Energy-Water Nexus

Water Use in Electrical Power Generation

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Overview

- Energy-Water Nexus
- U.S. Electrical Demand
- Water Use in Thermoelectric Power Generation
- Alternative Waters for Power Plant Cooling

Energy-Water Nexus

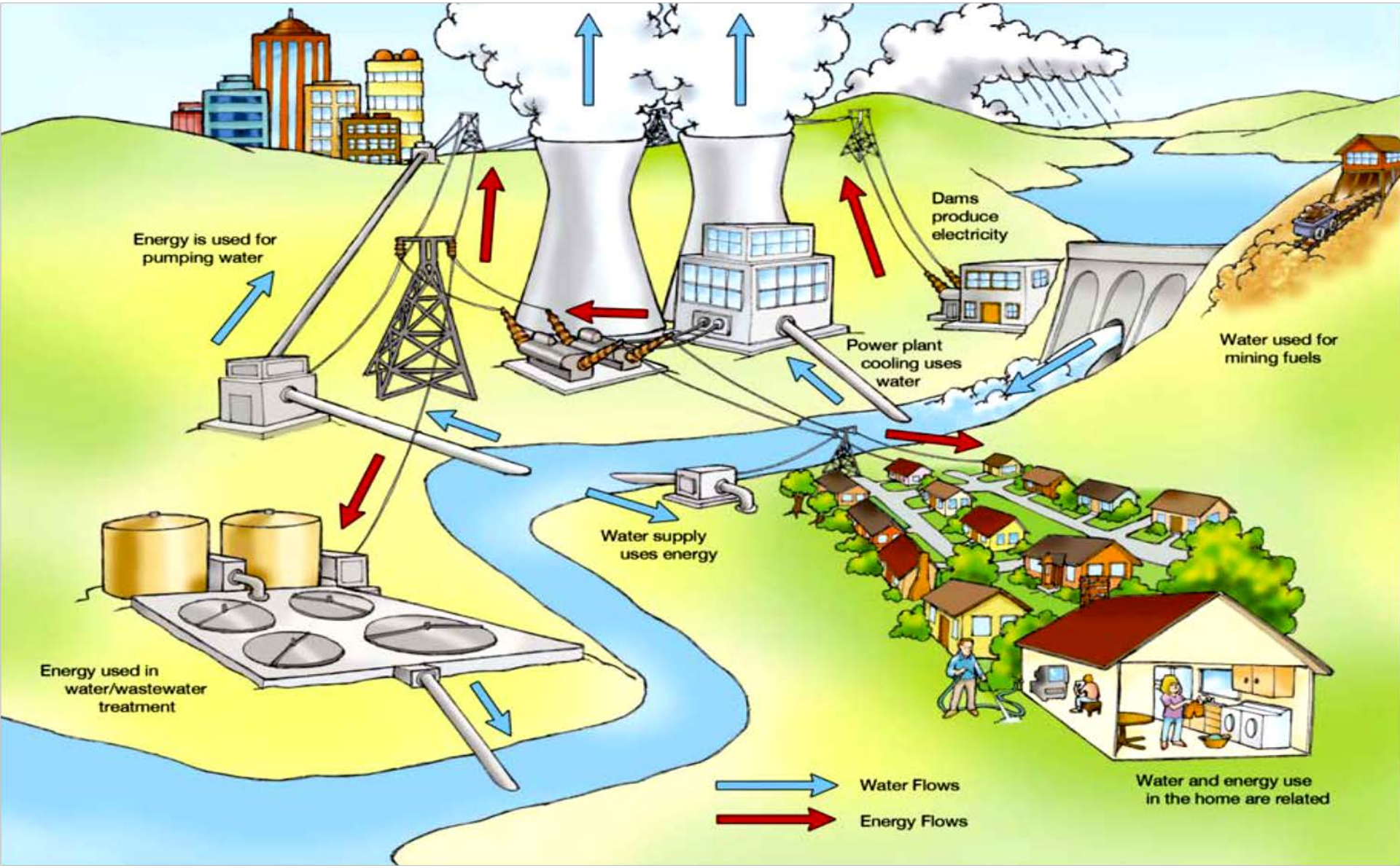


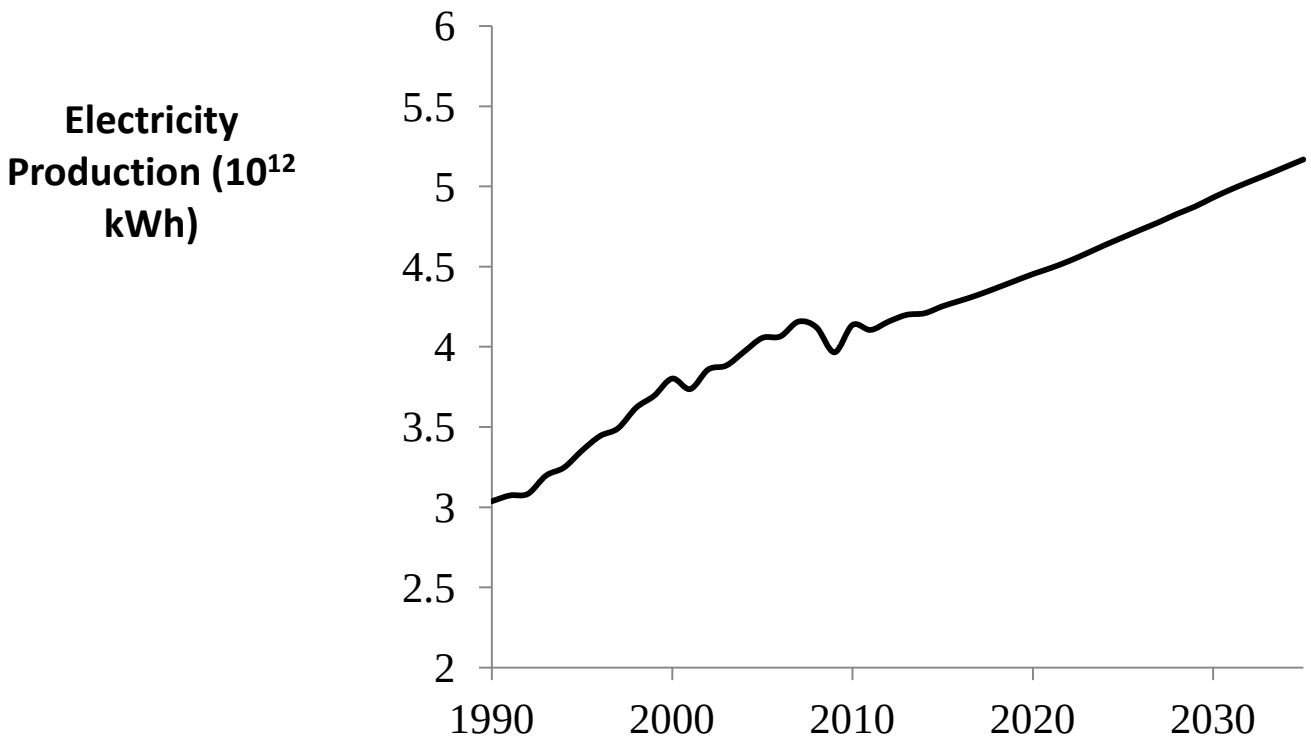
Image Source : Energy Demand on Water Resources DOE 2006

