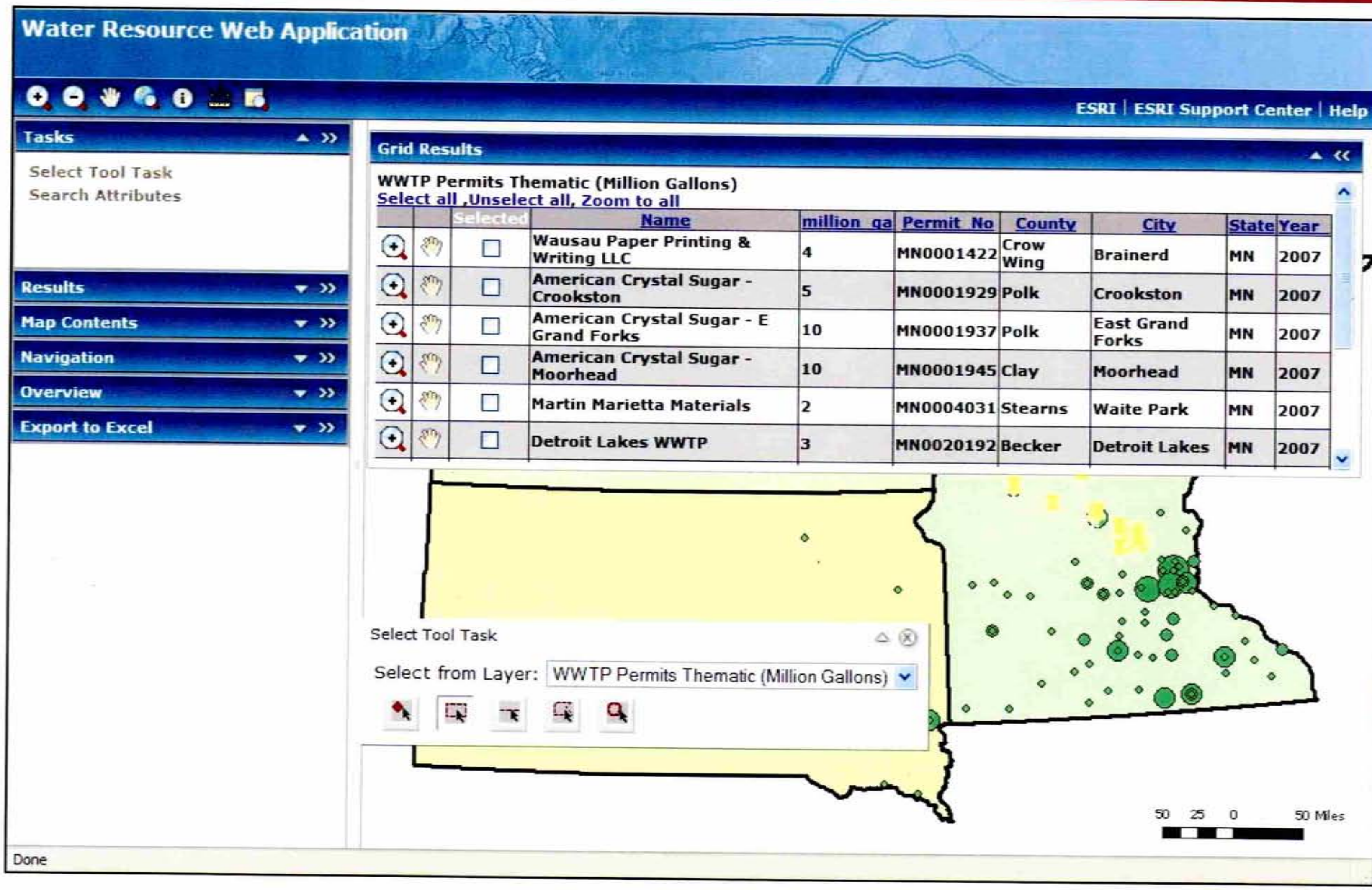
Thematic Map of Wastewater Discharge Data



Selection of Wastewater Treatment Plants (WWTPs)

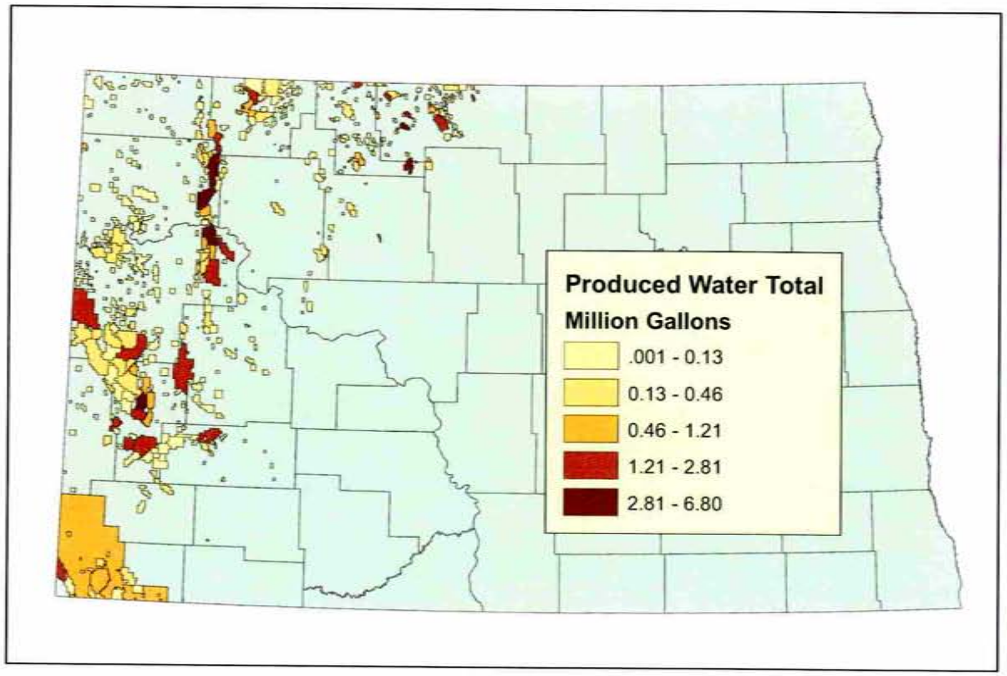


Results Window Showing WWTP Information



Nontraditional Water

- Produced water from oil and gas production
- Distributed resource
  - Unreliable
  - Low quantity
- Deep saline waters



Water Quality Issues

- Total dissolved solids (TDS)
- Silica
- Iron
- Ca/Mg
- Chemical oxygen demand (COD)
- Fecal contamination

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Water Quality

- Currently integrating locations from EPA's STORET database

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U.S. Water Law

- Annotated links to the following:
  - Eastern vs. Western Water Law
  - Indian Reserved Water Rights
  - South Dakota Water Law
  - North Dakota Water Law
  - Minnesota Water Law

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U.S. Water Law

Western – prior appropriation doctrine – "first in time – first in right." First to put water to beneficial use has senior water right.

Eastern – riparian rights doctrine – reasonable use by owners of land physically touching water body.

Indian Reservations – water rights reserved when land reserved for reservation. Tribal water rights usually senior to other claimants.

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Project Status

- Recent acquisition of software package to augment functionality of interface.
- Compilation of GIS-based information nearly complete.
  - STORET data to be attached next
- Text-based information being integrated into Web layout and tables.
- Test version available for DOE and industry review before December 15.

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DSS Phase 2

- Expanded region
- Also include produced water where sufficient quantities exist
- Expand information on deeper (saline) aquifers

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EERC Technology... Putting Research into Practice

Northern Great Plains Water Consortium (NGPWC)

NETL Water Projects Meeting

Pittsburgh, Pennsylvania

October 28, 2008

RRWMC®

Northern Great Plains Water Consortium

NETL

Background

- Water is the most critical limiting resource throughout the world.
- Sustainable water supplies are needed for:
  - Energy production.
  - Growing and processing high-value crops.
  - Industrial manufacturing.
  - Expanding populations.

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NGPWC

- The EERC is developing a partnership between the U.S. Department of Energy and key stakeholders, representing electrical power generation utilities, oil and gas companies, industry, municipalities, and other interested entities to address critical issues that impact the water resources of the northern Great Plains region.

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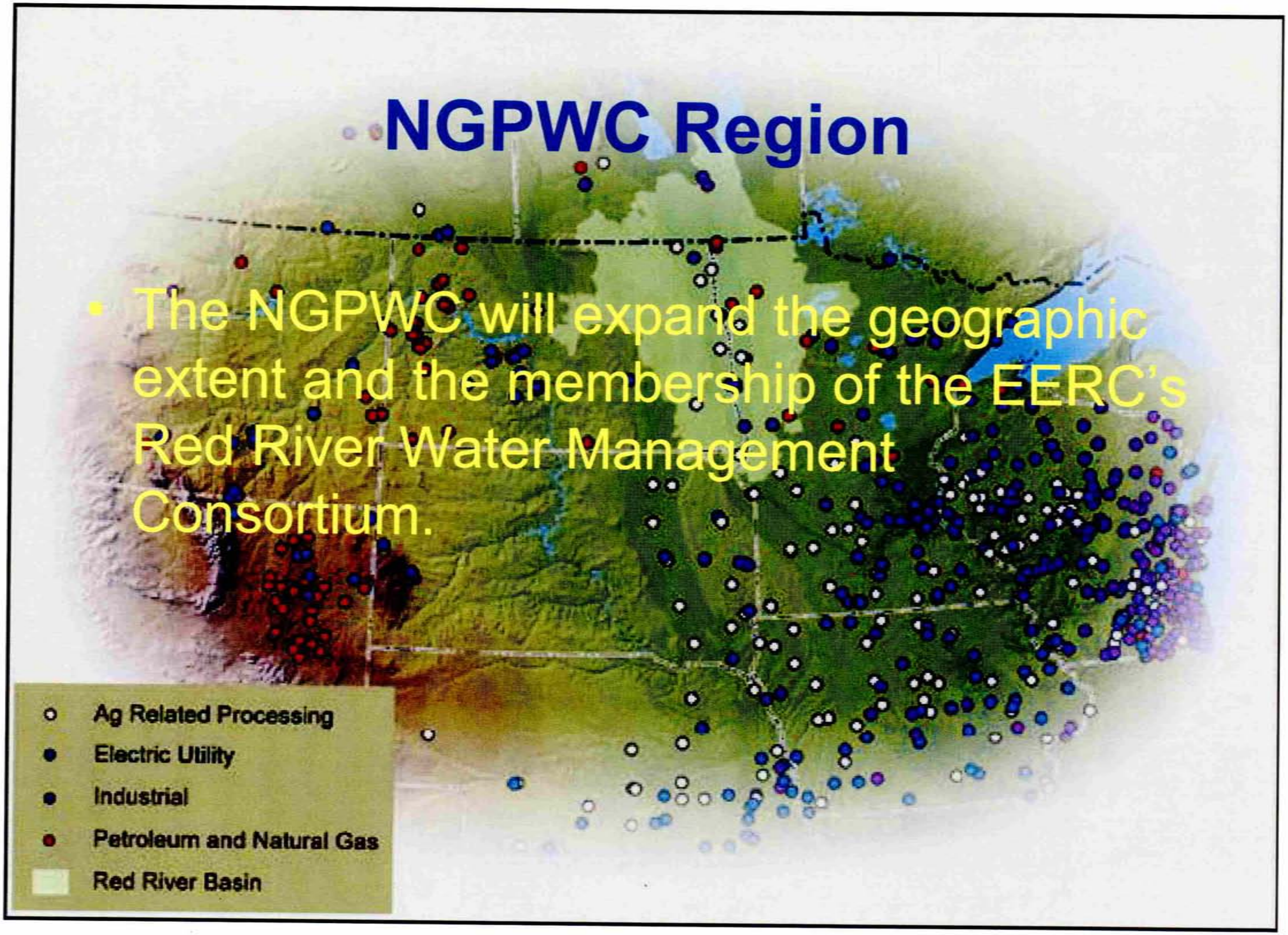
NGPWC Region
• The NGPWC will expand the geographic extent and the membership of the EERC's Red River Water Management Consortium.
Ag Related Processing
Electric Utility
Industrial
Petroleum and Natural Gas
Red River Basin

NGPWC Membership

- Membership requires an annual fee for participation.
- Members provide input for the development of project activities.

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NGPWC Goals and Objectives

- The overall goal of this program is to assess, develop, and demonstrate technologies and methodologies that minimize water use and reduce impacted water discharges from a range of energy technologies, including coal combustion, coal gasification, coalbed methane, and oil and natural gas production.

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NGPWC Fact Sheet

DRAFT

Northern Great Plains Water Consortium (NGPWC)

Water Use Fact Sheet

The Demand for Water

Water is the most critical limiting resource throughout the world. Sustainable economic growth requires a reliable supply of water for energy, agriculture, and a growing population. Water is necessary for urban development, power production, growing and processing high-value crops, oil and gas development and processing, and industrial manufacturing. Satisfying all of these competing needs requires a better understanding of water resources and new approaches to water management. Energy, agriculture, industry, and municipalities all urgently need a scientifically valid basis upon which to make management and regulatory decisions related to water use and quality.

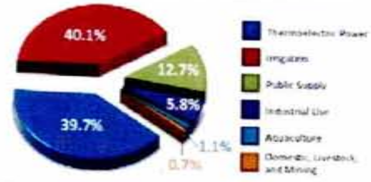


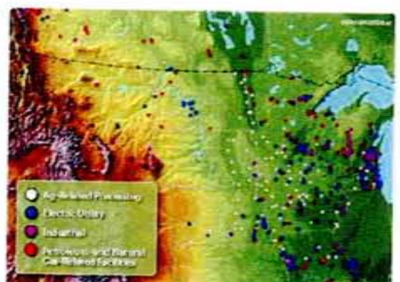
Figure 1. The major users of freshwater within the United States.

The Energy & Environmental Research Center (EERC) is developing a partnership between the U.S. Department of Energy (DOE) and key energy-producing entities in the northern Great Plains to address issues related to water availability, reducing freshwater use, and minimizing the impacts of facility and industry operations on water quality. The key goals of this partnership, called the Northern Great Plains Water Consortium (NGPWC), are:

- To evaluate water demand and consumption from competing users in the northern Great Plains region, including energy production, agriculture, industry, and domestic/municipal users.
- To assess, develop, and demonstrate technologies and methodologies that minimize water use and reduce wastewater discharges from energy production and agricultural processing facilities.
- To identify nontraditional water supply sources and innovative options for water reuse.

Thinking Outside the Box to Address Water Issues

As the United States continues to pursue economic development and the population increases, demand for ever-increasing amounts of energy to support that growth will require water. In areas where water resources are limited or become scarce because of overallocation and/or drought, competing interests for water could limit energy development and production. With the vibrant oil, gas, and utility interests in the region, potential water reuse synergies among energy-related industries should be explored. For example, thermoelectric power generation is second only to agriculture as the largest domestic user of water, accounting for approximately 40% of all freshwater withdrawals in the United States (Figure 1). A portion of that cooling water effluent could be used in other industries, perhaps even prior to cooling to capitalize on the waste heat. Significant volumes of water are also used in the drilling and completion of oil and gas wells. Wastewater from other industries could be used to supply water needed for drilling operations, and options may exist to treat and reuse the produced water from oil and gas operations. Finding innovative solutions that expand water resource options for the energy industries in the region is one of the key goals of the NGPWC.



Northern Great Plains Water Consortium region showing the locations of key energy, agricultural, and industrial facilities.

DRAFT

Putting Regional Water Use in Perspective

The various industries and water users within the region often use different units of reference when referring to water consumption and discharge. To gain a perspective on the relationship between municipal, industrial, and agricultural water use, it is helpful to compare some common units and examples of water use among the sectors.

Approximate Volumetric Equivalents

barrels	gallons	acre-ft	cubic feet	cubic meters
1	42	0.000129	5.6146	0.15897
7,758	325,851	1	43,560	1,233
23,810	1,000,000	3.1	133,681	3,785

Conversion Factors

1 cubic foot = 7.4805 gallons
1 gallon = 3.785 liters
1 cubic meter = 1,000 liters
1 acre = 43,560 square feet

Approximate Flow Equivalents

barrels per day (bbl/day)	million gallons per day (Mgd)	gallons per minute (gpm)	cubic feet per second (cfs)	cubic meters per second (m^3/s)
23,810	1.0	694.4	1.55	0.04381
34.3	0.00144	1.0	0.0022	0.00006
100	0.0042	2.9167	0.0065	0.000184

Water Use Comparisons

Use	gallons (millions)	barrels (thousands)	acre-ft	cubic meters
Typical **daily** use for a 50,000-person midwestern city	10	238.1	30.7	37,850
Daily pumping volume for a center-pivot irrigator for 130 acres (¼ section)	1.008	24	3.1	3,815
Average **daily** water withdrawal for once-through cooling at a 400-MW coal-fired power plant	365	8,691	1,120	1,381,525
Water used to fracture the formation for an oil well in the Bakken Formation (**one-time use**)	0.5–1.0	11.9–23.8	1.5–3.1	1,893–3,785
Proposed maximum **daily** volume of water imported for the Red River Valley Water Supply Project	77.56	1,847	238	293,556

Interested in Joining?

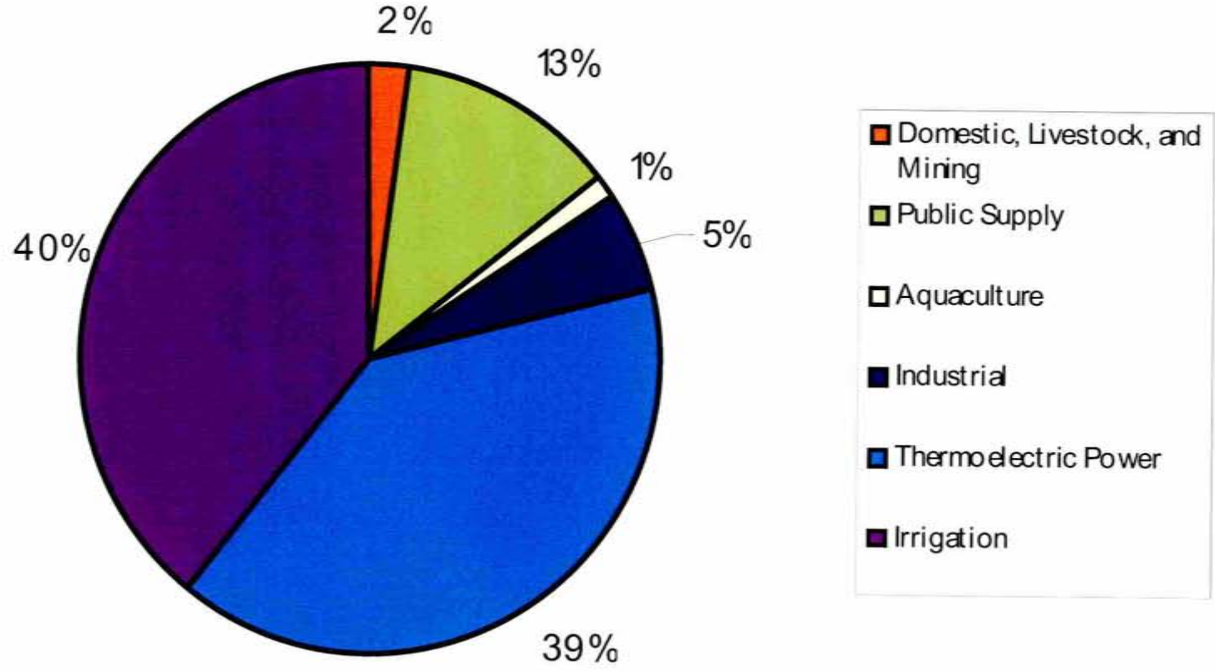
The EERC is actively seeking charter members to complement secured DOE funding and to help direct the program's efforts. The NGPWC is currently engaged in Phase I of the program, wherein future program efforts and demonstration projects will be selected and prioritized. Phase II of the effort, scheduled to begin in 2009, will focus on demonstrating the water minimization and beneficial reuse strategies and technologies prioritized in Phase I.

The NGPWC is a partnership of key public and private water users in the northern Great Plains region. New members are welcome. To learn more, contact:

John A. Harju, EERC Associate Director for Research, (701) 777-5157
Daniel J. Stepan, Senior Research Manager, (701) 777-5247
Bethany A. Kurz, Senior Research Manager, (701) 777-5050

Sponsored in Part by the U.S. Department of Energy

U.S. Water Withdrawals



(USGS Circular 1268, 2004)

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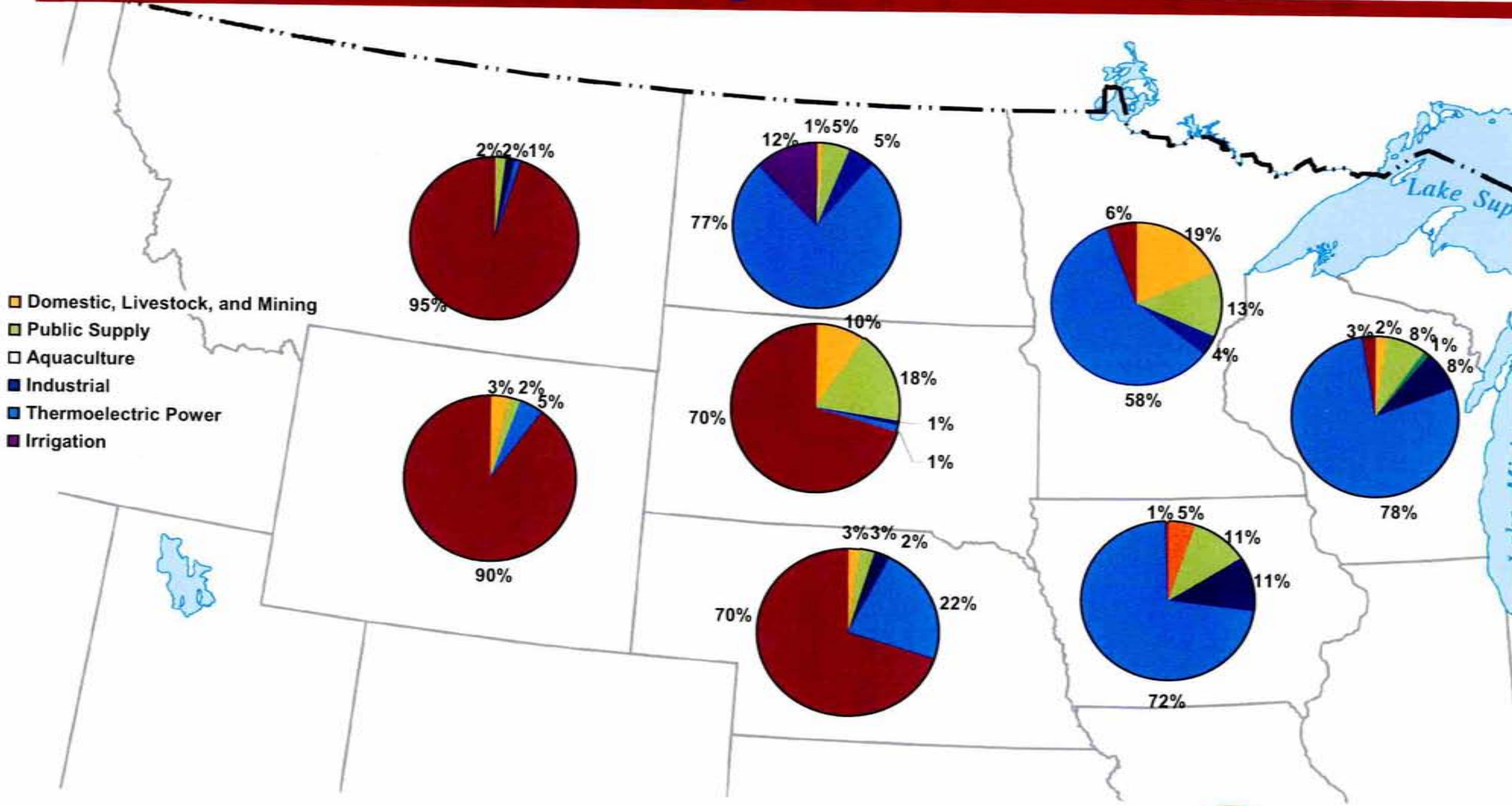
Regional Water Withdrawal Comparison



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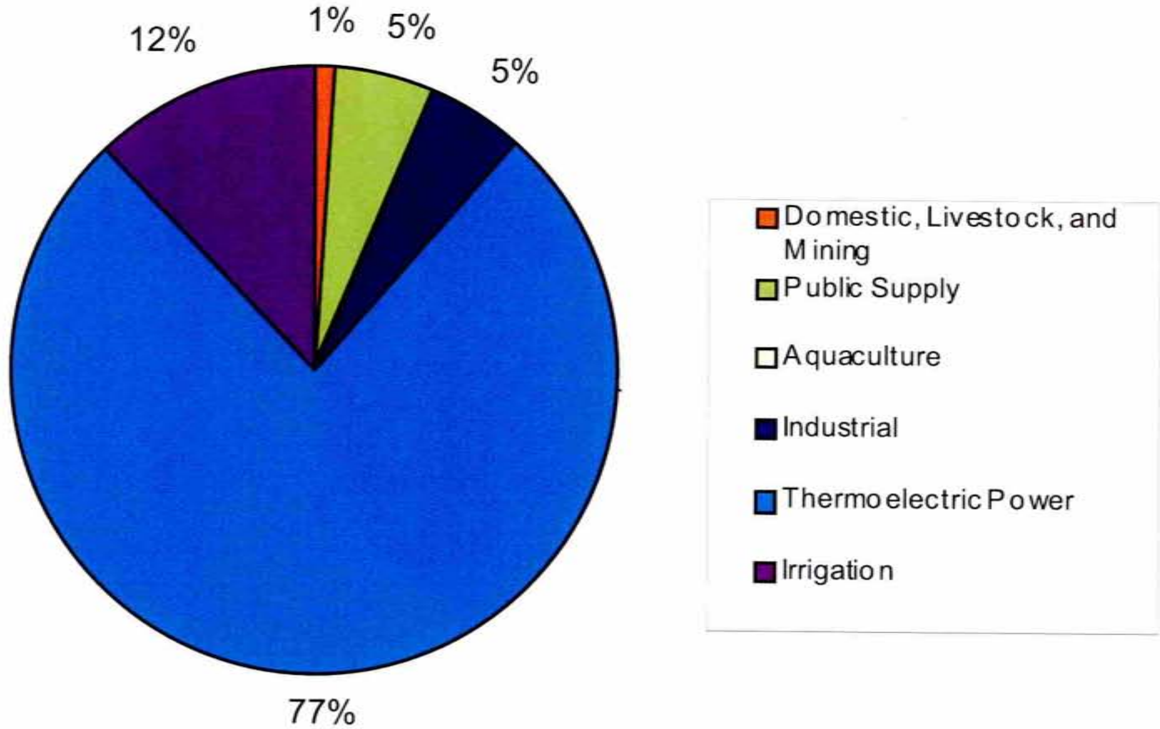
North Dakota Water Withdrawals



(USGS Circular 1268, 2004)

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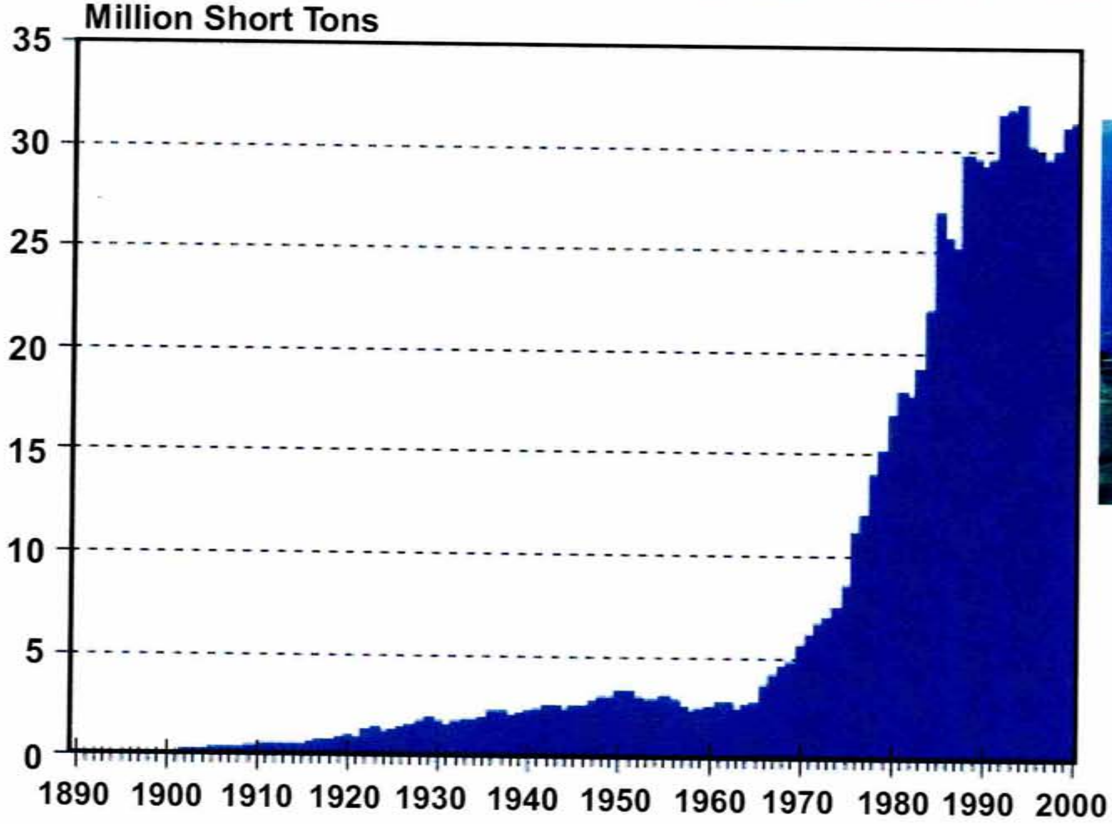
Annual History of North Dakota – Coal Mined



ND State statistics publicly available at www.oilgas.nd.gov/stats/statisticsvw.asp.

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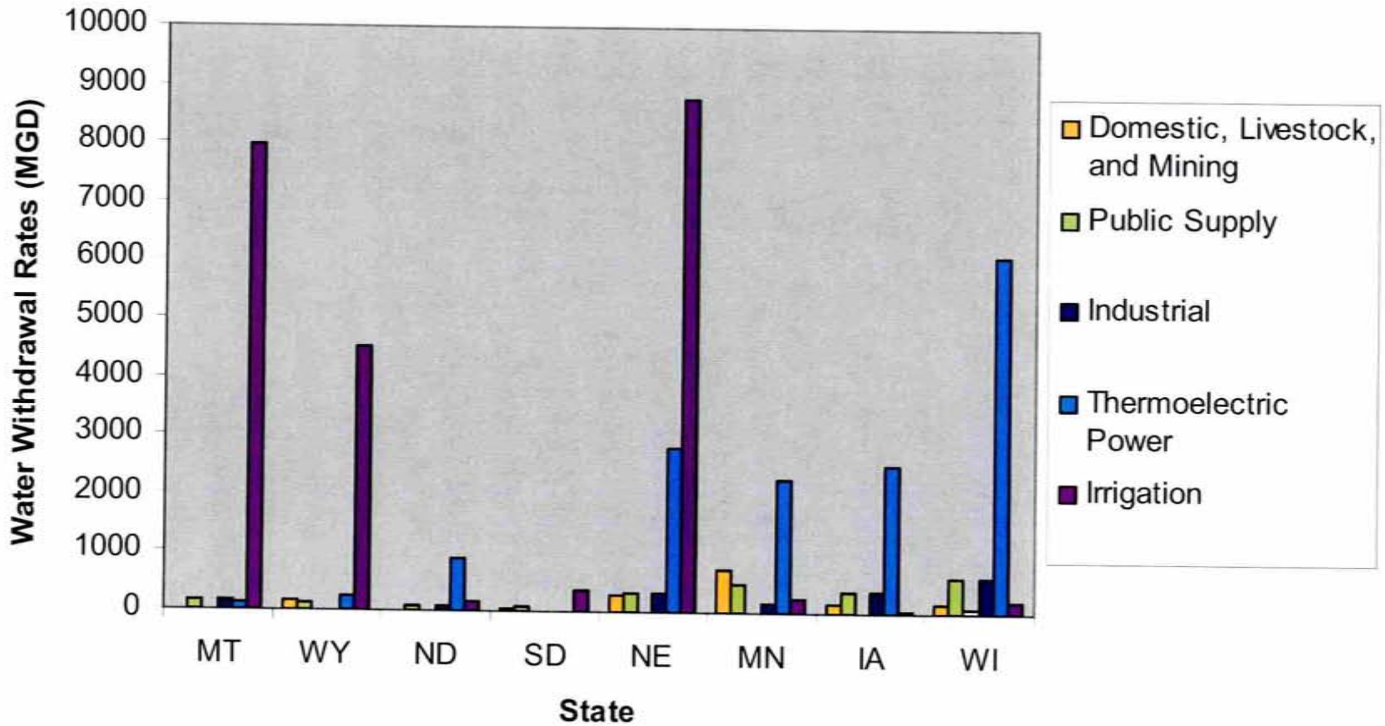
Withdrawal Rate Comparison



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Withdrawal vs. Consumption

State	***Once-Through (MGD)***	***Closed-Loop (MGD)***
Montana	84.4	25.6
Wyoming	179	64.6
North Dakota	887	14.5
South Dakota	0	5.24
Nebraska	2390	424
Minnesota	1330	939
Iowa	2510	27.6
Wisconsin	6090	8.99

Bakken Formation

- Estimated 3.0 to 4.3 billion barrels of technically recoverable oil.
- Largest "continuous" oil accumulation ever assessed by the U.S. Geological Survey.
- Located mainly in North Dakota and Montana.

Canadian Plains Research

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Bakken Frac Water

- Frac water is freshwater that is used to pressurize and fracture oil-bearing formations to increase permeability and enhance the flow and recovery of oil.
- As much as 1.0 million gallons of water per well to fracture the Bakken Formation.
- Transported to well site in 7500 to 8000-gallon tanker trucks.
- Transportation costs for long haul distances can be excessive.

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Frac Water Recycling

- Recovery/treatment/reuse of frac flowback waters may be an extremely attractive economic alternative.
- The EERC, along with the North Dakota Petroleum Council and its members, have initiated a project to investigate the economic potential to recover, treat, and reuse frac flowback water.

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Bakken Water Opportunities

- Task 1 – Inventory freshwater needs and geographical distribution
- Task 2 – Assess flowback water characteristics
- Task 3 – Evaluate current water costs
- Task 4 – Assess current state of mobile water recycling technologies
- Task 5 – Assess technical and economic feasibility of recycling
- Task 6 – Formulation of a potential field demonstration project

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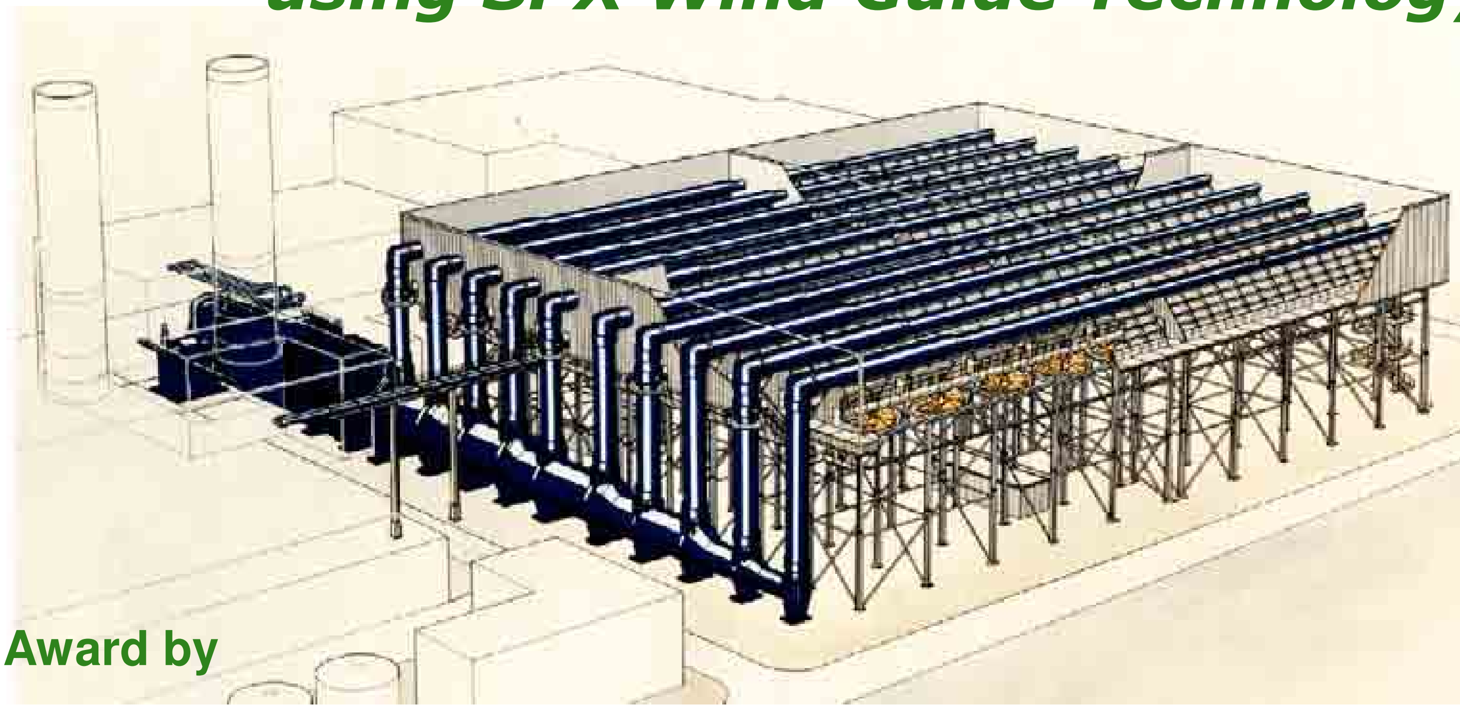
"Improved Performance of ACC using SPX Wind Guide Technology"

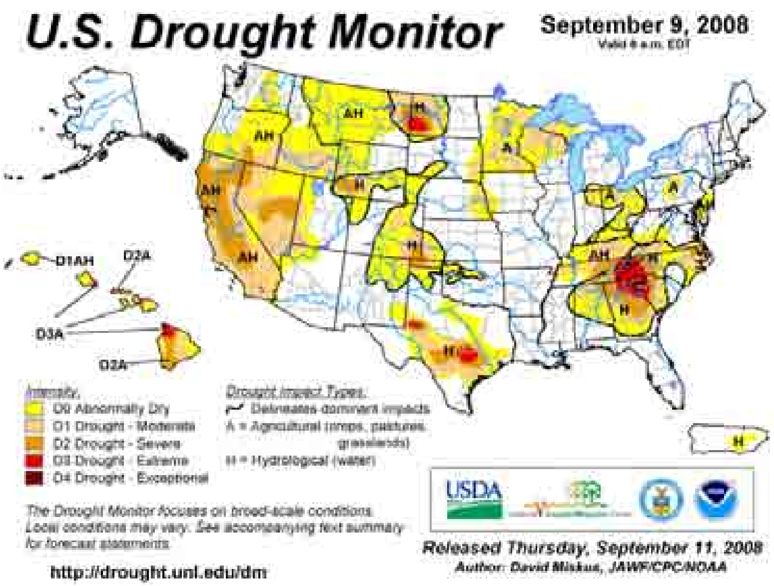


Award by

National Energy Technology Laboratory,

Department of Energy

October 27, 2008



"Lake Mead is lower than it has been in 40 years." "Lake Powell Reservoir is over 100 feet below its normal level."

