The Metropolitan Water Reclamation District of Greater Chicago

WELCOME
TO THE FEBRUARY EDITION
OF THE 2011
M&R SEMINAR SERIES

BEFORE WE BEGIN

- **SILENCE CELL PHONES & PAGERS**
- **QUESTION AND ANSWER SESSION WILL FOLLOW PRESENTATION**
- **SEMINAR SLIDES WILL BE POSTED ON MWRD WEBSITE AT (www. MWRD.org)**
- **Home Page $\Rightarrow$ (Public Interest) $\Rightarrow$ more public interest $\Rightarrow$ M&R Seminar Series $\Rightarrow$ 2010 Seminar Series**

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Select Publications

- **Karamalidis, A. and Dzombak, D.A. (2010), Surface Complexation Modeling: Gibbsite, John Wiley & Sons, New York.**
- **Khaitan, S., Dzombak, D.A., and Lowry, G.V (2009), *"Mechanisms of Neutralization of Bauxite Residue by Carbon Dioxide,"* Journal of Environmental Engineering, 135(6):433-438.**
- **Liu, R., Wolfe, A.L., Dzombak, D.A., Stewart, B.W., and Capo, R.C. (2008), *"Comparison of Dissolution under Oxic Acid Drainage Conditions for Eight Sedimentary and Hydrothermal Pyrite Samples,"* Environmental Geology, 56(1):171-182.**
- **Kutchko, B.G., Strazisar, B.R., Lowry, G.V., Dzombak, D.A., and Thaulow, N. (2008), "*Rate of CO_2 Attack on Class H Well Cement under Geologic Sequestration Conditions,"* Environmental Science & Technology, 42(16):4787-4792.**
- **Dzombak, D.A., Ghosh, R.S., and Wong-Chong, G.M. (2006), Cyanide in Water and Soil: Chemistry, Risk, and Management, Taylor & Francis/CRC Press, Boca Raton, FL, 603pp**

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THE NEED AND CHALLENGE OF ALTERNATIVE SOURCES OF WATER FOR USE IN ELECTRIC POWER PRODUCTION

David Dzombak
Carnegie Mellon University
Dept of Civil and Environmental Engineering

AEESP Lecture
Spring 2011

OVERVIEW

- U.S. electrical energy demand
- Water requirements in thermoelectric power production
- Alternative waters for power plant cooling
- Reuse of secondary treated municipal wastewater for power plant cooling
- Corrosion studies
- Summary

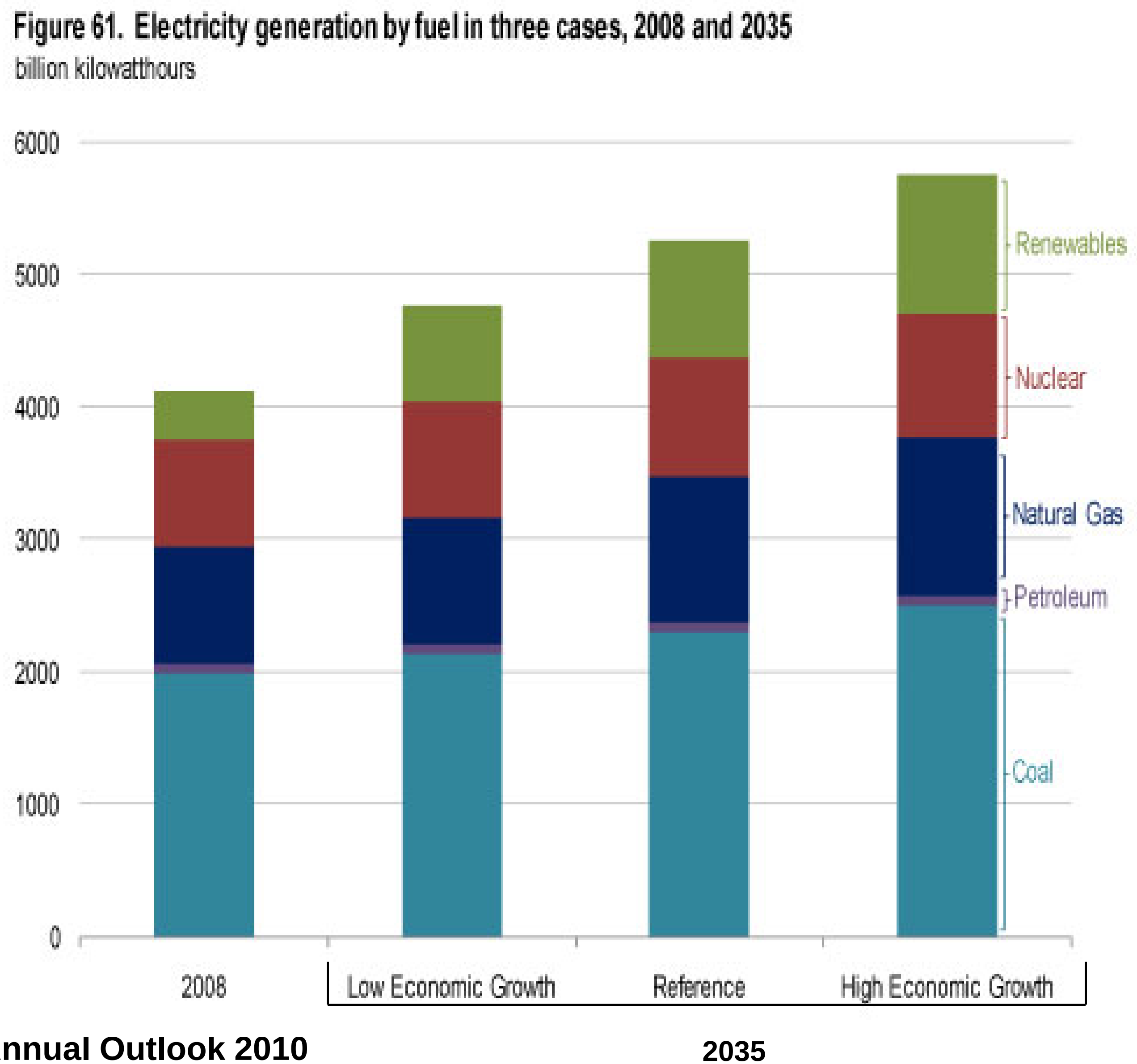
U.S. ELECTRICAL ENERGY DEMAND

- Increases in response to population growth and economic growth
- In short term, fluctuates in response to business cycles and weather trends
- Growth has slowed progressively in each decade since the 1950s
- Population and economic growth increase absolute demand

U.S. ELECTRICAL ENERGY DEMAND IN 2035 – EIA Annual Outlook 2010

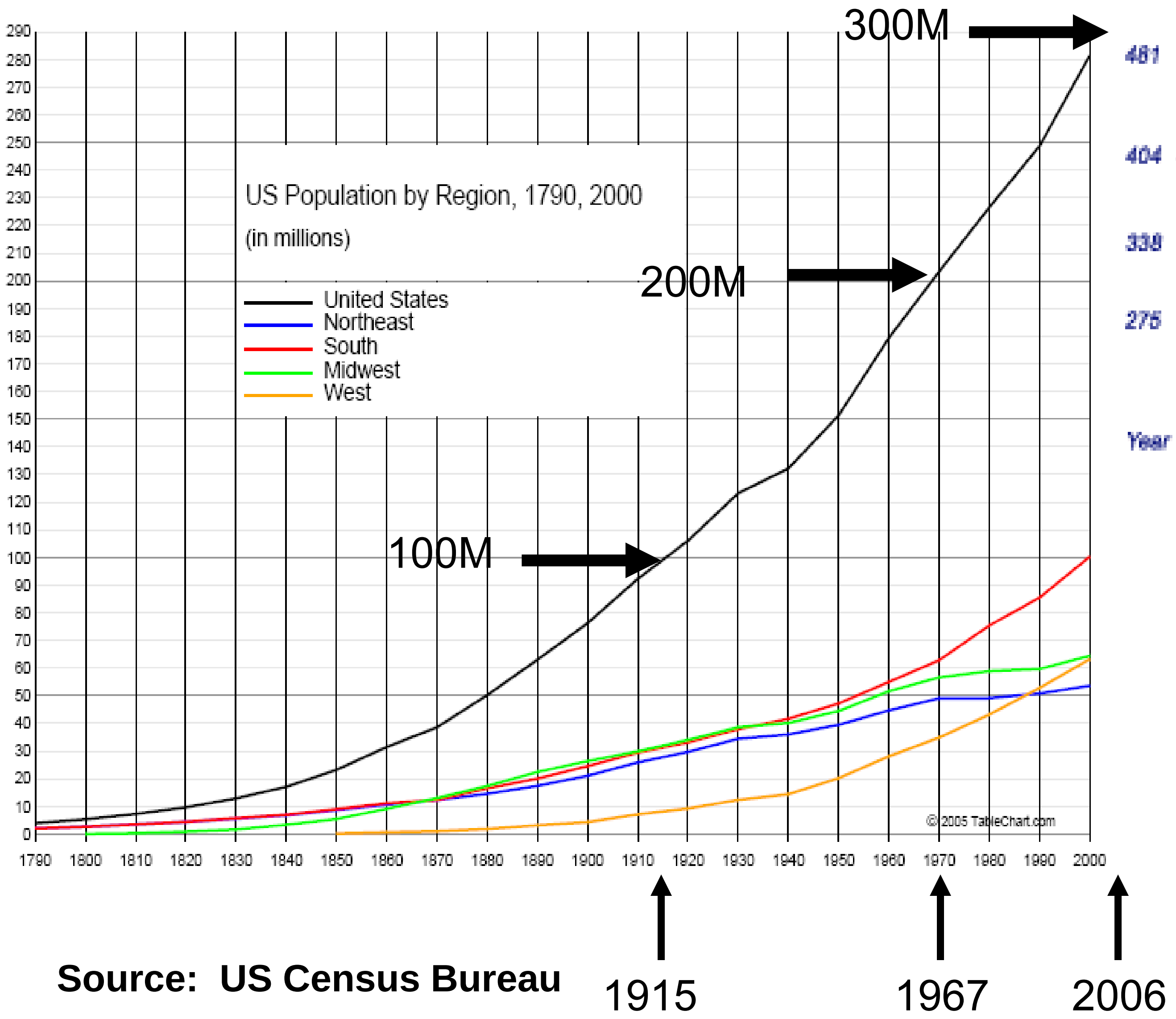
- Projected to increase by 30% from 2008 to 2035
- Largest increase in commercial sector, especially service industries
- Next largest increase, residential demand - “due to growth in population … and continued population shifts to warmer regions with greater cooling requirements.”
- Small increase for heavy industry “as a result of efficiency gains and slow growth.”

