SAND2019-14395C

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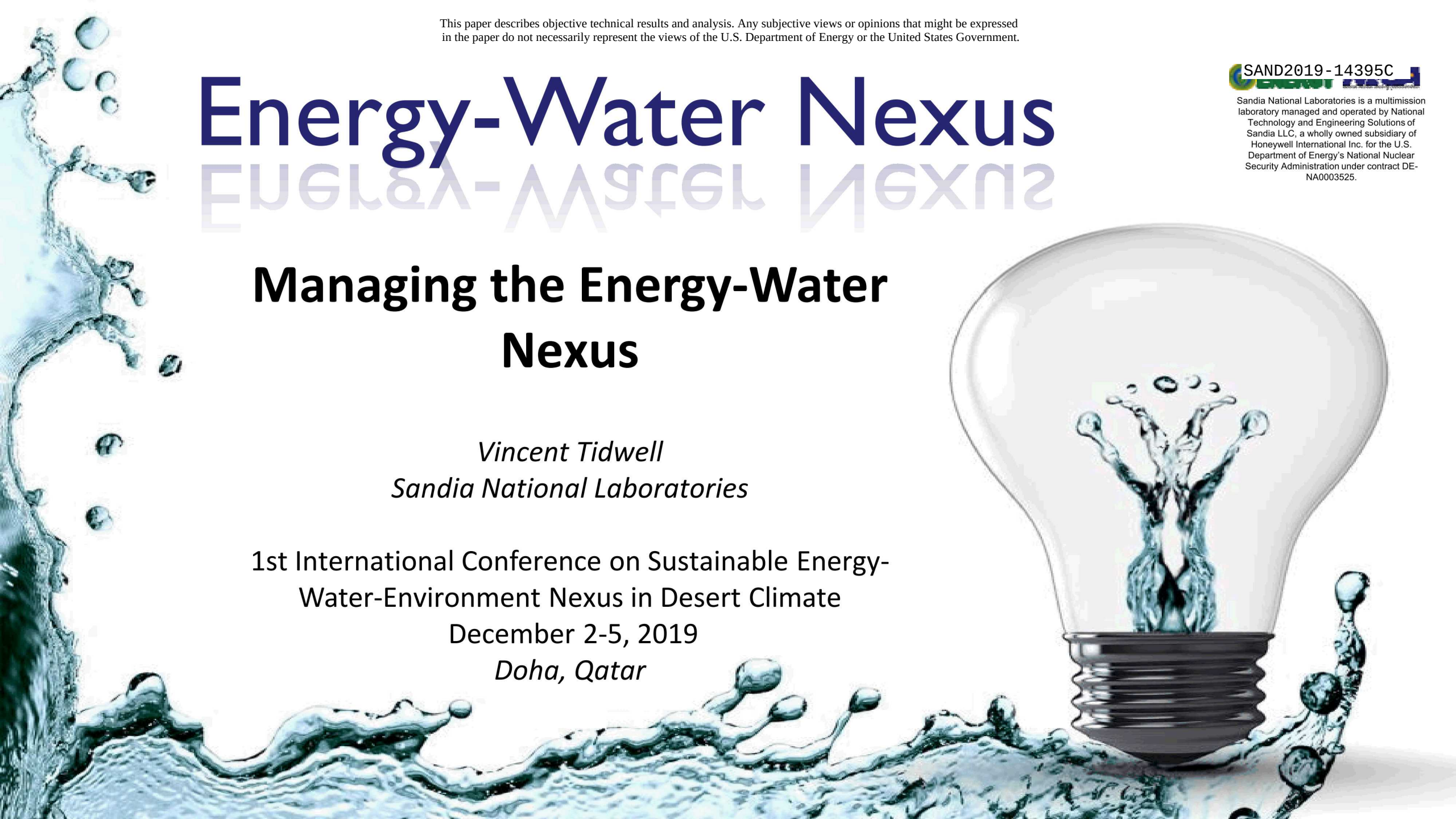
Energy-Water Nexus

Managing the Energy-Water Nexus

Vincent Tidwell
Sandia National Laboratories

1st International Conference on Sustainable Energy-Water-Environment Nexus in Desert Climate
December 2-5, 2019
Doha, Qatar



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- Michael Bailey
- Byron Woertz

Key Points

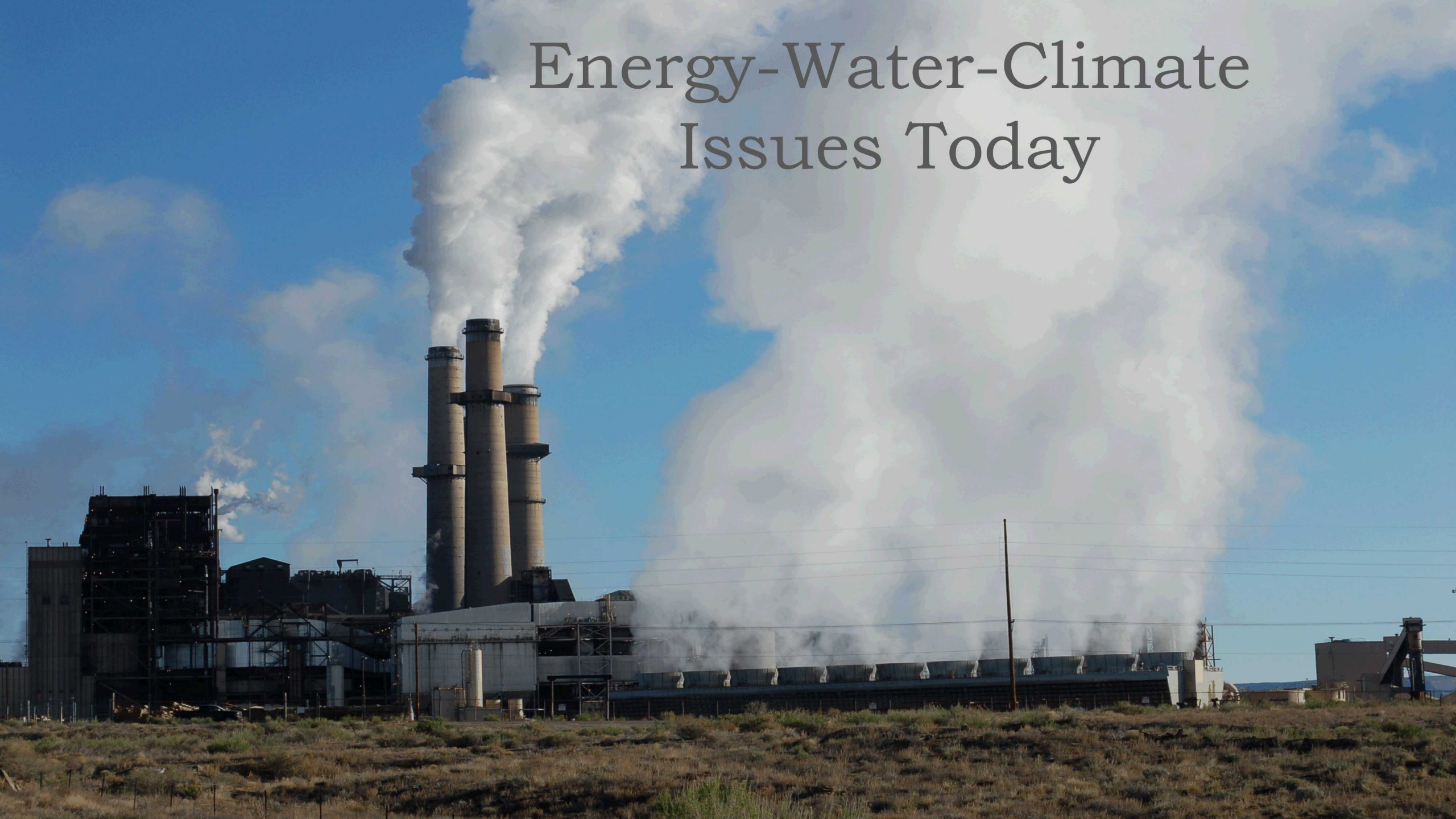
1. Energy-Water-Climate issues are affecting energy production today.

2. Without attention these issues will intensify.

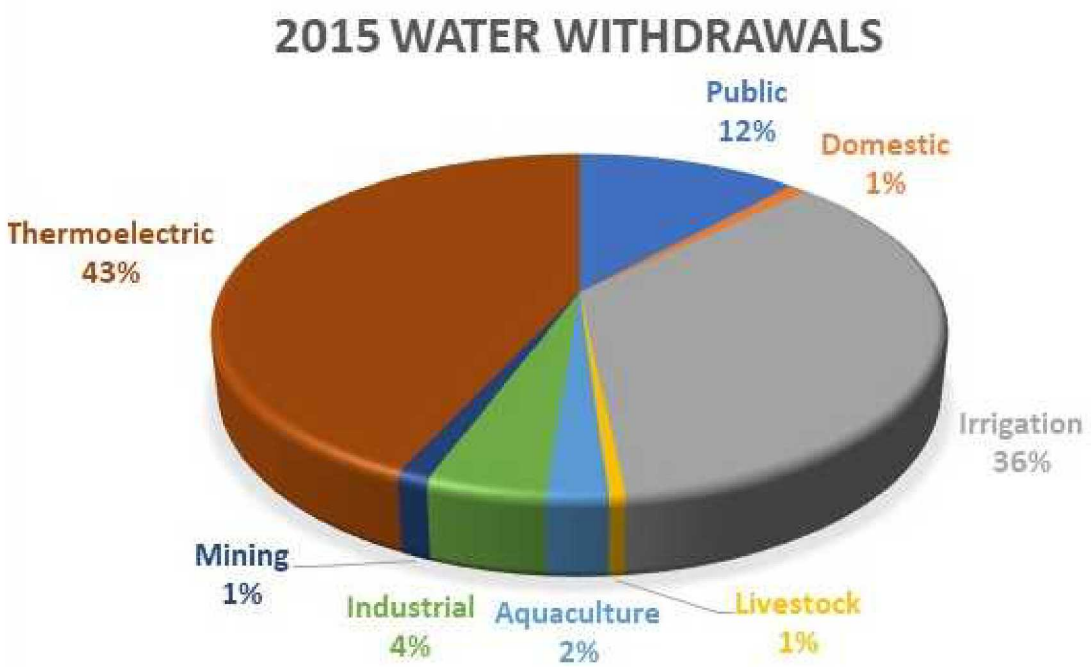
3. Changes in the energy sector are mitigating some climate vulnerabilities.

