

The Great Lakes and Power Production: A Sustainable Relationship?

David T. Michaud
Session One: Power Generation
Sustainable Water Resources Workshop
Ann Arbor, MI

The Great Lakes: A Quick Primer

- Collectively represent ~18% of the world's fresh water
- Cover nearly 94,000 sq. miles
- Over 25 million people live on or near their shores
- The largest lakes...Superior and Michigan...are well oxygenated, surface to bottom, in spite of their great depth

Lake Michigan and Power Production

- Currently serves as the principal cooling water supply for 15 Investor-owned power plants, 4 of which are nuclear fueled
 - 13 plants utilize once-through cooling
- Numerous multi-year, plant-specific (one lake-wide assessment) studies suggest that operational impacts of these plants on the Lake's aquatic system has been insignificant
- By contrast, Lake Michigan impacts on the plants has been non-trivial and is growing

Lake Michigan Impacts on Power Production

- Lake level fluctuation
 - From 1986-2003 , $-\Delta$ 6 ft
 - Water loss equivalent to 85.6 million ac-ft!
 - Intake, fuel delivery impacts
- Ice flows, frazil ice
- Non-indigenous species
 - Zebra, quagga mussels
- Due to NIS, near shore zone characterized by enhanced Cladophora production
 - Operators now encounter more debris-induced outages

The “New” Lake, Regulations Prompt Design Alterations for Power Planners

- Location for intakes, discharges
 - Navigation, aquatic life considerations
 - Fluctuating water levels, 316 (a, b) regulations
- Cooling water flow, optimal design ΔT
 - energy efficiency, CAA, GCC considerations
- Bio-fouling, anti-fouling treatment strategies
 - NIS, debris loading, frazil ice formation esp. for offshore intakes
- Advanced water treatment systems
 - GLI, also the need to address residuals from APCD's

Conclusions

- Steam electric power plants using cool, clean GL water have the potential to be extremely efficient
 - Maximum power output per unit energy input
 - Efficient power generation is in society's best interest
- There is a need for coordinated regulation to assure that this ideal is achieved
- For society, there's no free "energy lunch"
 - Regulations that impact basic thermal efficiency of plants will have long-term economic impact on energy users
 - APCD's, including closed cycle cooling, **consume energy and water**
 - Need to replace the "power penalty" associated with new APCD applications, especially for retrofits at existing plants
 - CWIS designs need to balance true cost and likely env. benefits
- Integrated environmental impact assessments involving emissions to all media (air , water, land) should be our nation's goal

Conclusions, continued

- Research Ramifications of previous slide:
 - Methodologies to optimize intake design, location, capacity (trade-off with thermal efficiency)
 - Technologies to combat biofouling, ice & debris fouling problems with offshore intakes (offshore location seems preferable for minimizing entrainment concerns)
 - Technologies to minimize trace element release into the aquatic environment from APCD's

Harmonizing Our Goals

Presented by Dennis Leonard

April 5, 2005

Sustainable Water Resources Roundtable

University of Michigan

DOE/Office of Fossil Energy's Power Plant Water Management R&D Program – *Responding to Emerging Issues*

Sustainable Water Resources Roundtable Workshop & Symposium on Research Needs

*Ann Arbor, MI
April 5-6, 2005*



Thomas J. Feeley, III
Technology Manager
thomas.feeley@netl.doe.gov

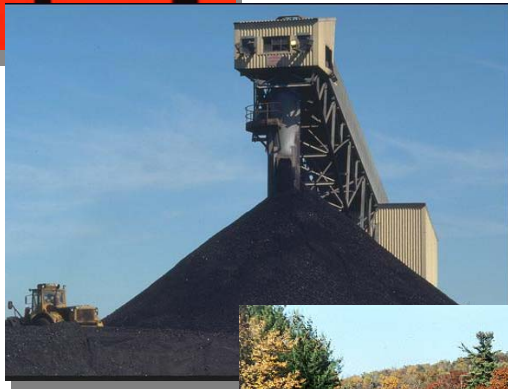
US Department of Energy/National Energy Technology Laboratory



Three Things Power Plants Require



1) Access to transmission lines



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

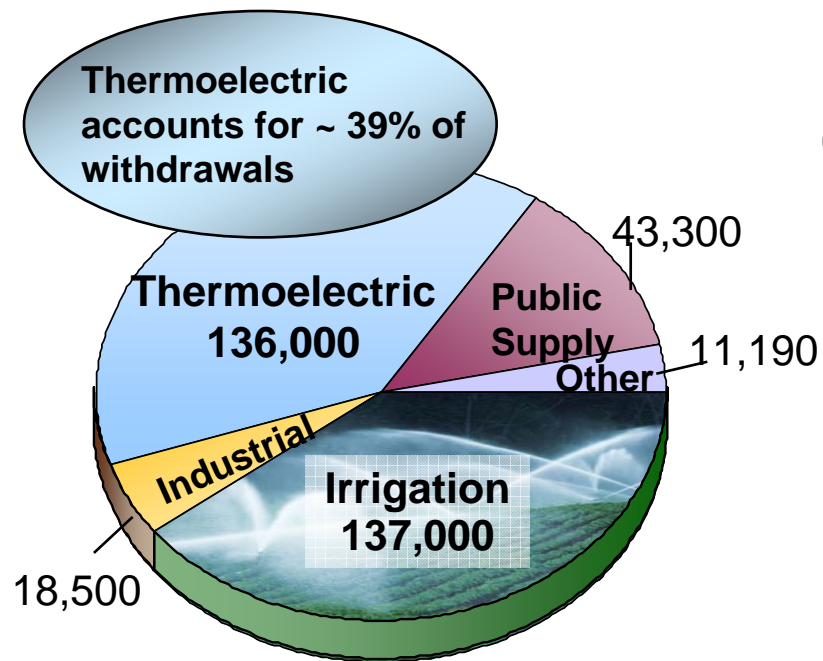


3) Water

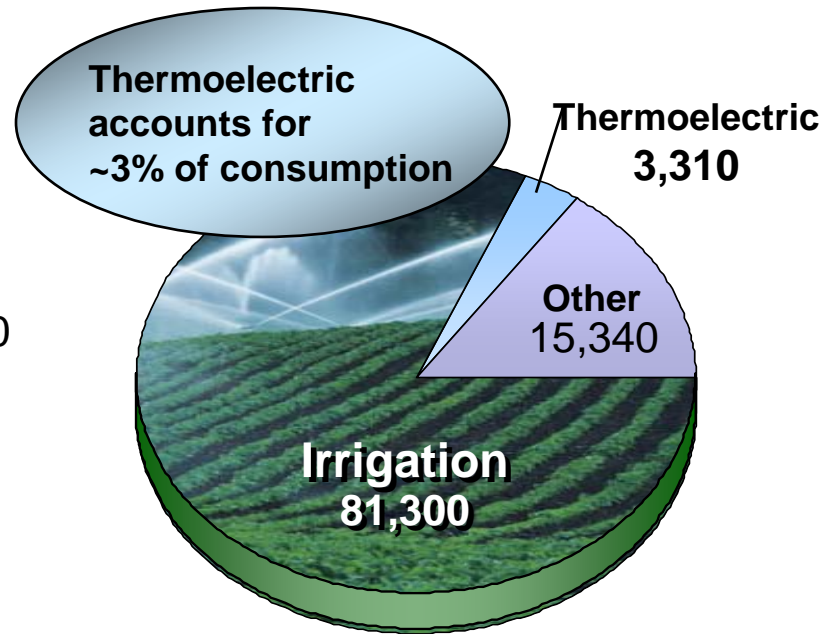


Freshwater Withdrawals and Consumption

Mgal / Day



Withdrawal



Consumption

Water is essential in generation of thermoelectric power!