Water Use in Power Production

- **Acquiring & shipping fuels**
- **Generating power (primarily cooling)**
  - Air cooling is much less efficient
- **Available surface water is fixed (and largely allocated)**
- **Ground water is being depleted**

Energy Demand

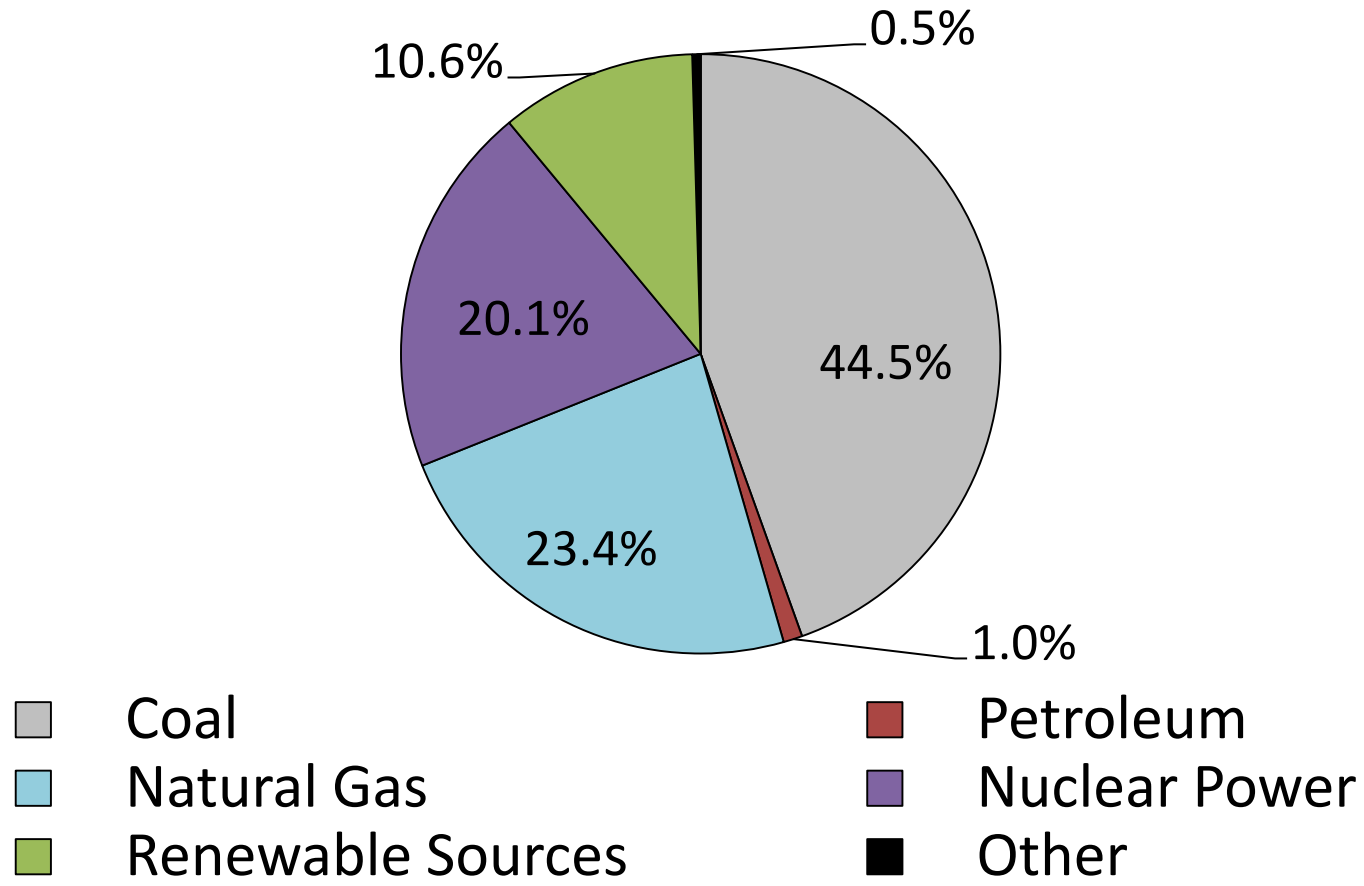
U.S. Electricity Production 1990-2035



Demand for electricity has grown steadily throughout the past decades, and is projected to continue to grow at ≈1% per year

Energy Demand

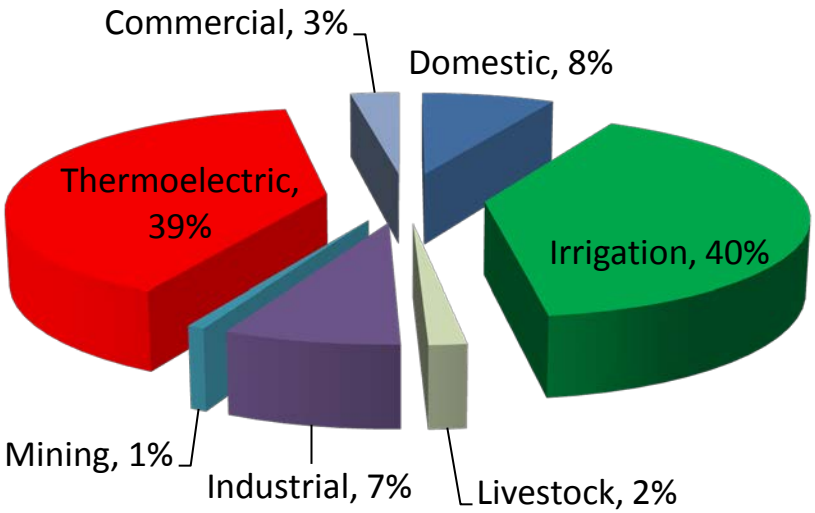
2009 U.S. Electricity Production = 3.98 x 10^{12} kWh



Approximately 90% of electricity is generated from thermoelectric sources

Competing Water Demands

U.S. Freshwater Withdrawal[2]

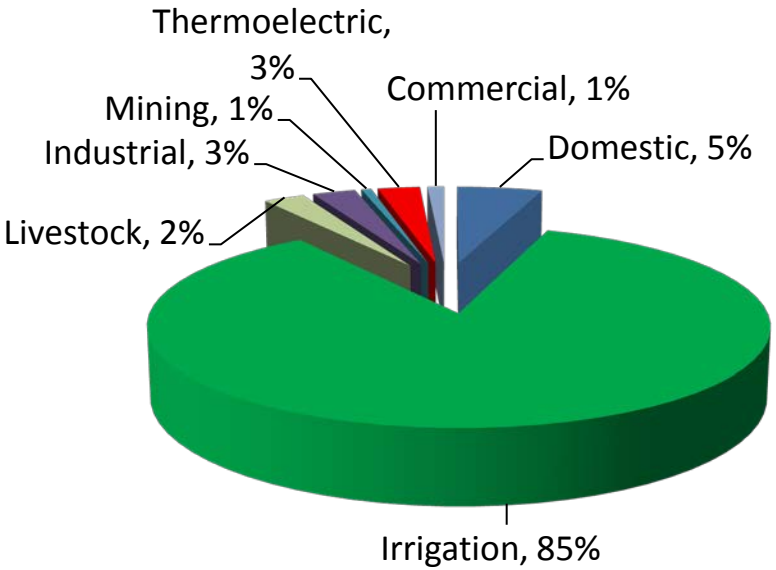


2000 Thermoelectric water requirements[1]:

Withdrawal: ~ 136 BGD

Consumption: ~ 4 BGD

U.S. Freshwater Consumption[2]



