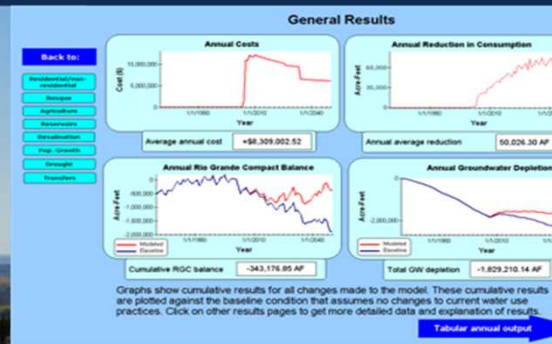


Exceptional service in the national interest



Energy-Water Nexus Past, Present and Future

Vincent Tidwell

Sandia National Laboratories

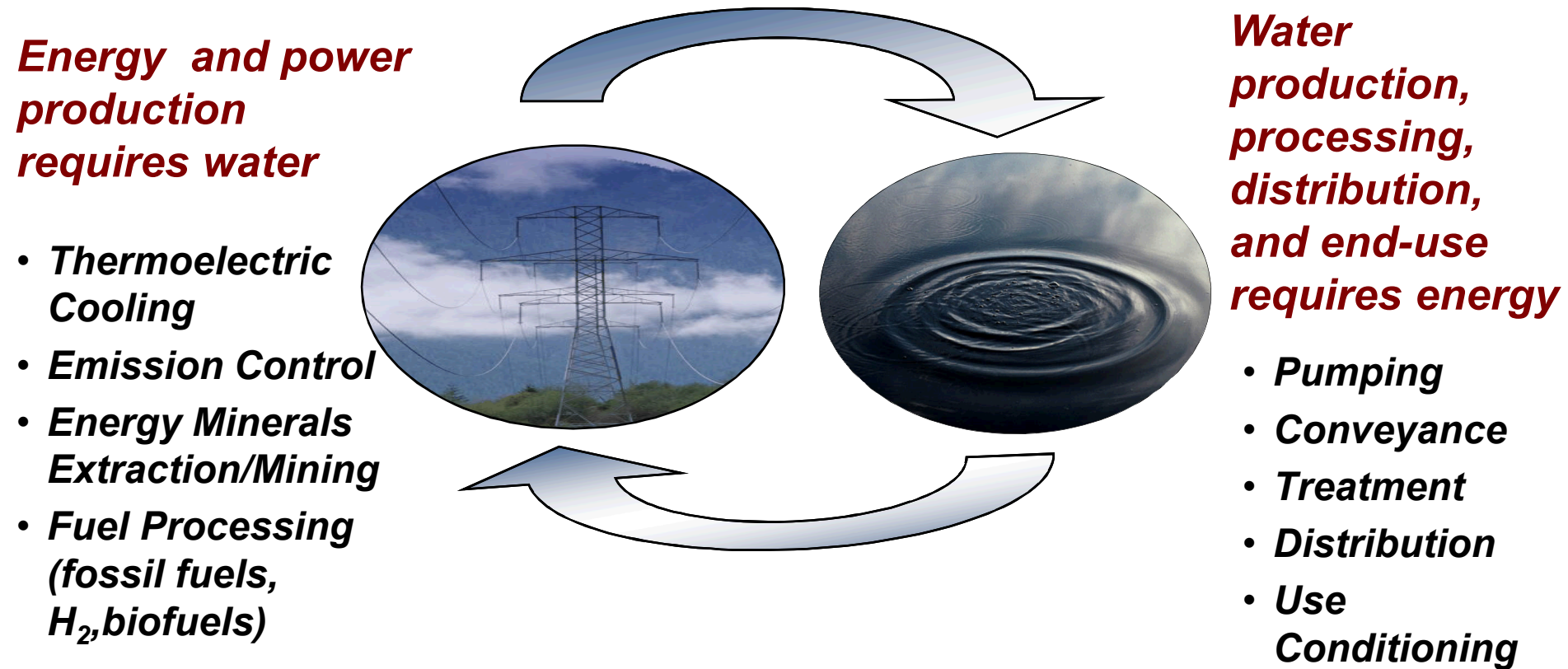
State of America's Water: Present and Future

February 10, 2015



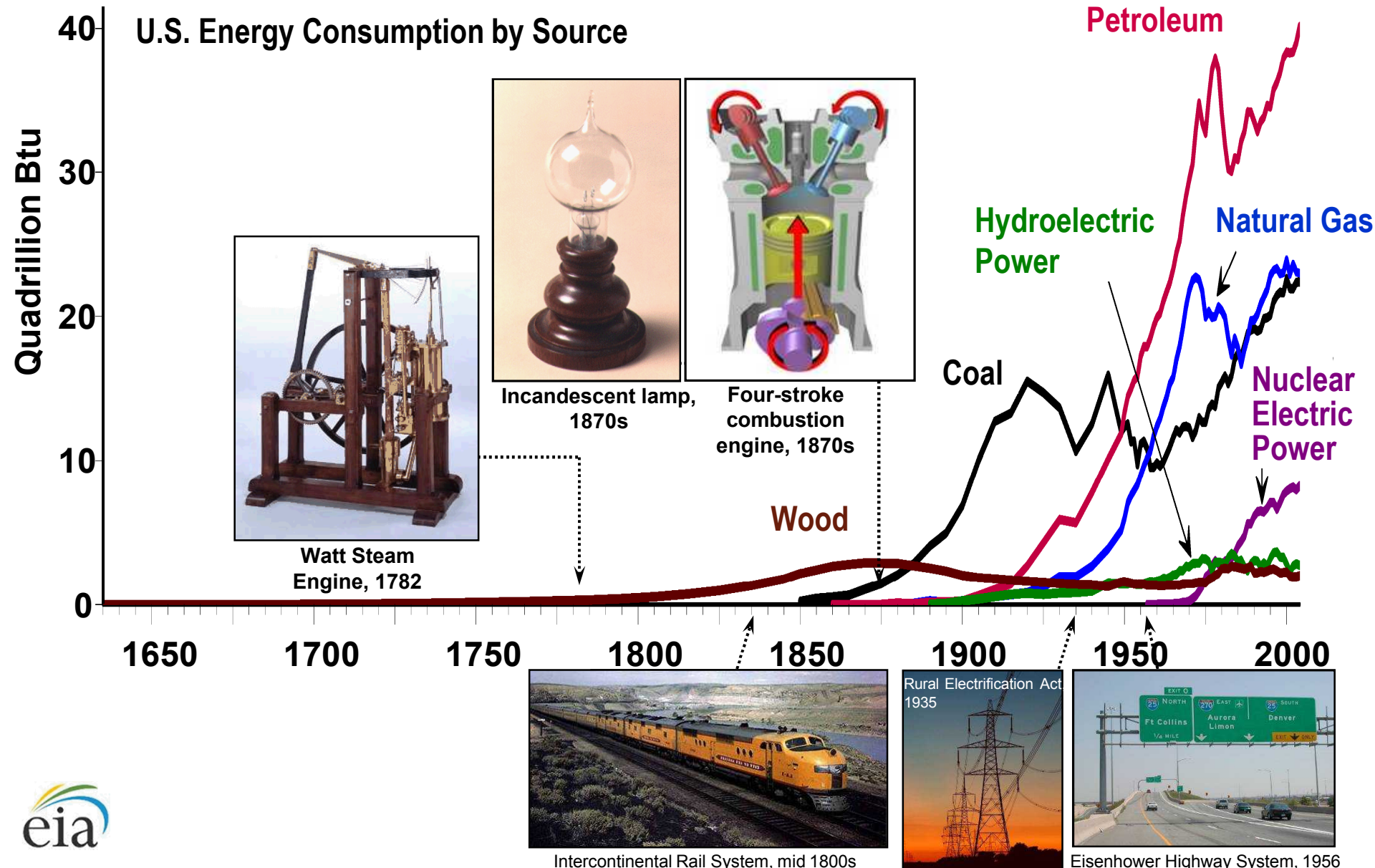
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Energy-Water Nexus

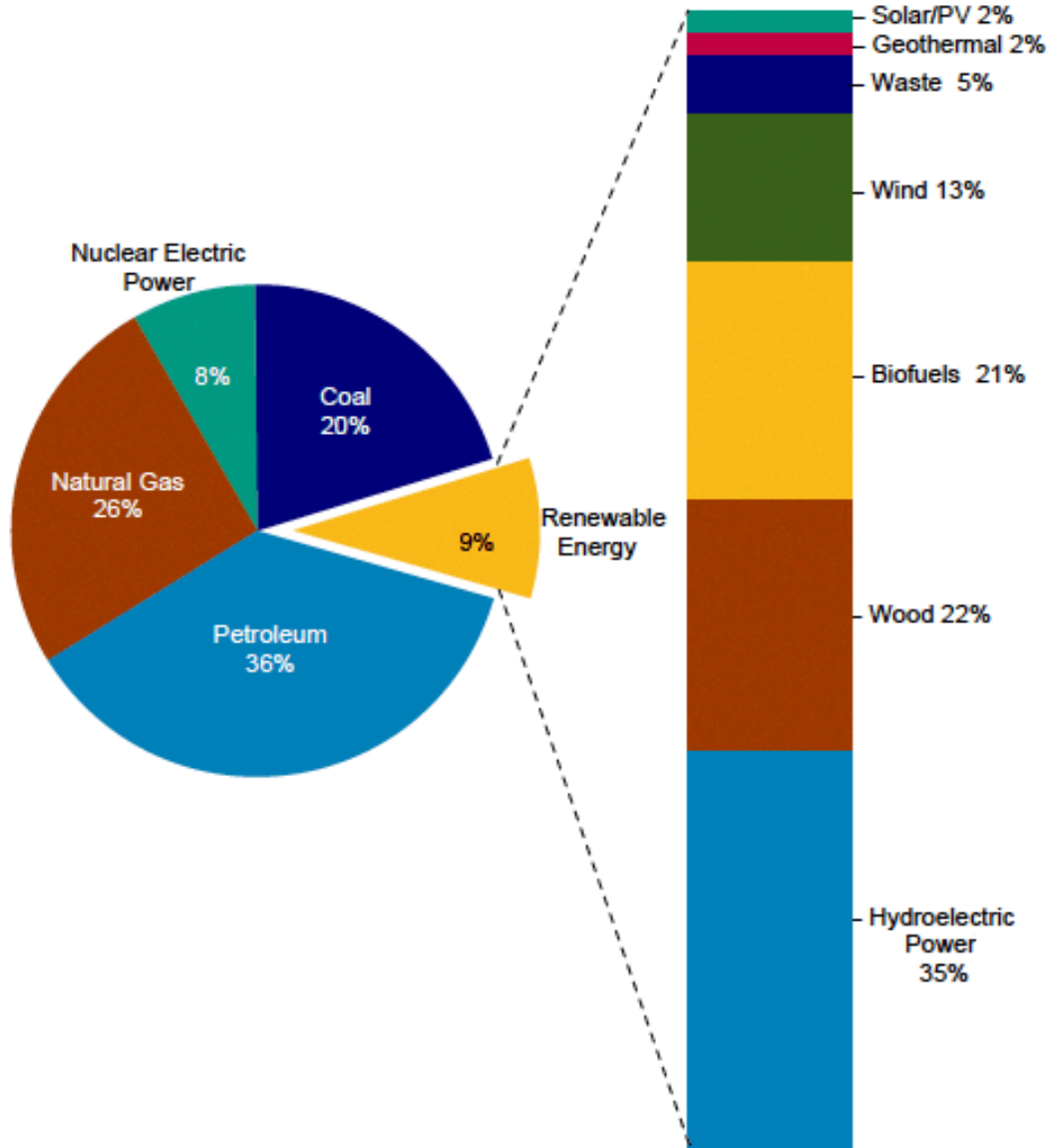


***Energy-
Water
Nexus
Past***

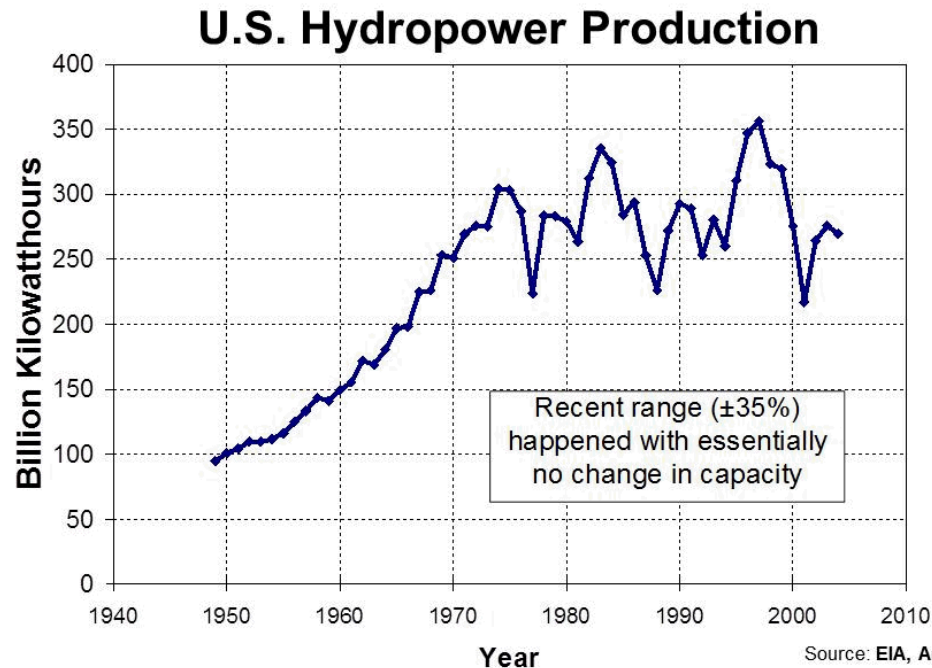
400 Years of Energy Use in the U.S.



High Fossil Fuel Use

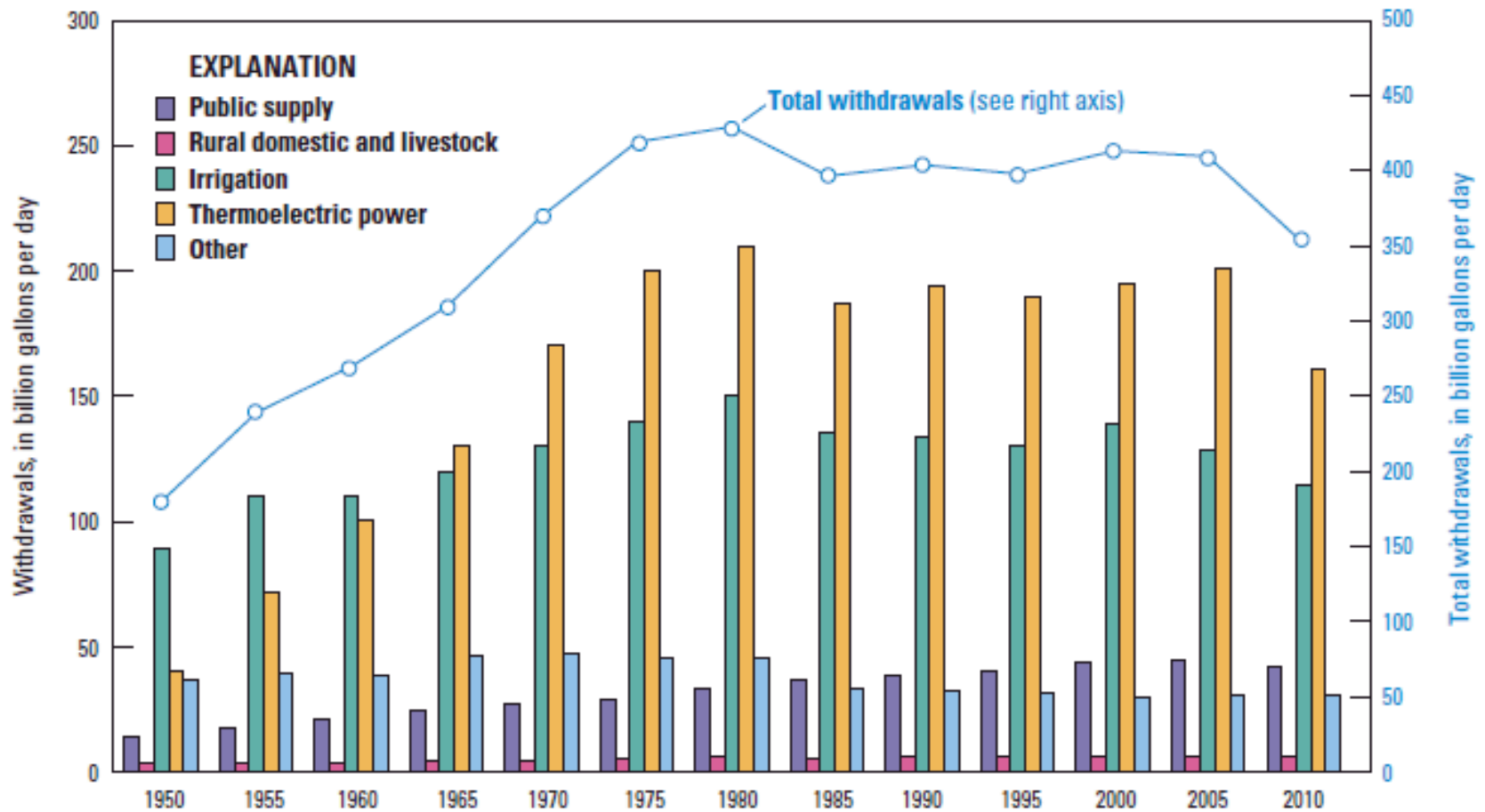


Variability of Hydropower Production



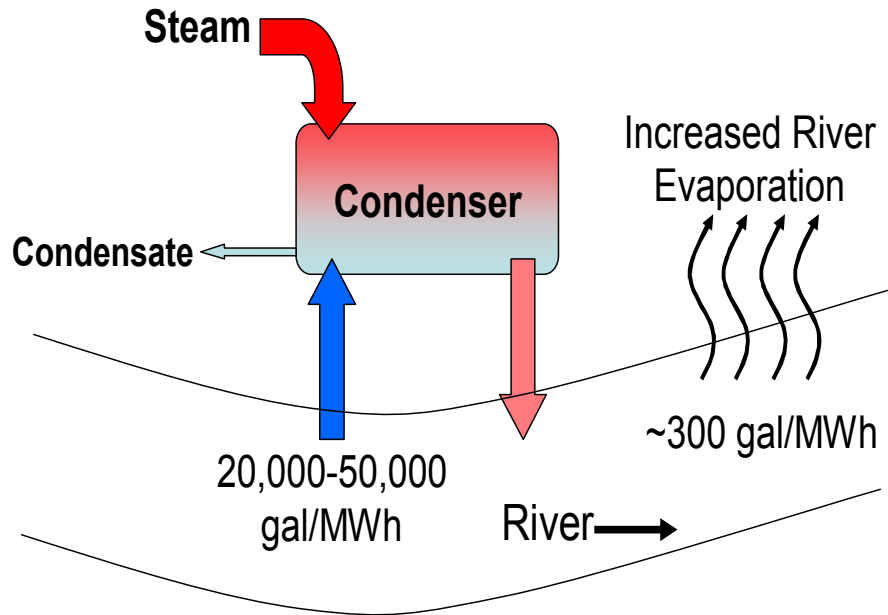
- Since 1980s, hydroelectric power has satisfied about 6% of the Nation's total electricity demand.
- Dispatchable renewable energy source often used to balance wind and solar production.
- 3,700 MW of generating capacity on the lower Colorado River is particularly vulnerable due to variety of issues.