National Park Service 2003/2005

USES:

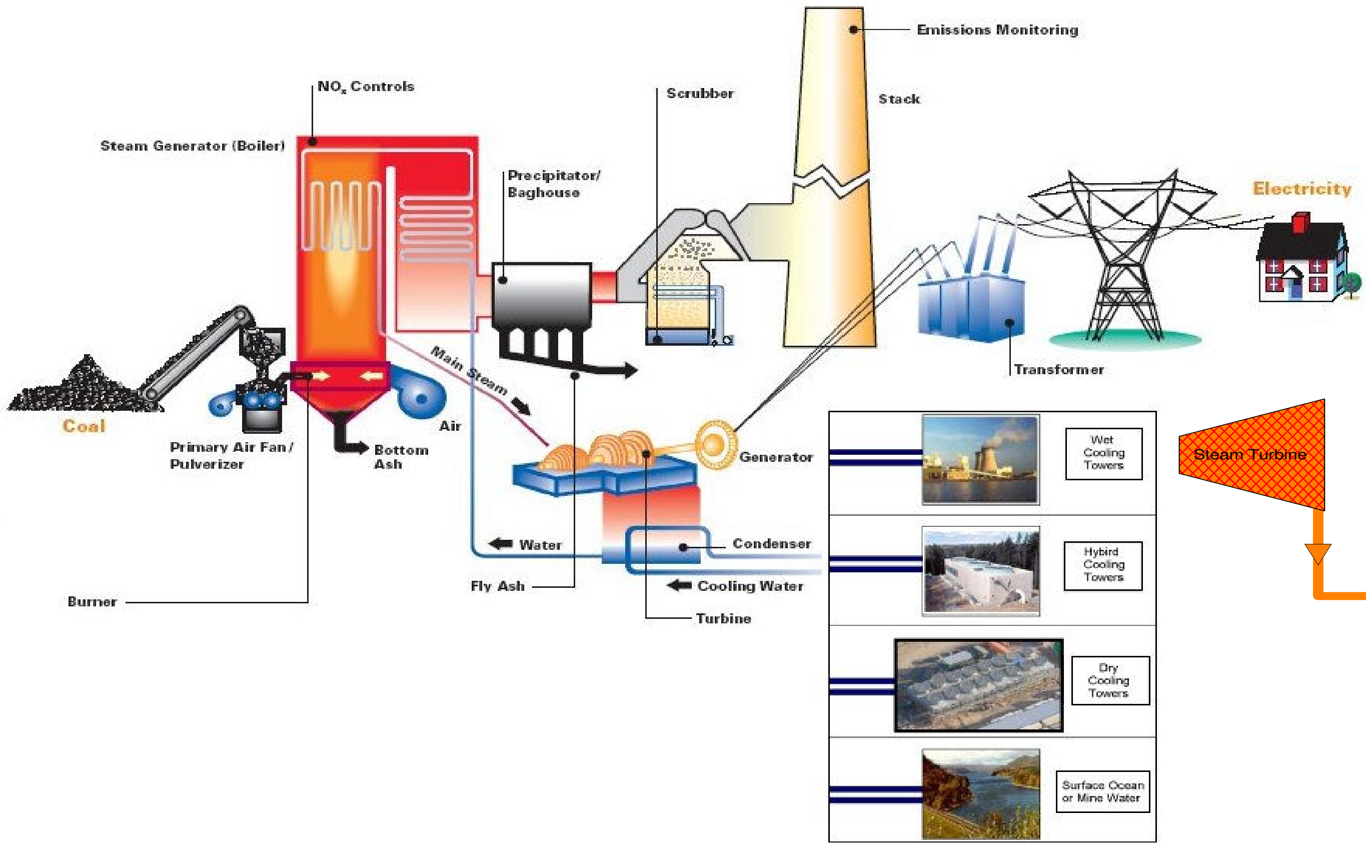
1. **Agriculture, Livestock and Irrigation**
2. **Fossil Fuel Power Generation**

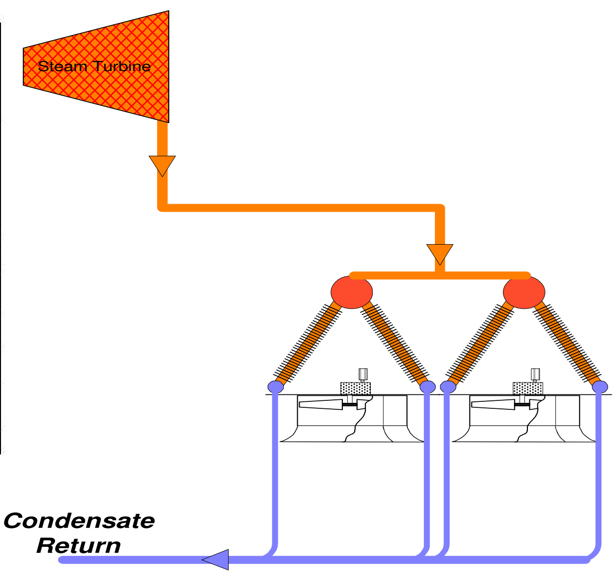
Source: USGS Circular 1268, 2004

Cooling towers represent substantial water usage at power plants, "Producing a kilowatt-hour of electricity… takes about 3/5ths of a gallon of water." Joey Bunch, Denver Post

SPX

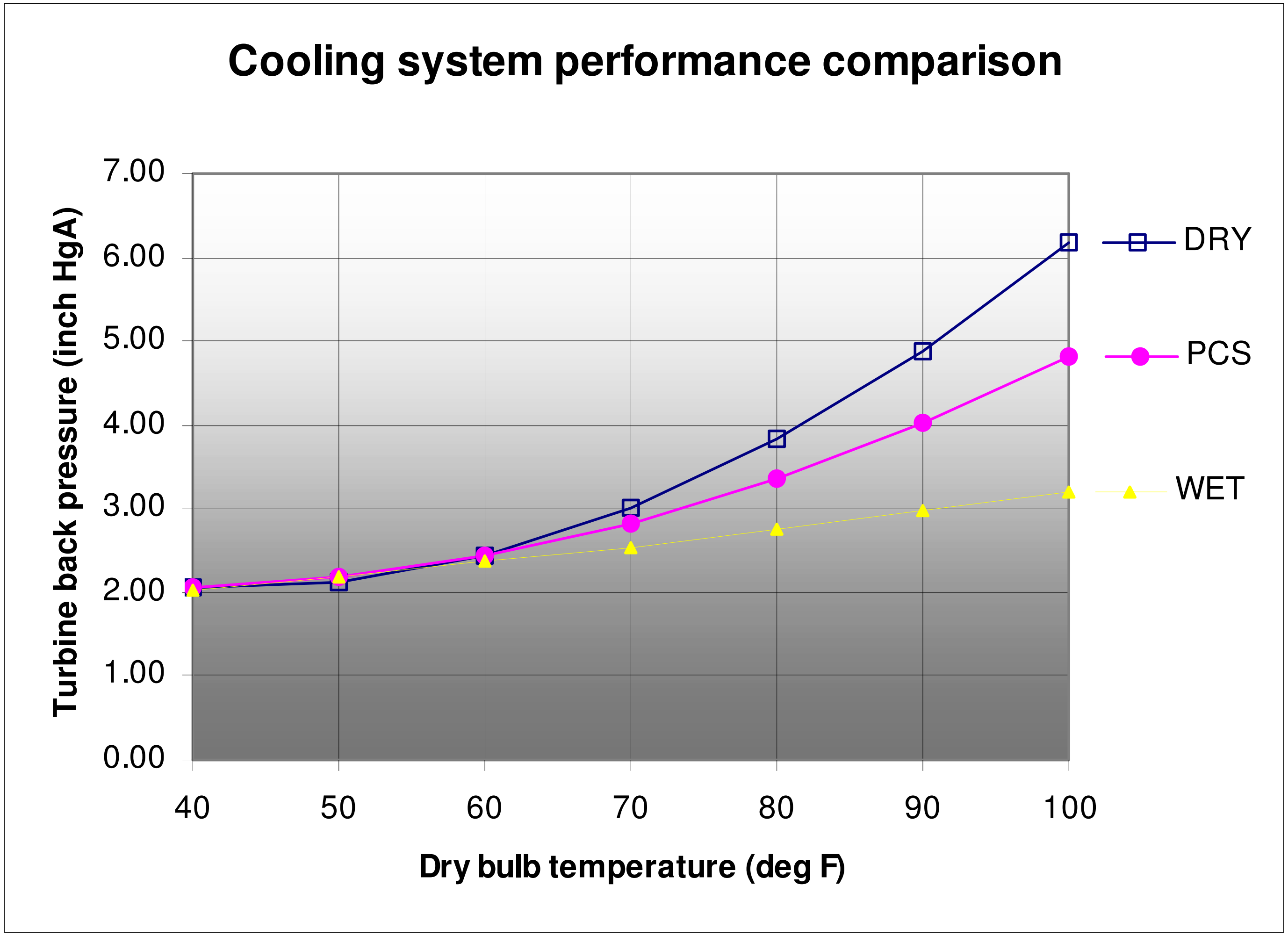
Water at Power Plants





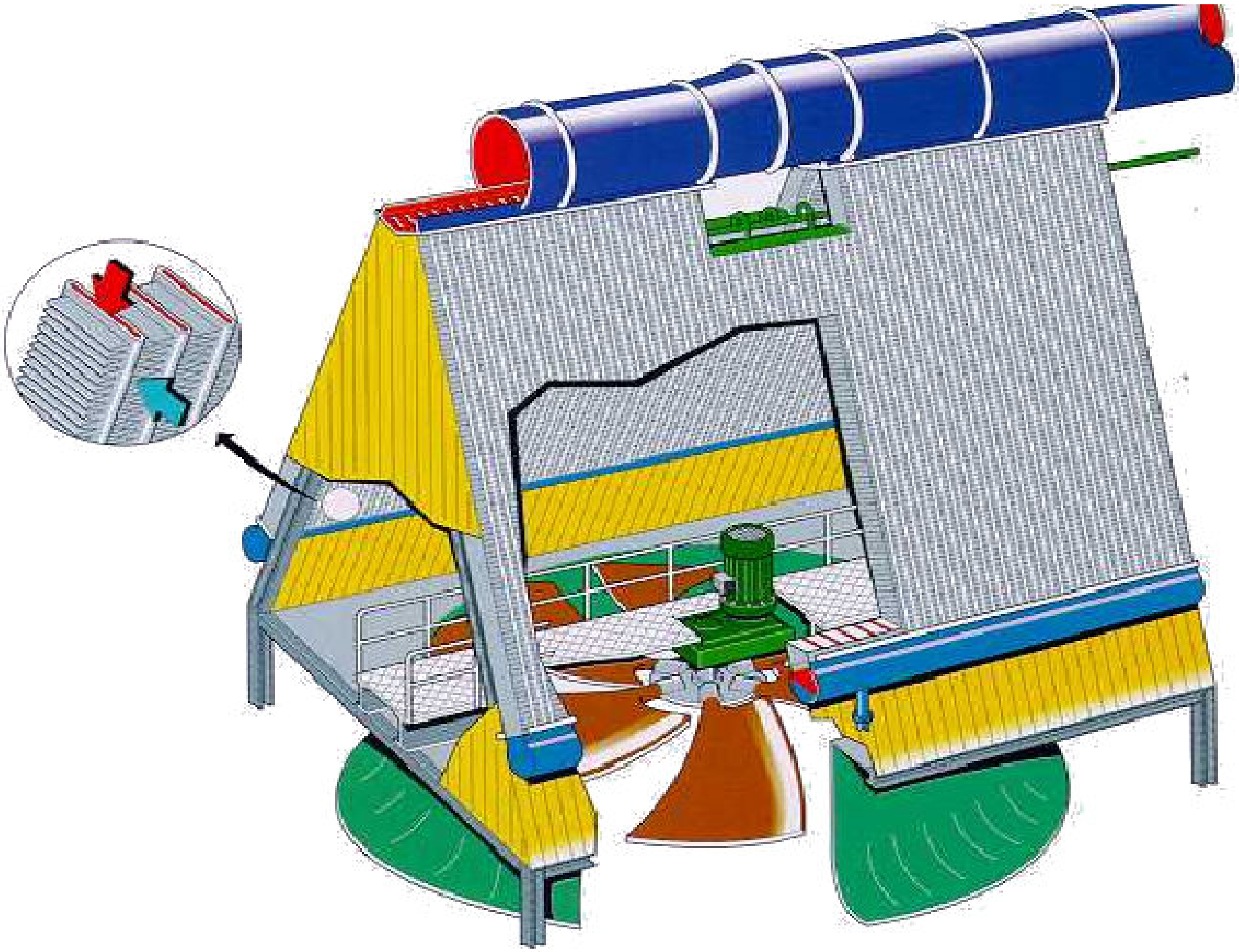
Adapted from http://www.eei.org/industry_issues/environment/air/New_Source_Review/coal1.pdf

- Grant Program Title is “Research And Development Of Advanced Technologies And Concepts For Minimization Of Freshwater Withdrawal And Consumption In Coal-Based Thermoelectric Power Plants”
  - “Research in this area is intended to develop technologies that improve performance and reduce costs associated with wet cooling, dry cooling, and hybrid cooling technologies.”
  - “DOE nearer-term target is to have advanced technologies ready for commercial demonstration by 2015”
  - “…when used alone or in combination, can reduce freshwater withdrawal and consumption”

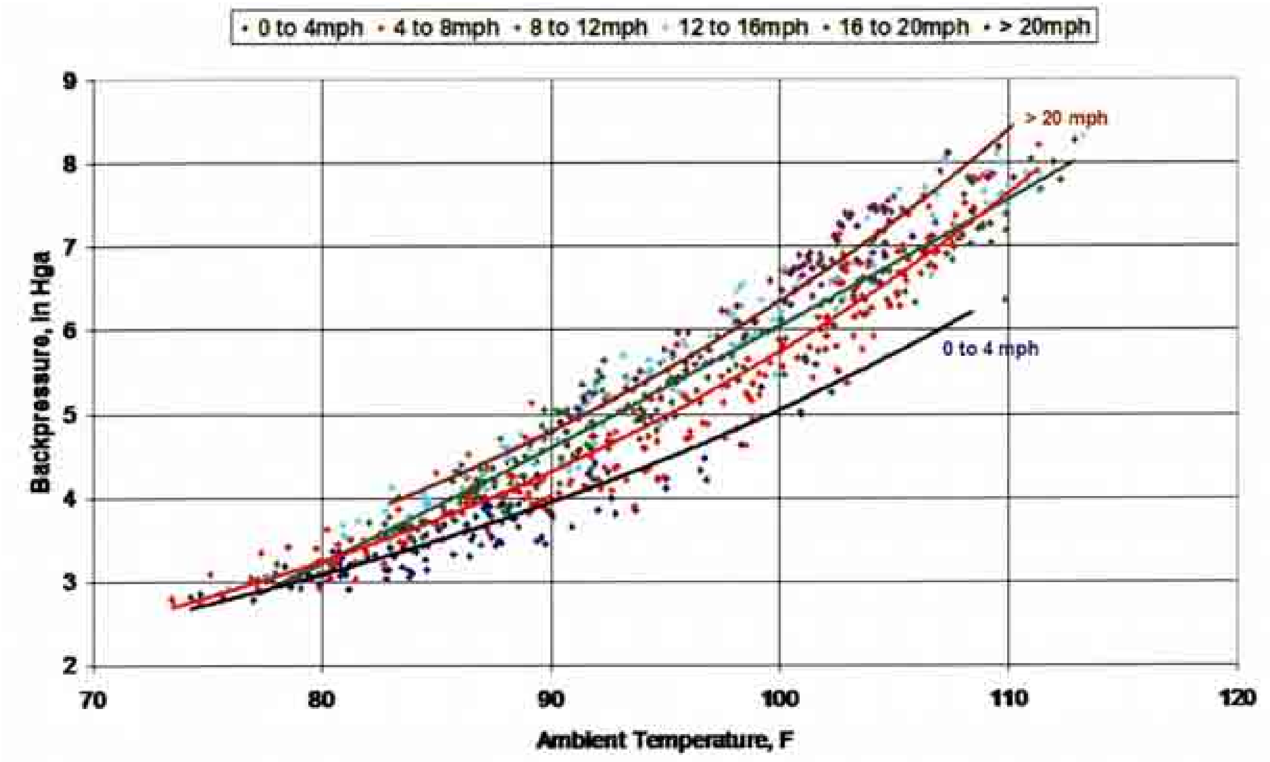

Cooling system performance comparison
Turbine back pressure (inch HgA)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
40
50
60
70
80
90
100
Dry bulb temperature (deg F)
DRY
PCS
WET

SPX

ACC Module



Wind Effects Performance



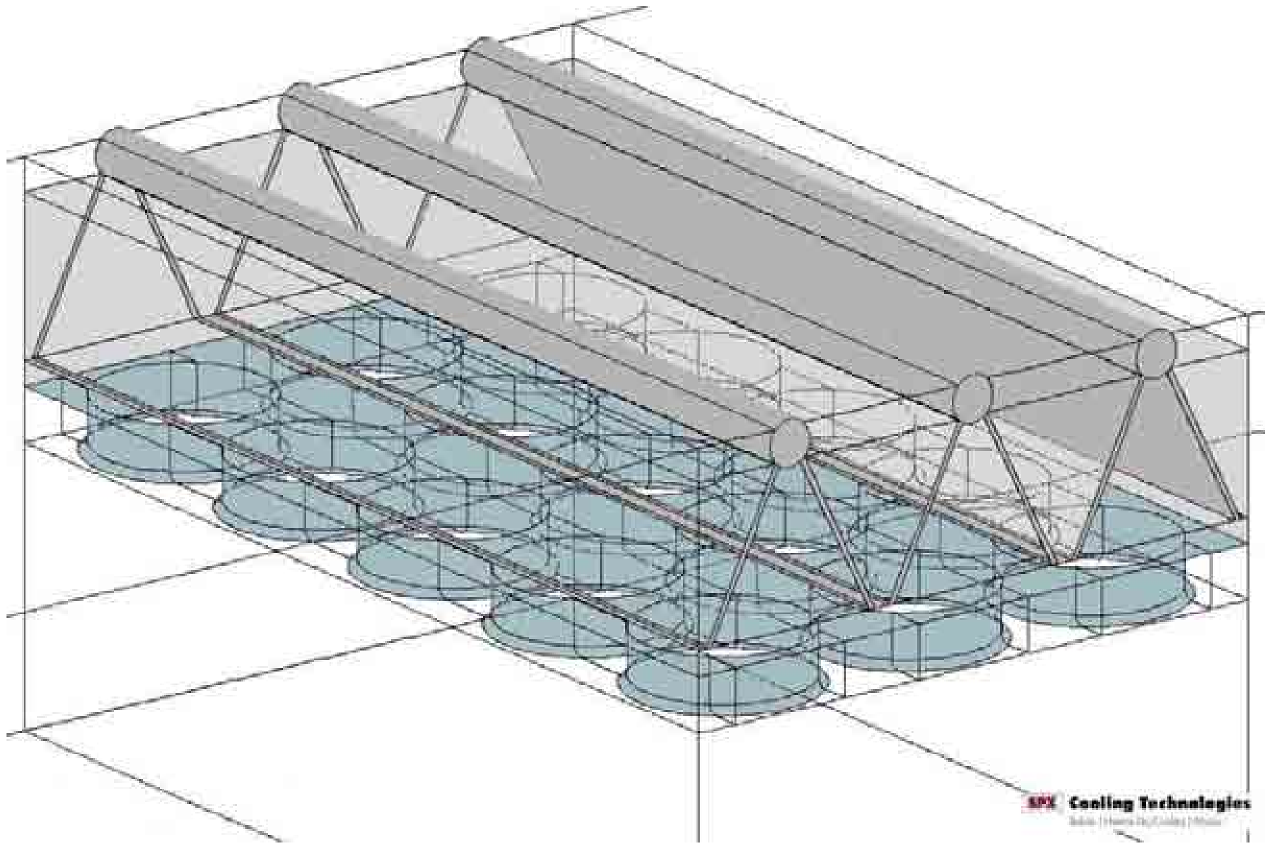
- Fan starving / Stalling
- Recirculation
- Site model testing or CFD analysis to predict performance effects
- Performance of most concern during summer

SPX

> Wind Effects – Mitigation

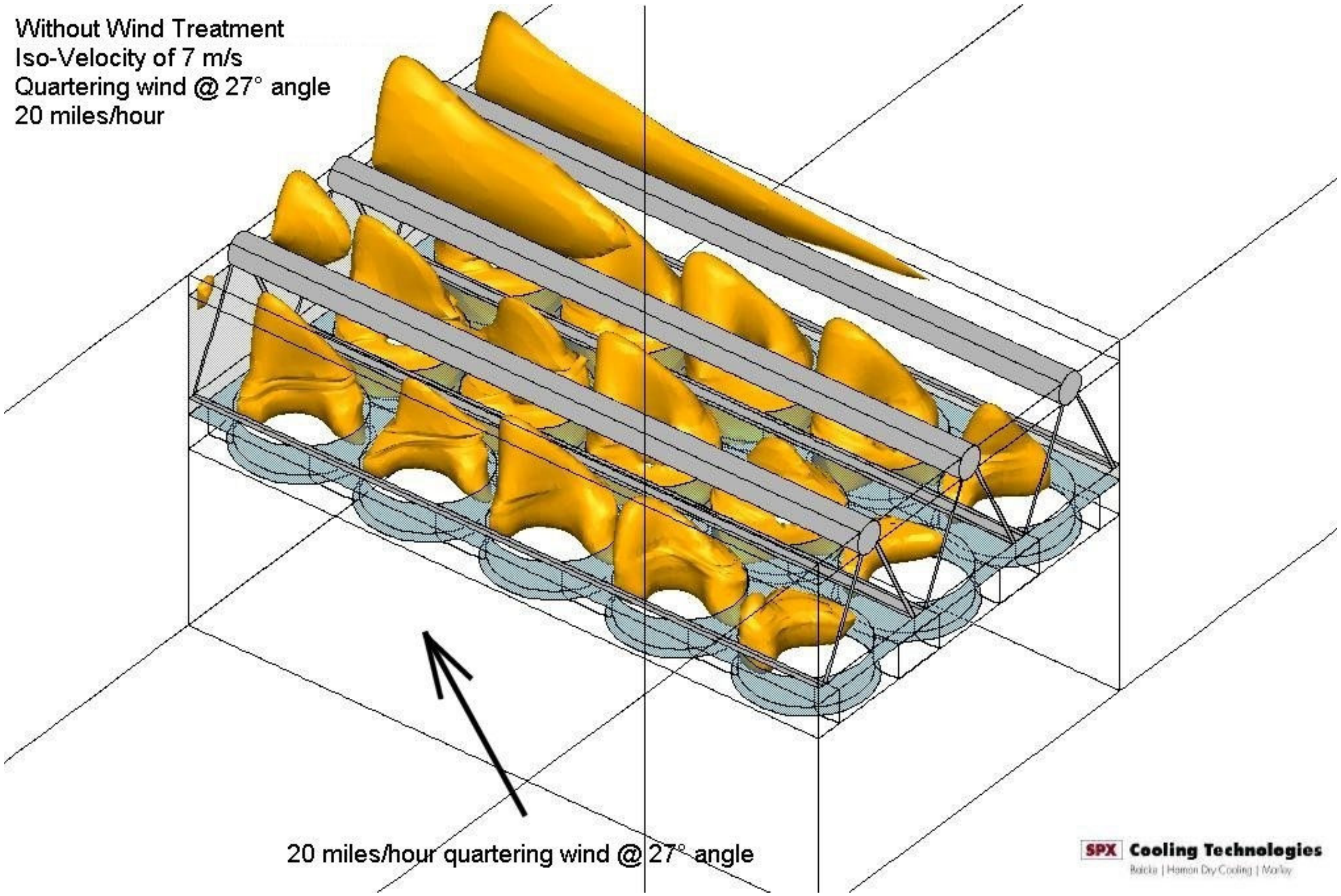
- Optimal orientation
- Reserve capacity
- Conservative design specifications
- **Wind Baffles / Screens / Diverters**
- Fan margin

ACC Configuration – Base Design

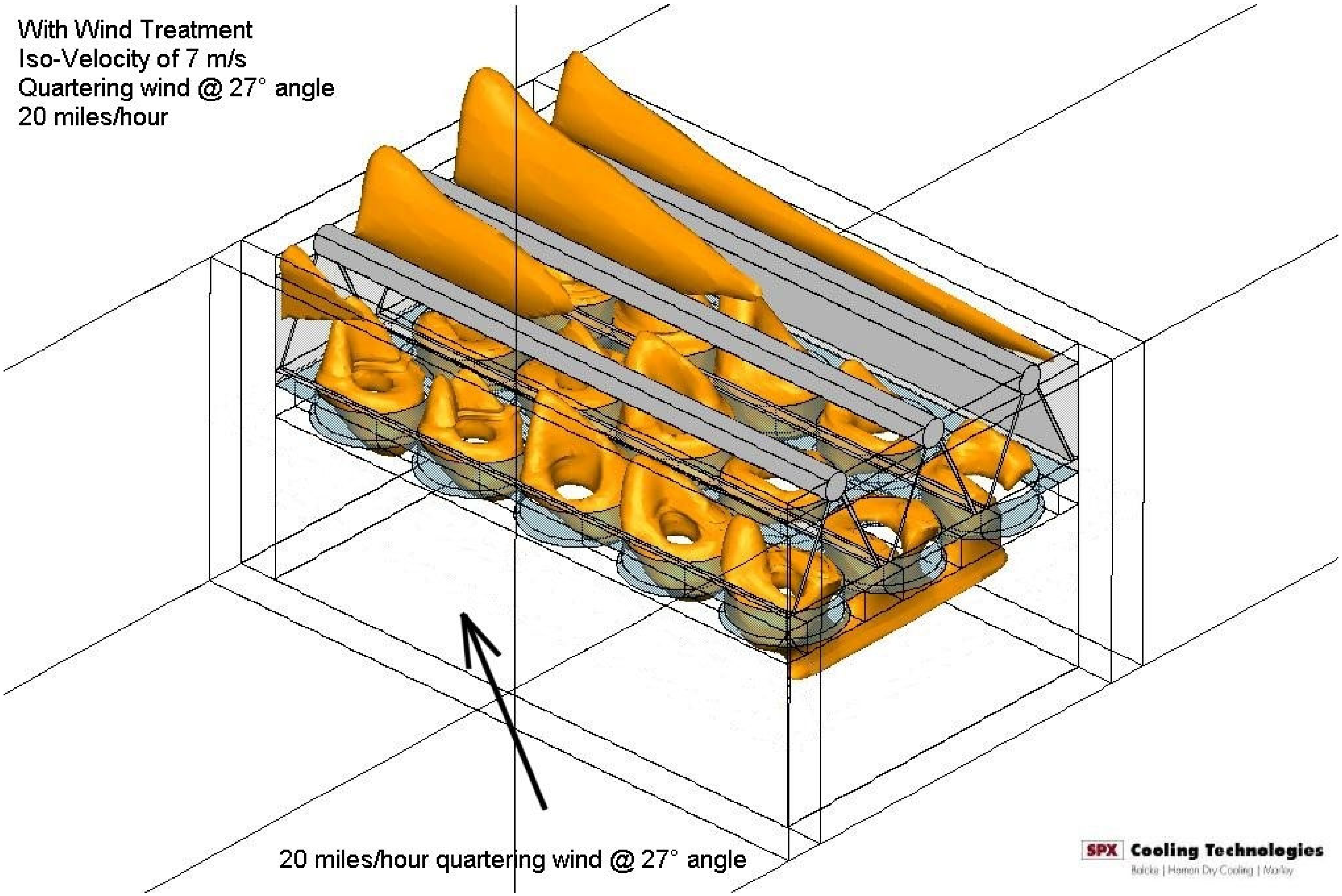


SPX

CFD Modeling – Base Design



CFD Modeling – Modified Design



Patent Pending

Item	Projected Milestone	Date
1	Partner w/Utility: Host Site Agreement	1/09
2	Model Existing ACC Condition	4/09
3	Monitor the Existing ACC Performance	9/09
4	Install Modification	3/10
5	Evaluate Resulting ACC Efficiency Improvement	9/10
6	Reporting	12/10

> Data for verification of an efficiency improvement:

- Exhaust steam pressure (turbine back pressure)
- Exhaust steam temperature
- Condensate flow rate
- Wind speed and direction
- Atmospheric pressure
- Ambient dry-bulb temperature
- ACC inlet/outlet dry-bulb temperature
- Fan motor horsepower

- ACC Efficiency Improvement / Reduced Costs
  - Lower turbine backpressure
  - Less parasitic power
  - Better summer efficiency
  - Potential for improvement at no/low wind conditions
- DOE/Industry Effort in an ongoing water conservation investigation

WHERE IDEAS MEET INDUSTRY

Thanks to the NETL/Department of Energy for this Opportunity

A2A Configuration & Packmaking

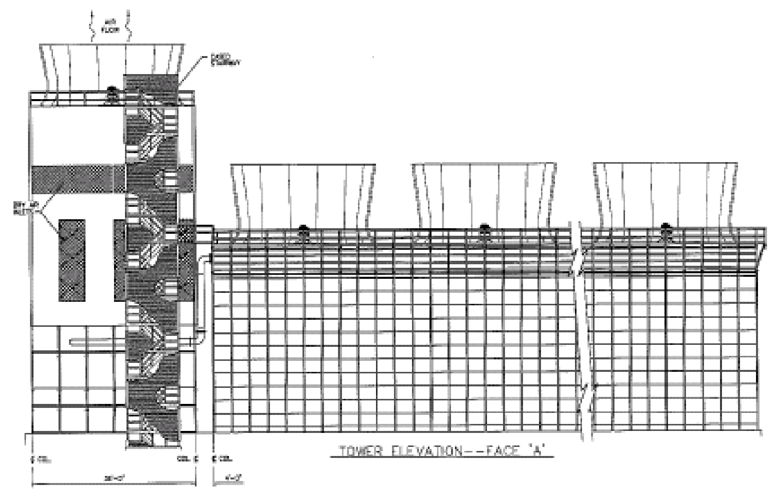
October 27, 2008

Award by

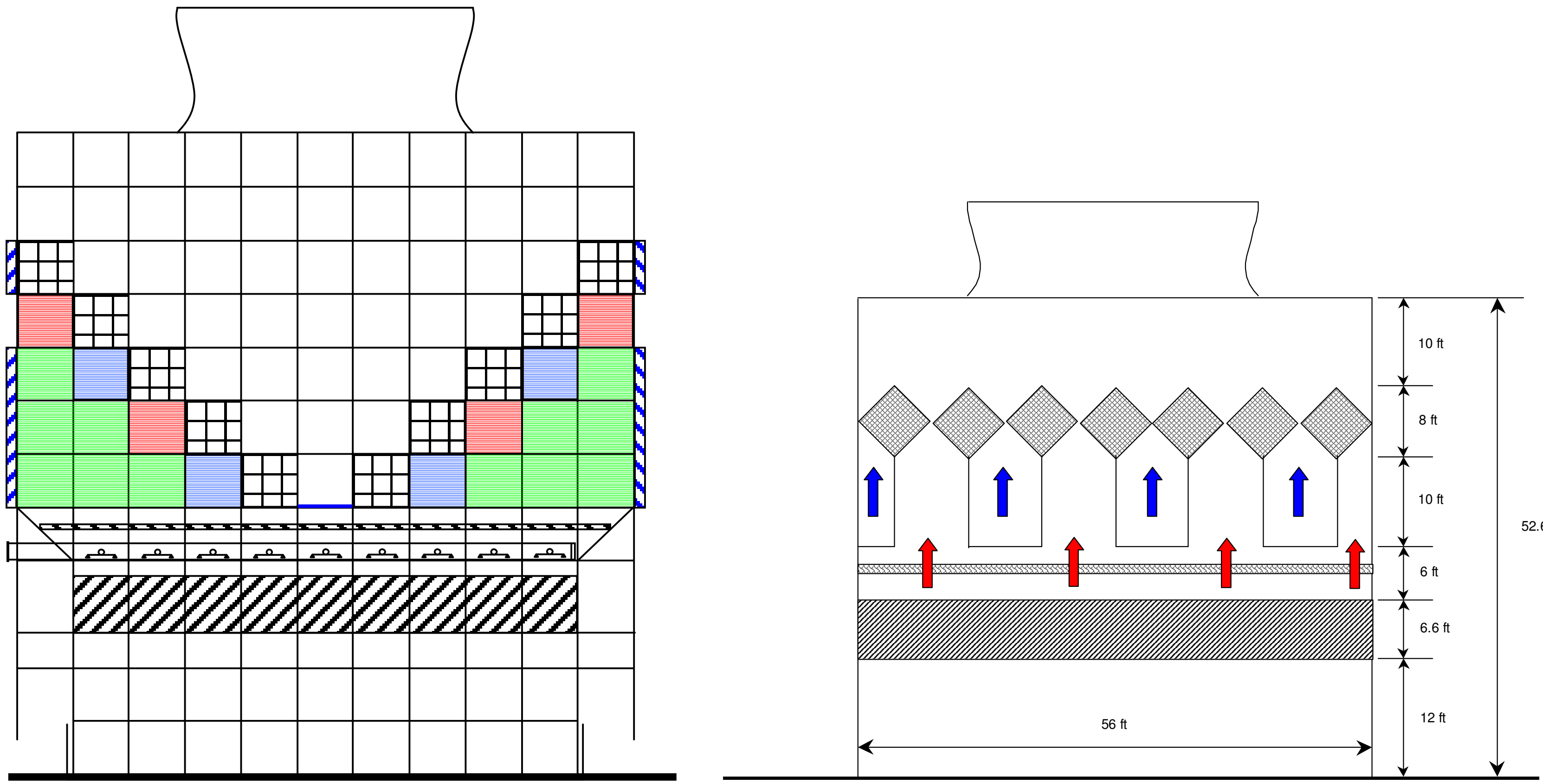
National Energy Technology Laboratory,

Department of Energy

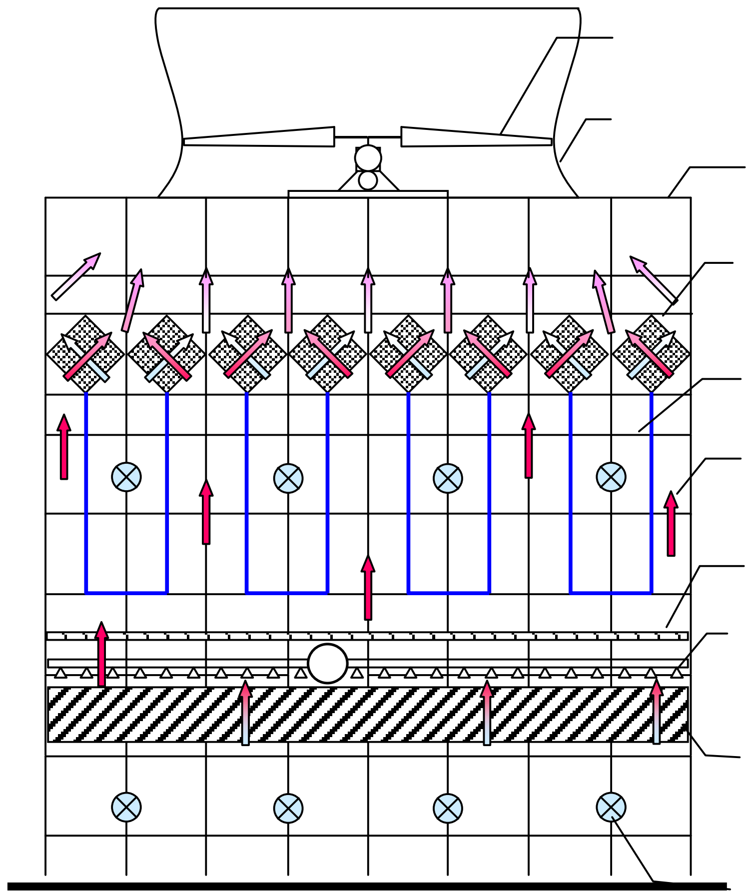
"Improvement to Air2Air™ *Cooling Tower Technology* for Thermoelectric Power Plants"



A2A Configuration Change



A2A Tower Configuration Change



Re-Positioned A2A Module Configuration

SPX

Item	Projected Milestone	Date
1	A2A Tower Configuration Analysis	12/08
2	A2A Heat Exchanger Enhancement Analysis	12/08
3	Pack Seal Development	4/10
4	Evaluate Resulting A2A Pack	3/10
5	Reporting	9/10

Water Conservation

- Less make-up
- Less blow-down
- Less chemical treatment

Reduced Plume -

- **Lowers Actual Humidity of Exit Air**
- No Change Pump-head
- No Water to A2A Heat-exchanger
  - ***No Icing***
  - ***No Fouling***

Thanks to the NETL/Department of Energy for this Opportunity

Application of pulse spark discharges for scale prevention and continuous filtration methods in coal-fired power plant

Oct. 1, 2008 – Sept. 30, 2011

U.S. DEPARTMENT OF ENERGY
National Energy Technology Laboratory

Drexel University
Y. Cho, A. Fridman, and A. Starikovskii

Oct. 28, 2008

Background

Thermoelectric generation accounted for 39% (136 billion gallons per day) of all freshwater withdrawals in 2000.

→ Why so high?

High concentration of mineral ions in the circulating cooling water due to evaporation of pure water evaporates

→Mineral fouling problem, reducing condenser capacity

To maintain a desired calcium level in the cooling water,

→ cycle of concentration, COC = 3.5

→ continuously blowdown with fresh makeup water

Three reactions leading to mineral fouling

Reaction 1: dissociation of bicarbonate ions into hydroxyl ions and carbon dioxide

$$HCO_3^- \ (aq) \leftrightarrow + \ OH^- \ (aq) + CO_2(g)\uparrow$$

Reaction 2: hydroxyl ions produced further react with existing bicarbonate ions, producing carbonate ions and water

$$HCO_3^- \ (aq) + OH^- \ (aq) \leftrightarrow CO_3^{2-} \ (aq) + H_20 \ (l)$$

Reaction 3: reaction between calcium and carbonate ions, resulting in the precipitation and crystallization of calcium carbonate particles

$$Ca^{2+} \ (aq) + CO_3^{2-} \ (aq) \leftrightarrow CaCO_3 \ (s)\downarrow$$

Rationale

COC → Calcium level in cooling water → Condenser tube fouling

An innovative water treatment technology
utilizing spark discharges in water for scale prevention.

The key issue:
How to precipitate and remove dissolved calcium ions in cooling water
so that the COC can be increased and at the same time calcium carbonate scales can be avoided.

Objectives

To reduce the amount of fresh water needed to achieve power plant cooling by preventing the buildup of mineral scale on condenser tubes, thereby increasing the Cycle of Concentration (COC) in the cooling water system from the present operational value of 3.5 to at least 8.

New scale-prevention technology
→ Use electrical pulse spark discharges to precipitate dissolved mineral ions
→ Remove them using a self-cleaning filter from cooling water.

Specific objectives of the proposed work

1. Determine whether the spark discharge can promote the precipitation of mineral ions in cooling water.

2. Determine whether the proposed technology can increase the COC through a continuous precipitation of calcium ions and removal of the precipitated salts with a self-cleaning filter.

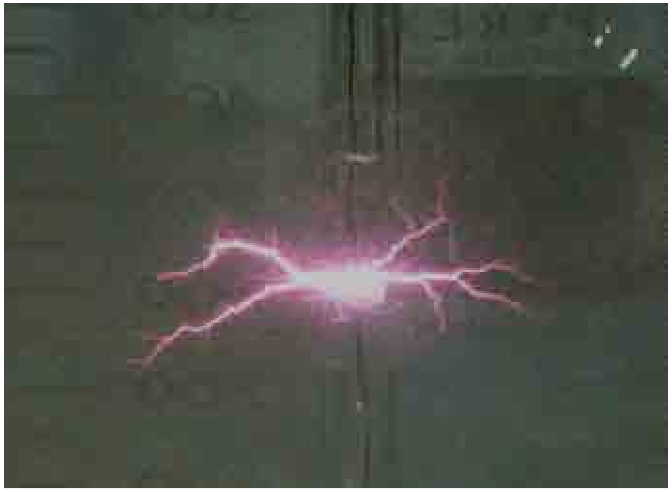
3. Demonstrate that mineral scale on condenser tubes can be prevented or minimized if a COC of 8 or almost zero blowdown can be achieved via the proposed spark discharge technology.

TASKS TO BE PERFORMED

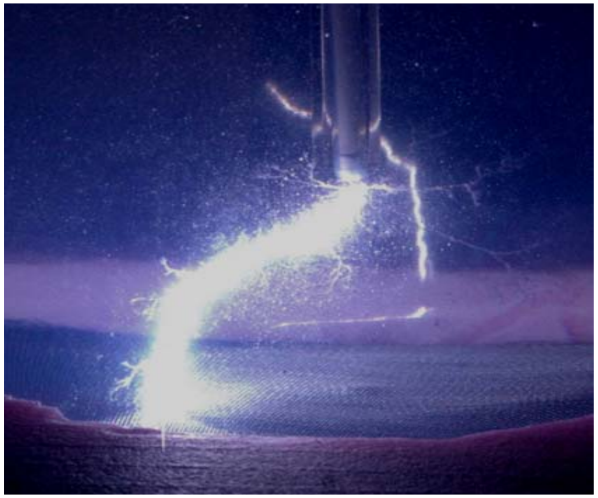
Task 1 – Precipitation of dissolved calcium ions using spark discharge

Task 1 attempts to maintain the desired calcium ion concentration (~ 400 mg/L) in circulating cooling water by precipitating dissolved calcium ions with spark discharges instead of via local heating or blowdown.

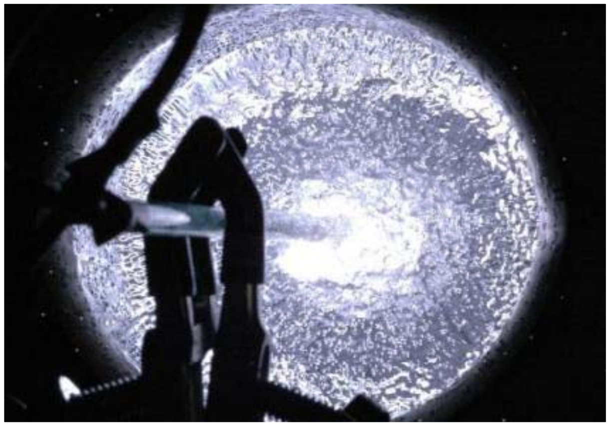
Plasma Discharges in Water
(Drexel University)



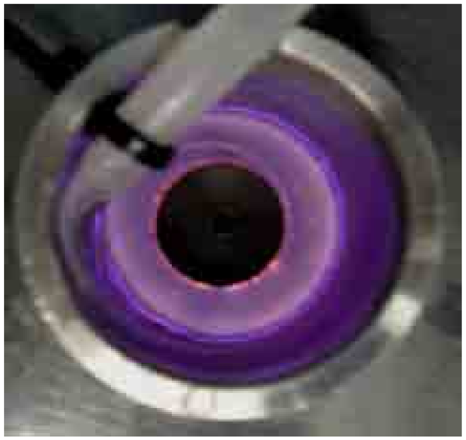
Pulsed Corona in water



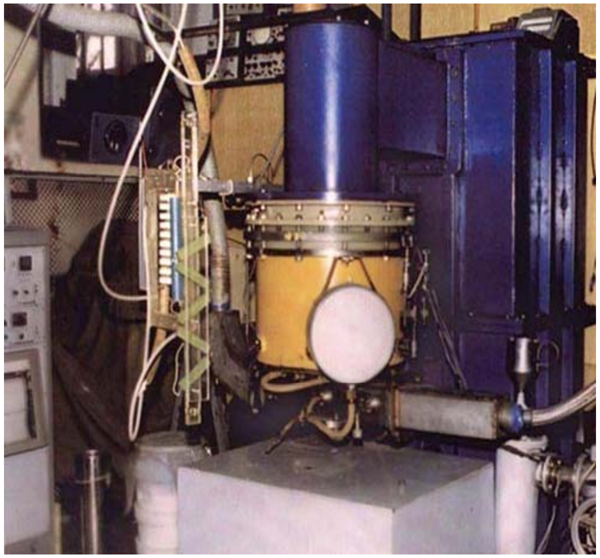
Spark Discharge in water



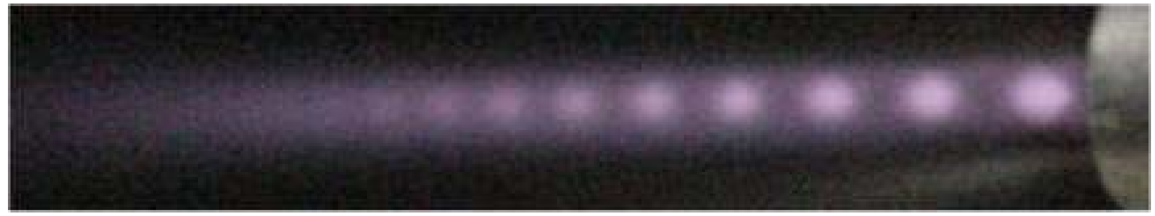
Spark Discharge in water



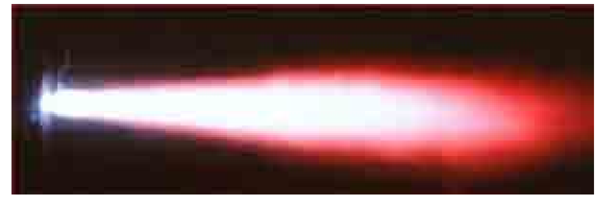
Gliding Arc in water



Electron Beam



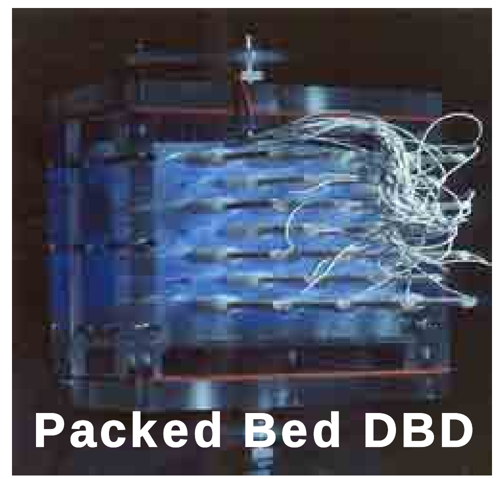
SuperSonic flame plasma



Plasma Torch

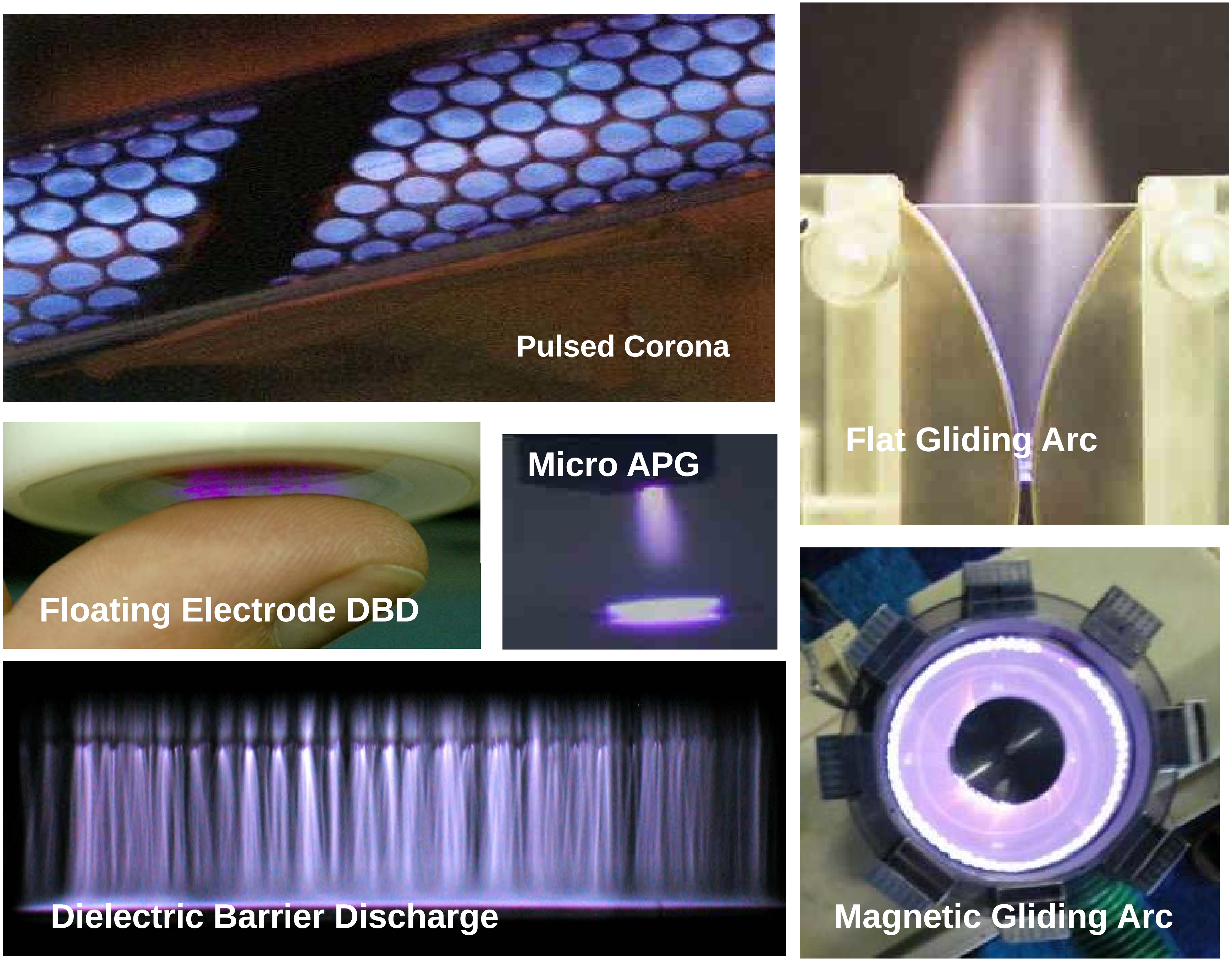
Micro-discharge

Gliding Arc



Packed Bed DBD

10kW Pulsed Corona


Pulsed Corona
Flat Gliding Arc
Floating Electrode DBD
Micro APG
Dielectric Barrier Discharge
Magnetic Gliding Arc

Task 1 – Precipitation of Dissolved Calcium Ions using Spark Discharge

Subtask 1.1 Modeling of Ca^{2+} precipitation process using water-related variables

The objective of this subtask is to investigate whether different cooling water conditions alter the Ca^{2+} precipitation efficiency of the spark discharges through computer modeling of the precipitation process.