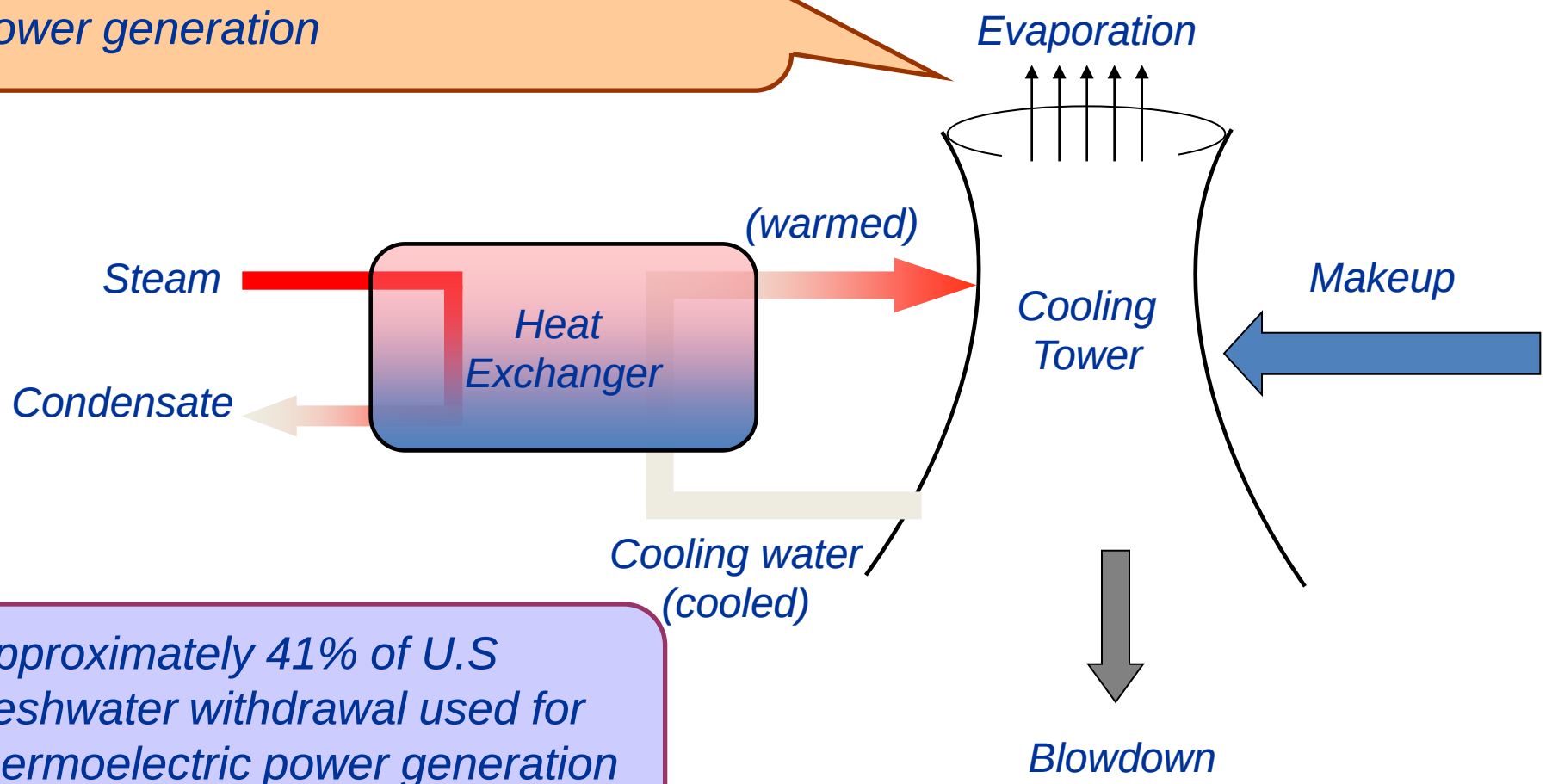
- **Withdrawal**: Amount of water taken from the source body
- **Consumption**: Amount of withdrawn water *not returned* to the source body

Thermoelectric power plants compete with other use sectors.

[1]*USGS, Estimated Use of Water in the United States in 2000, USGS Circular 1268, March 2004*
[2]*USGS, Estimated Use of Water in the United States in 1995, USGS Circular 1200, 1998*

Freshwater Use in Thermoelectric Power Plant

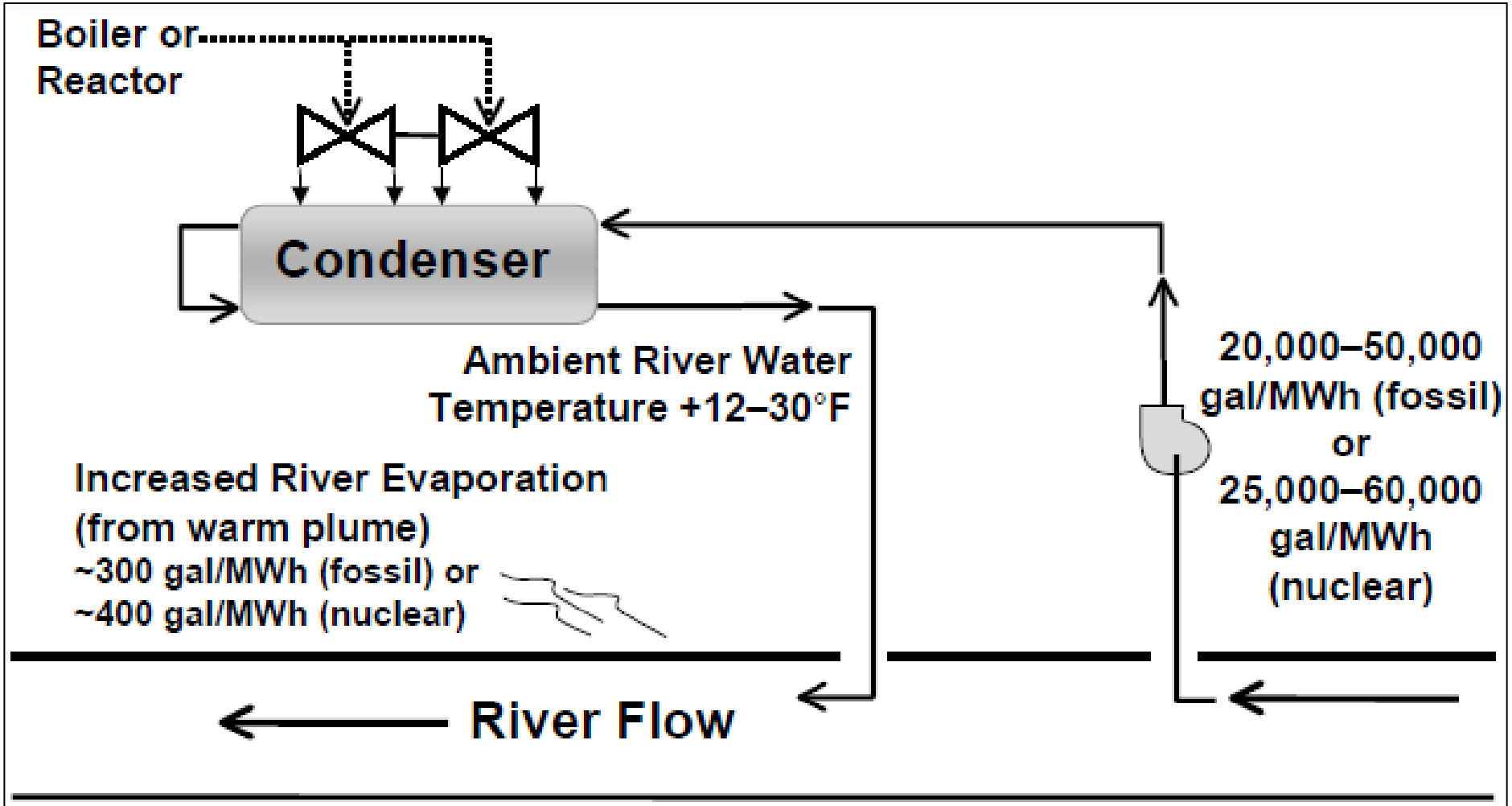
Approximately 3% of U.S. freshwater consumption used for thermoelectric power generation