Trends in Water Use by Category: 1950-2010

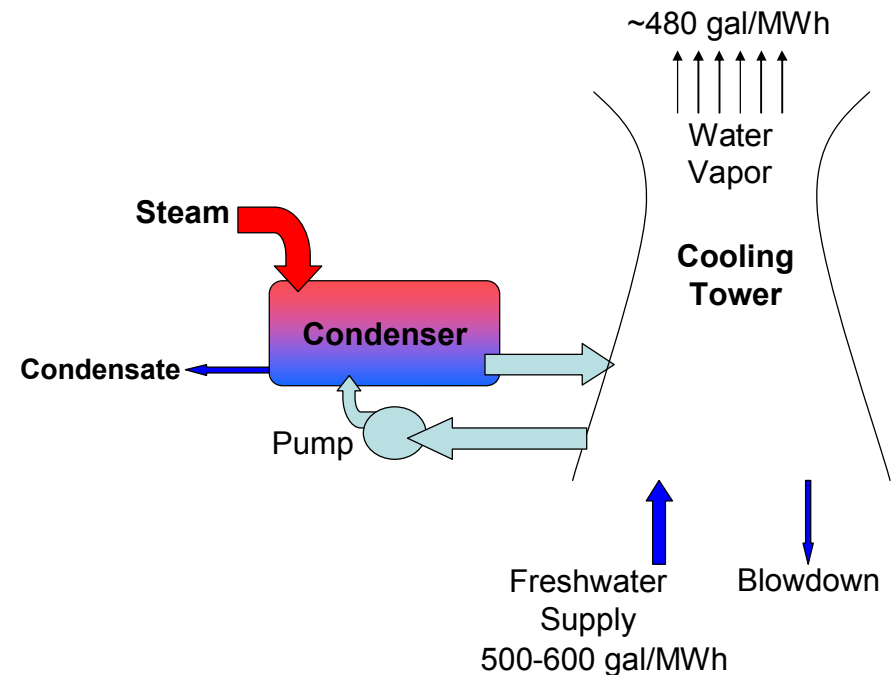


Source: USGS 2014

Power Plant Cooling Options



Open-loop "once-through" cooling cycle



Closed-loop cooling cycle

Source: EPRI 2002

Energy-Water Nexus

“Many times in recent years, water use practices proposed for new energy conversion facilities have been the subject of great controversy. Many people anticipate that the frequency and bitterness of these conflicts will increase.”

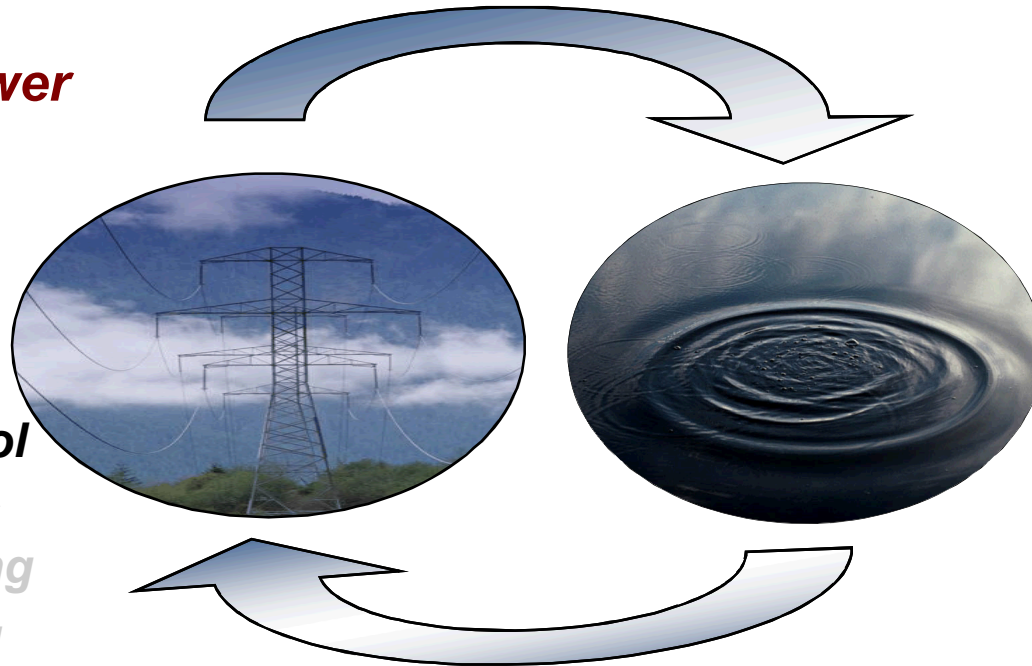
(DOE, 1980)

***Energy-
Water
Nexus
Present***

Energy-Water Nexus

Energy and power production requires water

- **Thermoelectric Cooling**
- **Emission Control**
- *Energy Minerals Extraction/Mining*
- *Fuel Processing (fossil fuels, H₂, biofuels)*

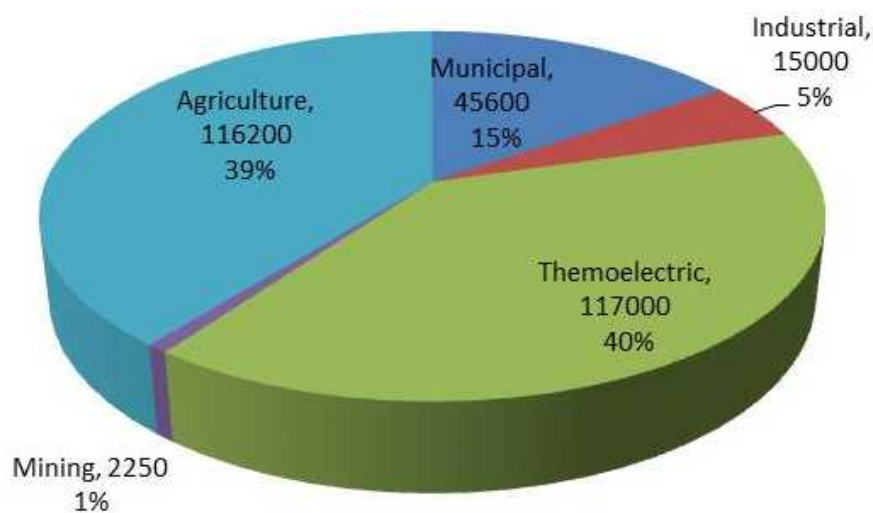


Water production, processing, distribution, and end-use requires energy

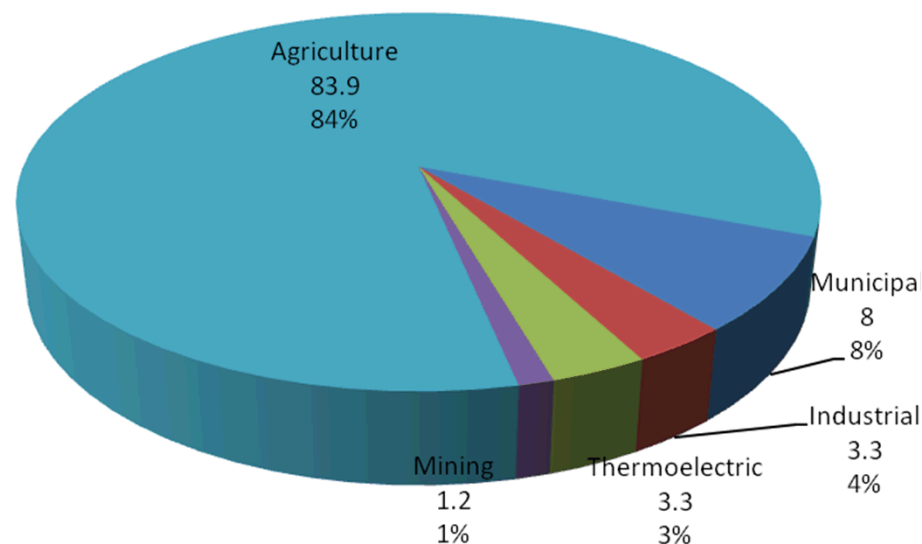
- *Pumping*
- *Conveyance*
- *Treatment*
- *Distribution*
- *Use Conditioning*