4. Options are available to adapt to a changing and uncertain future.

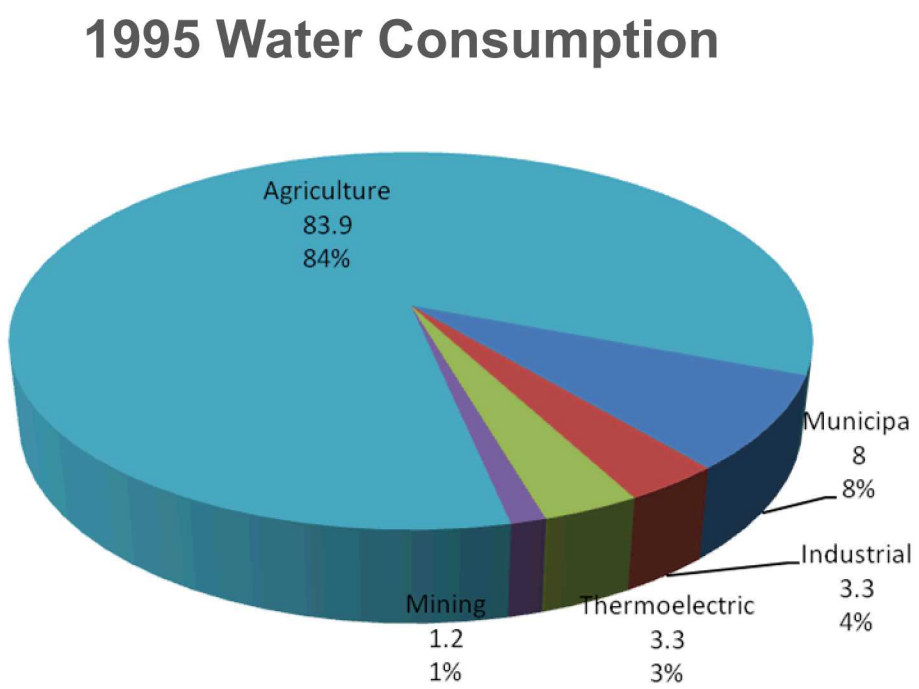
Energy-Water-Climate Issues Today



Water for Energy Today



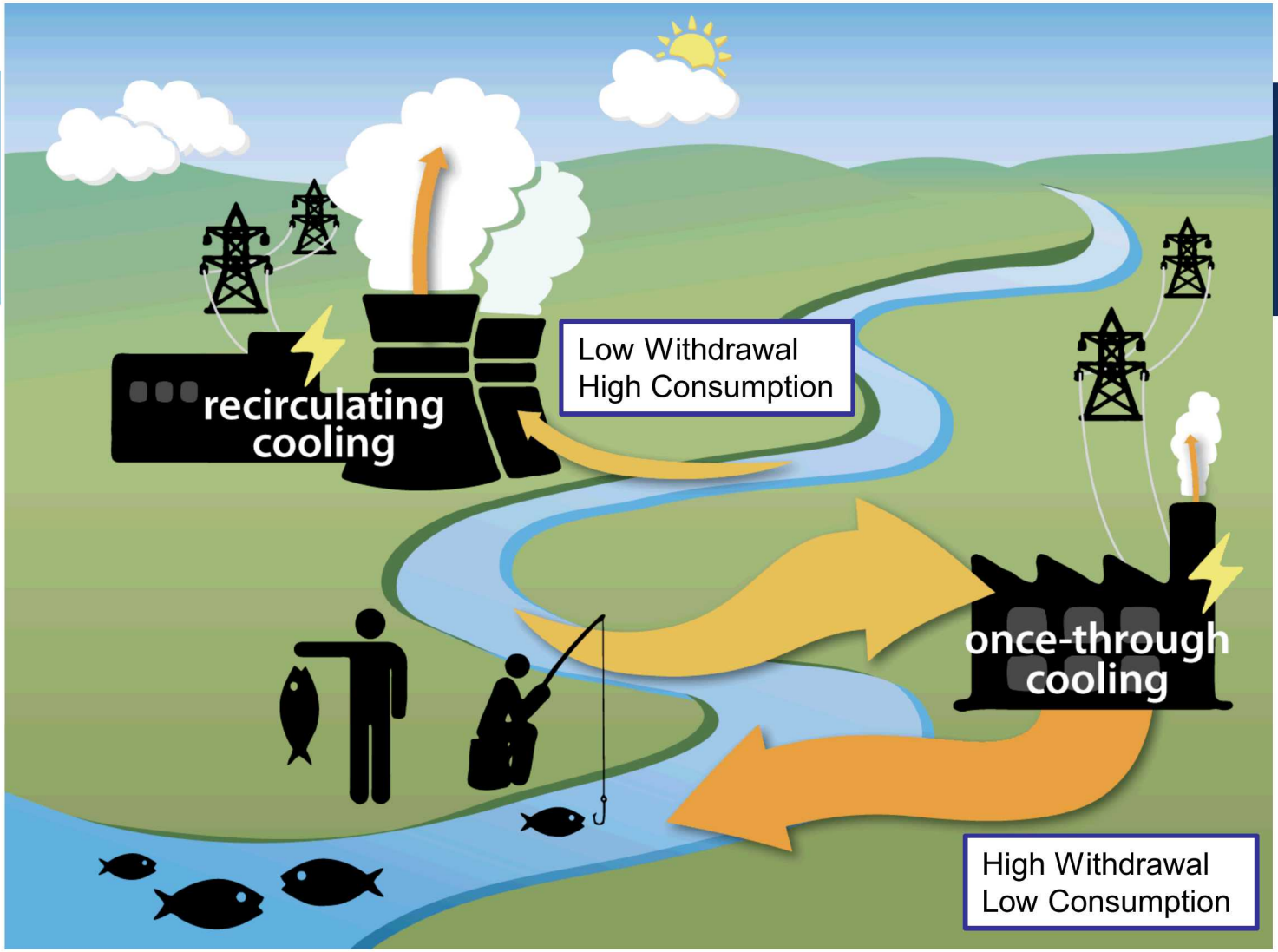
Source: USGS 2018



Estimated at ~2.6 BGD consumed in mining and fuel processing

Power Plant Cooling Systems

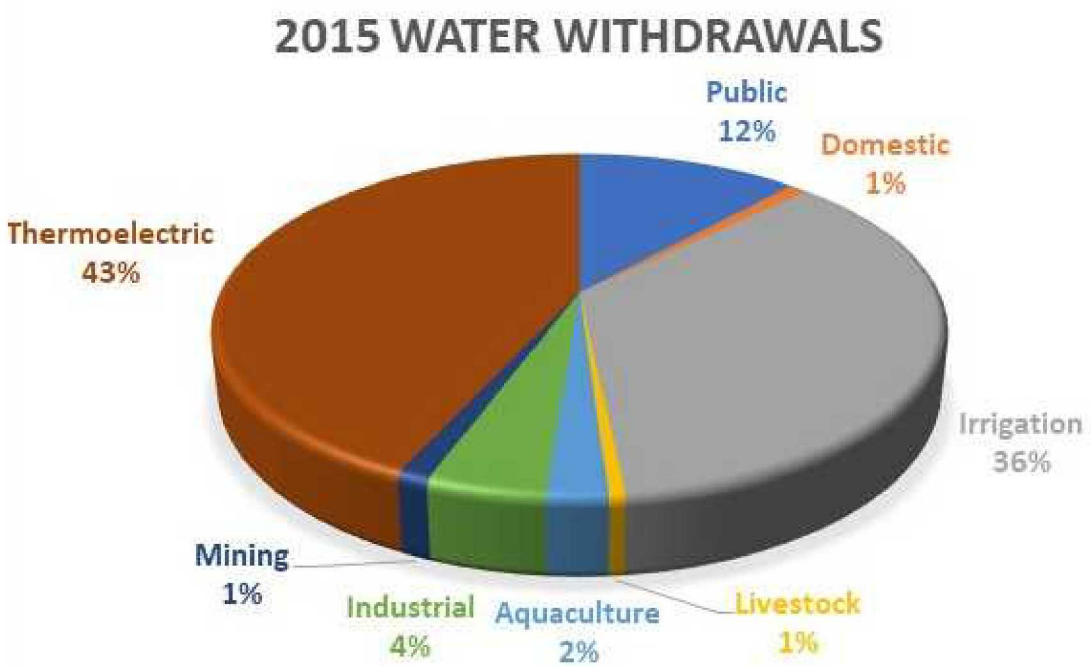
Water withdrawals: water removed from the source (e.g. river, lake, or ocean) for use



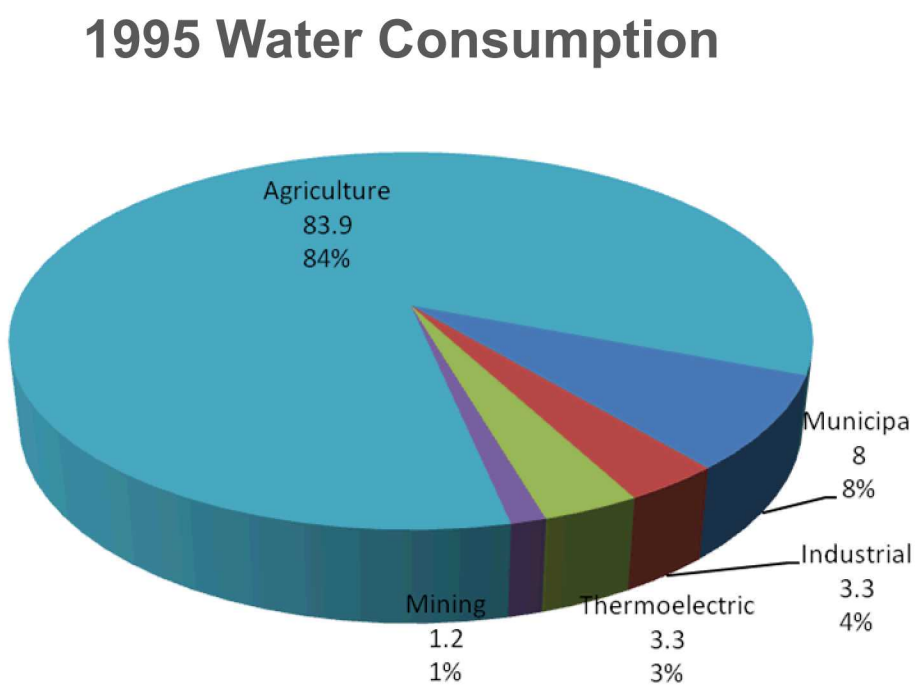
Water consumption: water that is withdrawn and is not available for reuse at the same location or downstream