Subtask 1.2 Parametric study of Ca^{2+} precipitation process using power-related variables

The objective of this subtask is to investigate whether different spark configurations alter the Ca^{2+} precipitation efficiency of the spark discharges.

Subtask 1.3 Optimization of electrode configuration for most efficient spark discharges

The objective of this subtask is to investigate the effects of electrode materials and geometry on the Ca^{2+} precipitation efficiency.

SUCCESS CRITERIA AND DECISION POINTS

Criteria for success for Task 1

The success of Task 1 study will be judged if the proposed spark discharge technology can reduce the concentration of calcium ions by more than 50% for different levels of hardness of cooling water. The actual hardness of recirculating cooling water can be as high as 400 ppm. If we can reduce the hardness of the cooling water by at least 50% for the maximum hardness case, we should consider Task 1 study successful.

TASKS TO BE PERFORMED

Task 2 – Validation experiments to increase COC

Task 2 will include building a laboratory cooling tower (Figure 2), where pure water continuously evaporates as heat is added through a small heat exchanger. In the laboratory tower, the water lost by evaporation, wind, and blowdown is automatically replaced by makeup water whose flow rate is controlled by a floating valve located at the tower sump. The cooling tower will have an automatic blowdown capability with a solenoid valve which is turned on-off by a preset conductivity meter. The laboratory tower will simulate a typical cooling tower operation using the tap water supplied by the City of Philadelphia as makeup water.

Task 2 – Validation Experiments to Increase COC

Subtask 2.1 Tests with COC of 4

The objective of this subtask is to investigate whether the proposed spark discharge system can increase the COC, starting at a COC of approximately 4.

Subtask 2.2 – Tests with COC of 6

Subtask 2.3 Tests with COC of 8

Subtask 2.4 Tests with zero blowdown

Subtask 2.5 Tests with bulk heating for COC of 4

Task 2 – Validation Experiments to Increase COC

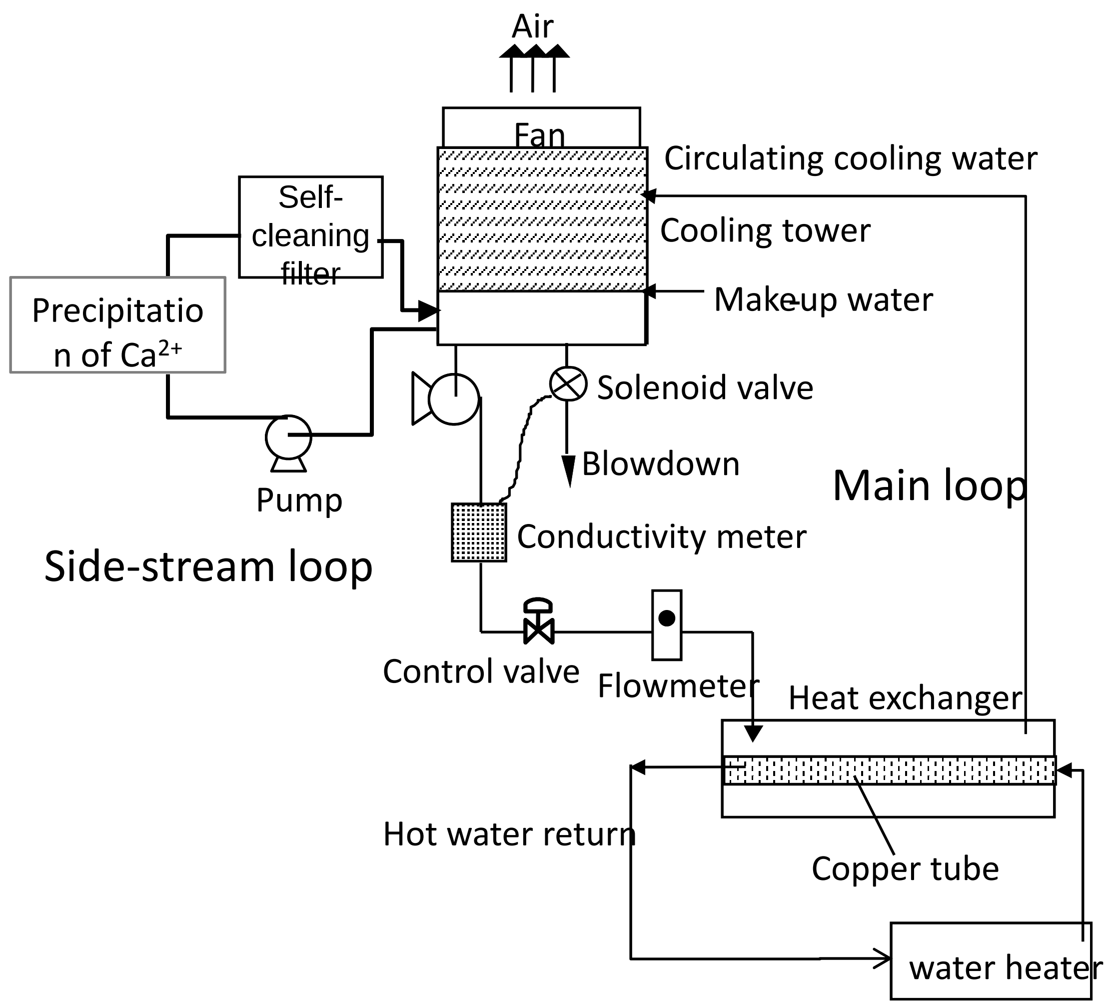


Figure 2 - Schematic diagram of a laboratory cooling tower test facility for the proposed study

Task 2 – Validation Experiments to Increase COC (Sample Water Data)

	Makeup	Baseline (Day 11)	PWT-S (Day 12)
Total alkalinity (ppm)	120	260	240
Chloride (ppm)	125	1,240	1,320
Total hardness (ppm)	190	1,720	1,680
Calcium (ppm)	170	1,360	1,240
Magnesium (ppm)	20	360	440
pH	6.8	6.9	7.2
Conductivity (micromho/cm)	445	4,600	4,550

Table 1 – Previous water analysis conducted at Drexel University

SUCCESS CRITERIA AND DECISION POINTS

Criteria for success for Task 2

The success of Task 2 study will be judged if the proposed spark discharge technology at least doubles the COC of the present practice. In other words, if the spark discharge technology can provide a steady operation of cooling tower operation at a COC of 8 over at least one week at the laboratory cooling tower system, we should consider Task 2 successful.

TASKS TO BE PERFORMED

Task 3 – Validation experiments for scale prevention (Year 3)

The objective of Task 3 is to investigate whether the proposed spark discharge technology can prevent or minimize scale deposits on the condenser tubes. A series of heat transfer fouling tests will be conducted using a condenser heat exchanger in the laboratory cooling tower. The fouling resistance will be experimentally determined by measuring the inlet and outlet temperatures at both cooling-water side and hot-fluid side. The fouling resistance obtained with the proposed scale-prevention technology will be compared with the no-treatment case as well as the scale-free case.

Task 3 – Validation experiments for scale prevention (Year 3)

Subtask 3.1 Tests with COC of 4

This task will deliver fouling test data, in terms of fouling resistance over time, for the baseline (no treatment) case, and for the proposed spark discharge technology conducted under the identical conditions as the baseline test.

Subtask 3.2 – Tests with COC of 6

Subtask 3.3 Tests with COC of 8

Subtask 3.4 Tests with zero blowdown

Task 3 – Validation experiments for scale prevention (Year 3)

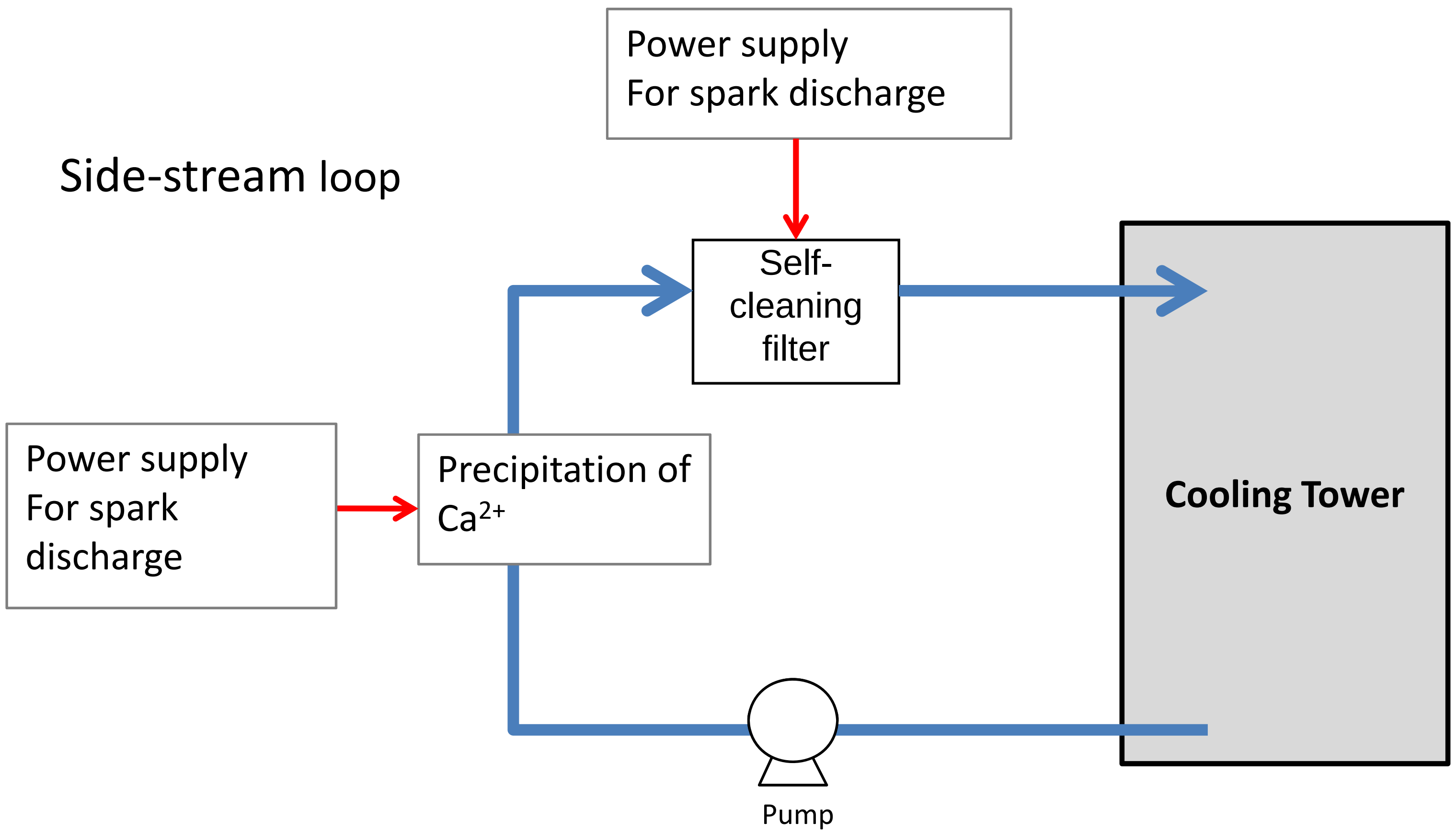


Figure 4 - Schematic diagram of the side-stream loop in a laboratory cooling tower test facility for the proposed study

Task 3 – Validation experiments for scale prevention (Year 3)

COC (Hardness)

- COC = 4
- COC = 6
- COC = 8
- No Blowdown

Spark discharge for Precipitation of Ca^{2+} Variables

- Frequency and strength of spark discharge
- Electrode geometry, material
- Flow velocity around electrode

Self-cleaning filter Variables

- Frequency and strength of spark discharges

Figure 5 - Block diagram of parameters that may affect the outcome of fouling tests

Task 3 – Validation experiments for scale prevention (Sample Fouling Data)

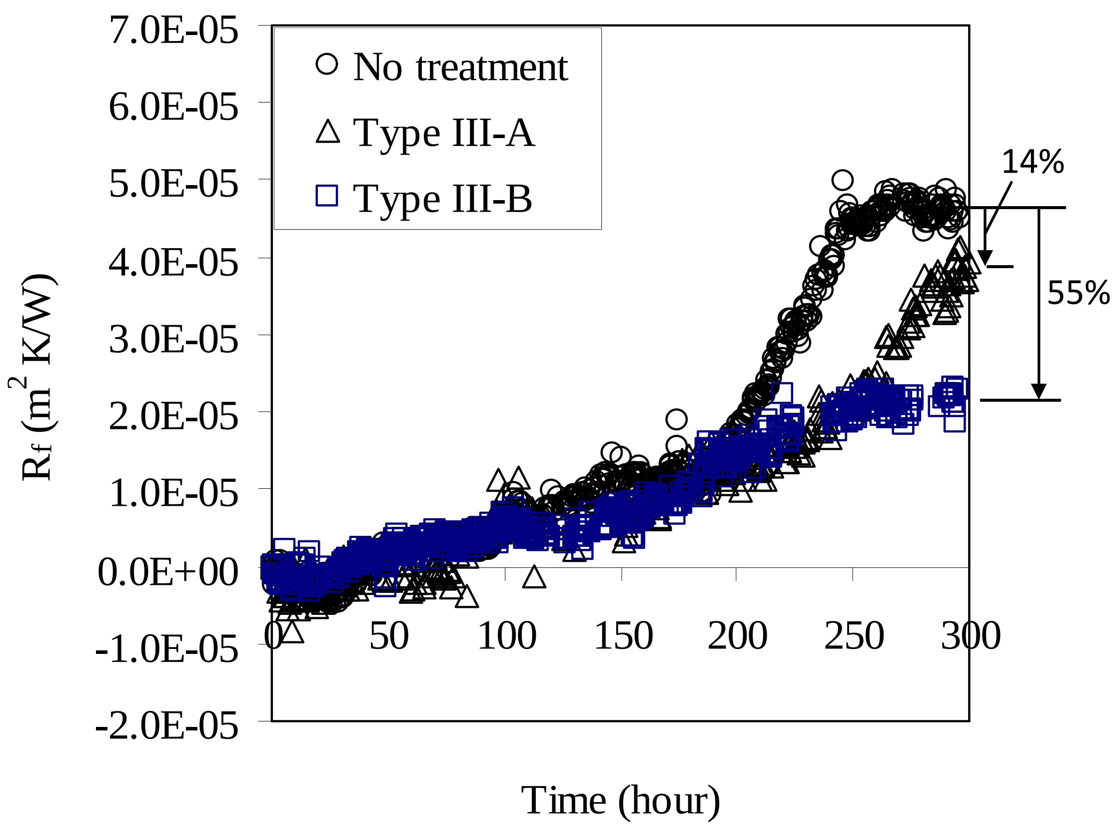
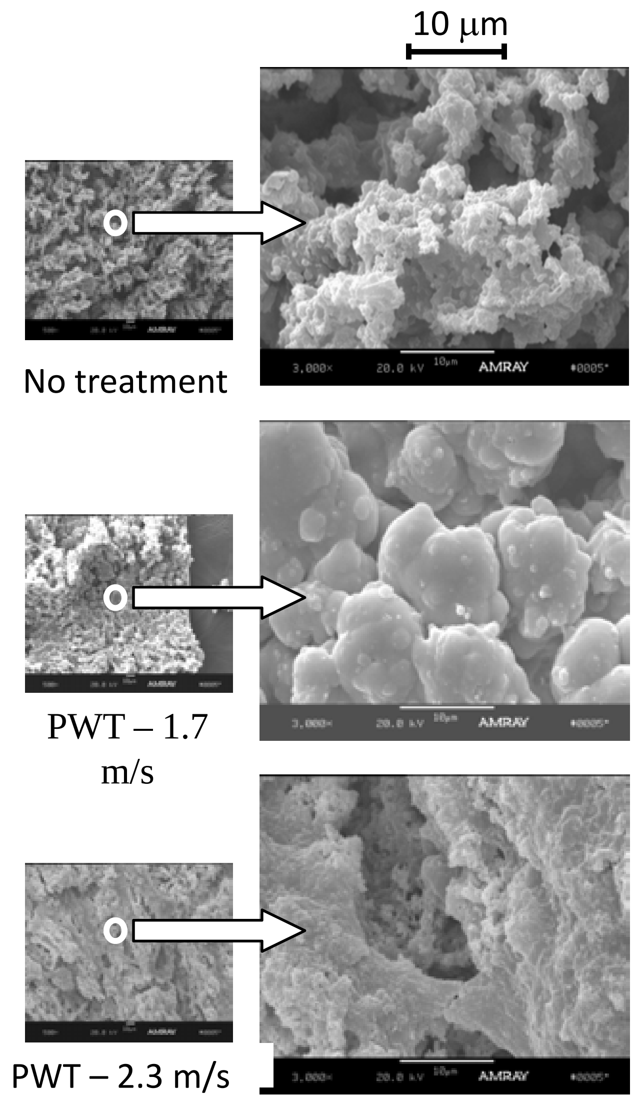
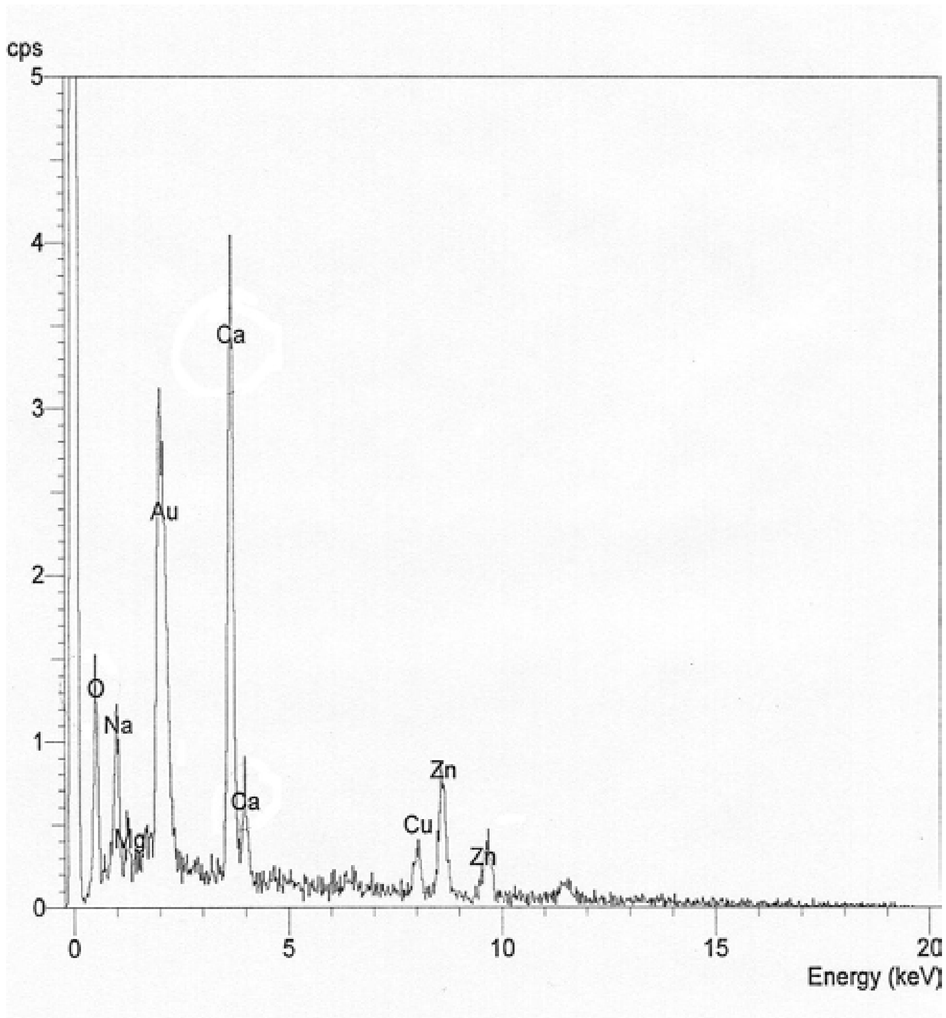


Figure 6 - Previous fouling test results obtained at Drexel University using two different types of permanent magnets [18]. R_f = fouling resistance; Zero fouling resistance means a perfectly maintained condenser tube.

Example of SEM photographs of CaCO3 Deposits on Condenser Tubes (Sample data from previous study)



Example of Energy Dispersive Spectrum (EDS) of CaCO3 Deposits on Condenser Tubes (X-ray diffraction)



SUCCESS CRITERIA AND DECISION POINTS

Criteria for success for fouling test

The success of the proposed fouling test will be judged if the proposed spark discharge technology can reduce the fouling resistance by at least 90% compared to those obtained from the baseline test for COC = 4. For higher COC cases (i.e., COC = 6 and 8, and no blowdown case), the improvement may be less than 90%, but still greater than 75%.

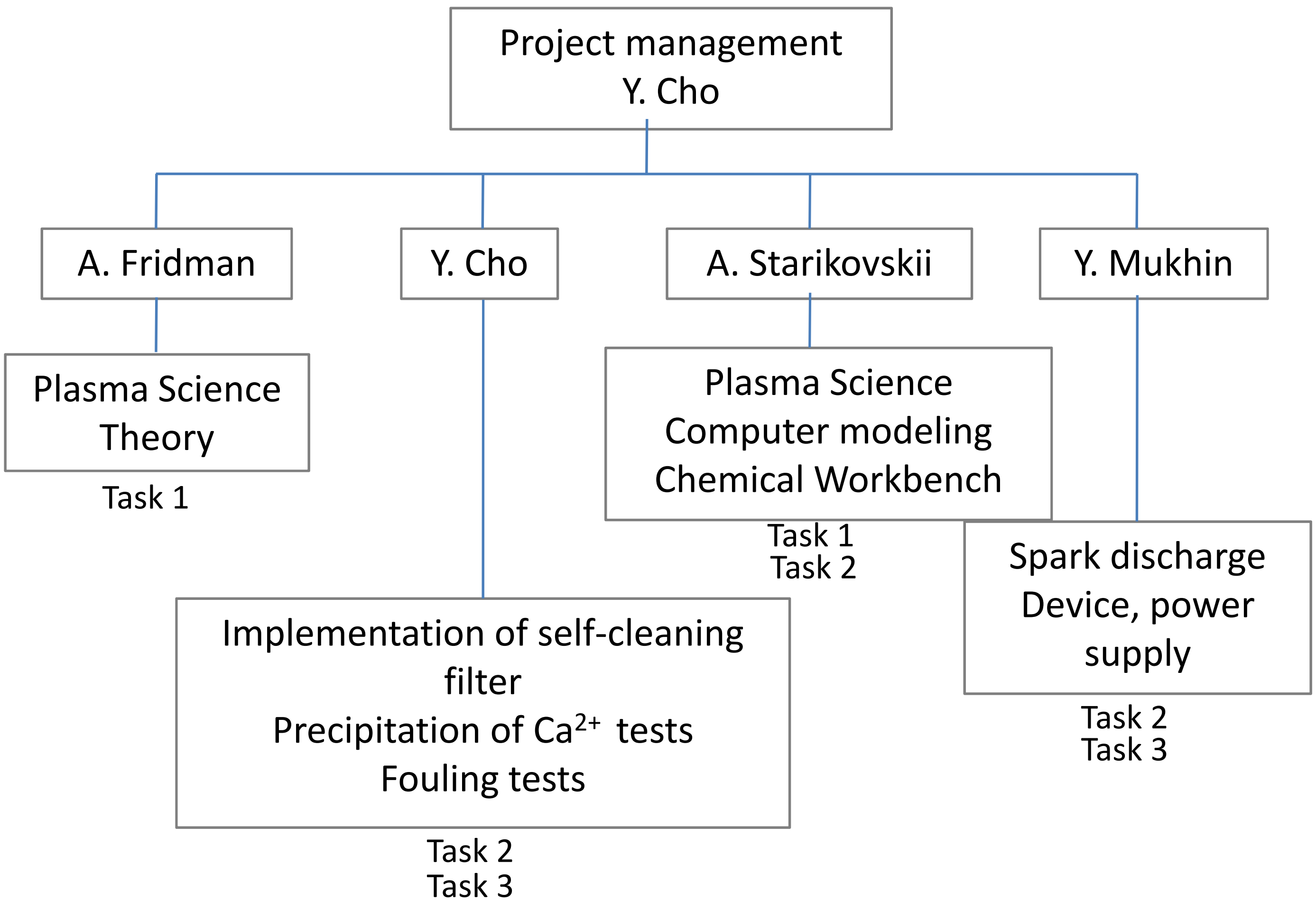
DELIVERABLES - Expected Results

If the excess calcium ions in cooling water can be successfully precipitated and removed, condenser-tube fouling can be prevented and the COC can be doubled at the same time. This accomplishes one of the major DOE goals of reducing/minimizing freshwater withdrawal in thermoelectric power plants.

The proposed study will begin with basic scientific research to better understand the mechanism of pulse spark discharges in water and conclude with a series of validation experiments to simulate scale build-up using hard water in a laboratory cooling tower equipped with the pulse spark discharge treatment system.

At the completion of the proposed work, a new prototype hardware using pulse spark discharges will be available for scale-up with validating test results. It will be a true mechanical water softener, which continuously converts hard water to soft water with a very little energy consumption.

Task 4 – Project Management, Planning, and Reporting



Risk Management

Under a previous DOE NETL project (DE-FC26-06NT42724), Drexel has successfully demonstrated that pulse spark discharges could be produced directly in water using 40,000 V at a frequency of 1-10 Hz with a pulse duration of 10-50 nanoseconds.

Scale-up from a small laboratory size to a large cooling tower application.
→ Two electrodes to produce spark discharges in water at Drexel lab.
→ In a large power plant, we need 1,000 or more electrodes.

Risk Management - Energy Requirement

The power of the spark discharge is approximately 2 J/pulse and about 10-20 pulses are needed for a volume of 0.5-L water for an effective removal of impurities from the filter membrane.

Hence, approximately 80 J/L of electric energy were consumed in laboratory tests.

The proposed spark discharge requires only 5 KW of electrical energy to treat water at a flow rate of 1,000 gpm.

The power needed to treat the cooling water in the 1000-MW power plant will be 200 KW, which is only 0.02% of the full capacity of 1000 MW.

Risk Management - Energy Requirement

Plasma Discharge in Water Comparison Chart			
	Gliding Arc Discharge	**Pulsed Spark Discharge (Drexel)**	**Pulsed Corona Discharge (Max)**
Energy per Liter for 1 log reduction in E. Coli (J/L)	860	77	150000
Power requirement for household water consumption at 6 gpm (kW)	0.326	0.029	56.8
Power requirement for village water consumption at 1000 gpm (kW)	54.3	4.9	9463.5
Efficiency of power supply required	Excellent	Excellent	Poor
Maximum Water throughput based on Maximum power (gpm)	95	2058	0.03
Central lethal biological agent of discharge	UV and Chemical Radicals	UV	Chemical Radicals (OH, H_3O+, H_2O_2)

Risk Management

Risk: The pulse spark discharge system may fail to achieve the desired amount of calcium ion precipitation.

Mitigation/Management Approach: If this happens, the cause of the failure may be most likely due to the high electrical conductivity of circulating water in cooling tower system. In order to mitigate this risk, the cause of the failure will be investigated by reducing the electrical conductivity of water to see if the failure disappears. After this confirmation, the energy level of spark pulse will be increased so that a sufficient spark discharge can take place in water. This may require a significant improvement in the design of the power supply. It is believed that Drexel University has enough in-house expertise to handle the new design of the power supply.

Risk Management

<u>Risk:</u> The pulse spark discharge system may not achieve a significant increase in the COC when integrated with the laboratory-scale cooing tower.

<u>Mitigation/Management Approach:</u> Previously it was demonstrated at Drexel University with a relatively clean filter that the COC could be significantly increased with a combined use of physical water treatment and a filtration. However, in the present study, the failure of not being able to increase the COC to a level of 8 can occur. This may happen mostly likely due to the poor performance of a self-cleaning filtration system. If this failure occurs, an attempt will be made to improve the performance of the self-cleaning filter by adding additional electrodes to improve the self-cleaning performance.

Risk Management

Risk: The pulse spark discharge system may fail to achieve a significant reduction in fouling resistance when tested with the laboratory-scale cooling tower.

Mitigation/Management Approach:

If this happens, the causes of the failure can be multivariable,

1. the poor performance of the calcium precipitation process,
2. the poor performance of the self-cleaning filter,
3. the performance degradation of the spark-discharge system which utilizes a sharp tip electrode, and
4. too small flow velocity at the heat exchanger such that the deposition rate of calcium salt is much greater than the removal rate.

MILESTONE LOG

Milestone Title	Planned Completion Date	Milestone Verification Method
Task 1 – Precipitation of dissolved calcium ions using spark discharge (Year 1) (Oct. 1, 2008 – Sept. 31, 2009)	**Year 1**	
Subtask 1.1 Parametric study of Ca^{2+} precipitation process in water side		
Subtask 1.2 Parametric study of Ca^{2+} precipitation process in power supply side	Jun. 31, 09	
Subtask 1.3 Optimization of electrode configuration for most efficient spark discharges	Sept. 31, 09	
Task 2 – Continuous removal of precipitated calcium particles (Year 2) (Oct. 1, 2009 – Sept. 31, 2010)	**Year 2**	
Subtask 2.1 Tests with COC of 4		
Subtask 2.2 Tests with COC of 6		
Subtask 2.3 Tests with COC of 8	Jun. 31, 10	
Subtask 2.4 Tests with zero blowdown	Sept. 31, 10	
Subtask 2.5 Tests with bulk heating at COC of 4	Sept. 31, 10	
Task 3 – Validation experiments for scale prevention (Year 3) (Oct. 1, 2010 – Sept. 31, 2011)	**Year 3**	
Subtask 3.1 Tests with COC of 4		
Subtask 3.2 Tests with COC of 6		
Subtask 3.3 Tests with COC of 8	Jun. 31, 11	
Subtask 3.4 Tests with zero blowdown	Sept. 31, 11	

PROJECT TIMELINE

	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1 – Precipitation of dissolved calcium ions using spark discharge												
Subtask 1.1 Modeling of Ca^{2+} precipitation process	↔	↔										
Subtask 1.2 Parametric study of Ca^{2+} precipitation process in power supply side		↔										
Subtask 1.3 Optimization of electrode configuration for most efficient spark discharges			↔	↔								
Task 2 – Validation experiments to increase COC (Year 2)												
Subtask 2.1 Tests with COC of 4					↔							
Subtask 2.2 Tests with COC of 6						↔						
Subtask 2.3 Tests with COC of 8							↔					
Subtask 2.4 Tests with zero blowdown								↔				
Subtask 2.5 Tests with bulk heating for COC of 4								↔				
Task 3 – Validation experiments for scale prevention (Year 3)												
Subtask 3.1 Tests with COC of 4									↔			
Subtask 3.2 Tests with COC of 6										↔		
Subtask 3.3 Tests with COC of 8											↔	
Subtask 3.4 Tests with zero blowdown												↔
Task 4 – Project Management, Planning, and Reporting	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

NATIONAL ENERGY TECHNOLOGY LABORATORY

Design, Analysis, and Optimization of Integrated Power Plant and Water Management Systems

Urmila Diwekar

Center for Uncertain Systems: Tools for Optimization and Management (CUSTOM), Vishwamitra Research Institute

Stephen E. Zitney

NETL, Office of Research & Development

Director, Collaboratory for Process & Dynamic Systems Research

Outline of Presentation

- **Project Overview**
  - Goals and Objectives
  - Milestones
- **Case Studies**
  - Integrated Power Plant and Water Network
  - PC and IGCC w/ and /wo CO2 Capture
- **Optimal Synthesis Approach**
  - Heat and Mass Exchange Networks
  - Multiobjective Optimization under Uncertainty
- **Conclusions**

Project Overview

- **Goal**
  - Develop a simulation-based tool for the synthesis, design, analysis, and optimization of integrated power plant and water management systems under uncertainties
- **Objectives**
  - Develop water system modeling guidelines, assumptions, and methodologies
  - Algorithm development for the synthesis, design, analysis and optimization of integrated process/water systems
  - Establish process/water simulation baselines for PC and IGCC systems with and without CO_2 capture
  - Study and simulate new water management technologies

Project Milestones (Year 1)

- Generate report summarizing findings on power plant water usage, reuse, recovery, and treatment data
- Deliver detailed three-year project development plan to develop integrated power plant and water management tools
- Develop and exercise Aspen Plus simulations for baseline PC and IGCC power plant /w and /wo carbon capture, including water systems
- Deliver report on Aspen Plus PC and IGCC plant simulations with water network models

Project Milestones (Year 1)

- **Deliver plan for development of an Aspen Plus case for water technology developed under the DOE Power Plant Water R&D Program**
- **Generate Aspen Plus PC plant simulation to evaluate advanced water technology developed under DOE Power Plant Water R&D Program**
- **Generate report on opportunities for applying APECS to evaluate water mgmt technologies using potential PDE/CFD-based equipment models**
- **Develop plan for developing probability distributions for uncertainties and variabilities in water management technologies**

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Integrated Plant/Water Case Studies
PC and IGCC w/ and wo/ CO2 Capture

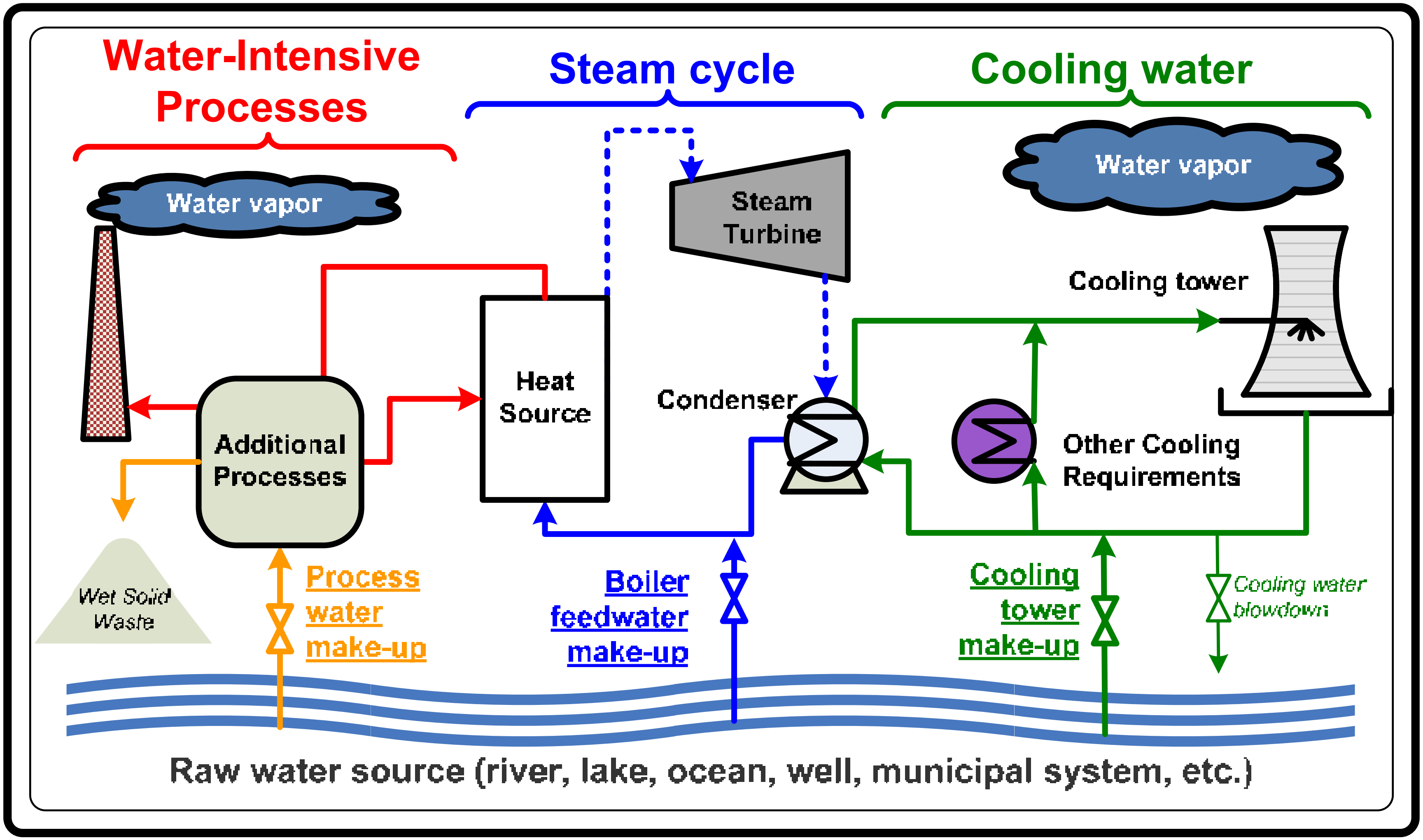
Plant Type	ST Cond. (psig/°F/°F)	GT	Gasifier/ Boiler	Acid Gas Removal/ CO_2 Separation / Sulfur Recovery	CO_2 Cap
IGCC	1800/1050/1050 (non-CO_2 capture cases)	F Class	GE	Selexol / - / Claus	
	1800/1000/1000 (CO_2 capture cases)			Selexol / Selexol / Claus	90%
PC	2400/1050/1050		Subcritical	Wet FGD / - / Gypsum	
				Wet FGD / Econamine / Gypsum	90%

Coal-Fired Power Plant

IGCC Power Plant

"Cost and Performance Baseline for Fossil Energy Power Plants Study, Volume 1: Bituminous Coal and Natural Gas to Electricity," National Energy Technology Laboratory, www.netl.doe.gov, August 2007.