Water for Thermoelectric Power Generation

Water Withdrawal (BGD) 2010

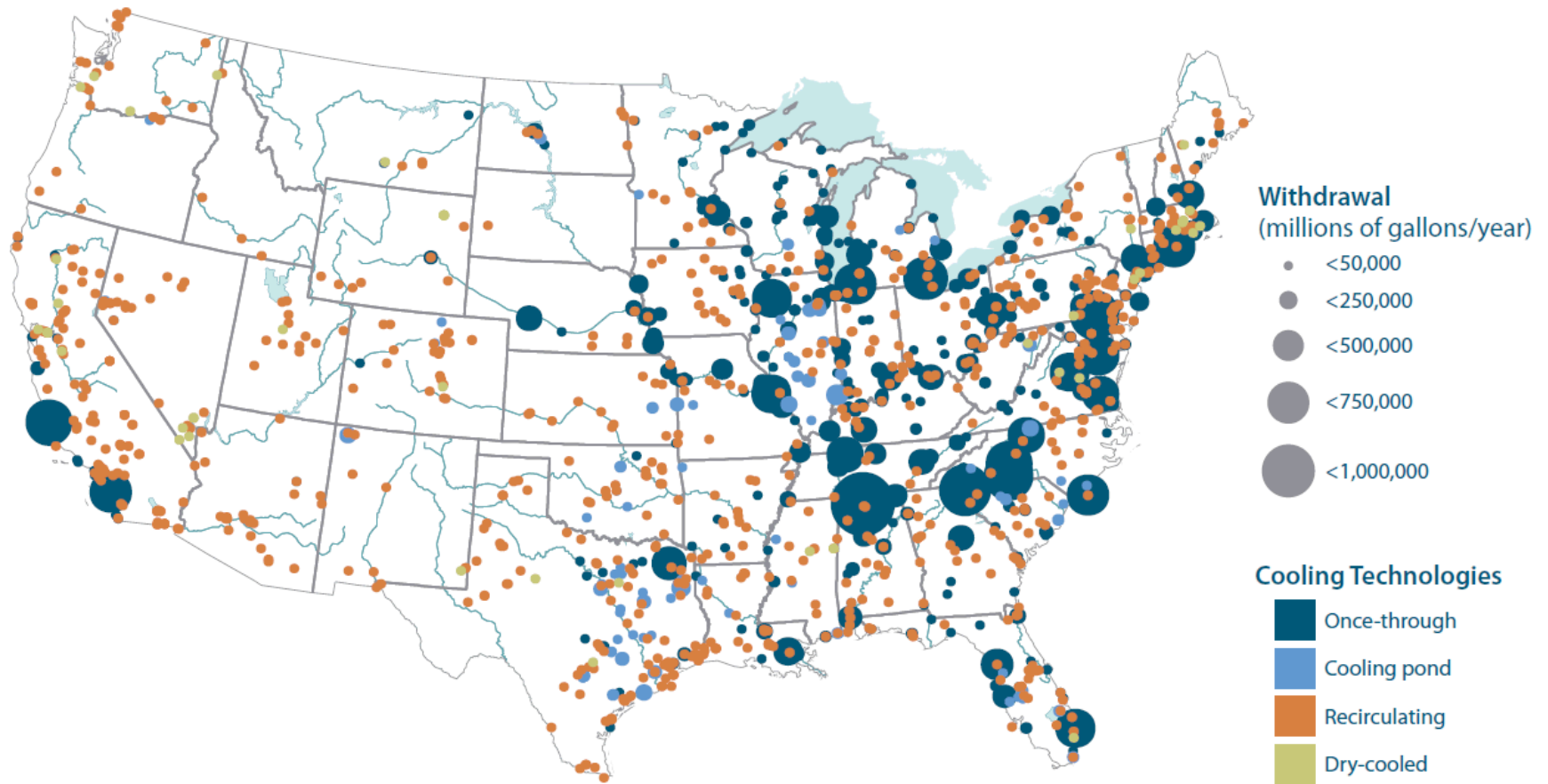


Water Consumption (BGD) 1995



Source: USGS 1995, 2014

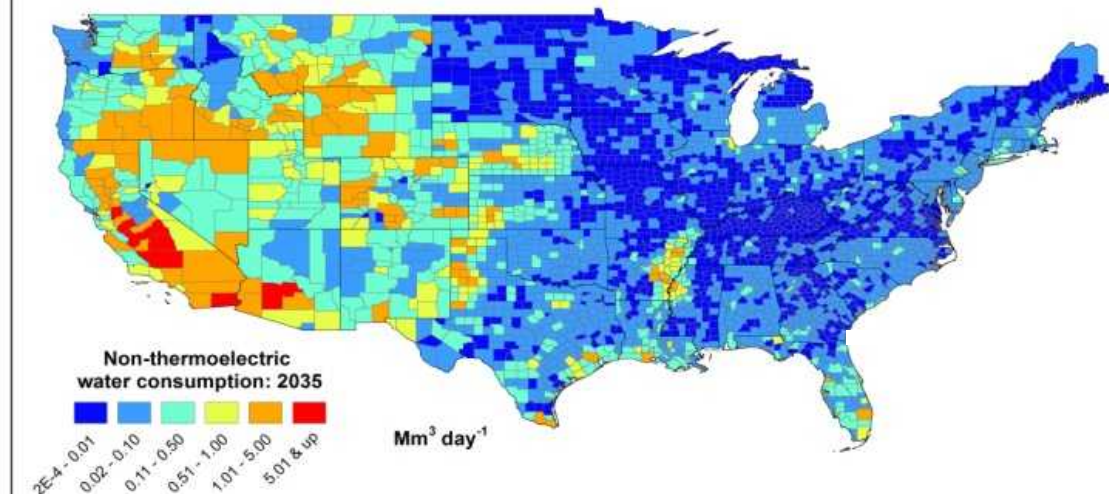
Power Plant Water Withdrawals: 2008



Source: UCS 2011

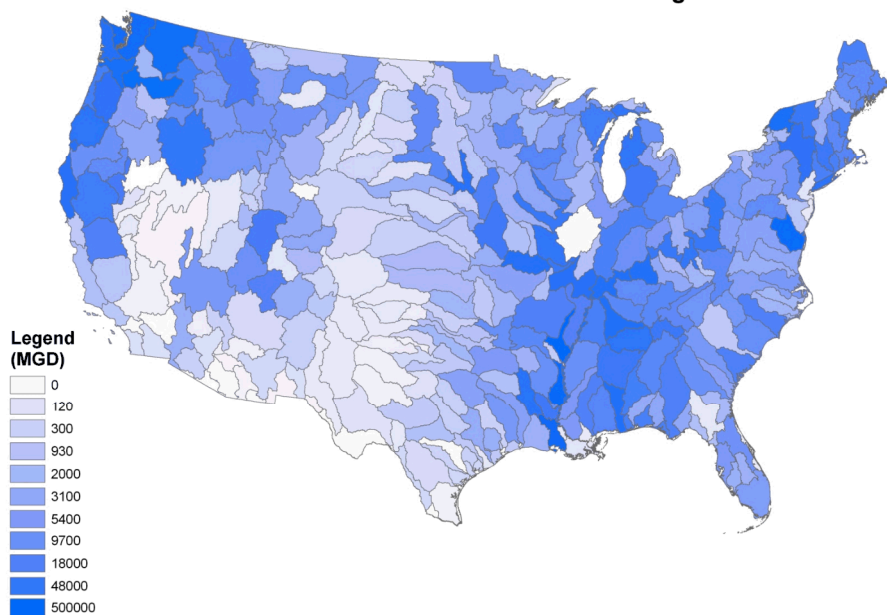
Place Matters: Water Consumption

Non-Thermoelectric Consumption 2010

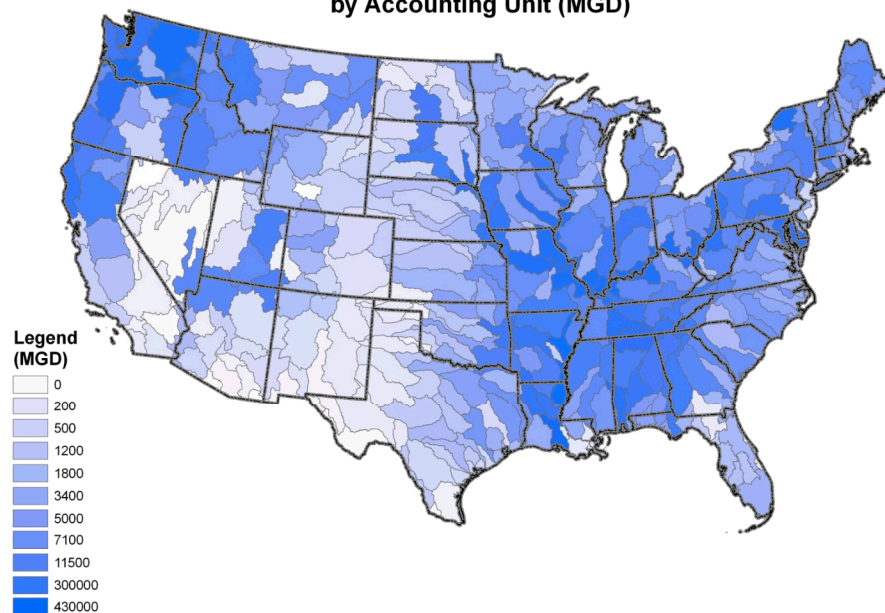


Place Matters: Water Supply

Sustainable Groundwater Recharge

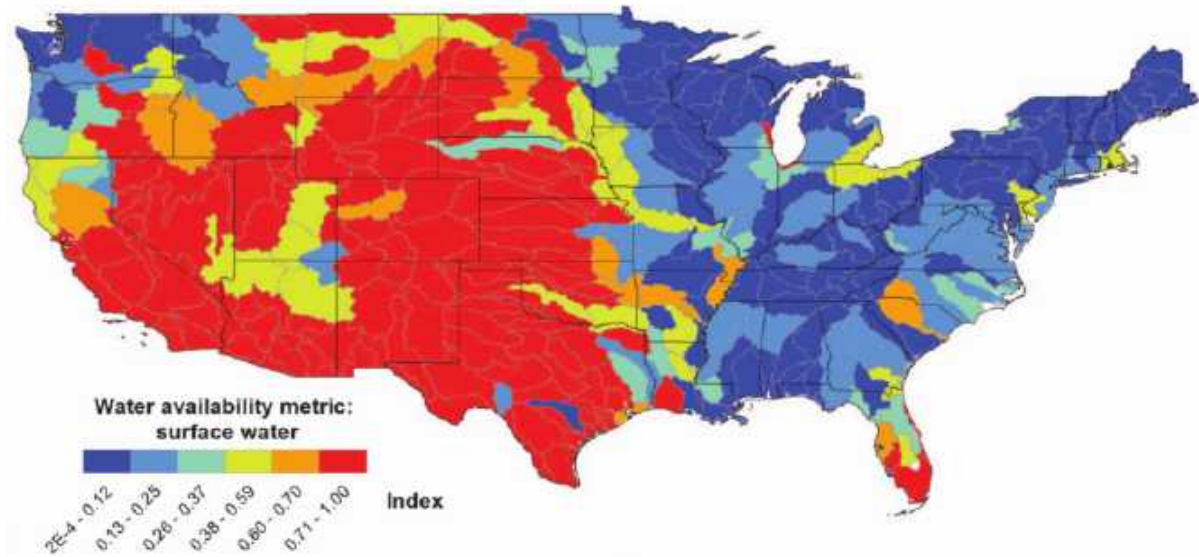


**Annual Average Flow
by Accounting Unit (MGD)**

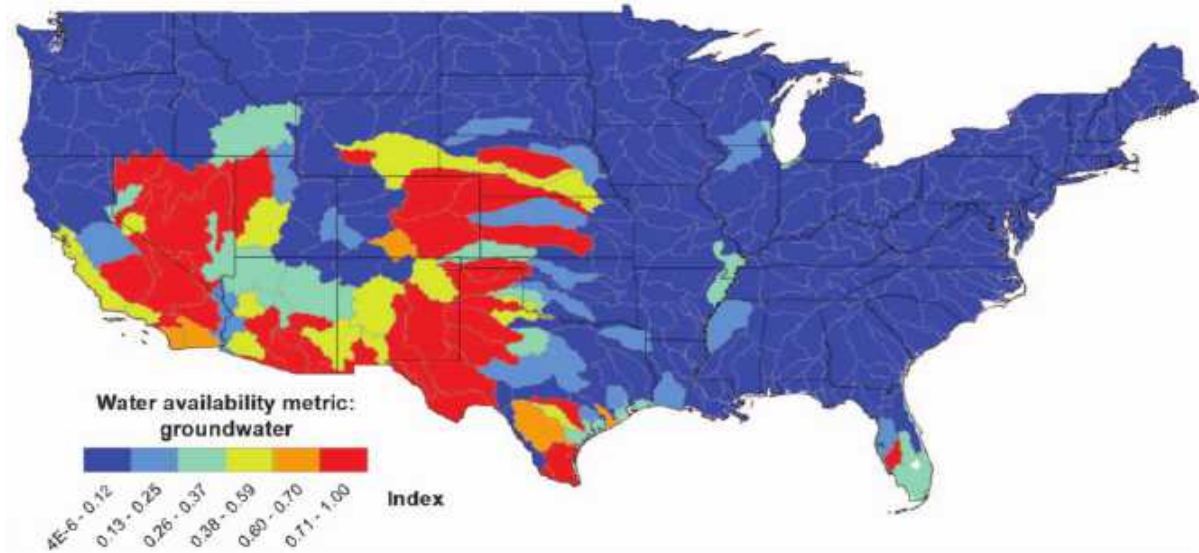


Limited Water Basins

Limited
Surface Water

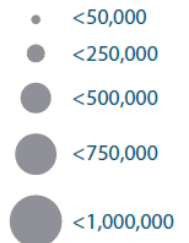


Limited
Groundwater

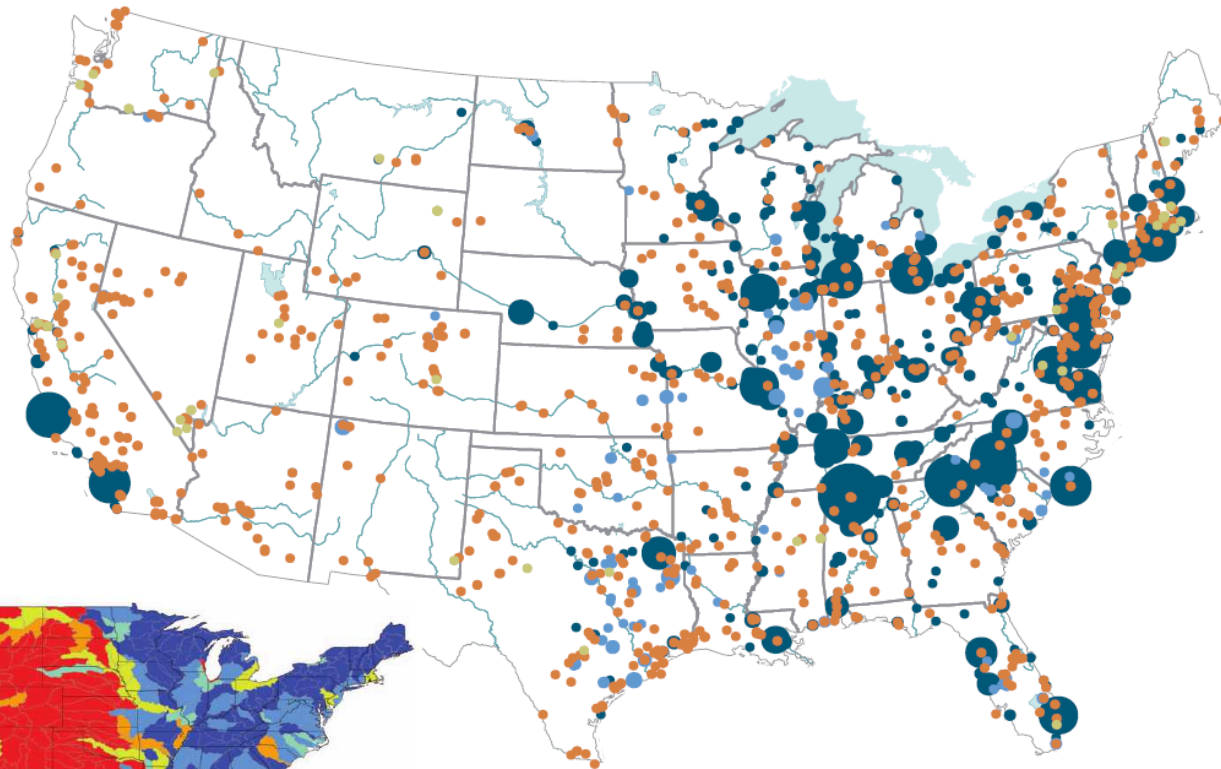
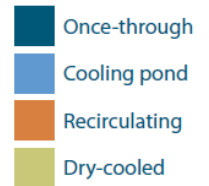


Energy-Water Nexus

Withdrawal
(millions of gallons/year)

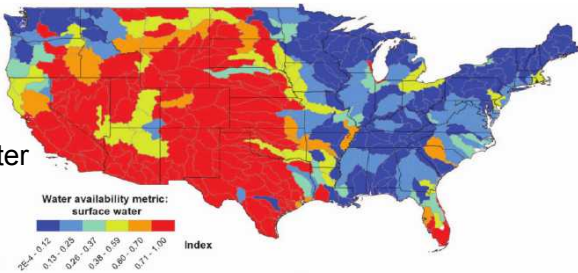


Cooling Technologies

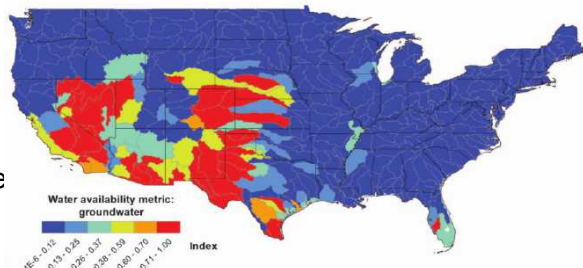


Source: UCS 2011

Surface Water
Availability



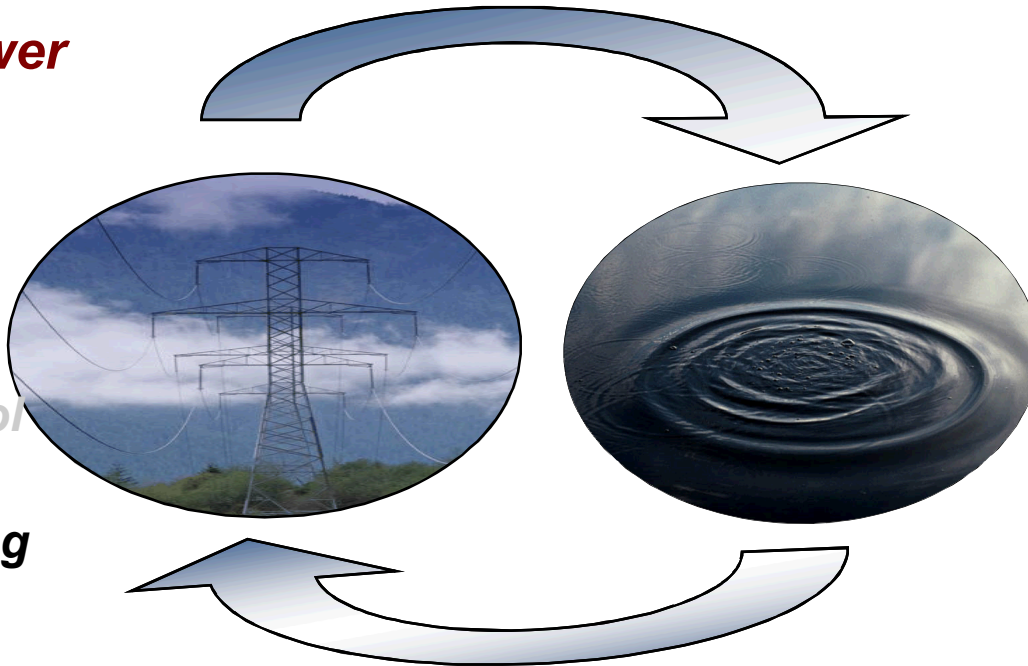
Groundwater
Availability



Energy-Water Nexus

Energy and power production requires water

- *Thermoelectric Cooling*
- *Emission Control*
- **Energy Minerals Extraction/Mining**
- **Fuel Processing (fossil fuels, H₂, biofuels)**

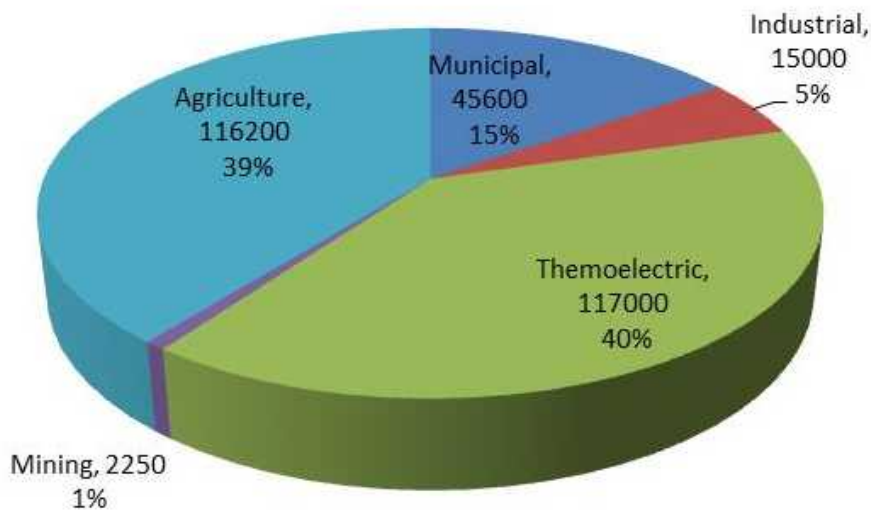


Water production, processing, distribution, and end-use requires energy

- *Pumping*
- *Conveyance*
- *Treatment*
- *Distribution*
- *Use Conditioning*

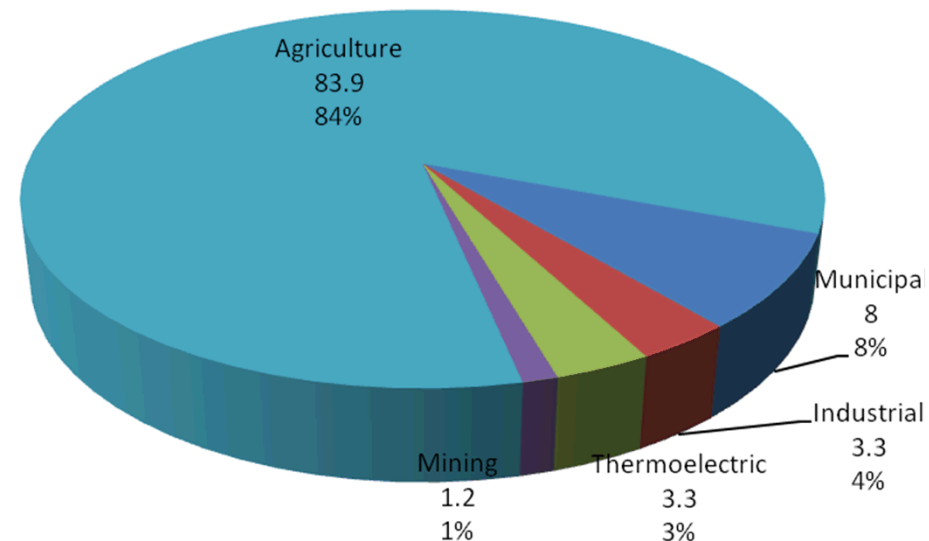
Water for Mining and Fuel Processing

Water Withdrawal (BGD) 2010



Estimated at ~2.6 BGD consumed in mining and fuel processing

Water Consumption (BGD) 1995

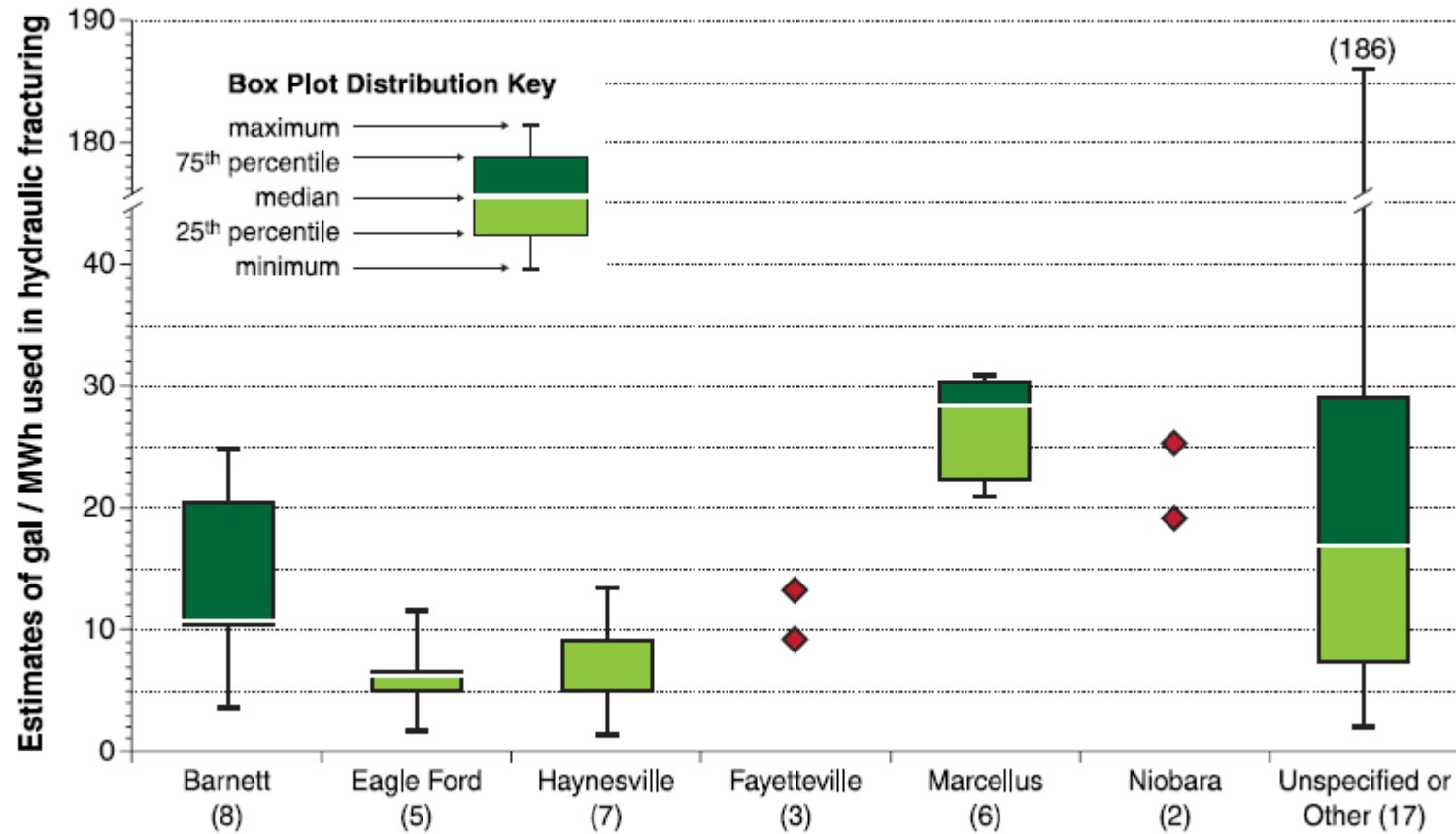


Source: USGS 1995, 2014

Gas and Oil Shale Development



Water Use in Hydraulic Fracturing

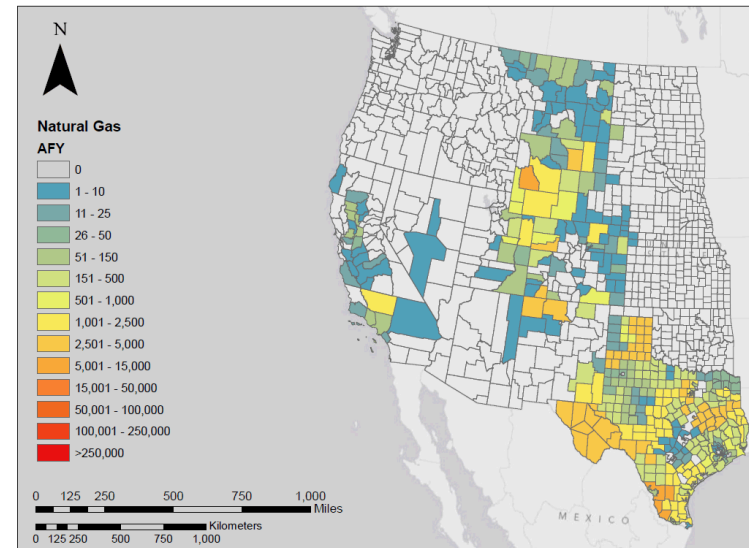
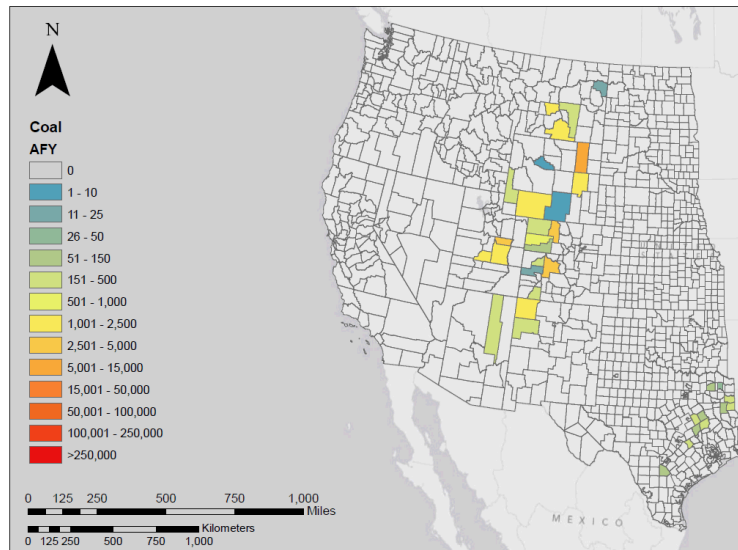