Source: Union of Concerned Scientists

Water for Energy Today



Source: USGS 2018

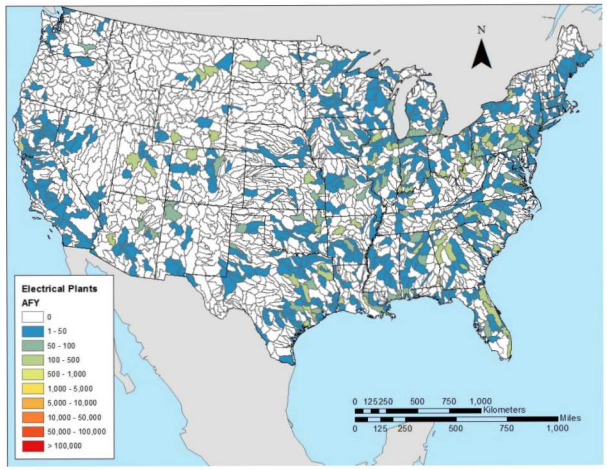


Estimated at ~2.6 BGD consumed in mining and fuel processing

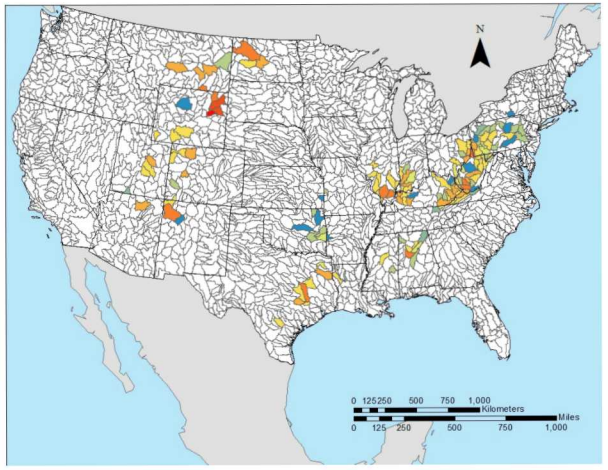
Varies by Sector and Location

Water Consumed in Energy Production

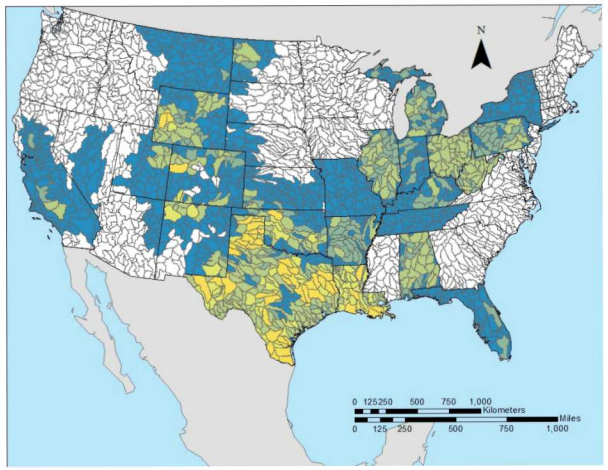
Thermoelectric



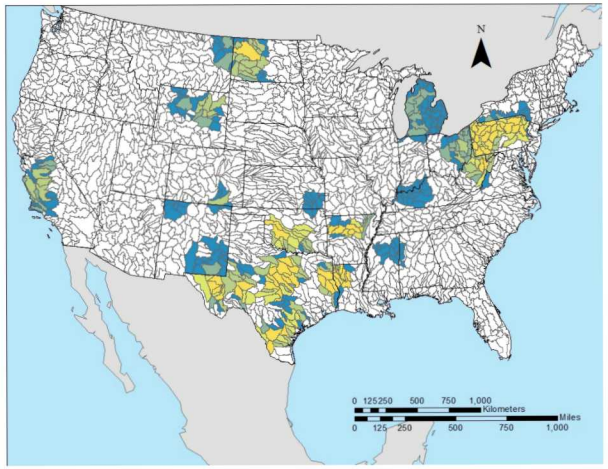
Coal



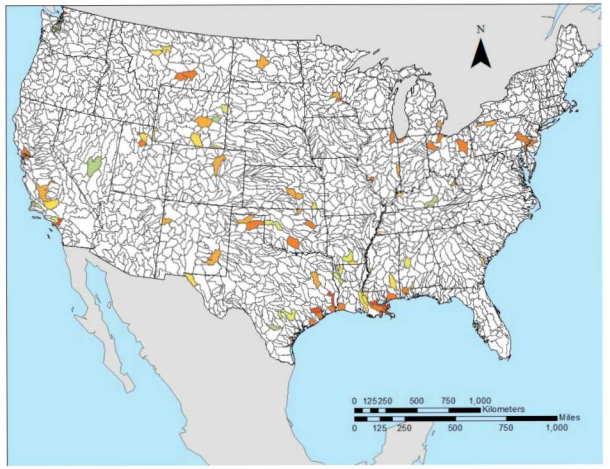
Oil and Gas



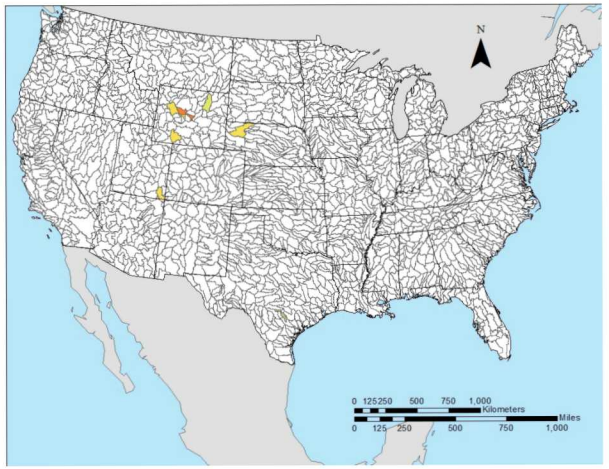
Unconventional Oil and Gas



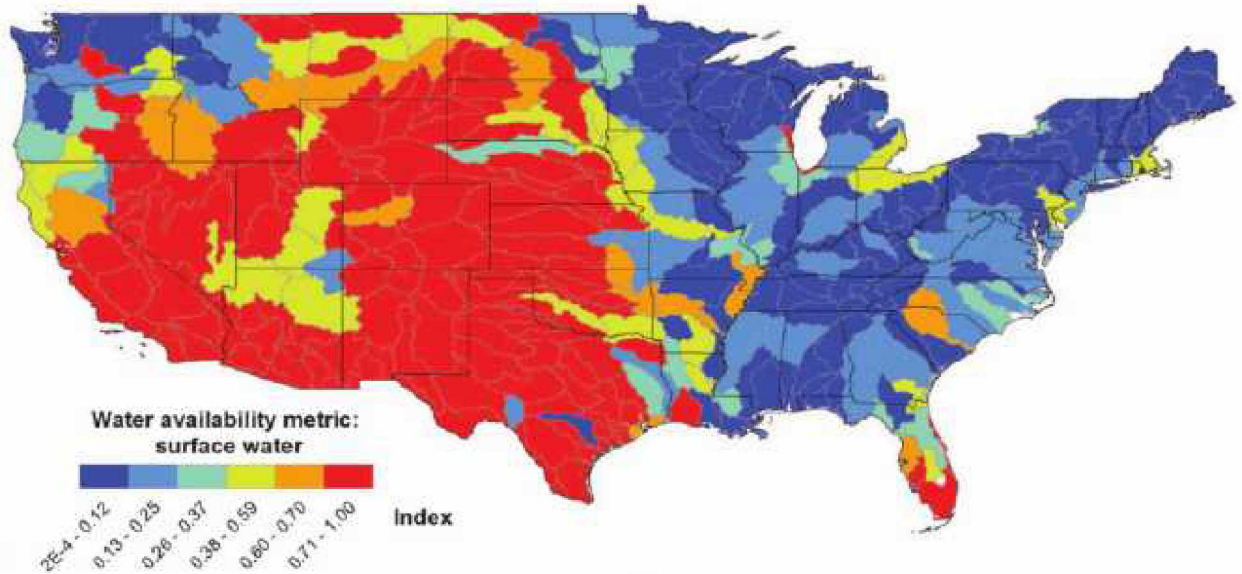
Refineries

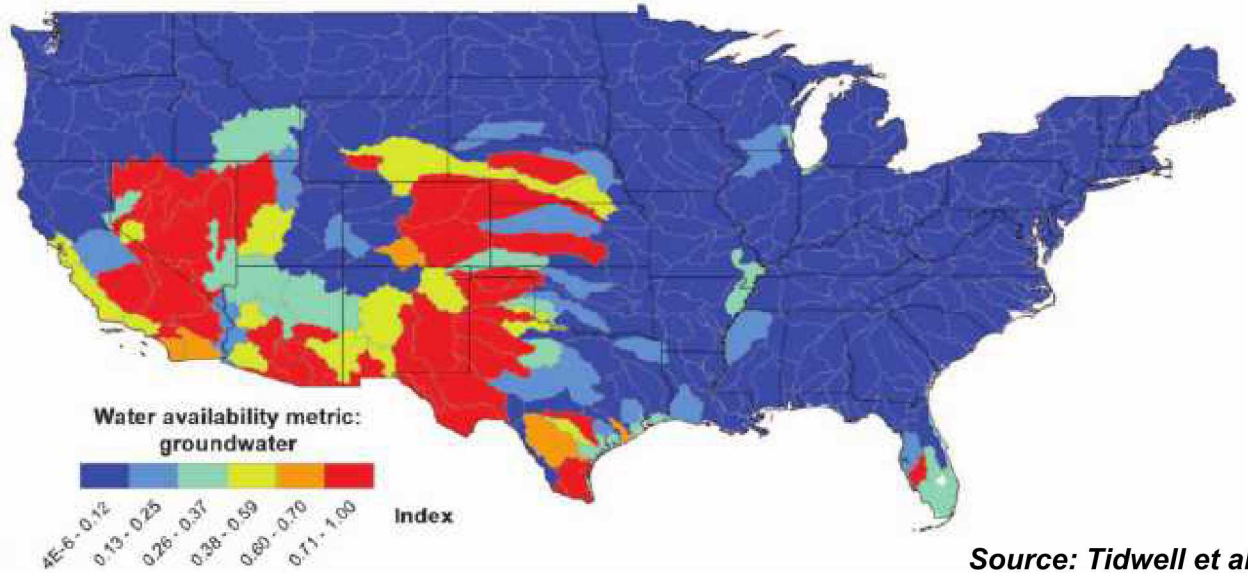


Uranium



Water Stress





Source: Tidwell et al. 2013

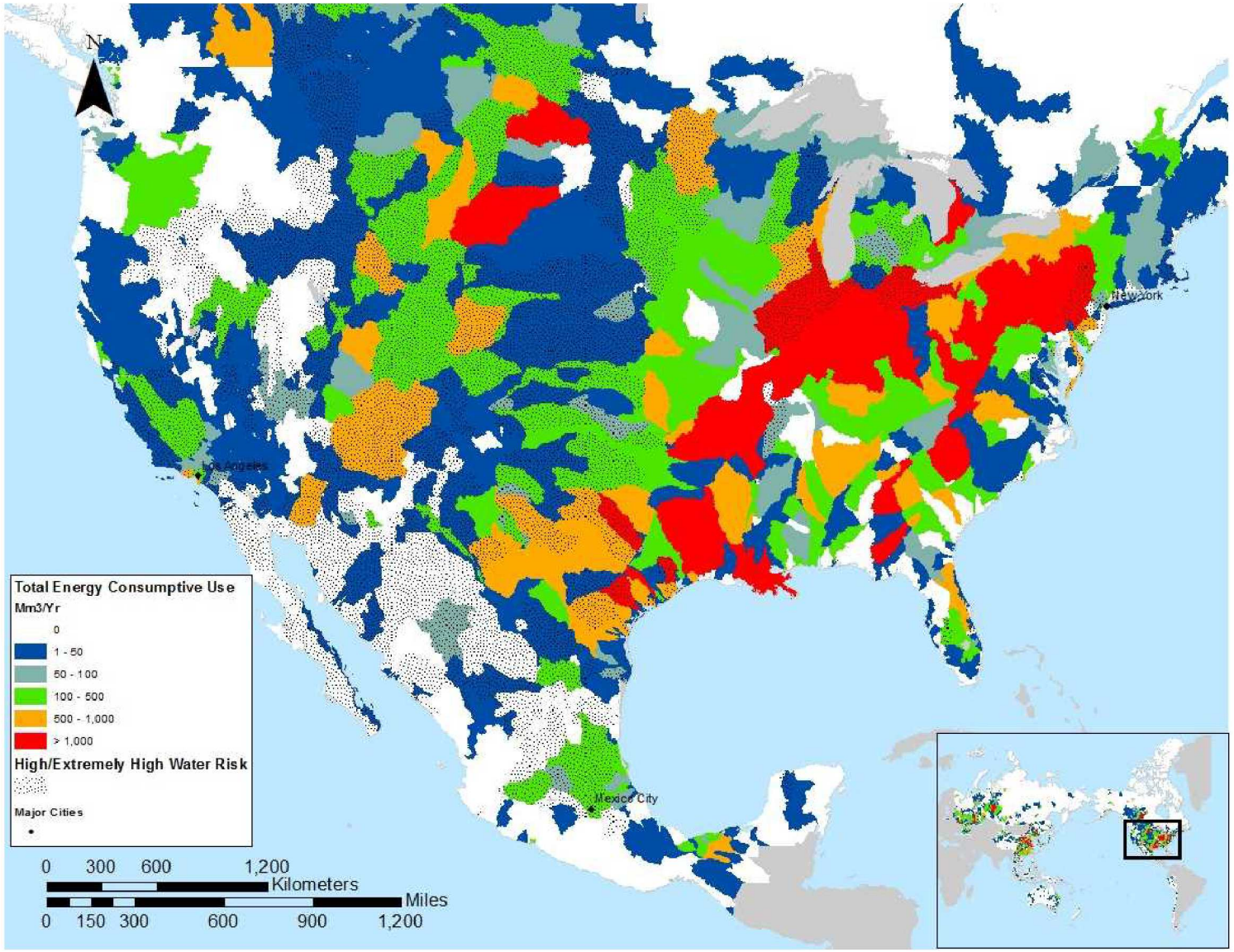
Surface Water Stress

- Ratio of consumption to water supply
- Measured at annual low flow
- Red marks region where over 70% of physical water is currently used

Groundwater Stress

- Ratio of pumping to sustainable recharge
- Red marks region where over 70% of recharge is currently used

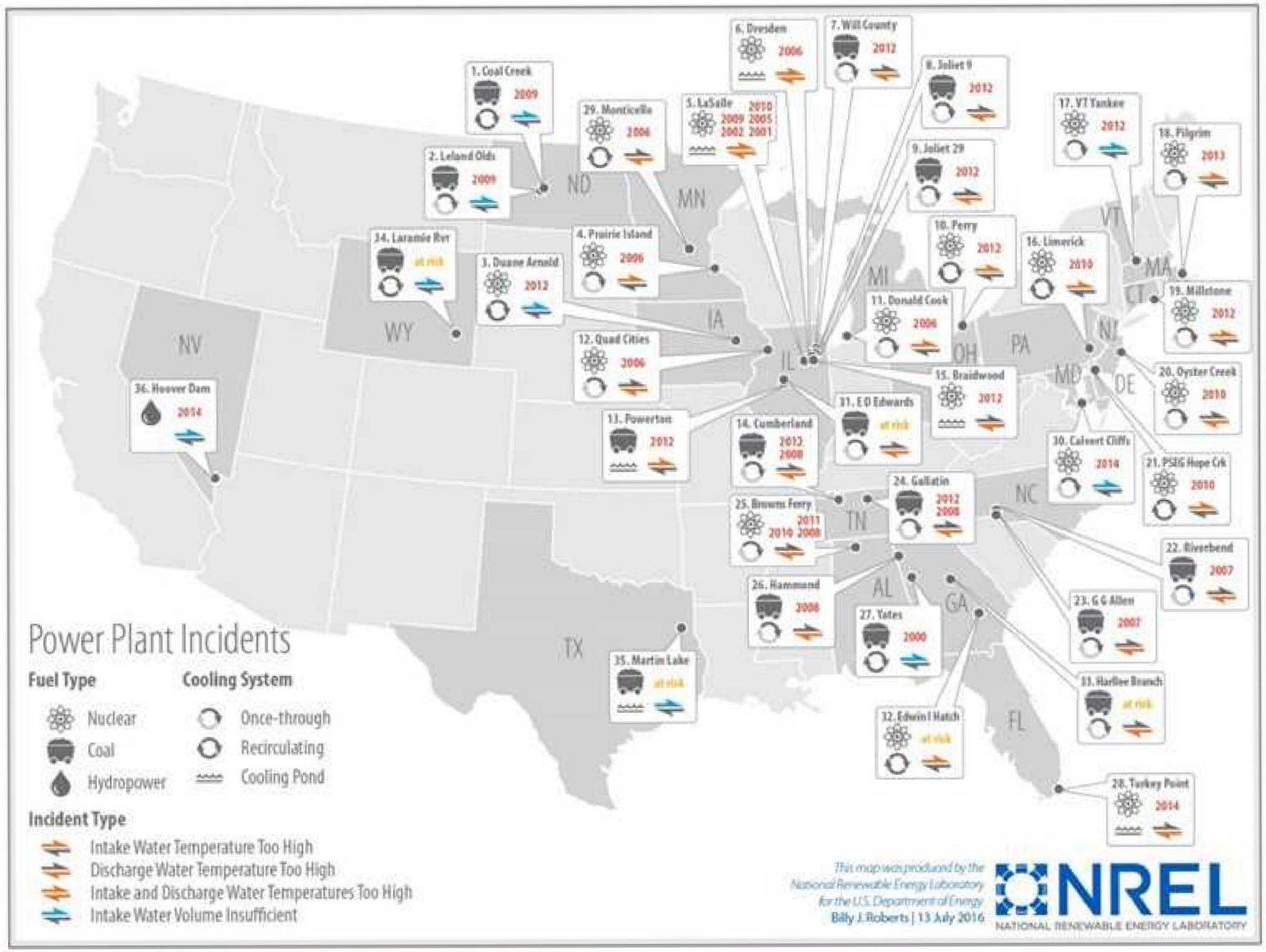
Energy-Water Risk



Almost 40% of the energy producing basins in the U.S. are considered water stressed

Source: Tidwell et al. 2016

Impacts Today



Water Extremes have impacted:

- Power plant operations (shown here),
- Hydropower operations,
- Impacted energy extraction, and
- Damaged production, transmission and processing facilities

Impacts Today

The Availability, Reliability and Cost of Water is Impacting the Siting of New Power Generation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6/20/2019

State denies permit to Burrillville power plant

BURRILLVILLE – In a gripping decision that followed several years of debate, the state Energy Facility Siting Board today denied an application by Chicago-based Invenergy to build an oil-and-gas-burning power plant off Wallum Lake Road.

The decision came after just a few hours of public debate during which members of the state board expressed doubt about the state's need for the energy produced by the plant, a key argument made by representatives of the company.

The decision was a victory for conservationists and local residents, many of


CENTER for BIOLOGICAL DIVERSITY Because life is good.

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For Immediate Release, February 9, 2009

Contact: Amy Atwood, Center for Biological Diversity, (541) 914-8372

Statement on NV Energy Inc.'s Abandonment of Plans to Construct Coal-Fired Power Plant in Eastern Nevada

LAS VEGAS, *Nev.*— The Center for Biological Diversity is celebrating NV Energy Inc.'s announcement today that it will abandon original plans to construct the Ely Energy Center, a coal-fired power plant in eastern Nevada. Citing growing environmental and economic concerns, the company stated that the project has been postponed until greenhouse gas capture and storage capture technology becomes commercially viable, which is "not likely before the end of the next decade."

"Today's announcement reflects the fact that power companies are starting to recognize coal's bleak future," said Amy Atwood, public lands energy director at the Center for Biological Diversity. "The Obama administration should take swift action to halt regulatory approvals for other coal-fired power plants that are still proposed for the region. Not another acre of public lands should be destroyed for coal combustion in an age of global warming."

Ely Energy Center, which would have been located about 20 miles north of Ely in White Pine County, Nevada, would have consisted of two coal-fired 750-megawatt (MW) ultra-supercritical steam turbine units, two 500-MW integrated gasification combined cycle units, and associated facilities. The Center would have had a 2,500-MW generating capacity and an estimated lifespan of 50 years.

Ely Energy Center would consume approximately 8,000 acre-feet of water per year during the first phase alone, compromising the viability of local threatened and endangered species while contributing an estimated 10.6 million tons of CO_2 to the atmosphere every year. Additional greenhouse gas emissions would have resulted from the mining and transportation of coal between eastern Nevada and the Powder River Basin in Wyoming.

The Center will continue to monitor developments to see that regulatory permitting processes for the Ely Energy Center are halted or withdrawn.

The Center for Biological Diversity is dedicated to ensuring that atmospheric CO_2 pollutant levels are reduced to below 350 ppm, which leading climate scientists warn is necessary to prevent devastating climate change. Further development of greenhouse gas-intensive energy sources, including oil shale, tar sands, and coal-fired power plants, is fundamentally incompatible with achieving this goal. If greenhouse gas emissions are not immediately reduced, the current atmospheric CO_2 level of 385 ppm will rise to approximately 500 ppm by mid-century, triggering mass wildlife extinctions, catastrophic global weather and ecosystem changes, and tragic human suffering.

Arizona • California • Colorado • Florida • N. Carolina • New York • Oregon • Virginia • Washington, D.C. • La Paz, Mexico

BiologicalDiversity.org

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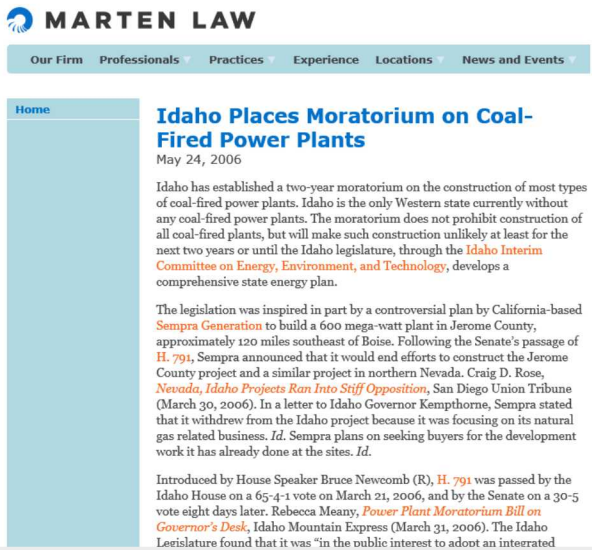
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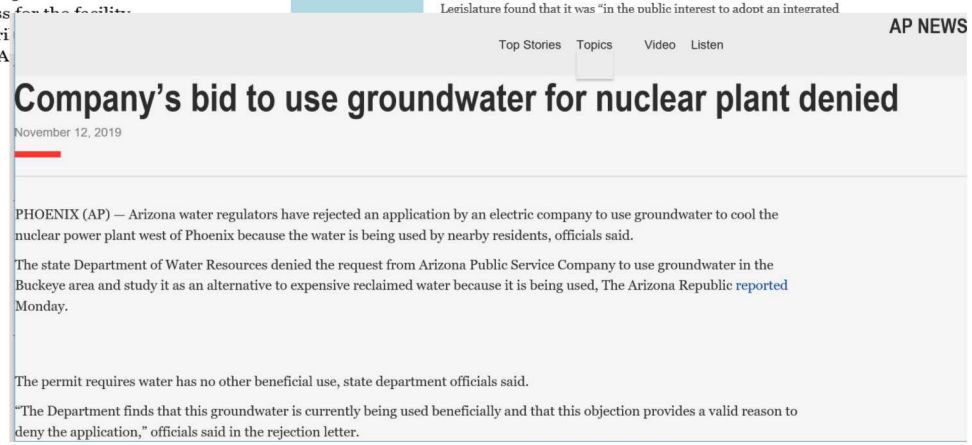
Idaho Places Moratorium on Coal-Fired Power Plants

May 24, 2006

Idaho has established a two-year moratorium on the construction of most types of coal-fired power plants. Idaho is the only Western state currently without any coal-fired power plants. The moratorium does not prohibit construction of all coal-fired plants, but will make such construction unlikely at least for the next two years or until the Idaho legislature, through the Idaho Interim Committee on Energy, Environment, and Technology, develops a comprehensive state energy plan.

The legislation was inspired in part by a controversial plan by California-based Sempra Generation to build a 600 mega-watt plant in Jerome County, approximately 120 miles southeast of Boise. Following the Senate's passage of H. 791, Sempra announced that it would end efforts to construct the Jerome County project and a similar project in northern Nevada. Craig D. Rose, *Nevada, Idaho Projects Ran Into Stiff Opposition*, San Diego Union Tribune (March 30, 2006). In a letter to Idaho Governor Kempthorne, Sempra stated that it withdrew from the Idaho project because it was focusing on its natural gas related business. *Id.* Sempra plans on seeking buyers for the development work it has already done at the sites. *Id.*

Introduced by House Speaker Bruce Newcomb (R), H. 791 was passed by the Idaho House on a 65-4-1 vote on March 21, 2006, and by the Senate on a 30-5 vote eight days later. Rebecca Meany, *Power Plant Moratorium Bill on Governor's Desk*, Idaho Mountain Express (March 31, 2006). The Idaho Legislature found that it was "in the public interest to adopt an integrated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Company's bid to use groundwater for nuclear plant denied

November 12, 2019

PHOENIX (AP) — Arizona water regulators have rejected an application by an electric company to use groundwater to cool the nuclear power plant west of Phoenix because the water is being used by nearby residents, officials said.