Ref.: "Estimated Use of Water in the United States in 1995," USGS Circular 1200, 1998

"Estimated Use of Water in the United States in 2000," USGS Circular 1268, March 2004

Sufficient Water for Power Plants is a National Issue

- **Driven by:**
 - Regional, state, and local constraints on water availability
 - Competition from other use sectors such as
 - Agriculture
 - Industrial
 - Domestic
 - In-stream
 - Environmental regulations, e.g., §316 (a) and (b)

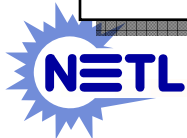
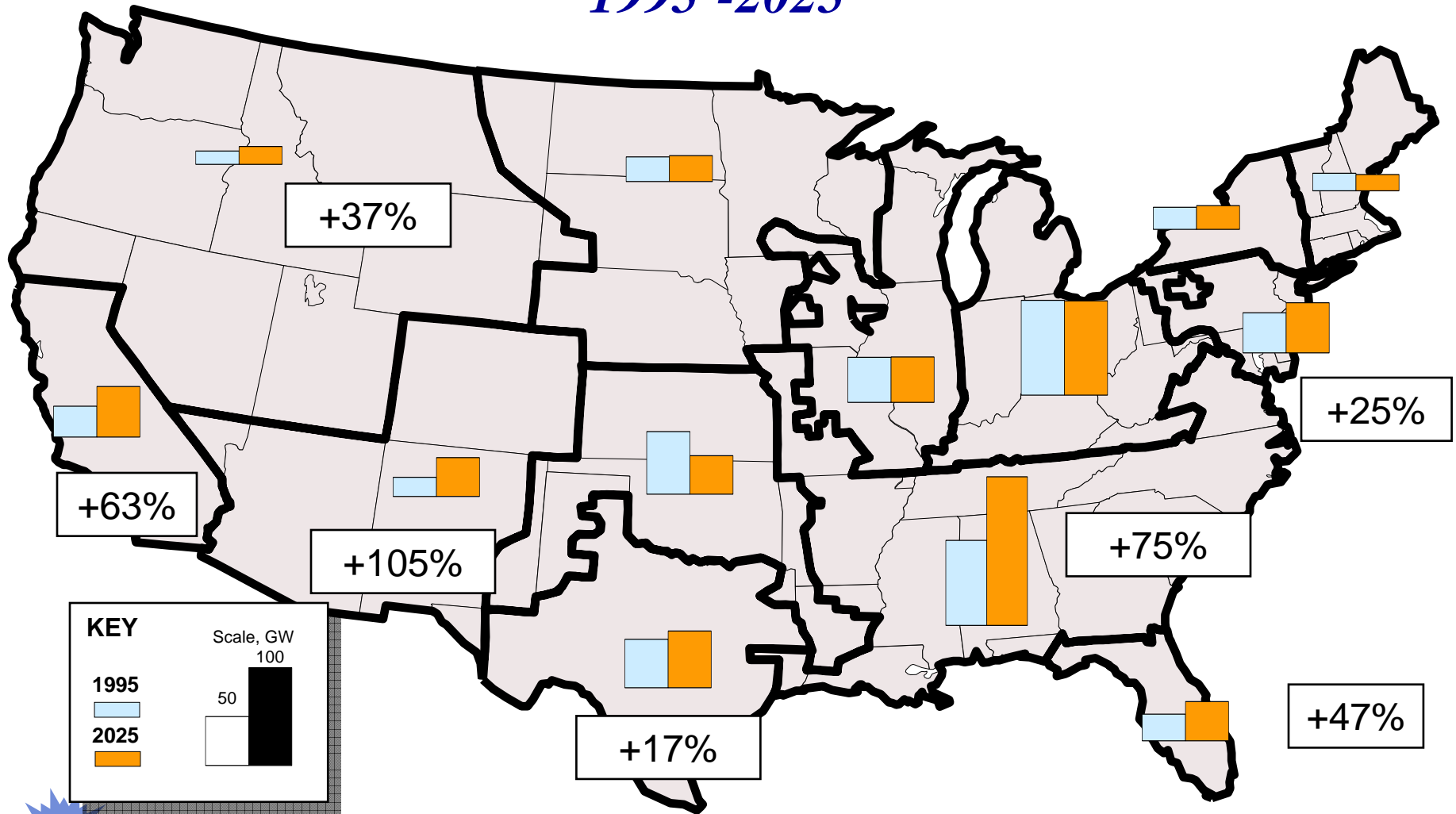


In the News -- Water-Related Impacts on Power Plants

- **Feds Order Susquehanna Power Plants and Others to Stop Killing Fish**
 - Lancaster (PA) New Era, February 24, 2005
- **Nevada Residents Wary of Sempra Water Rights Purchases**
 - Greenwire, February 22, 2005
- **Enviros Say Wisconsin Energy Plant Discharges Could Harm Fish**
 - Greenwire, February 17, 2005
- **Missouri River Power Plants Potentially Affected by Varying River Levels**
 - Platts Energy Bulletin, February 15, 2005
- **Nevada Power Plant Threatens Honey Lake Valley Water**
 - Lasson County (NV) News, January 25, 2005

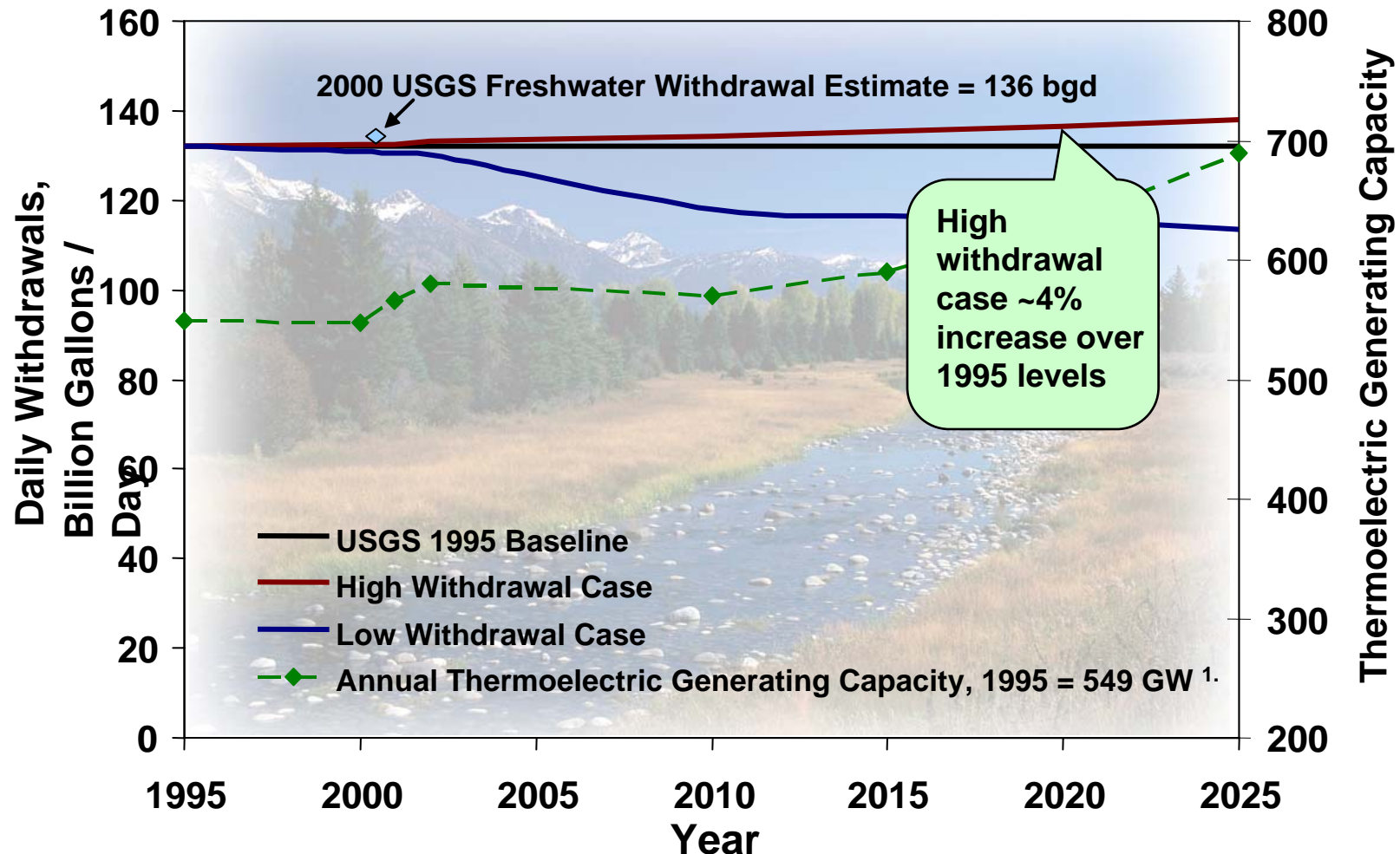


Comparison of Regional Thermoelectric¹ Generation Capacity by North American Electric Reliability Council Region, 1995²-2025³



Notes 1. For combined-cycle capacity, thermoelectric capacity is assumed 1/3 of generation capacity.
2. Source: Energy Information Agency, AEO 1997
3. Source: Energy Information Agency, AEO 2005