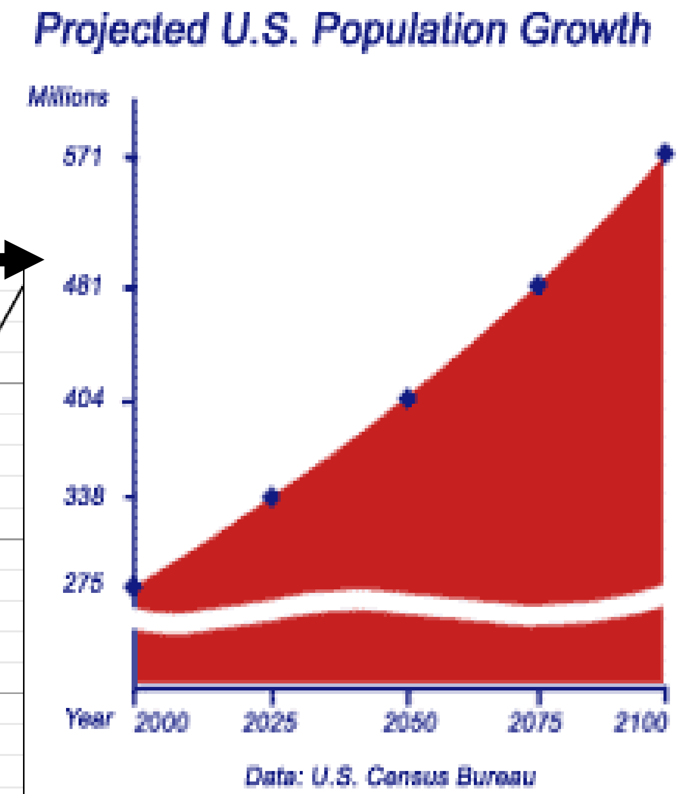
U.S. ELECTRICITY DEMAND GROWTH



Source: EIA Annual Outlook 2010

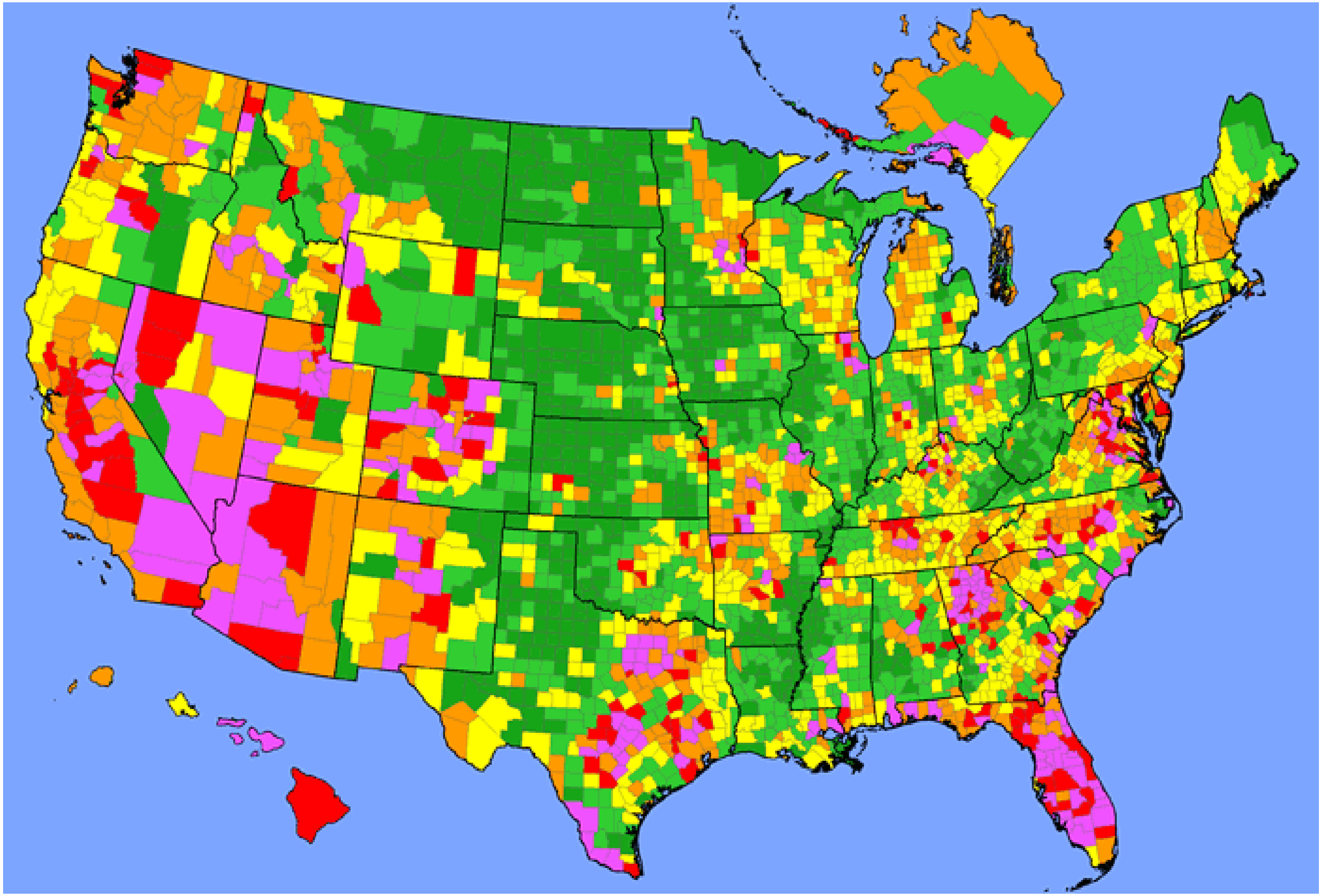
US POPULATION 1790-2006





Source: US Census Bureau

U.S. POPULATION CHANGE 1980-2008



Green: -50 – 10% Yellow: 10-30% Orange: 30-70% Red: 70-100% Pink: >100%

Source: NumbersUSA

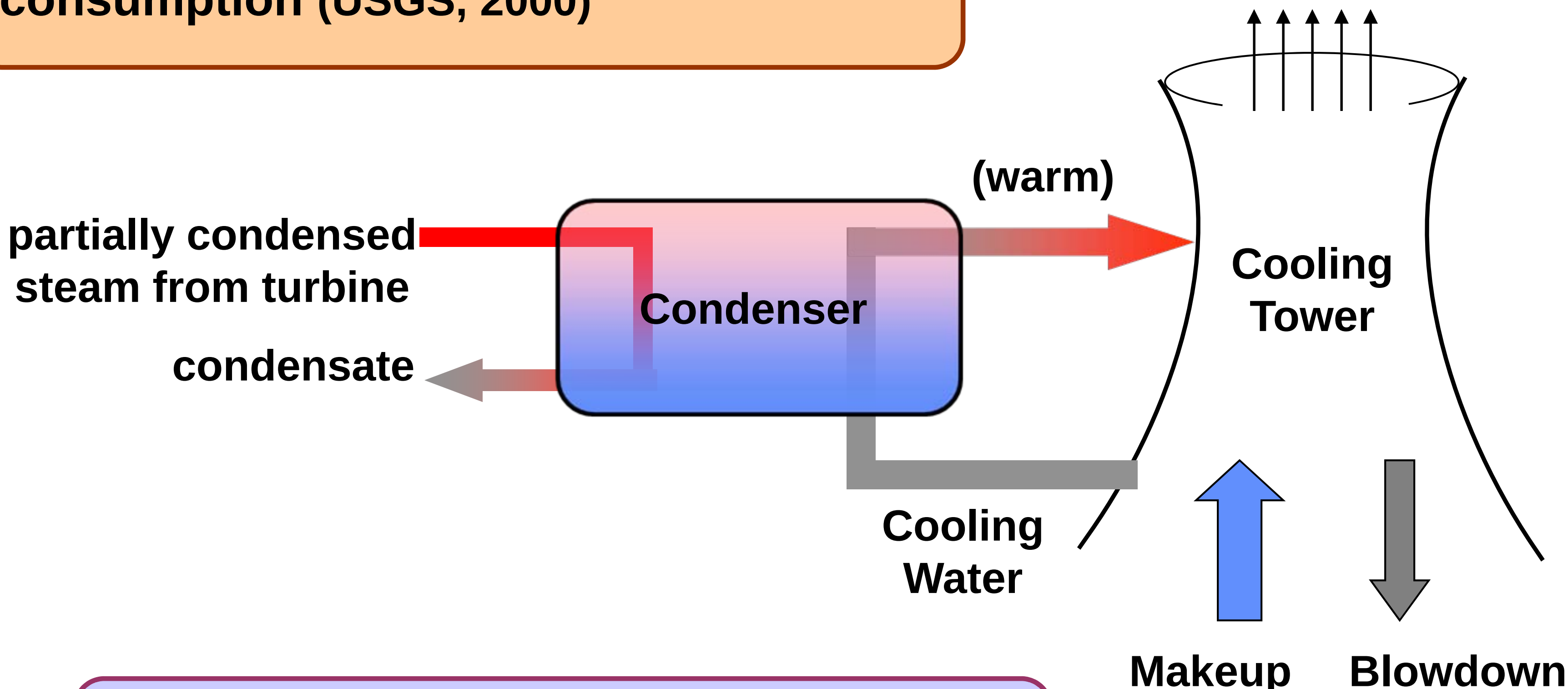
WATER REQUIREMENTS IN THERMOELECTRIC POWER PRODUCTION

WATER-ENERGY NEXUS

- Water is needed for thermoelectric power production, in acquiring and shipping fuels, and in generating power (primarily for cooling)
- Air cooling is much less efficient and more expensive than water cooling
- In next 25 years, US population will grow by 50-80 million and electricity demand by 30%
- Available surface water supplies are fixed (and largely allocated) and groundwater supplies are depleting