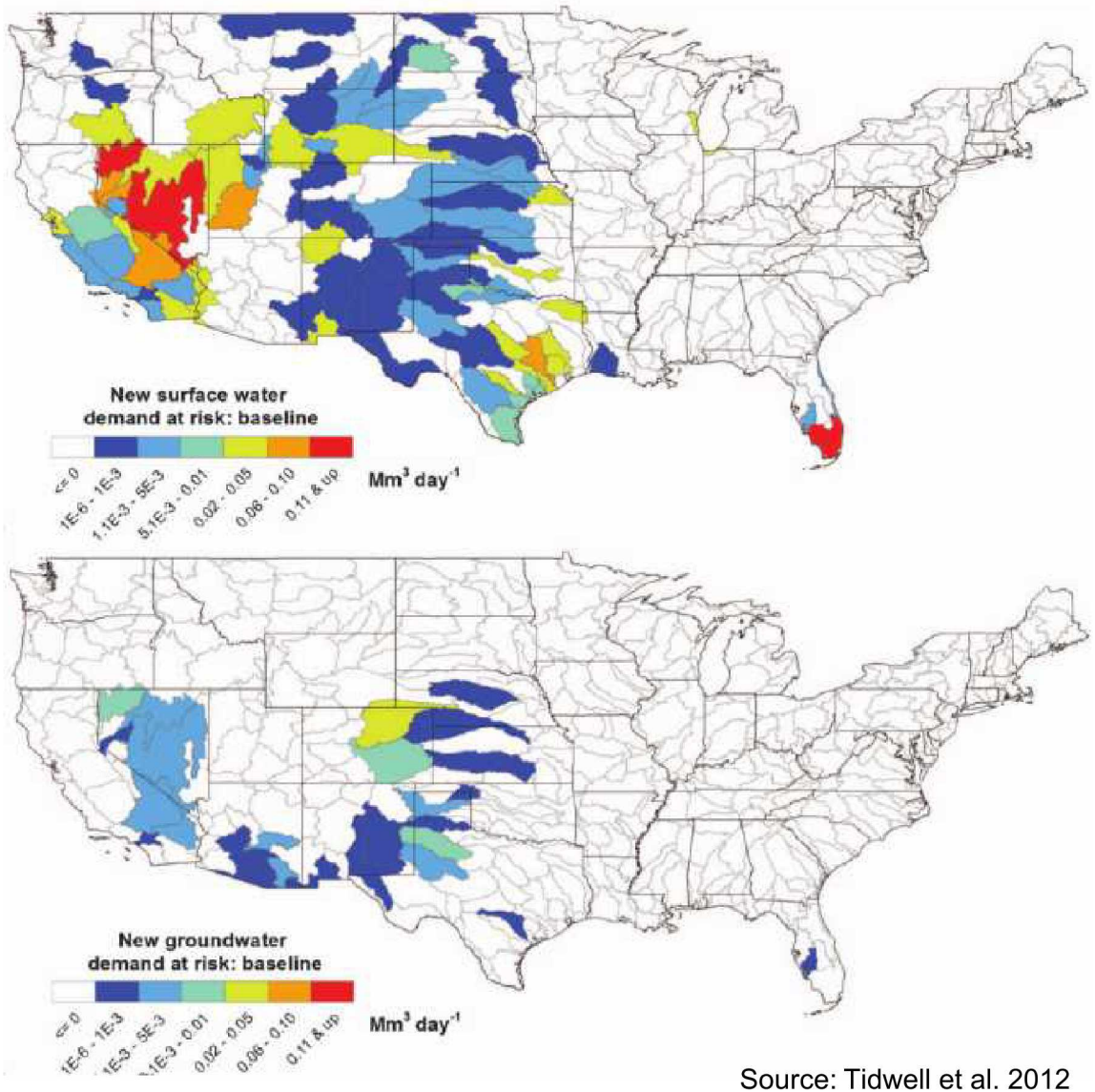
The state Department of Water Resources denied the request from Arizona Public Service Company to use groundwater in the Buckeye area and study it as an alternative to expensive reclaimed water because it is being used, The Arizona Republic reported Monday.

The permit requires water has no other beneficial use, state department officials said.

"The Department finds that this groundwater is currently being used beneficially and that this objection provides a valid reason to deny the application," officials said in the rejection letter.

Intensifying Nexus

Thermoelectric Development

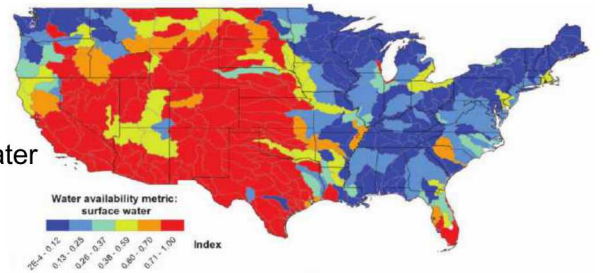


Source: Tidwell et al. 2012

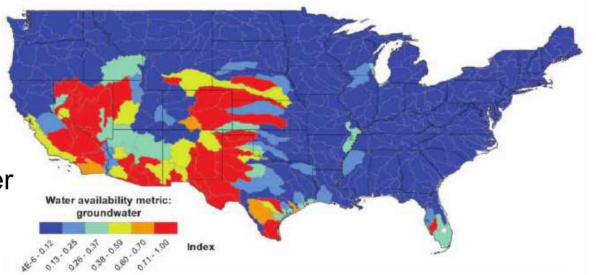
Water and Power at Siting Risk

	Power (MMWh)		Water (Mm^3/day)	
Scenario	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%)

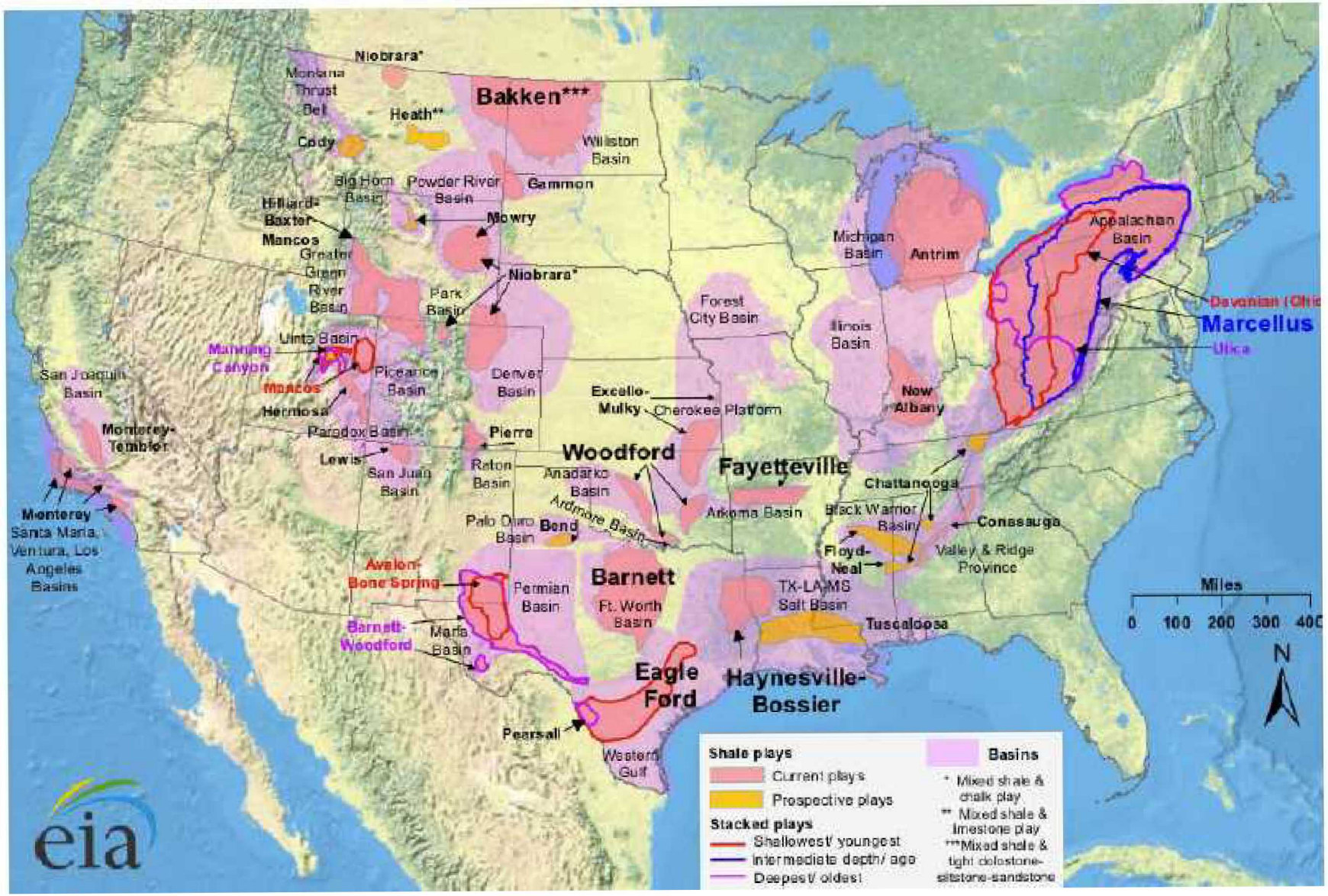
Surface Water Availability



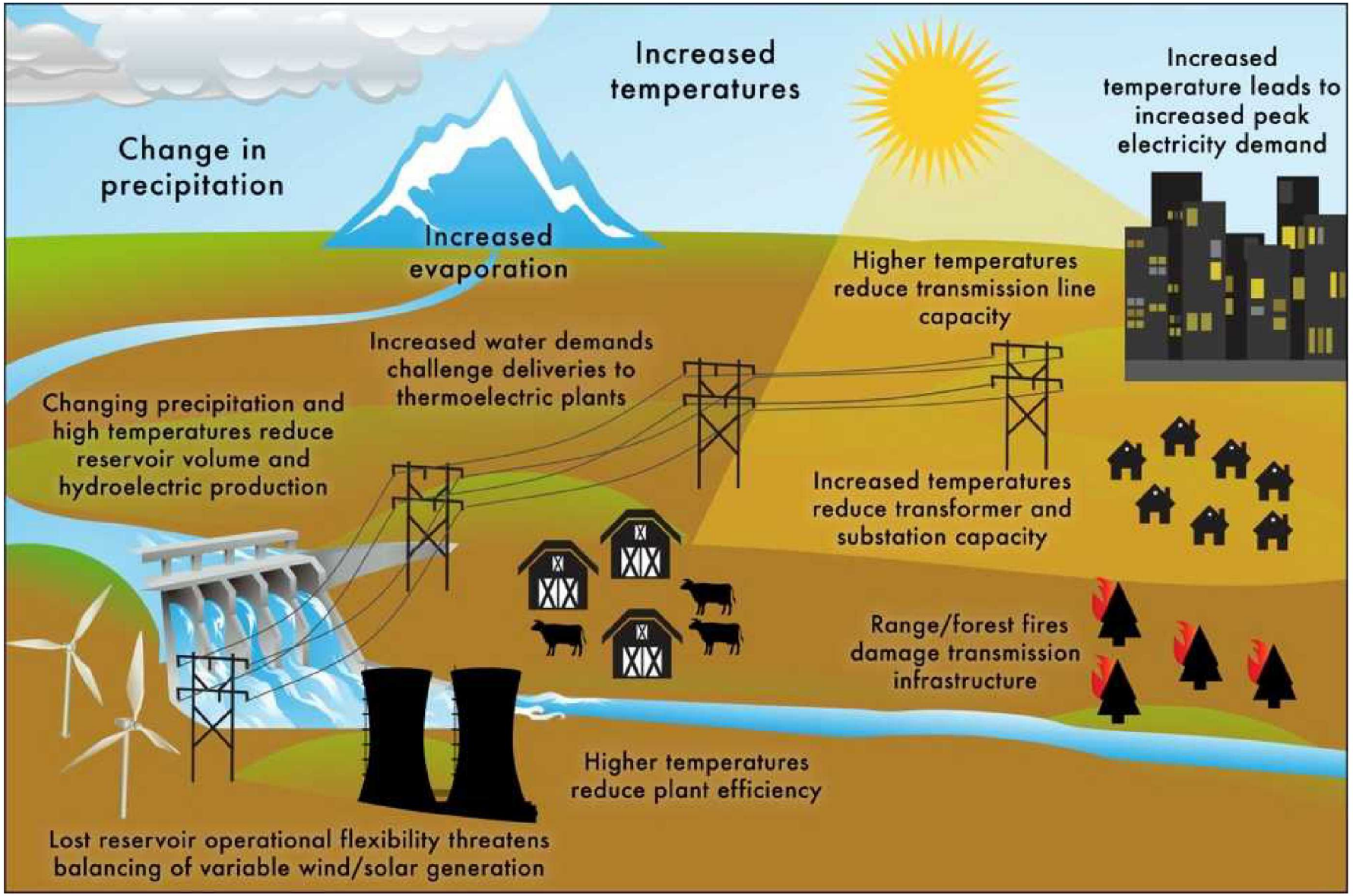
Groundwater Availability



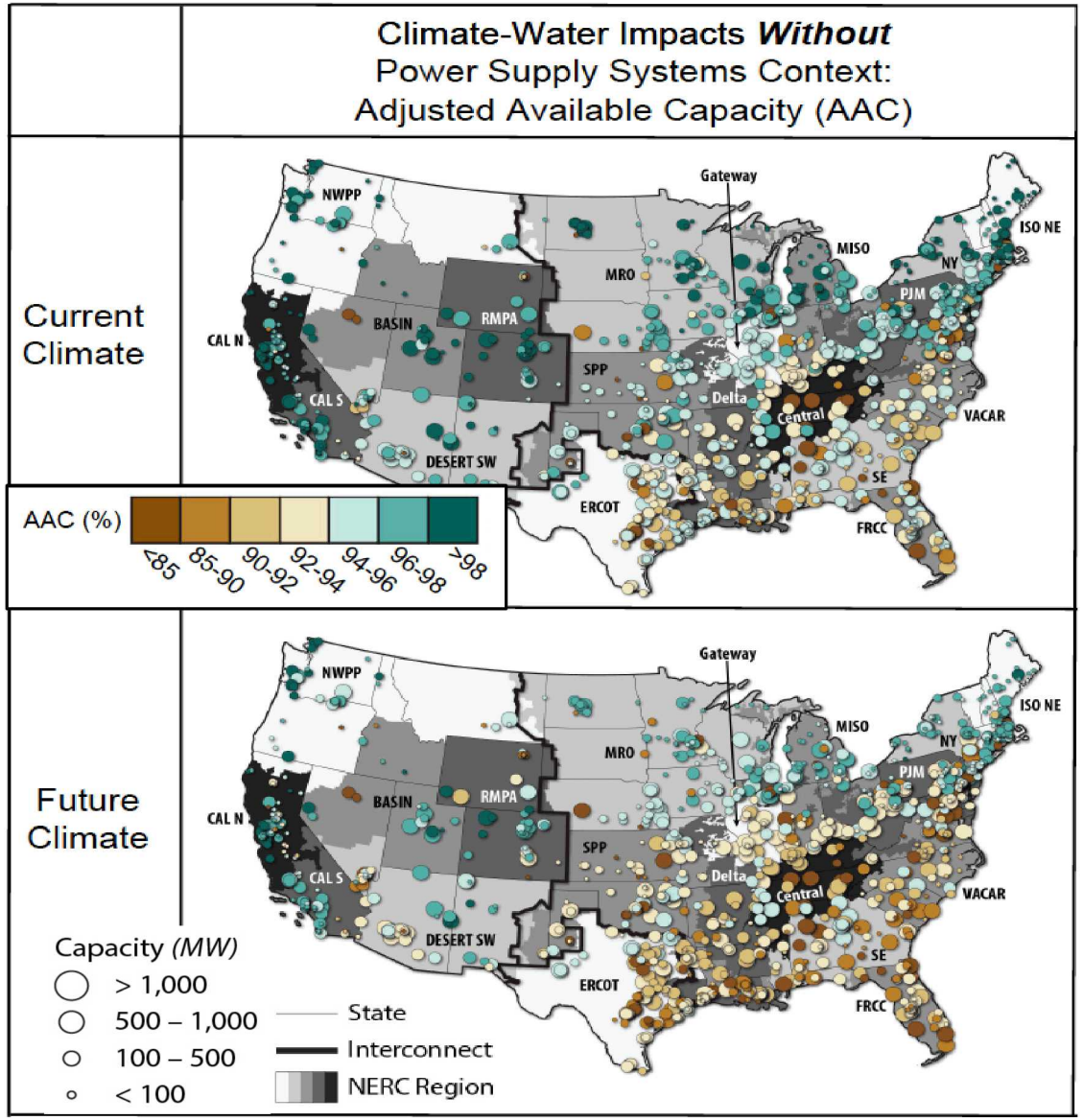
Gas and Oil Shale Development



Cascading Impacts on Electric Power



Drought Exposure



- Power generation at risk from drought.
- Elevated water temperatures can necessitate plants to limit their generation.
- Show is potential impact on current generation capacity:
  - Under current climate, and
  - Under future climate conditions.