Approximately 41% of U.S freshwater withdrawal used for thermoelectric power generation

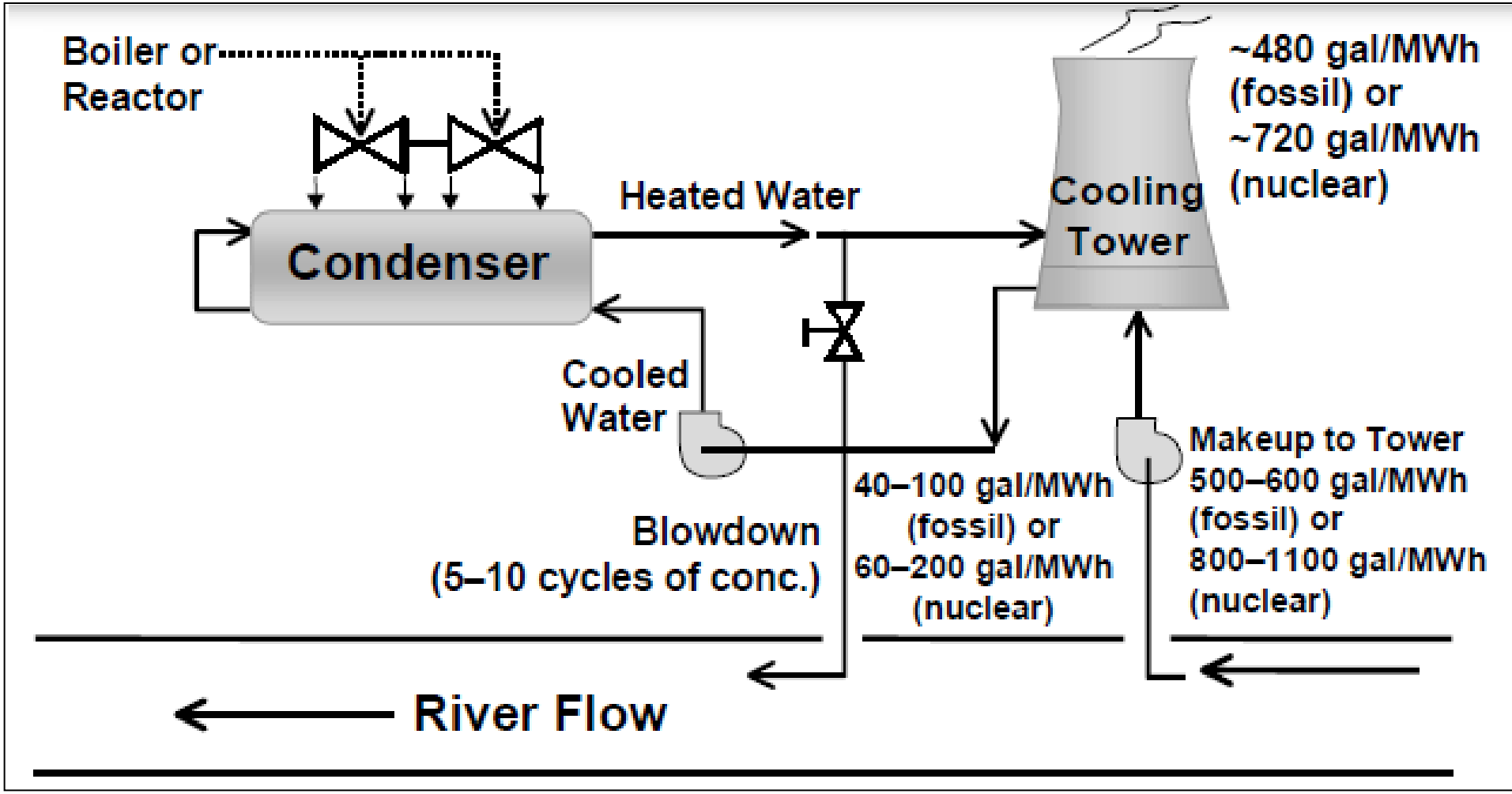
USGS (2009) Estimated use of water in the United States in 2005. Circular 1344.

Once Through Cooling



** High flow value corresponds to low ΔT value, and vice versa*

Recirculating Cooling



"Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production—The Next Half Century", EPRI, Palo Alto, CA: 2002. 1006786.