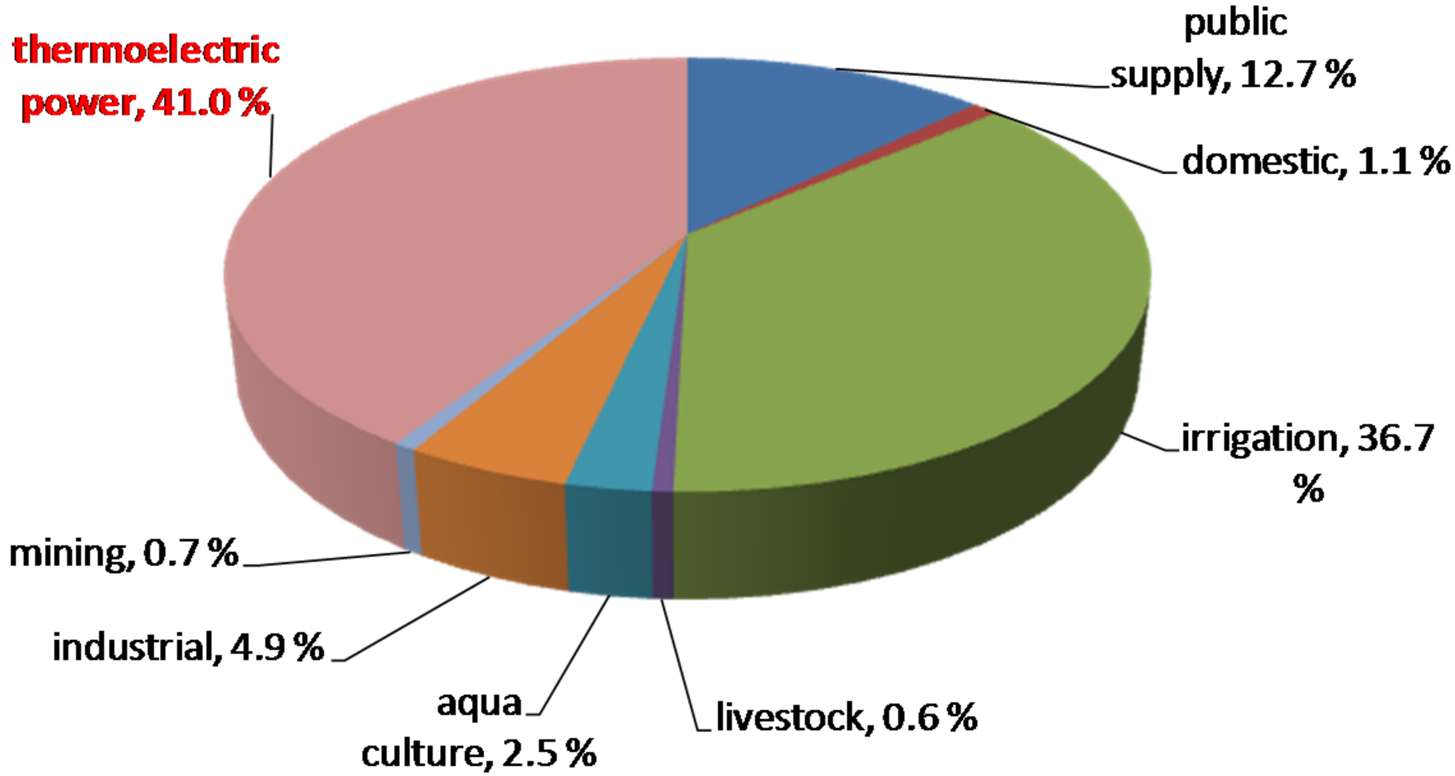
FRESHWATER USE IN THERMOELECTRIC POWER PRODUCTION

Approximately *3%* of U.S. freshwater consumption (USGS, 2000)



Approximately *41%* of U.S freshwater withdrawal (USGS,2009)

2005 FRESHWATER WITHDRAWALS IN US



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

POWER PLANT COOLING TECHNOLOGY BY GENERATION TYPE

- Once–through cooling: 25-30 gal/kwh
- Recirculating cooling: 0.6 – 1.2 gal/kwh
- Across all types of power plants, 43% are water once-through and 42% are water recirculating

Plant type	Recirc water (%)	Once-through water (%)	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

Source: USDOE/NETL, 2009

COOLING TOWERS AT HOMER CITY ELECTRIC POWER GENERATING STATION

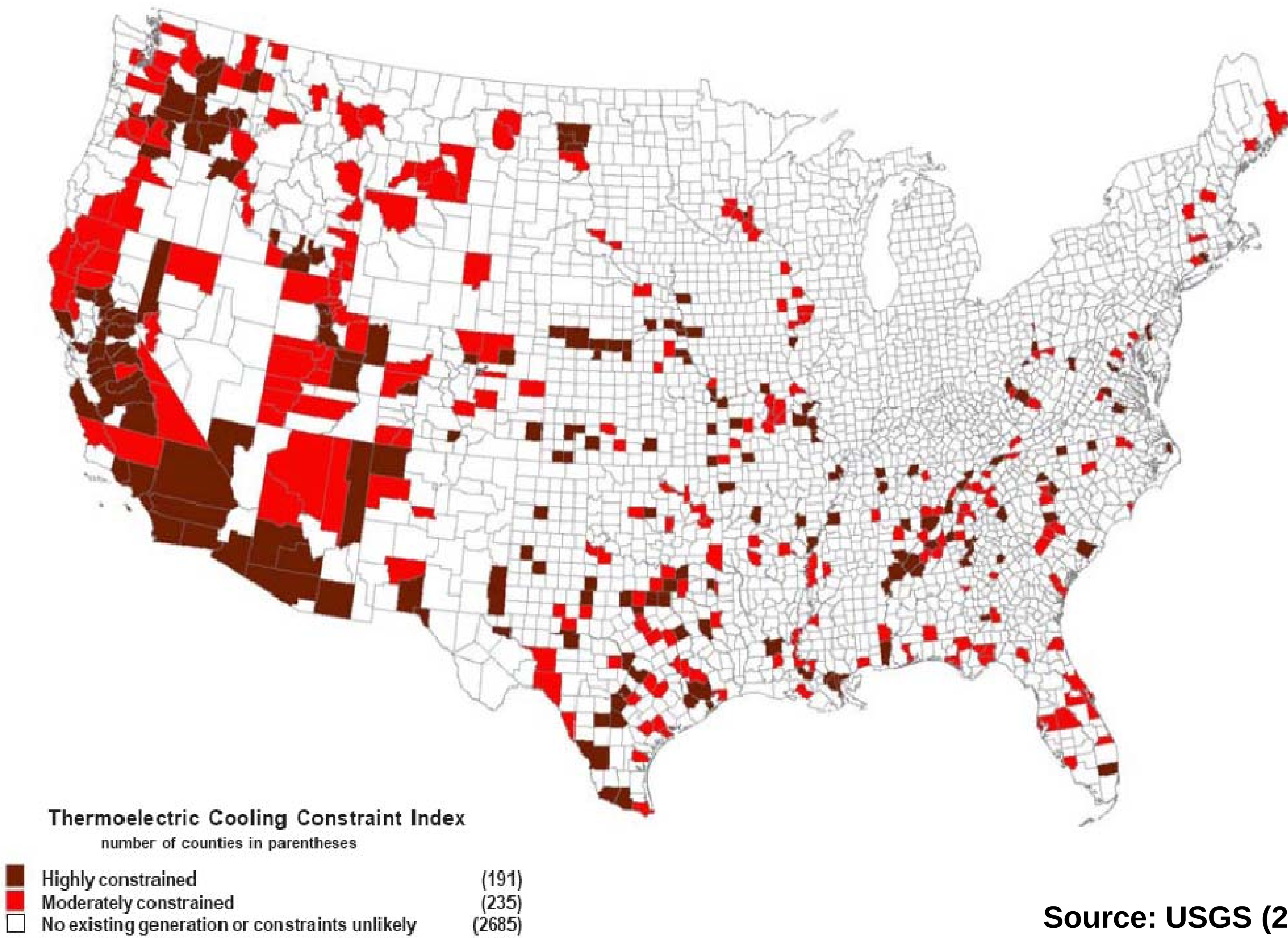
Source: C.J. Rodkey, 2008

Source: Pittsburgh Post-Gazette, 2011


TECO
TAMPA ELECTRIC
BIG BEND STATIO

COOLING WATER DISCHARGE AT TAMPA ELECTRIC BIG BEND POWER STATION

LIMITATIONS IN WATER AVAILABILITY FOR POWER PLANT COOLING



Source: USGS (2004)

ALTERNATIVE WATER SOURCES FOR THERMOELECTRIC POWER PRODUCTION – FOR RECIRCULATING SYSTEMS

- Treated municipal wastewater
- Mine drainage
- Industrial process waters
- Saline groundwater
- Seawater

SOME NON-SEAWATER ALTERNATIVE SOURCES OF COOLING WATER

Municipal Wastewater

Ash Pond Water

Abandoned Mine Drainage

REUSE OF TREATED MUNICIPAL WASTEWATER IN THE COOLING SYSTEMS OF THERMOELECTRIC POWER PLANTS

REUSE OF TREATED MUNICIPAL WASTEWATER IN THE COOLING SYSTEMS OF THERMOELECTRIC POWER PLANTS

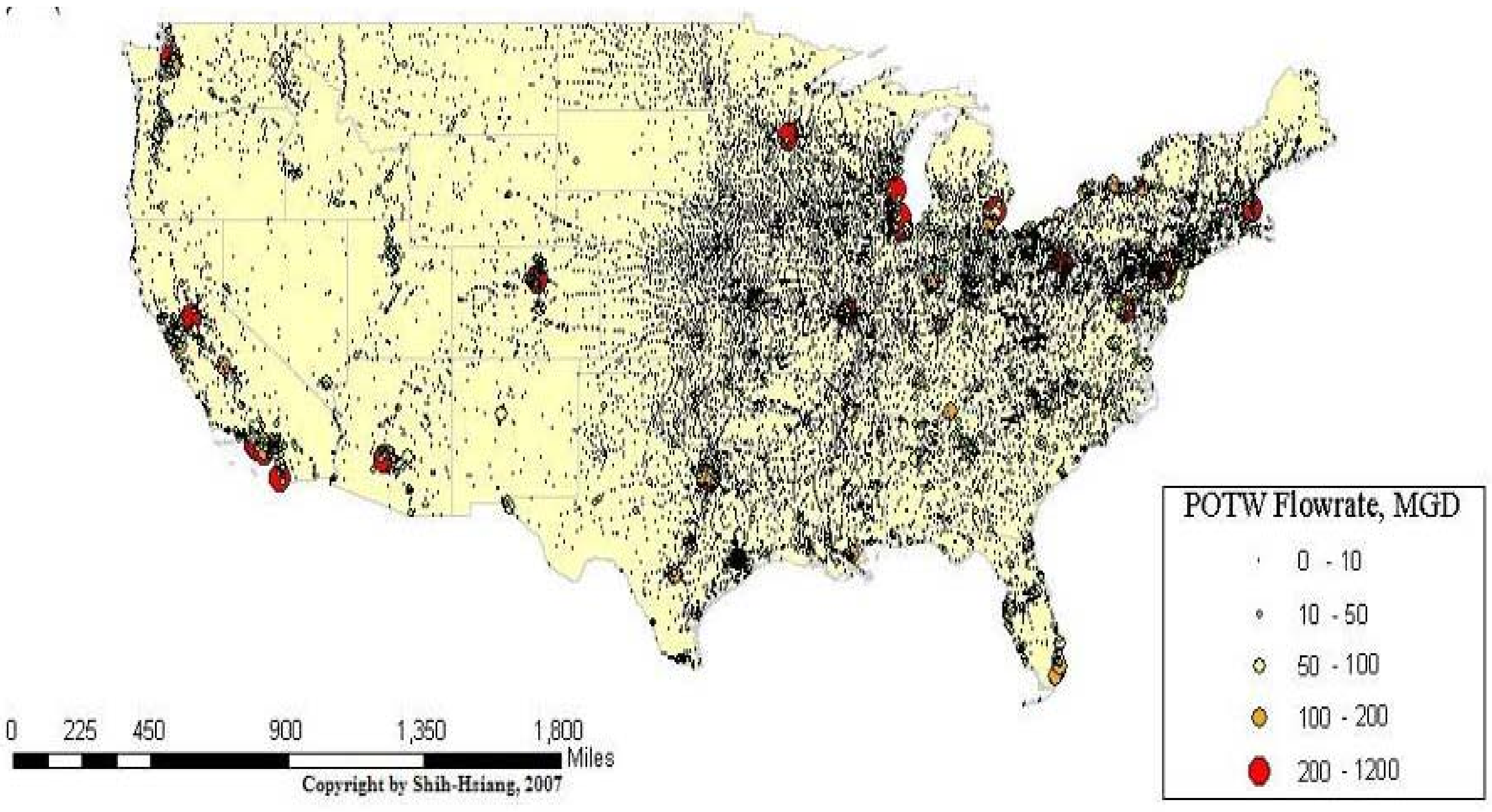
- 11.4 trillion gallons of municipal wastewater collected and treated annually in U.S.
- Experience with use of treated municipal water for power plant cooling in arid west; e.g., Burbank, Las Vegas, Phoenix
- Significant additional treatment beyond secondary treatment (e.g., clarification, filtration,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