Water Flow Schematic for Power Plants



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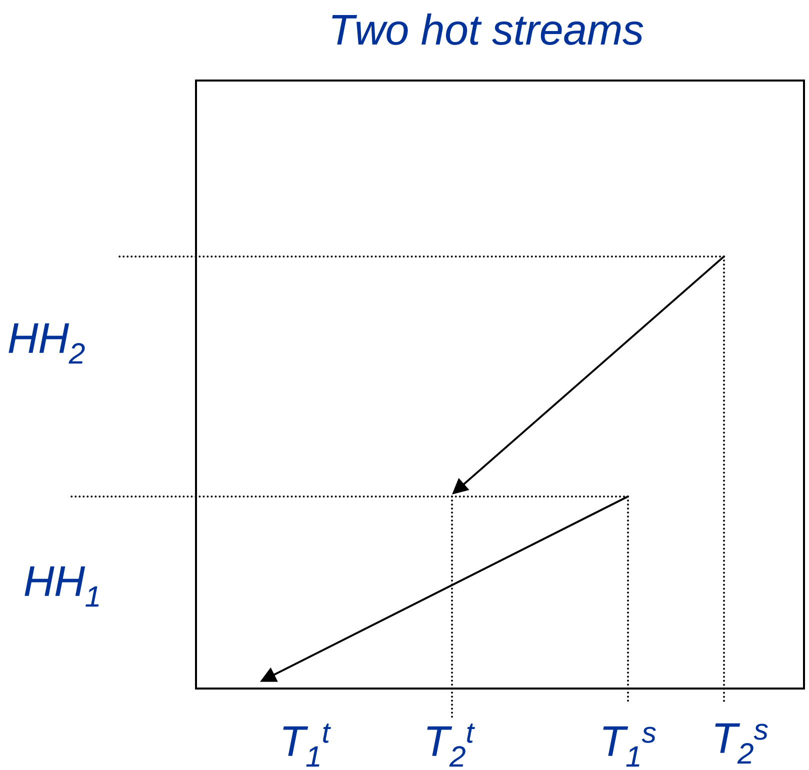
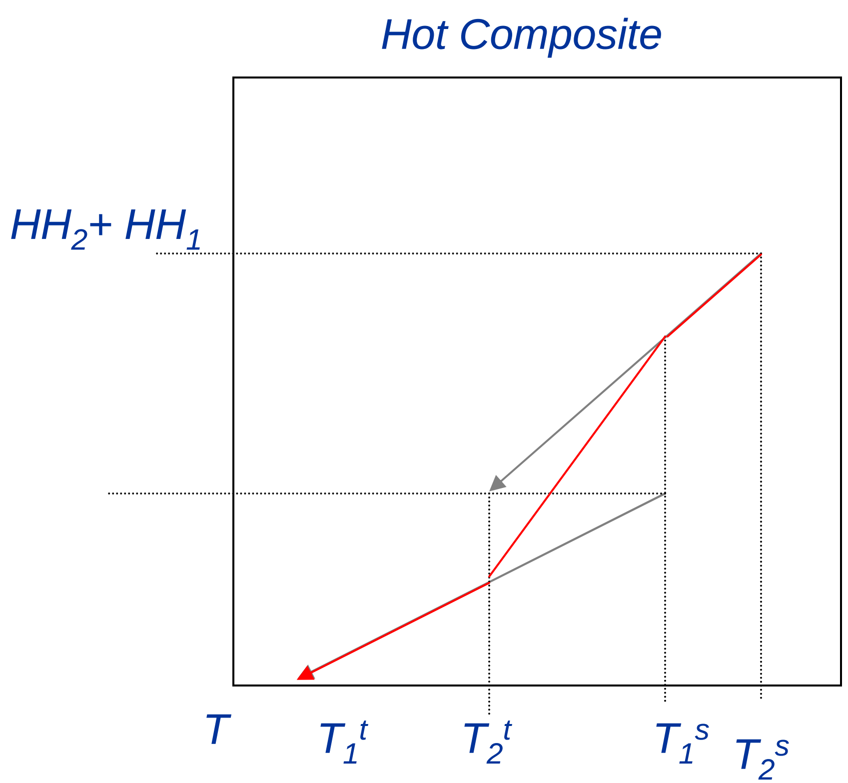
Optimal Synthesis Approach

- **Heat Exchanger Network Synthesis**
  – Minimize use of cooling water
- **Mass Exchanger Network Synthesis**
  – Minimize use of process water
- **Optimization Approach to Process Synthesis**

Heat Exchanger Network Synthesis

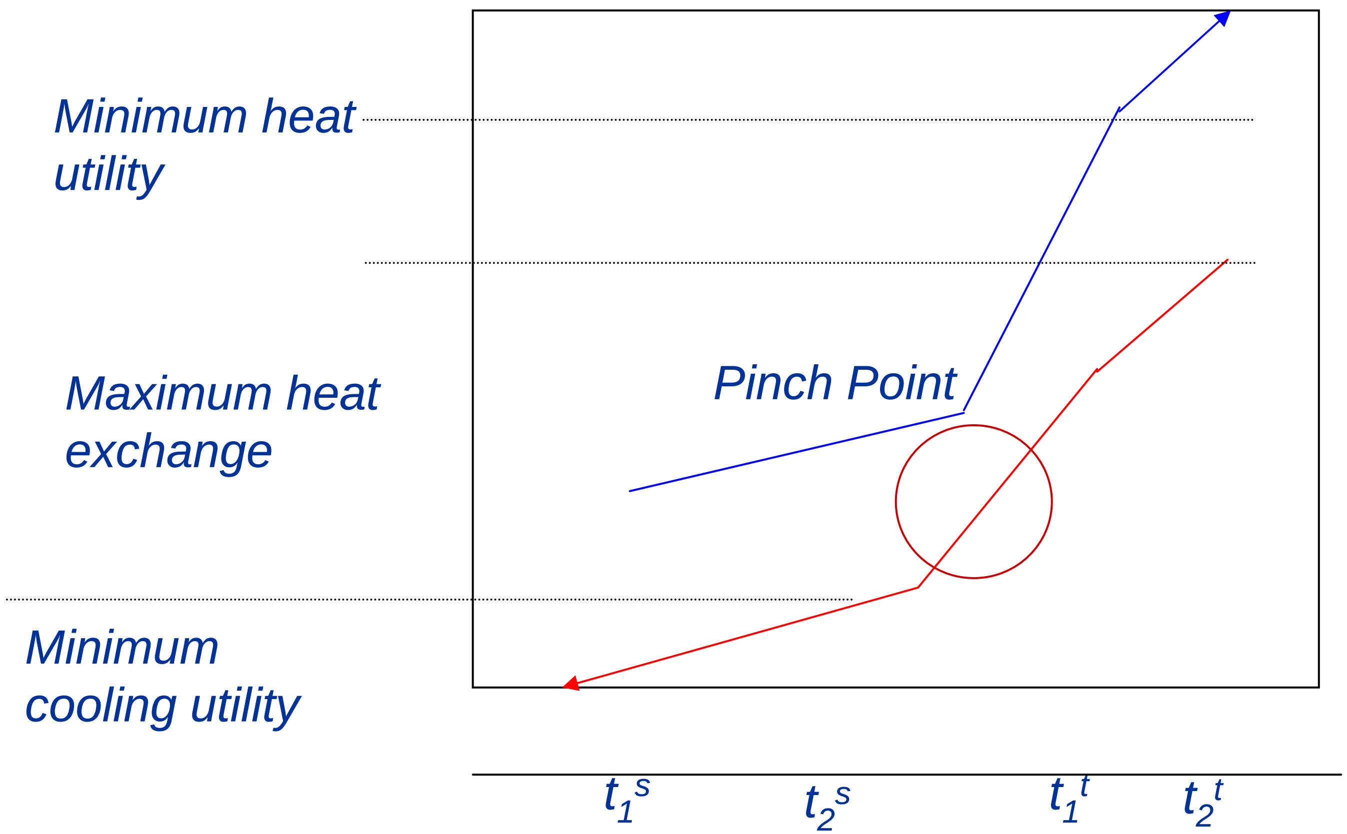
- **Heat exchange pinch diagrams**



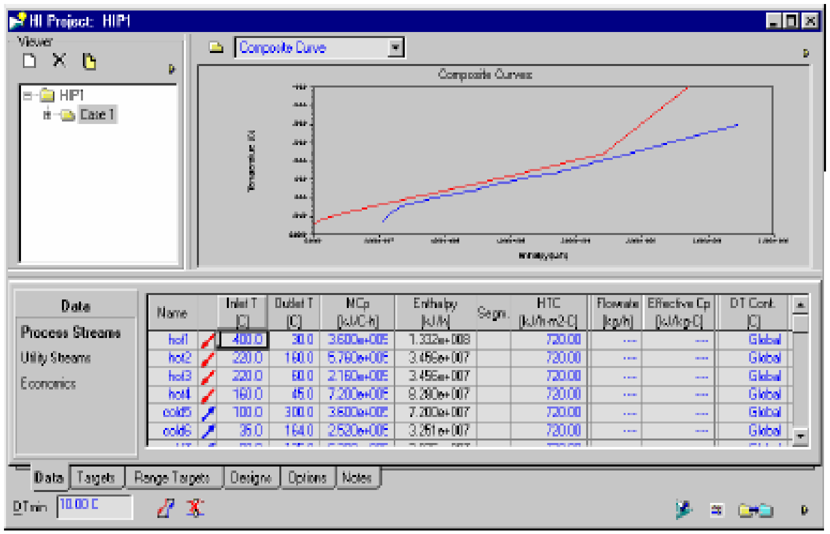


$$HH_u = F_u Cp_u (T_u^s - T_u^t)$$

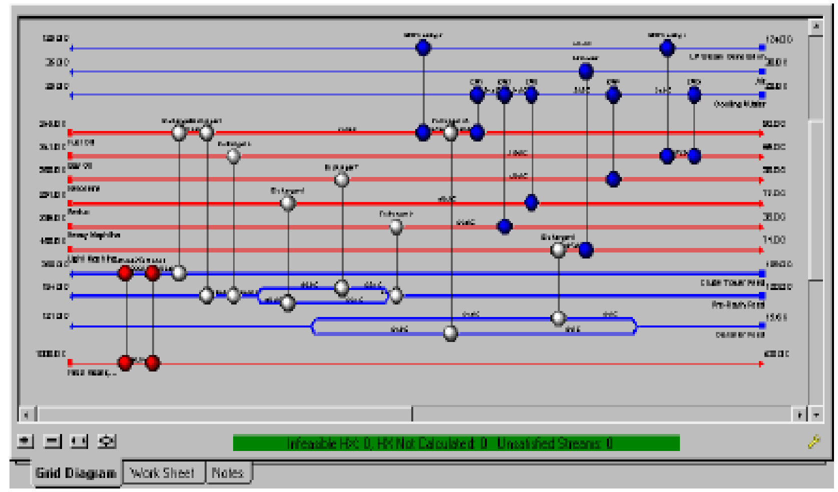
Heat Exchange Pinch Diagram



Optimal Heat Exchange Network Design



Aspen Energy Analyzer

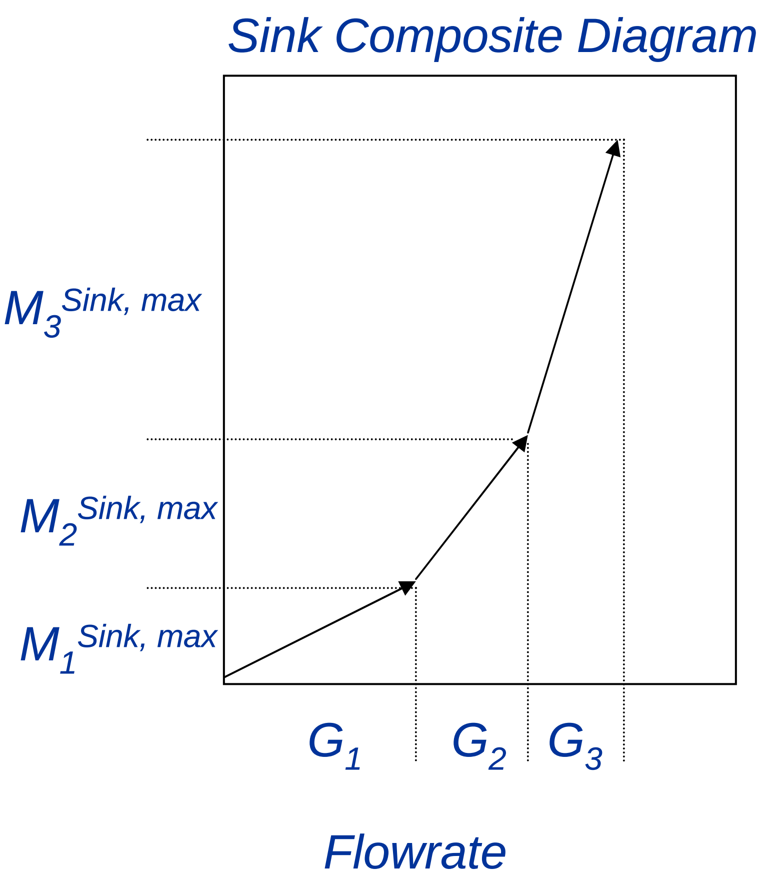


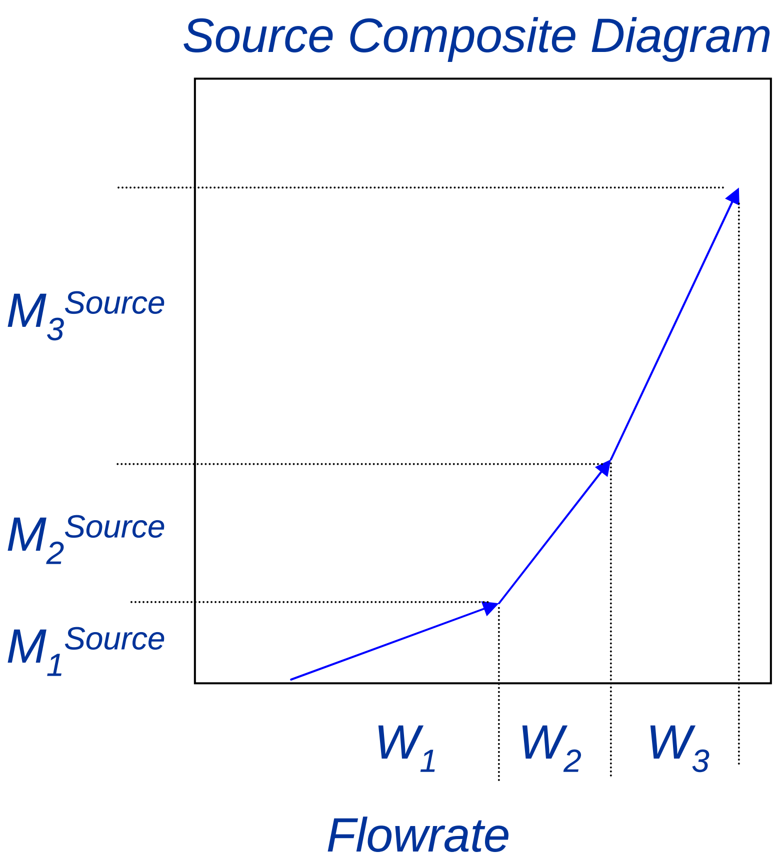
- **Calculates targets for energy and capital investment**
- **Enables the development of improved heat integration projects, significantly reducing operating, capital, and design costs, and minimizing energy-related emissions**
- **Provides tools for performing process optimization**
- **Provides both graphical and algorithmic methods**

Analogy between MENs and HENs

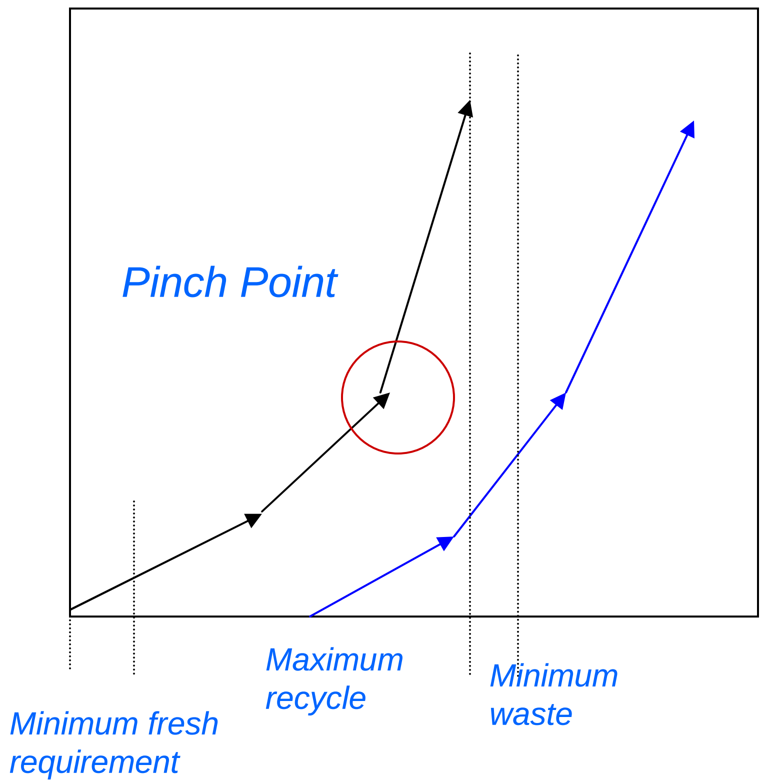
Category	MENs	HENs
Transferred Commodity	Mass	Heat
Donors	Rich streams	Hot streams
Recipients	Lean streams	Cold streams
Rich variable	Composition y	Hot temperature T
Lean variable	Composition x	Cold temperature t
Slope of equilibrium	m	1
Intercept of equilibrium	b	0
Driving force	e	ΔT^{min}

Source Sink Mapping





Mass Exchange Pinch Diagram



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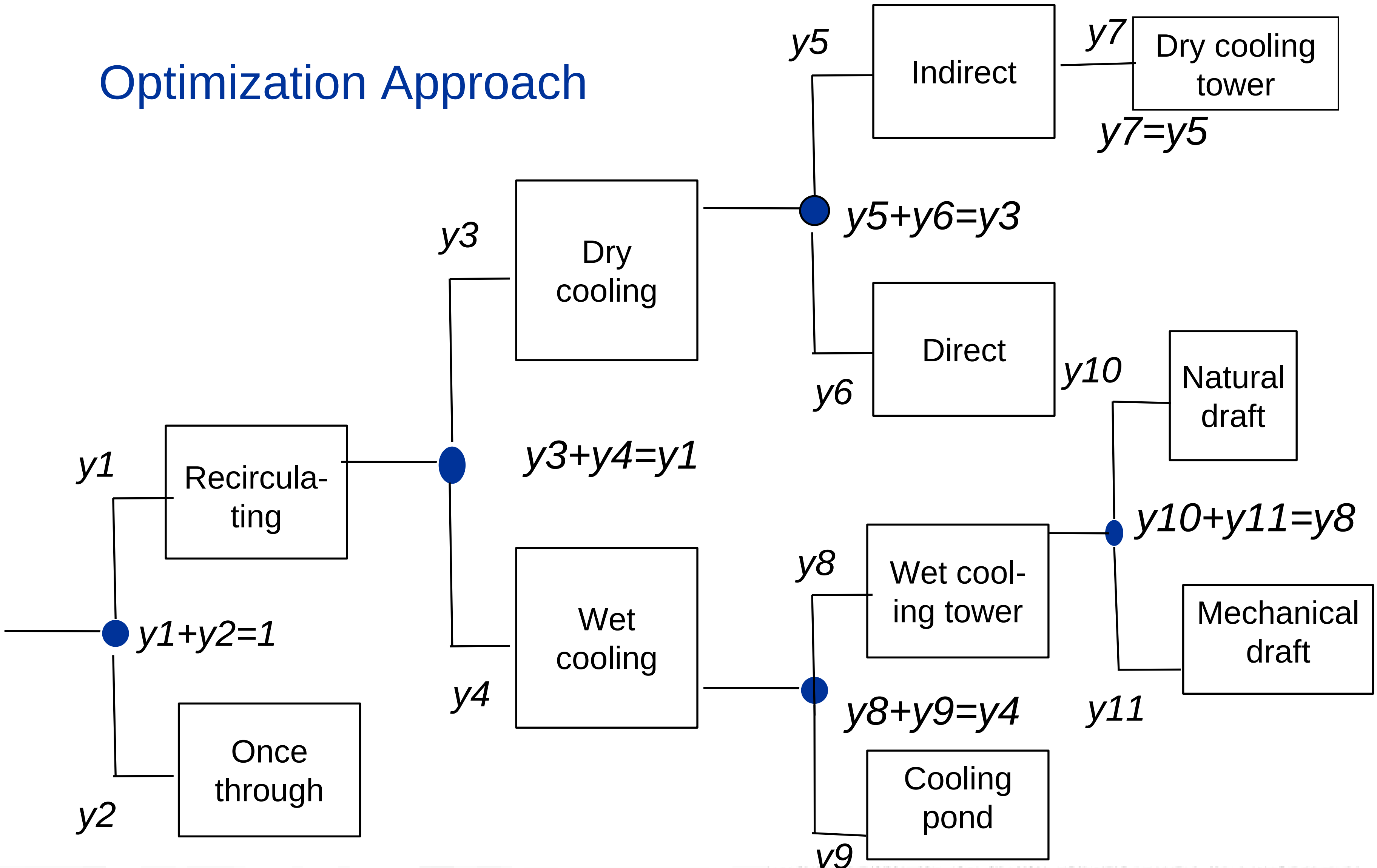
Cooling Water System Configurations

Optimization Approach



Mixed Integer Nonlinear Programming (MINLP)

$$\underset{x,y}{Optimize}\ Z = z(x, y) = a^T y + f(x)$$

$$h(x) = 0$$

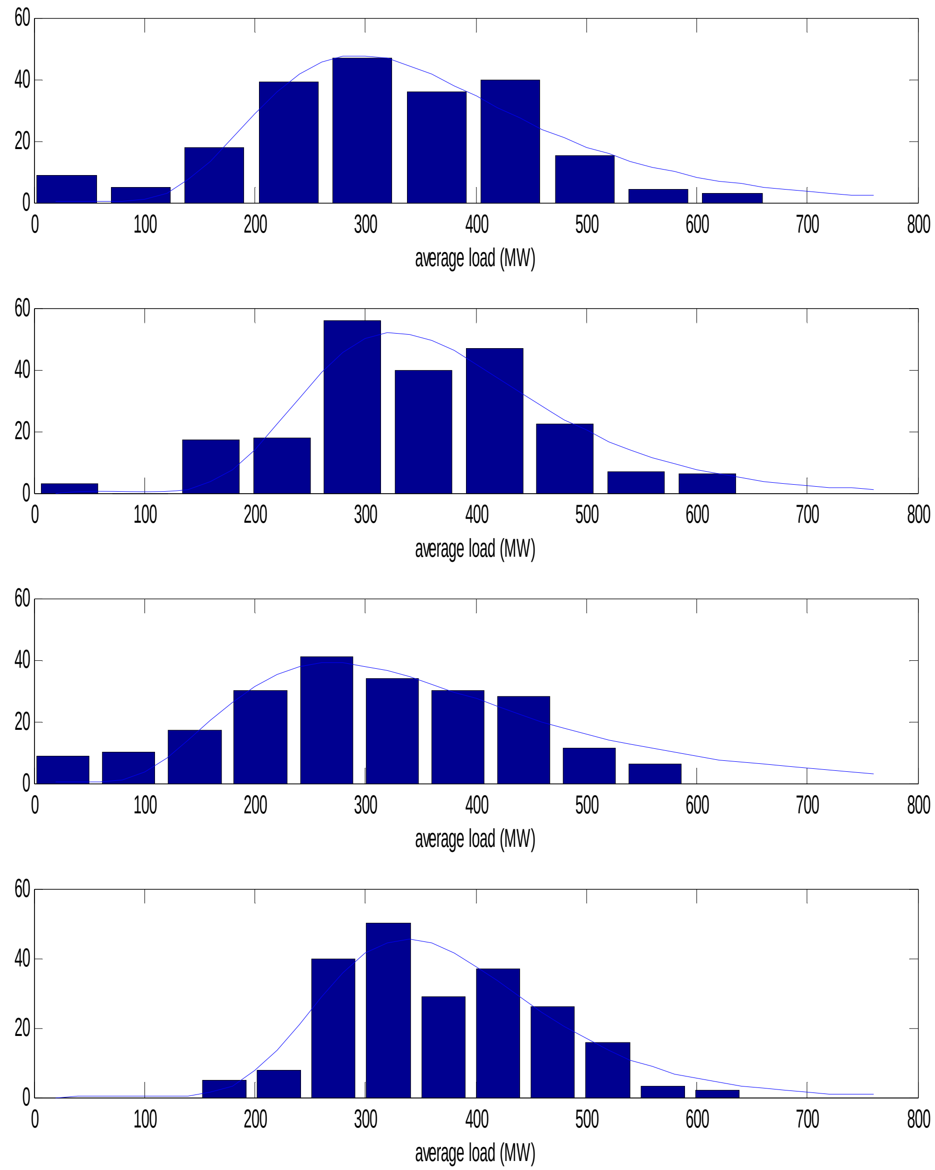
$$g(x, y) = -B^T y + g(x) \leq 0$$

Where x represents continuous variables

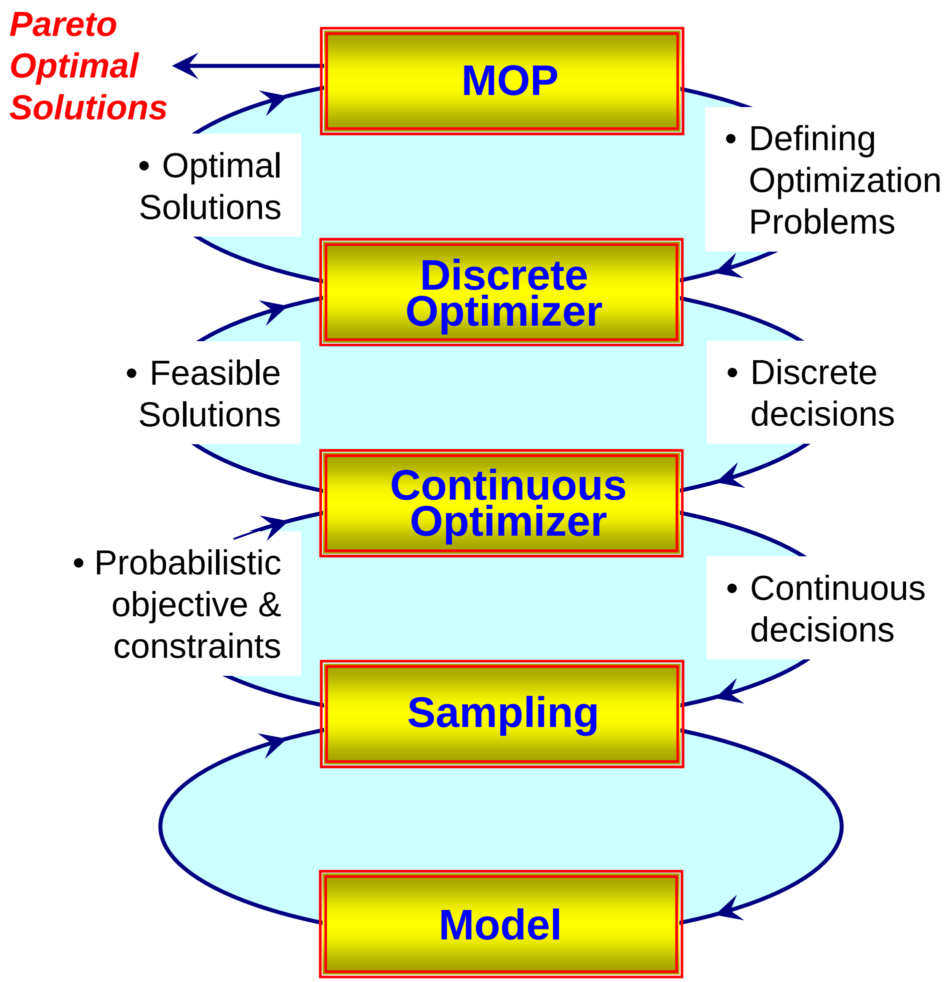
y represents binary variables, 0 or 1.

Uncertainties

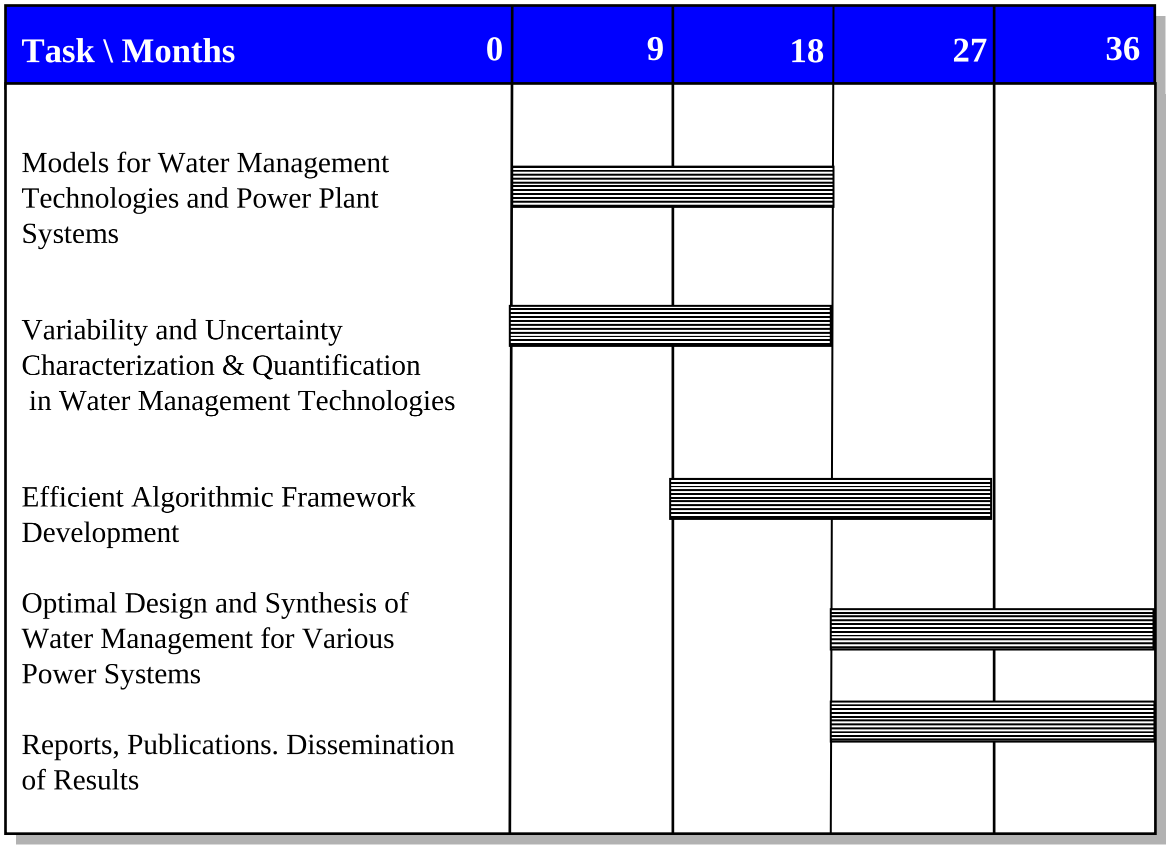
- Frequency distribution of average load for plants with an estimated peak capacity between 400 and 700 MW for four seasons: from top to bottom fall, winter, spring and summer



Multiobjective Optimization under Uncertainty



Scope of Work and Timetable



Conclusions

- **Heat exchanger network synthesis provides assessment of minimum heat and cooling utilities**
- **Mass exchanger network synthesis will reduce process water requirements**
- **Optimization of the process structures and process design will provide:**
  – cost effective and reduced water power plants in the face of uncertainties
  – trade-offs between cost and water requirements
  – optimal water networks

Evaluating Wetland Restorations for Power Plant Water Cooling

DE – NT0006644

"Wetland Water Cooling Partnership: The Use of Restored Wetlands to Enhance Thermoelectric Power Plant cooling and Mitigate the Demand of Surface Water Use"

Applied Ecological Services, Inc.

Sterling Energy Services, LLC

Steven I. Apfelbaum

Ken W. Duvall

J. Doug Eppich, Ph.D., PE

Phase 1. Evaluate Potential Value of Wetlands as a Cooling water Source for Power Producers

- **Develop empirical hydrologic, water quality and physical assessment tools to evaluate the potential for restored wetlands to be used for water cooling.**
  - Quantify potential benefits to water cooling, cooling efficiency, make-up water availability, operational costs.
  - Quantify potential benefits to reduce local potable water demands for cooling.
  - Evaluate regulatory links and conservation partnership values.
- **Use modeling to project the potential benefits of restoring "water cooling wetlands" for also reducing existing watershed and riverine impairments at watershed and subwatershed scales.**
  - Quantify potential restoration opportunities and outcomes for "scenario" projects.
  - Establish links between hydrologic parameters and measures of habitat, biodiversity, and ecological function
  - Develop monitoring plans that measure hydrologic and ecologic benefits of restoration projects – identify key parameters
- **Draft a set of evaluation tools and testable scenarios that can be applied to demonstration project(s) to measure the value of "water cooling wetlands" for the power production systems and to contribute to improved hydrology, water quality and ecosystem conditions and functions in the watersheds.**

Phase 2. Design, Implement Demonstration Project(s) to test Wetlands Water Cooling for Power Producers

- **Test and Affirm the empirical hydrologic, water quality and physical assessment tools to evaluate the potential for restored wetlands to be used for water cooling.**
  - Measure water cooling, cooling efficiency, make-up water availability, operational costs.
  - Measure reductions to local potable water demands for cooling.
  - Document real regulatory project links and permitting needs.
  - Establish conservation-power producer "conservation partnership" around wetland restoration investments for cooling waters.
- **Test and Affirm the potential benefits of restoring "water cooling wetlands" for also reducing existing watershed and riverine impairments at watershed and subwatershed scales.**
  - Establish Quantify potential restoration opportunities and outcomes for "scenario" projects.
  - Establish links between hydrologic parameters and measures of habitat, biodiversity, and ecological function
  - Develop monitoring plans that measure hydrologic and ecologic benefits of restoration projects – identify key parameters
- **Refine the evaluation tools and testable scenarios that can be applied to demonstration project(s) to measure the value of "water cooling wetlands" for the power production systems and to contribute to improved hydrology, water quality and ecosystem conditions and functions in the watersheds.**

Why Consider Restoring Wetlands For Water Cooling

Benefits:

- Habitat
- Water Quality
- Flood Damage Reduction
- GHG management
- Make up water capacity
- Biofuels for co-firing
- Evaluate Economics
- Avoid unit derating

Wide Applicability:

Many types of wetlands:

- Perennial - Seasonal
- Riverine- Depressional- Seeps

Many water sources

- Freshwater-Brackish-Estuarine
- Sewage water re-use
- Mine/quarry sourced

Why Consider Restoring Wetlands For Water Cooling

- Use the same water for multiple outcomes
- Link power generation Investments with Conservation Investments on the land.
- Reduce PR, Financial and regulatory impediments to new power projects and existing operations.

% Reduction in Wetlands Correlates with Impairment to US Waterways

- Imperviousness
- Dam Storage
- Canals/Ditches
- Minor Road Intersect
- Major Road Intersect
- Potential Restorable Wetlands
- 8-digit HUC watersheds

Role of Wetlands on the Landscape

Historic Functions:

- Flood water retention and management
- Ground water infiltration
- Micro-site climate cooling
- Habitat values and benefits
- Modulation seasonal in-stream flows.
- Soil carbon sequestration and biomass production

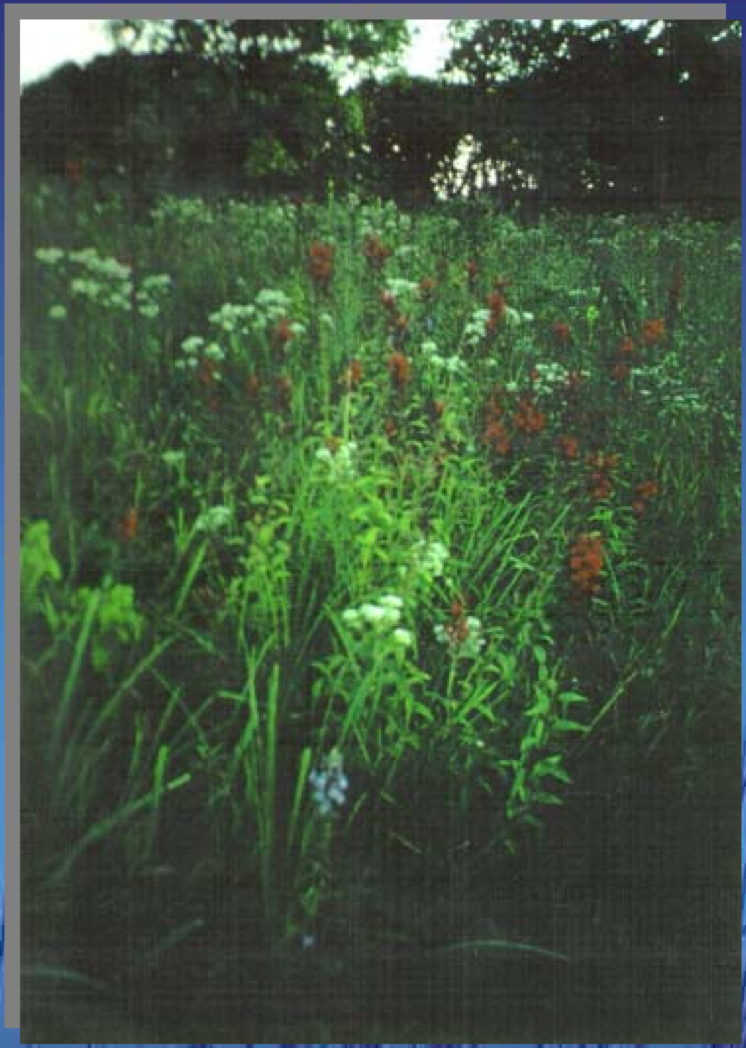
NOW

- Nationally→80 % reduction in wetland acres due to agriculture and land development
- Reduced flooding and improved in-stream flows and water quality in watersheds with > wetland acreages.
- Higher biodiversity in watersheds often with highest % wetlands remaining.

Increased Flood Risk

Impaired Ecology and Water Quality

Degradation of Remaining Wetlands

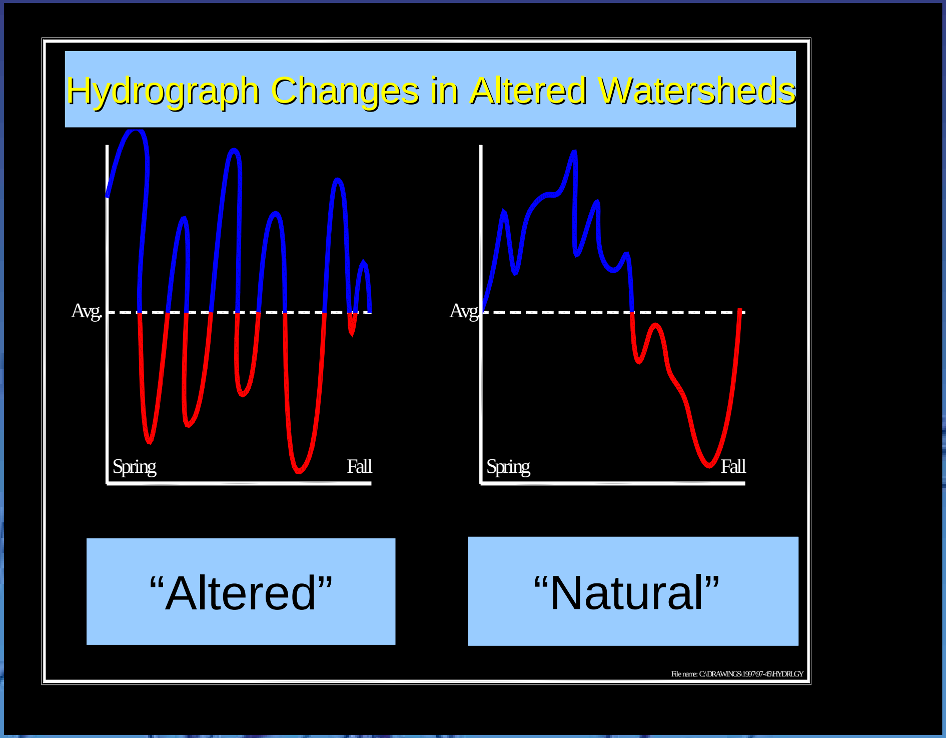


Ecotoxicological Impacts in the Ecosystem

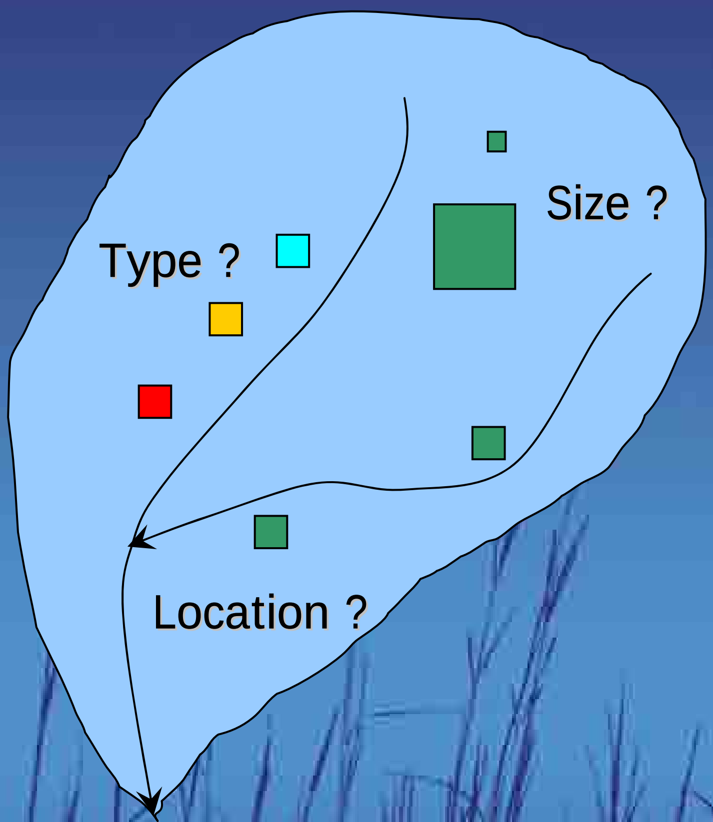
Restoring historic wetlands for water cooling

Restore:

- Altered in-stream/lake/estuarine hydrology regimes
  - Frequency
  - Magnitude
  - Timing
  - Duration
  - Rate of Change
  - Base-flows
  - Thermal regimes
  - Water quality
- Ecological Conditions, habitats



Wetlands for Water Cooling



- How much water is retained and stored by restored wetlands?
- What are important factors that control wetland water cooling?
- Assess different water cooling scenarios based on:
  - Wetland type
  - Wetland size
  - Location
  - Thermal relations
  - Seasonality
  - Wetland design
  - Regulatory drivers
  - Conservation partner drivers

STELLA

Model Tool for Assessing Wetland Function and Performance

Analysis Tasks

Evaluate:

- Water Availability from Sources
- Water Availability vs. Water Usage and Heat Transfer for a Sustained Time Period
- Wetland water quality treatment functions.

Model Requirements

- easy to use and change
- accurate
- able to apply input data
- able to output results in usable format

STELLA Assets

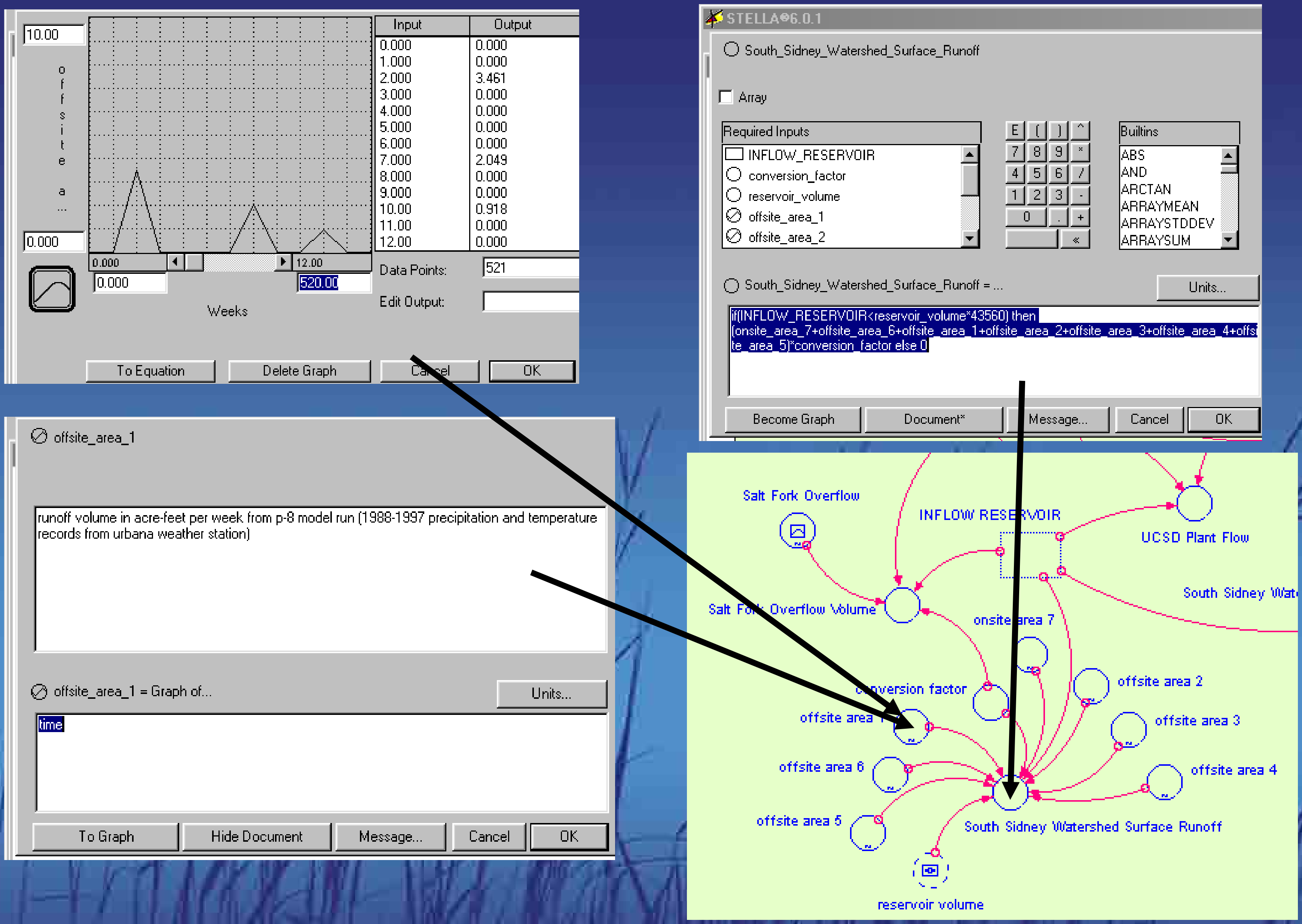
- model platform accepts data for continuous time periods and simulates user specified processes with user specified inputs

- includes run-time version so model users can perform additional analysis and change the input parameters