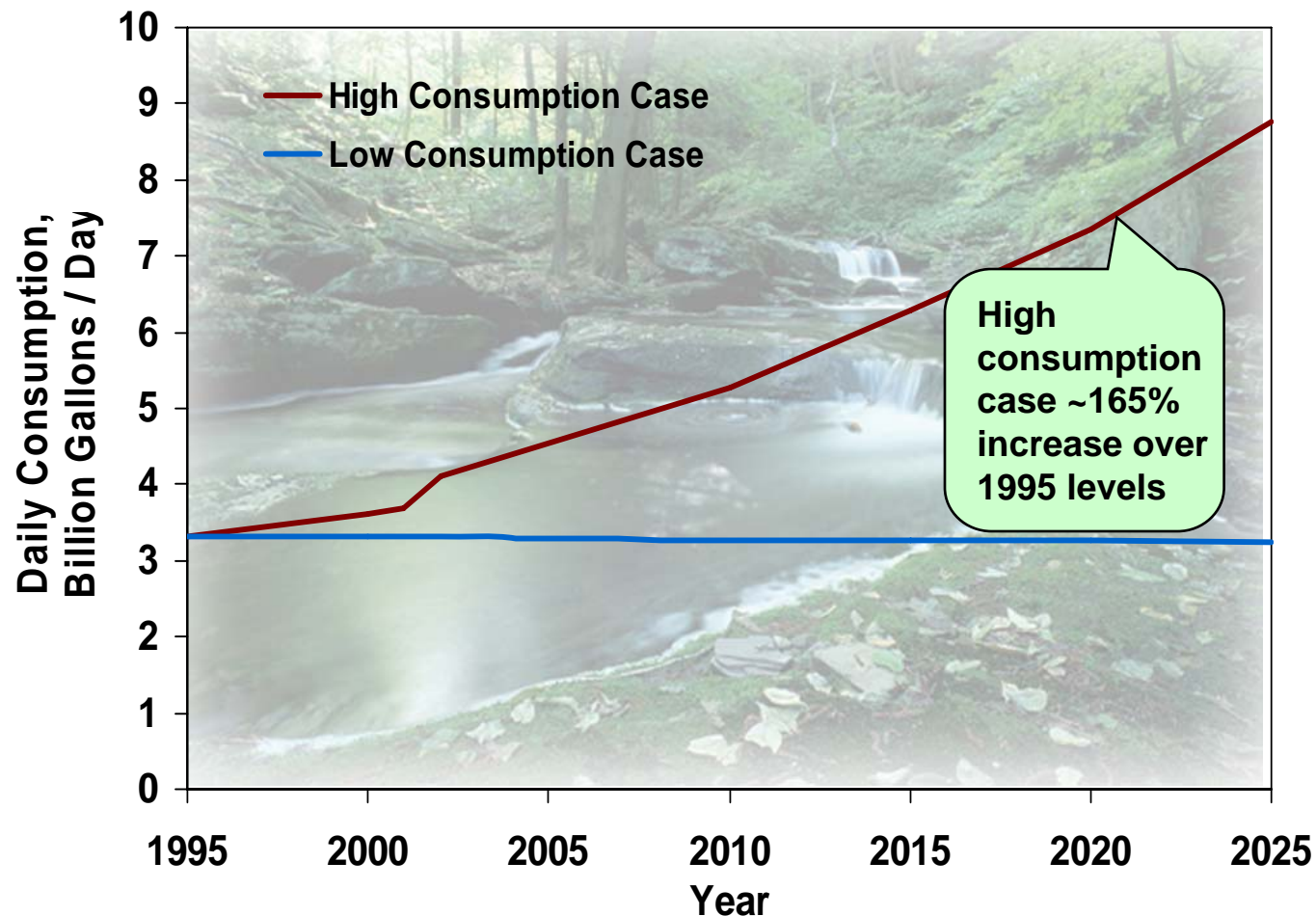
Daily Freshwater Withdrawals Needed to Meet Forecasted Increases in Thermoelectric Capacity



Ref. DOE/NETL, "Estimating Freshwater Needs to Meet 2025 Electricity Generating Capacity Forecasts," June 2004.



Daily Freshwater Consumption Needed to Meet Forecasted Increases in Thermoelectric Capacity



Ref. DOE/NETL, "Estimating Freshwater Needs to Meet 2025 Electricity Generating Capacity Forecasts," June 2004.

Key Takeaways

- Water will be required to meet future electricity demand
- On national basis freshwater withdrawals for new fossil-based generating capacity may either increase slightly or decrease through 2025, while freshwater consumption could increase significantly
- Water is also a regional issue:
 - Population growth and concomitant increases in electricity demand will occur in regions that are water challenged
- Demand for water for power will increasingly compete with other sectors such as agriculture, industrial, domestic, and in-stream use – **who gets water first?**



DOE/FE's National Energy Technology Laboratory Power Plant Water R&D Program *Research Objectives*¹.

- **Reduce withdrawal of fresh surface and/or ground water for thermoelectric power generation**
 - Reduce withdrawals and consumption by 5%-10% by 2015
- **Minimize potential impacts of power plant operations (both air emissions and effluent discharges) on water quality**

¹DOE/CURC/EPRI "*Clean Coal Technology Roadmap,*" www.netl.doe.gov



Future Plans

- Issued targeted solicitation, ***“Advanced Technologies and Concepts to Minimize Freshwater Use in Coal-Based Thermoelectric Power Plants,”*** on April 15, 2005
 - Use of Non-Traditional (Impaired) Water
 - Advanced Cooling Technology
 - Advanced Water Recovery and Reuse Technology
 - Use of Produced Water from Carbon Sequestration
- Anticipate **\$3.5-\$4 million in project funding over next 3 years**





**“When the well runs
dry we know the
worth of water.”**

– Benjamin Franklin

***To learn more about NETL’s energy-
water R&D activities, please visit us
at:***

<http://www.netl.doe.gov/coal/E&WR/index.html>



- Great lakes Water Levels are affected by a number of variables
- Precipitation, Temperature, Industrial water use, municipal water use and diversions are commonly understood variables.
- However, diversions account for a net increase, not decrease in water entering the basin

(graph comparing the Long Lac and Ogoki inflows to Lake Superior to the Chicago canal outflow from Lake Michigan)

Additionally land use changes and the associated changes to the basin's evapotranspiration, changing relative elevations of the Upper and Lower lakes, and changes brought about by navigation are often overlooked in analyzing the lakes

(Graph comparing relative impact to be inserted later)

The lakes are impacted by numerous variables and man is controlling lake levels to a large extent. The lakes are no longer a natural system.

- Some of the proposals and suggestions under the Annex have sought to minimize any additional use, even non-consumptive uses of the lakes
- However, the lakes have been altered by both man and nature. Man will likely try to overturn the major alterations caused by nature. (e.g., greater natural rebounding of the earth's crust in the upper basin.)
- How should we look at new water uses and sustainability?

- Production of electricity is also affected by a number of different goals
- 4 major factors affect a new power plant's use of water.
 - ✓ 316
 - ✓ Annex
 - ✓ Energy policy's focus on efficiency
 - ✓ Economic competition

First we have the EPA 316 rule which is narrowly focused on a single issue - minimizing fish entrainment and impingement through the use of cooling towers.

Cooling Towers however cause about twice as much evaporation or consumptive water use as once through systems.

(Figure to be inserted here)

Second we have the Annex which seeks to limit consumptive uses of the Great Lakes, but has yet to resolve the trade-offs associated with withdrawals, consumptive uses and diversions; or economic and societal trade-offs.

Third we have a new emerging Energy Policy which among other things encourages efficiency. More efficient power production reduces all air, water and land impacts on the environment.

Cooling towers required by the Clean Water Act rules for new power plants are less energy efficient than once through cooling and are inconsistent with the Federal Energy Policy.

Forth, we have Competition. Power producers in the Great Lakes' basin are competing with each other and with power producers outside of the basin as a result of deregulation. As a result of globalization and free trade with China, industry in the basin has to compete with cheap labor and lax environmental standards in Asia.

How do we harmonize these 4 sometimes conflicting goals which effect power plants and the multiple variables affecting the lakes?