REDHAWK AND PALO VERDE POWER PLANTS

- Redhawk: 530MW, natural gas
- Palo Verde: 4000 MW, nuclear
- Use treated municipal wastewater from Phoenix
- RPS: 6.5 MGD
- PVNGS: 68 MGD
- Additional treatment at power plant: chlorination, pH adjustment, phosphorus removal, membrane filtration

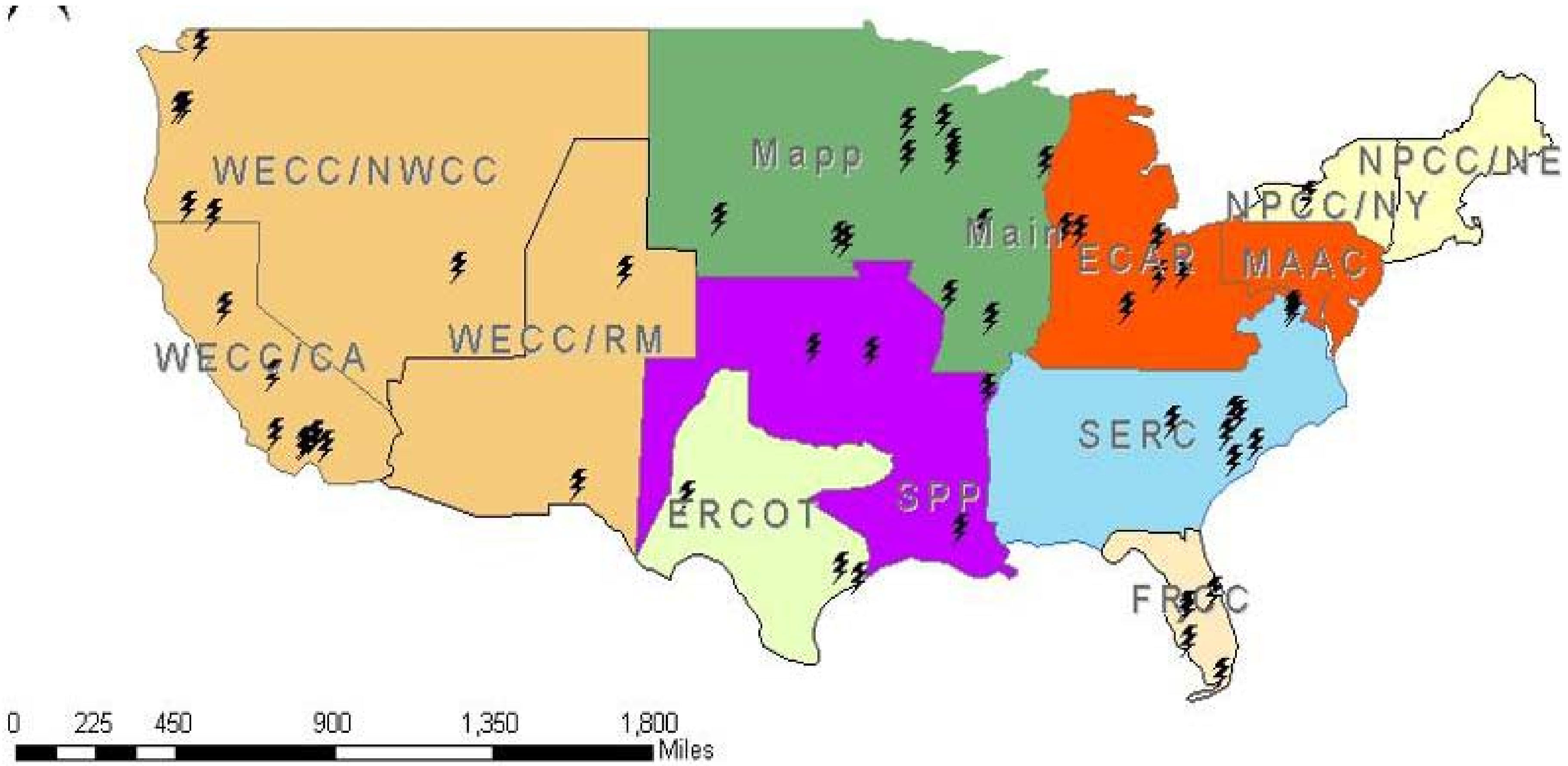
INVENTORY OF AVAILABLE WASTEWATER

GIS-based tool developed to assess availability of secondary effluent from publicly owned treatment works (17864 POTWs in lower 48 states).



INVENTORY OF WATER NEEDS

- 110 proposed power plants from EIA annual report 2007
- U.S. is divided into major NERC regions



ESTIMATION OF WATER NEEDS

Project list of proposed power plants as water demand layer on the same GIS map → Estimate the cooling water need based on generating capacity

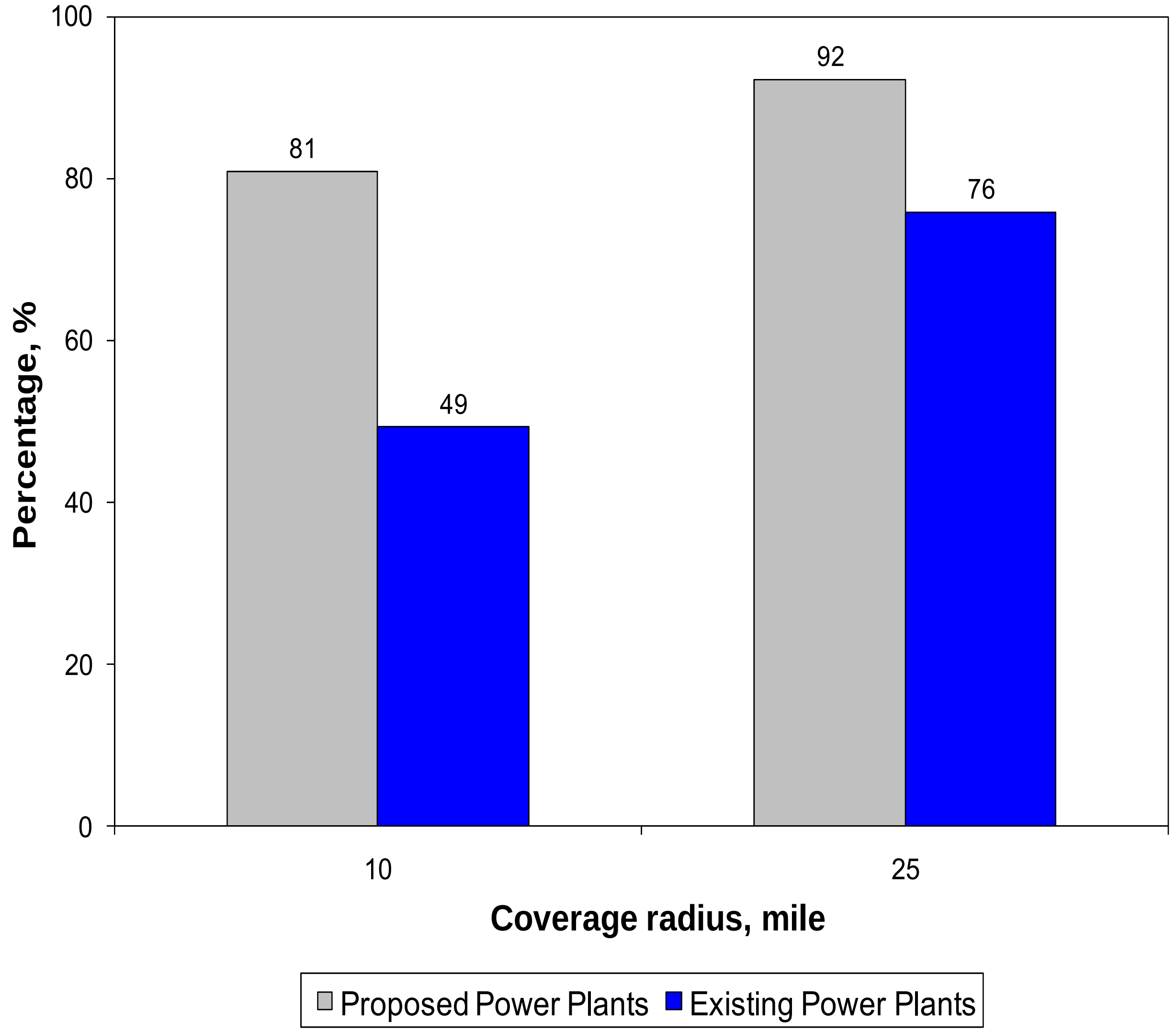
- A total of 110 power plants proposed in 2007 was used to assess water demand
- Water needed for power generation is *0.6-1.2 gallon/kWh* (for recirculating cooling systems)
- Cooling water need estimate =

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

POTWs NEEDED TO SATISFY POWER PLANT COOLING WATER DEMAND

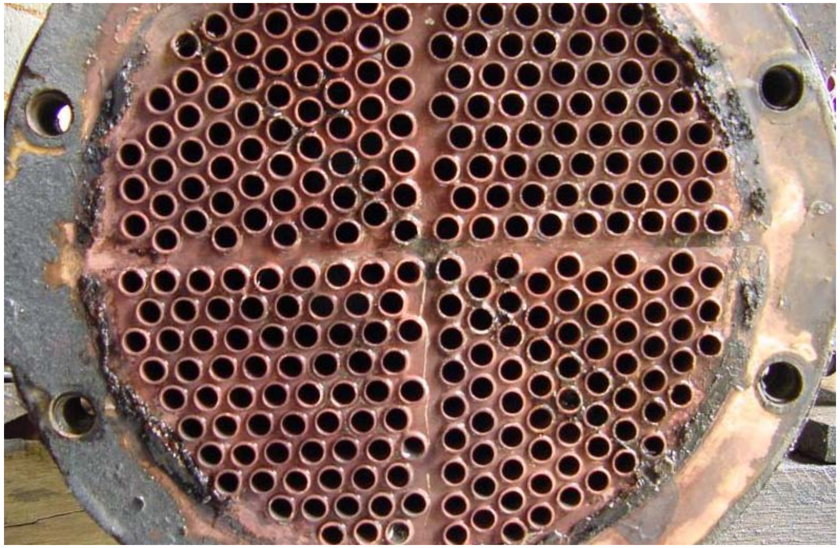
N. Am. Electric Reliability Council (NERC) Region	Proposed power plants with sufficient wastewater within 10 mi to satisfy cooling water needs, %	Average number of POTWs within 10 mile radius of proposed power plant	POTWs needed to satisfy cooling water needs within a 10 mile radius
ECAR	86	2.9	1.1
ERCOT	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