STELLA

Application Examples

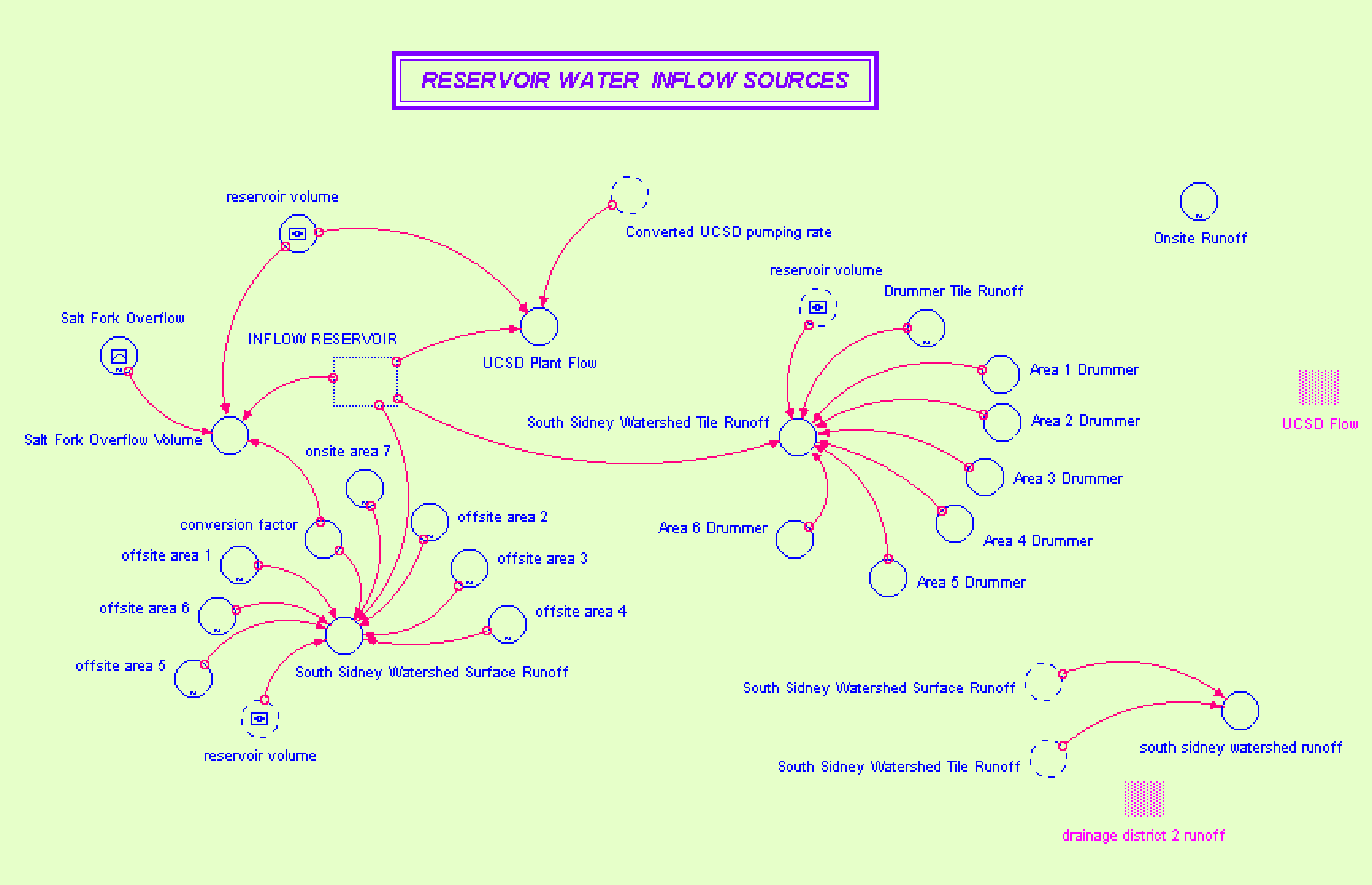
Defining Source Water Inflows



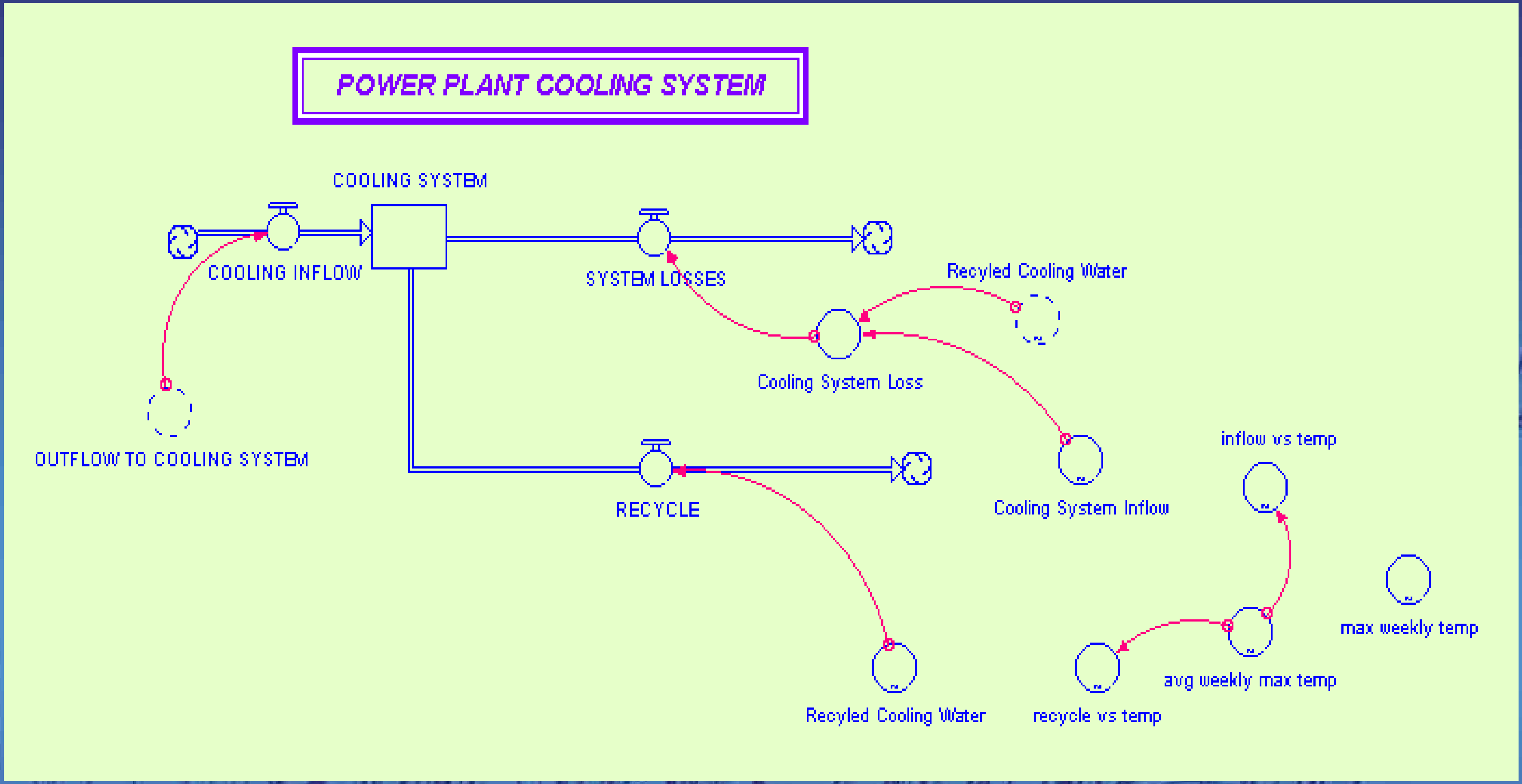
Anticipated Water Sources

- Surface Waters
  - tiled discharge
  - overland runoff
- Sanitary Treatment Plant Discharges
  - piped from treatment plant
  - taken from receiving water body
- Stream Flood Overflows
- Recycled Plant Cooling Water

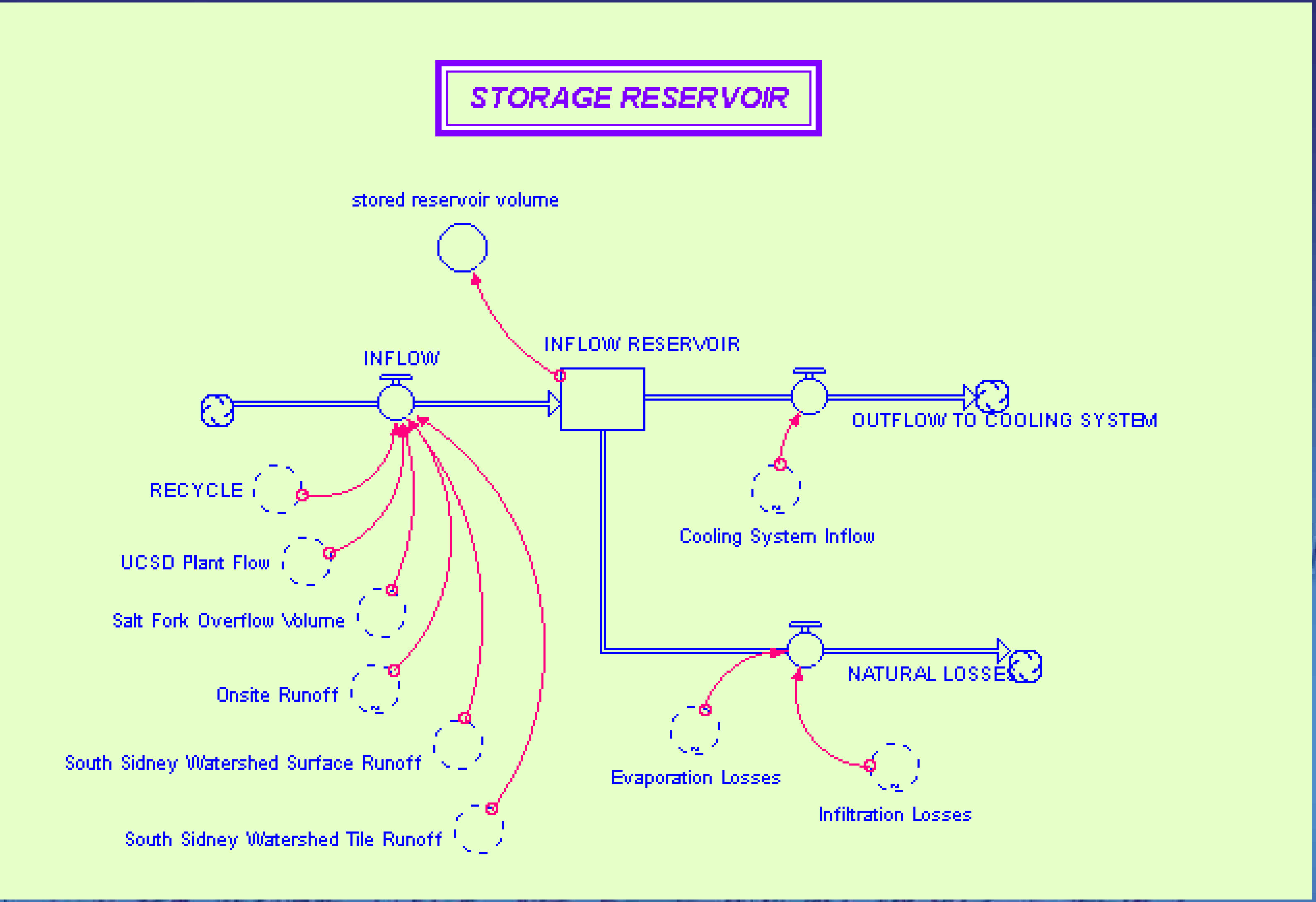
Combining Wetland Water Sources



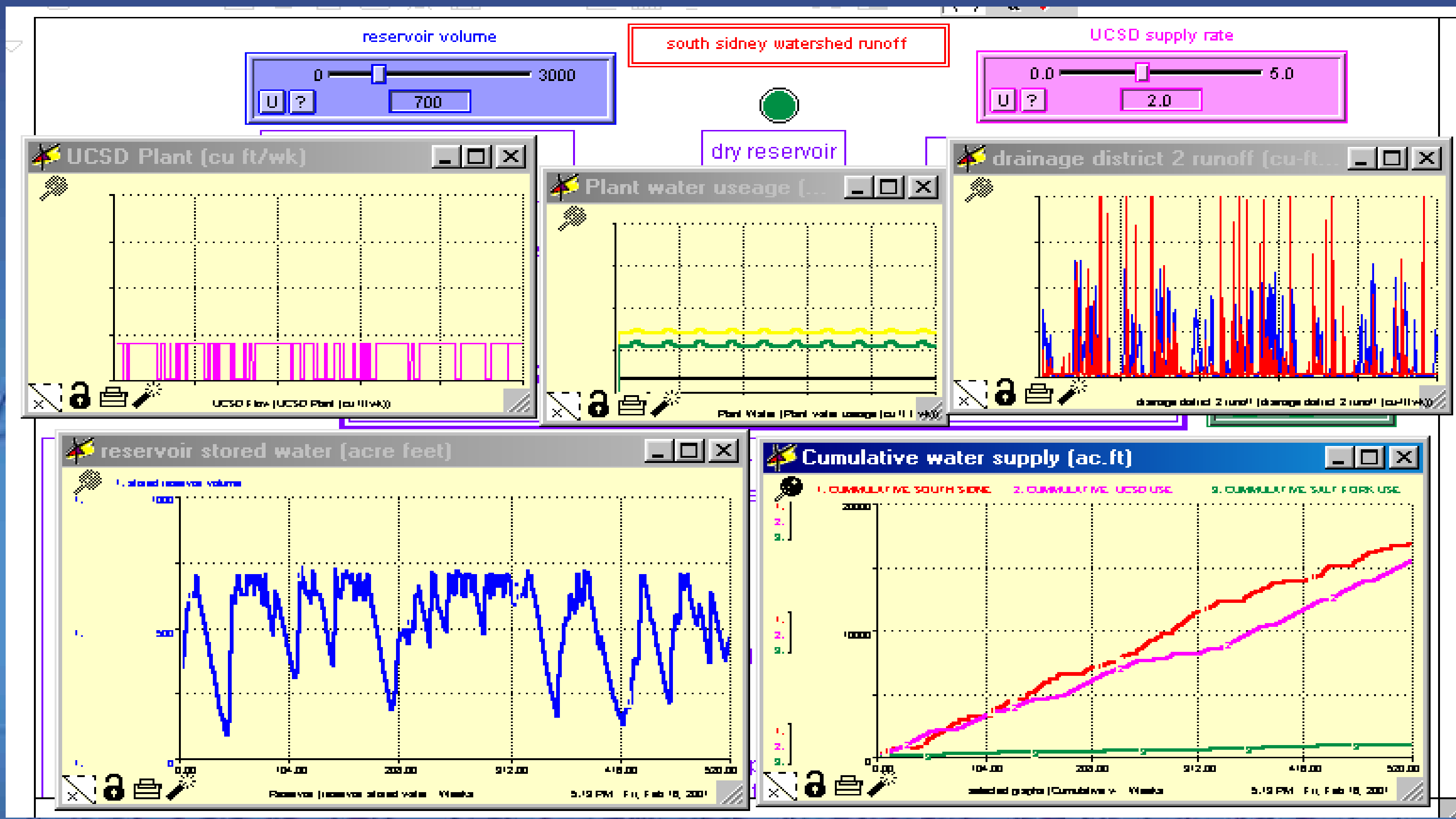
Quantifying Power Plant Water Usage



Defining Wetland Variables



Balancing Wetland Requirements to Water Supply and Usage



Example Wetland Restoration Projects

Otter Creek Wetland Park

St. Charles, Illinois

56-acre restoration

Otter Creek Wetland Bank –
First Private U.S. Wetland Bank – Goals:

1. Restore 56 acres of tile and ditch drained historic wetlands, and degraded agricultural lands.

2. Restore these lands to native grasslands, various wetlands, riparian forest.

3. Generate and sell 47 acres of wetland mitigation credit.

4. Generate wetland credit revenue to finance restoration, expansion and protection of a greenway for St Charles, Illinois and investments in a community park now serving 85,000 school children every year as an outdoor laboratory.

5. Use wetland credit revenue to do other wetland banks. We have over 33 banks that were successfully started or are underway currently using the model from Otter Creek.

6. Establish Otter Creek Bank as a National model for establishing US banking policy.

Otter Creek Wetland Park

St. Charles, Illinois

56-acre restoration

Economics

Costs

Land …………………………………......$60,000

Design/Engineering ………………….... $50,000

Construction, Management …………….$790,000

Credit Sales

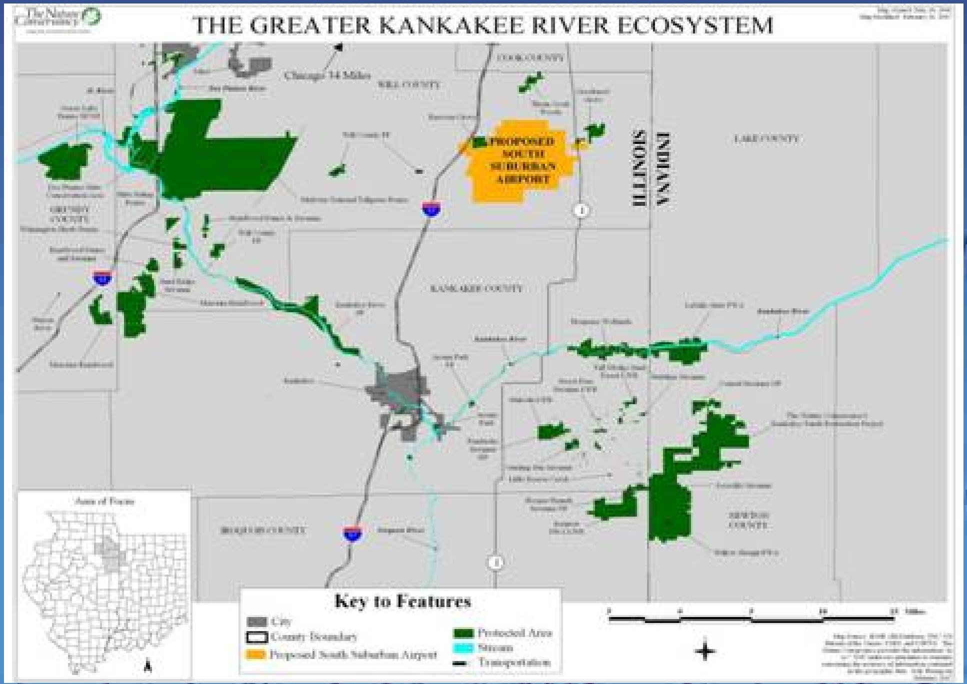
47 credits at $45,000 per acre …………..$2.1 Million

Net Economics ……………………….. $1.2 Million in 6 years

Kankakee Sands

Enos, Indiana

7,300 acre restoration



Kankakee Sands Goals

Enos, Indiana

7,300 acre restoration

1. Restore 7300 acres of agricultural land to 5200 acre of wetland, 2000 acres of prairie and 100 acres of savanna.

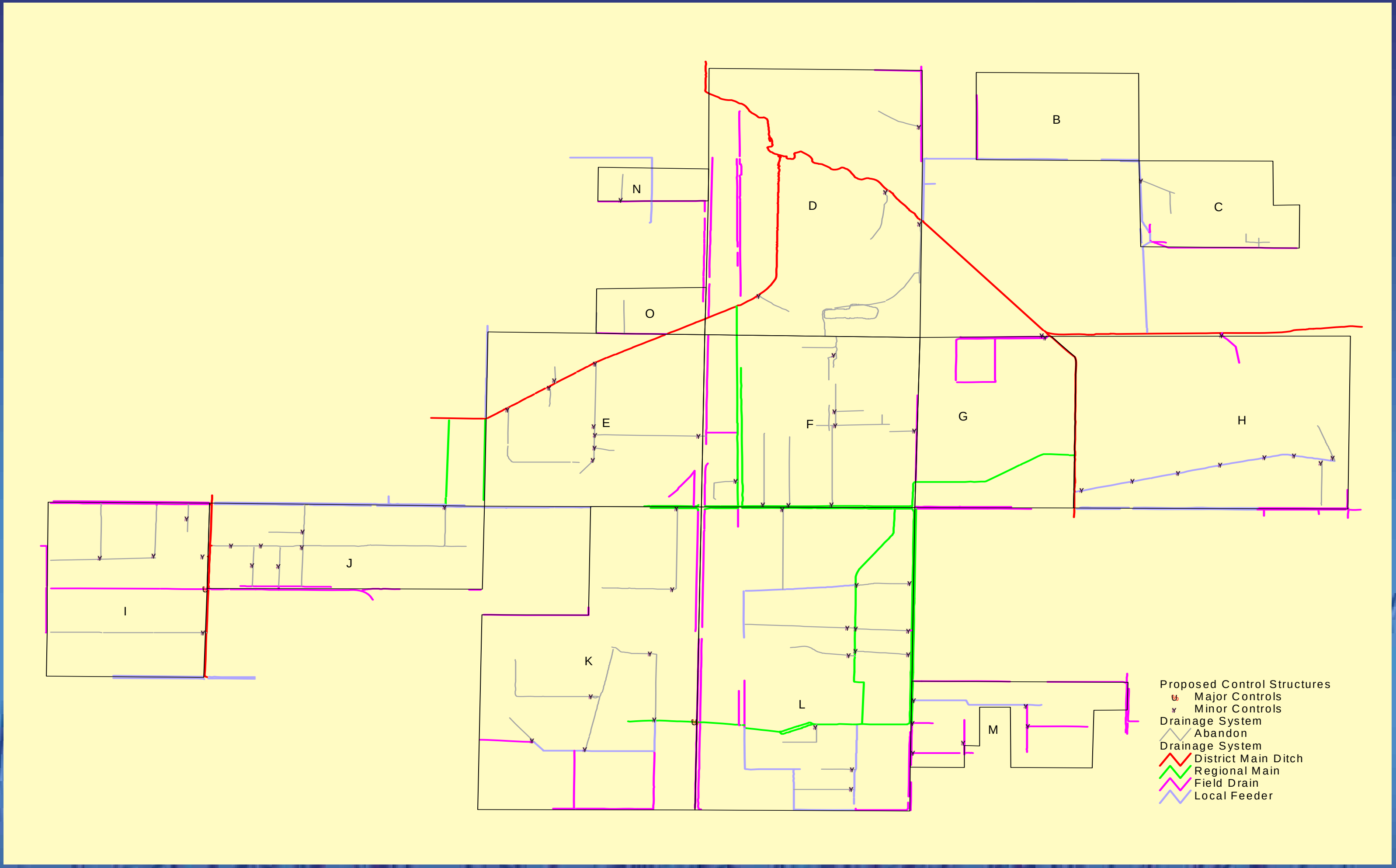
2. Restore soil carbon from current depleted levels to an equilibrium over a period of 30 years to achieve 5 million tons of total C02 accrual.

4 Generate revenue to finance restoration, expansion-protection and restoration of other conservation lands and outreach, education and community investments.

5. Demonstrate multiple revenue sources from marketing environmental services.

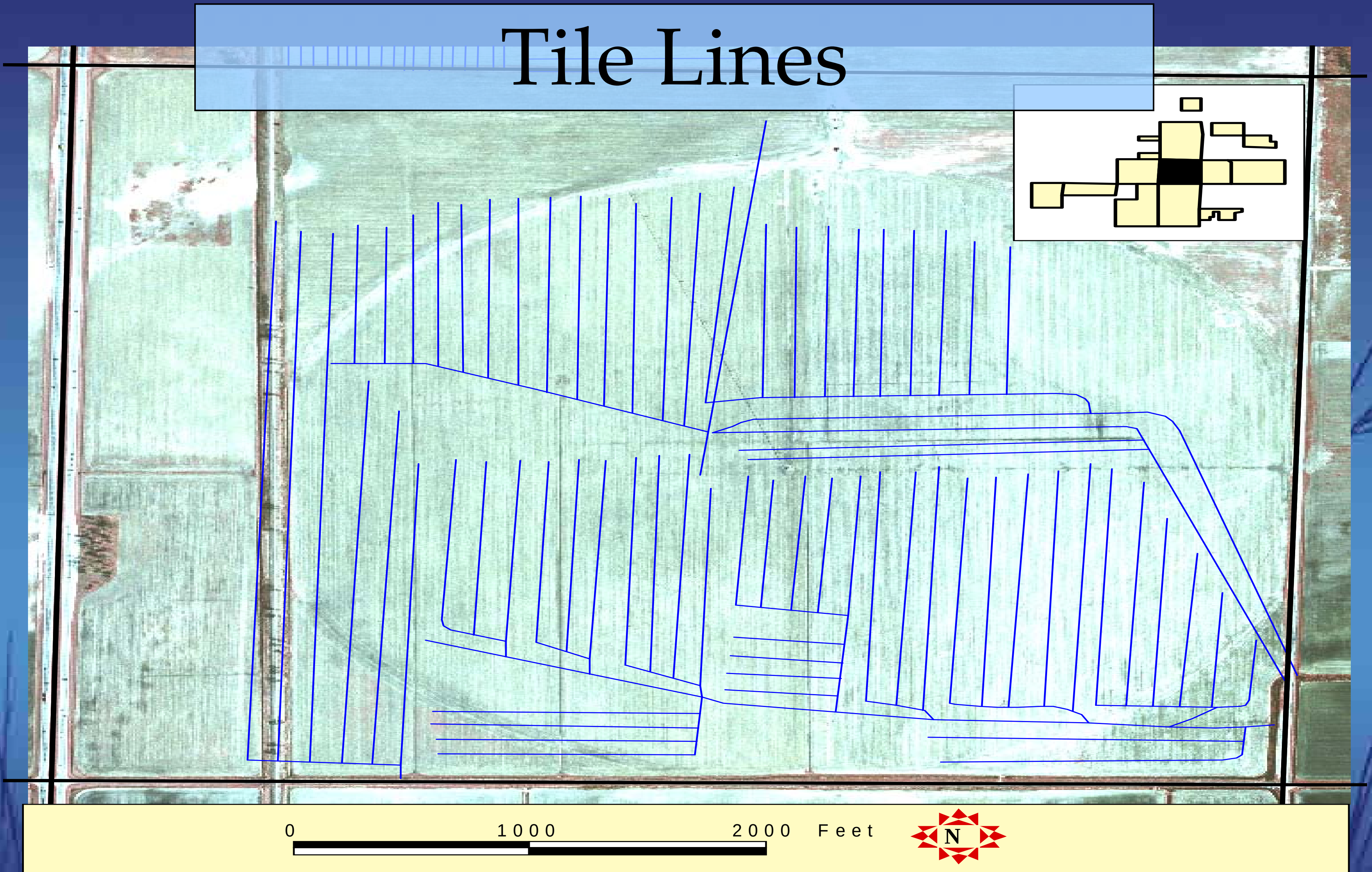
Kankakee Sands

Ditch Hierarchy and Restoration



Fair Oaks Farm

1997 Digital Aerial Photography & Drain Tiles

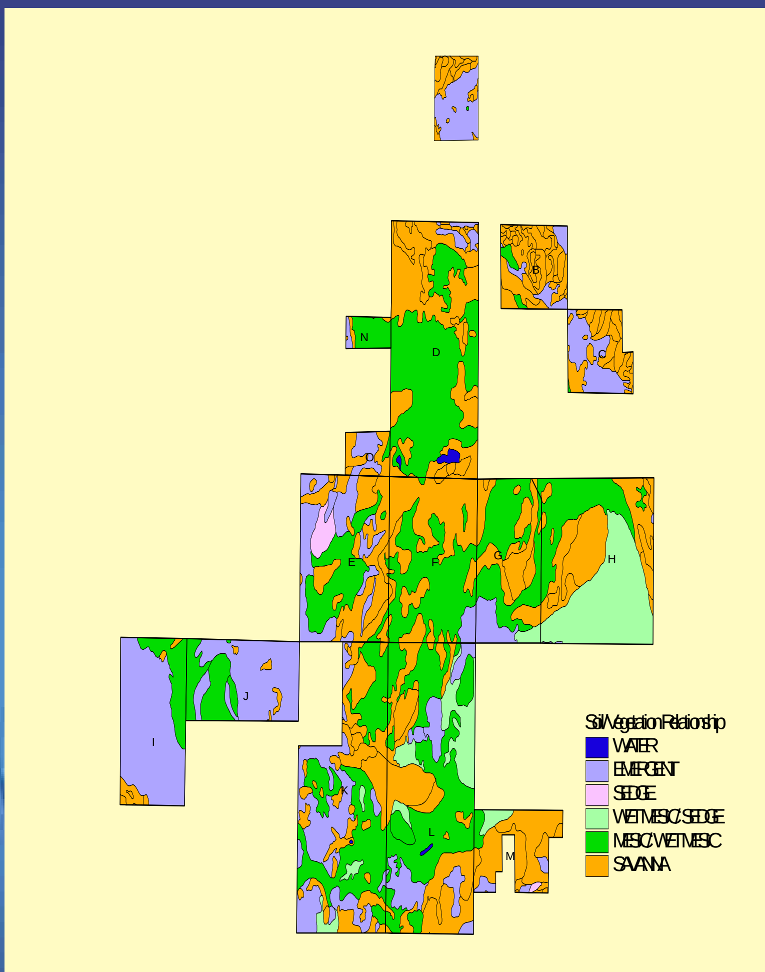


Kankakee Sands

Enos, Indiana

7,300-acre restoration

The Nature Conservancy®



Applied Ecological Services, Inc.™

Sterling Energy Services, LLC

the Energy to Lead

Transport Membrane Condenser for Water and Energy Recovery from Power Plant Flue Gas

NETL project kickoff meeting
Project #: DE-NT0005350

Dexin Wang
Gas Technology Institute
October 28, 2008

Gas Technology Institute

> Main Facility:

18-Acre Campus
Near Chicago

- Over 200,000 ft^2 of laboratory space
- 28 specialized laboratories and facilities

> Staff of 250

- 70% are scientists and engineers
- 45% with advanced degrees

> Over 1,000 patents
> Nearly 500 products commercialized

Addressing Key Issues for the Natural Gas Industry

- Contract Research
- Program Management
- Technical Services
- Education and Training

Energy & Environmental Technology Center

gti

the Energy to Lead

Background for Transport Membrane Condenser (TMC) Technology

High Efficiency Goal for Super Boiler

- Objectives of Super Boiler program:
  94% thermal efficiency
- Current gas- fired boiler efficiency status:
  75-85% thermal efficiency, 68% of stack heat loss is latent heat
- TMC, a device for recovering latent heat of water vapor from flue gas, is the key component for the Super Boiler to achieve its efficiency goal. Two patents were awarded to GTI on TMC-based heat recovery.

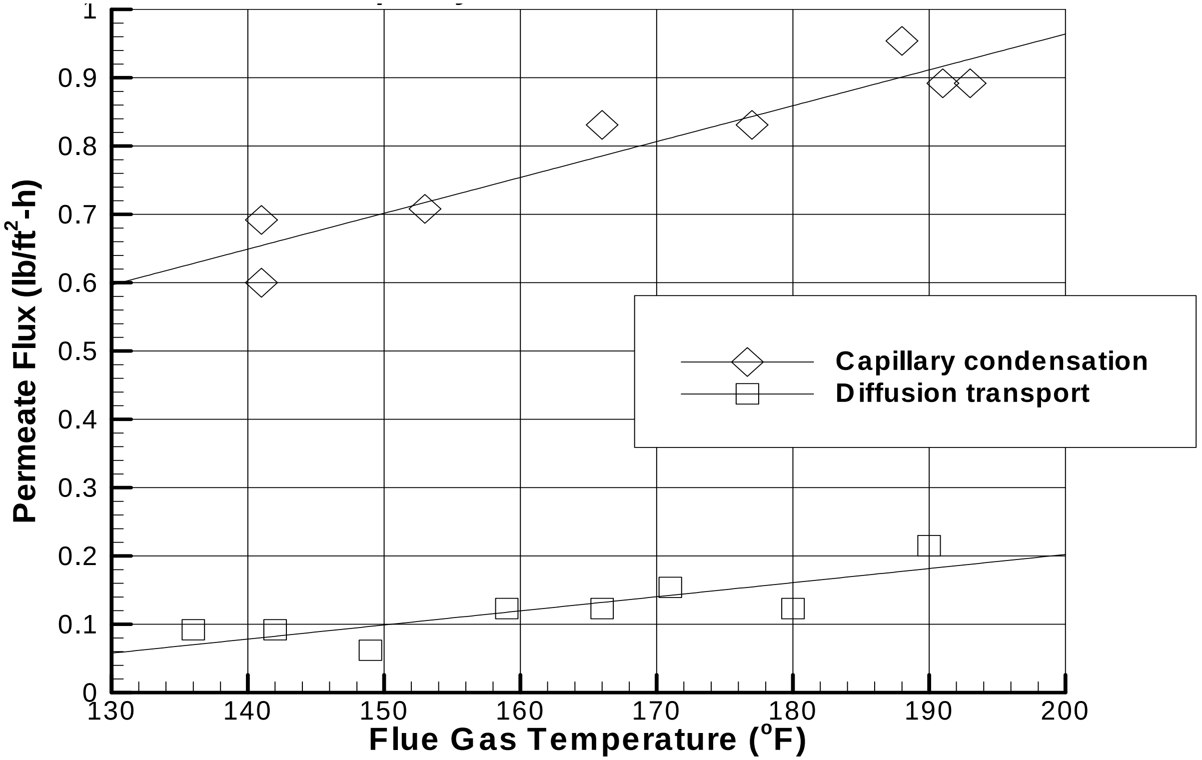
gti

Water Vapor Membrane Separation Study at GTI

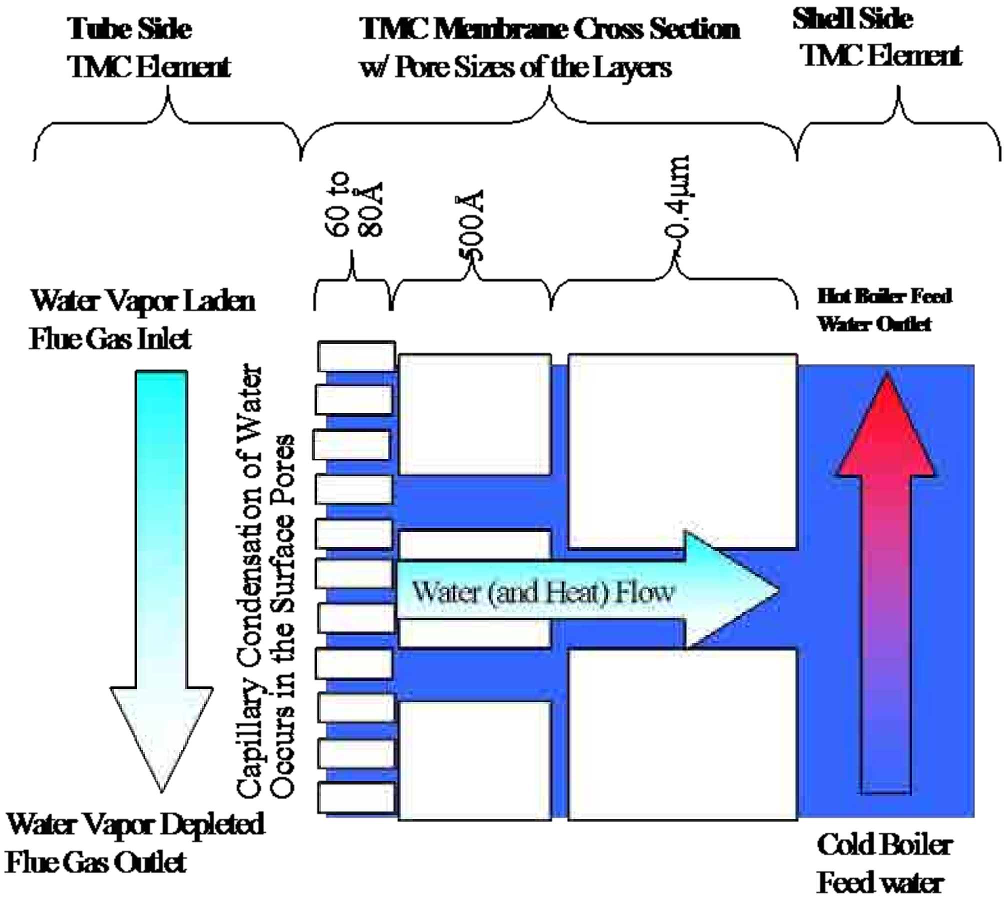
1. Porous and non-porous membranes
2. Porous Membrane Vapor Separation Modes:
   - Molecular Sieving
   - Knudsen diffusion
   - Surface diffusion, and
   - Capillary condensation
3. Working mode of porous membrane is critical for water vapor transportation.

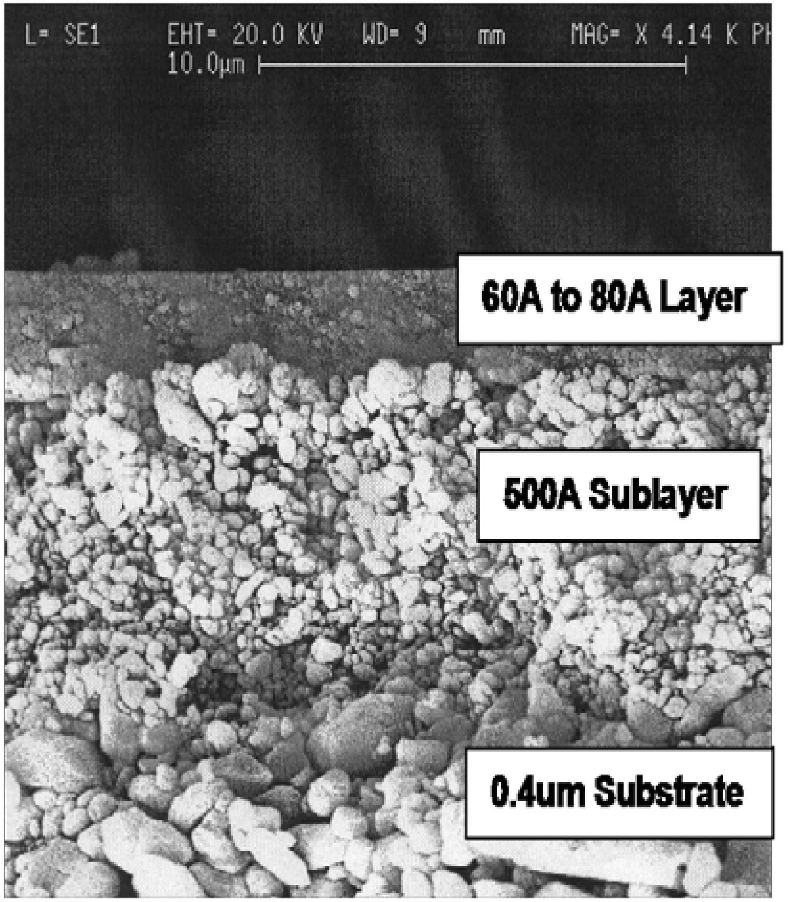
   High permeate flux and high separation ratio could only be achieved in a capillary condensation mode.

Capillary Condensation for Water Vapor Separation Study at GTI

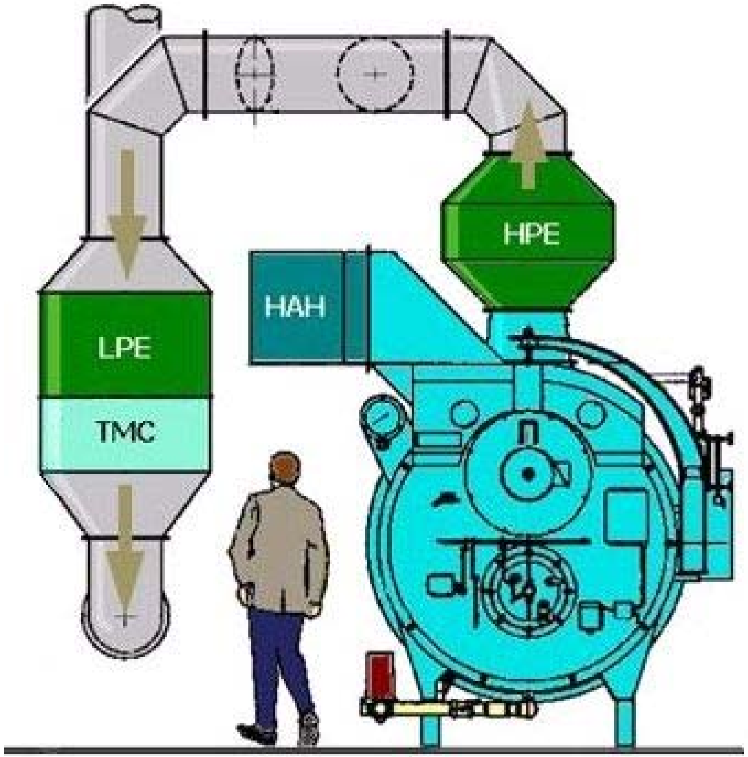


TMC Concept and Nanoporous Ceramic Membrane

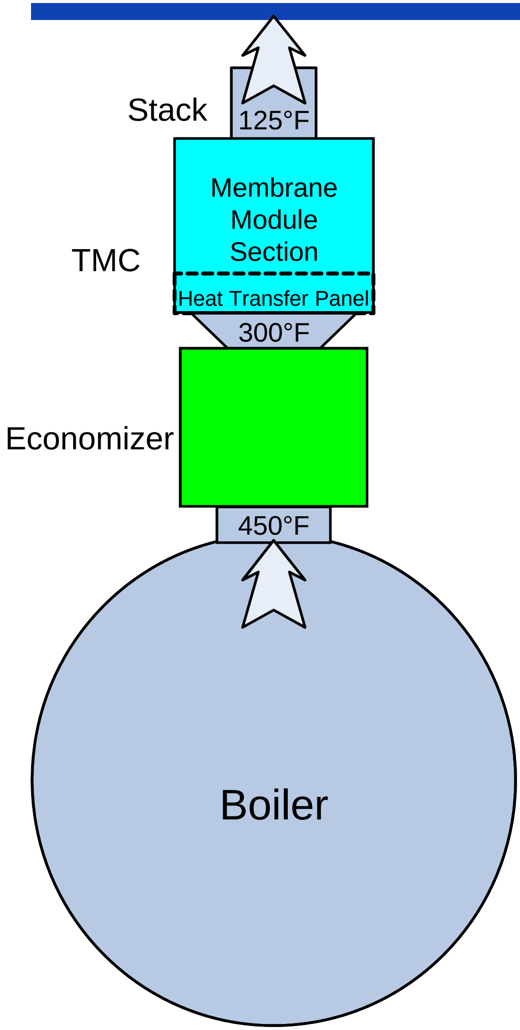




First Generation TMC Heat Recovery Field Demonstration for a 300HP Boiler (12MMBtu/hr)



Second Generation TMC Heat Recovery In Testing for a 200HP Boiler (8MMBtu/hr)



the Energy to Lead

Transport Membrane Condenser for Water and Energy Recovery from Power Plant Flue Gas

gti

TMC Potential Application for Water Vapor Recovery from Coal Flue gases

Advantages:

1. Higher moisture content in coal flue gas:
   - With Wet FGD, flue dew point 160 to 180 F
   - With Dry FGD, flue dew point 130 to 140 F
   - Compared with natural gas boiler flue gas: 130 to 136 F

2. More favorable cooling conditions for TMC:
   - Steam condensate can be one cooling water source, typically at 90 to 115 F.
   - Cooling water flow rate is typically at 25 times of the boiler feed water flow rate, from 50 to 100 F.
   - Compare with industrial boiler which has only 10 to 50% of feed water flow rate.