Changing Energy Sector

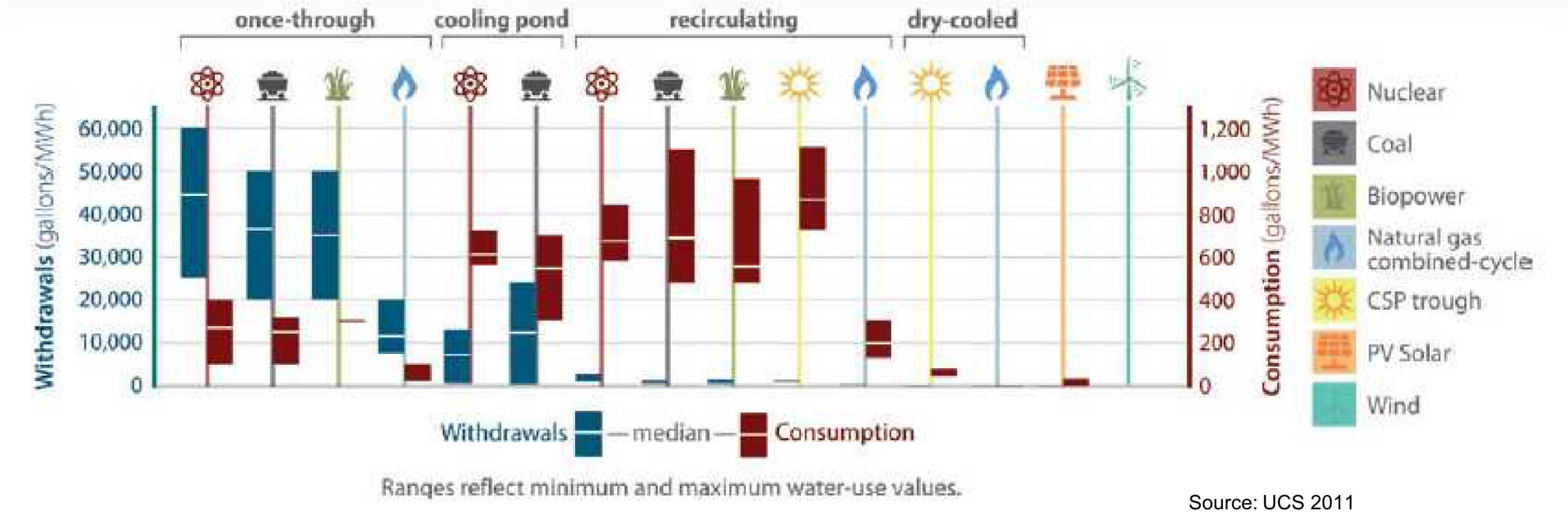
Fuel Switching

Current generation relies on high-water use technology:

- Coal
- Gas-Steam
- Nuclear

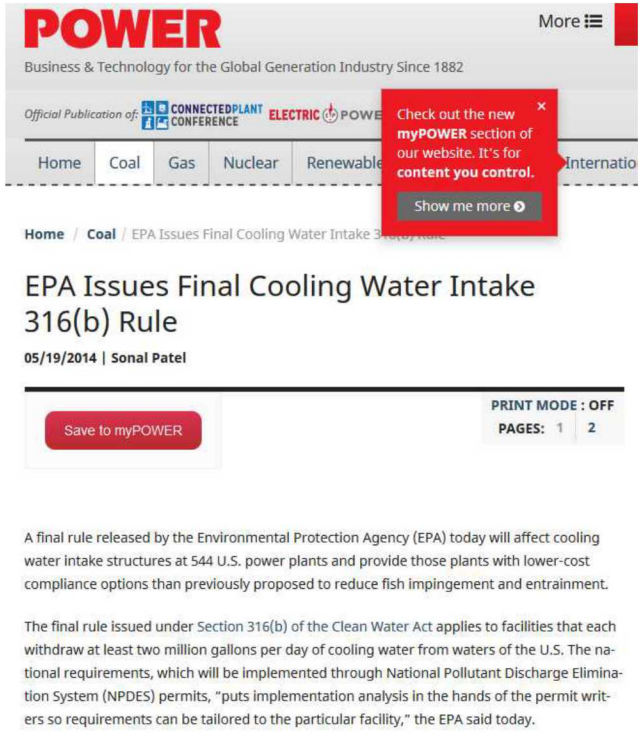
New capacity favors low-water use technology:

- Natural gas combined cycle
- Wind
- Solar PV



Source: UCS 2011

Cooling System Switching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EPA Issues Final Cooling Water Intake 316(b) Rule

05/19/2014 | Sonal Patel

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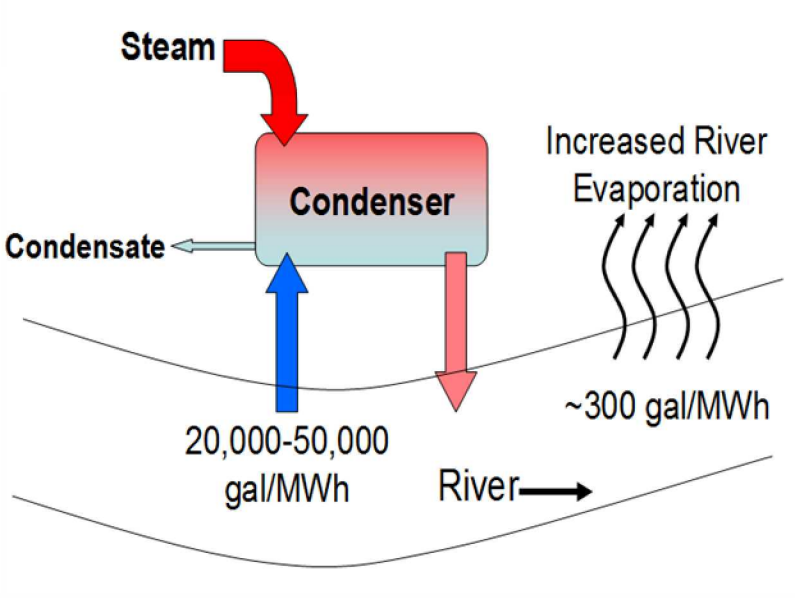
A final rule released by the Environmental Protection Agency (EPA) today will affect cooling water intake structures at 544 U.S. power plants and provide those plants with lower-cost compliance options than previously proposed to reduce fish impingement and entrainment.

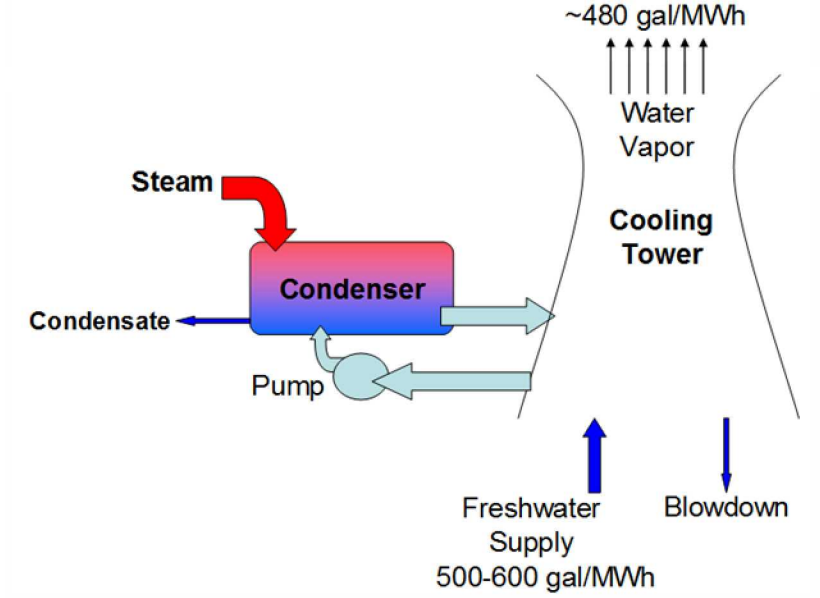
The final rule issued under Section 316(b) of the Clean Water Act applies to facilities that each withdraw at least two million gallons per day of cooling water from waters of the U.S. The national requirements, which will be implemented through National Pollutant Discharge Elimination System (NPDES) permits, "puts implementation analysis in the hands of the permit writers so requirements can be tailored to the particular facility," the EPA said today.

High Water Withdrawal Low Water Consumption



Open-loop "once-through" cooling cycle

Low Water Withdrawal High Water Consumption

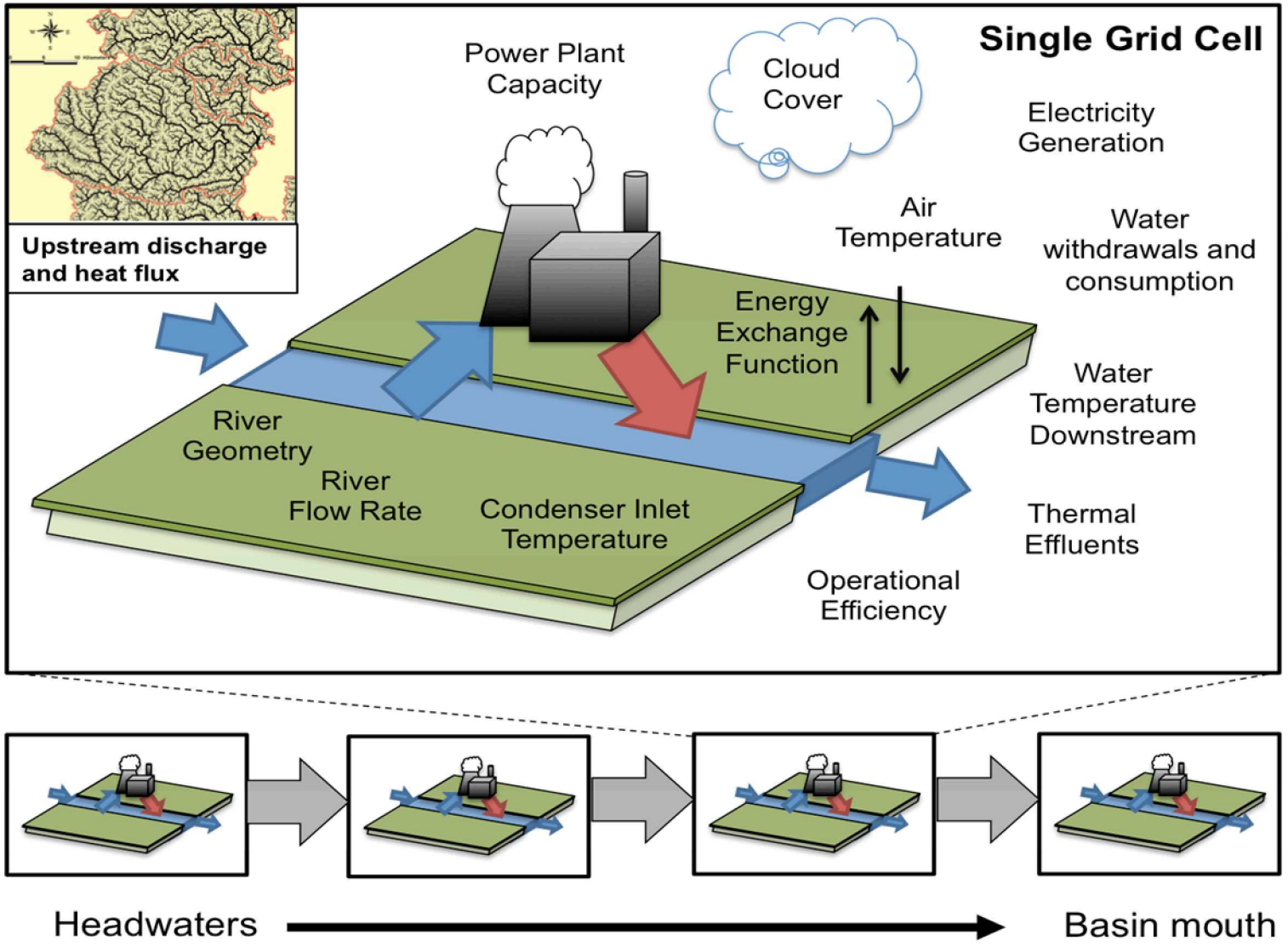


Closed-loop cooling cycle

Source: EPRI 2002

Improved Drought Resilience

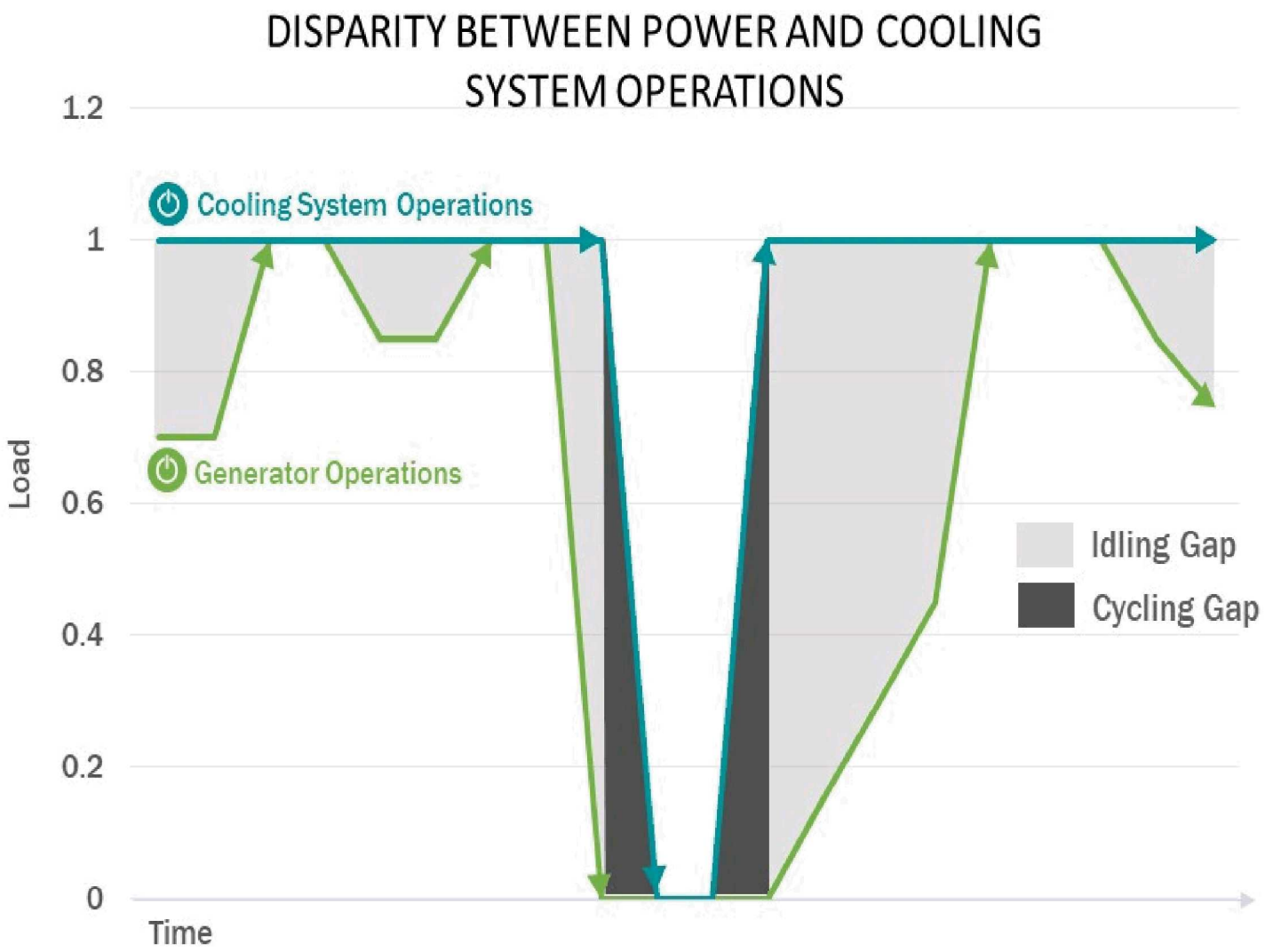
- Open loop cooling at greatest risk.
- Open loop plants are old and being retired and replaced by closed loop plants.
- Also reduces heat load to river limiting impact on downstream plants.