Source: Meldrum et al. 2013

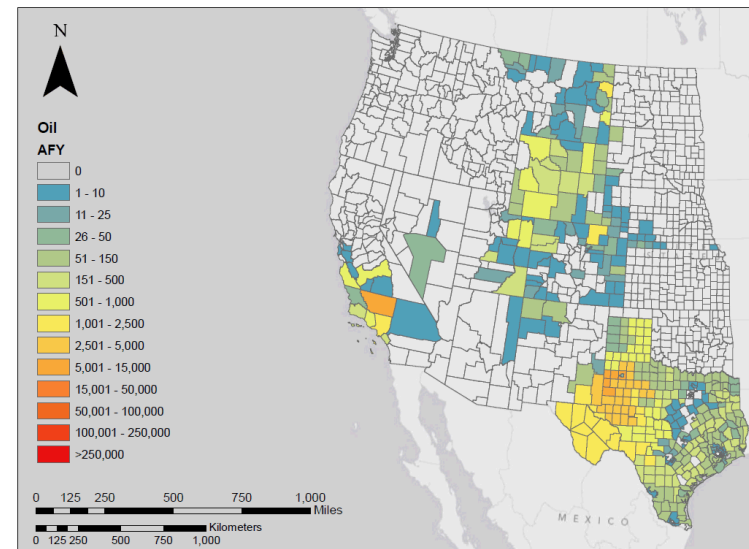
Water for Fuel Extraction

Water Use NATURAL GAS

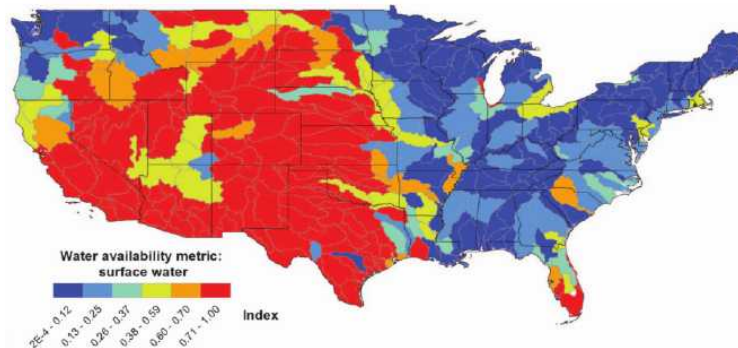
Water Use COAL



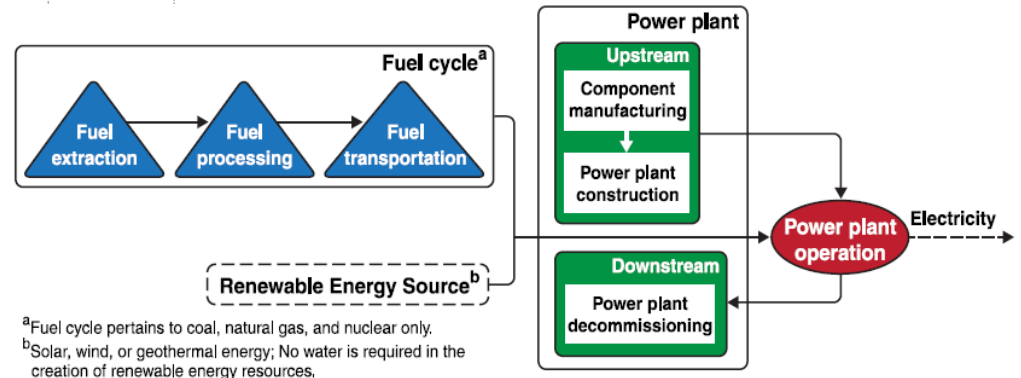
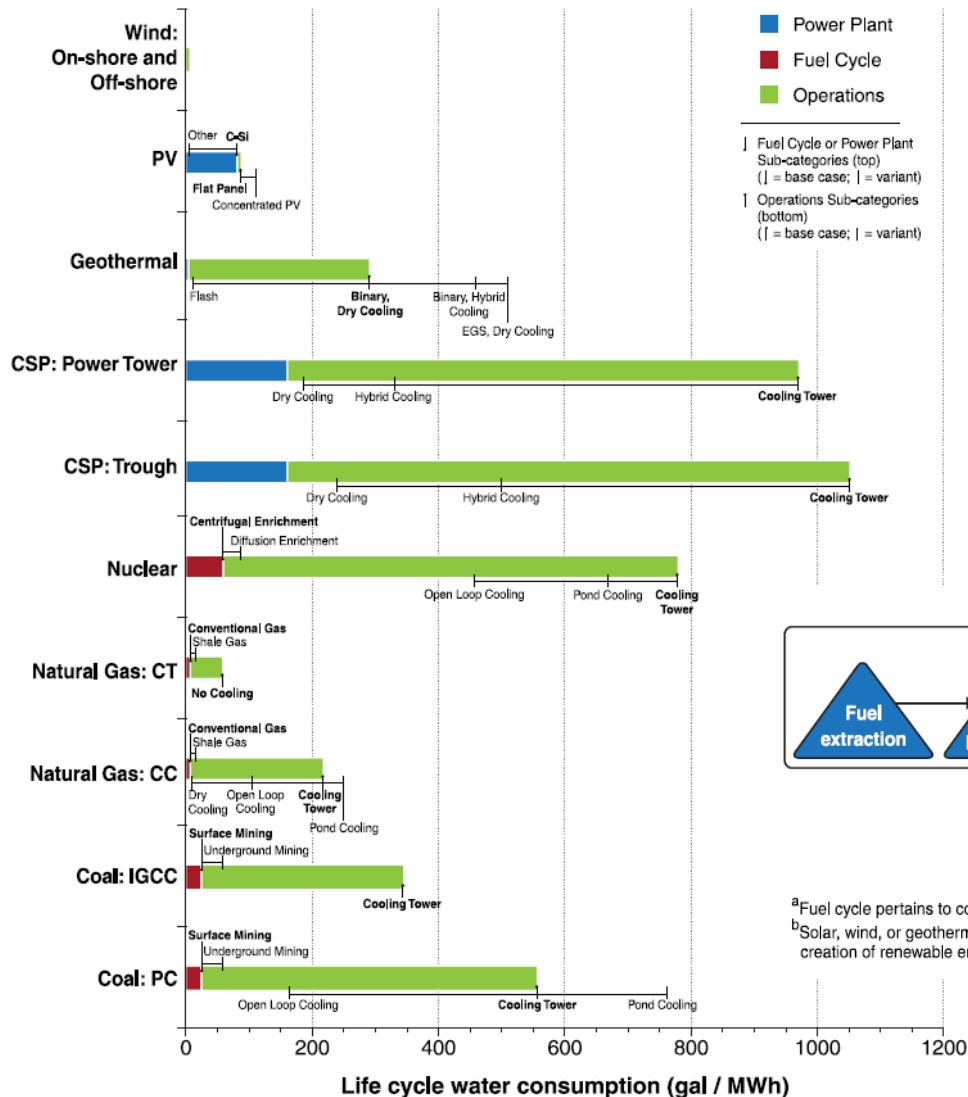
Water Use OIL



Limited Surface Water



Life Cycle Water Use

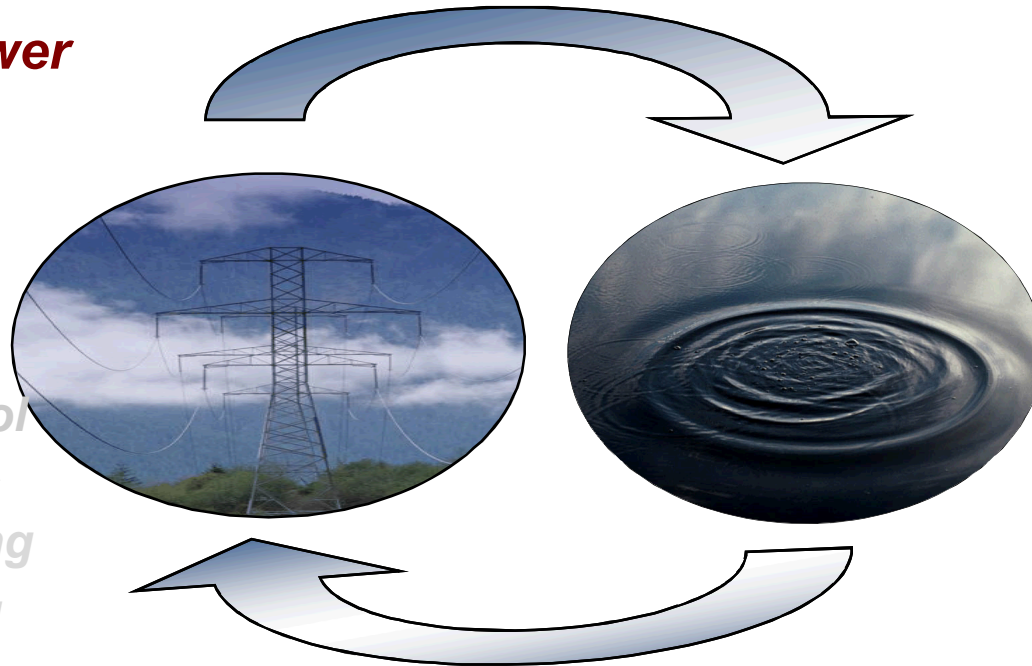


Source: Meldrum et al. 2013

Energy-Water Nexus

Energy and power production requires water

- Thermoelectric Cooling
- Emission Control
- Energy Minerals Extraction/Mining
- Fuel Processing (fossil fuels, H_2 , biofuels)

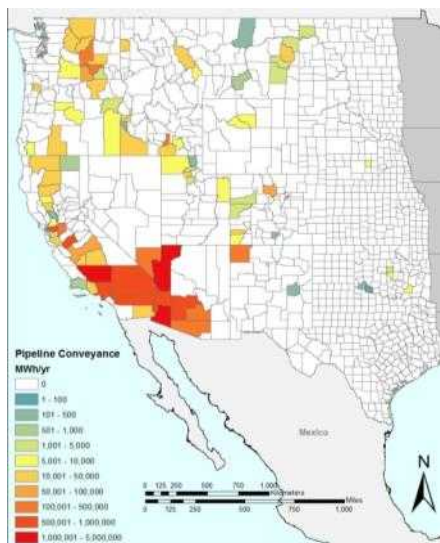


Water production, processing, distribution, and end-use requires energy

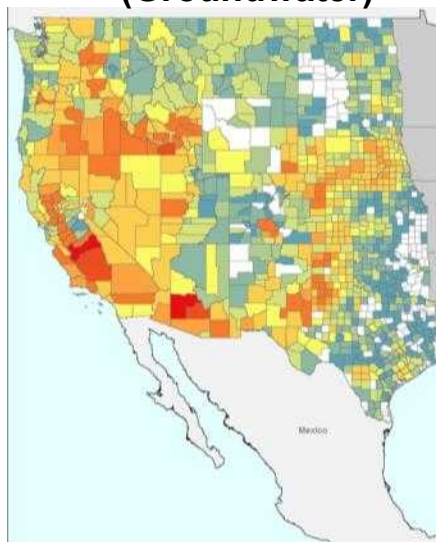
- Pumping
- Conveyance
- Treatment
- Distribution
- Use Conditioning

Energy for Water

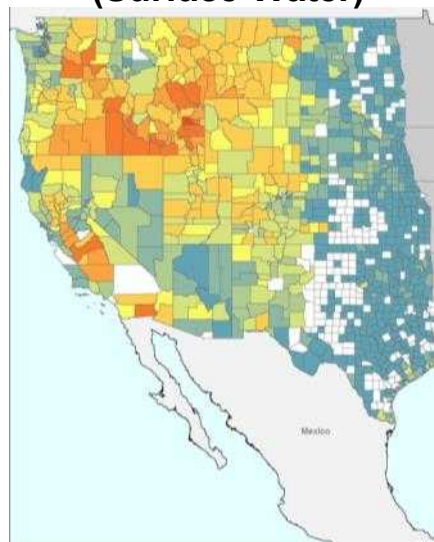
Large-Scale Conveyance



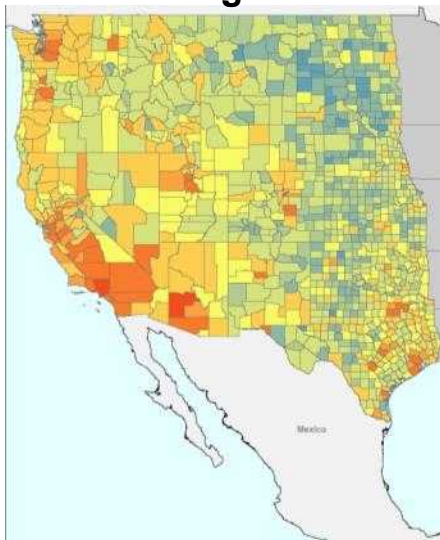
**Agricultural Pumping
(Groundwater)**



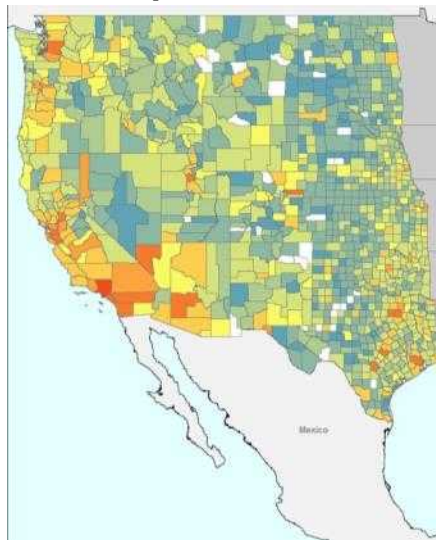
**Agricultural Pumping
(Surface Water)**



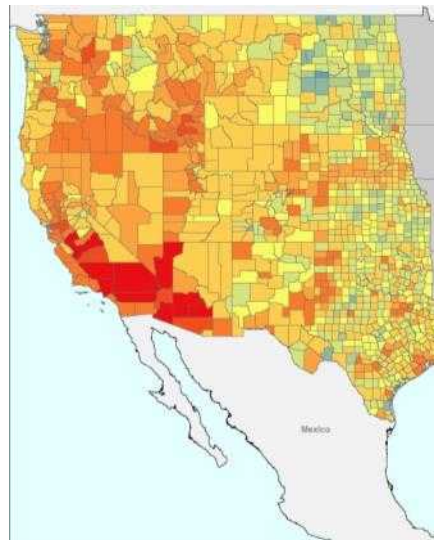
Drinking Water



Municipal Wastewater



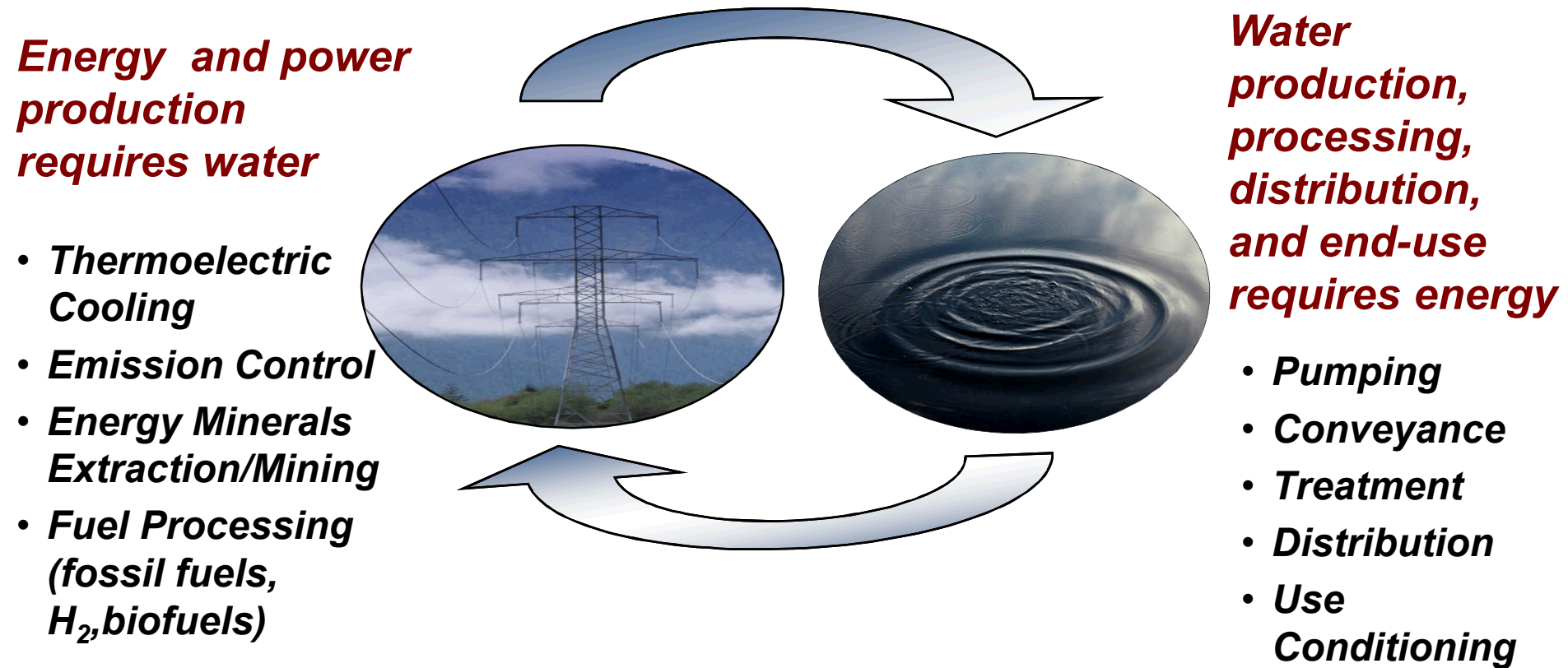
All Water Services



~6% of
electricity use
goes to
providing
water services.

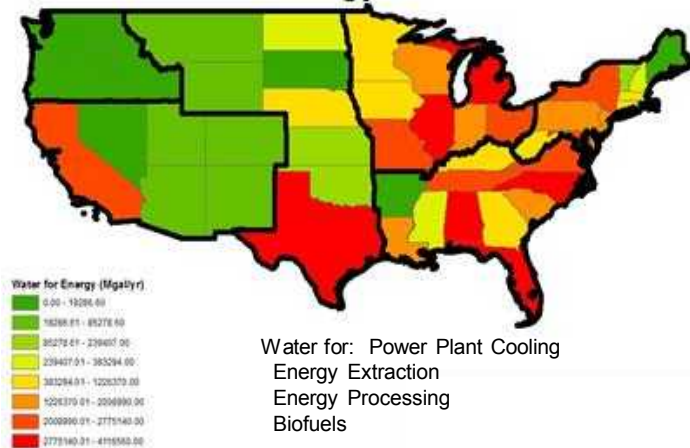
Source: Tidwell et al. 2014

Energy-Water Nexus

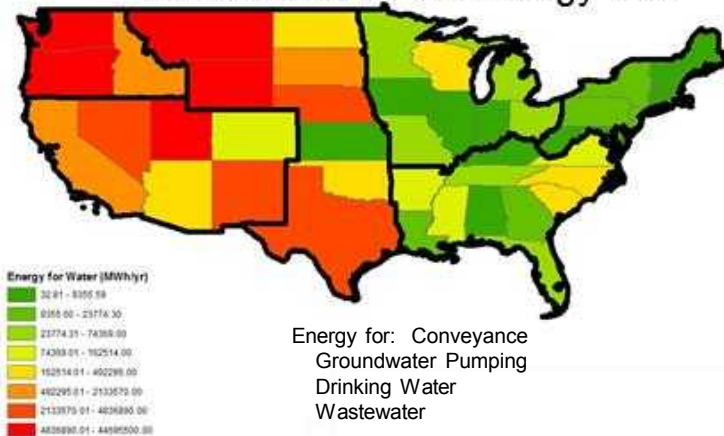


Regional Challenge

Effect of energy on water use



Effect of water on energy use



Regional Challenges

West Coast: Seawater desalination and interbasin transfers

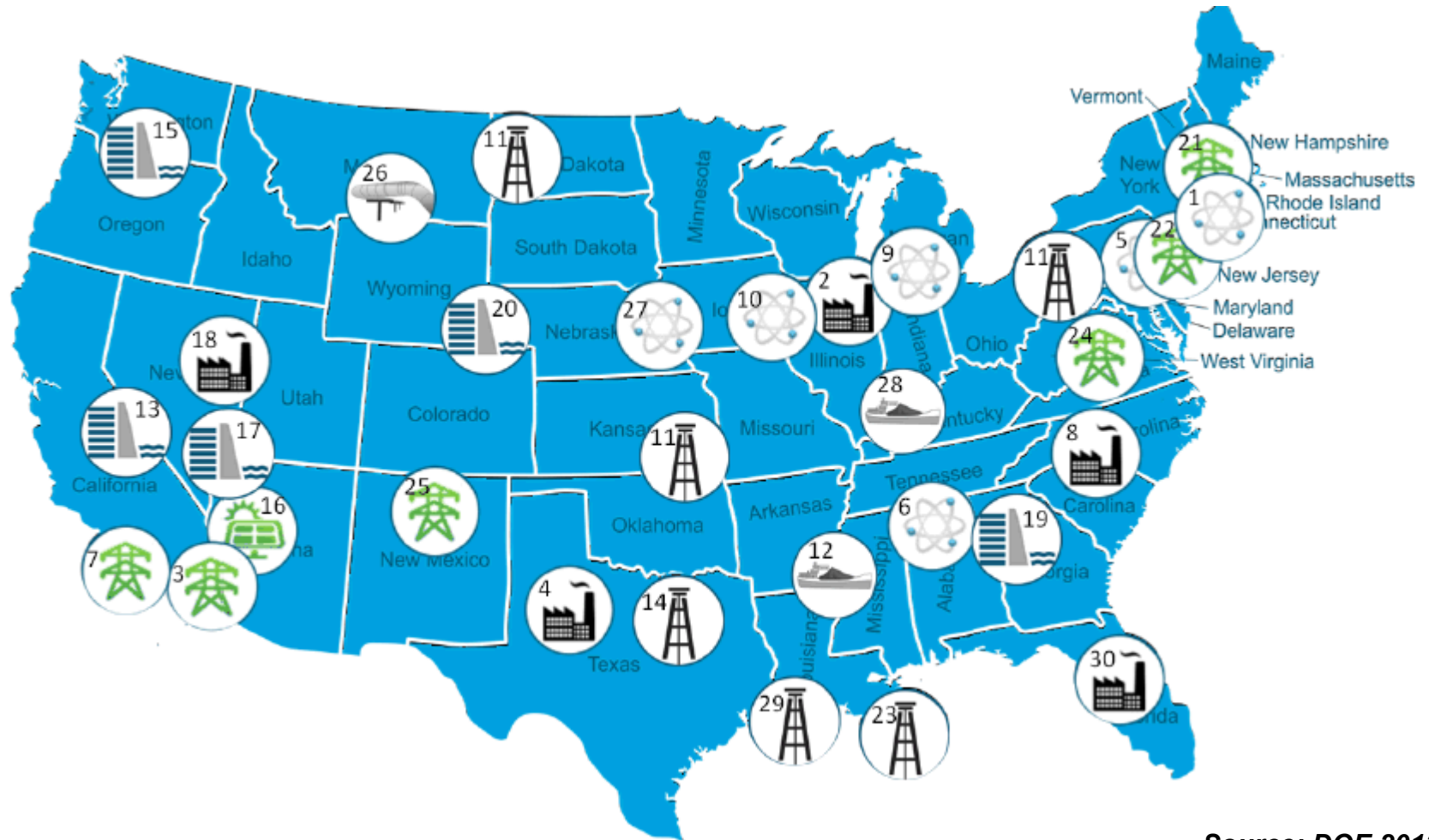
Rocky Mountain/Southwest: Brackish desalination, alternative water resources, unconventional oil & gas, thermoelectric cooling

Central region: Biofuels, thermoelectric cooling

Eastern: Infrastructure, thermoelectric cooling, flooding, urban issues, shale gas

Gulf: Oil and gas exploration, storm impacts, nuclear impacts, and seawater cooling