-
- Through innovation and environmental programs that have a broad, rather than narrow scope. Innovation allows North American industry to rise above the global challenges and we need to look towards innovation and flexibility in environmental programs to harmonize our goals of growth and stewardship.
 - We certainly need to address fish protection issues, but we should not have regulations which needlessly prevent innovation.
 - Given more reasonable criteria we could likely discover new technology that would minimize impingement and entrainment yet allow the more energy efficient and less consumptive once through cooling designs.
 - We certainly shouldn't allow frivolous diversions of water far outside of the basin to western North America or Asia, but given our present ability to manipulate large volumes of water in the basin, we should be able to find some way to serve growth in industry and municipalities.

Conflicts and Opportunities at the Energy~Water Nexus

***Sustainable Water Resources Roundtable
April 5-6, 2005***

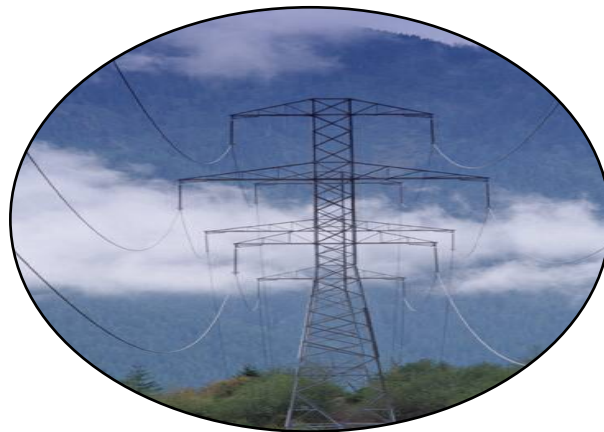
***Presented by John Gasper
Strategic Area Manager
Environmental Assessment Division***

***Argonne National Laboratory
Operated by The University of Chicago
for the U.S. Department of Energy***



Energy and Water are Fundamentally Linked

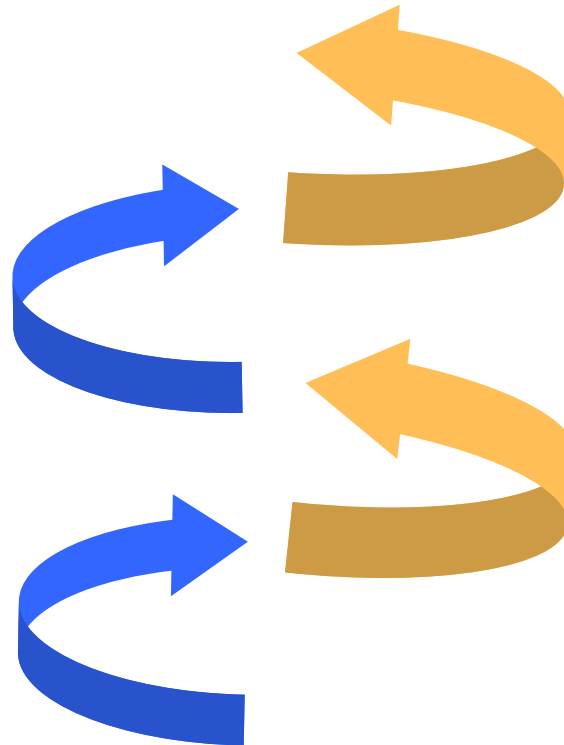
Energy production and generation require water



Water pumping, treatment, and distribution require energy

Costs of Energy and Water are Self-Reinforcing

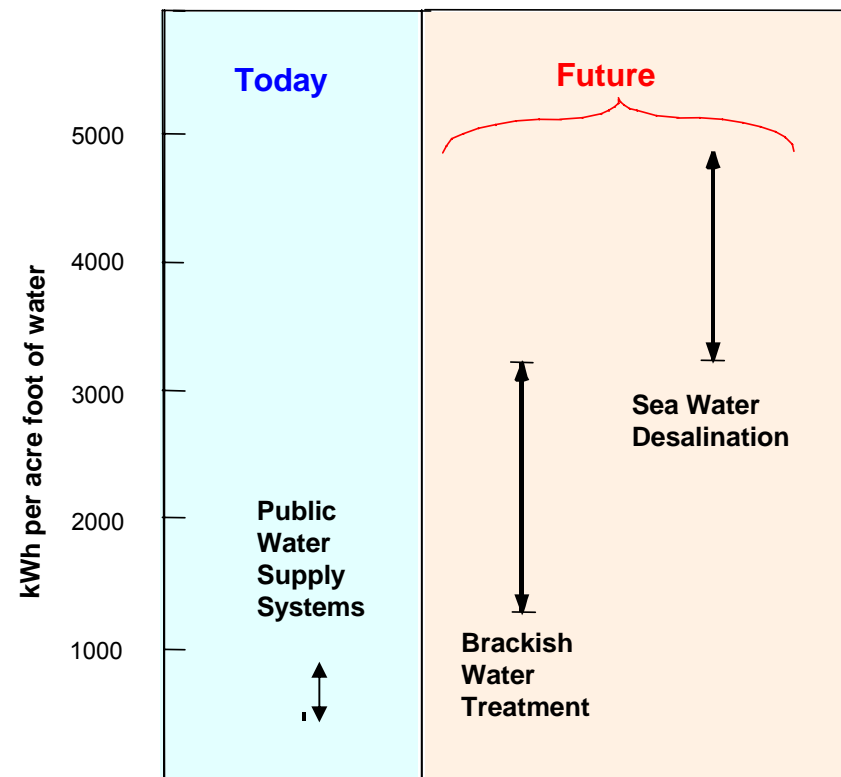
- **As water availability decreases, cost increases**
- **As water cost increases, energy cost increases**
- **As energy cost increases, water cost increases**
- **And so on.....**



Treatment of Future Water Supplies Will Be Energy Intensive, Increasing Energy Demand

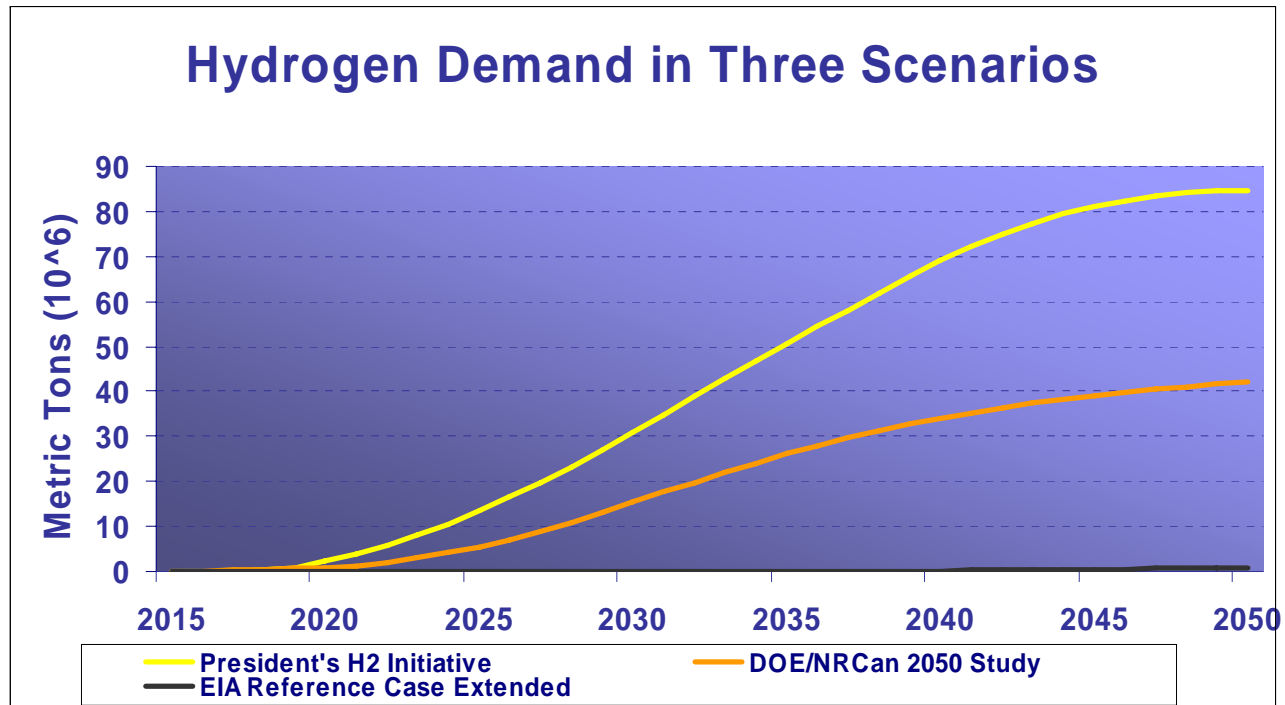
- **Readily accessible water supplies have been harvested**
- **New technologies are required to reduce energy requirements to access non-traditional sources (e.g., impaired water, brackish water, or sea water)**