Miara and Vörösmarty (2013)

Systems Operations

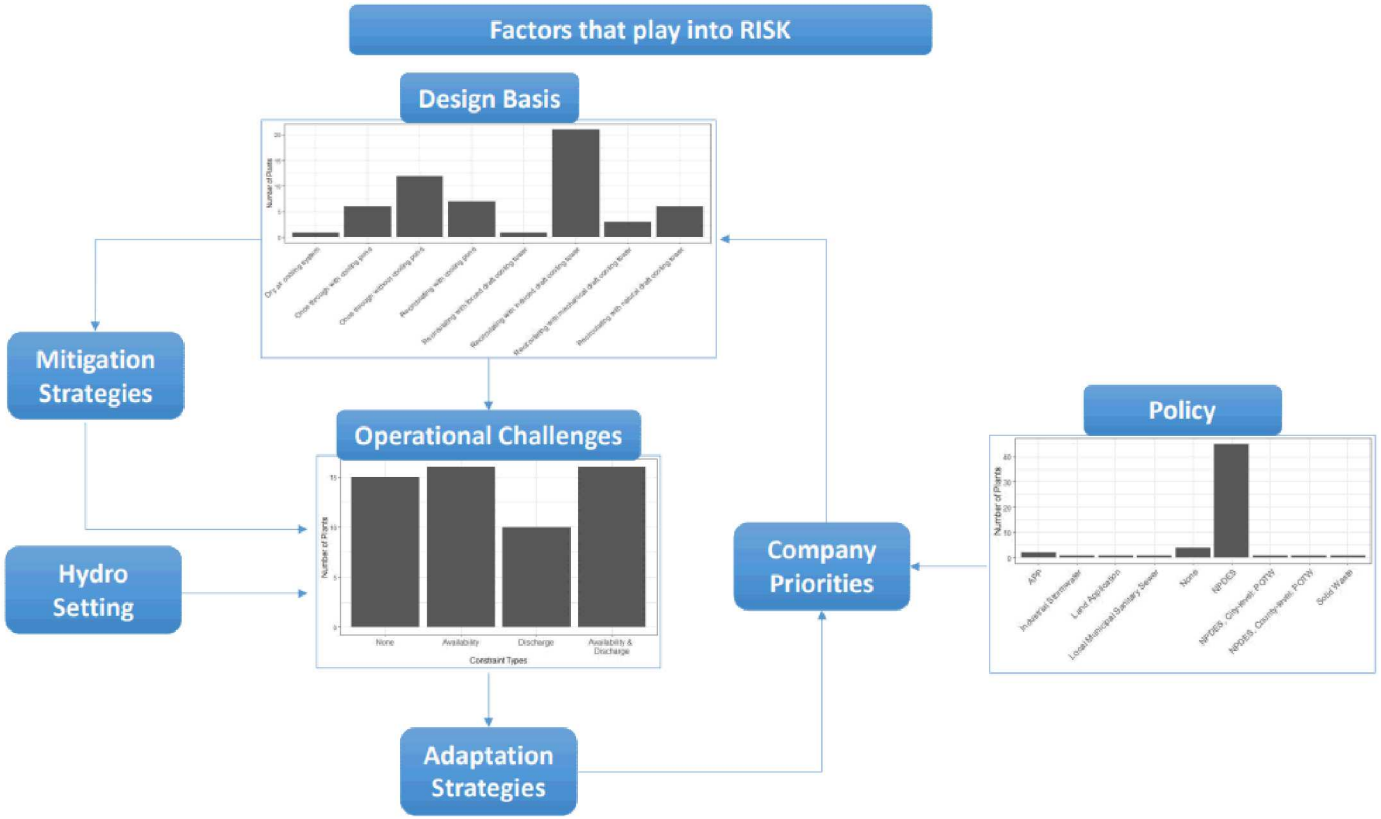
- ***Idling Gap***—cooling systems continue to operate for a period of time after its power system is idled (on average 13% longer).
- ***Cycling Gap***—cooling systems operate at full capacity although their associated power systems cycle over a range of loads (on average 30% below full load).



Climate Adaptation Opportunities

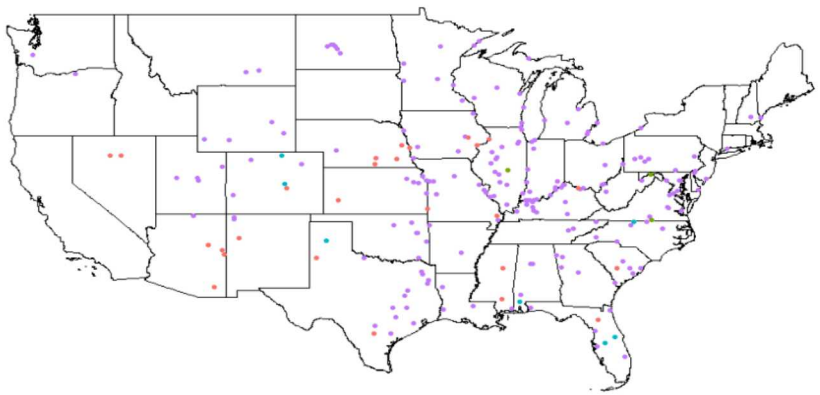
Survey of Plant Level Water Risks

- A semi-structured interview approach with plant owners and operators was implemented to obtain water constraint information.
- The collected data was coded and captured in a database to identify patterns and compare strategies among power plants.
- Our dynamic hypothesis covers various factors that create a risk to power plants.



Important Details

Perceived Risks are Very Different from East to West



Unexpected Challenges

- Environmental constraints,
- Overflowing evaporation ponds,
- Seniority of rights,
- Rights owned by others.

Contingency Planning

- Water leasing,
- Alternative supplies,
- On-site storage,
- Auxillary cooling,
- Zero liquid discharge,
- Informed operations.

Alternative Water Source

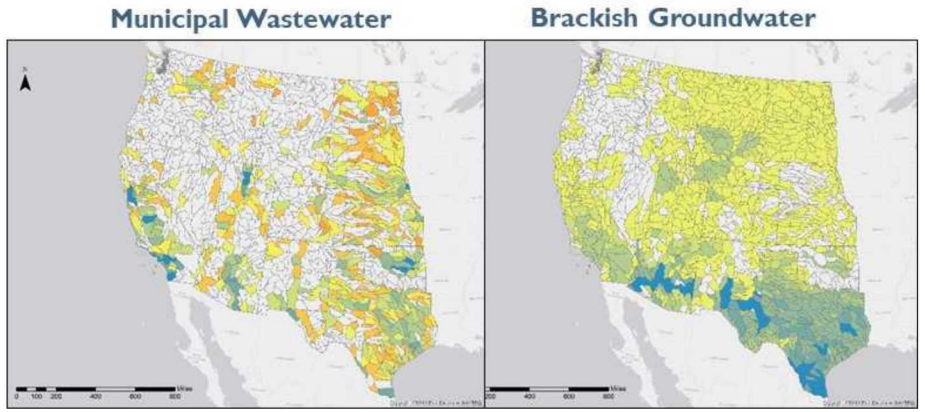
Retrofit existing plants to eliminate freshwater use

- Retrofit options:
  - Dry cooling
  - Municipal waste water
  - Brackish groundwater

1,178 Freshwater Using Thermoelectric Power Plants

- Costs:
  - Capital
  - Operating and Maintenance
  - Capture
  - Treatment
  - Parasitic energy losses

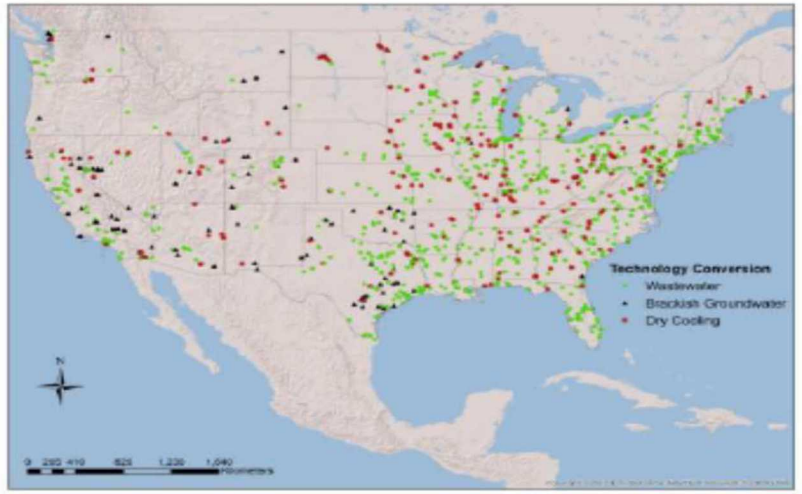
Water Availability



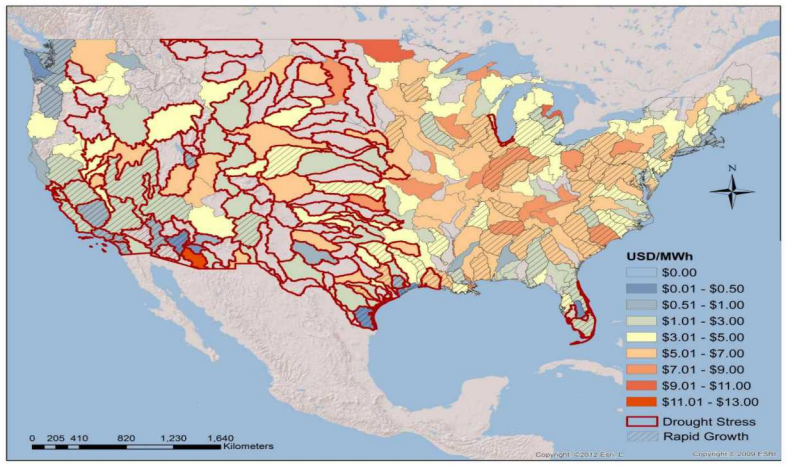
Alternative Water Source

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

1,178 Freshwater Using Thermoelectric Power Plants



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



Least cost alternative values mapped on watersheds vulnerable to drought (outlined in red)

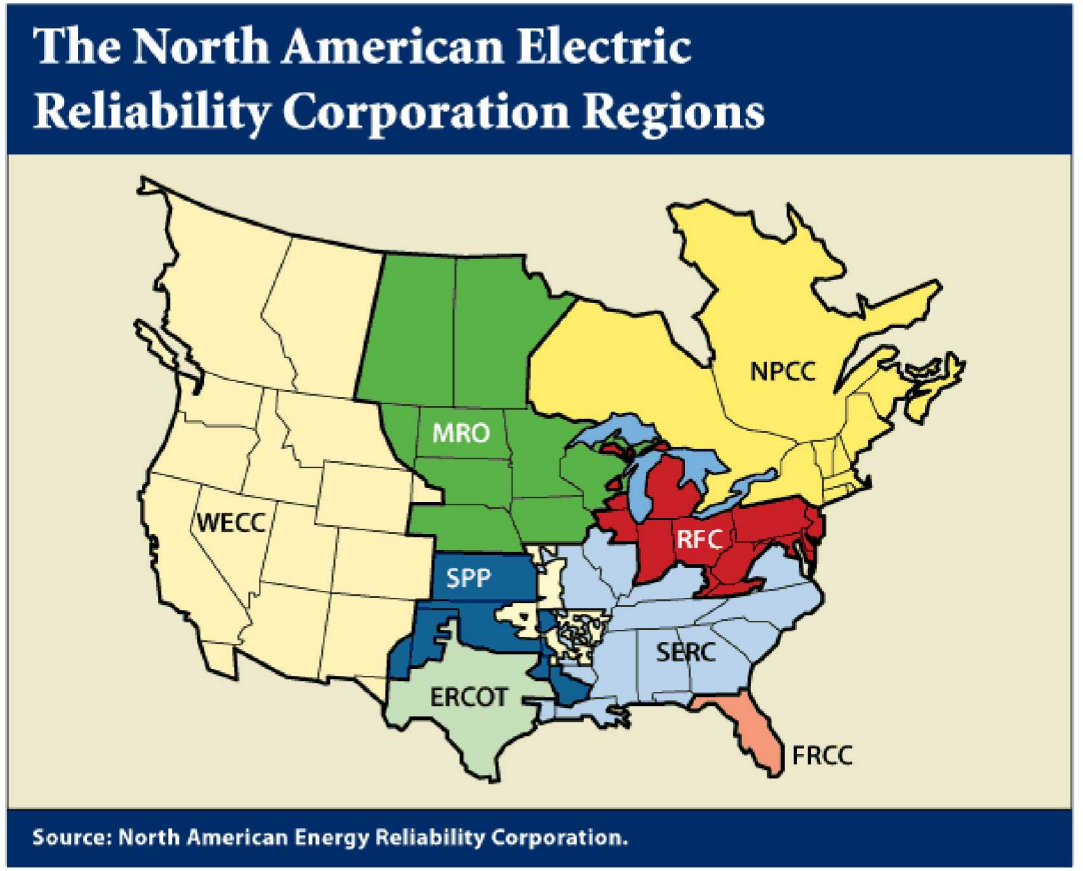
Source: Tidwell et al. 2014

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

Integrated Planning

- Integrate water related concerns into long-range transmission expansion planning (20 yrs.) of WECC:
  - Siting of new power plants
  - New transmission capacity