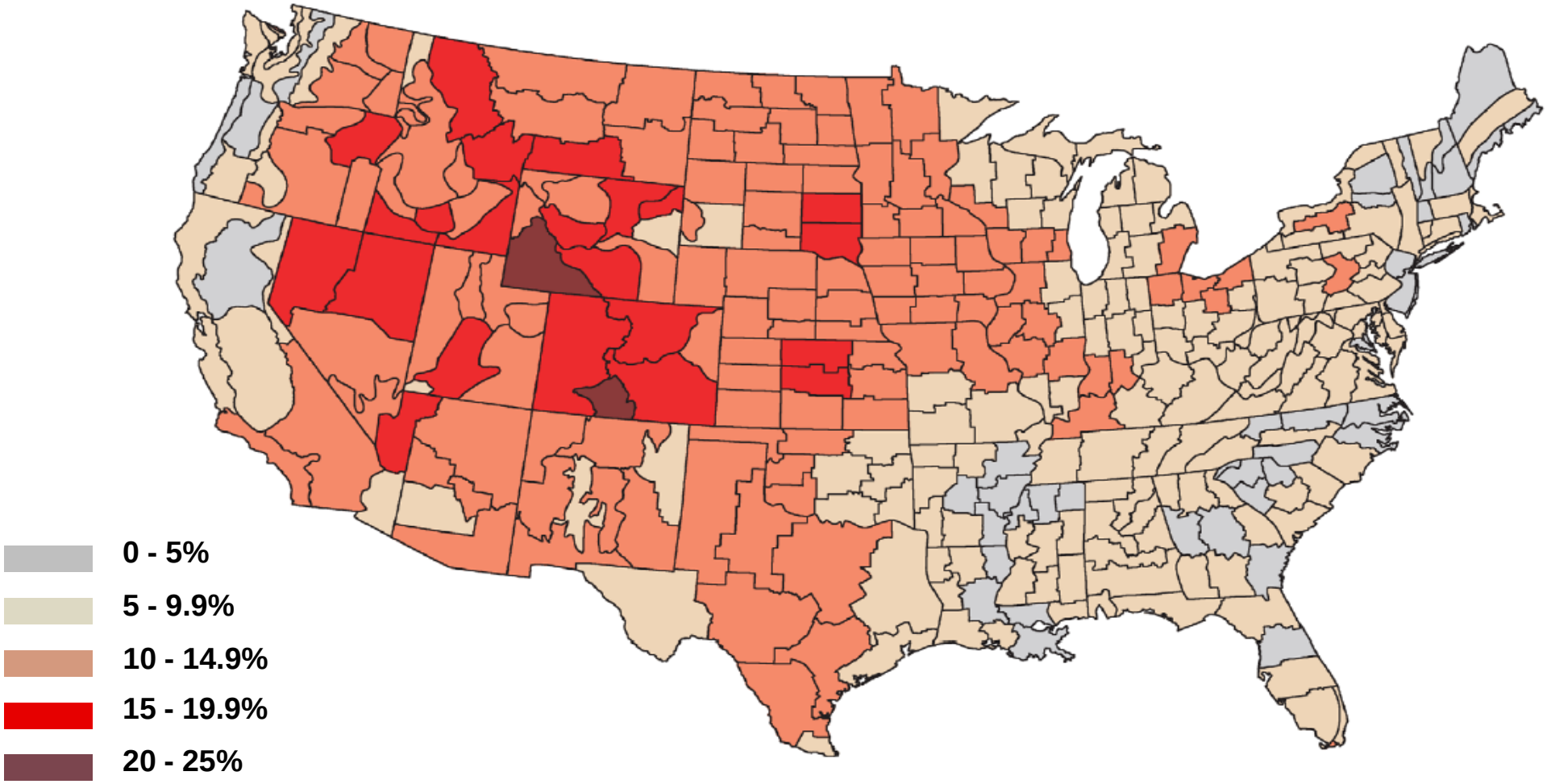
Power Plant Cooling Requirements by Type

Plant type	Recirculating (%)	Once-through (%)	Dry (%)	Cooling Pond (%)
Coal	48.0	39.1	0.2	12.7
Nuclear	43.6	38.1	0.0	18.3
All	41.9	42.7	0.9	14.5

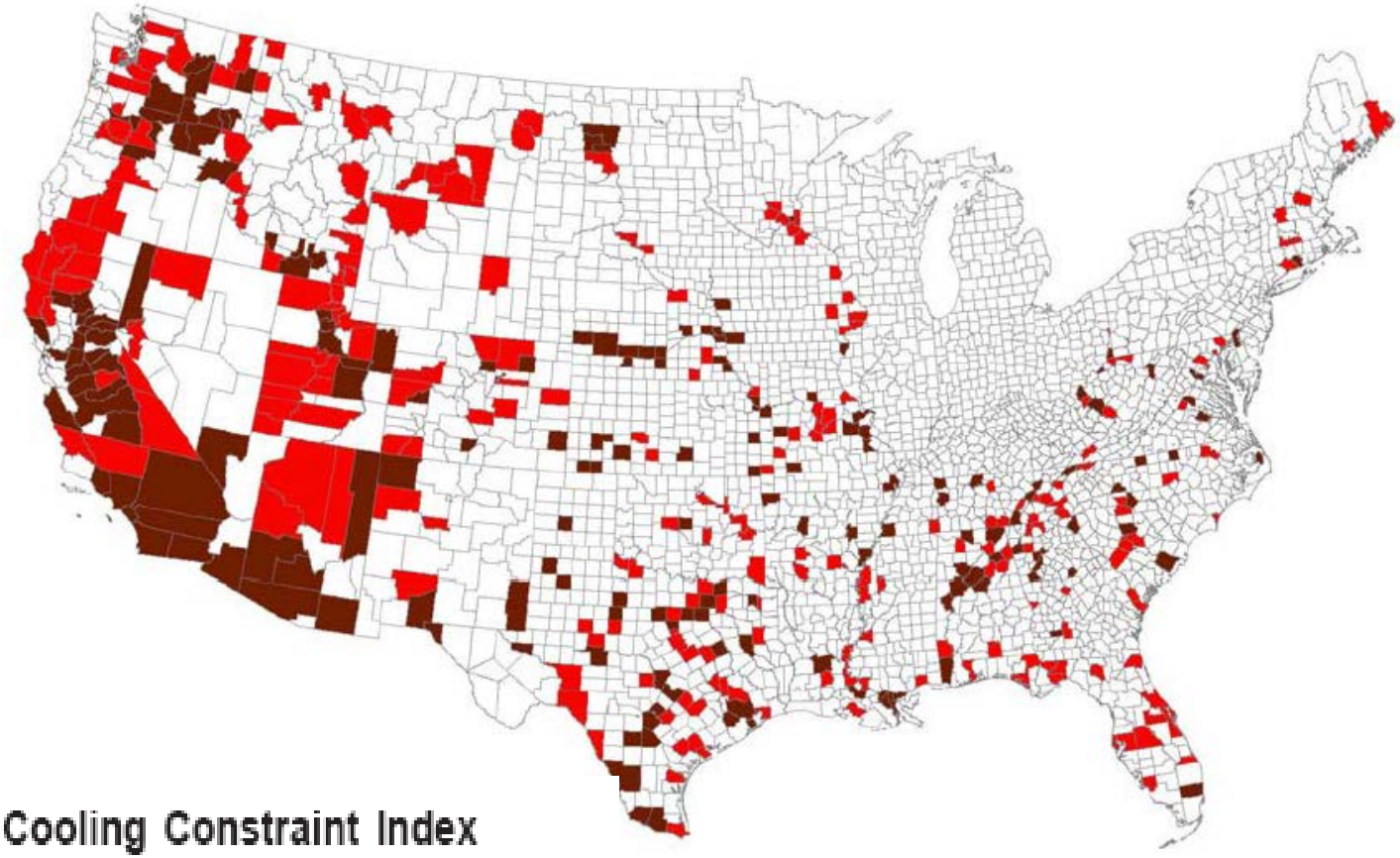
USDOE/NETL, 2009

Percent of Time Spent in Severe to Extreme Drought: 1895-199

The uncertainty and variability of rainfall leads to localized strain on freshwater resources, particularly in arid regions of the U.S.