Power requirements for current and future water supply



Source: Energy Water Nexus Initiative 2004

Future Energy Demand and Supplies Will Add to Water Demand



- **New Hydrogen Water Demand**
 - 35 gals/Kg H₂ via high temperature electrolysis (~70-450 Bgals/yr in 2050)
 - 5 gals/Kg via methane steam reforming (~25-65 Bgals/yr in 2050)
- **Biomass, coal liquefaction, coal gasification, others**

Sources: ANL, Singh, M. ORNL, Binder, J , 2004

Legal, Institutional Barriers Potentially Limit Availability of Water for Energy

- **Water allocation/use is based on complex array of legal contracts**
 - Allocation Doctrines
 - *Riparian rights/Prior Appropriation*
 - Treaties
 - *Interstate Water Compacts*
 - *International Water Treaties (Mexico, Canada)*
 - *Indian Tribal Water Rights*
 - Environmental Regulations
 - *Water Quality*
 - Thermal, Chemical
 - *Entrainment, impingement*
 - *Endangered species*

- **U.S. water allocation/use structure not easily modified**

Broader Factors Increase Uncertainties for Water and Energy

- **Economic Activity**



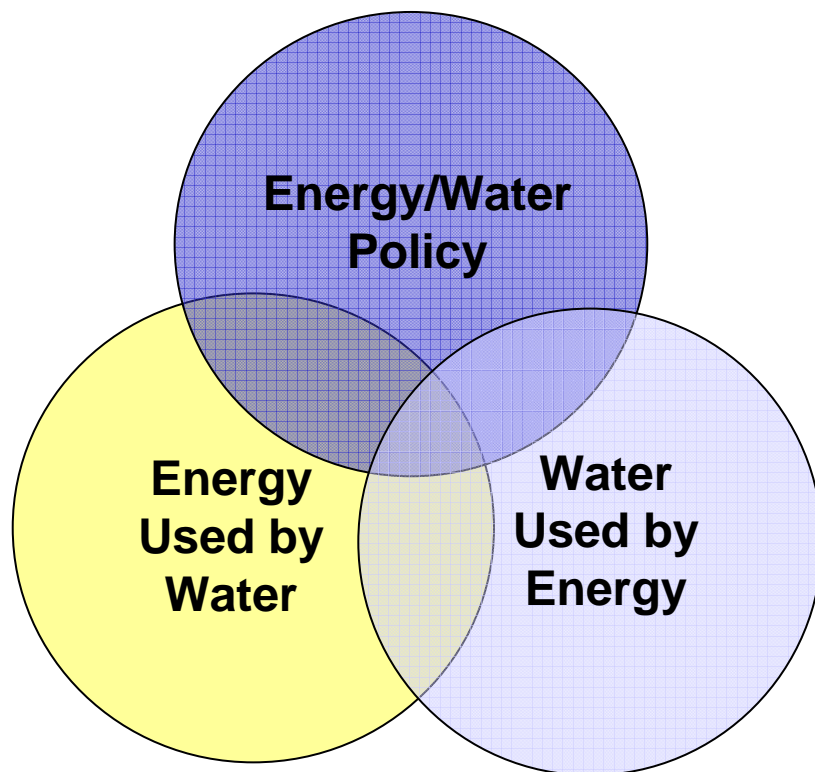
- **Weather**



- **Climate**



Science and Technology Can Play Critical Role Resolving Conflicts at the Energy~Water Nexus



- *Assessment, Prediction, Decision Support*
- *Basic Science*
- *Technological Innovation and transfer*

New Science and Technology Opportunities Abound

- Policy Decisions
 - Advanced understanding of interdependencies between water, energy and other critical infrastructures
 - Tools for integrated analysis, visualization of complex interdependent systems
 - Quantification of water needs for sustainable energy development
- Energy and Water Efficiency
 - High-performance, high-resolution computer simulation capabilities
 - Advanced sensors and controls
- Impaired Waters
 - Materials separation, tribology, nano-science
 - Advanced water treatment and water reuse technologies

Growing Federal Awareness Science and Technology has a Critical Role at the Energy~Water Nexus

- **Administration**

- *Department of Interior - Water 2025: Preventing Crisis and Conflict in the West*
- *Department of Energy – Selected, technology focused water assessments*

- **Congress**

- Energy Policy Act of 2003, Section 961, Subtitle (f) Water and Energy Sustainability Program
- Energy and Water Appropriation - FY2005
 - *Calls for DOE to assess water for energy, energy for water and develop R&D program plan*
- Water Supply Technology R&D Act
 - *S. 2658, H.R. 4835 Call for \$200M/y, National Lab-centered, University-partnered, technology-focused program to increase water supply*

The Interrelationship of Energy and Water will be of Increasing Importance

- **Growing conflict at energy~water nexus on national, regional, local levels**
- **R&D including assessment, basic science and technology innovation can play an important role in reducing potential conflicts**
 - Policy decisions
 - Water and energy efficiency
 - Use of impaired waters
- **Energy~Water Nexus becoming a national priority**



**ACC at PacifiCorp's Wyodak Power
Plant (courtesy of R. Garan)**

EPRI Advanced Cooling Program

Kent D. Zammit
Environment Sector
EPRI
650-855-2097
kezammit@epri.com

Program Goals

- Use Degraded Water Sources
 - Preserve evaporative cooling option
 - Identify known sources and treatment requirements
- Address capacity and efficiency penalties of dry cooling
- Investigate other water conservation alternatives

Advanced Cooling Deliverables

EPRI FUNDED WORK

- *Comparison of Alternate Cooling Technologies for U.S. Power Plants – Economic, Environmental, and Other Tradeoffs*, August 2004, 1005358
- Advanced Nozzle Development for Spray Cooling of ACCs

CEC-PIER FUNDED RESEARCH

- *Use of Degraded Water Sources as Cooling Water in Power Plants*, 2003, Published as CEC report
- *The Formation and Fate of Trihalomethanes in Power Plant Cooling Water Systems*, March 2004, 1009486
- *Water Quality Parameters for Cooling Systems*, Published as CEC report
- *Cost and Value of Water Use at Combined-Cycle Power Plants*, Draft report in review\
- *Spray Cooling Enhancement of Air-Cooled Condensers*, September 2003, 1005360

DOE FUNDED RESEARCH

- *Use of Produced Water in Recirculated Cooling Systems at Power Generating Facilities*

Advanced Cooling – Current Research

EPRI Funded Research

- ACC Seminar and Advanced Cooling Conference
 - May 31 (seminar) June 1&2 (conference), Sacramento CA
- ACC Design and Operational Guidelines – effort started in 2004, report due mid-2005
- Potential Advanced Cooling Interest Group

CEC Funded Research

- Spray Enhancement Testing at Reliant Bighorn Station
 - Includes testing of one advanced spray nozzle design
- CEC funding Advanced Cooling Conference (see above)
- Wind Effects on Air Cooled Condensers – 2 new projects
 - Kroger – CFD modeling of ACC wind effects
 - Maulbetsch – Survey of US wind impacts and potential mitigation
- Salt Water Cooling Towers (new)

Advanced Cooling – Current Research (cont.)