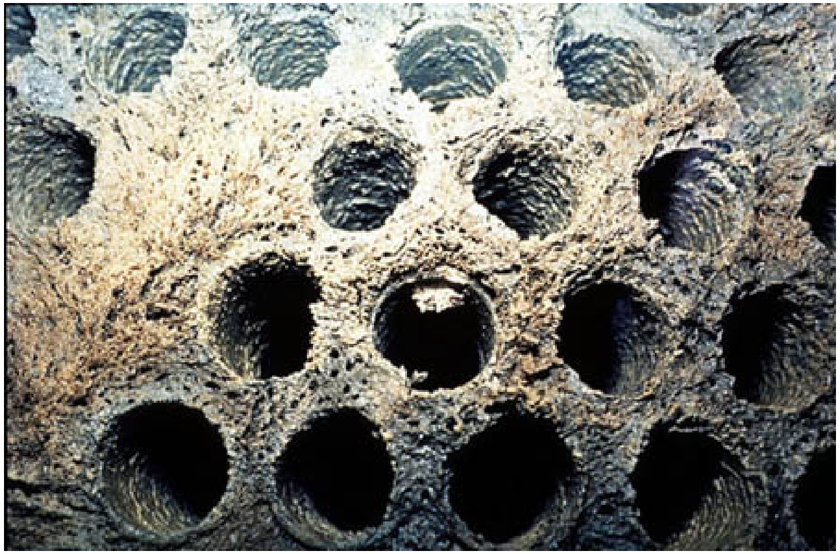
POWER PLANTS WITH SUFFICIENT MUNICIPAL WASTEWATER FOR COOLING



KEY TECHNICAL CHALLENGES WITH THE USE OF IMPAIRED WATERS

- Precipitation and scaling
- Accelerated corrosion
- Biomass growth

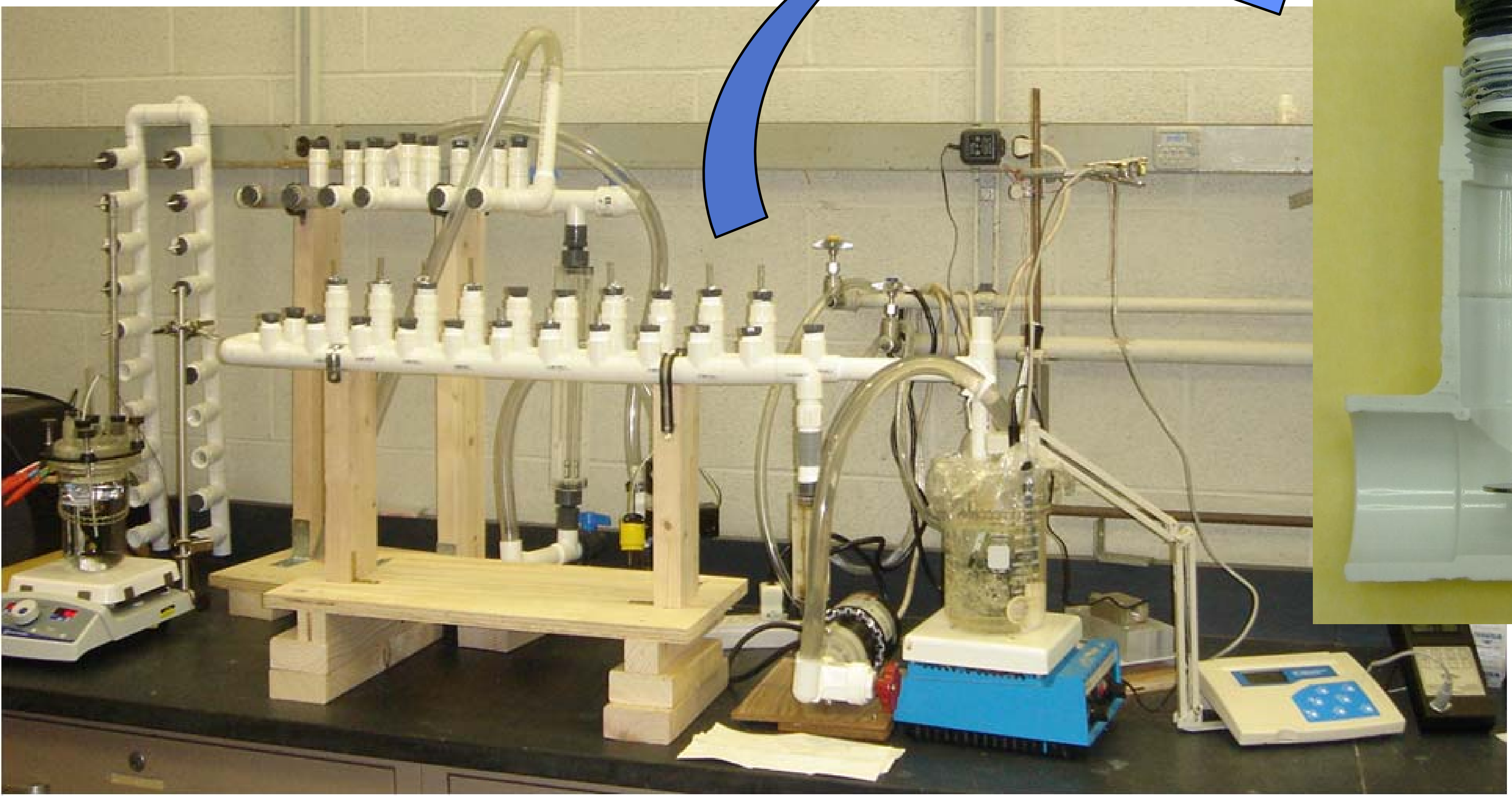


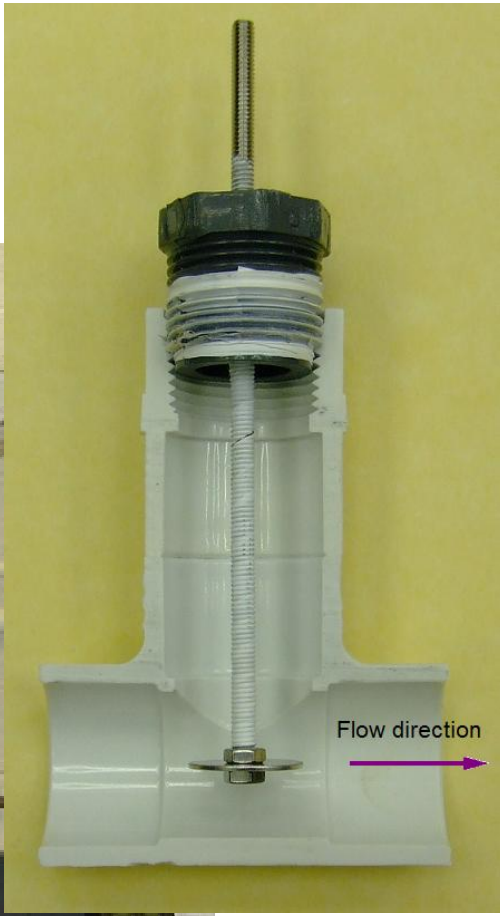


CARNEGIE MELLON – UNIV PITTSBURGH USDOE PROJECT GOALS

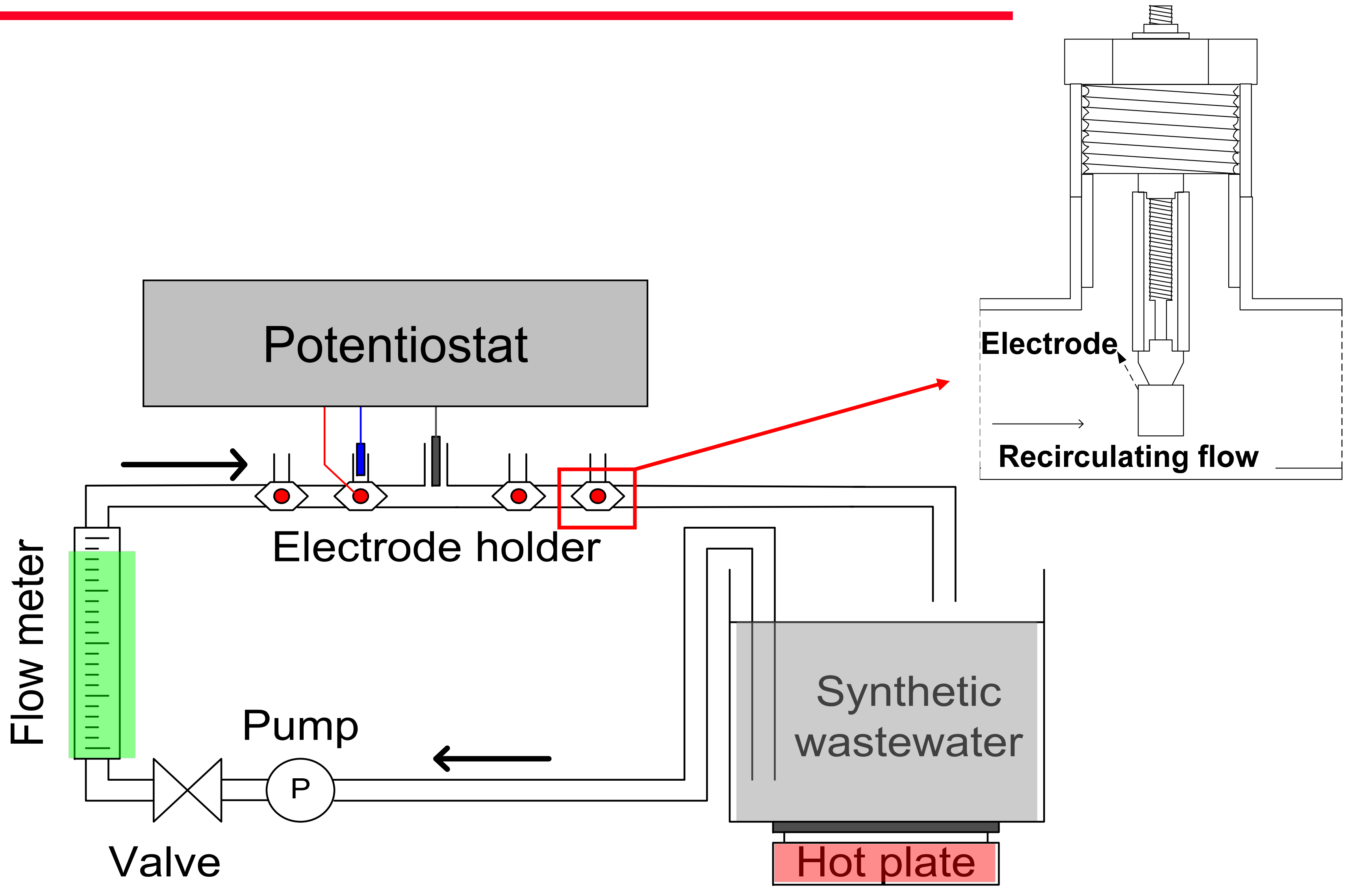
- Evaluate feasibility of controlling corrosion, scaling, and biofouling through different combinations of phys/chem/bio treatment
- Evaluate performance, costs, and environmental impacts of different treatment combinations
- Develop methods of measuring corrosion, scaling; evaluate mechanisms