Expected Cooling Water Shortage in 2025



Thermoelectric Cooling Constraint Index

number of counties in parentheses

Highly constrained	(191)
Moderately constrained	(235)
No existing generation or constraints unlikely	(2685)

Roy et al., (2003) A Survey of Water Use and Sustainability in the United States with a Focus on Power Generation. EPRI

Alternative Water Sources (Recirculating Systems)

- **Treated municipal wastewater**
- **Mine drainage**
- **Industrial process water**
- **Saline groundwater**
- **Seawater**

Municipal Wastewater

Abandoned Mine Drainage

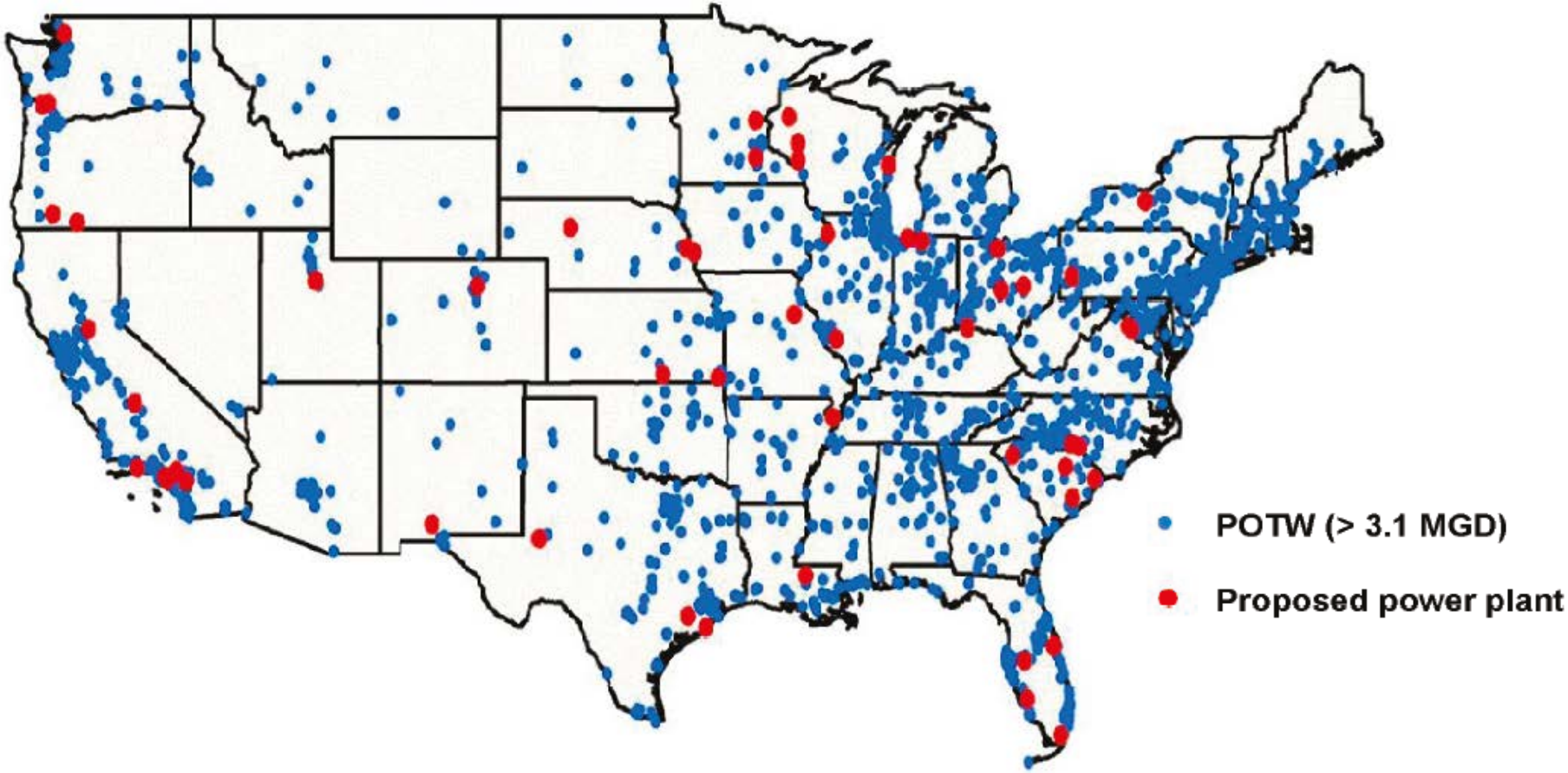
Ash Pond Water

Reuse of Treated Municipal Wastewater

- **11.4 trillion gallons collected and treated annually in U.S.**
- **Experience with use of this water for power plant cooling in arid west: Burbank, Las Vegas, Phoenix**
  - Redhawk (530 MW natural gas) 6.5 MGD
  - Palo Verde (4 GW nuclear) 68 MGD
- **Significant additional treatment required beyond standard secondary treatment**
  - Chlorination
  - pH adjustment
  - Phosphorous removal
  - Membrane filtration

Image from Wikipedia, http://en.wikipedia.org/wiki/File:PaloVerdeNuclearGeneratingStation.jpg

Alternative Cooling Water Source: Effluent from POTWs



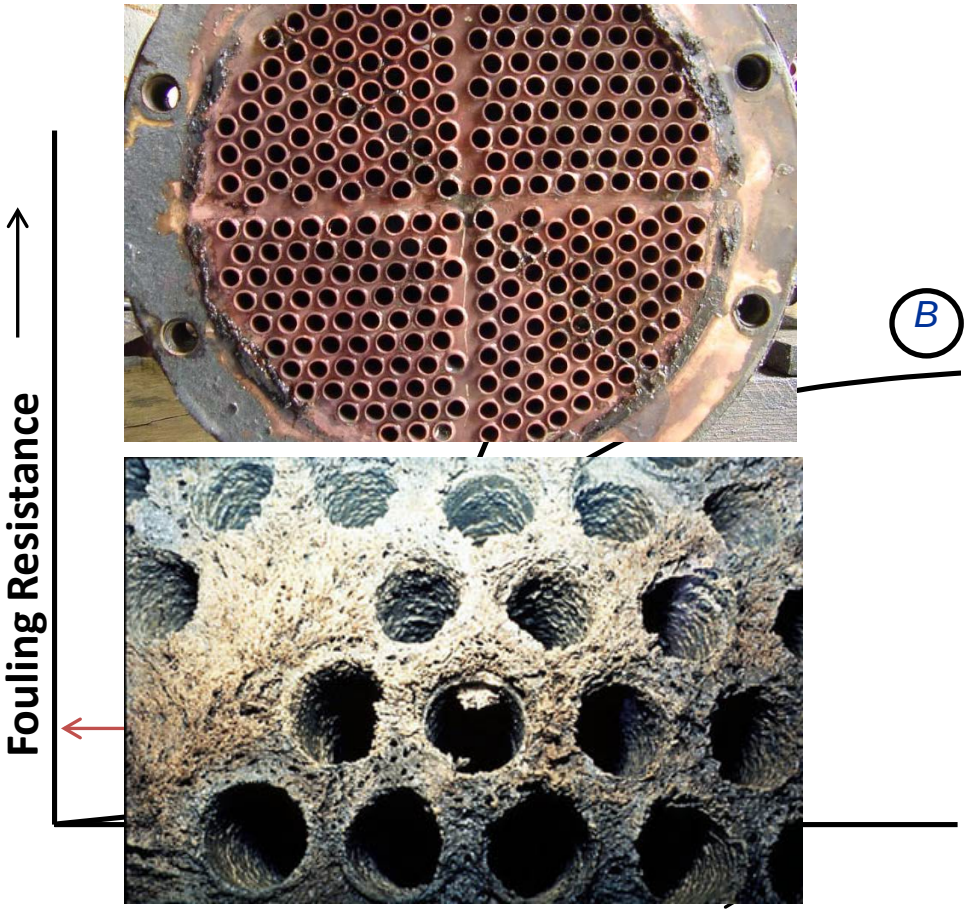
Heng Li, Shih-Hsiang Chien, Ming-Kai Hsieh, David A. Dzombak, and Radisav D. Vidic, Environ. Sci. Technol., 2011, 45 (10), pp 4195–4200.