DOE FUNDING

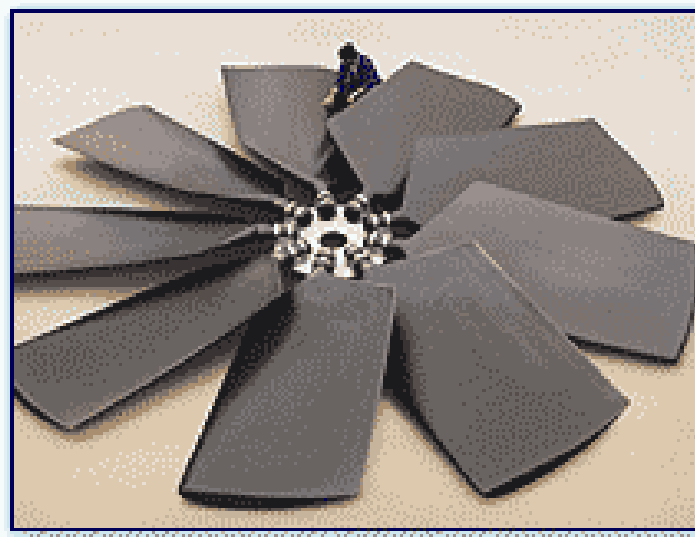
- Use of Produced Water in Recirculated Cooling Systems at Power Generating Facilities
 - Ceramem testing on ceramic membrane wastewater treatment beginning next month
 - Complete project and issue final report by August 2005

ZERONET FUNDING (through DOE-NETL)

- Testing of Wet Surface Air Cooler Technology for primary cooling
- Testing summer 2005 with cooling tower blowdown as makeup to WSAC
- Planned testing (unfunded) of WSAC using produced water

Future Advanced Cooling Research

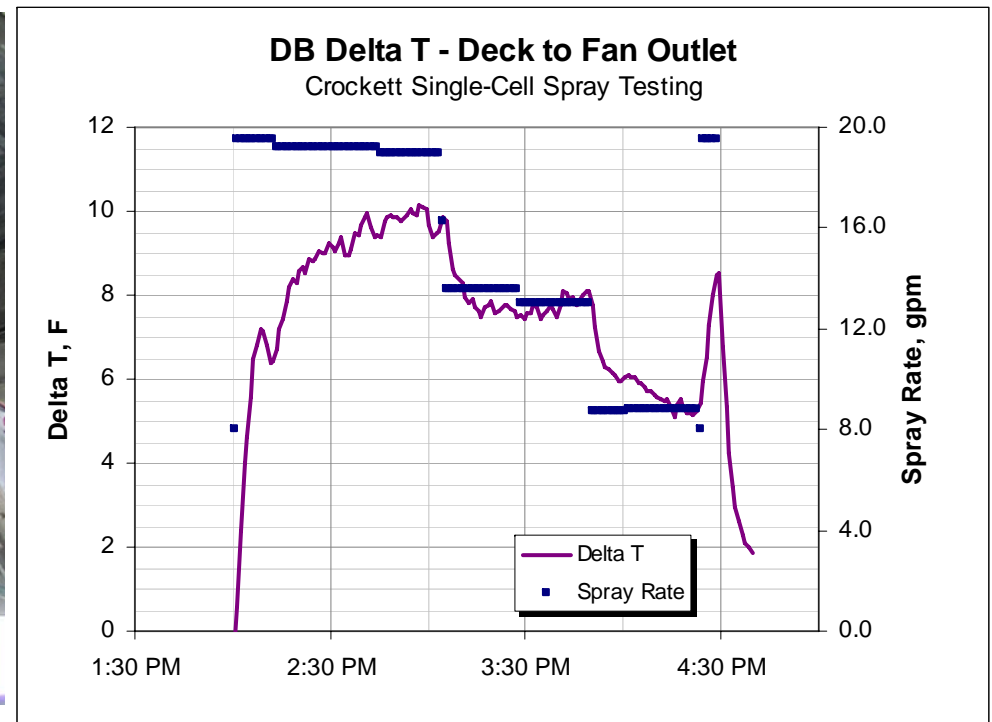
- Mitigation of wind impacts on ACCs
- Development of advanced spray enhancement systems
- Testing of WSAC on other degraded water sources
- Salt and brackish water cooling towers
- Proof of concept on produced water and other degraded water sources



Low-Noise Fan
(courtesy of Howden Fans)

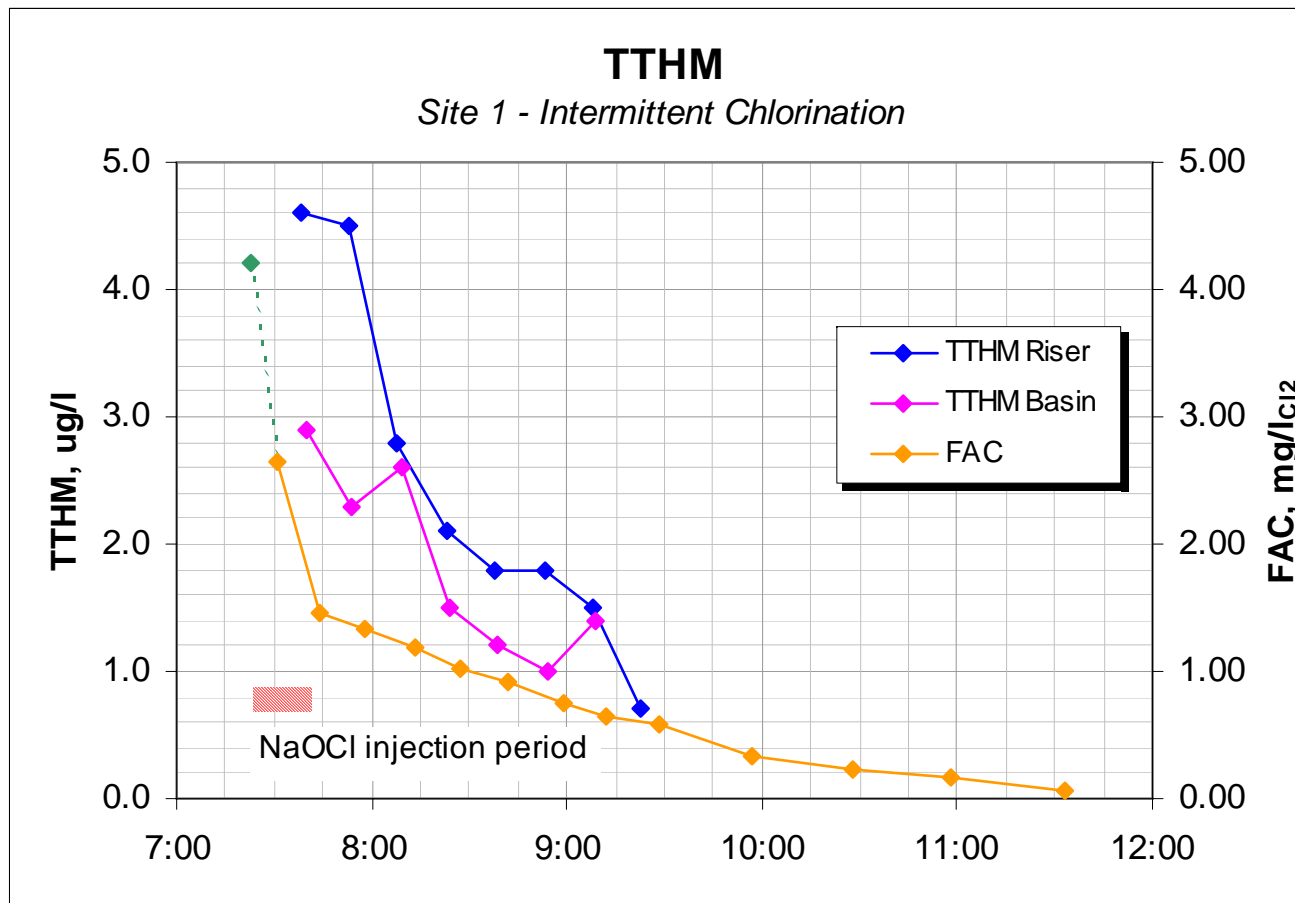
Spray Enhancement of ACCs

- The allocation of cooling water in modest quantities (less than 10 to 15% of what would be required annually for the use of recirculating wet cooling) was shown to reduce the hot day penalties by 50% or more



Formation and Fate of Trihalomethane

- THM compounds (carcinogenic) will form when organics are halogenated – exposure is a concern



Produced Water Project
EPRI/DOE-NETL/PNM
San Juan Generating Station



PNM Water Issues in the San Juan Basin.....

- San Juan Generating Station (SJGS) consumes 22,000 acre-feet of water per year (467,600 BPD or 13,640 gpm)
- SJGS needs a reliable source(s) of water to operate
- There are continuing political pressures to use less water in New Mexico
- Researchers Predict a long-term drought for the region
- SJGS is a long-term energy production site – it will be there 25 years from today
- PNM has negotiated short-term and long-term water contracts to ensure supply
- Endangered species in the San Juan River will likely reduce the reliability of water supply
- If SJGS uses less water through conservation and obtains alternative supplies (e.g. produced water), more water will be available for others in the San Juan Basin

PNM Project Benefits.....

- Conserve river water for other beneficial uses in New Mexico
- Reduce the diversion of water from the San Juan River for cooling at San Juan Generating Station
- Enable the San Juan Generating Station to be more drought resistant

Oil & Gas Producer Benefits.....