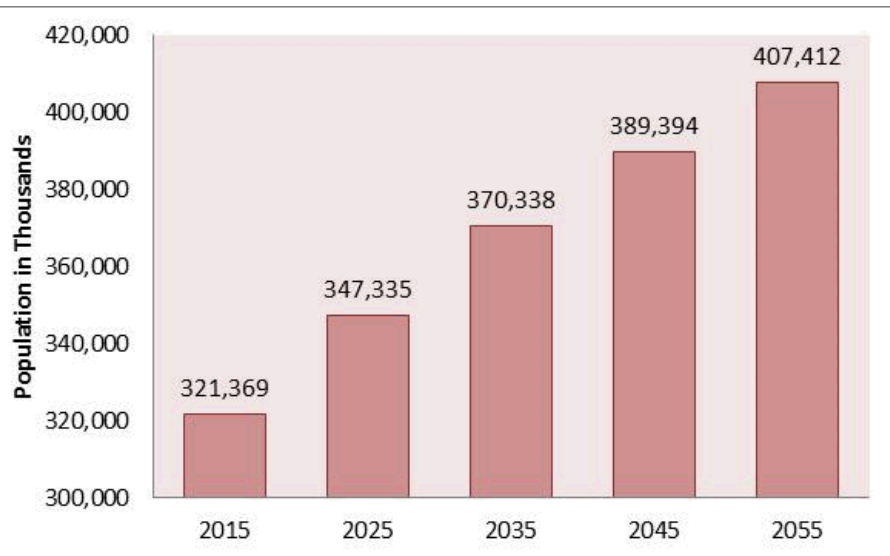
Energy-Water-Climate Nexus in the News



Source: DOE 2013

***Energy-
Water
Nexus
Future***

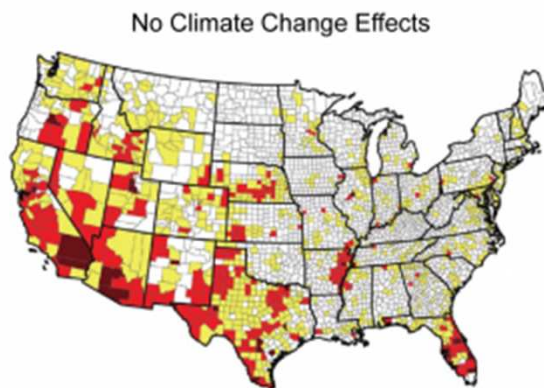
Growth and Change



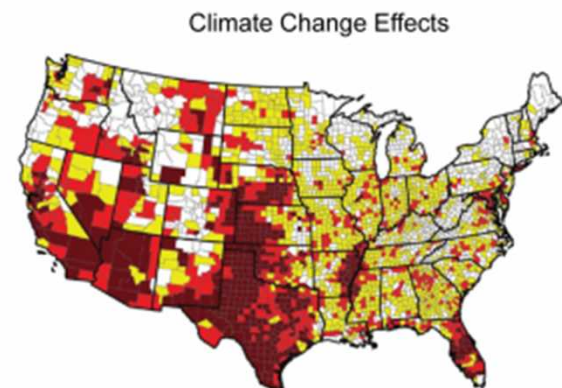
Source: U.S. Census Bureau 2014

Growing Population & Climate Change

Water Supplies Projected to Decline



Water Supply Sustainability Risk Index (2050)



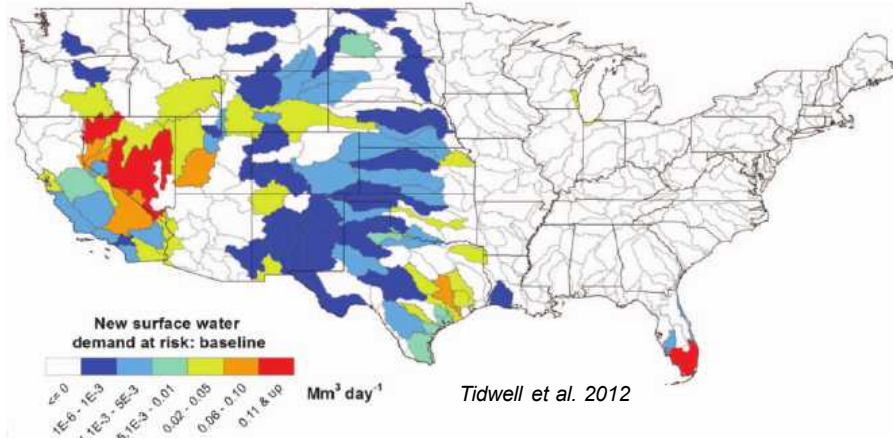
Water Supply Sustainability Risk Index (2050)



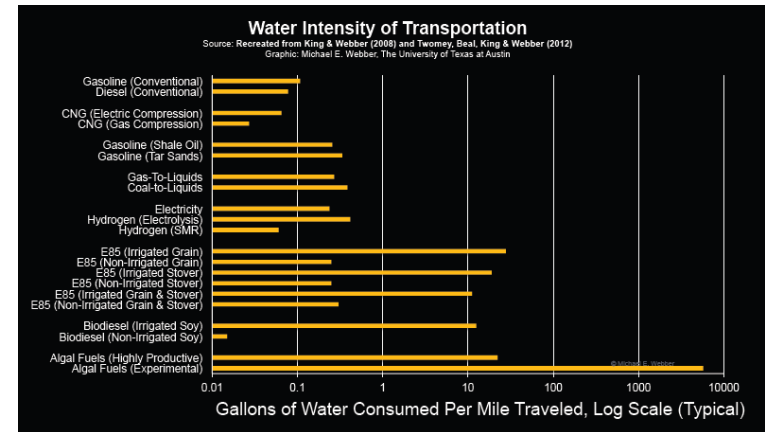
Source: National Climate Assessment 2014

Growing Demands

Thermoelectric Demands for Water



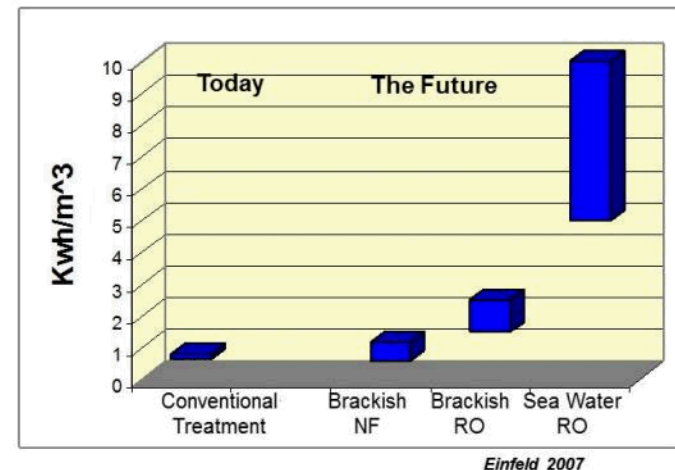
Liquid Fuels Demand for Water



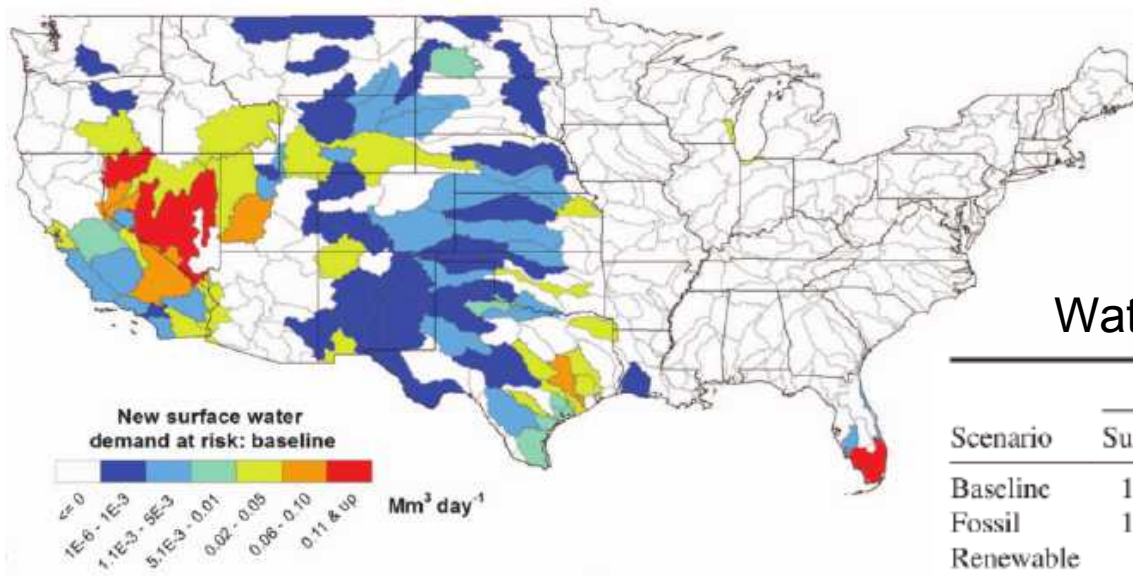
Shale Gas/Oil Demands for Water



Energy Demands for Water Treatment

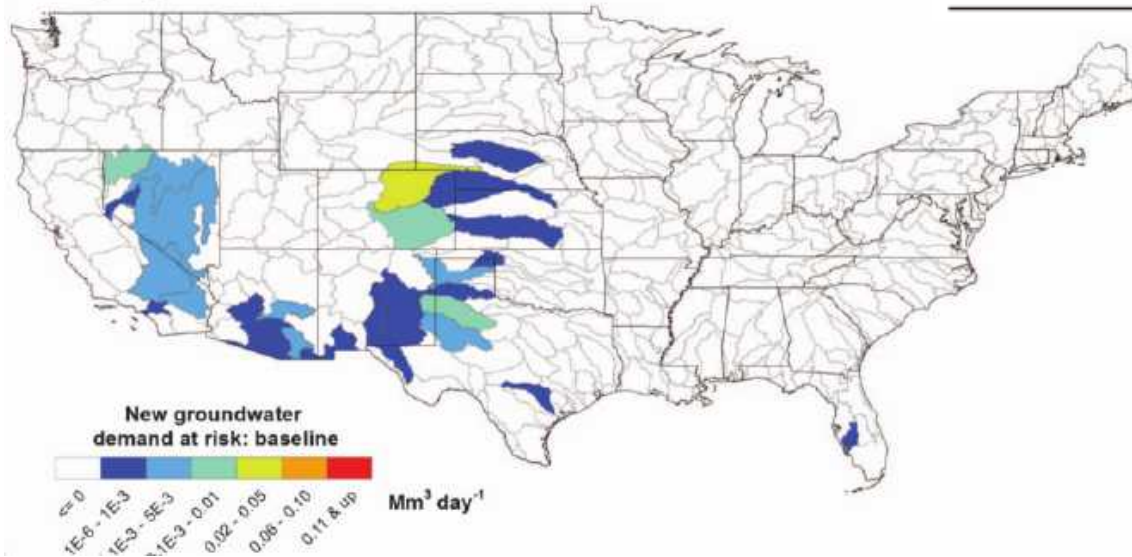


Thermoelectric Development in Water Limited Basins



Water and Power at Siting Risk

Scenario	Power (MMWh)		Water (Mm ³ /day)	
	Surface water	Ground water	Surface water	Ground water
Baseline	163 (18%)	11 (1%)	1.18 (24%)	0.06 (1%)
Fossil	139 (15%)	19 (2%)	1.24 (23%)	0.10 (2%)
Renewable	84 (9%)	5 (0.5%)	0.85 (19%)	0.04 (1%)



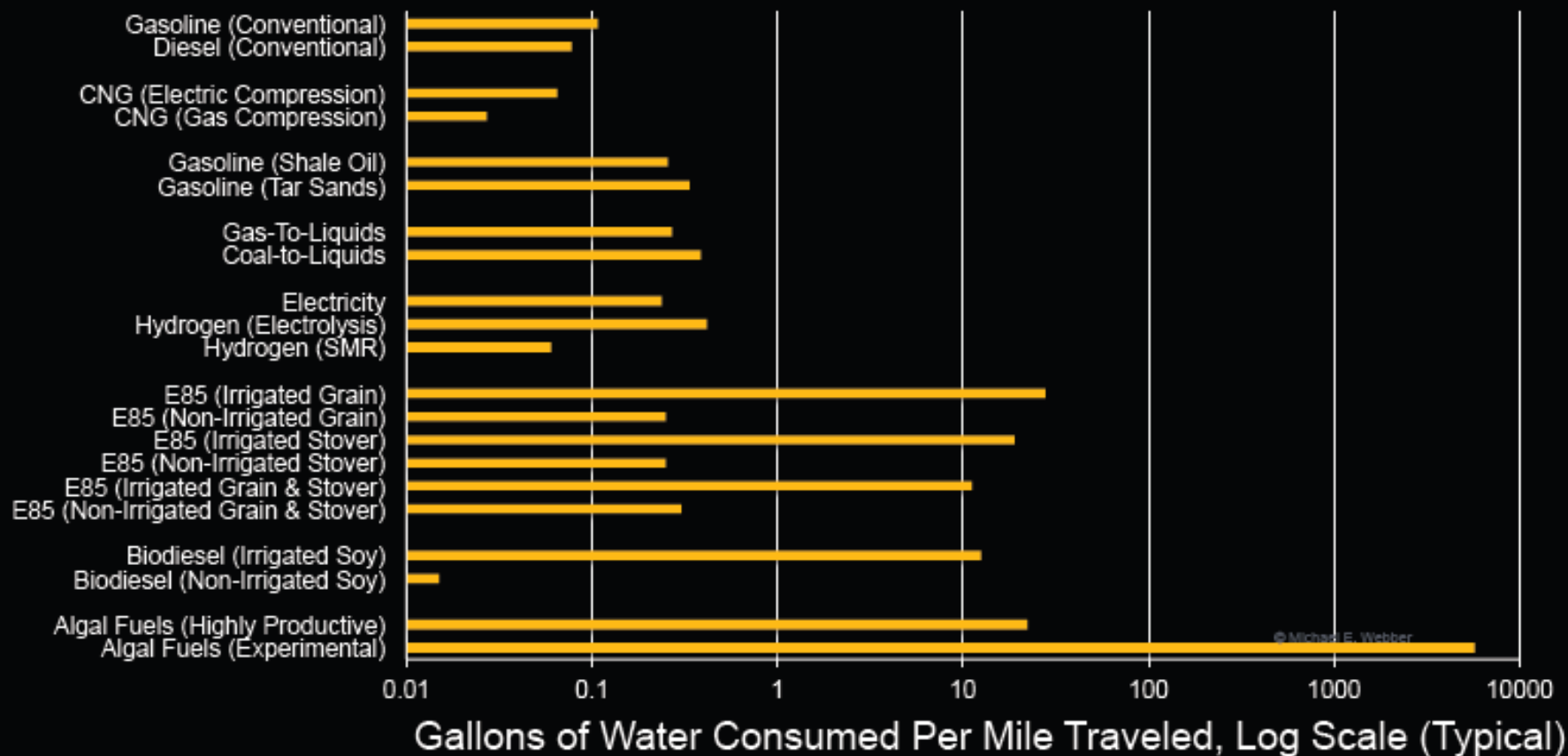
Source: Tidwell et al. 2012

Water for Transportation Fuels

Water Intensity of Transportation

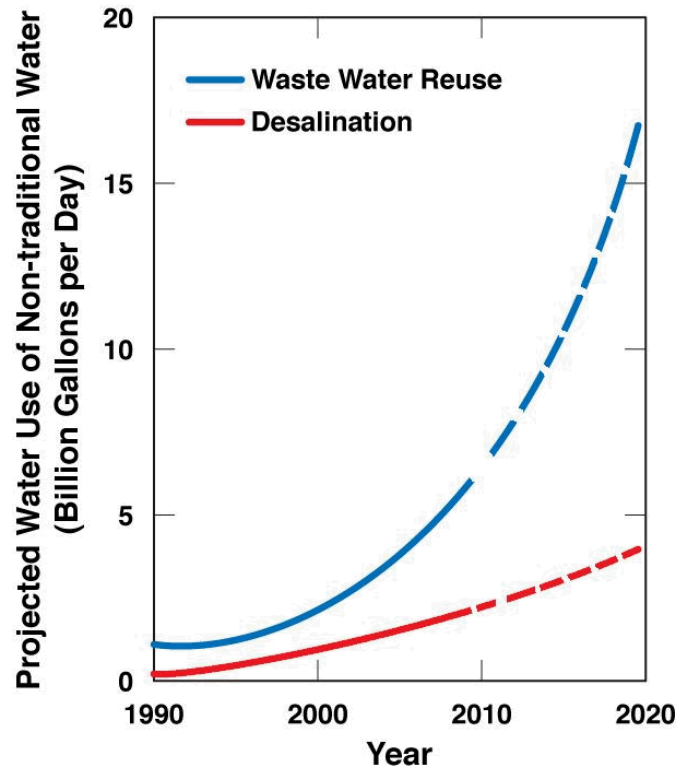
Source: Recreated from King & Webber (2008) and Twomey, Beal, King & Webber (2012)

Graphic: Michael E. Webber, The University of Texas at Austin

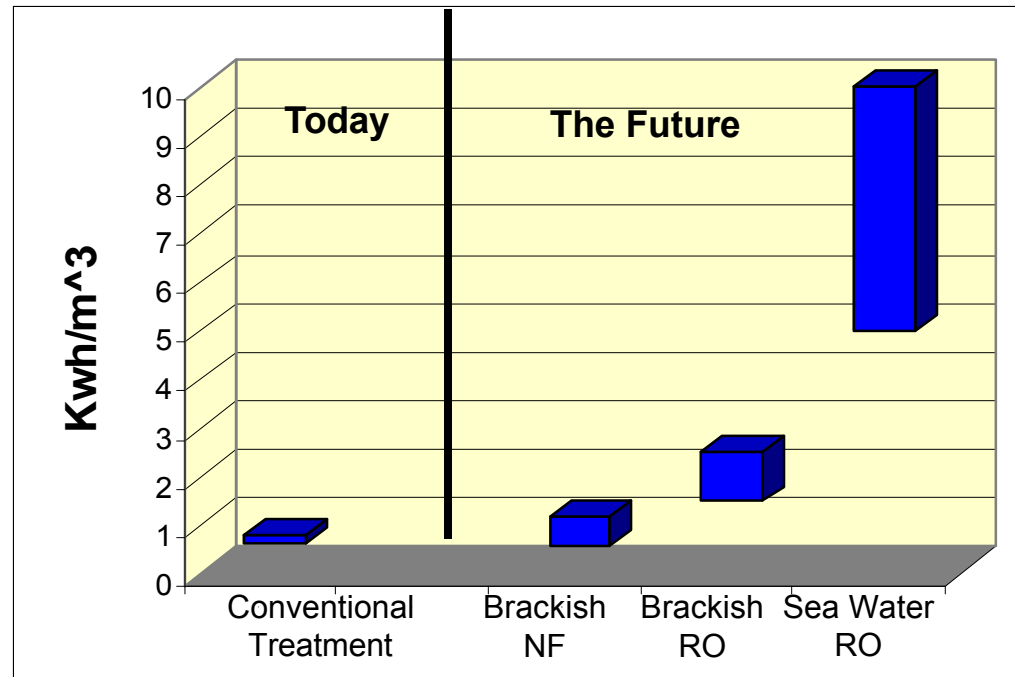


Energy for Water

Power Requirements For Treatment



(Modified from Water Reuse 2007, EPA 2004, Mickley 2003)



(Einfeld 2007)

- Desal growing at 10% per year, waste water reuse at 15% per year
- Non-traditional water use is energy intensive

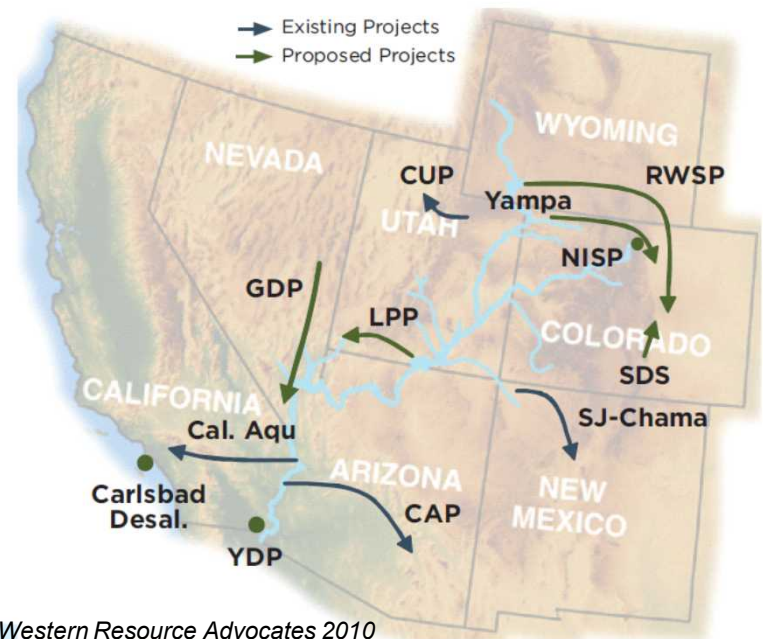
Energy for Water

- EPA is struggling with regulating pharmaceuticals in our Nation's drinking water.
- Treatment technologies for removing these contaminants at these concentrations are energy intensive.
- Numerous pipelines for trans-basin water transfers are in the planning and construction stage.