BENCH-SCALE WATER RECIRCULATING SYSTEM: SCALING STUDIES





BENCH-SCALE WATER RECIRCULATING SYSTEM: CORROSION STUDIES



PILOT SCALE COOLING TOWERS

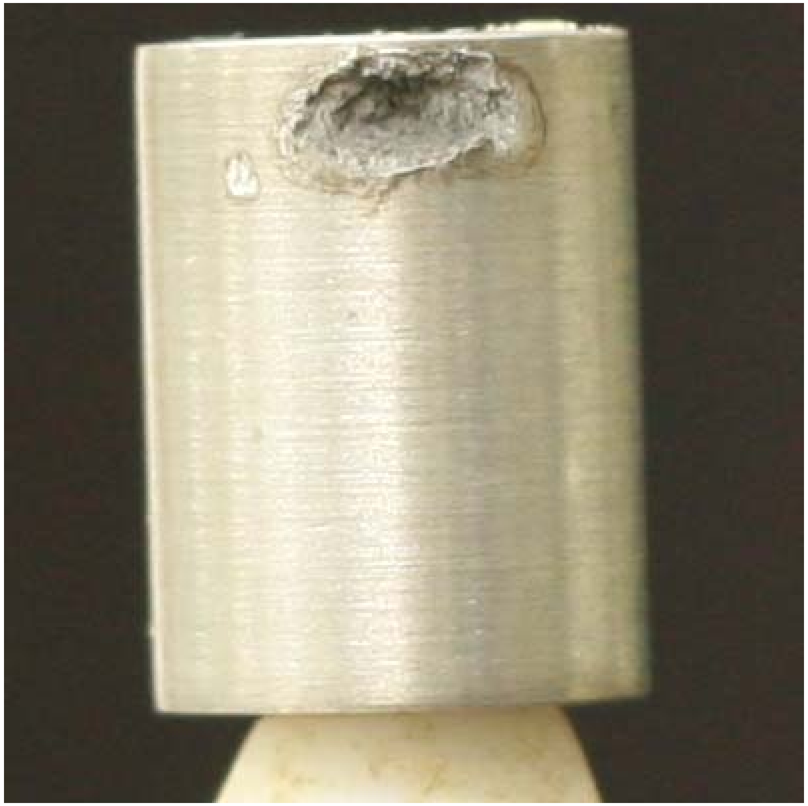
Franklin Township Municipal Sanitary Authority, Murrysville, PA

PILOT SCALE COOLING TOWERS

PILOT SCALE COOLING TOWERS

MILD STEEL FROM PILOT B2 AFTER 21-d EXPOSURE (before/after acid cleaning)

ALUMINUM FROM PILOT B2 AFTER 21-d EXPOSURE (before/after acid cleaning)



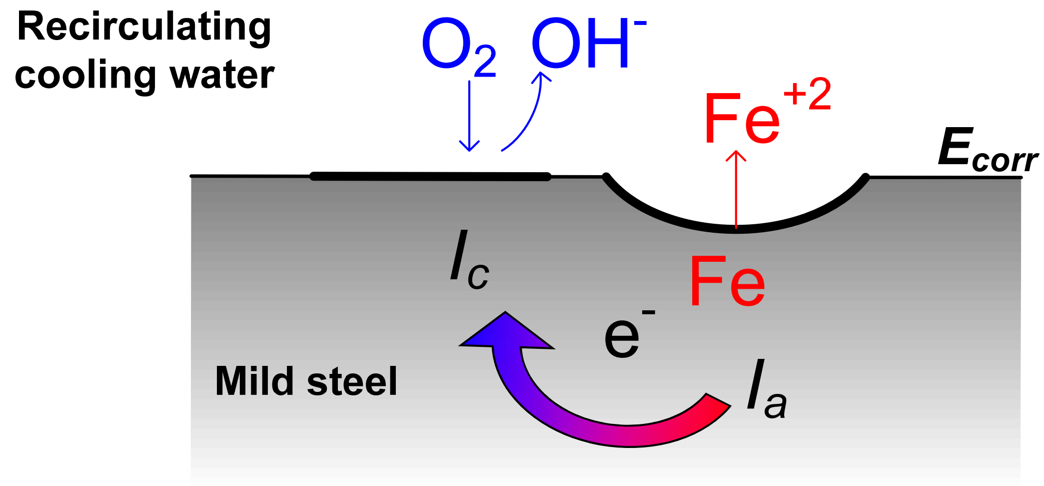
SUMMARY: SCALING AND CORROSION

- Various strategies for controlling scaling and corrosion to acceptable levels (inhibitors; pH control; removal of PO_4, NH_3, organic matter)
- Tradeoffs: e.g., PO_4 reduces corrosion, but increases scaling; lower pH reduces scaling, increases corrosion
- Determining optimal approach requires testing and modeling

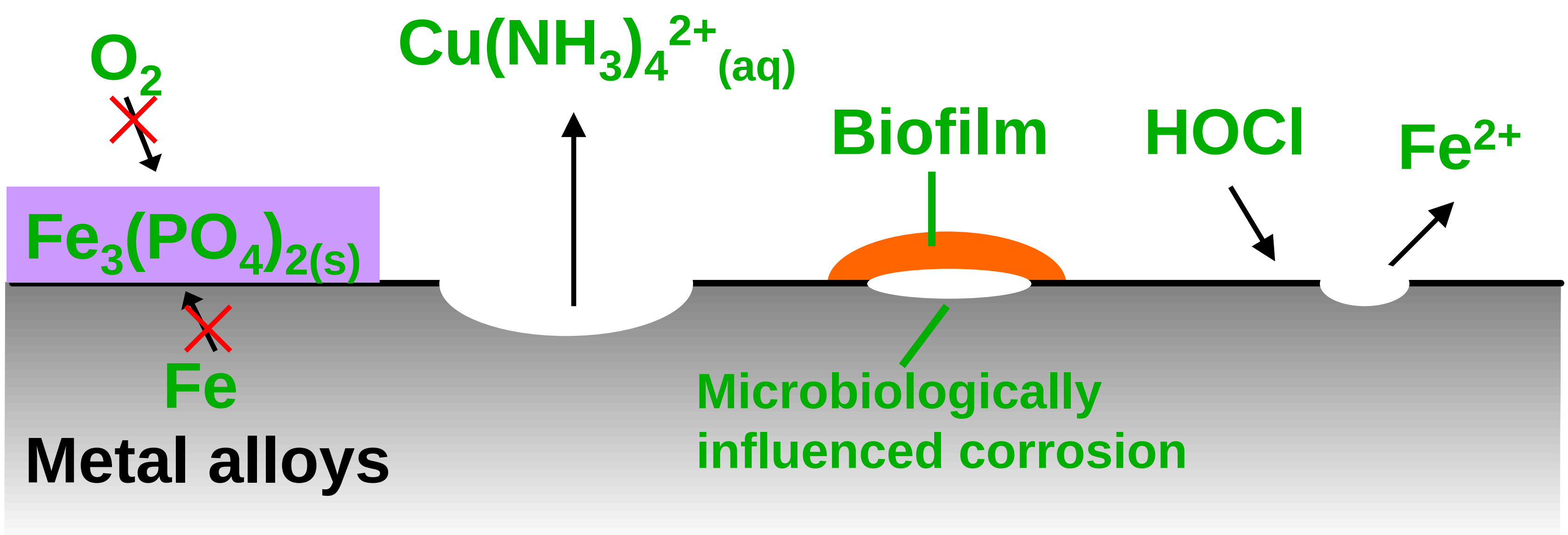
SUMMARY: BIOFOULING

- Secondary-treated wastewater has high potential for biofouling
- Addition of chlorine as a biocide impaired effectiveness of antiscalants and accelerated corrosion
- Chloramine found to be an effective biocide and much less corrosive than chlorine