Proximity to Sufficient TMWW for Cooling

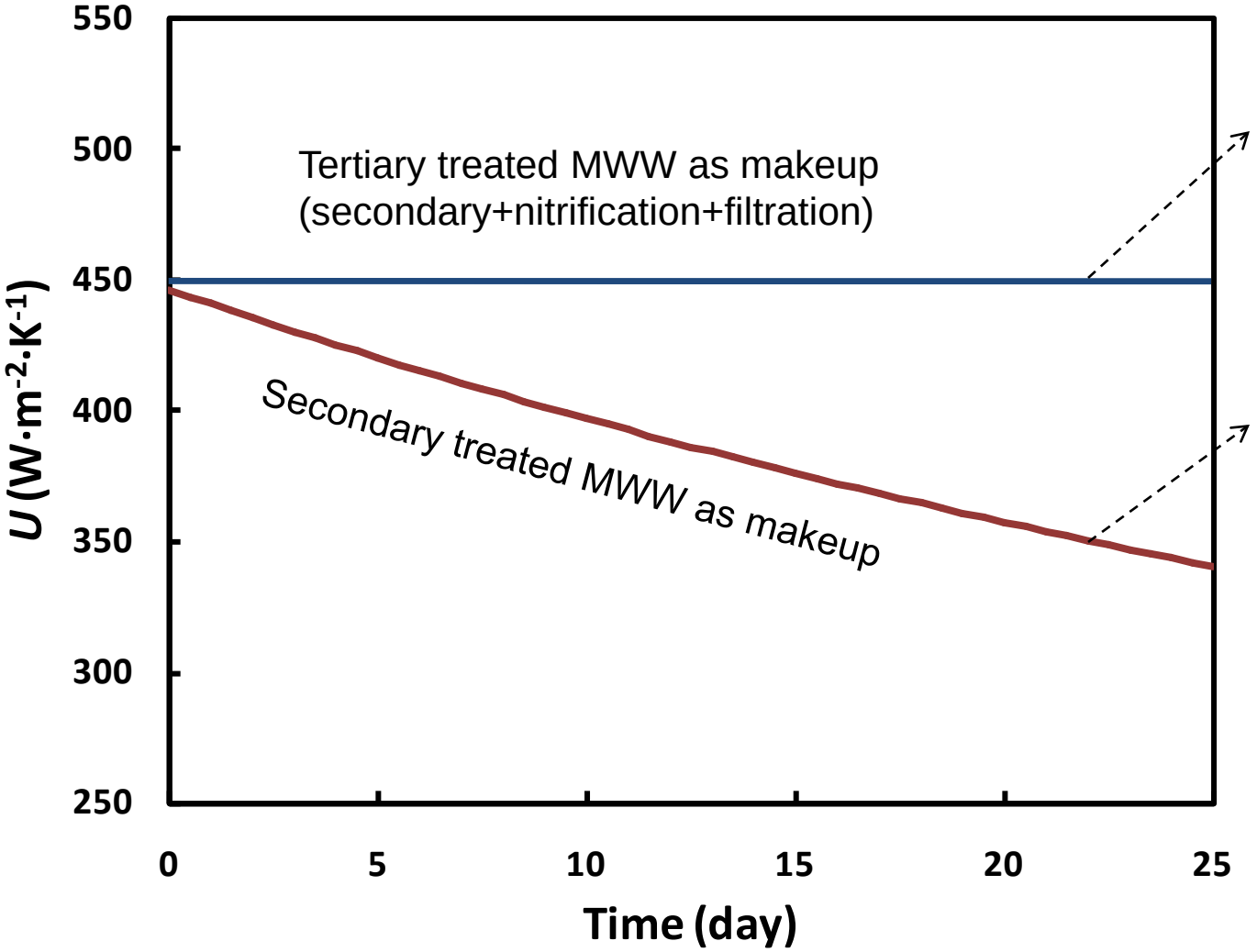
- **Proposed Plants**
  - 81% within 10 miles
  - 92% within 25 miles
- **Existing Plants**
  - 49% within 10 miles
  - 76% within 25 miles

Water Quality and Scaling Tendency

- Higher TDS, TSS, organic content, NH3, PO4, bacteria
- Degraded water can increase scaling, resulting in higher rate of fouling and corrosion
- Relationships between water quality and fouling is needed to asses the economic impact of degraded water usage