Source: detoxifynow.com

Existing and Proposed Western Water Supply Projects

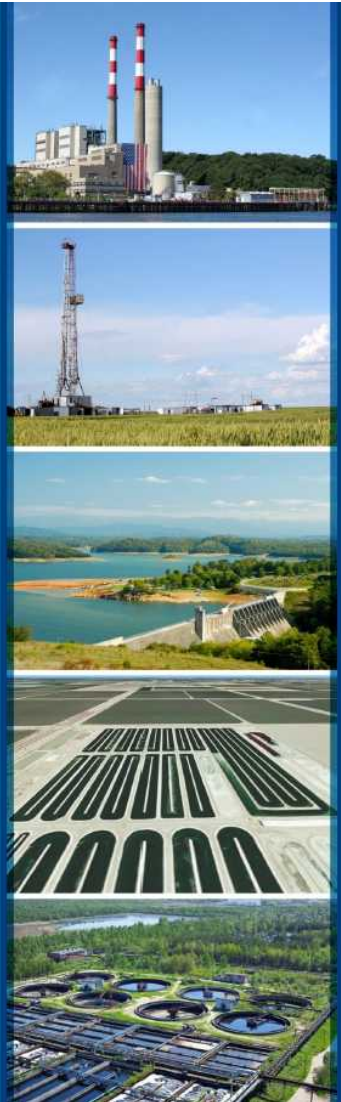


Water-Energy Nexus Report

The Water-Energy Nexus:

Challenges and
Opportunities

June 2014

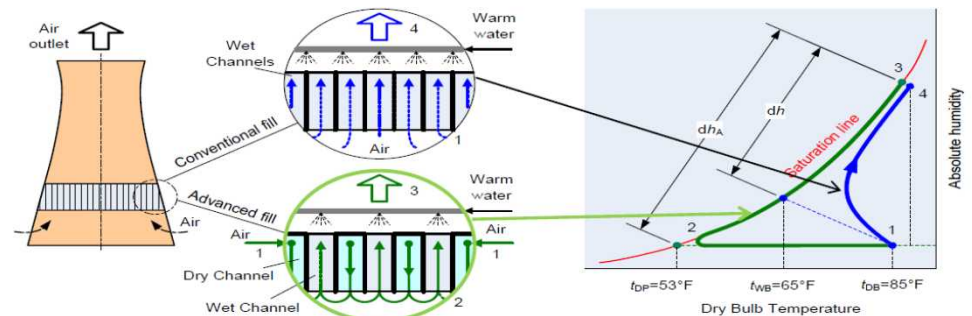


- Prepared by the Department of Energy
- Released June 2014
- Purpose:
 - Provides a foundation for future DOE action,
 - Provide data and analysis to frame opportunities, and
 - Broadly engage others in the dialogue.

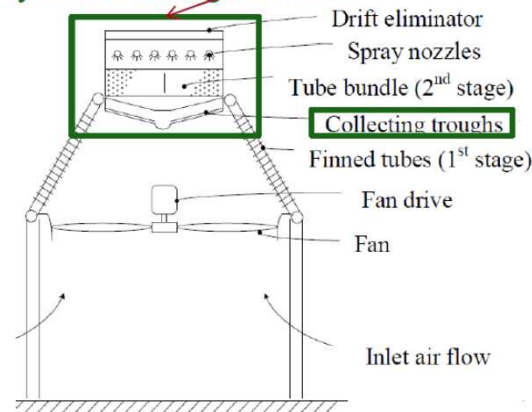
Six Strategic Pillars to Address Water-Energy Nexus

Enhanced Wet and Dry Cooling Systems

- Optimize the freshwater efficiency of energy production, electricity generation and end use systems.



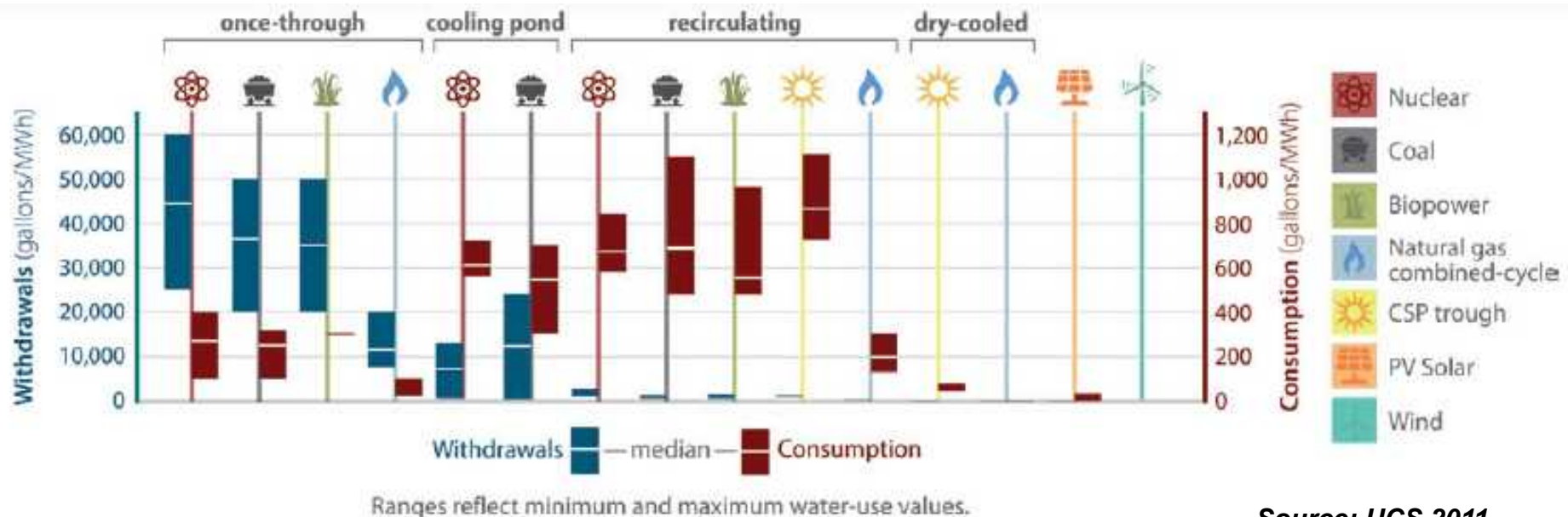
Dry/Wet Cooling Addition



Water for Thermoelectric Power

- Water use influenced by:

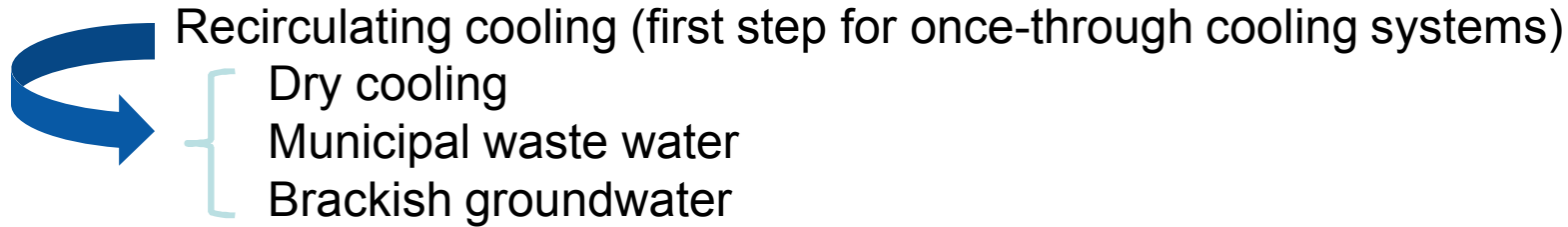
- Fuel type,
- Cooling type,
- Emission controls,
- Age, and
- Location



Source: UCS 2011

Transitioning to Zero Freshwater Withdrawal

Retrofits considered: *average difficulty, according to EPA guidelines*



Costs:

Capital

Operating and Maintenance (O&M) costs

Capture (e.g., conveyance costs for waste water, drilling and pumping costs for brackish groundwater)

Treatment

Parasitic energy losses

Availability:

Municipal waste water: within 50 miles

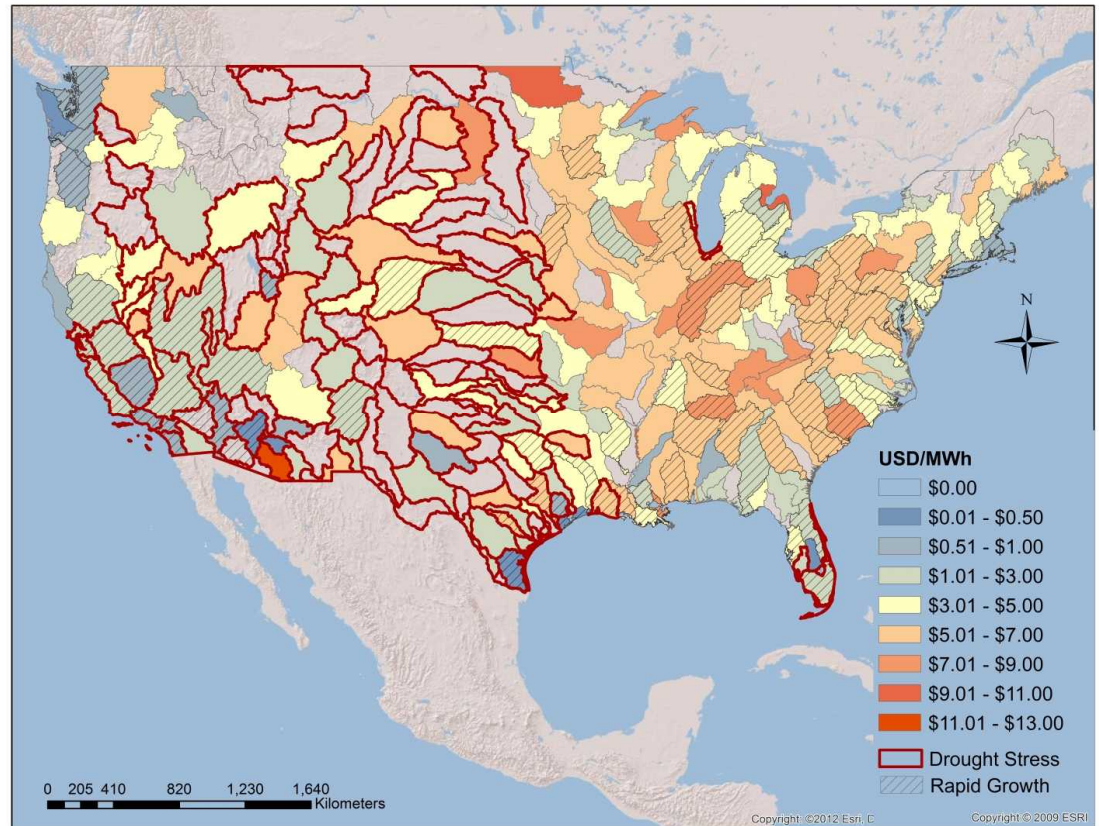
Brackish water: <2500 ft deep, salinities >10,000 TDS

* NOTE: not taking into consideration site-specific constraints such as land availability, local regulations, technology vintage

Opportunities for Retrofit

Technology	Number of plants
Waste water	823
Brackish water	109
Dry cooling	246

Note: Δ LCOEs tend to be lower in the West, Texas Gulf Coast and south Florida, which are areas prone to drought stress



Source: Tidwell et al. 2014

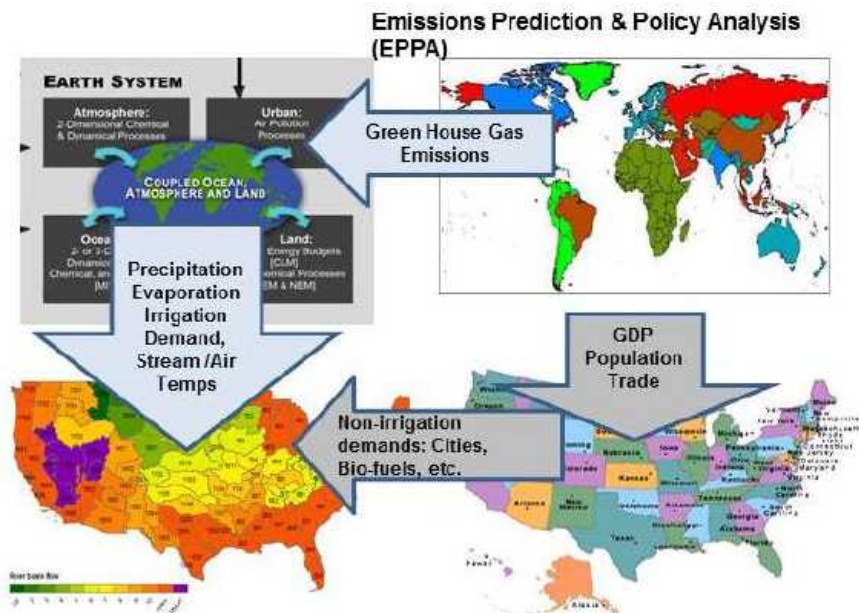
With wholesale cost of electricity about \$40/MWh, many retrofits could be accomplished at levels that would add less than 10% to current power plant generation expenses.*

*average 2012 wholesale cost over 3 US trading hub regions

Six Strategic Pillars to Address Water-Energy Nexus

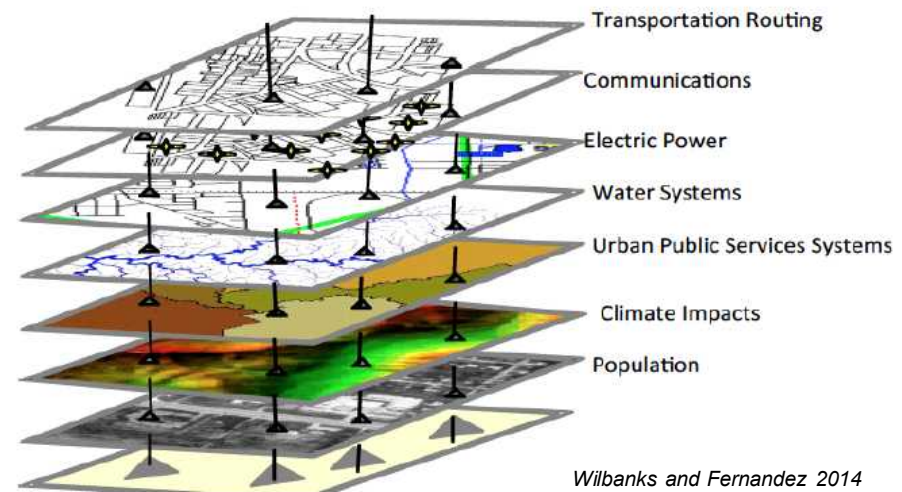
- Enhance the reliability and resilience of energy and water systems.

Integrated Modeling



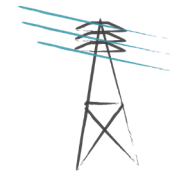
Schlosser et al. 2014

Infrastructure Risk Analysis

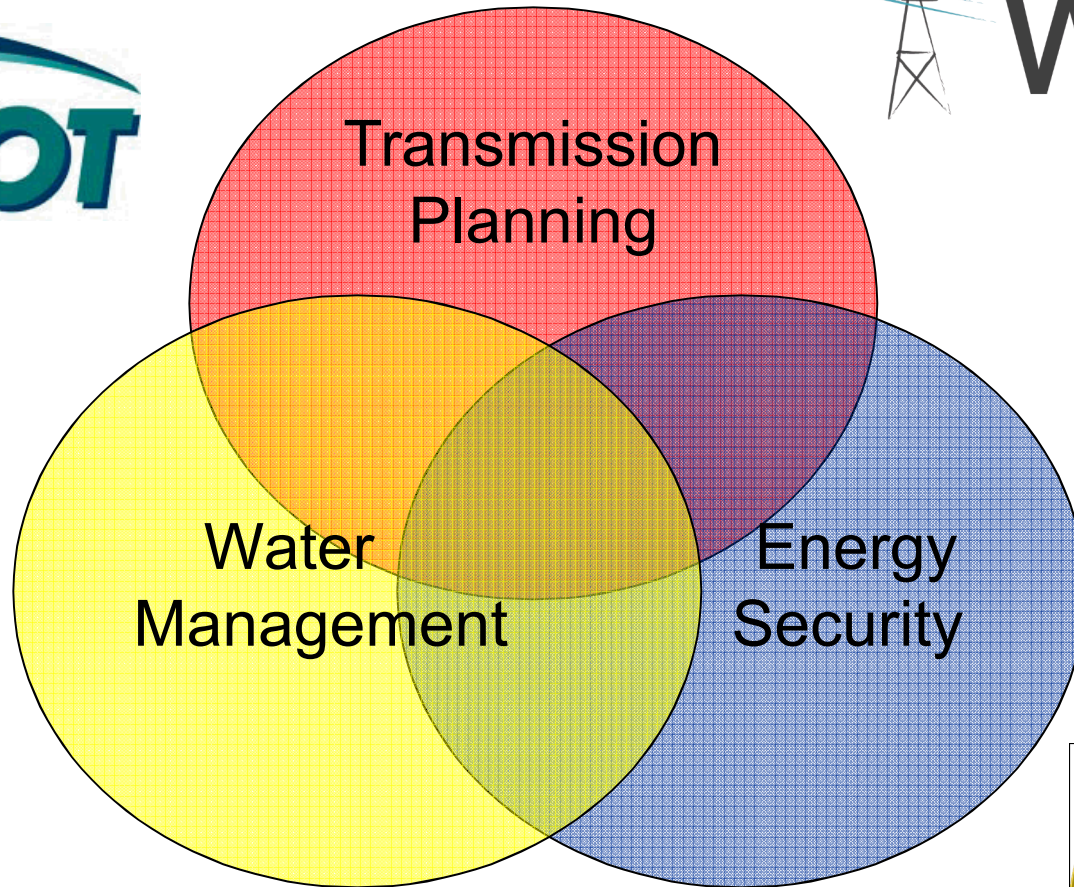


Wilbanks and Fernandez 2014

Integrated Planning



WECC



**WESTERN
GOVERNORS'
ASSOCIATION**

Serving the Governors of 19 States and 3 US-Flag Pacific Islands



WSWC

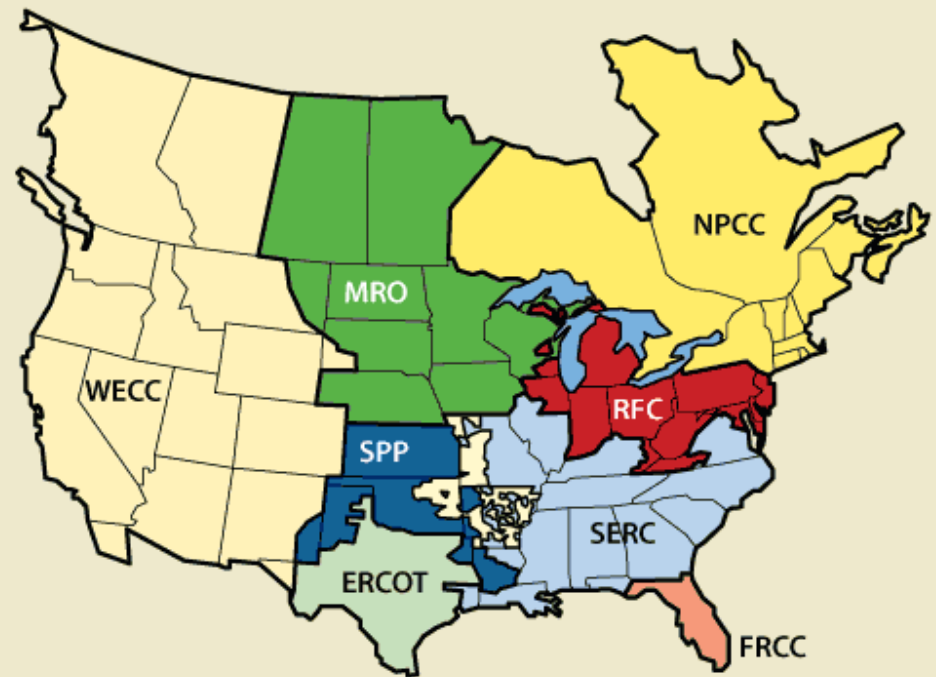
Western States Water Council



Transmission Planning

- WECC and ERCOT are conducting long-range transmission planning (20 yrs.) to direct:
 - Siting of new power plants
 - New transmission capacity