CORROSION PROCESSES

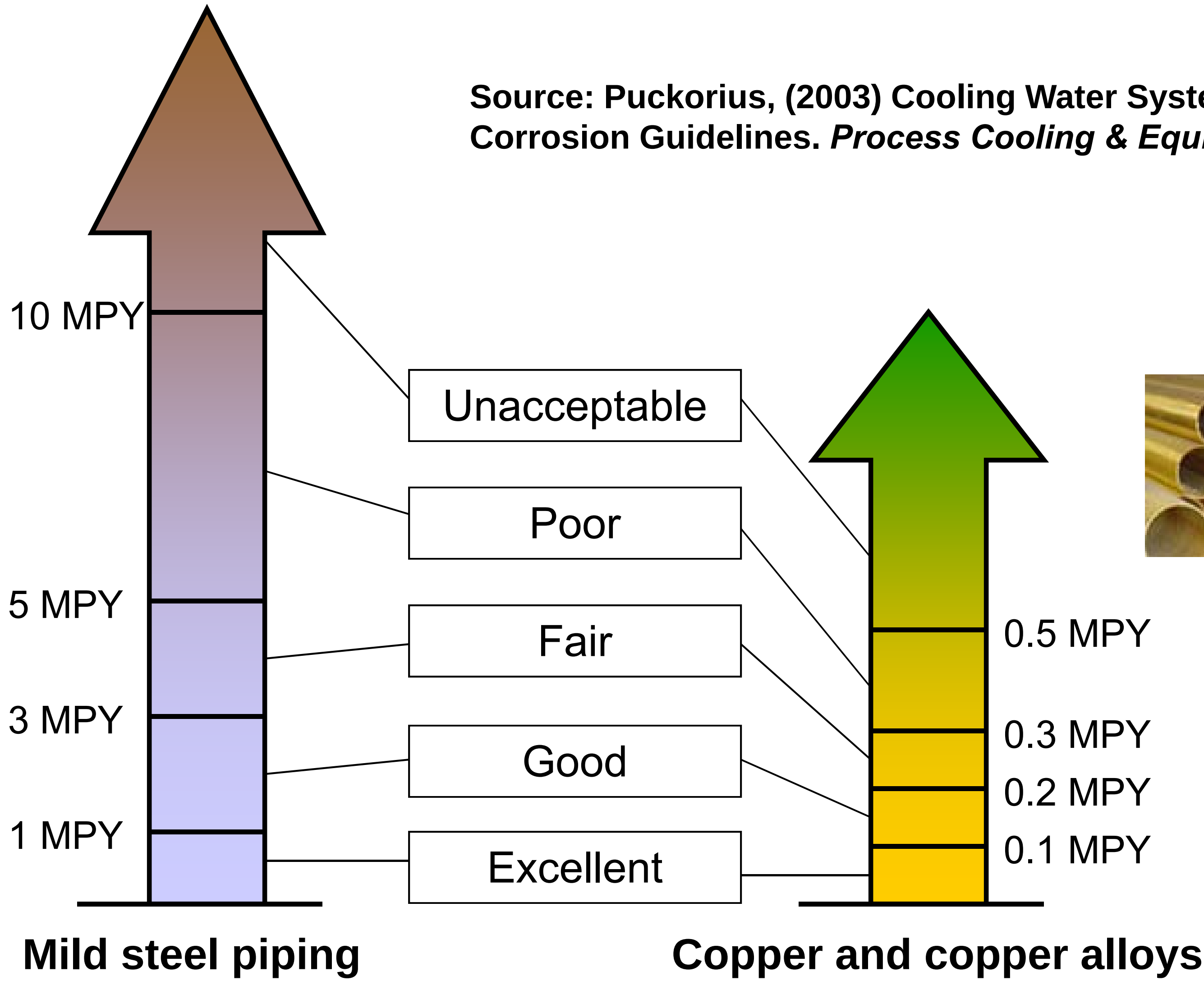


Phosphate; ammonia; microbial activity; oxidizing agent



CORROSION CRITERIA FOR COMMONLY USED ALLOYS

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



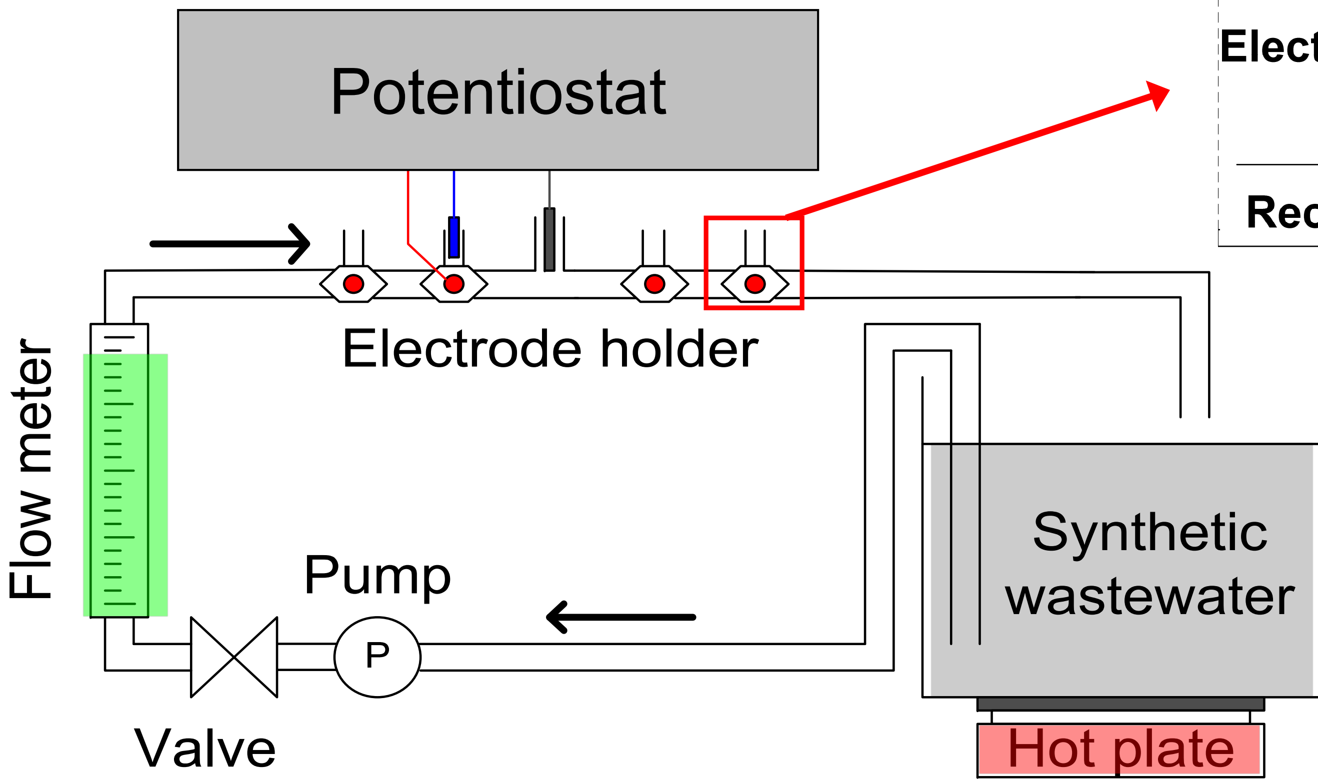
OBJECTIVES – CORROSION STUDIES

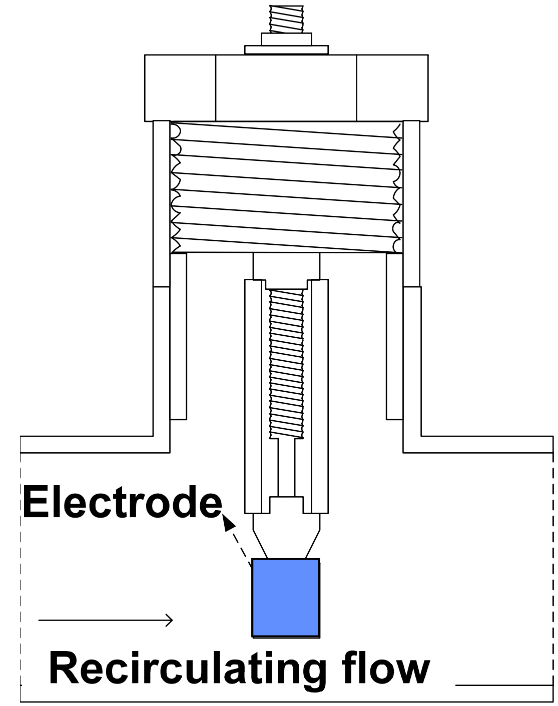
- Investigate corrosion rates and corrosion control when using impaired waters in cooling systems
- Study mechanisms of tolyltriazole (TTA) protection of copper against oxidizing agents
- Establish method to determine instantaneous corrosion rates in cooling systems

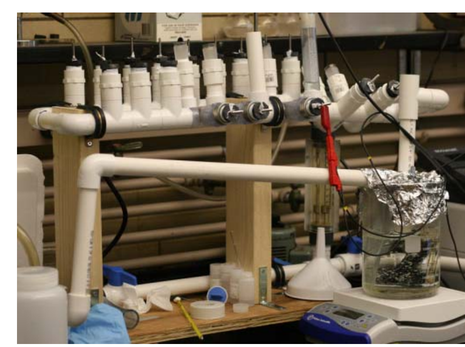
ESTABLISH INSTANTANEOUS CORROSION RATE (ICR) MEASUREMENT METHOD

- Application of gravimetric weight loss method (WLM)
- Application of electrochemical polarization resistance method (PRM)
- Combination of PRM and WLM to relate R_P to weight loss and hence *ICR*