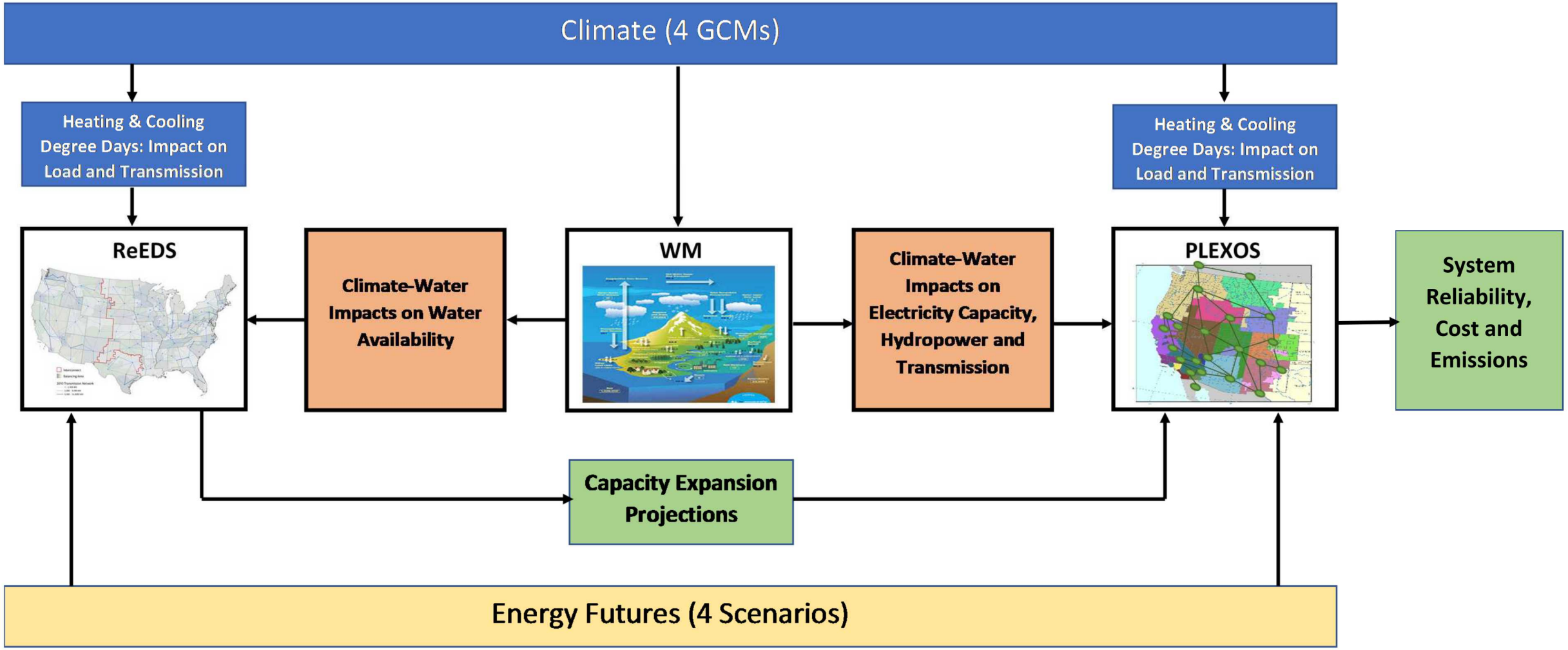


Western Governors' Association
Serving the Governors of 19 States and 3 US-Flag Pacific Islands

WECC

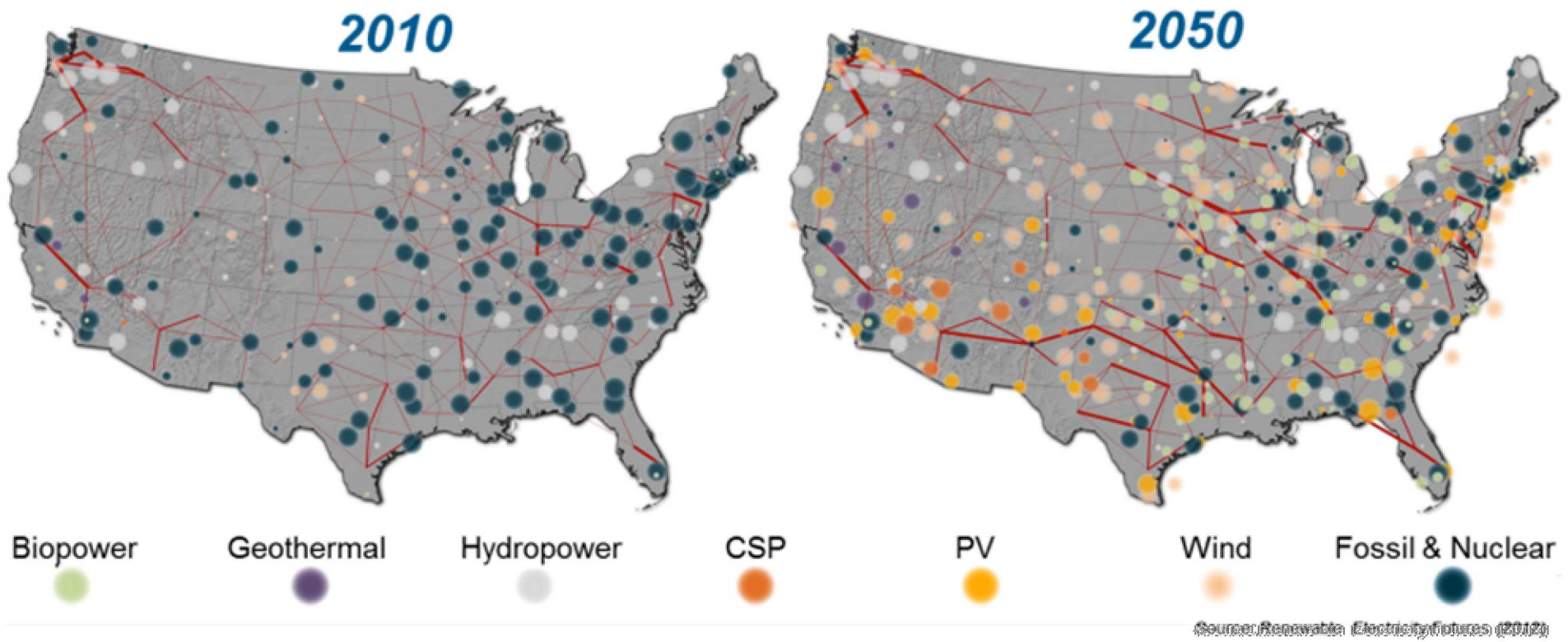
WSWC
Western States Water Council

Modeling Platform



Capacity Expansion Modeling

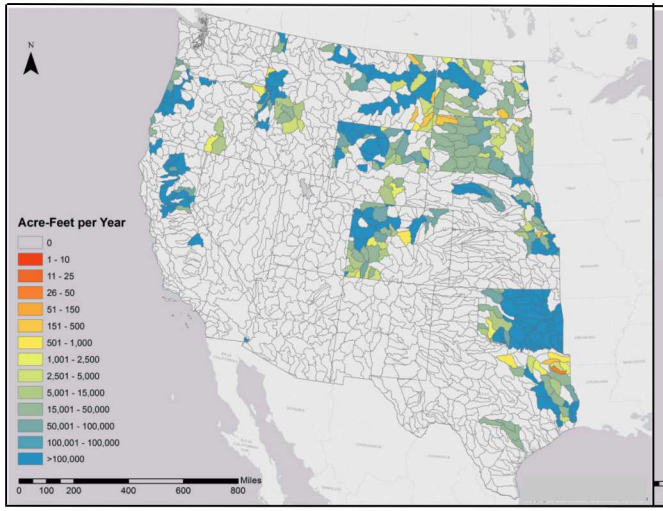
Regional Energy Deployment System (ReEDS) generates scenarios of the future U.S. power system



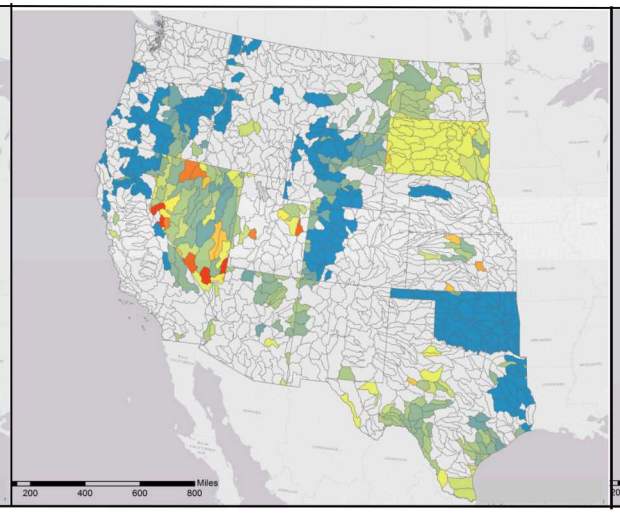
ReEDS finds the regional mix of technologies that meet requirements of the electric sector *at least cost*.

ReEDS is Constrained by Water Availability and Cost

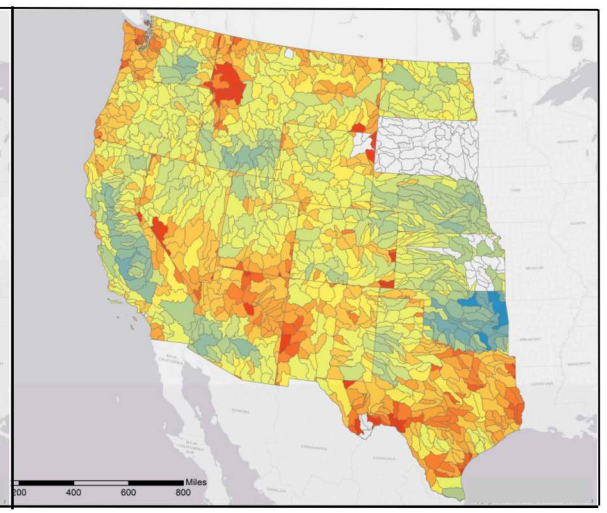
Unappropriated Surface Water



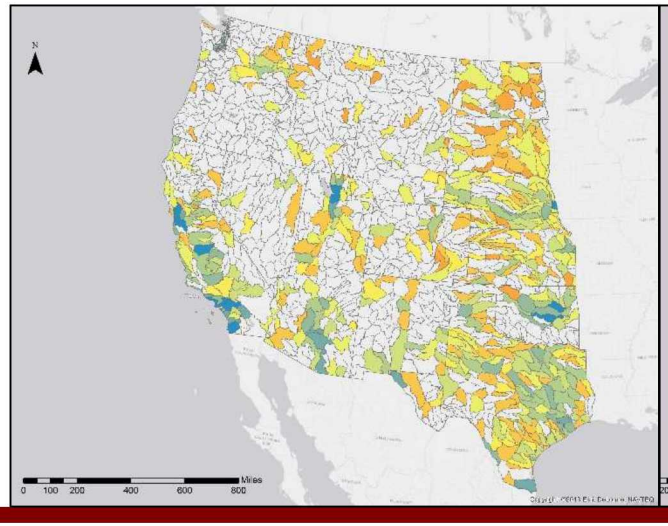
Unappropriated Groundwater



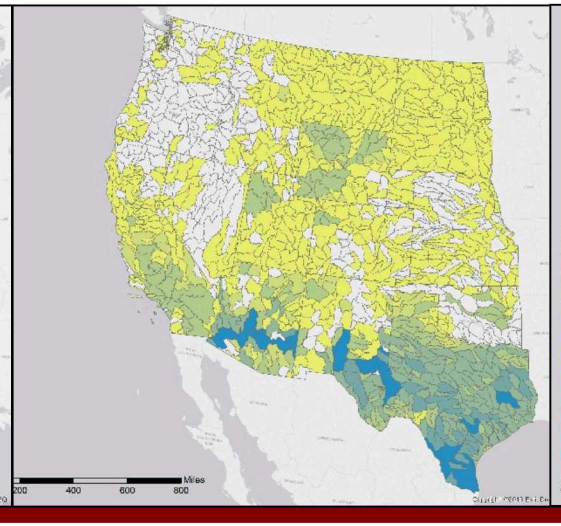
Appropriated Water



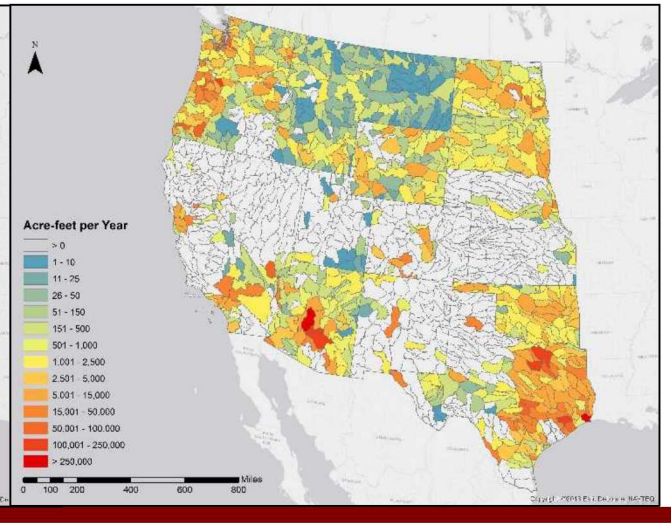
Municipal Wastewater



Brackish Groundwater



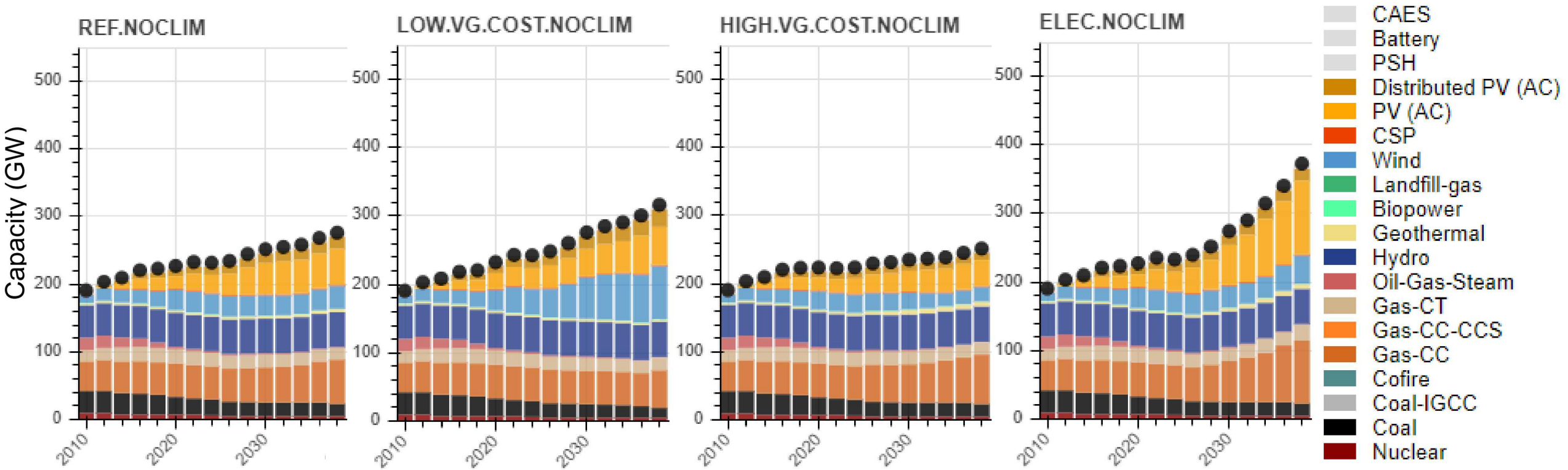
Consumptive Demand 2010-2030



- Water cost and availability forms a water supply curve in ReEDS
- Data was developed with help of state water managers
- ReEDS requires new water access purchases and restricts water withdrawals