- Reduce the volume of produced water that must be handled and injected
- Establish an infrastructure to minimize produced water injection in the San Juan Basin
- Establish area-wide opportunities to reduce produced water handling and injection costs

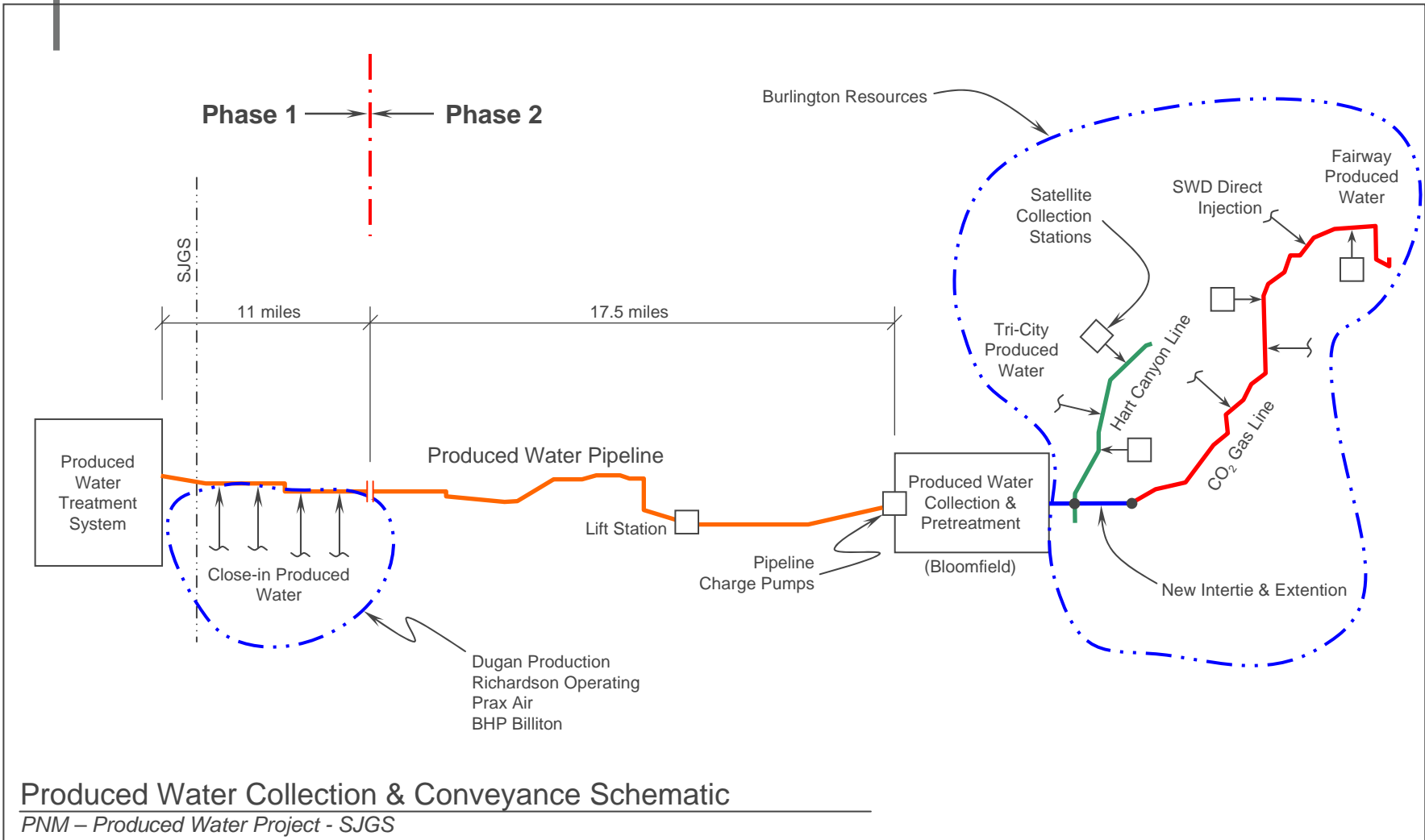
The project would be implemented in two phases.....

Phase 1

- An 11-mile pipeline would be build to collect water from Close-in producers (exclusively CBM production)
- Producers would inject filtered water into the line
- Producer disposal costs reduced by \$0.25/bbl

Phase 2

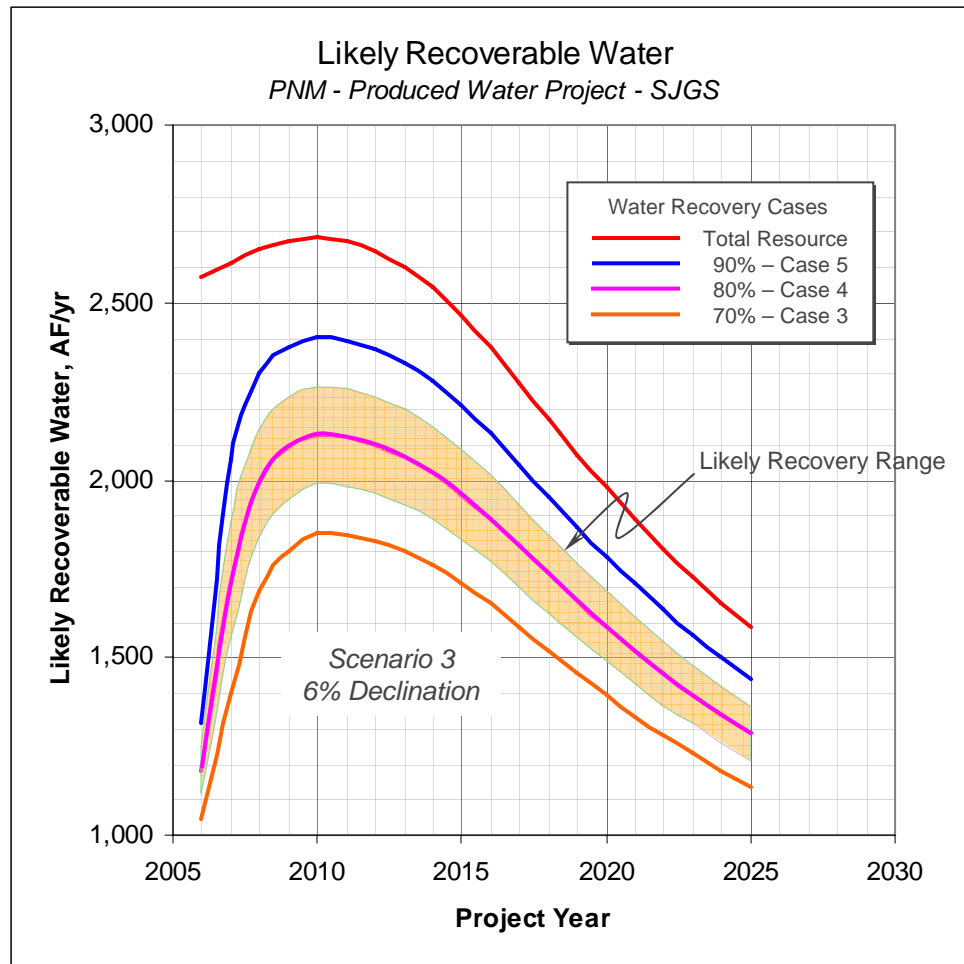
- PNM would extend the pipeline an additional 17.5 to Bloomfield
- Burlington resources would refurbish two existing pipelines and install satellite collection stations to gather theirs and other producer's water in areas of heavy tanker-truck traffic
- PNM would build a collection Center in Bloomfield to accept and pretreat water gathered by Burlington Resources
- Producer disposal costs reduced by up to \$1.00/bbl
- Some SWDs could be put on stand-by and the life of costly injection wells (\$1.5 to \$2.5 million per well) would be extended