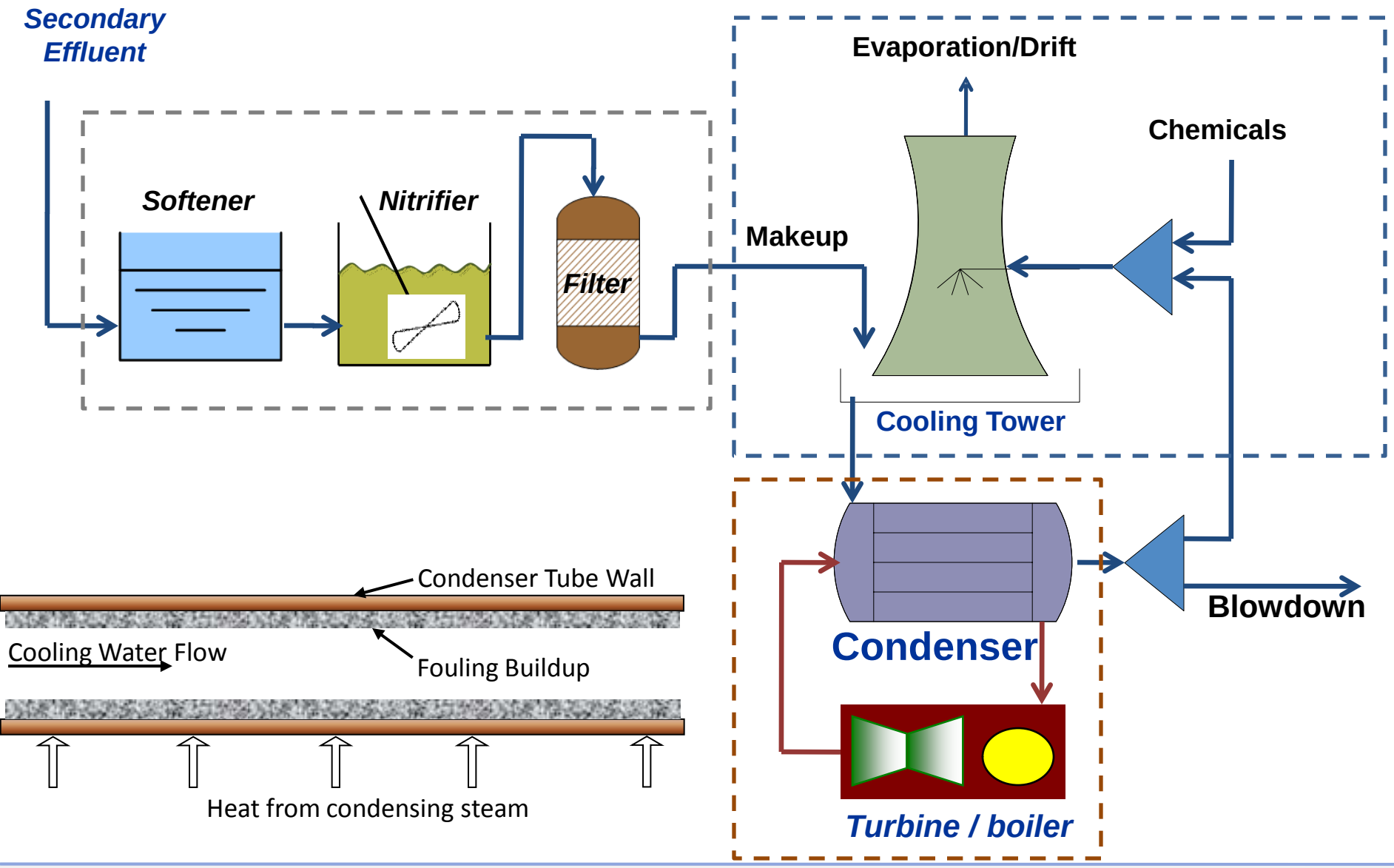
Performance of Condenser Using TMWW



Lower condenser maintenance cost; higher water treatment cost

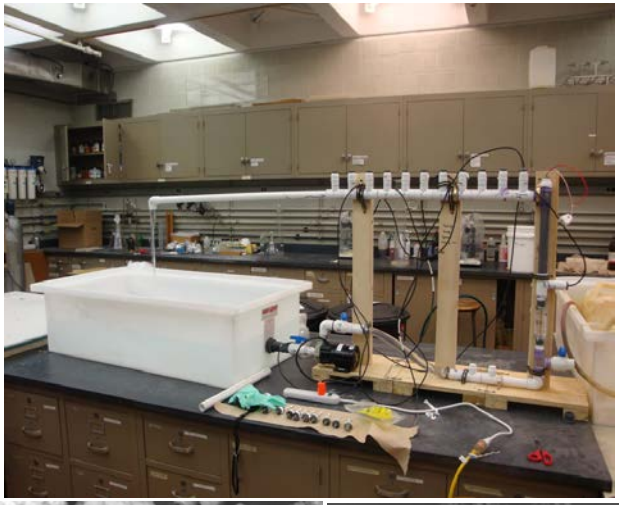
Higher condenser maintenance cost; lower water treatment cost

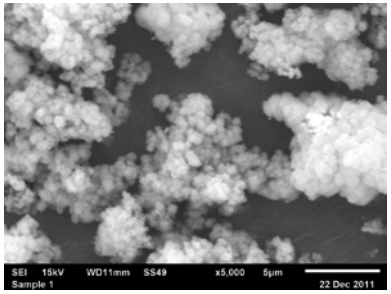
Assessing Costs of Utilizing TMWW for Makeup Water

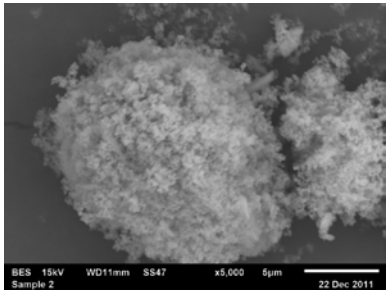


Model Development Combined with Experiments

Salt formation in cooling loop





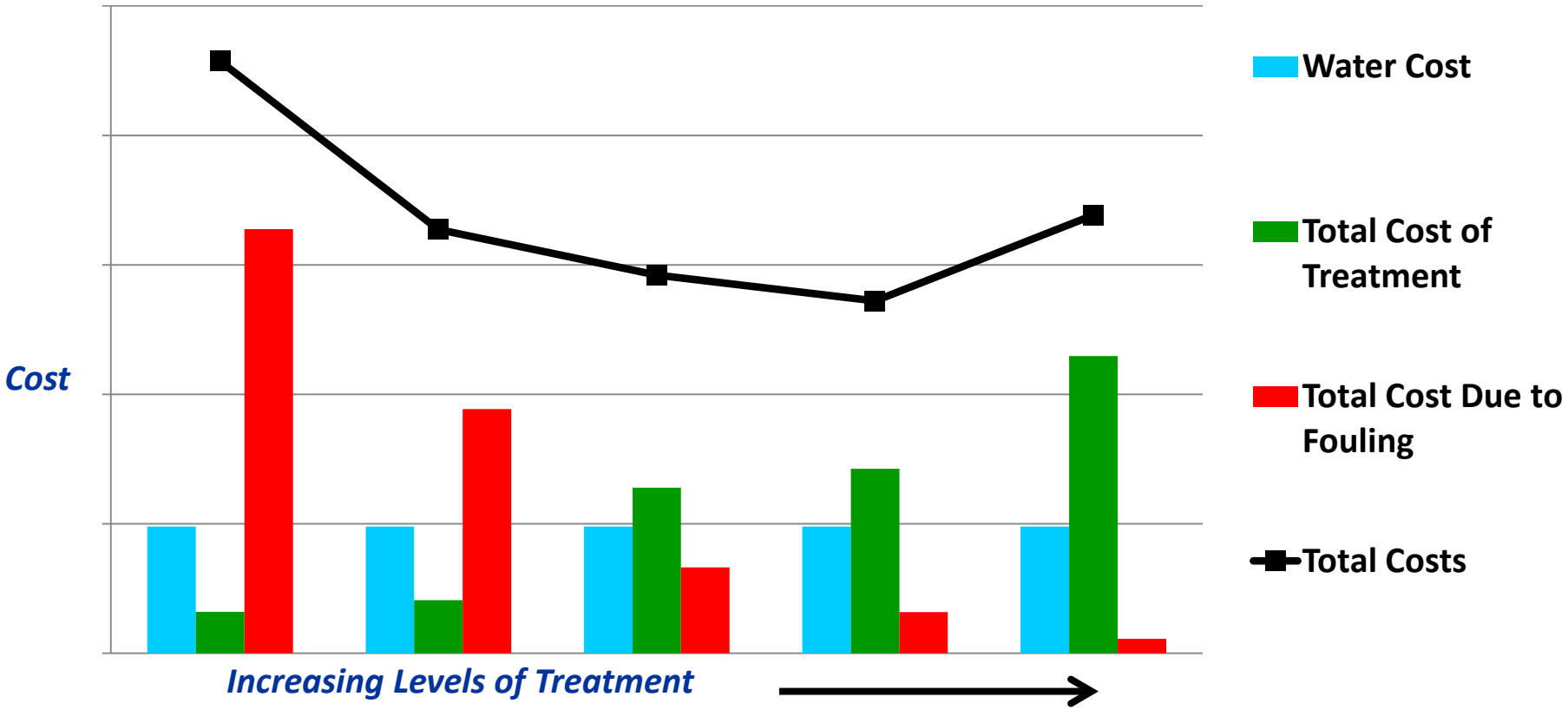


Measurement of Fouling Rate

Safari I., Walker M. E., Hsieh M.-K., Dzombak D. A., Liu W., Vidic R. D., Miller D. C. and Abbasian J. (2013), Utilization of Municipal Wastewater for Cooling in Thermoelectric Power Plants, Fuel. (accepted)

Evaluating the Cost of Utilizing Degraded Waters

The model is used to determine the optimal water treatment strategy that results in the lowest total cost impact of degraded water use



Summary

- Energy & Water are tightly linked
  - Producing/generating energy
  - Obtaining/treating water

- Thermoelectric power production relies on water, primarily for cooling
  - Increased costs with air cooling due to efficiency loss

- Alternative water sources are possible
  - Need to balance costs when evaluating alternatives

Acknowledgements

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