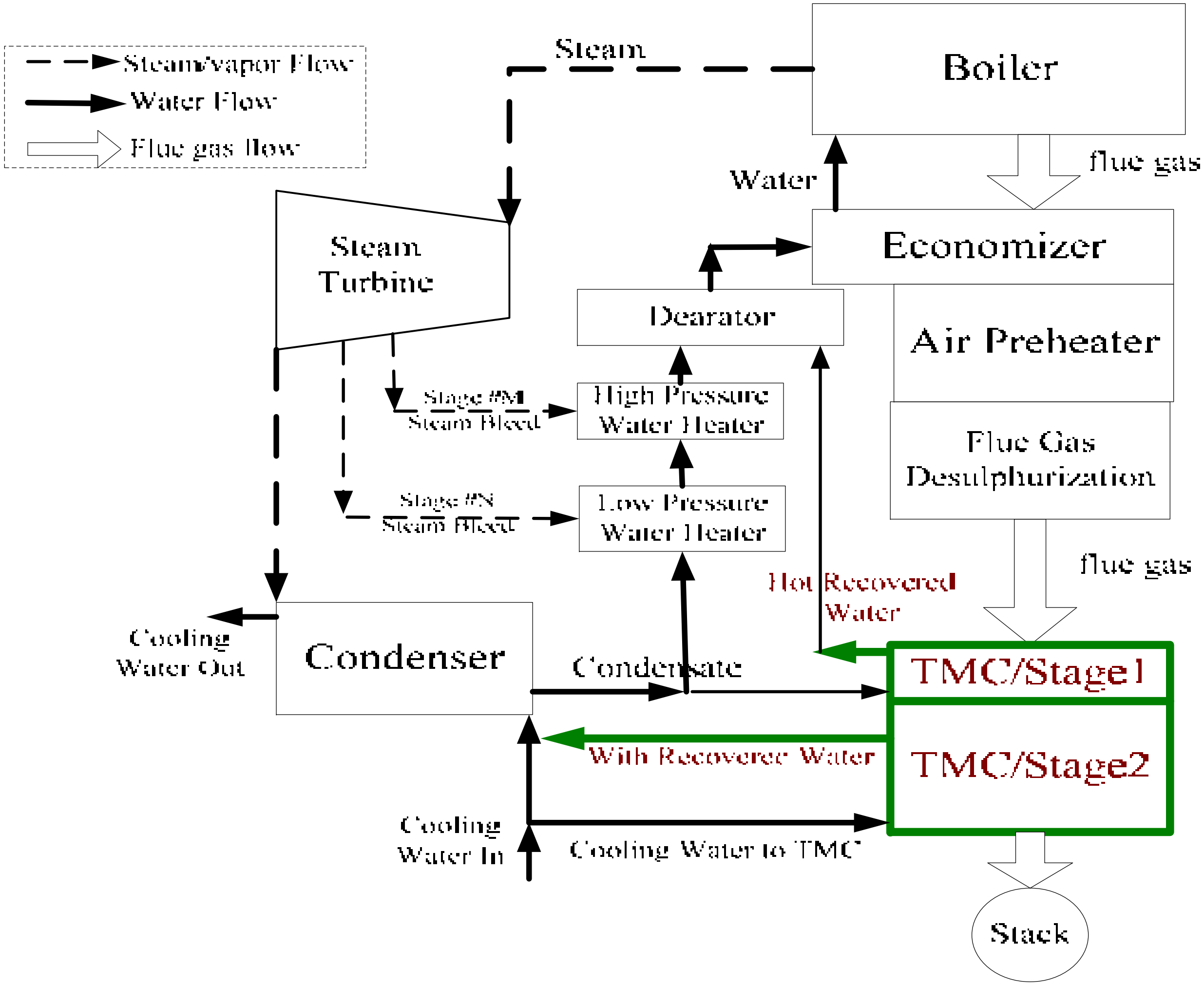
TMC Potential Application for Water Vapor Recovery from Coal Flue gases

Disadvantages:

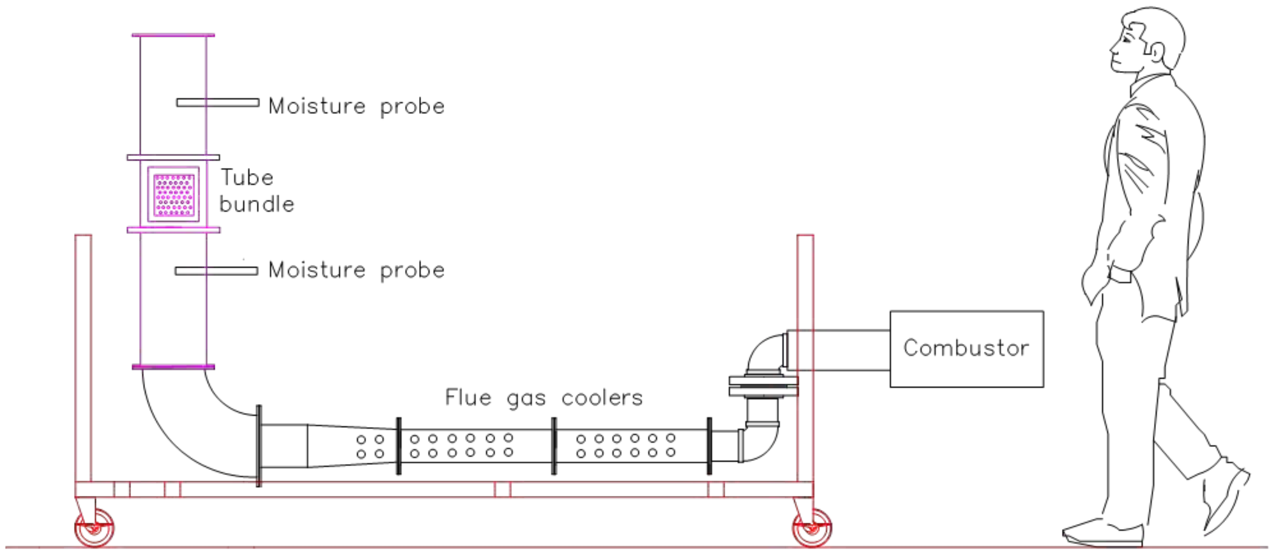
More complicated components in coal flue gas:

- SO_2, heavy metals, particulate matter, etc.
- Compare with relatively “clean” natural gas-based flue gas

Power Plant Flue Gas Water Recovery with a Two-Stage TMC



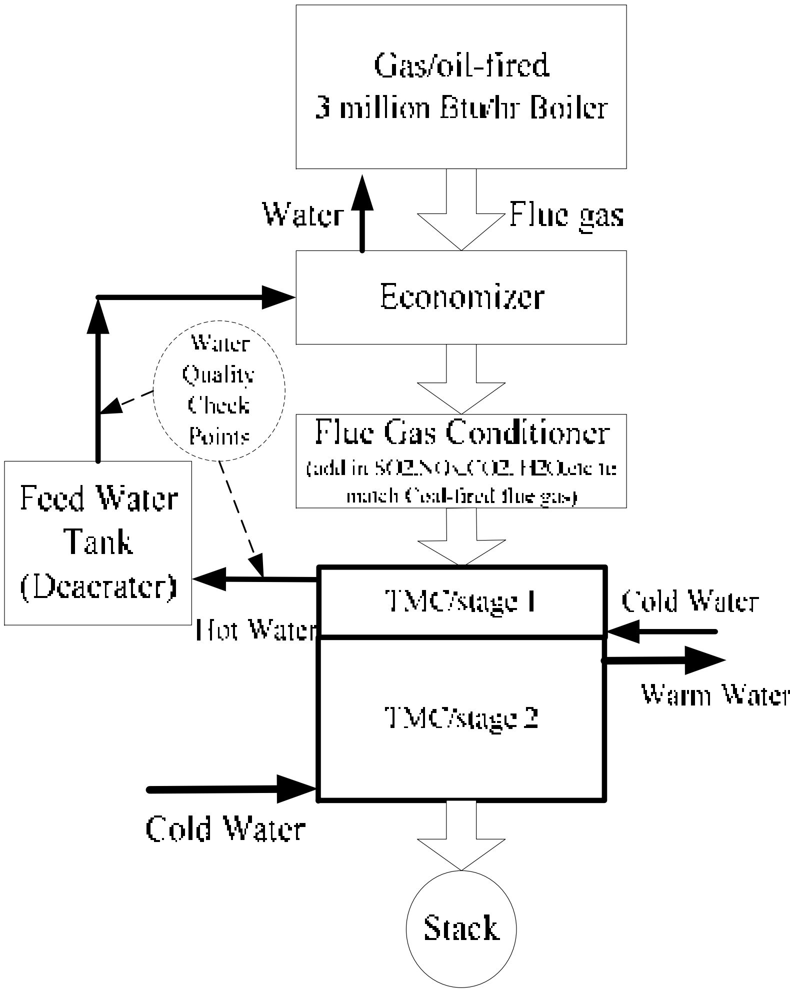
Lab test setup for membrane module performance tests

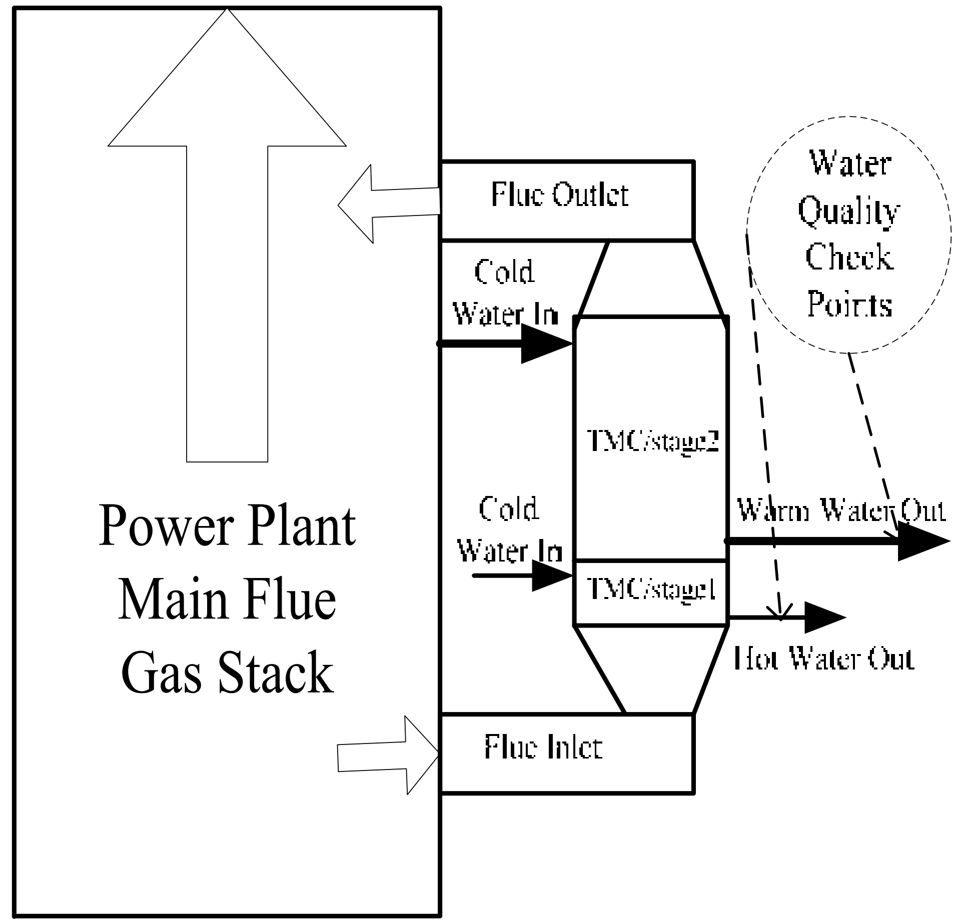


Membrane water/heat transfer study:

- Select the optimized membranes for the two stages
- Membrane contamination condition study

Pilot-Scale TMC Test Setups at GTI (left) and at a Power Plant (right)





Scale-up and Technology Transfer Study

1. Scale-up Design Investigation:
   - Based on the pilot-scale test data, develop a preliminary design for an appropriate size power generation unit to employ this technology, and integrate the recovered water to the boiler water management system.
2. Technology Transfer and Commercialization Plan.
   - Identify potential manufacturers and customers for field demonstration, and develop a manufacturing plan to meet the needs of utility customers.

Questions?

This research was made possible with support, in part, by the Illinois Department of Commerce and Economic Opportunity through the Office of Coal Development and the Illinois Clean Coal Institute.

EERC Technology… Putting Research into Practice

Water and Energy Sustainability and Technology (WEST)

NETL – EXISTING PLANTS WATER PROJECTS MEETING

October 27 and 28, 2008

Dan Stepan
Bruce Folkedahl
Energy & Environmental Research Center
University of North Dakota

Carbon Dioxide Capture, Transportation, and Sequestration Process

Capture → Compression → Pipeline Transport → Underground Injection

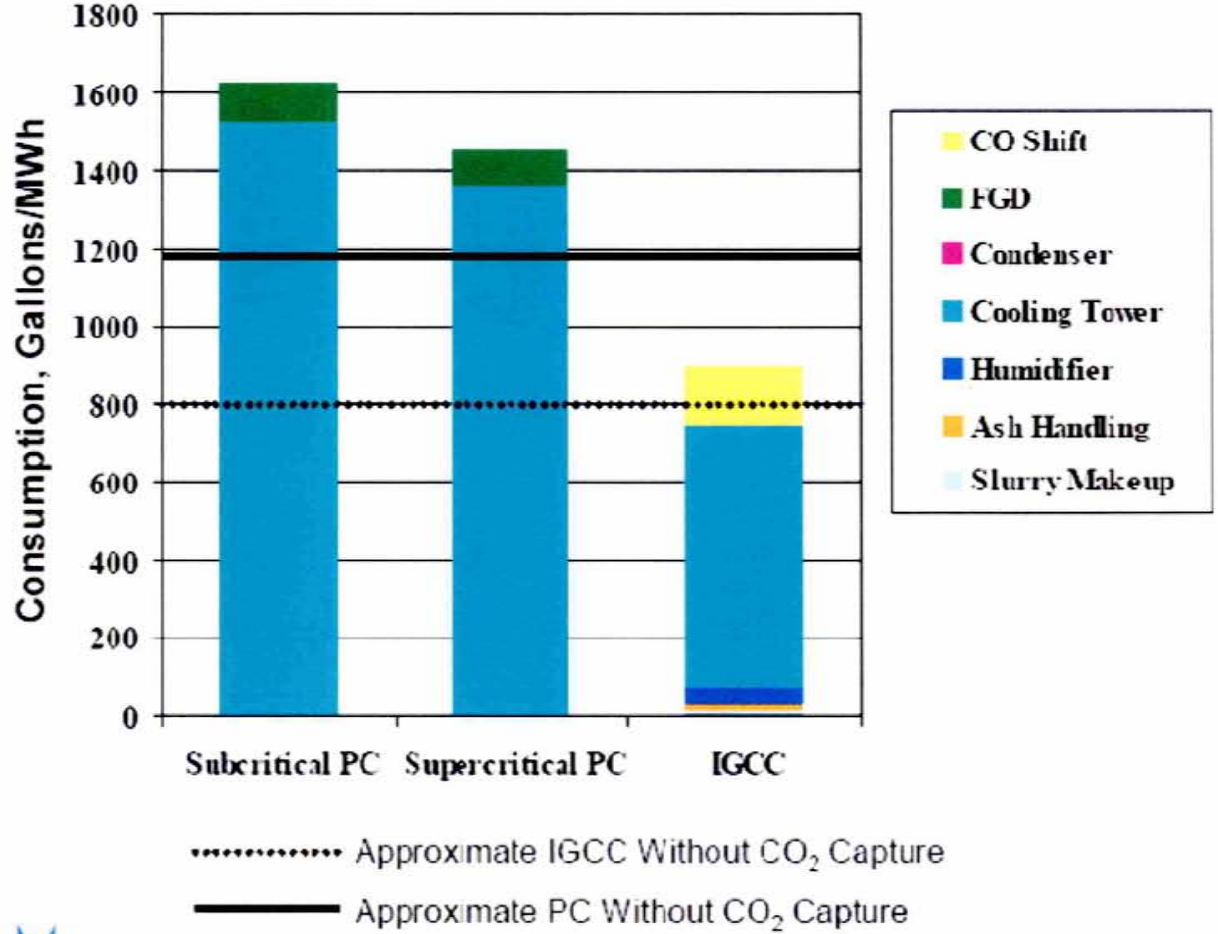
Impacts of Operation on Water:

Capture & Compression: Increased power consumption for capture and compression directly reduces the facility power output -- results in increased water consumption above that for a similar facility without capture

Pipeline Transport: Pumping power required to boost carbon dioxide pressure during pipeline transport to maintain supercritical conditions further diminishes power generation facility output -- results in increased water consumption

Underground Injection: Additional power may be required for injection operations -- indirectly increases water consumption; water may be produced by sequestration operations which displace reservoir fluids

CO_2 Capture & Compression Impact on Water Usage at PC & IGCC Power Generation Facilities



Water Consumption (gallons/kWh)

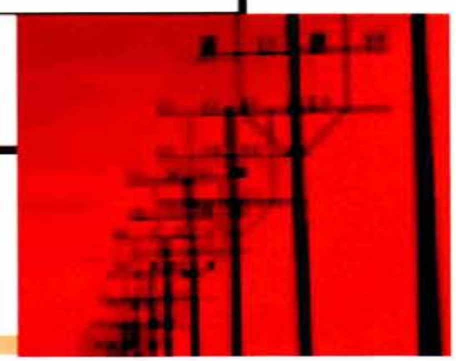
Subcritical PC	1.6
Supercritical PC	1.4
IGCC	0.9

NETL

Source: DOE/NETL Calculations

Summary

Operation	Water Consumption/Production (gallons/kWh)
Electricity Production, CO_2 Capture and Compression:	
Subcritical PC	1.6
Supercritical PC	1.4
IGCC	0.9
Transport	0.01
Enhanced Oil Recovery (EOR)*	0 – 1+
Coal Bed Methane (CBM) Recovery*	0.01 – 1+
Salt-water Formations*	0 – 0.5
Depleted Oil and Gas Reservoirs*	0 – 0.5



* Potential water consumption during sequestration under certain conditions

NETL

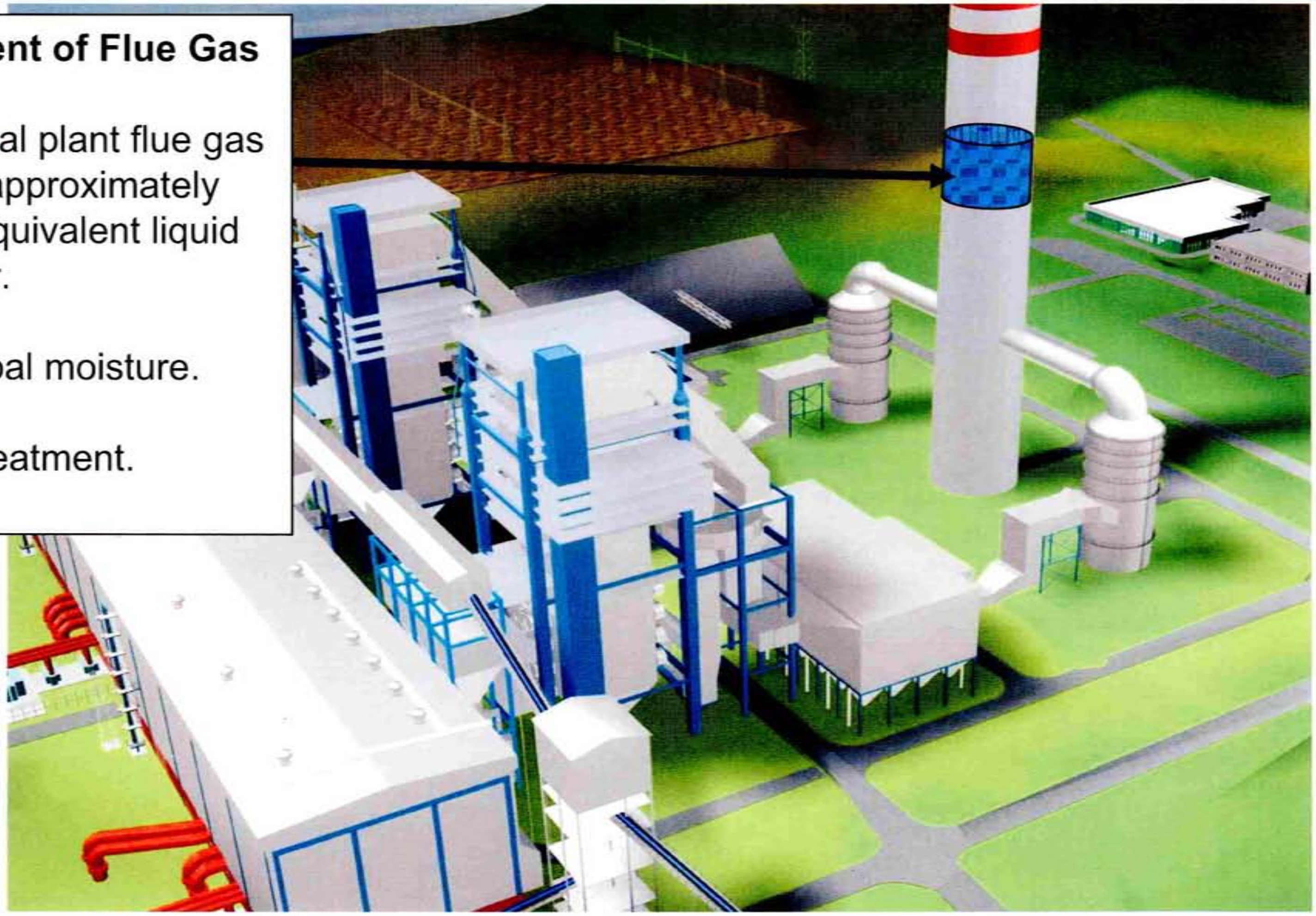
Potential Water Available (coal)

Water Content of Flue Gas

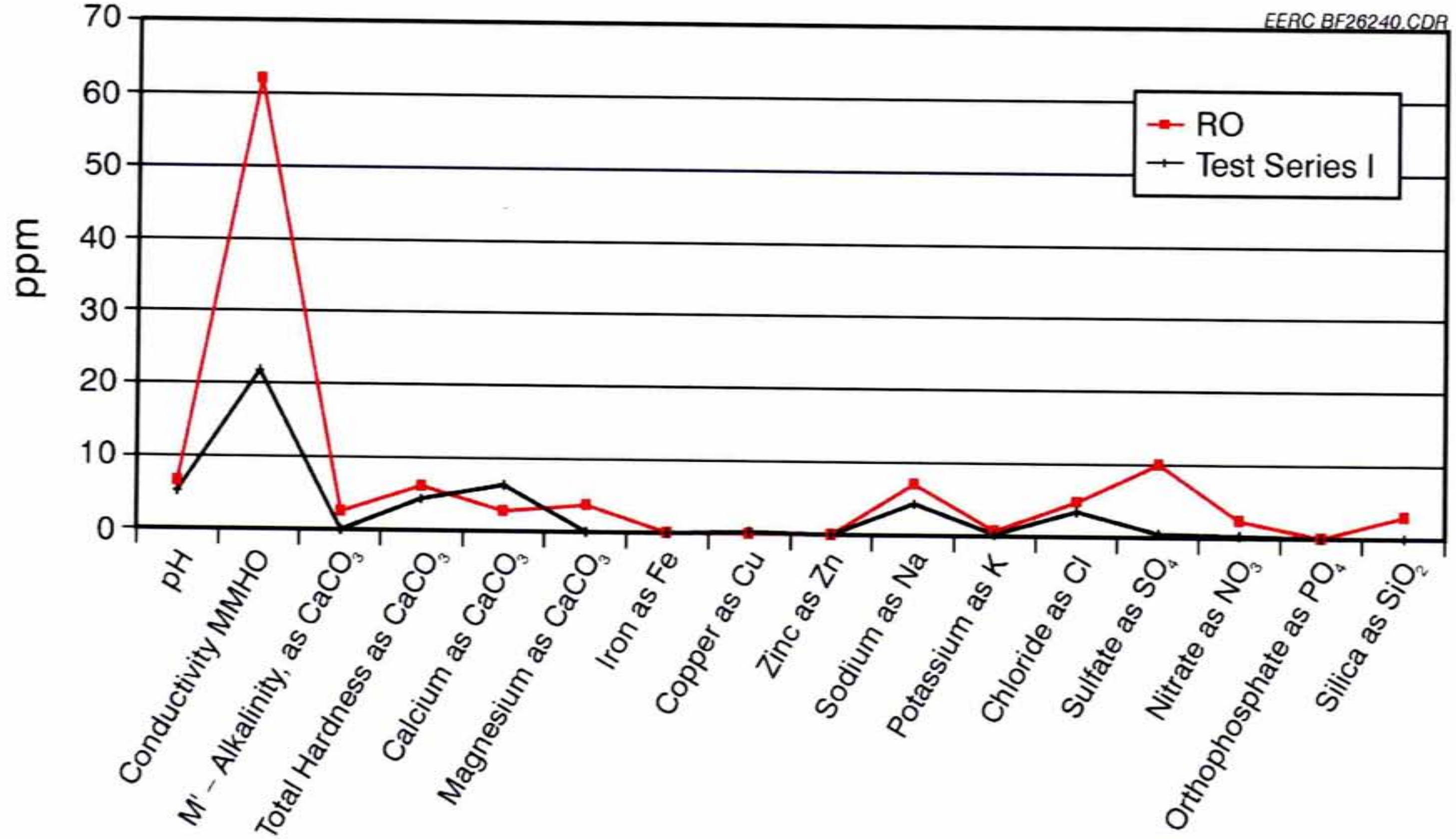
A 700-MW coal plant flue gas may contain approximately 1000–2400 equivalent liquid GPM of water.

Varies with coal moisture.

Varies with treatment.



Water Quality of Liquid Desiccant Dehumification System (LDDS)



EERC
Energy & Environmental Research Center

Current Study

- In previous work, the cost of heating and cooling desiccant solution was the largest operational cost. This study will investigate the use of a condensing heat exchanger to provide the heat loads required to run the LDDS at high-performance levels and the effect of the LDDS on water consumption in a CO_2 capture and sequestration train.

EERC
Energy & Environmental Research Center

Statement of Work

- Design and construction of pilot-scale system for postcombustion testing of water removal and capture technologies in conjunction with the EERC-led Partnership for CO_2 Capture (PCO_2C) Program.
- Conduct initial shakedown and testing of selected water separation technologies.
- Perform systems engineering analysis of selected systems for incorporation into existing facilities as well as future energy systems.

EERC
Energy & Environmental Research Center

Project Structure

- Activity 1 – System Design and Modeling
- Activity 2 – Materials Fabrication and Procurement
- Activity 3 – Test Equipment Installation
- Activity 4 – Test Plan Development
- Activity 5 – Testing
- Activity 6 – Project Management and Reporting

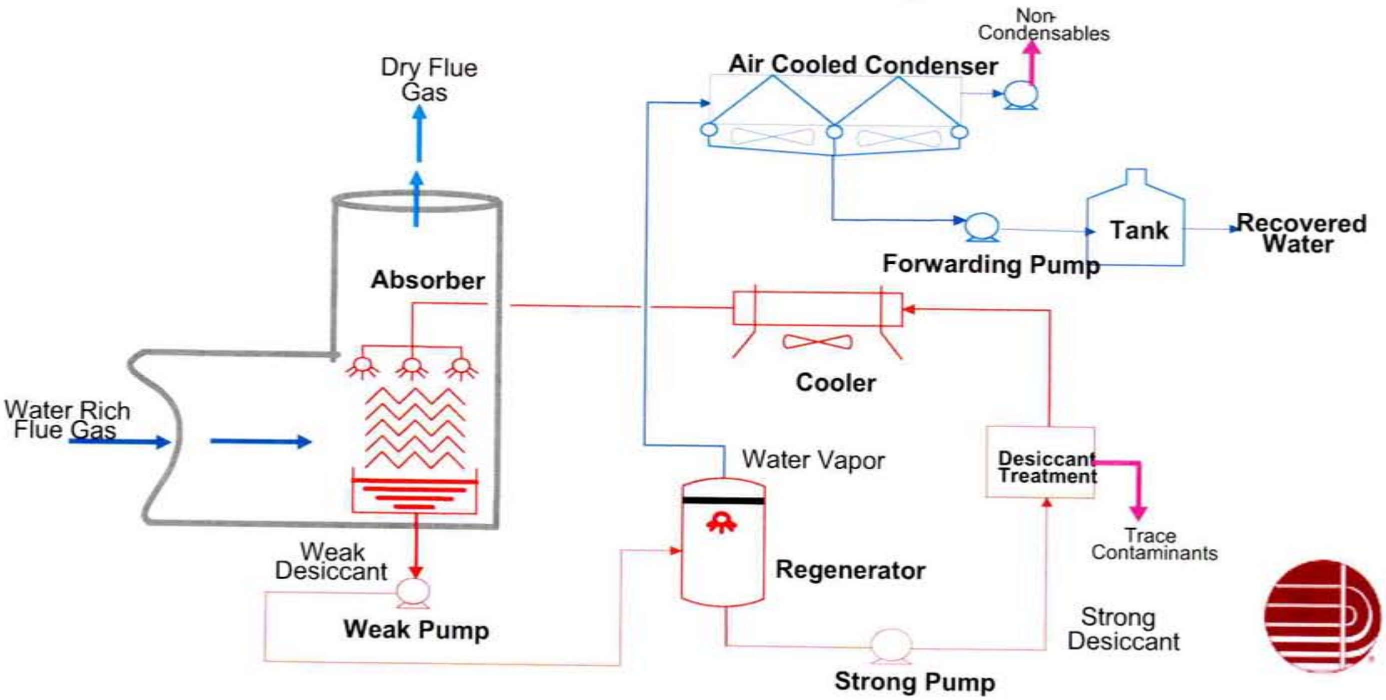
EERC
Energy & Environmental Research Center

Activity 1 – System Design and Modeling

Aspen Plus®, CHEMKIN™, and FactSage™

P&ID, Preliminary Material and Energy Balances

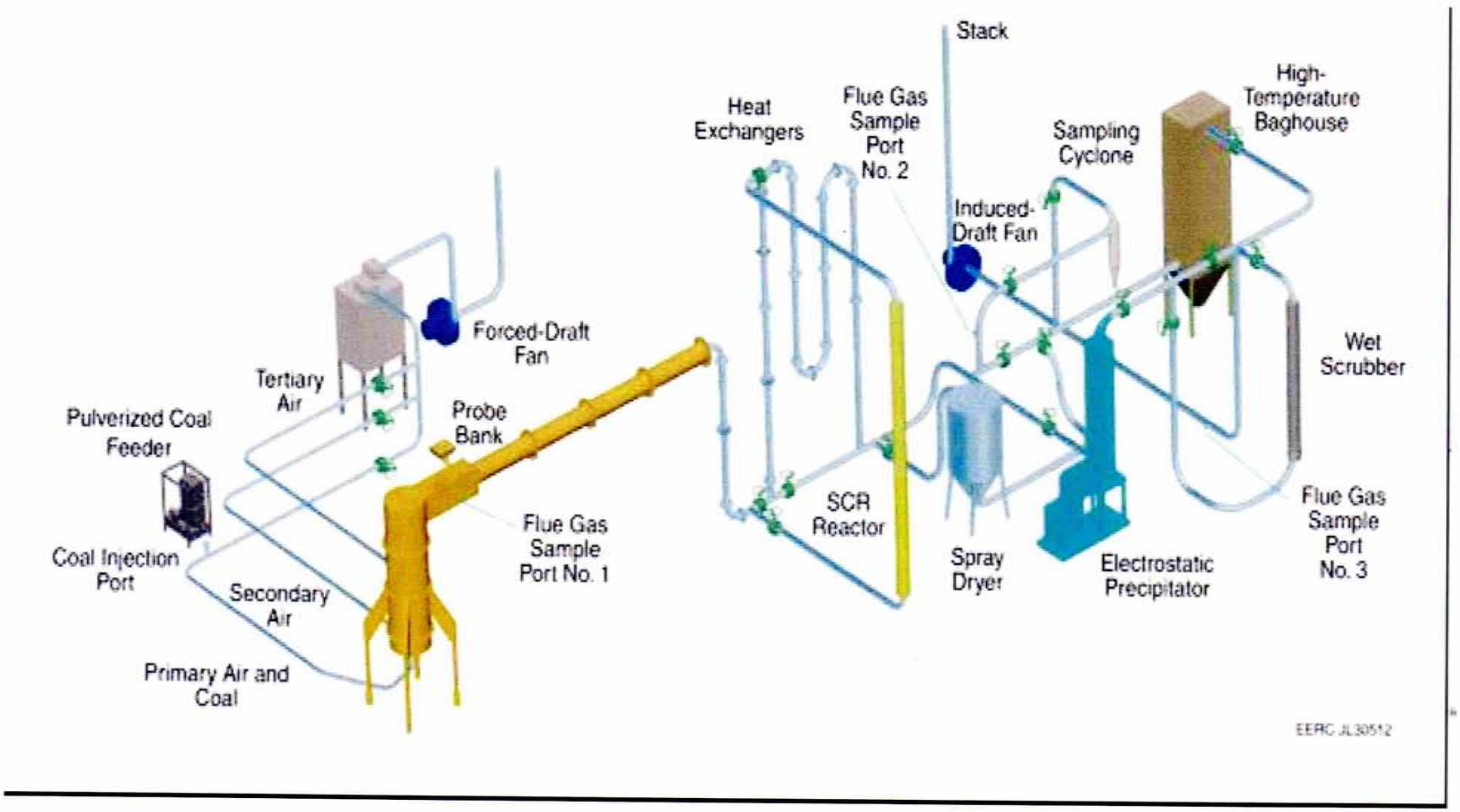
H_2O Absorber/Stripper Column Design



EERC Energy & Environmental Research Center

Activity 3 – Test Equipment Installation

EERC Combustion Test Furnace



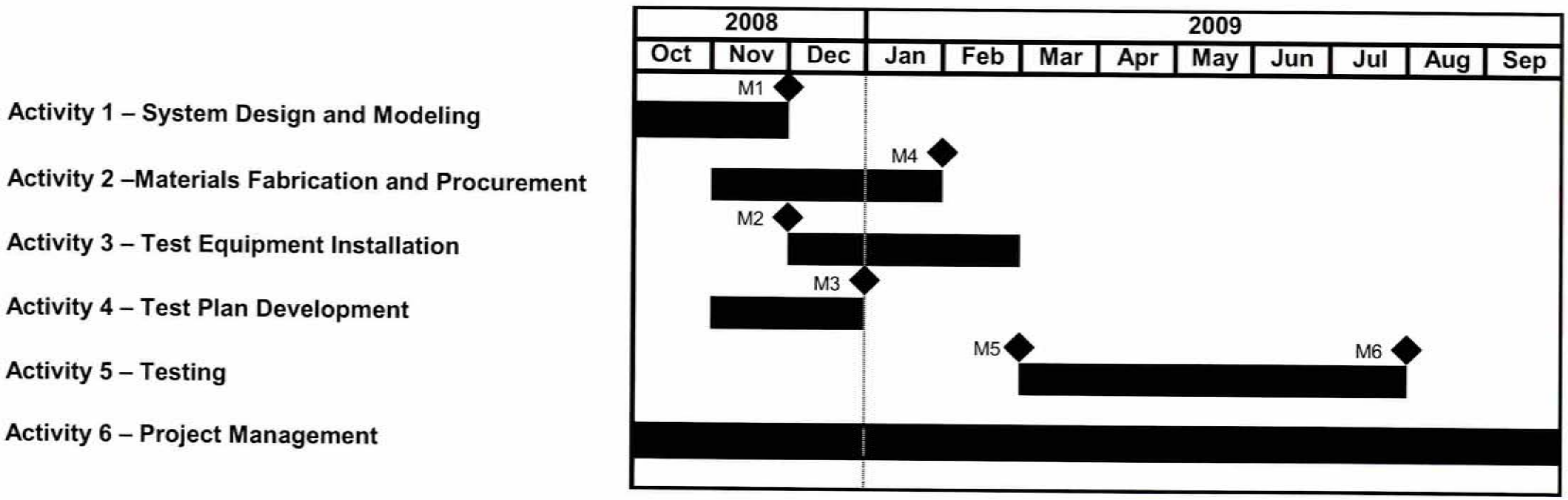
Activity 4 and 5 Test Plan Development and Testing

- Will coincide with PCO_2C Program testing to reduce cost.
- PCO_2C Program has up to 8 weeks of testing planned.
  - 2 weeks of system shakedown
  - 2 weeks of baseline testing, air and O_2
  - 3 weeks of capture technology testing
  - 1 week of O_2 firing for sequestration

EERC
Energy & Environmental Research Center

WEST Project Task Schedule

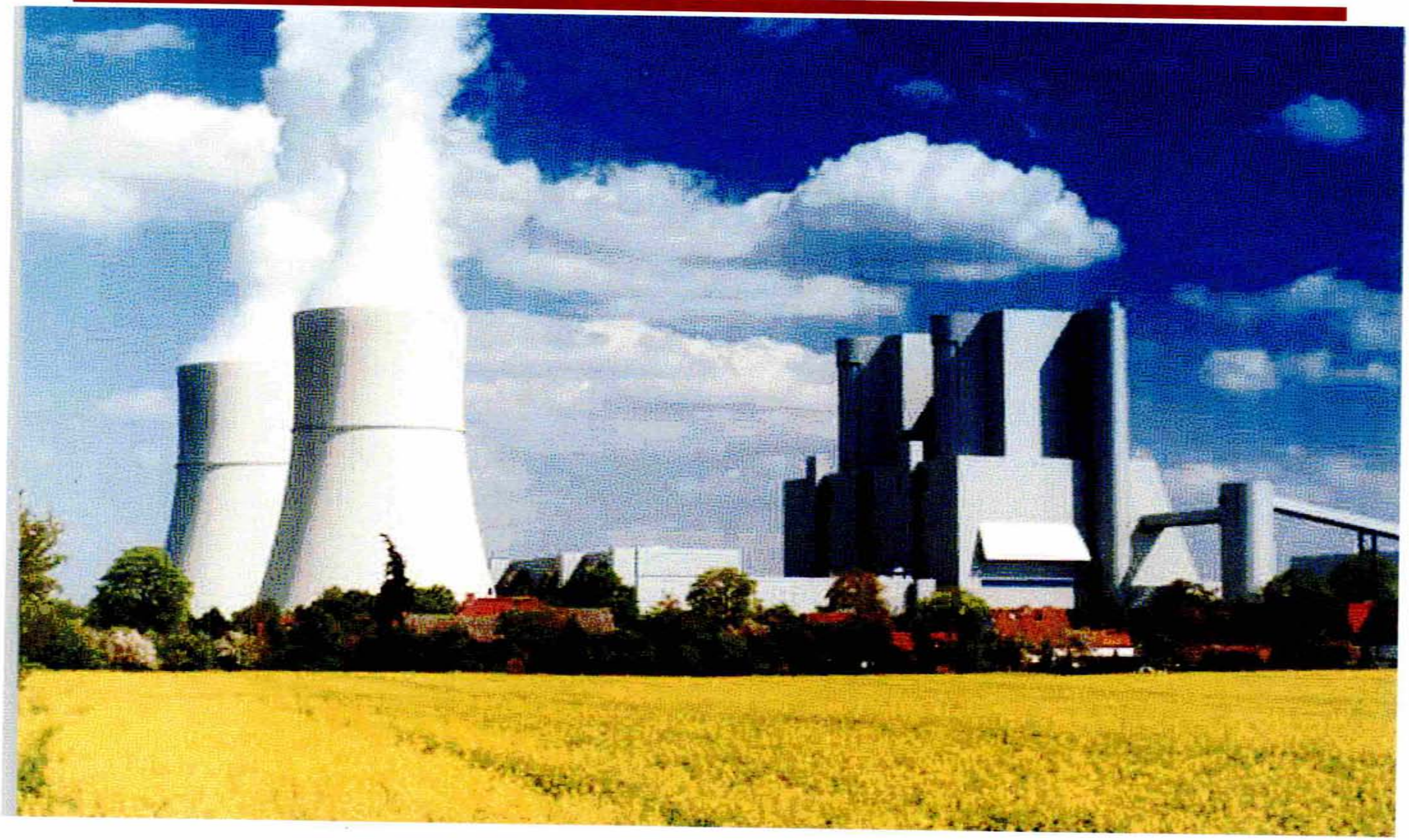
Period of Performance: October 1, 2008 – September 30, 2009



EERC
Energy & Environmental Research Center

Anyone who can solve the problems of water will be worthy of two Nobel prizes – one for peace and one for science."

John F. Kennedy



Minimization of Fresh Water Usage at Coal-Fired Power Plants

Non-traditional Sources of Process and Cooling Water

Technology to Facilitate the Use of Impaired Waters in Cooling Towers

3-year $2MM Program
DE-NT0005961

Donald Whisenhunt, GE Global Research
Jeff Melzer and Ashok Shetty, GE Water and Process Technologies

imagination at work

October 28, 2008

This is GE

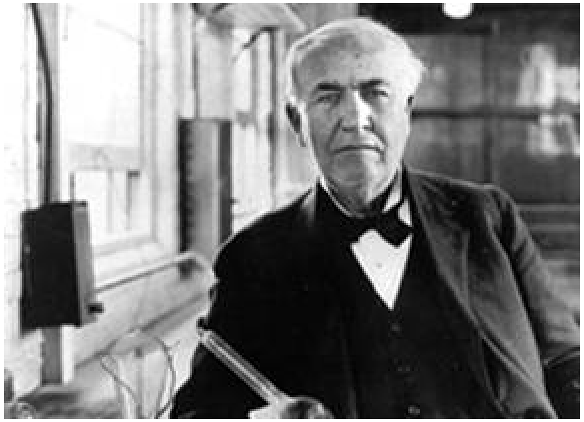
GE ... a heritage of innovation

Founded in 1892

$173 billion in annual revenues

Only company in Dow Jones index originally listed in 1896

330,000 employees worldwide



Four segments aligned for growth

Infrastructure - Technology	Infrastructure - Energy	GE Capital	NBC Universal
 	 	 	

GE Power and Water

The world today…

Global trends ...

Population

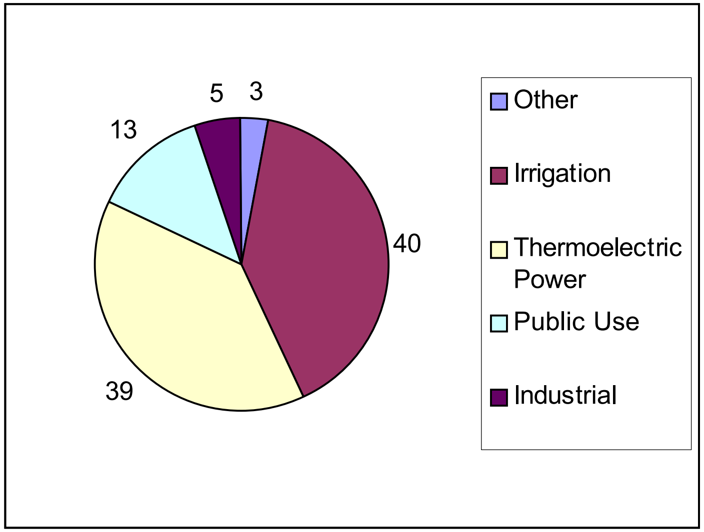
Consumption

Energy Security

Environment

... create big challenges

Fresh Water Minimization at Coal Fired Power Plants



Per-day water use in The U.S. = 345 billion gal

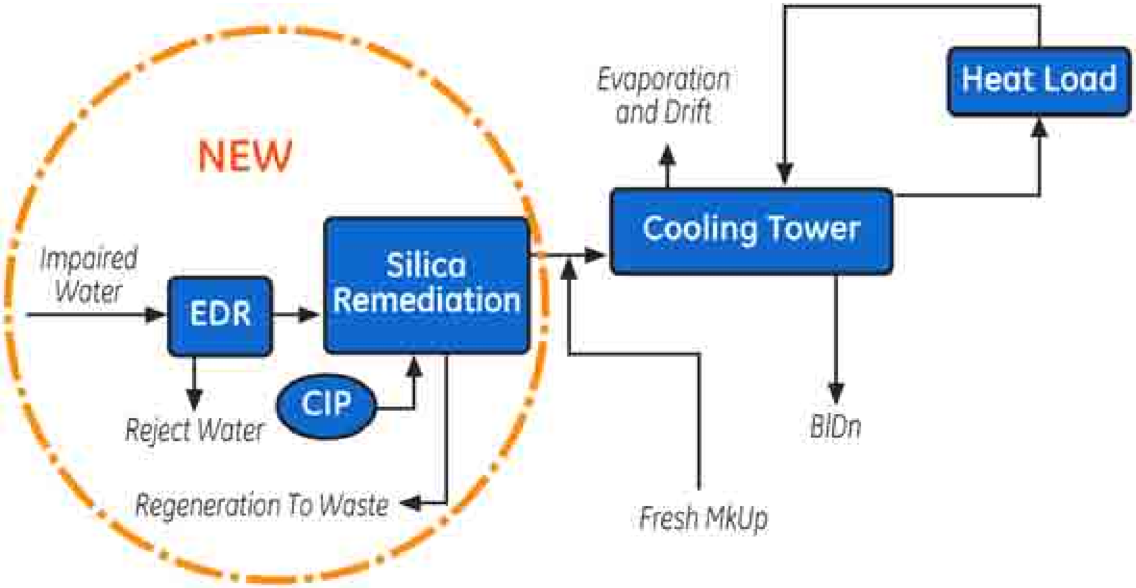
From C&EN Oct 6, 2008

Short Term DOE Goal:

By 2015
50% Reduction
$3.90/kgal

imagination at work

GE Approach



No Change Other Than Use of Impaired Water

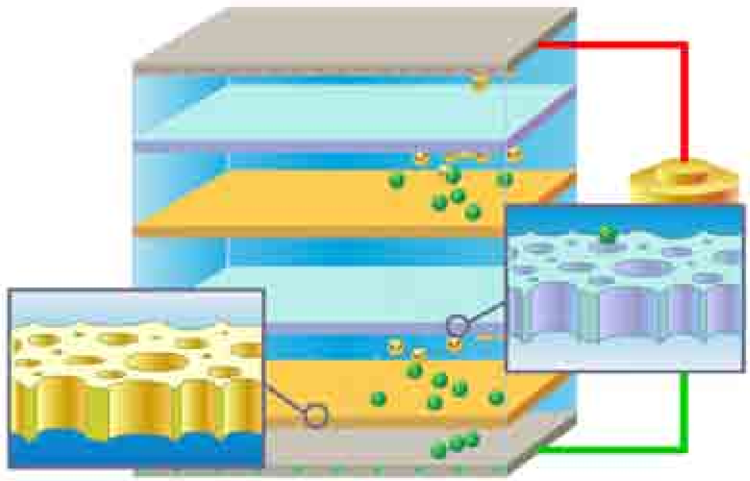
State	Fresh MkUp	BlDn	Impaired	EDR BlDn	Regen BlDn	Evaporation	% Savings of Fresh Water
Current	11,194	2,239	0	0	0	8,955	0
New	5,547	2,239	6,101	-554	-7	8,955	50