Produced Water Collection & Conveyance Schematic

PNM – Produced Water Project - SJGS

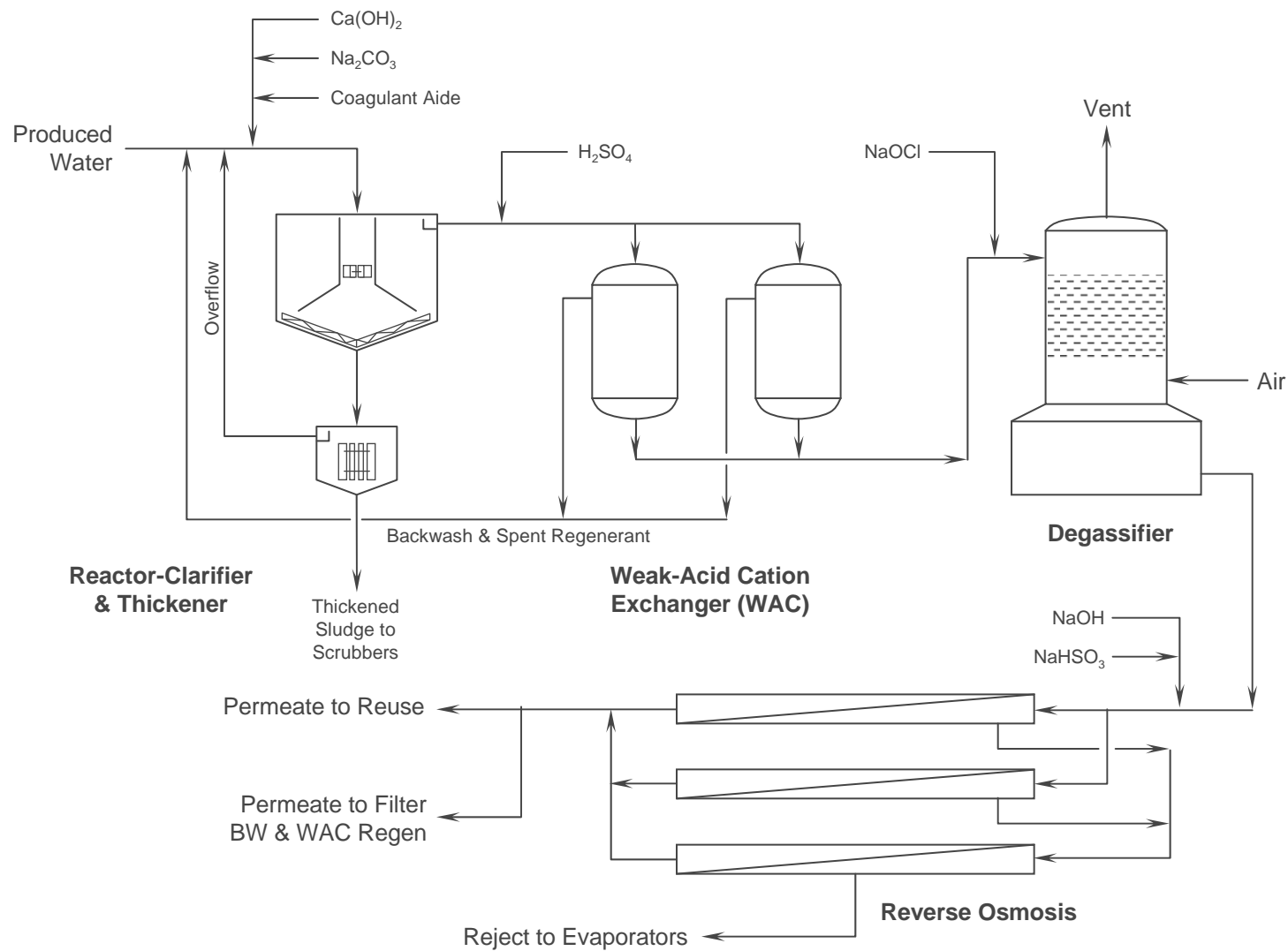
Life-of-project recoverable water.....



McGrath SWD (Salt Water Disposal) Facility



McGrath is a large, well-operated SWD near Farmington, New Mexico. Produced water generated at the wellhead is transported by tanker trucks to SWDs. At the SWD, oil is separated from the produced water. The water is then filtered and injected into a non-producing formation at depths that sometimes reach 5,000 feet. In some locations, injection pressures exceed 1,500 psi. There are 53 SWDs in the San Juan Basin.



Produced Water Treatment System – HERO® (High Efficiency Reverse Osmosis)

San Juan Generating Station

Project Economics.....

- Produced water project economics are based on capital/operating costs as well as a revenue stream
- The capital cost of PNM's portion of the project would be \$38 million
- The producers capital investment would be \$5 million
- PNM's operating costs, which would include treatment chemicals, power, labor, materials, maintenance and capital recovery costs, would be offset by two revenue streams
- The first revenue stream would be a tax credit of \$1,000/AF provided by the State of New Mexico (the tax credit would have an annual limit and life-time cap)
- The second revenue stream would be a share of the savings derived from reduced disposal of produced water and deferred costs of injection wells
- Depending on the revenue scenario, the 20-year, life-of-project costs would vary as follows:

50-50 Share of producers savings with the New Mexico tax credit	\$720 to \$970/AF
50-50 Share of producers savings without the tax credit	\$1,200 to \$1,500/AF
<i>No revenue streams</i>	\$2,500 to \$3,000/AF

Wet Surface Air Cooler (WSAC) Project *San Juan Generating Station*



Full size WSAC in Gallop, New Mexico

WSAC Pilot Test.....

- The Wet Surface Air Cooler (WSAC) utilizes deluge spray water to indirectly release heat from cooling water for a power plant
- WSAC is established, off-the-shelf technology
- Deluge cooling allows the WSAC to operate at higher concentrations of cooling water than in a conventional cooling tower
- WSAC cooling could take the wastewater from the cooling towers (blowdown) plus produced water and carry a significant portion of the cooling load at San Juan Generating Station (SJGS)
- The amount of freshwater saved by WSAC would be equal to blowdown (made-up to the WSAC) plus produced water
- The first phase of testing at SJGS will determine to what extent cooling tower blowdown can be utilized in the WSAC
- The second phase will determine to what extent produced water can be used for cooling



WSAC Spray Section (courtesy of Niagara Blower)

Wet Surface Air Cooler

① Air is induced downward over tube bundles

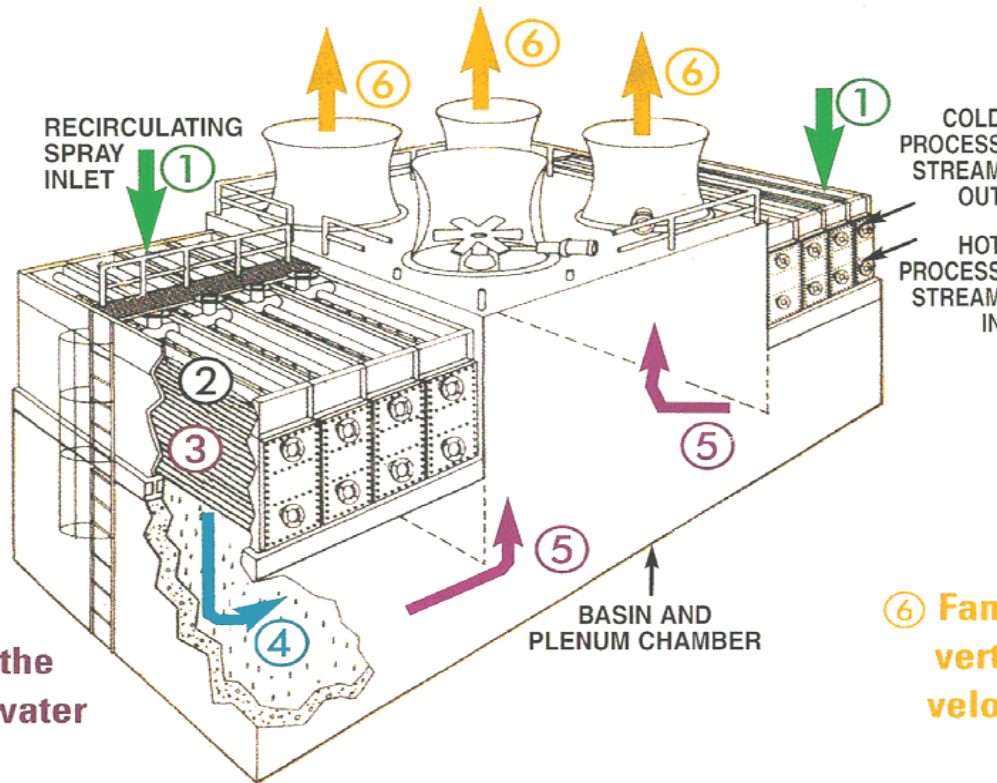
② Water flows downward along with the air

③ Heat from the process stream is released to the cascading water

④ Heat is transferred from the cascading water to the air stream via vaporization

⑤ Air stream forced to turn 180° providing maximum free water removal

⑥ Fans discharge air vertically at a high velocity preventing recirculation



Graphic provided by Niagara Blower, Buffalo, NY