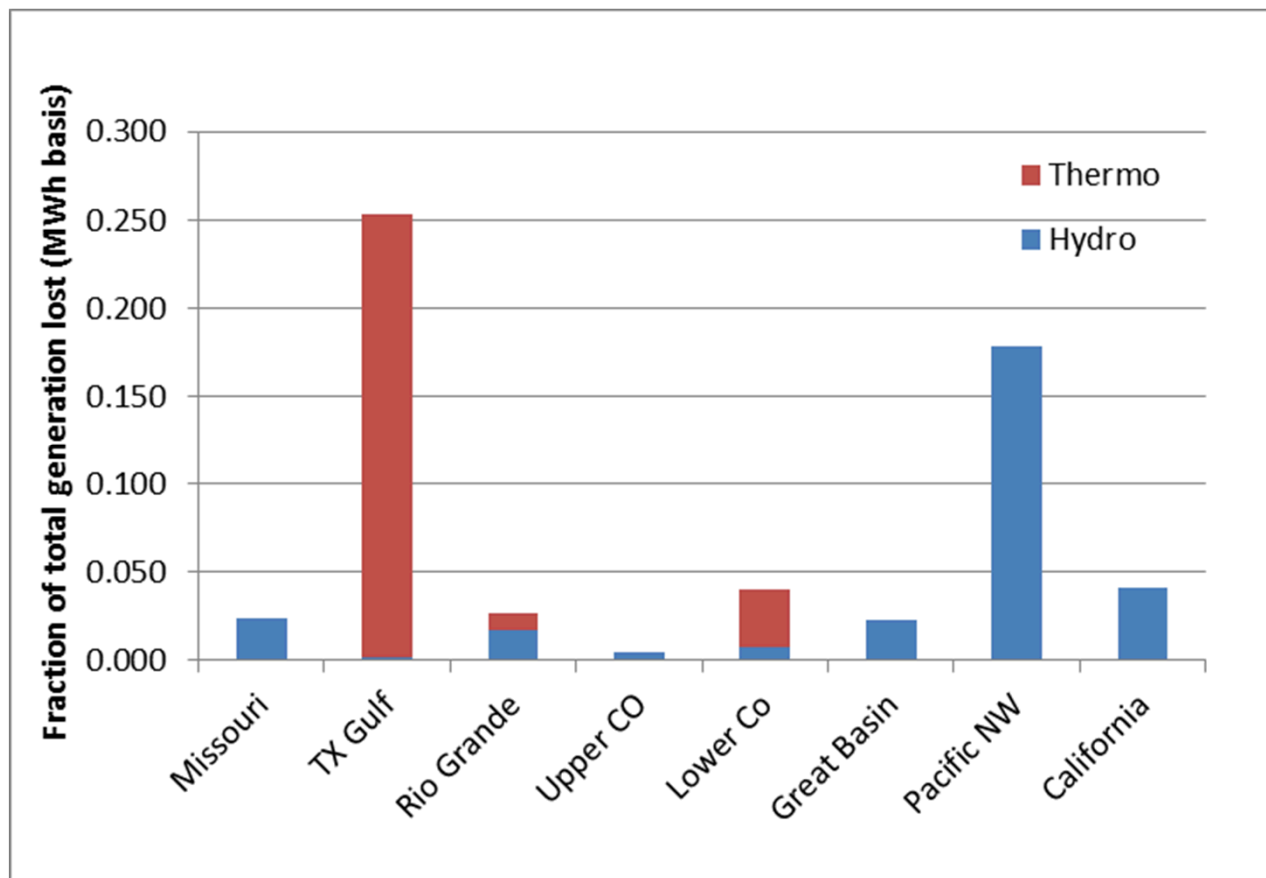
The North American Electric Reliability Corporation Regions



Source: North American Energy Reliability Corporation.

Climate Impact on Existing Plants

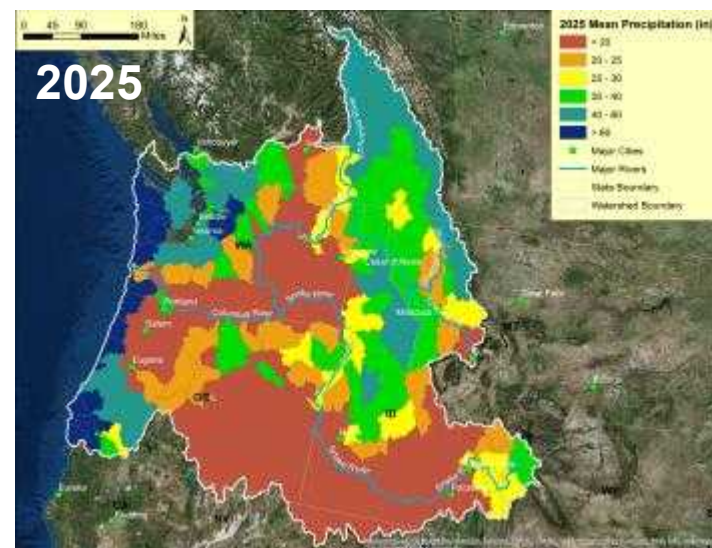
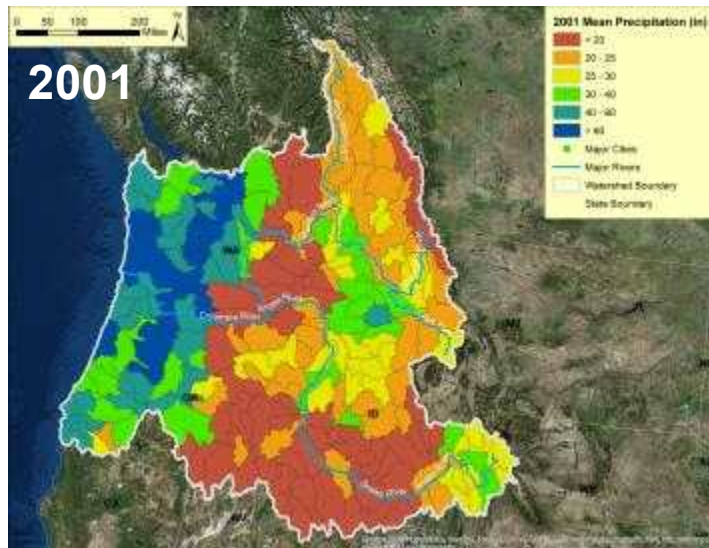
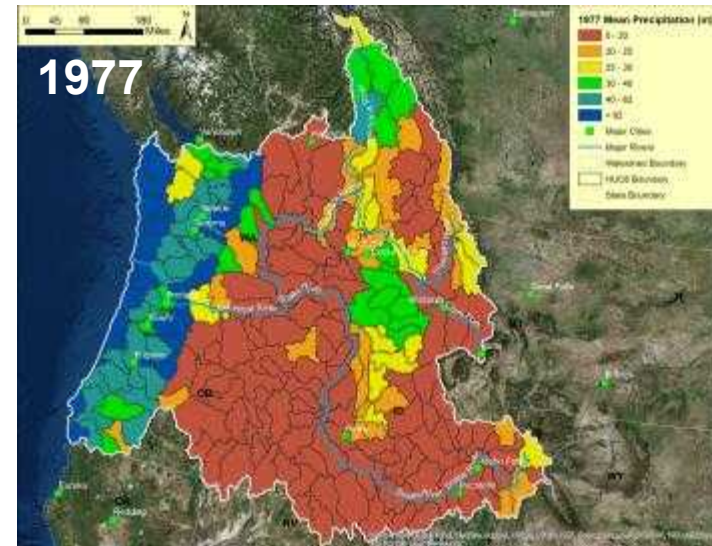
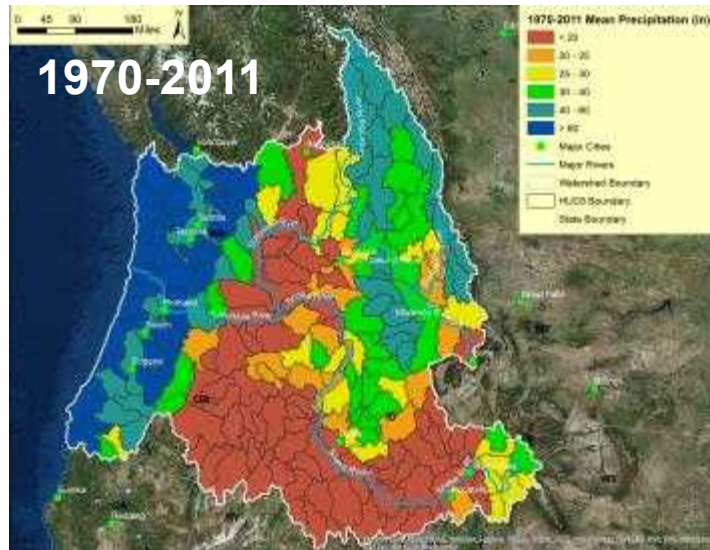
Fraction of Generation at Risk



Basin Map

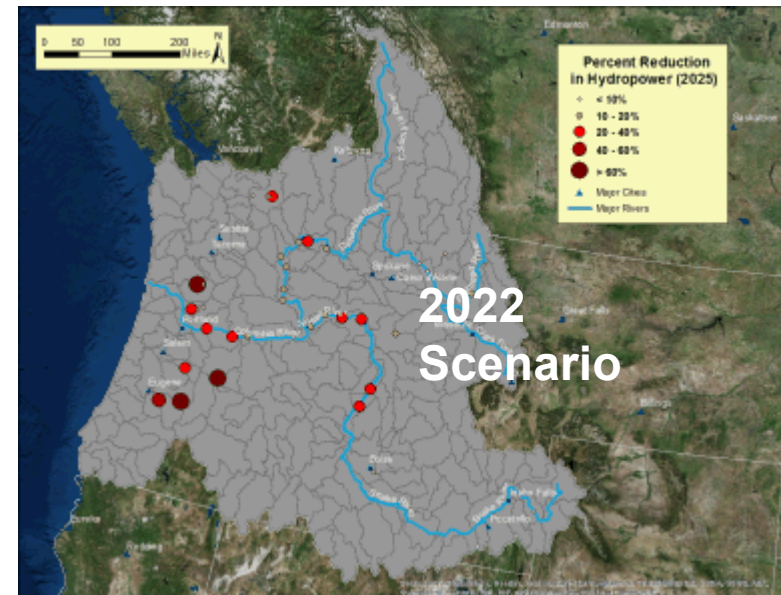
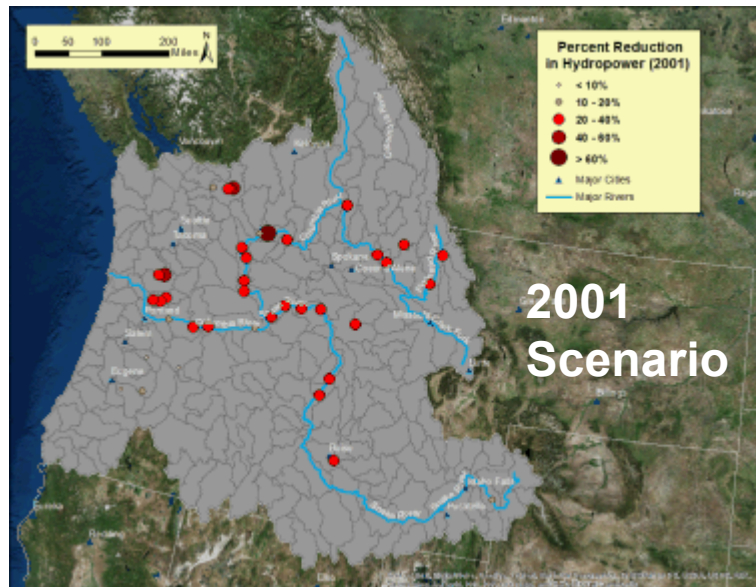
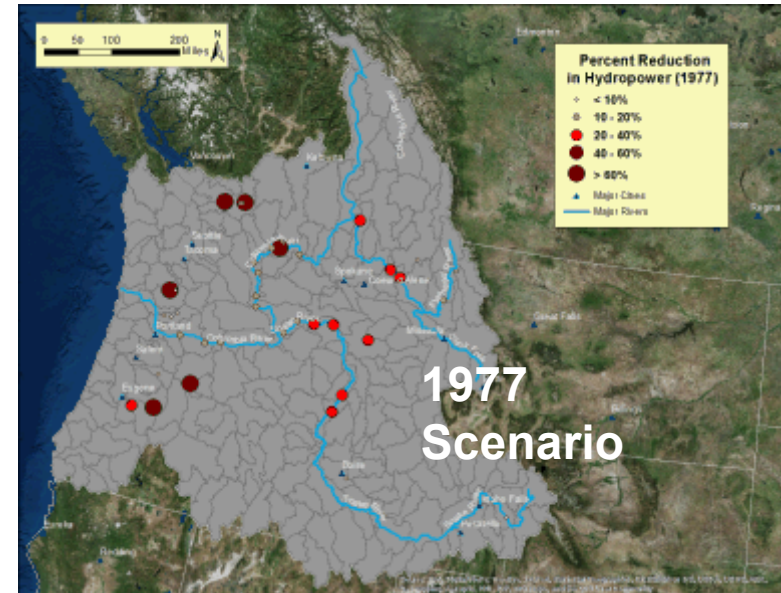
Source: ANL 2012

Precipitation Pattern (Annual Mean)



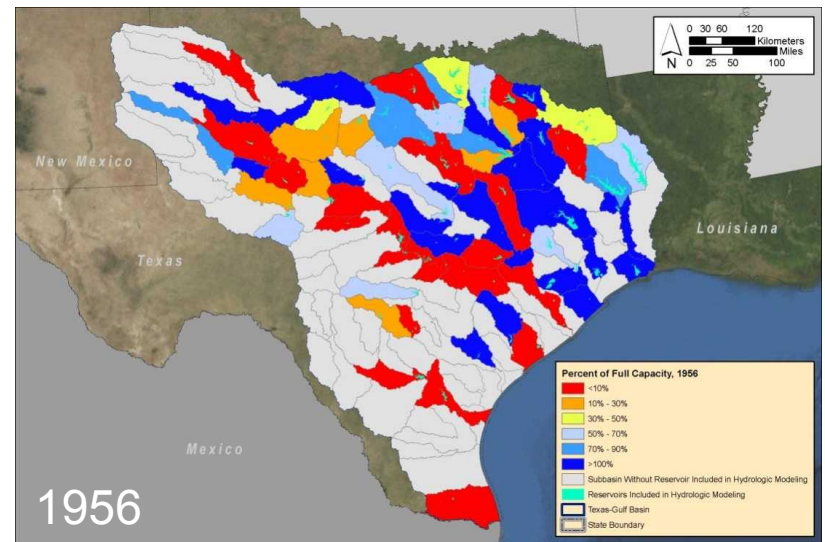
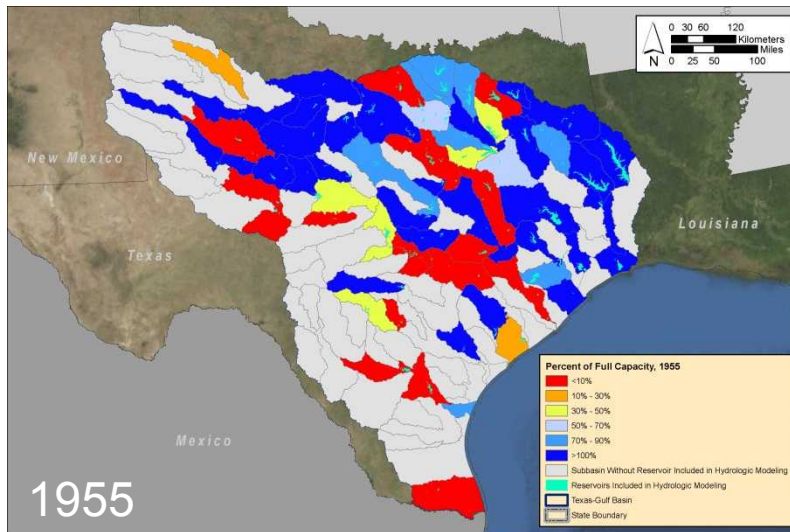
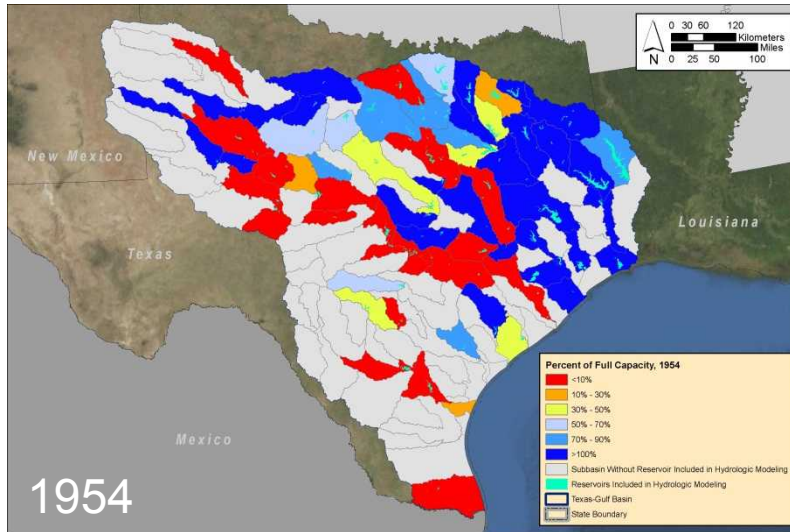
Potential Impact of Drought on Hydropower Generation

- Simulated reduction of hydropower
 - 1977 drought: 21% reduction
 - 2001 drought: 24% reduction
 - 2025 drought: 20 % reduction



Climate Impacts on the Hydrology

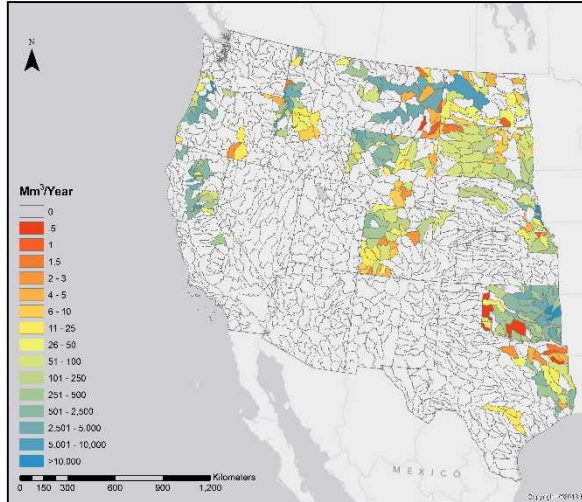
- Projected **reservoir storage** in HUC-8 basins under 1950-1957 drought scenario