Recirculation Rate = 430,000 gpm   Current Cycles = 5

Novel Silica Remediation Technology Coupled to EDR Solution

GE Approach

Impaired Water
2500 TDS
100 ppm Silica



EDR – Self Cleaning
0.5 mg/L Chlorine tolerant

EDR Treated Water
25-100 TDS
100 ppm Silica

Silica Remediation

Treated Water
25-100 TDS
20 ppm Silica

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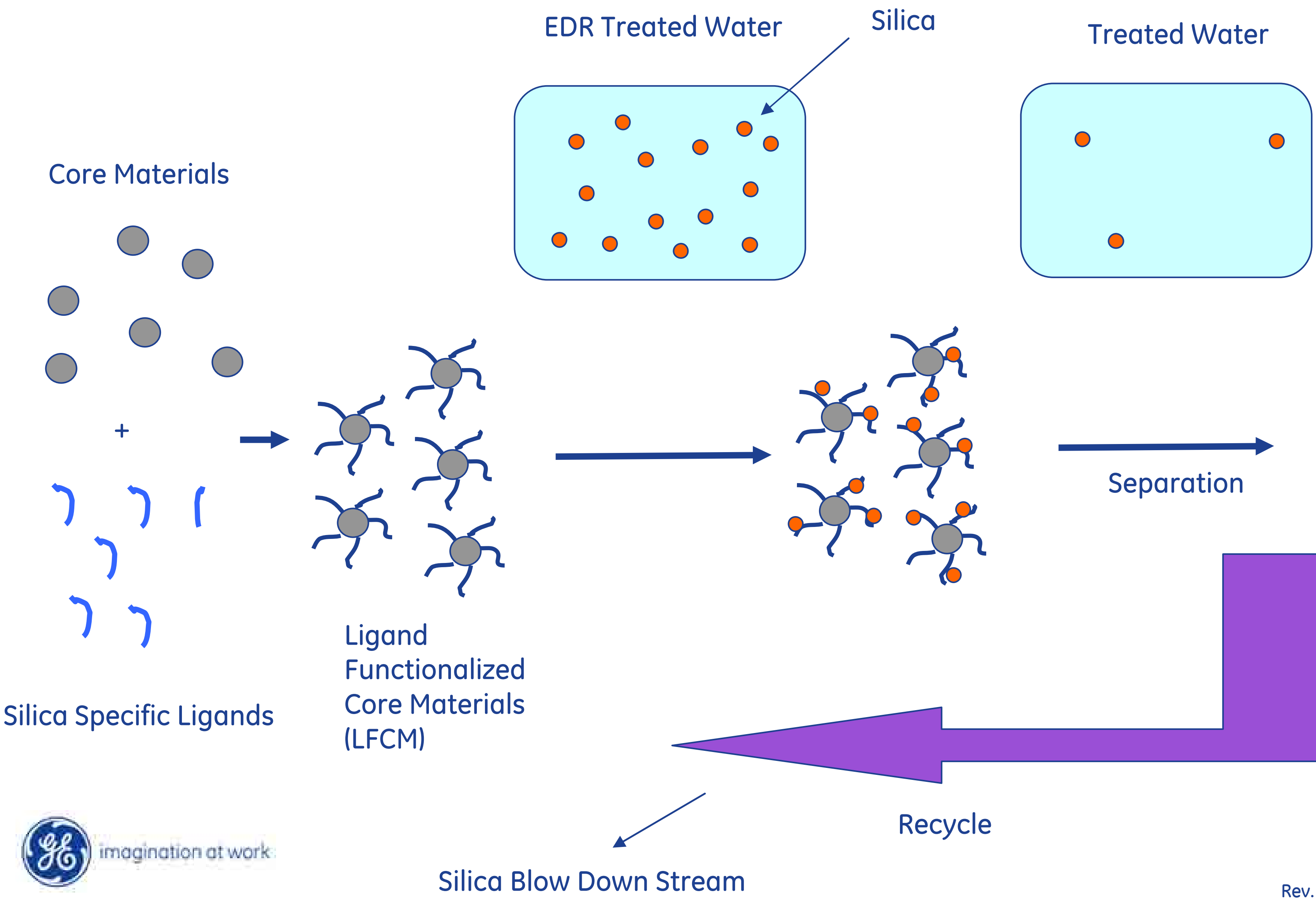
Silica Remediation Technology



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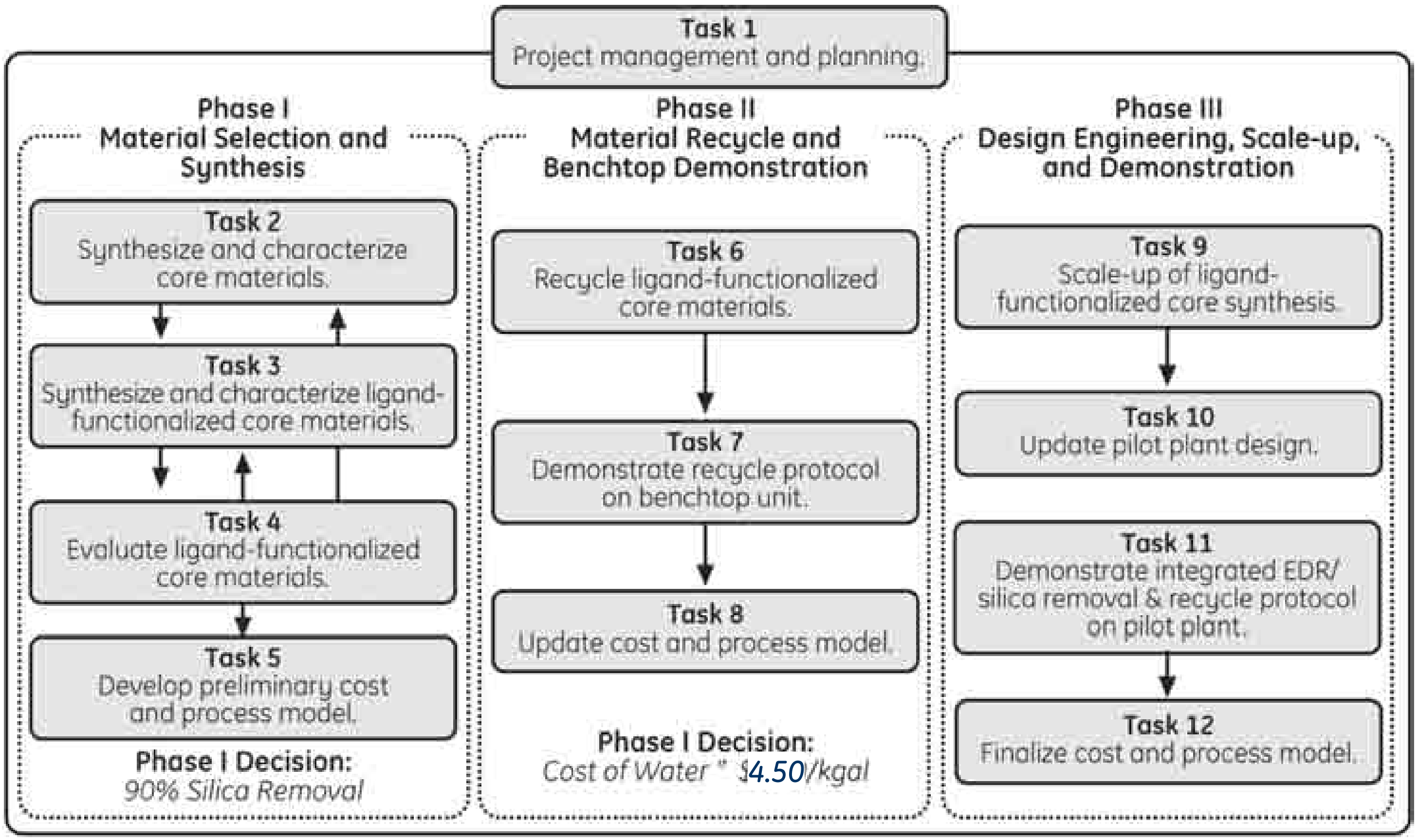
Project Plan



Unique Capabilities in High Throughput Synthesis and Screening

Project Team

Department of Energy

Program Manager & Principal Investigator
Dr. Donald W. Whisenhunt
Combinatorial Chemistry Lab

Technical Management Team

Dr. Terry Leib
Global Technology Leader
Materials Analysis & Chemical Sciences

David Polizzotti
Consulting Engineer
W&PT Technology Core Chemicals

Business Management Team

Mr. David Komoroske
Business Development Manager

Mr. Chang Wei
Business Program Manager

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Dr. Robert E. Colborn
Dr. Tao Deng
Dr. (Tunchiao) Hubert Lam
Ms. Oltea Siclovan
Dr. Ronald J. Wroczynski
Dr. Ying Zhou

GE Water & Process Technologies
Process Modeling & System Integration

Ashok Shetty
Claudia C. Pierce
Jeffrey I. Melzer

imagination at work

Internet-Based, GIS Catalog of Non-Traditional Sources of Cooling Water for Use at America's Coal-Fired Power Plants

Project Number: DE-NT0005957

David Alleman

ALL Consulting

NETL Project Kick-off Meeting

October 28, 2008

ARTHUR ▪ LANGHUS ▪ LAYNE
ALL CONSULTING

Project Facts

Project Number: DE-NT0005957

Funding:

DOE:	$ 451,385
Cost Share:	$ 177,250
Total Cost:	$ 628,635

Period of Performance: 36 Months

Project Performers

Recipient :

ALL Consulting

Principal Investigator: Dan Arthur, President

Primary Partner:

Ground Water Protection Council (GWPC)

Arthur Langhus Layne, LLC.

dba ALL Consulting

Energy, Engineering and Environmental Consultants

HubZone Certified Small Business

Headquartered in Tulsa, OK

Offices in MT, NM, TX, MO, and LA

ALL Consulting

Extensive Experience in :

- **Oil and Gas Private Industry Work and Research with NETL**
  - Beneficial Use of Produced Water
  - Water Management
  - Underground Injection Control
  - Coal Bed Methane
  - Shale Gas
  - Environmental
  - CO_2 EOR
  - Environmental Planning/Permitting
- **NEPA/Environmental Reviews**
  - Bureau of Land Management
  - Forest Service
  - Corps of Engineers

Ground Water Protection Council (GWPC)

- National association of state ground water and underground injection control agencies whose mission is to promote the protection and conservation of ground water resources for all beneficial uses
- Provides a forum for stakeholder communication and research in order to improve governments' role in the protection and conservation of ground water
- Membership includes more than 35 state water agencies, oil and gas associations, coal associations, public utility associations, etc.
- Working closely with NETL and EPA on CO_2 injection issues

Need for the NETL Program

- Water is a Looming National Crisis
  - "Water is the oil of the 21st Century"
  - "Water, unlike oil, has no substitute"
  - "Water consumption is doubling every 20 years"
  - "Water is not discretionary"
- New research can resolve environmental concerns, create new water resources, and promote energy development

Project Goals

- Allow reduced/minimized high quality freshwater withdrawals by identifying non-traditional sources of water.
- Ensure that operators are aware of their options and allow them to assess the availability of these waters to supplement or replace their water supply on a short-term or long-term basis.

Project Summary

- Identify Location and Water Needs of CFPP in the Lower 48 – Both Current and Planned
- Identify Location, Quality and Volume of Non-Traditional Sources of Water
  - Oil and Gas Produced Water
  - Mine Pool Water
  - Lower Quality Ground Water
  - Other Industrial Sources
  - Other?
- Create an Inter-net Based GIS Catalog of Non-Traditional Sources of Cooling Water

Project Overview

- **Budget Period I** – Data Collection
- **Budget Period II** – System Development
- **Budget Period III** – Beta Test, Launch, Operate

- Technology Transfer Will Occur Throughout the Life of the Project
- ALL and GWPC Plan to Continue Hosting the Site After Project Completion
- Guided by a Project Advisory Council

Project Advisory Council (PAC)

- GWPC Members
  - State Water Agency Representatives
  - Industry Association Representatives
- USGS Representatives
- Others as Identified

Synergies

- Energy Water Nexus
- NETL's Oil and Gas Program
- Conventional Oil and Gas
- Unconventional Oil and Gas
  - CBNG
  - CO_2 EOR
  - Gas Shale
- Other National Lab Water Efforts, e.g., SNL, LANL
- CO_2 Sequestration Program

Contact Information
ALL Consulting

Web-site: *www.ALL-llc.com*

Dan Arthur

Bruce Langhus

David Alleman

918-382-7581

ARTHUR ▪ LANGHUS ▪ LAYNE

ALL CONSULTING

Reuse of Produced Water from CO_2 Enhanced Oil Recovery, Coal-Bed Methane, and Mine Pool Water by Coal-Based Power Plants

Project DE-NT0005343

Seyed A. Dastgheib

University of Illinois at Urbana-Champaign (UIUC)
Illinois State Geological Survey (ISGS)

DOE/NETL – Existing Plants Water Projects Meeting
October 27-28, 2008
Pittsburgh

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Illinois State Geological Survey

Project Outline

- Objective
- Background
- Scope
- Tasks
- Schedule
- Summary

Objective

Evaluate feasibility of reusing three types of non-traditional water sources (produced water) for cooling and/or process water for coal-based power plants in the Illinois Basin

- CO_2 Enhanced Oil Recovery (EOR)
- Coal-Bed Methane (CBM)
- Active and abandoned coal mines

Extent of the Illinois Basin in Illinois, Indiana, and Kentucky

Power and thermoelectric freshwater demand in the US and Illinois

- U.S. and Illinois power demand will increase ~30% by 2030
- ~82% of total freshwater in Illinois withdrawn for the thermoelectric sector (vs. 39% U.S. withdrawal)
- Illinois thermoelectric water consumption may increase 55-160% by 2030 (vs. 28-50% U.S. increase)
- CO_2 capture will increase the U.S. thermoelectric water consumption considerably
- Emerging/future industries (e.g., biofuels, hydrogen production) will further increase the water demand

Total electricity generation	U.S. (billion kWh)	Illinois (billion kWh)
Year 2006	4,029 (49% coal)	192 (48% coal)
Year 2030	5,219 (54% coal)	257
Increase	30%	34%

Water	U.S. (BGD)	Illinois (BGD)
Total withdrawal	346	14
Thermoelectric	135 (39%)	11.3 (82%)
Total consumption	100	1.2
Thermoelectric	3 (3%)	0.4 (33%)

Increase in thermoelectric water demand by 2030 without CO_2 capture (NETL prediction)	U.S.	Illinois
Withdrawal	-21% to 6%	-16% to 14%
Consumption	28% to 50%	55% to 160%

Sources: Hudson et al. USGS 2004; Solley et al. USGS 1998; DOE/EIA 2008; Phase II MGSC Report, 2007; DOE/NETL 2007 and 2008

Nontraditional sources of water for power plant usage: NETL previous and on-going work

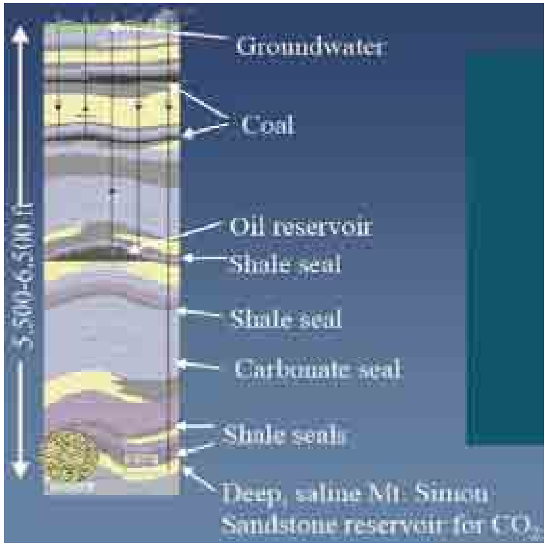
- Techno-economic study on using coal-mine discharges and underground coal mines (as heat sinks) for power plant cooling systems in the Pittsburgh Basin (West Virginia University)
- Modeling of using mine water for thermoelectric power generation in the Pittsburgh Basin (WVU)
- Reuse of three types of impaired water (treated municipal wastewater, coal-mine drainage, and ash pond effluent) for power plant cooling (University of Pittsburgh - Carnegie Mellon University)
- Use of produced water from oil and gas fields to supplement freshwater use in SJPS in New Mexico (EPRI)
- Use of saline water, produced from CO_2 sequestration in deep saline aquifers, for power plant cooling (Sandia National Lab)
- Utilization of advanced separation and chemical scale inhibitor technologies to use impaired water in re-circulating cooling systems (Nalco Company)

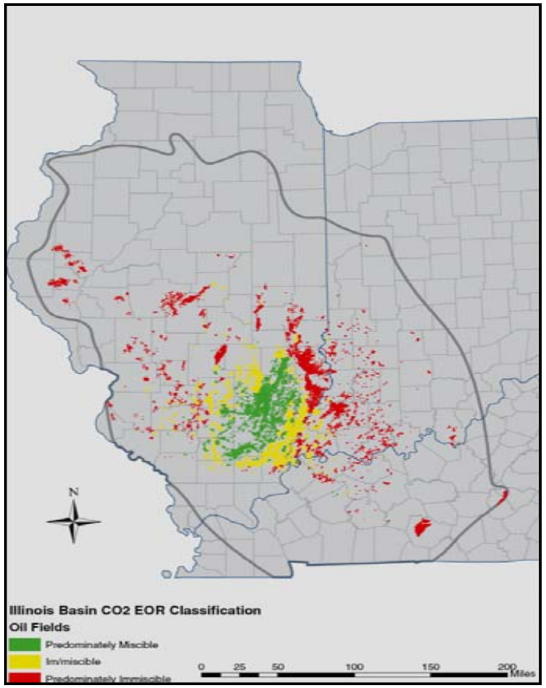
Nontraditional sources of water for power plant usage: Contributions of this project

- Characterize different types of produced water (i.e., from oil, CBM, and coal mines) in the Illinois Basin
- Evaluate feasibility of using produced water from oil and gas recovery and coal mines for power plants in the Illinois Basin
- Assess potential use of produced water from CO_2-EOR for power plants
- Assess potential use of produced water in PC (as cooling, FGD, or boiler water) and IGCC (as cooling, coal slurry, or boiler water) in the Illinois Basin
- Perform an overall techno-economic optimization study for the produced water use by power plants in the Illinois Basin

CO_2-EOR in the Illinois Basin

- ISGS/UIUC is leading Midwest Geological Sequestration Consortium (MSGC), one of 7 DOE partnerships, to capture and sequester CO_2 in the Illinois Basin
- Total CO_2 emission (billion metric tons, BMT) in 2005
  - U.S.: ~ 6
  - MSGS region: ~ 0.3
- MSGC geological CO_2 sequestration capacity
  - Depleted oil and gas reservoirs (0.4 BMT)
  - Coal seams (2.3-3.3 BMT)
  - Saline reservoirs (29-115 BMT)
- ISGS CO_2 sequestration activities
  - Completed a pilot CO_2-EOR project by injecting 43 tons of CO_2 into an oilfield in Southern Illinois
  - Planned to inject 10,000 tons of CO_2 into a deep saline reservoir in Phase II and 1,000,000 tons in Phase III

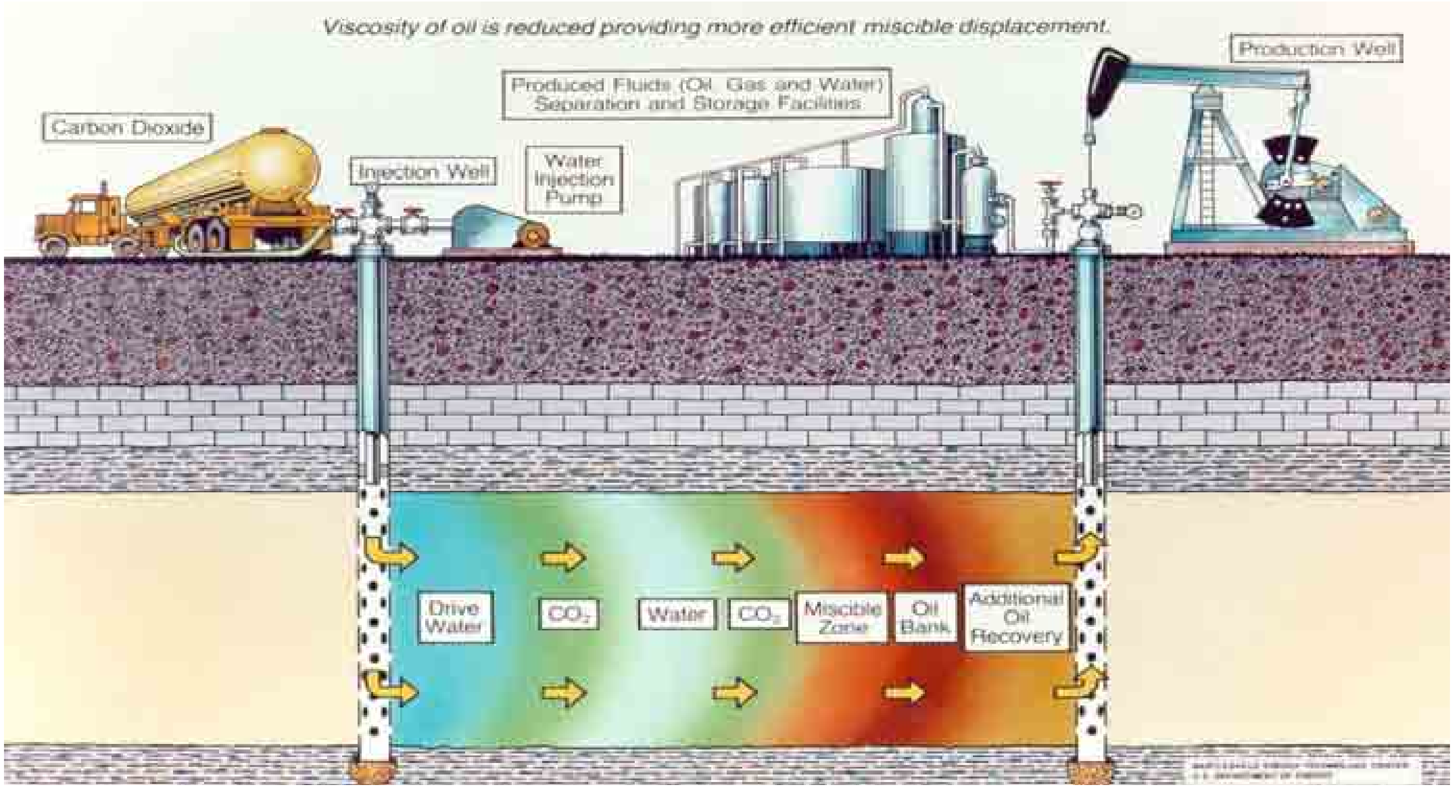




Sources: MSGS, DOE/NETL carbon sequestration atlas

Nontraditional sources of water: produced water from CO_2-EOR

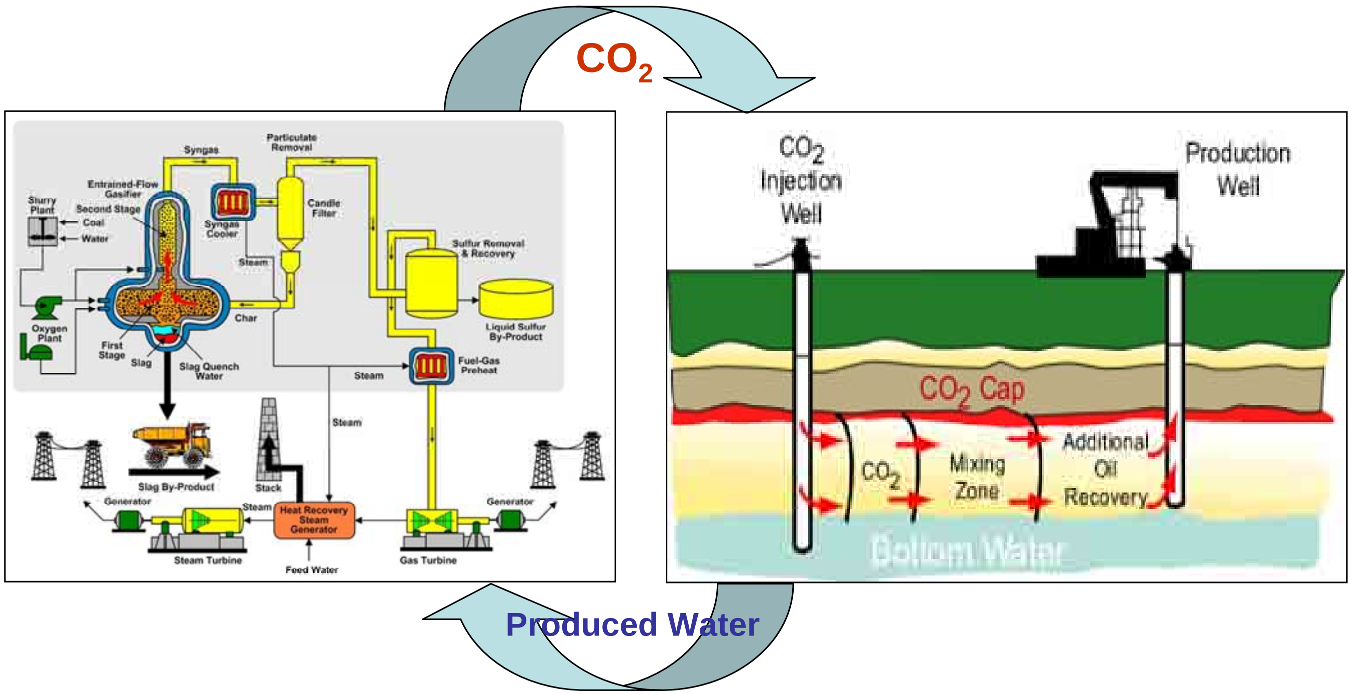
- Potential oil production by CO_2-EOR in the Illinois Bain: ~1 billion bbl (10% of OOIP)
- Produced water/oil ratio ~ 10-100, produced water volume: ~ 10-100 billion bbl
- Water quality: mostly high salinity; TDS = 6,000-200,000 mg/l



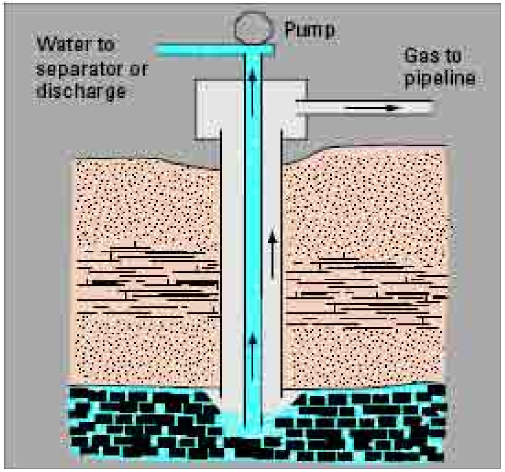
Sources: DOE/NETL, MSGS, USGS produced water database, ISGS floodwater database

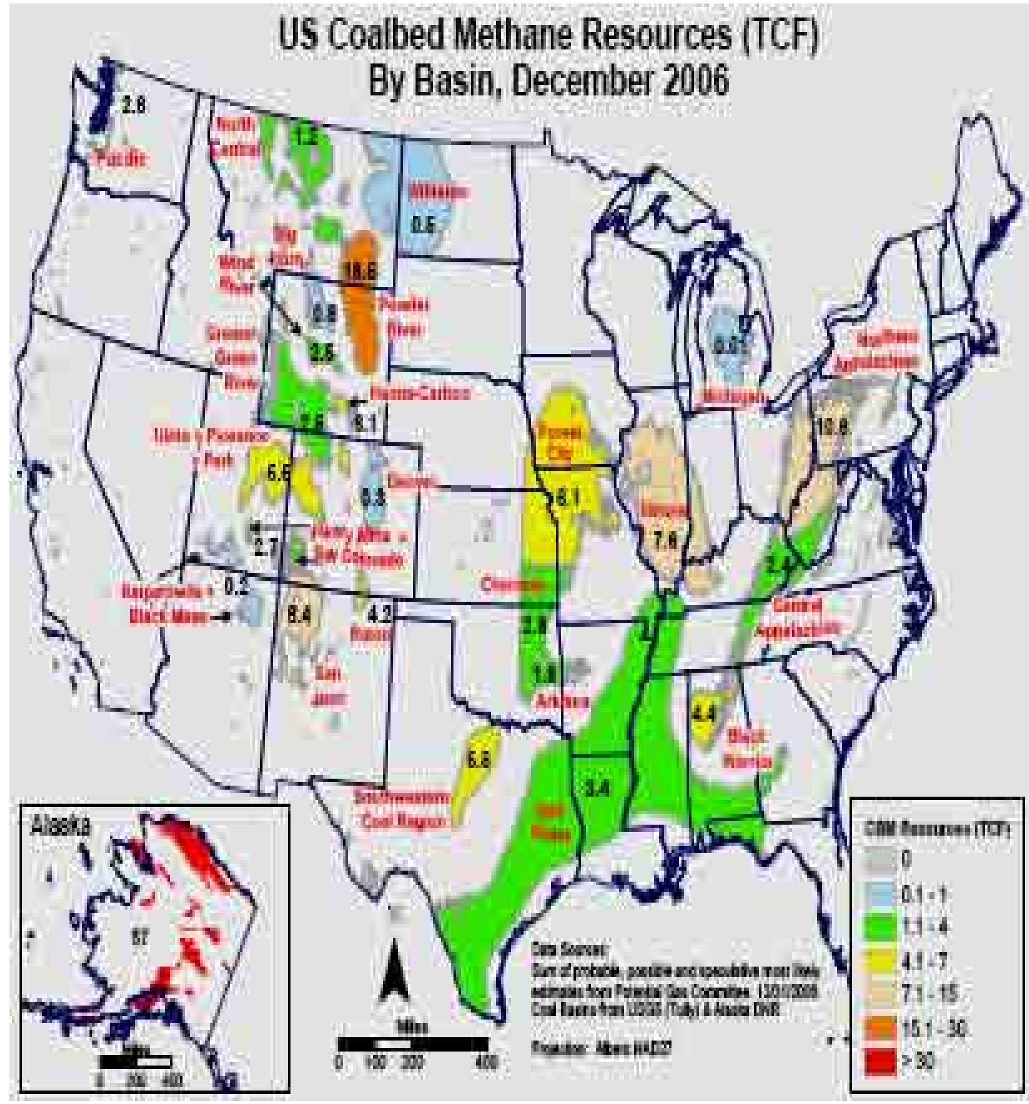
Nontraditional sources of water: produced water from CO_2-EOR

- Depending on future regulations, a large volume of CO_2 might be captured from power plants
- CO_2 geological sequestration by CO_2-EOR is one of the options that may provide economic incentives
- A portion of produced water will be re-injected and the rest should be properly managed
- Produced water could supplement cooling/process water demand of PC and IGCC power plants



Nontraditional sources of water: produced water from CBM





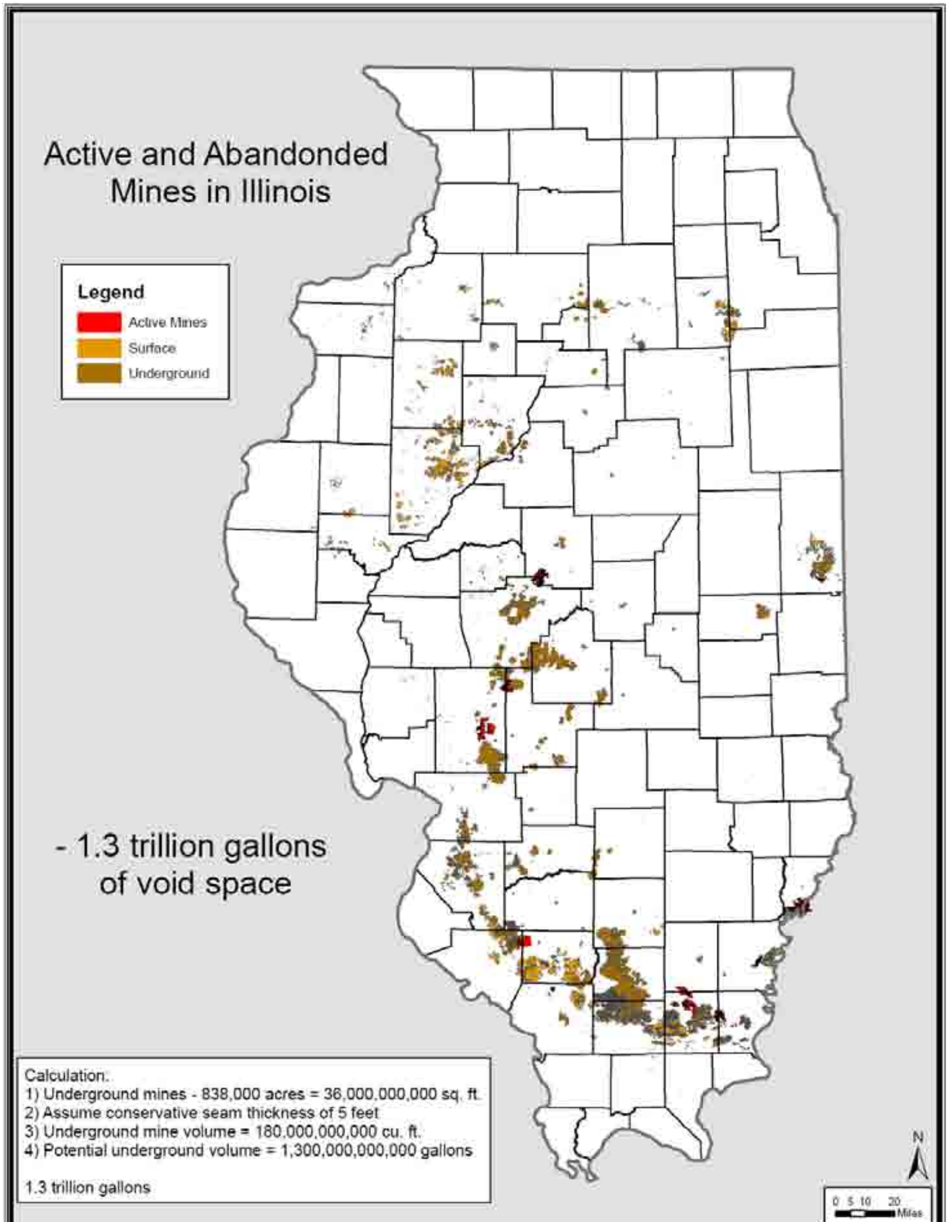
- Coal-bed methane
  - ~7.5% of total U.S. natural gas production
  - CBM resources: U.S.:157.9 tcf, Illinois: 7.6 tcf

- Produced water from CBM
  - Water quantity varies from basin to basin
  - Water/gas ratio: 0.03-2.75 bbl/1000cf
  - Water quantity decreases with time
  - IL estimation: 0.3-20.9 billion bbl water
  - Water quality varies: 200-170,000 ppm TDS

Sources: USGS FS-156-00, DOE/EIA 2007

Nontraditional sources of water: produced water from coal mines

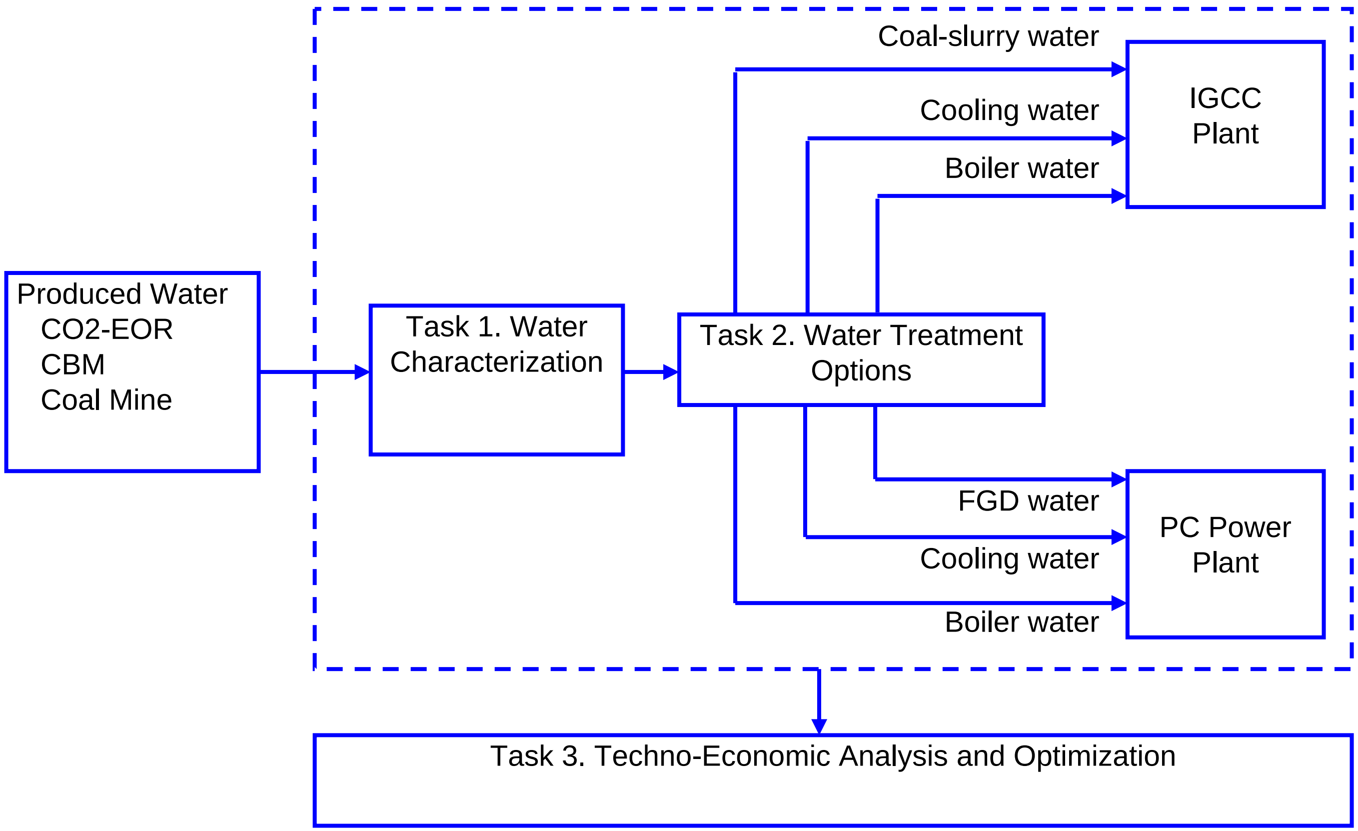
- 21 active and many abandoned coal mines in Illinois
- Potential underground mine volume: > 1 trillion gallons
- Void volume can be partially filled with water or used as a heat sink for power plant cooling
- Pattiki mine in White County produces ~ 0.5-1 MGD water with ~ 9000 mg/l TDS



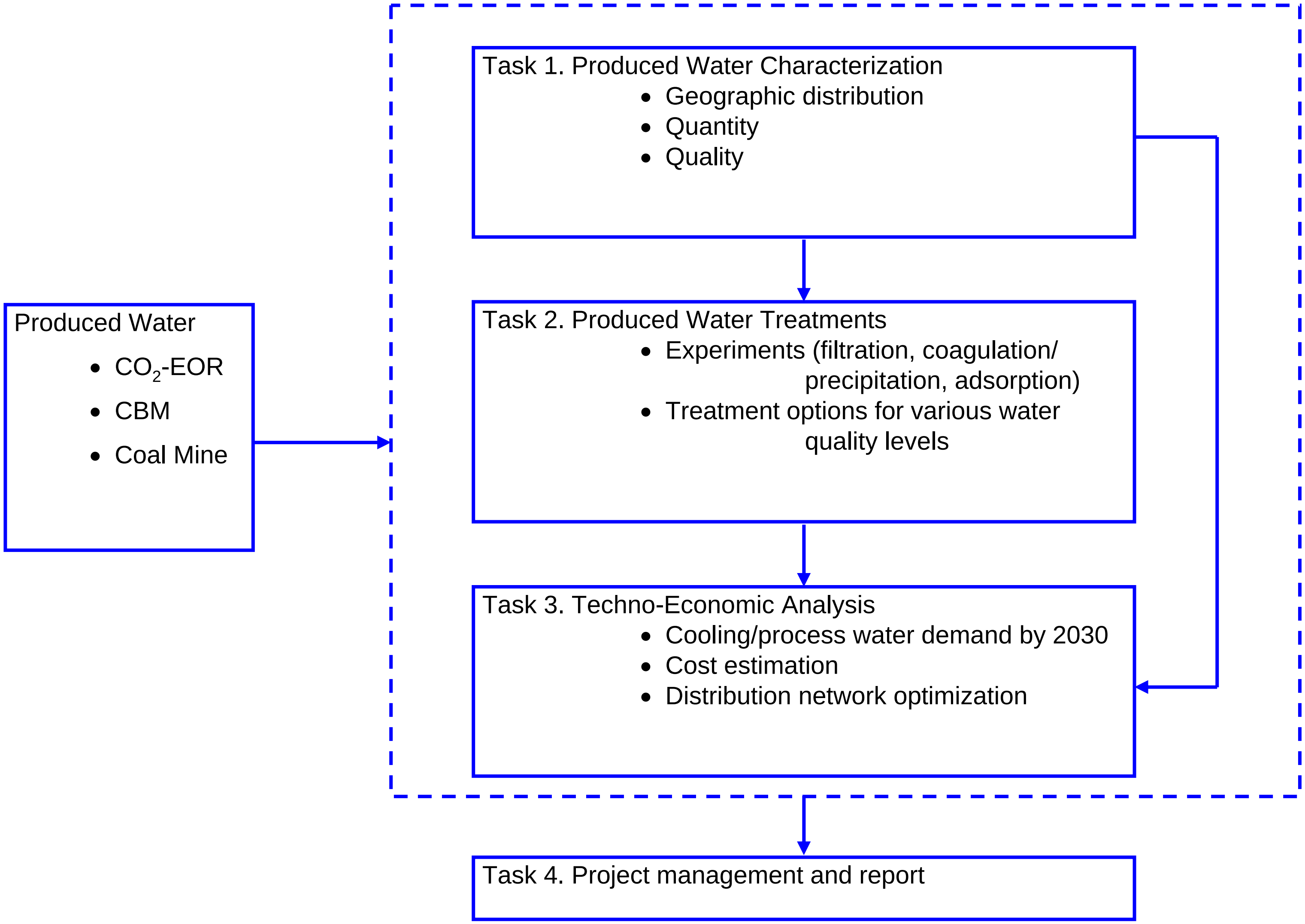
Project Scope

Participants:

- NETL/DOE
- ISGS/UIUS (Illinois State Geological Survey/University of Illinois at Urbana-Champaign)
- DCEO/ICCI (Illinois Department of Commerce and Economic Opportunity/Illinois Clean Coal Institute)
- MGSC (Midwest Geological Sequestration Consortium)
- BPI Energy, Inc. (A CBM producer in the Illinois Basin)
- White County coal, LLC (Pattiki coal mine)
- WaterCAMPWS (Center of Advanced Materials for the Purification of Water with Systems, a UIUC-based NSF research center)

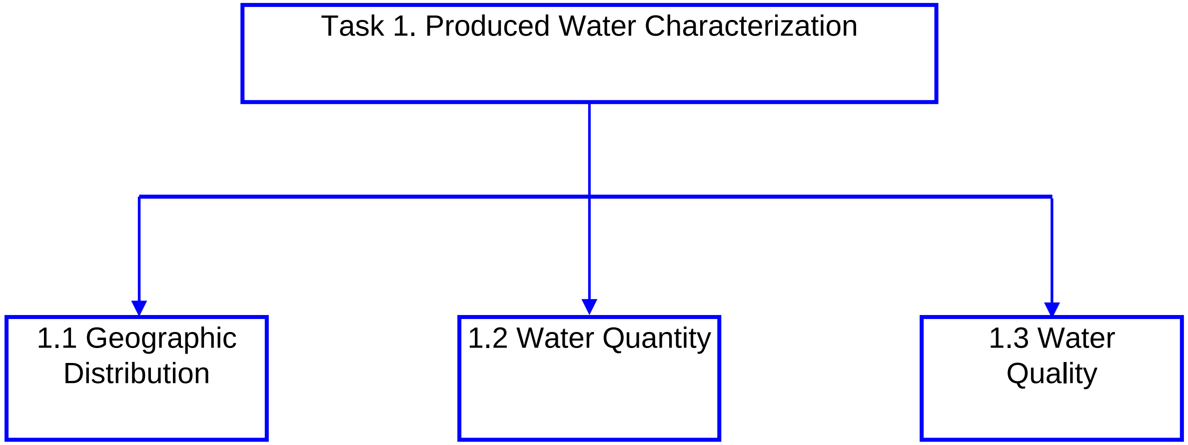


Project Tasks



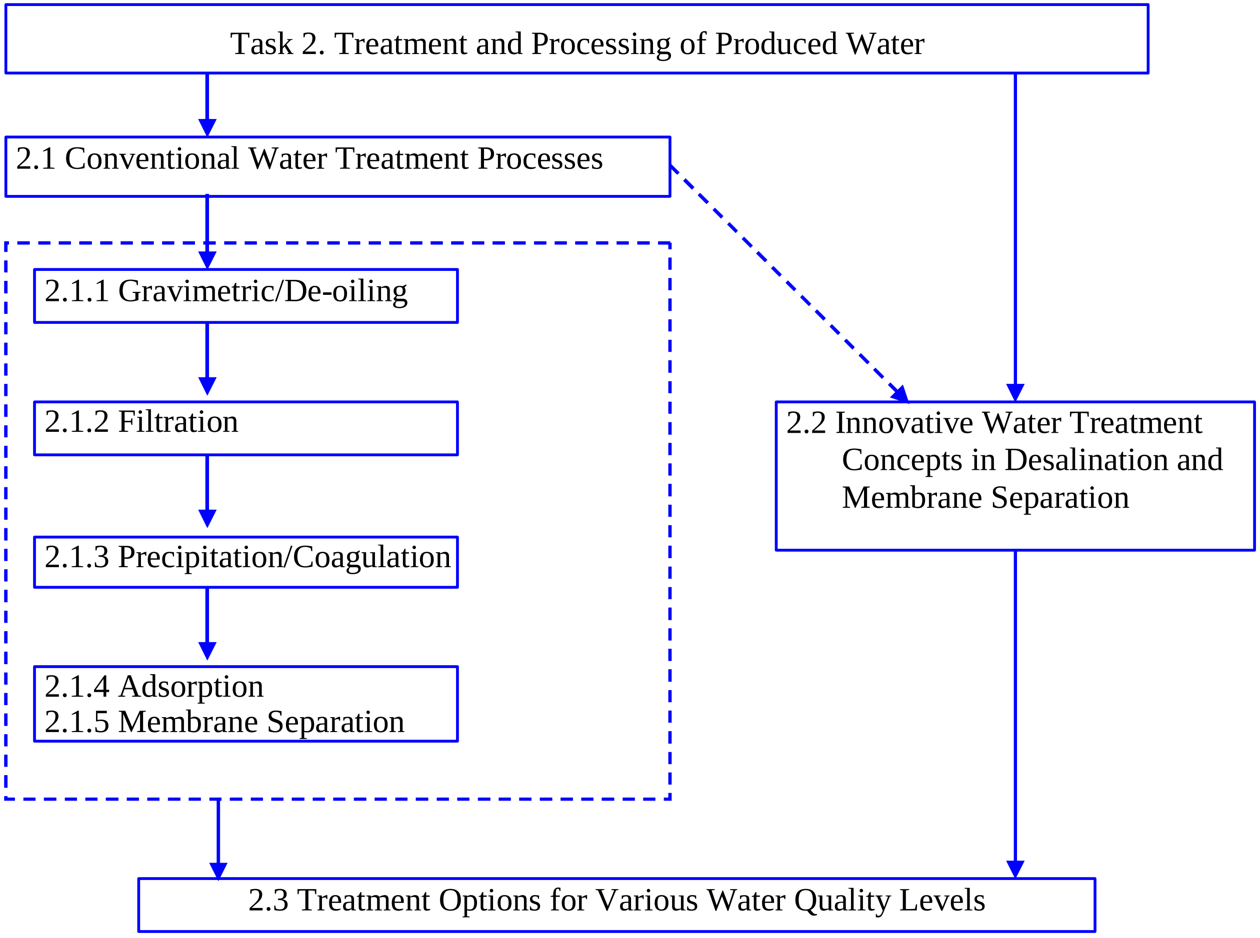
Task 1: Produced Water Characterization

- Use Information collected from the project participants and literature (e.g., USGS and ISGS databases, documents, and maps) to identify location and quantity of produced water sources in the Illinois Basin
- Collect available produced water quality data from USGS, ISGS, and EPA databases/documents
- Collect and characterize water samples from selected sources (pH, TDS, different anions and cations, alkalinity, …)
- Map produced water quantity and quality data for the Illinois Basin