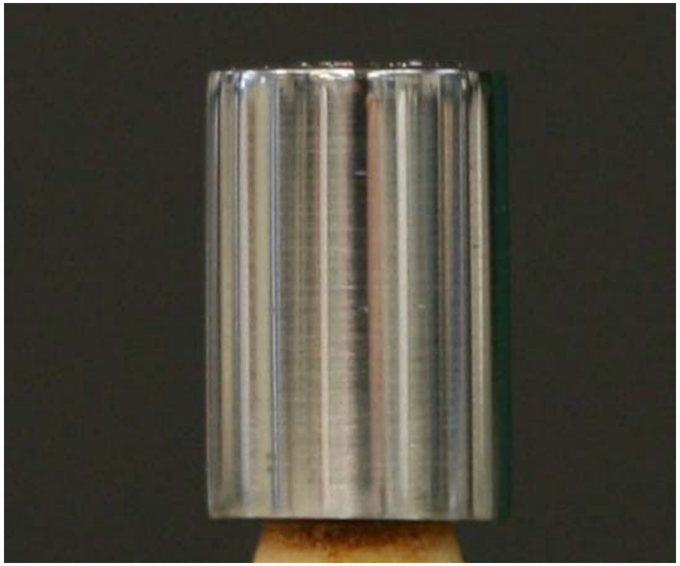
BENCH-SCALE WATER RECIRCULATING SYSTEM



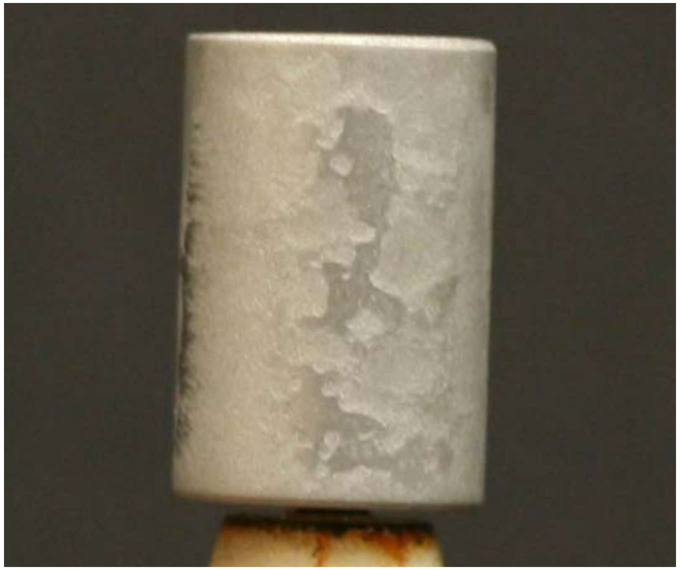




GRAVIMETRIC WEIGHT LOSS METHOD



New; W_i



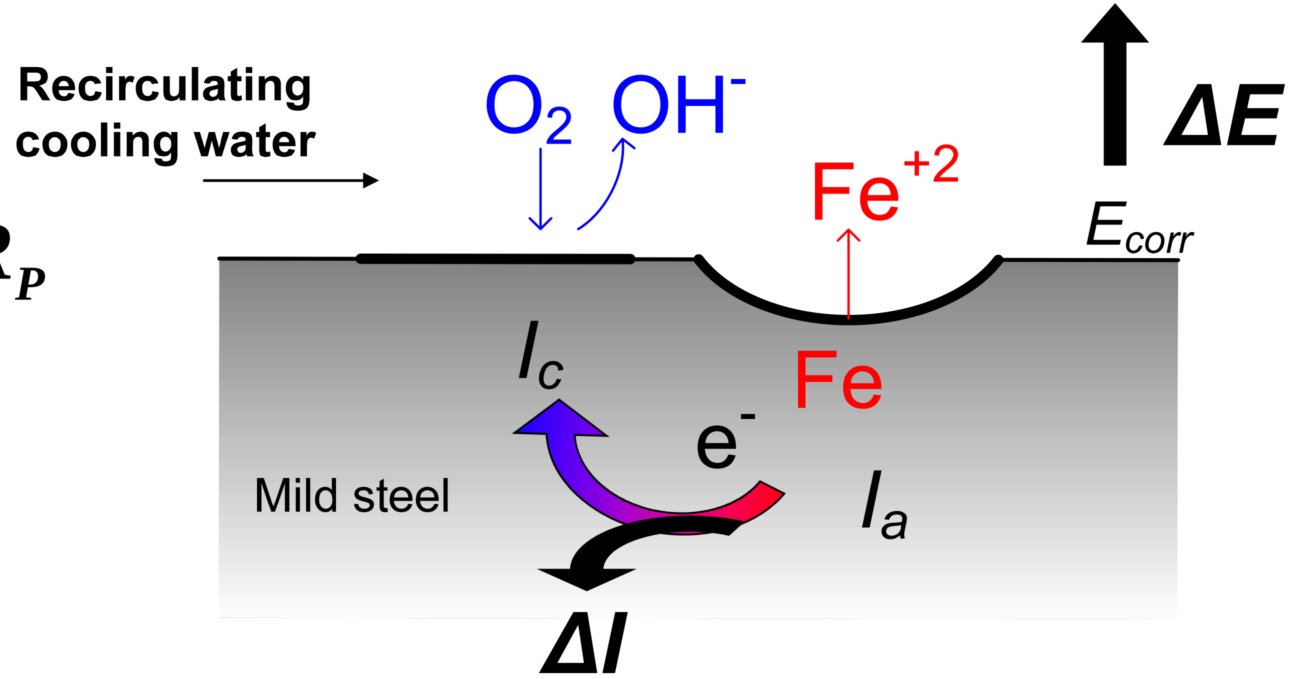
Corroded; W_f

(After surface cleaning)

$$W_L = W_i - W_f$$

POLARIZATION RESISTANCE METHOD AND INSTANTANEOUS CORROSION RATE

$$\left.\frac{\Delta E}{\Delta I}\right|_{\Delta E \to 0} \equiv R_P$$

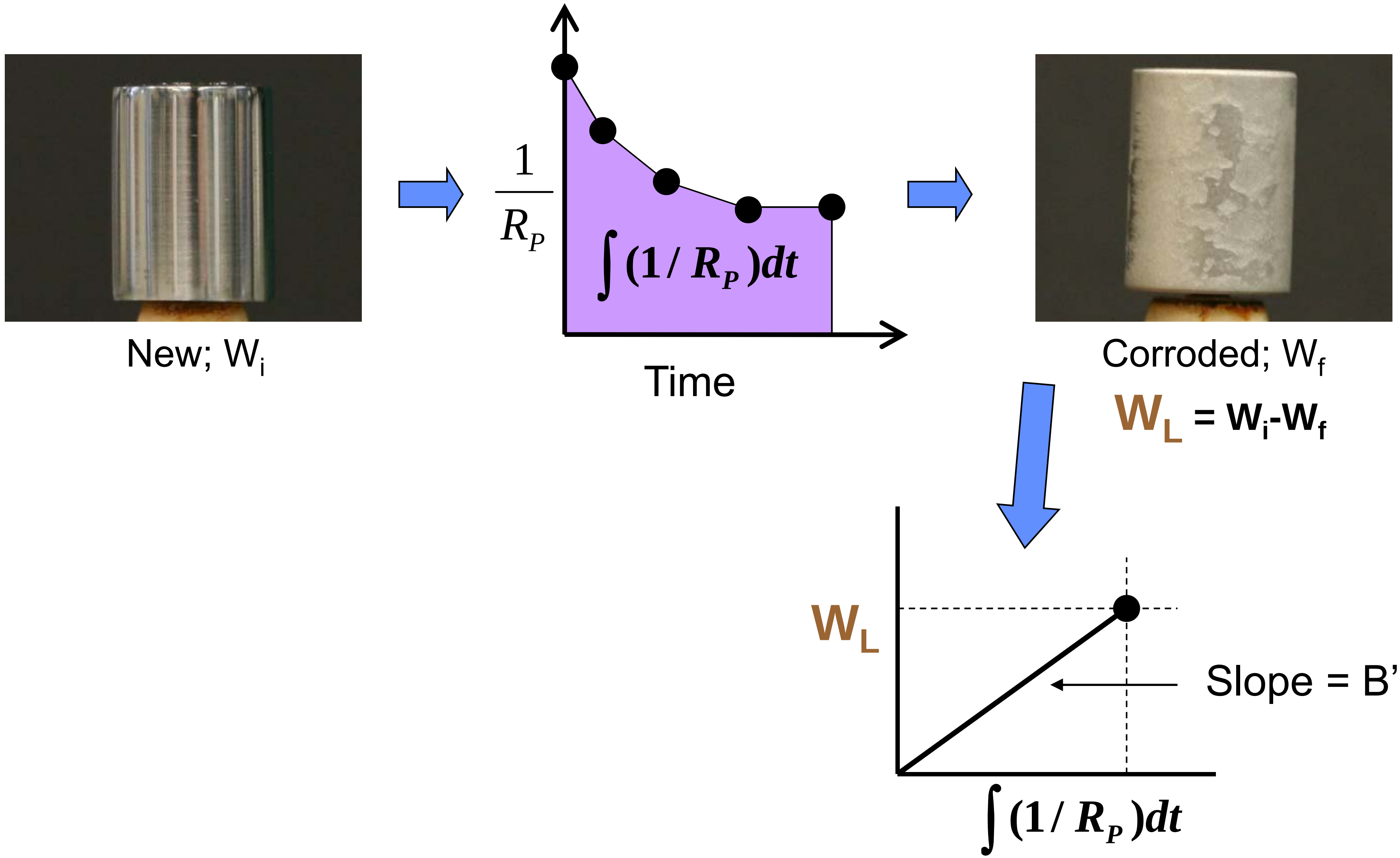


$$ICR \propto \frac{1}{R_P}$$

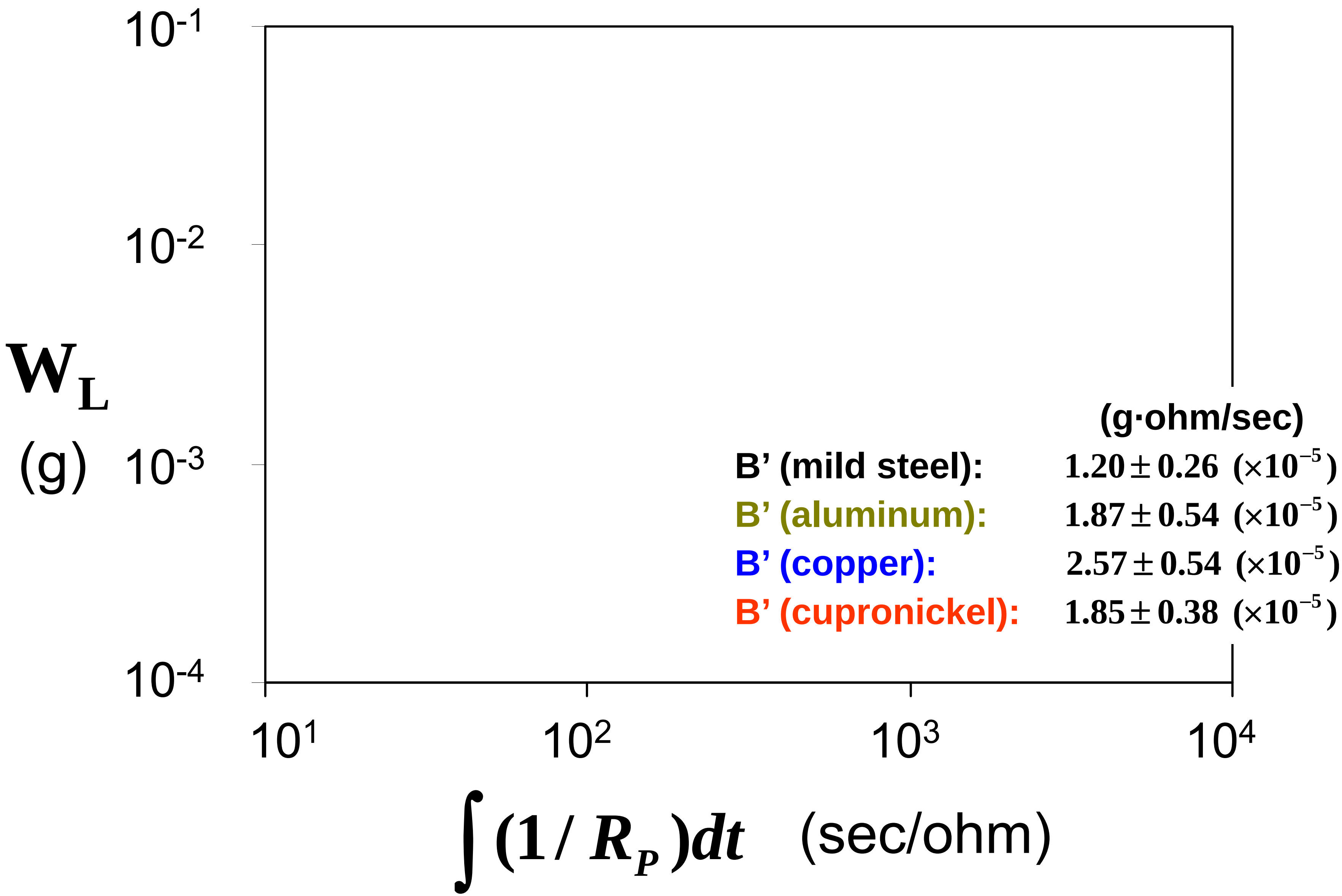
$$\int ICR\,dt \propto \int \frac{1}{R_P}\,dt$$

$$W_L \propto \int \frac{1}{R_P}\,dt$$

COMBINATION OF WLM AND PRM



B' VALUES FOR METAL ALLOYS IN SYN MWW



Source: Hsieh et al., IECR, 49:9117-, 2010

B' AND CORROSION RATE MEASUREMENT

- With knowledge of B' for a particular alloy in a particular system, ICR can be calculated from R_p measurement.

$$ICR = B'/A\rho \times (1/R_p)$$

- The determined ICR can be expressed in MPY and compared with the corrosion guidelines

ISSUES WITH THE USE OF IMPAIRED WATERS FOR POWER PLANT COOLING

- Optimization problem: Extent of pretreatment before use and chemical addition for control
- Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) of the alternatives
- Regulatory issues
- Social acceptance issues

SUMMARY

- Water needs for thermoelectric power production are substantial: 41% of all freshwater withdrawal.
- With increasing population and growing economy, increasing electricity demand
- Alternative water sources are needed for cooling in electric power production
- Impaired waters can be alternative water sources, but are more costly and complex to manage

MORE INFORMATION

http://cooling.ce.cmu.edu/

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