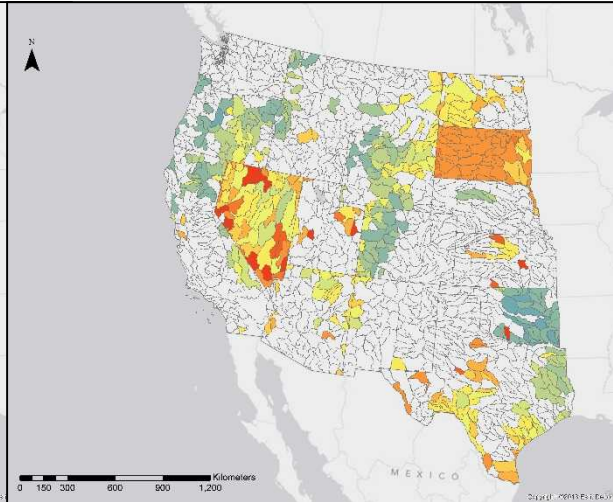
Source: ANL 2013

Water Availability and Future Demand Sandia National Laboratories

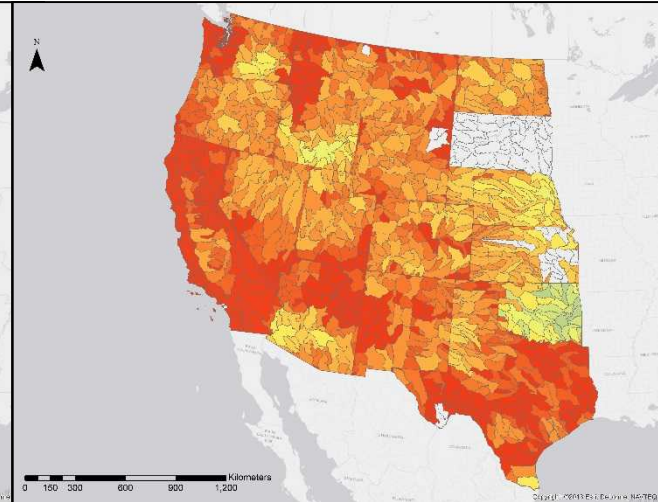
Unappropriated Surface Water



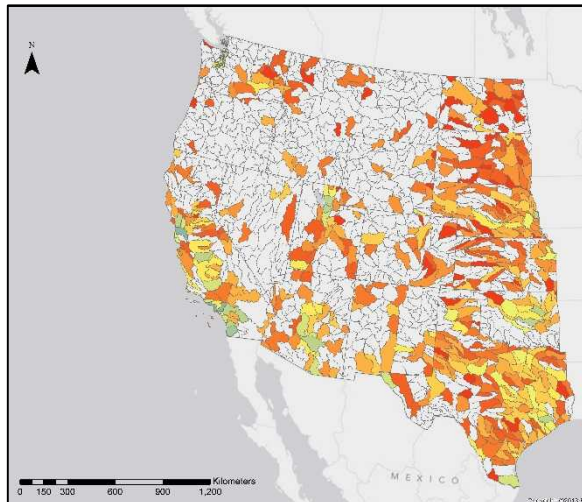
Unappropriated Groundwater



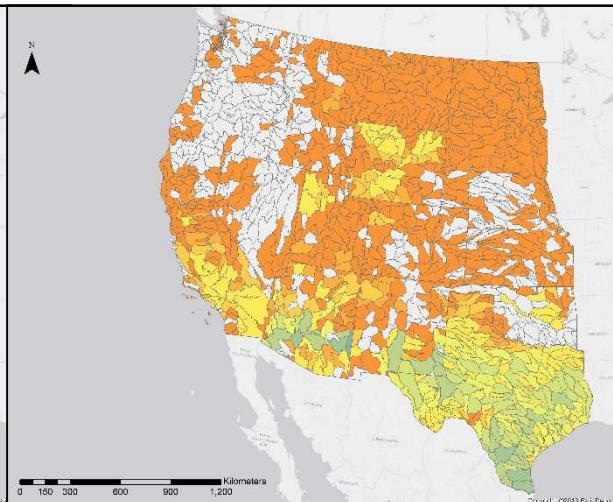
Appropriated Water



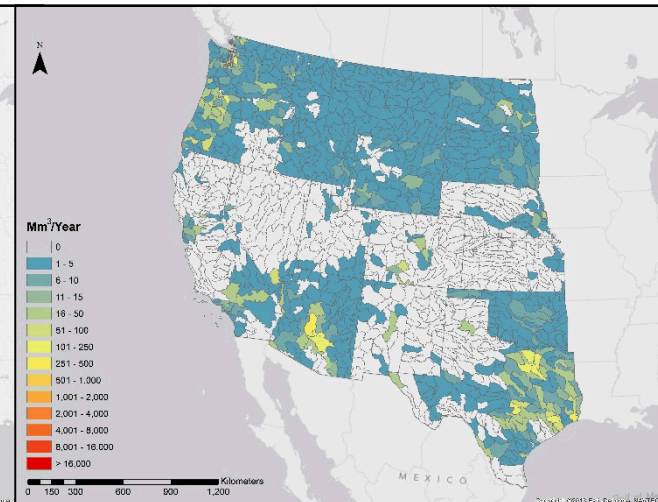
Municipal Wastewater



Brackish Groundwater

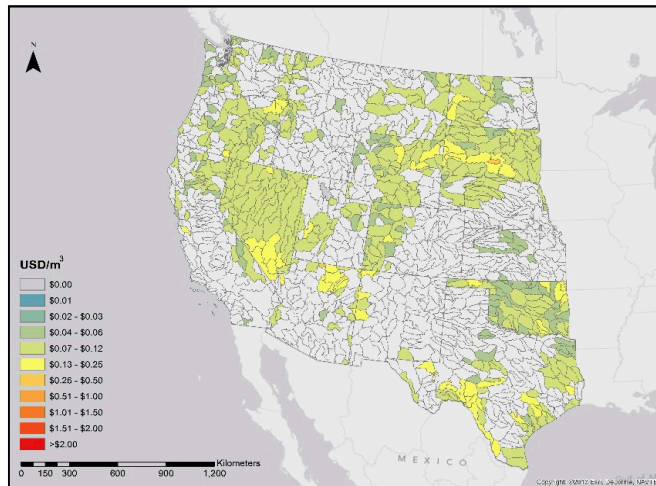


Consumptive Demand 2010-2030

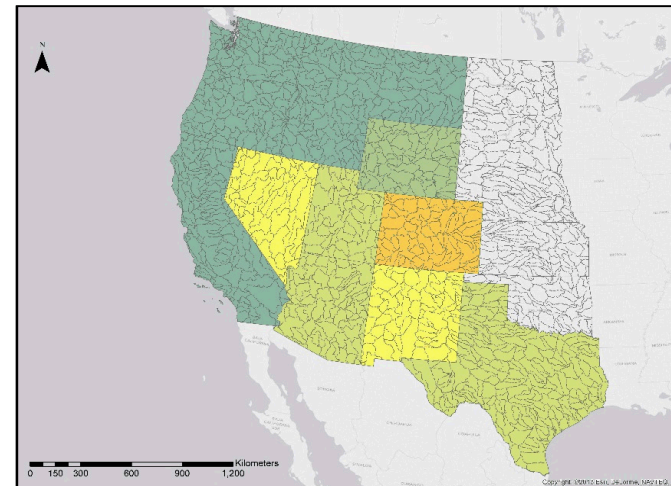


Relative Cost of Water

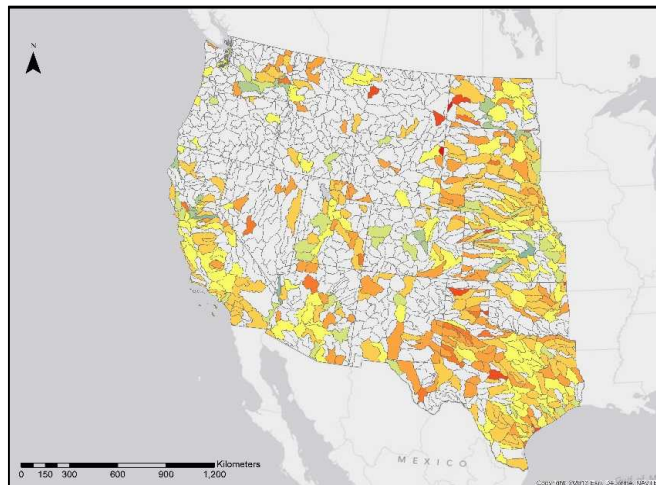
Unappropriated Groundwater



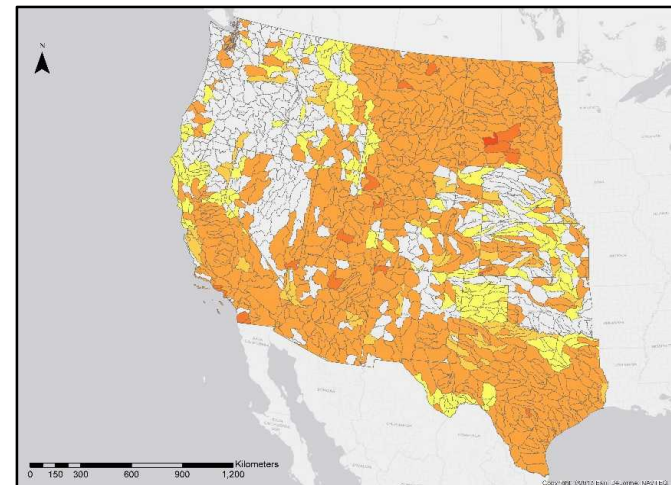
Appropriated Water



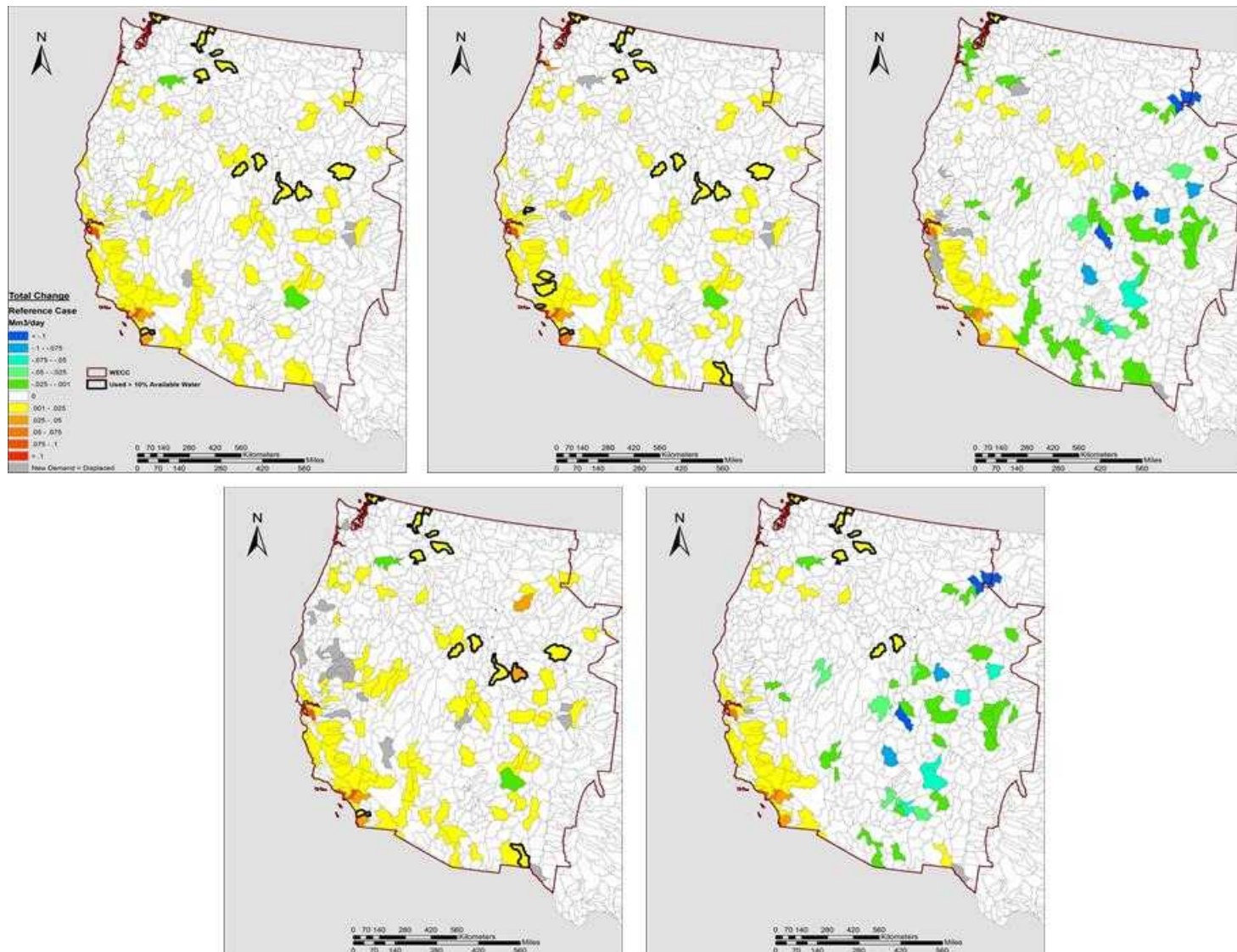
Municipal Wastewater



Brackish Groundwater

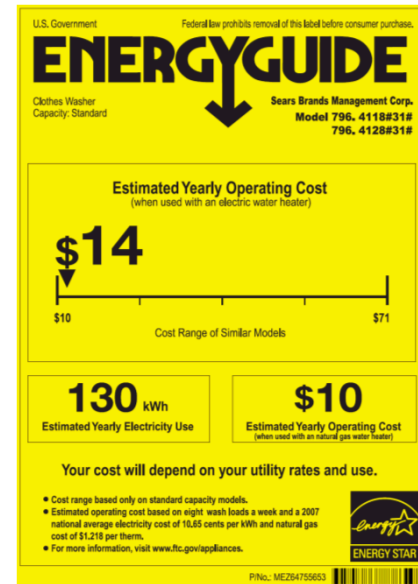


Change in Thermoelectric Water Use



Six Strategic Pillars to Address Water-Energy Nexus

- Optimize the energy efficiency of water management, treatment, distribution and end use system.



Appliance
Standards



Drinking Water Systems



Wastewater
Systems

Six Strategic Pillars to Address Water-Energy Nexus

- Increase safe and productive use of nontraditional water sources.



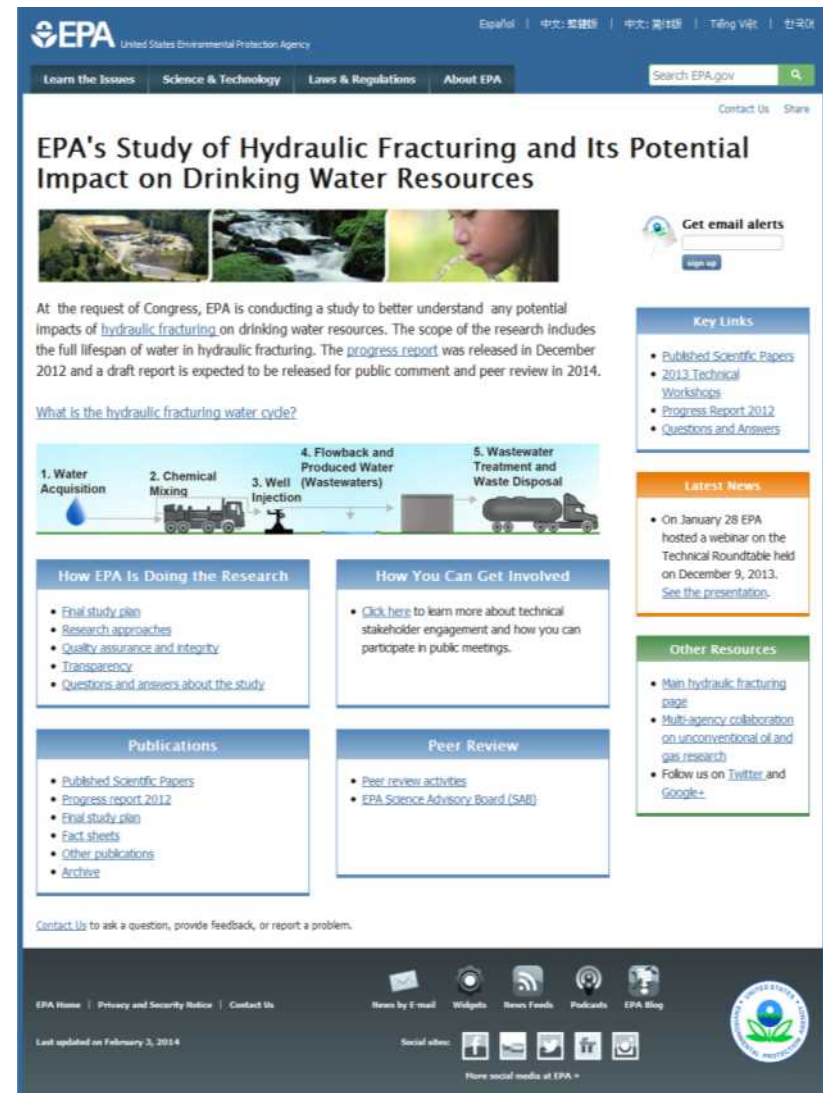
Use of Produced Water in Shale Gas/Oil Extraction



Wilbanks and Fernandez 2014

Six Strategic Pillars to Address Water-Energy Nexus

- Promote responsible energy operations with respect to water quality, ecosystem, and seismic impacts.
- Exploit productive synergies among water and energy systems



The screenshot shows the EPA website page for the study on hydraulic fracturing. The page includes a header with the EPA logo and navigation links. The main content area features the title 'EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources' and a sub-header 'What is the hydraulic fracturing water cycle?'. Below this is a diagram of the water cycle with five steps: 1. Water Acquisition, 2. Chemical Mixing, 3. Well Injection, 4. Flowback and Produced Water (Wastewaters), and 5. Wastewater Treatment and Waste Disposal. The page also includes sections for 'How EPA is Doing the Research', 'How You Can Get Involved', 'Publications', and 'Peer Review'. The footer contains contact information and social media links.

EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources

At the request of Congress, EPA is conducting a study to better understand any potential impacts of [hydraulic fracturing](#) on drinking water resources. The scope of the research includes the full lifespan of water in hydraulic fracturing. The [progress report](#) was released in December 2012 and a draft report is expected to be released for public comment and peer review in 2014.

[What is the hydraulic fracturing water cycle?](#)

How EPA is Doing the Research

- [Final study plan](#)
- [Research approaches](#)
- [Quality assurance and integrity](#)
- [Transparency](#)
- [Questions and answers about the study](#)

How You Can Get Involved

- [Click here](#) to learn more about technical stakeholder engagement and how you can participate in public meetings.

Publications

- [Published Scientific Papers](#)
- [Progress report 2012](#)
- [Final study plan](#)
- [Fact sheets](#)
- [Other publications](#)
- [Archive](#)

Peer Review

- [Peer review activities](#)
- [EPA Science Advisory Board \(SAB\)](#)

Key Links

- [Published Scientific Papers](#)
- [2013 Technical Workshops](#)
- [Progress Report 2012](#)
- [Questions and Answers](#)

Latest News

- On January 28 EPA hosted a webinar on the Technical Roundtable held on December 9, 2013. [See the presentation.](#)

Other Resources

- [Main hydraulic fracturing page](#)
- [Multi-agency collaboration on unconventional oil and gas research](#)
- Follow us on [Twitter](#) and [Google+](#)

■ Project data available at:
http://energy.sandia.gov/?page_id=1741

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 (505)844-6025

The screenshot shows the Sandia National Laboratories website. The main navigation bar includes 'Energy and Climate' and sub-sections like 'RENEWABLE SYSTEMS', 'CLIMATE/ENVIRONMENT', 'ENERGY INFRASTRUCTURE', 'ENERGY RESEARCH', and 'ABOUT EC'. The page title is 'Energy and Water in the Western and Texas Interconnects'. Below the title, there's a 'Background' section with a list of bullet points: 'Hydroelectric power generation', 'Thermoelectric power plant cooling and air emissions control', and 'Energy-resource extraction, refining, and processing'. To the right, there's a 'WATER SECURITY PROGRAM' sidebar with links to 'Water Infrastructure Security', 'Water, Energy, and Natural Resource Systems', and 'Energy and Water in the Western and Texas Interconnects'. Below this is an 'ENERGY-WATER DATA PORTAL' featuring a map of the United States. The page also includes social media sharing buttons (Facebook, Twitter, Print, Share) and a 'Last Updated: August 7, 2014' timestamp.

The footer section is titled 'Exceptional service in the national interest'. It contains several columns of links and information:

- EC**: About Energy and Climate (EC), Energy Security, Climate Security, Infrastructure Security, Energy Research, Key Facilities, Partnerships.
- EC Highlights**: Sandia Report Presents Analysis of Glac Impacts of Vernalis Solar Power Site, Sandia Wins Award for Best Paper at IEEE Photovoltaic Specialist Conference (PVSC), Sandia Completes Hydrostructural Analysis of Coastal Renewable Power Company's TIGER® Turbine, The Influence of Solar Blade Design on Wake Development.
- EC Top Publications**: Solar Energy Grid Integration Systems: Final Report of the Florida Solar Energy Center Team (4.71 MB), Modeling System Losses in PVyrst (365.05 KB), Improved Test Method to Verify the Power Rating of a Photovoltaic (PV) Project (319.74 KB), Solar Energy Grid Integration Systems (SEGIS) Productive Intelligent Advances for Photovoltaic Systems (267.26 KB), View all EC Publications.
- Related Topics**: Concentrating Solar Power, CSP EPRC Energy, Energy Efficiency Energy, Security Infrastructure, Infrastructure Security National, Solar Thermal Test Facility, NSTTF photovoltaic, Photovoltaics PV, Renewable Energy solar Solar, Energy solar power Solar, Research Solid-State, Lighting SSLs.
- Connect**: Contact Us, RSS, Google+, Twitter, Facebook, LinkedIn, YouTube, Flickr.