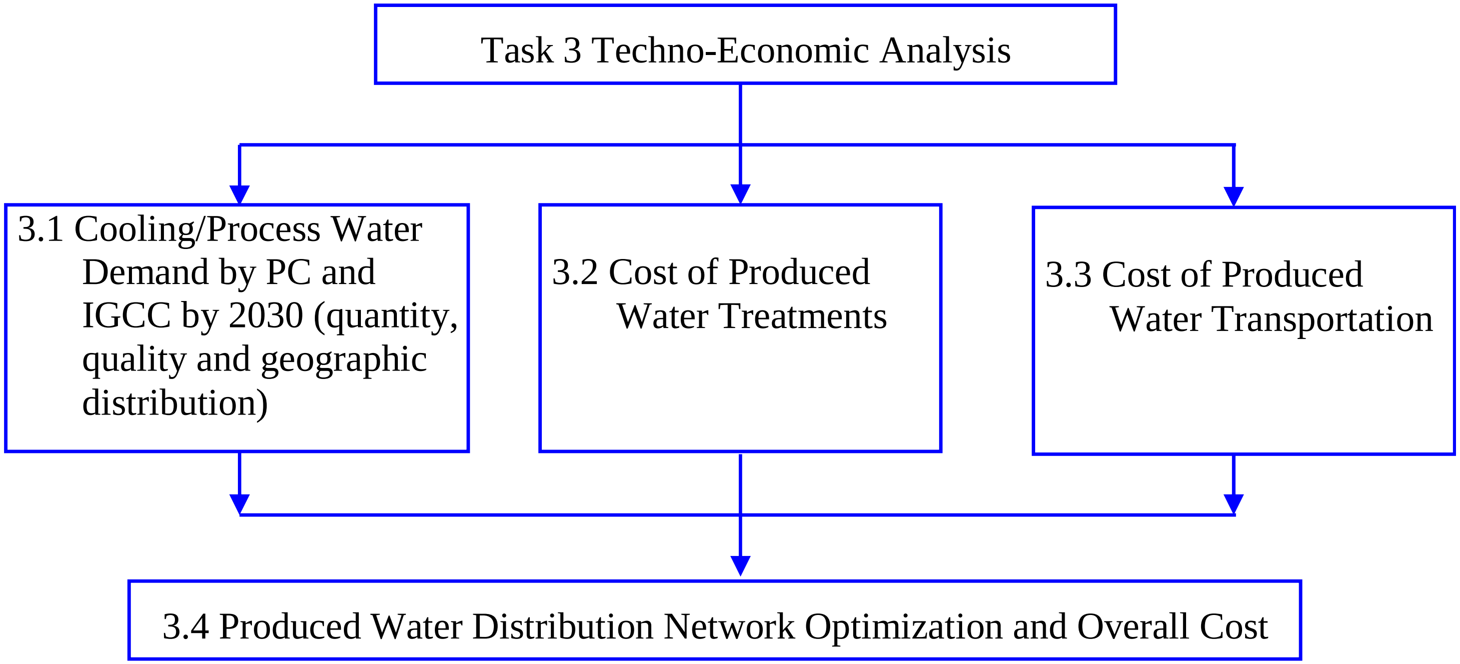
Task 2: Treatment and Processing of Produced Water

- Consider only produced water sources that provide a minimum required quantity of water (e.g., 10% of a 200MW closed-loop power plant water demand)
- Conduct water treatment studies considering the required water quality for different applications for PC and IGCC (i.e., water used for cooling, boiler make-up, coal slurry, and FGD)



Task 3 – Techno-Economic Analysis

- Assess cooling/process water demand by PC/IGCC by 2030 (new additions assumed to be 50/50 supercritical PC and IGCC)
- Collect literature information and conduct process simulation to estimate water demand (different types) in PC/IGCC
- Perform cost estimation of produced water treatment/transportation based on the results of Tasks 1 and 2, literature information, and standard Chemical Engineering cost estimation procedures
- Perform an overall network optimization analysis to identify an optimized pipeline distribution system from local water treatment facilities to the power plants. Optimization scenario will consider the cost of treating water to different quality levels, the demand volume of each quality level, and pipeline transportation cost



Project Schedule

Quarters	1	2	3	4	5	6	7	8	9	10	11	12
Task 1. Produced water characterization												
1.1 Geographic distribution												
1.2 Water quantity												
1.3 Water quality												
Task 2. Produced water treatments												
2.1 Conventional treatments												
2.2 Innovative treatments												
2.3 Treatment options												
3. Techno-economic analysis												
3.1 Cooling/process water demand												
3.2 Cost of produced water treatments												
3.3 Cost of produced water transportation												
3.4. Overall optimization												
Task 4. management & reports												

Summary

- Characterize different types of produced water (i.e., from CO_2-EOR, CBM, and coal mines) in the Illinois Basin
- Assess potential use of produced water in PC (as cooling, FGD, or boiler water) and IGCC (as cooling, coal slurry, or boiler water)
- Perform an overall techno-economic optimization study for the Illinois Basin

Thermoelectric Power plant Water Demands Using Alternate Water Supplies:

Power Demand Options in Regions of Water Stress and Future Carbon Management

Contributing Authors:
Peter H. Kobos, Malynda Cappelle, Jim Krumhansl, Tom Dewers,
Andrea McNemar, David J. Borns, Michael Hightower, and many others.

Acknowledgements: This work is developing under the funding and support of the National Energy Technology Laboratory.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. Work in Progress. SAND2008-7024P.

NNSA

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Regional Water Stress

- **Project Overview:**
  - Assess regions of the country that may face water shortages/stress
  - Help identify potential opportunities for expanding power supplies, while maintaining a healthy water management strategy
  - Evaluate potential non-traditional water sources in this region for their applicability for treatment and use in Thermoelectric Power Generation

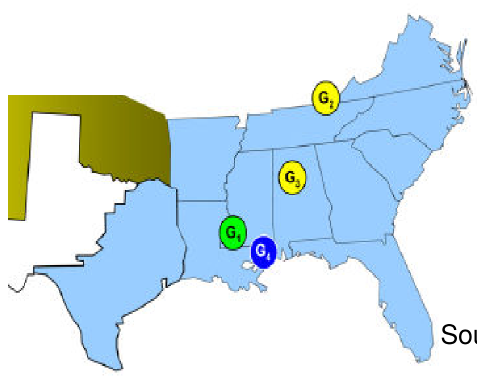
- **Project Plan:**
  - Down select to one or more regions of the U.S. to compare to the San Juan Basin in the SW U.S.
  - **Selected:** The region of interest for the Southeastern Regional Partnership on Carbon Sequestration **(SECARB)**
    - The area is immense and required a tiered approach to evaluating it's brackish water resources.

Dots show pilot test sites:

Yellow = Coal Formations

Blue = Saline Sandstone Aquifer

Green = Oil-Bearing Sandstone



Source: http://www.secarbon.org/

Progress of the Current NETL/SNL Project

Timeline

Summer

- **Completed:**
  - Identifying Regions of Interest
  - Identifying Sites with Some, Little or Limited Potential for Coupled CO_2 Sequestration with Groundwater Desalination and Use

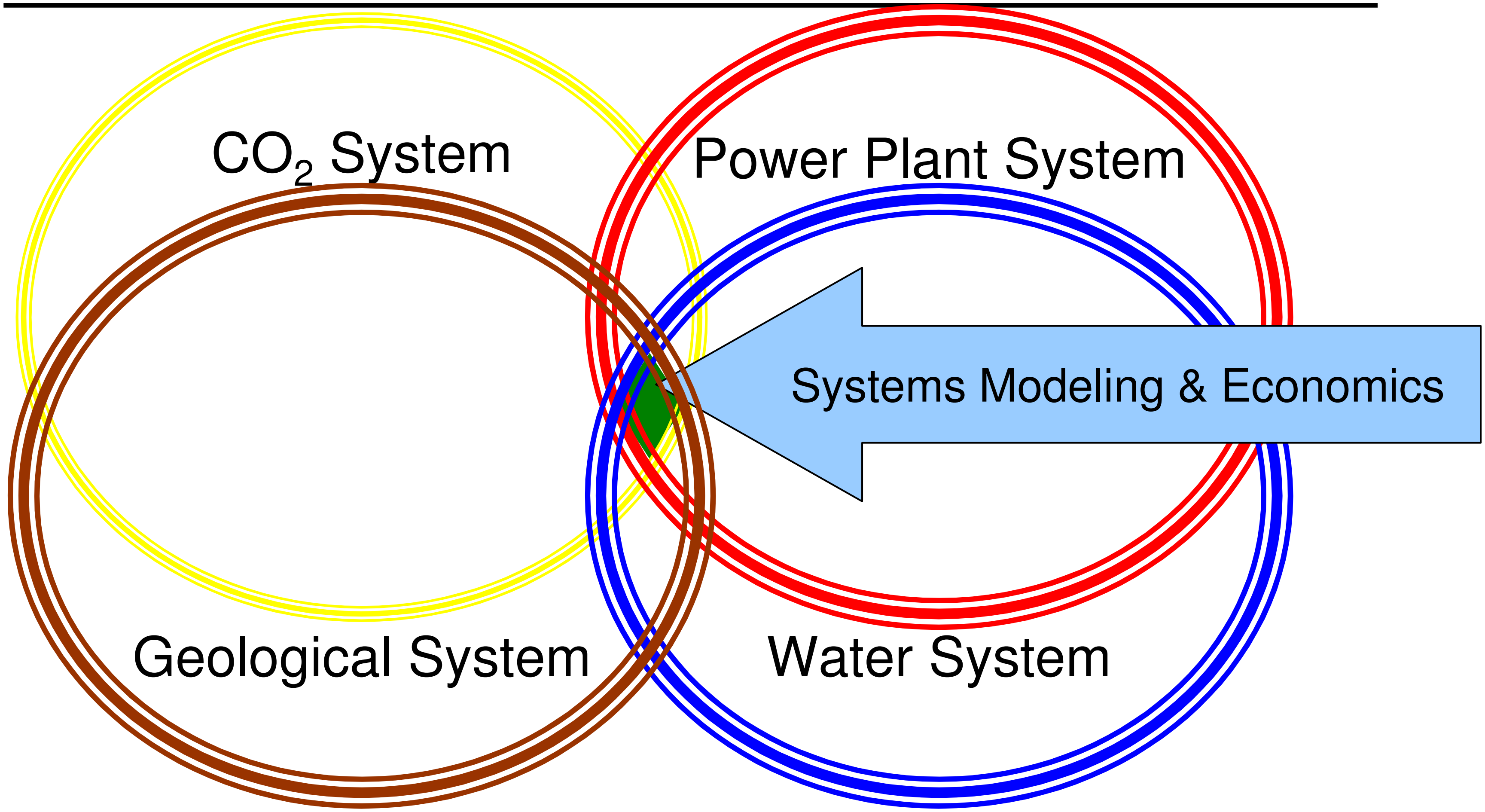
Fall 2008

- **Ongoing:**
  - Additional Site Evaluation
  - Additional Regional Geostudies & Evaluation

2009 +

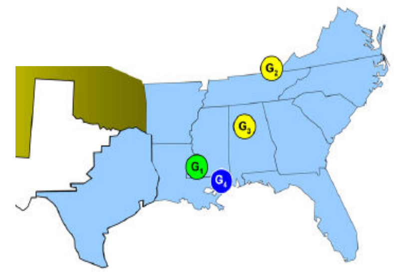
- **Where we are going:**
  - Developing a working set of guidelines / analytical framework
    - How to evaluate and then assess the viability of non-traditional water use and treatment
    - Potential Coupled CO_2 sequestration system with Water Treatment and Use for Cooling Water at Power Plants.
  - Developing a 'Regional Story' on the applicability of this framework
  - Identifying Regional Data Collection Gaps, Challenges, Opportunities, *and Collaborations*

Energy-Economic Modeling: Conceptual Layout of the Project



Can a power plant utilize non-traditional water for cooling or other uses as well as store CO_2 underground?

Initial Search Plan for the Regional Area



Selection Criteria:

1. Brines from depths greater than 2,500 feet,
2. Total dissolved solids ("TDS") between 10,000 and 20,000 mg/L.

Phase 1: (completed), Evaluating whether any of the SECARB pilot test sites would produce brines suitable for coupled-use applications.

Phase 2: (in progress), Regional assessment of whether areas other than Pilot Test sites might have aquifers suitable for coupled-use applications.

Phase 3: (in progress), A second regional evaluation, but from the perspective of whether the water resource expands significantly if the 10,000-20,000 TDS (mg/L) brine comes from a relatively shallow aquifer while, at the same site, a deep, highly saline aquifer is available for CO_2 sequestration (Decoupled Systems Geographically)

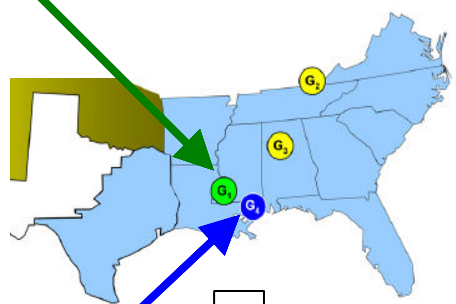
Initial Findings: Pilot Test Sites In "Saline" and Oil-Bearing Strata

Cranfield Site (SW Mississippi):

- Planned injection at a depth of 10,300 feet into the Tuscaloosa Sandstone
- Salinities* for nearby wells in this formation range from 147,000 mg/L to 211,000 mg/L TDS – far higher than can be treated for reuse.

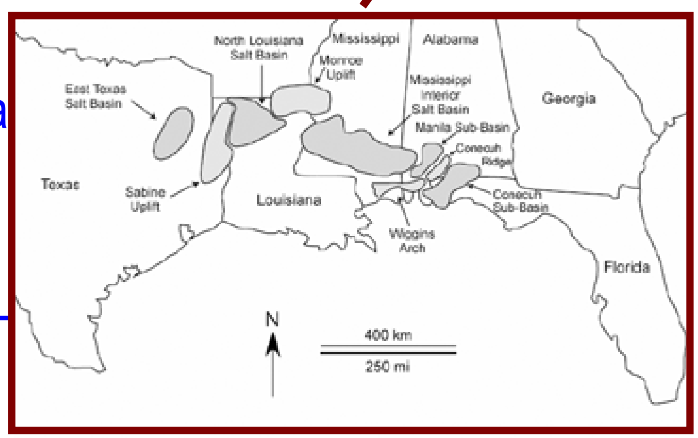
Gulf Coast Site (Mississippi):

- Planned injection at a depth of 8,800 feet, also into the Tuscaloosa Sandstone.
- Salinities for nearby wells range from 120,000 mg/L to 200,000 mg/L –far too high for reuse.



The Regional Issue:

- Presence of several interior salt-basins (shaded) and their attendant salt domes
- On a regional scale these features give rise to very saline ground-waters at shallow depths (900'-1500' typically).

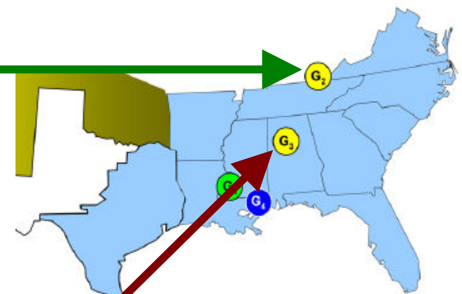


Sources of Graphics: SECARB, 2008; Mancini & Goddard, 2007, http://www.pttc.org/newsletter/2qtr2007/v13n2p9.htm

* from the NATCARB database

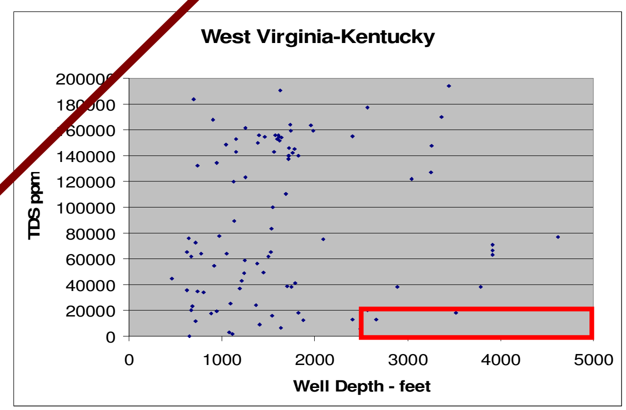
Results for Pilot Sites In Coal-Bearing Strata:

(Pilots conducted in conjunction with coal bed methane recovery operations.)



Central Appalachian Basin Coal Test:

- (“G2”, Virginia, Kentucky,& West Virginia): into the Pocahontas & Lee Formation coals at 1,600 to 2,200 feet deep
- No data is available from the deepest (Virginia) part of the basin (where pilot testing is likely)
- Data from a shallower parts of the basin in West Virginia suggests salinities will be too high.



Black Warrior Basin Coal Test.

- (“G3”, central Mississippi): CO_2 into the Pottsville coals (Pennsylvanian-age) at 1,500-2,500 feet.
- The southwest smaller, deeper, part of the basin (~250 square miles) meets all dual-use criteria.
    - *It is, however, only about a quarter of the total area occupied by the basin.*

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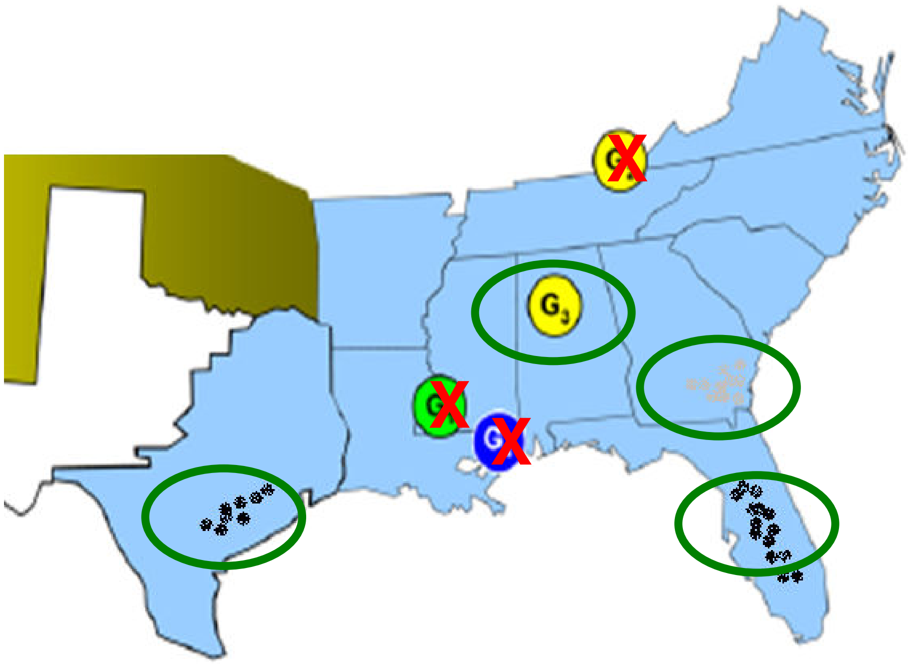
Preliminary Scope:
Promising Dual Use Basins/Regions



SECARB Regional Partnership Sites of Interest

<u>Viable coupled-use targets</u>

→ G3 SECARB Location
→ North-central Florida (lower "Floridan" aquifer)
→ Middle section of the Texas Gulf coast (Carrizo-Wilcox aquifer system)

<u>South Georgia Basin may also have potential</u>

→ Data is largely lacking for hydro-geochemical sites of interest to us at depth

<u>Need a better understanding of the constraints</u>

→ Using criteria designed for porous sandstones may lead to underestimating the size of the available sequestration resource

<u>**Decoupling**</u>

→ the cooling water and sequestration formations would greatly <u>expand the size</u> of the resources

Thermoelectric Power plant Water Demands Using Alternate Water Supplies:

Power Demand Options in Regions of Water Stress and Future Carbon Managment

Thank You

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Nanofiltration Treatment Options for Thermoelectric Power Plant Water Treatment Demands

Malynda Cappelle
Mark Rigali

Location:
October 27 – 28, 2008, NETL
Pittsburgh, PA Site Meeting

Acknowledgements: This work is developing under the funding and support of the National Energy Technology Laboratory.

Energy-Water Issues

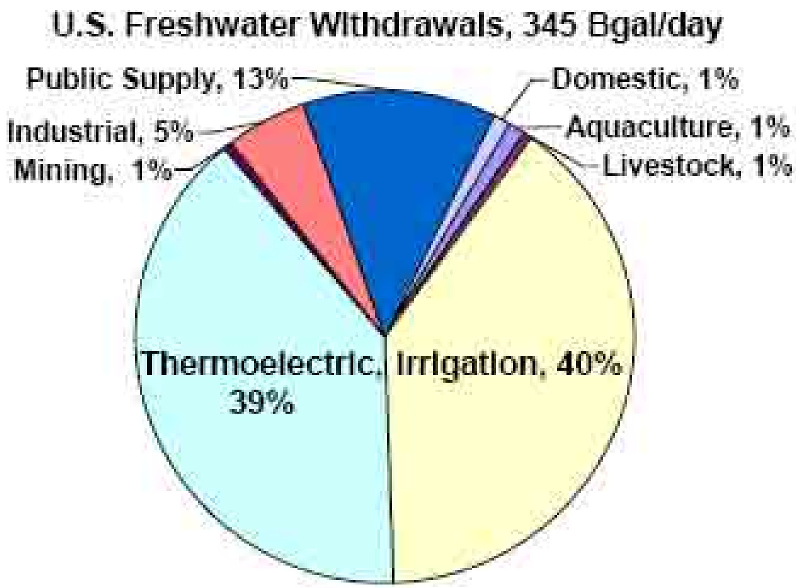


Figure II-1. Estimated Freshwater Withdrawals by Sector, 2000 (Hutson et al., 2004)

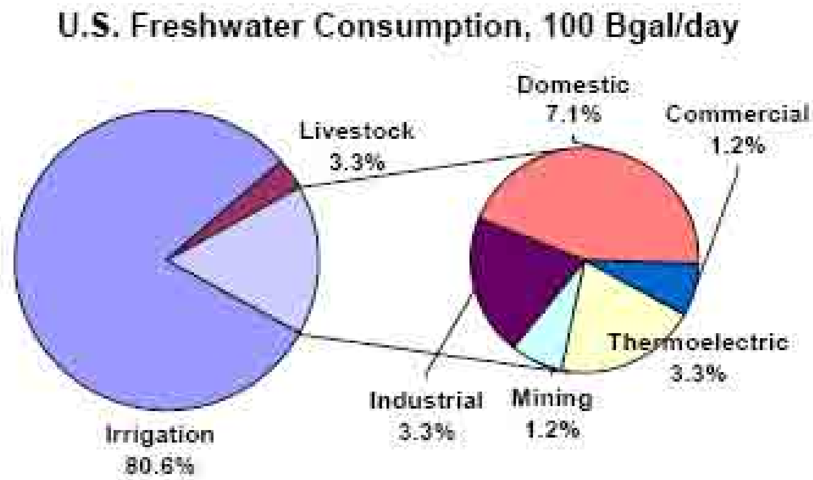
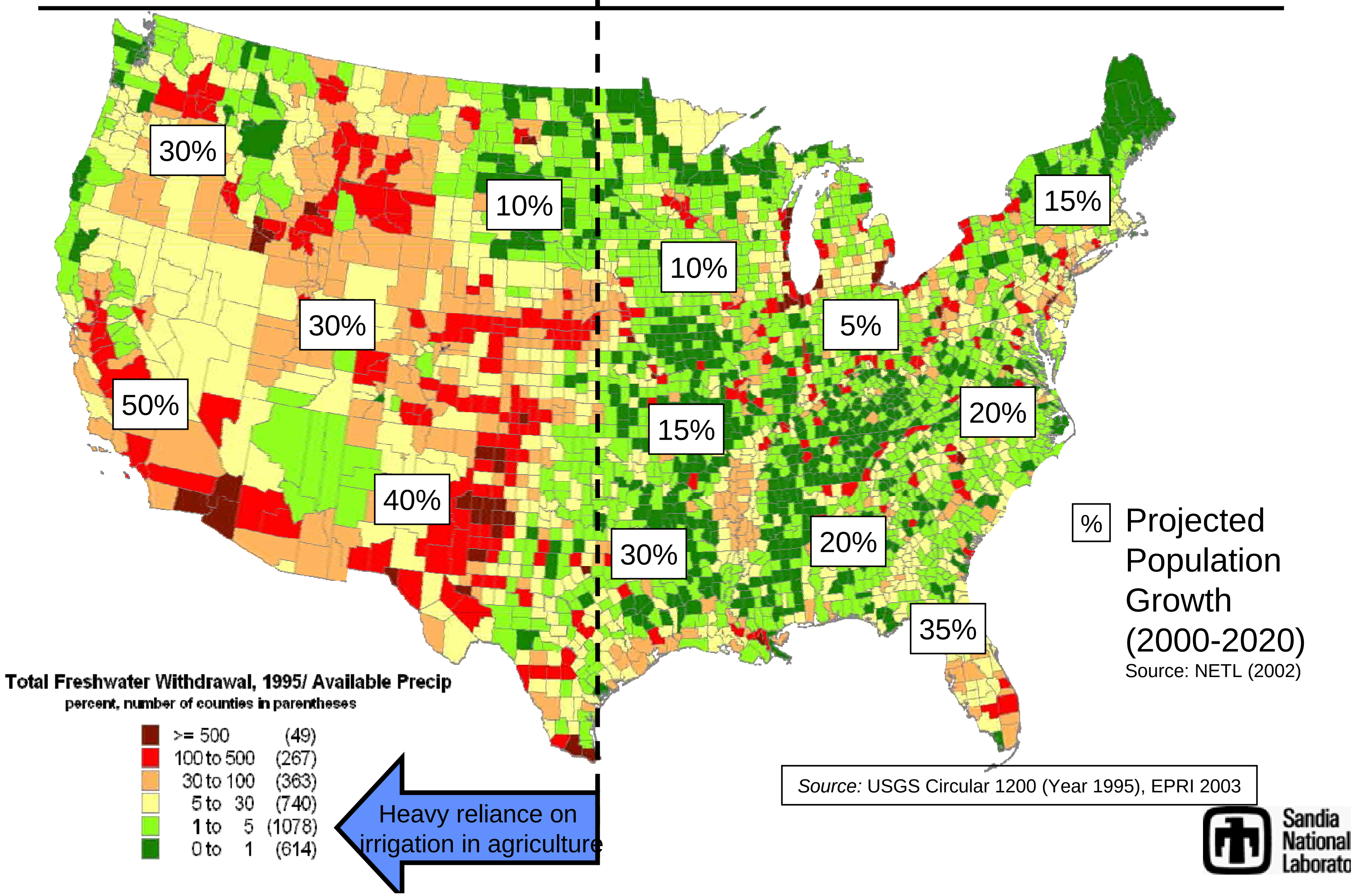


Figure II-4. Estimated Freshwater Consumption by Sector, 1995 (Solley et al., 1998)

Source: 2006 Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water

Effects of Drought, Groundwater Pumping



Project Goals

- Goal is to create "new water" for thermoelectric power plants
- Pilot operations will evaluate options for low cost desalination of two types of waters using nanofiltration:
  - Produced water (CBNG)
  - Cooling tower recirculating water
- Pilot operations end result:
  - Demonstrate a new treatment process to match needs of end use
  - Evaluate potential for new water sources for use in existing power plants

Why nanofiltration?

- Nanofiltration membranes have a high rejection rate for divalent ions and are capable of knocking down TDS significantly.
- Nanofiltration membranes are more tolerant (in general) for fouling conditions, as compared to reverse osmosis.
- Nanofiltration membranes operate at lower applied pressures, as compared to reverse osmosis saves energy and $.

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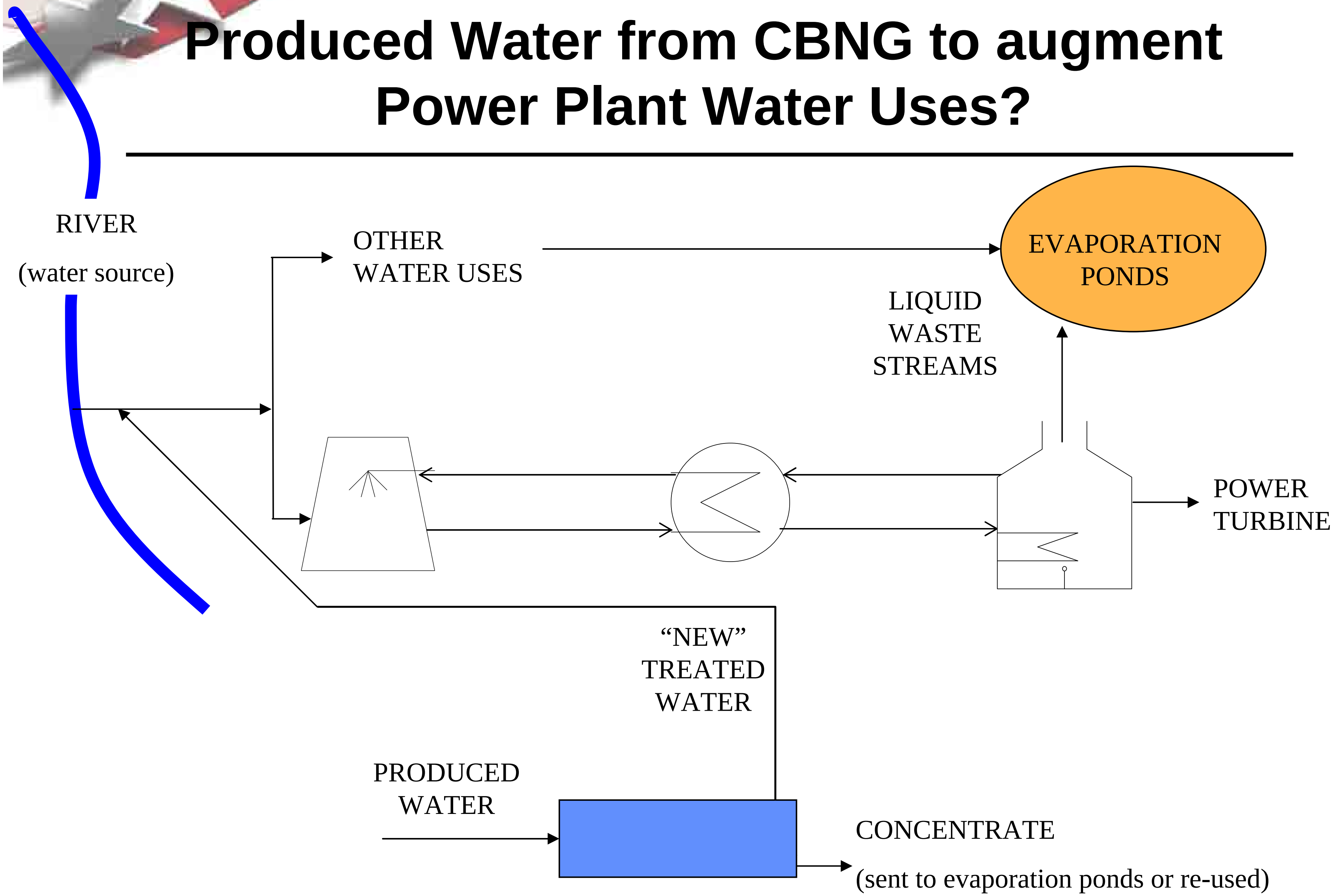
Produced Water from CBNG to augment Power Plant Water Uses?



Simplified Diagram of San Juan Generation Station

Produced Water CBNG Pilot

- **Existing CBNG Produced Water Pilot**
  - **~12,000 mg/L TDS produced water, primarily Na, HCO_3, Cl**
  - **Currently Producing 1-3 gpm of <100 mg/L TDS treated water**

- **NF membranes will replace RO membranes shown at the CBNG Pilot for the current study.**

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Produced Water CBNG Pilot

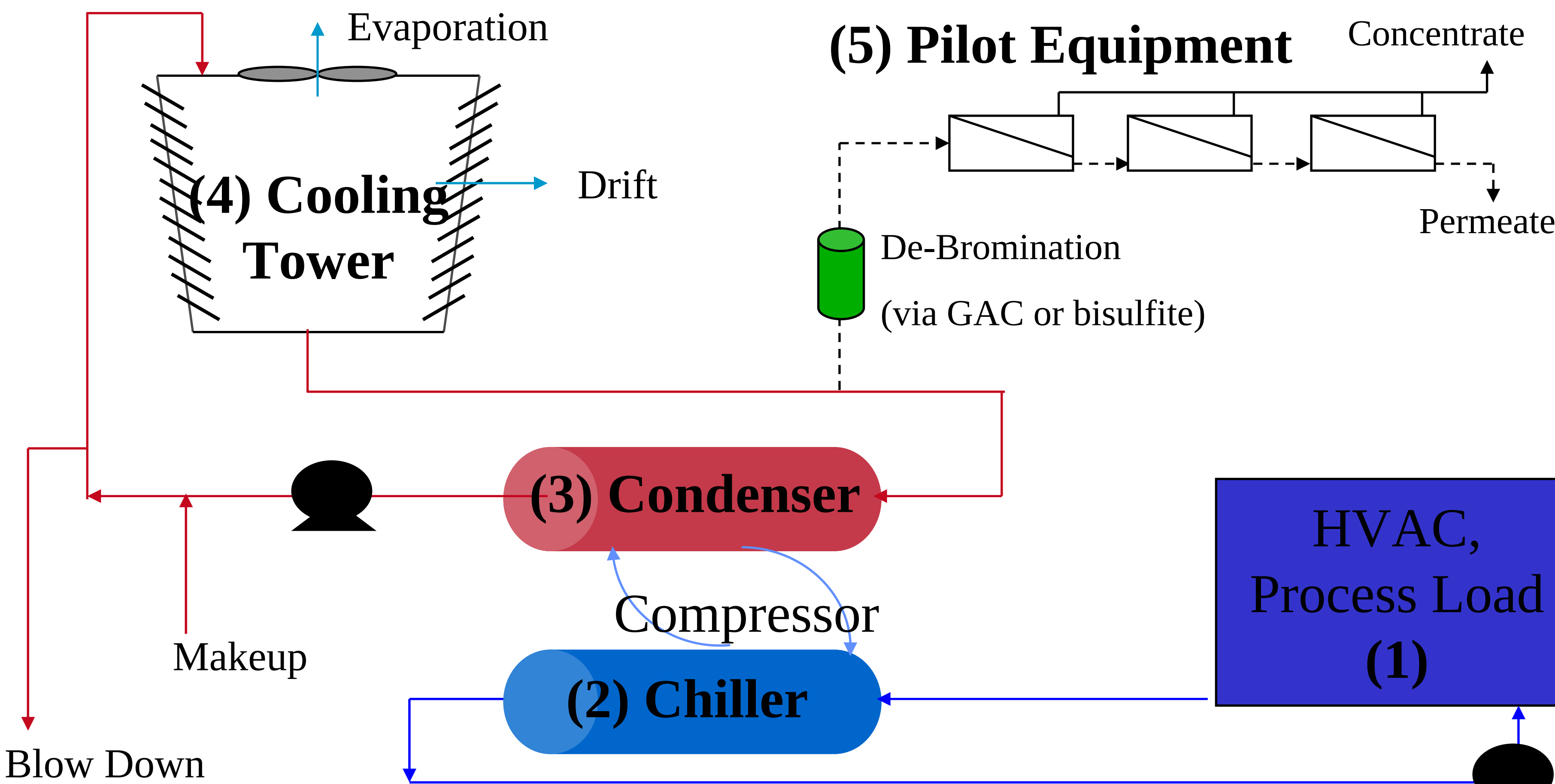
- **Actual RO Pilot Data:**
  - 500-550 psi pressure to RO (primarily due to lack of UF pre-treatment)
  - Operated at ~480 psi with UF pre-treatment
  - Permeate quality is pH 5.6 & 100-150 mg/L TDS
  - Partnering with ConocoPhillips, BEST, NMSU, BLM, OCD

- **Predicted (ROSA©) Nanofiltration Data:**
  - Operate at <300 psi to NF system
  - Permeate quality to be pH 7.0 &1500 mg/L TDS
  - Acceptable to blend with lower TDS water for cooling tower

Produced Water Pilot – Predicted Chemistry (ROSA©)

Name	Feed	After Recycle	NF Concentrate	**NF Permeate**	RO Rejection
Na	6158.38	8422.86	7116.39	**497.15**	89%
Mg	8.34	11.58	9.7	**0.24**	96%
Ca	37.97	52.73	44.17	**1.09**	96%
Ba	39.1	54.29	45.47	**1.11**	96%
CO3	311.55	498.2	384.13	**0.9**	100%
HCO3	10825.82	14664.3	12464.7	**912.44**	88%
NO3	4.12	5.26	4.61	**1.27**	61%
Cl	2941.84	4023.51	3398.14	**237.63**	89%
F	1.01	1.37	1.16	**0.09**	88%
SO4	4.01	5.6	4.67	**0.05**	98%
SiO2	13.65	18.86	15.84	**0.61**	94%
TDS	20345.79	27758.57	23489	**1652.59**	89%
pH	7.86	7.8	7.83	**7.04**	11%

Cooling Tower Pilot



Cooling Tower Pilot

- Install small nanofiltration system on circulation loop
- Partnering with Facilities Engineering group at SNL
- Monitor removal of scale-forming constituents
- All treated, wastewater to drain
- Proof of concept approach

Cooling tower for pilot:
600-1800 gpm
Installed in 1999

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Predicted Cooling Tower Pilot Chemistry (ROSA©)

Name	Feed	After Recycle	Concentrate	Permeate	RO Rejection
Na	176	219	326	27.2	84%
Mg	33	42	64	2.1	94%
Ca	130	165	252	8.1	94%
CO_3	54	69	107	2.1	96%
HCO_3	476	601	912	39.8	92%
Cl	232	289	429	36.0	85%
SO_4	34	43	67	0.8	98%
SiO_2	125	158	239	10.9	91%
TDS	1260	1586	2397	127.0	90%
pH	9.0	9.0	8.9	8.91	N/A

•Reduce/Eliminate feed (well water) with permeate mixture

•Run at higher cycles – conserve water & chemicals (?)

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Project Timeline

Oct-Dec 2008	Install & Operate NF membranes at CBNG Pilot Location – Status Report of Operations
Jan-Mar 2009	Install NF system at SNL cooling tower – Equipment and Modifications to existing HVAC system
April-July 2009	Operate NF pilot at SNL cooling tower –Status Report of Operations
Aug-Sept 2009	Write Final Report –Cost/Benefit Analysis of both pilots' results

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Nanofiltration Treatment Options for Thermoelectric Power Plant Water Treatment Demands

Thank you for your attention.

Questions?

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Mark Rigali, mjrigal@sandia.gov

Acknowledgements: This work is developing under the funding and support of the National Energy Technology Laboratory.

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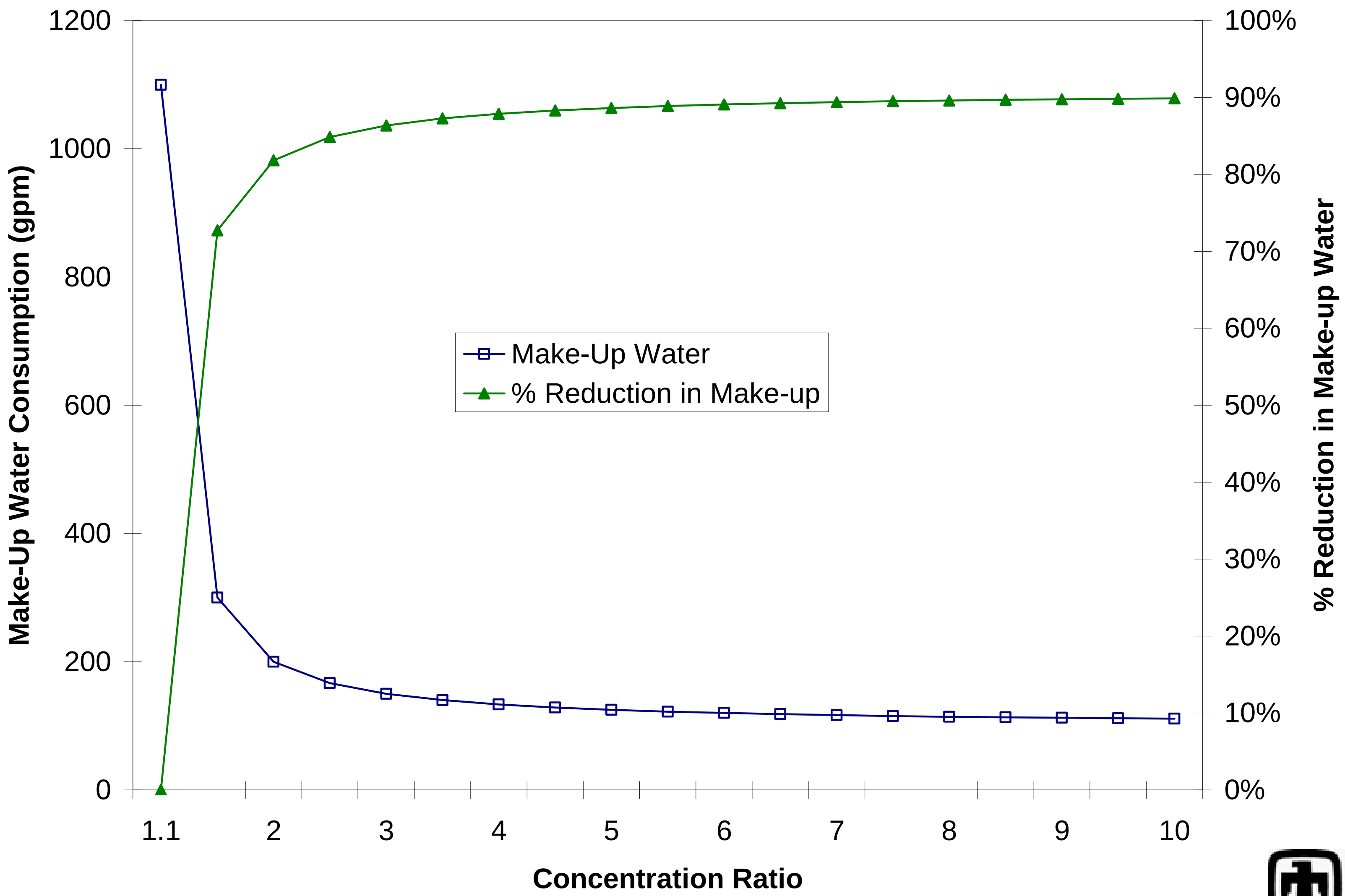
Effect of Cooling Tower Pilot



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