Source: Tidwell et al. 2014

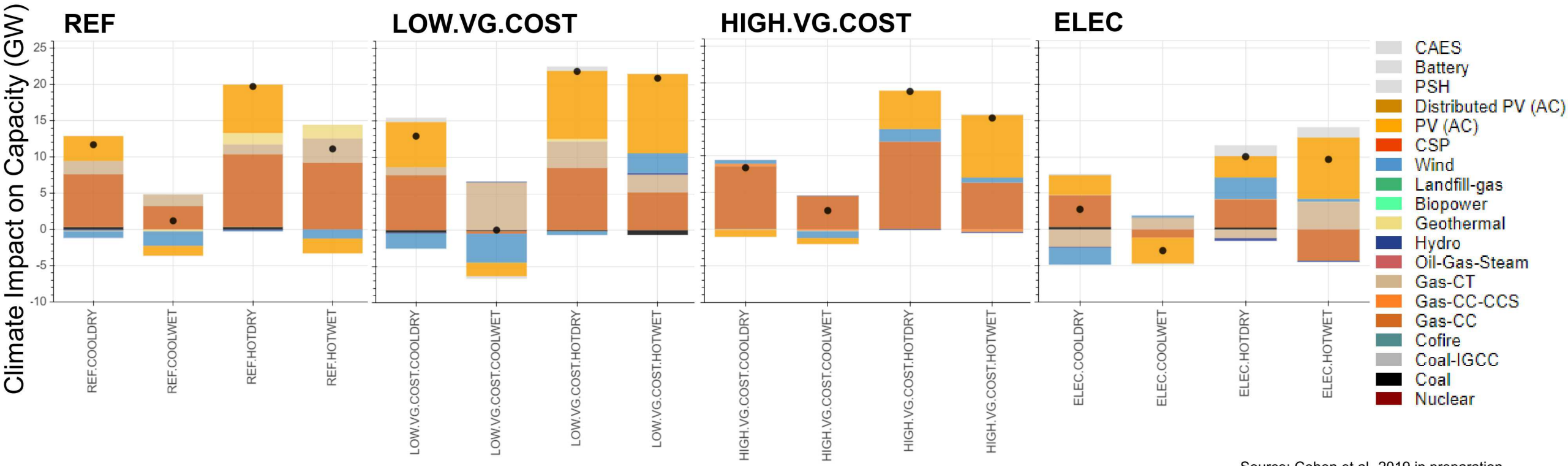
ReEDS Determines Future Expansion Trends



- Future growth is mostly PV, wind, and natural gas
- Technology growth trends depend on technology cost and demand
- Higher RE = higher capacity due to lower capacity factors

Source: Cohen et al. 2019 in preparation

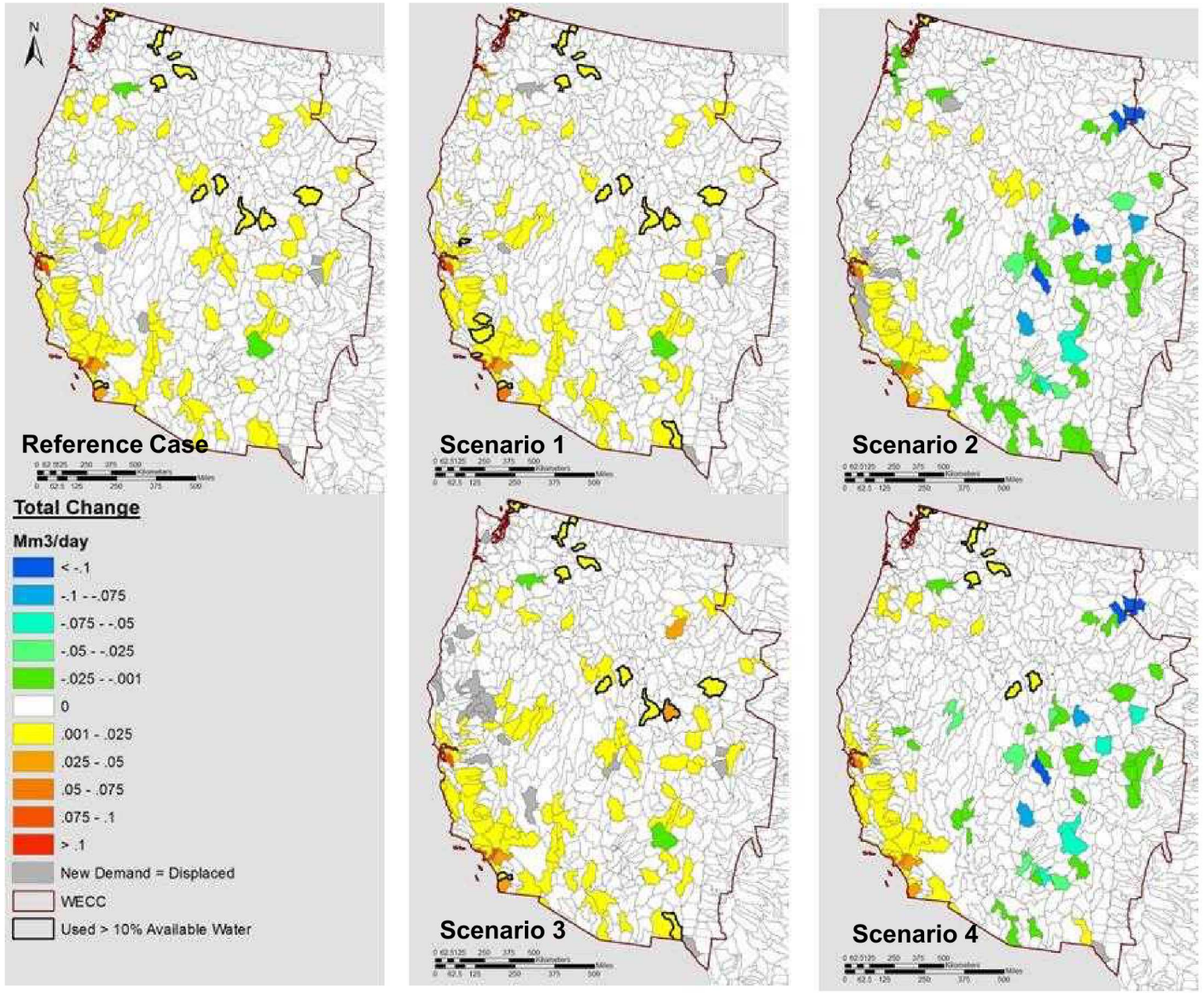
Impact of Water on Expansion Plan

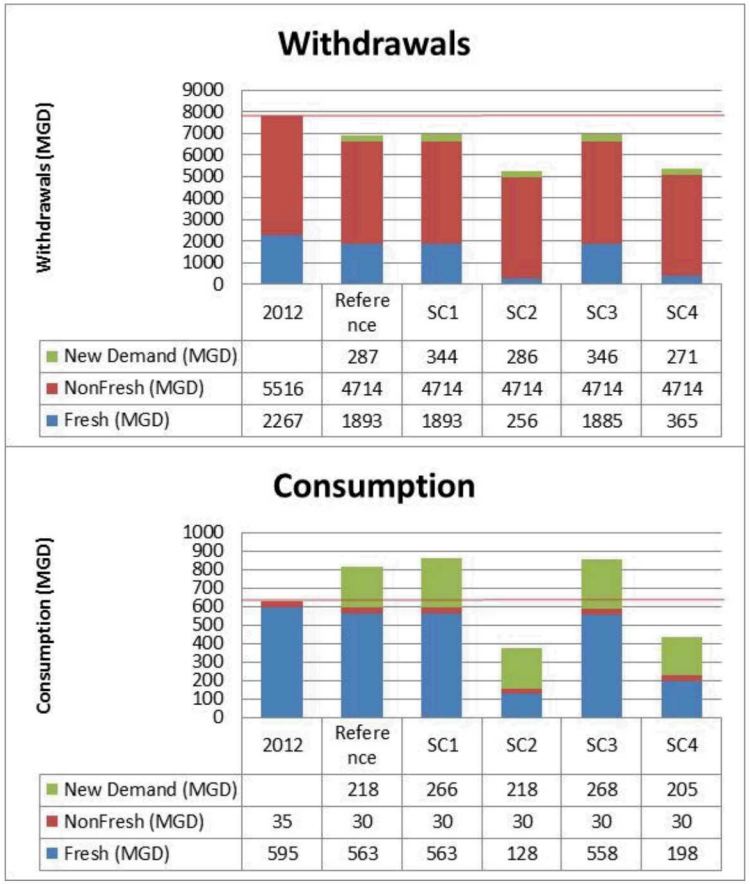


Source: Cohen et al. 2019 in preparation

- Climate change affects PV, gas, and wind deployment
- Hotter climate requires more total capacity
- Wetter climate can reduce capacity needs with additional hydropower generation
- Electrification reduces capacity needs through flexible demand

Managed Growth





	2012	Reference	SC1	SC2	SC3	SC4
New Demand (MGD)		287	344	286	346	271
NonFresh (MGD)	5516	4714	4714	4714	4714	4714
Fresh (MGD)	2267	1893	1893	256	1885	365

	2012	Reference	SC1	SC2	SC3	SC4
New Demand (MGD)		218	266	218	268	205
NonFresh (MGD)	35	30	30	30	30	30
Fresh (MGD)	595	563	563	128	558	198

Different scenarios result in differing impacts on water resources.

Source: Tidwell et al. 2014

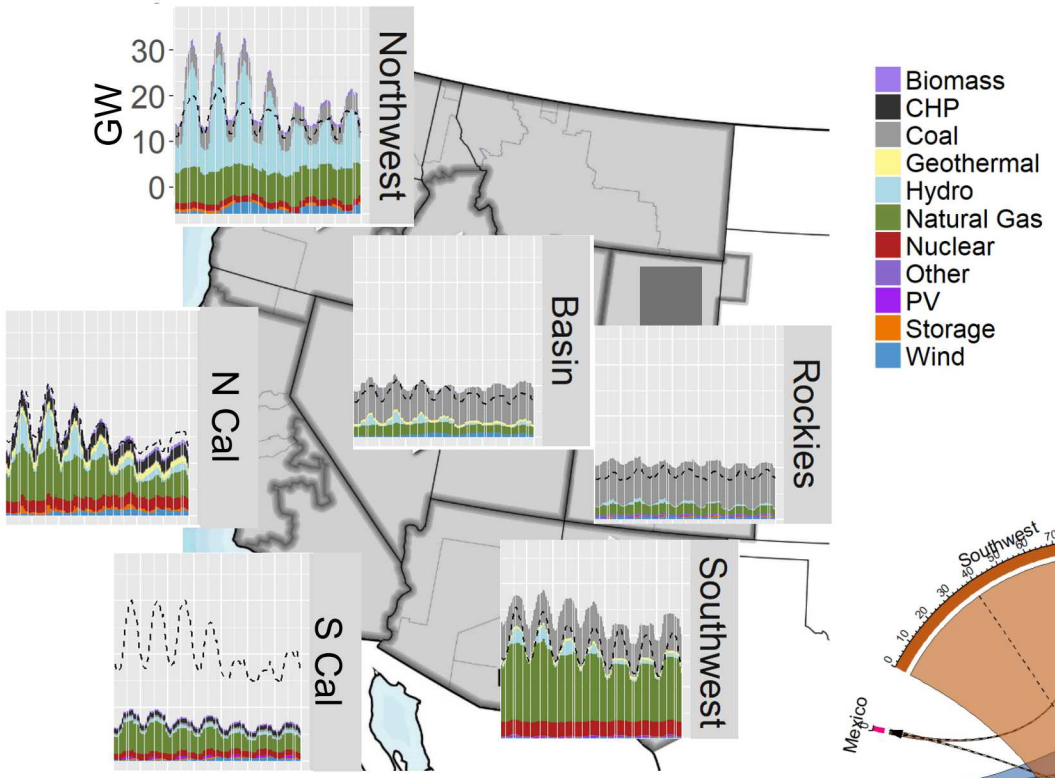
Need for Alternative Water

Scenario	Surface Water (%)	Groundwater (%)	Appropriated Water (%)	Wastewater (%)	Brackish Ground Water (%)
Reference Case	11	6	12	37	34
Scenario 1	16	6	10	35	33
Scenario 2	1	5	4	51	39
Scenario 3	16	7	12	31	34
Scenario 4	2	2	5	52	39

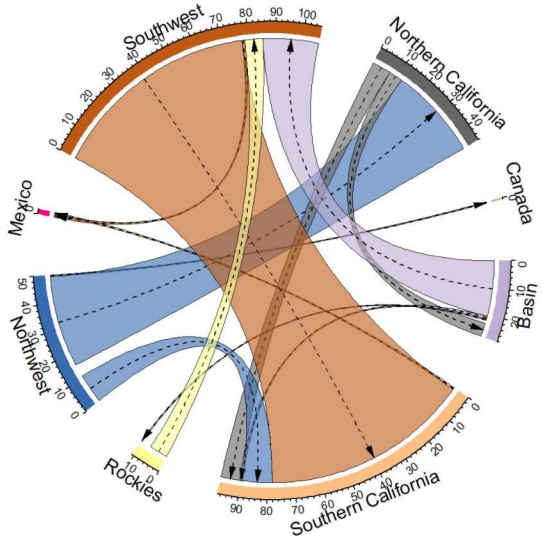
Over 80% of new water supply for transmission expansion will need to come from non-potable waters, regardless of scenario

Production Cost Modeling

- Simulation of a specific electric infrastructure
- Optimized operation for system-wide production cost
  - Mixed integer program
- Chronological simulation accounting for:
  - Load, wind, and solar availability
  - Simulated outages
  - Generator-level constraints (ramp rates, etc.)
  - Reserve requirements
  - Transmission constraints
- Relevant outputs:
  - Total production cost
  - Dispatch information
  - Reliability metrics: unserved energy, reserve shortages
  - Transmission congestion
  - Emissions



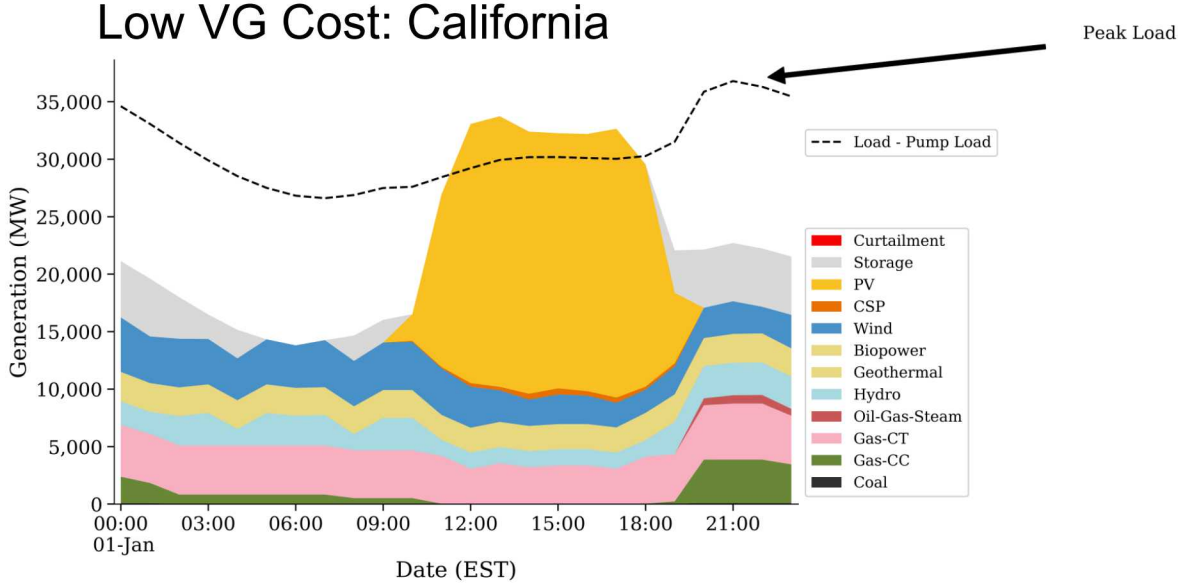
Example August week, dry ~2010 infrastructure



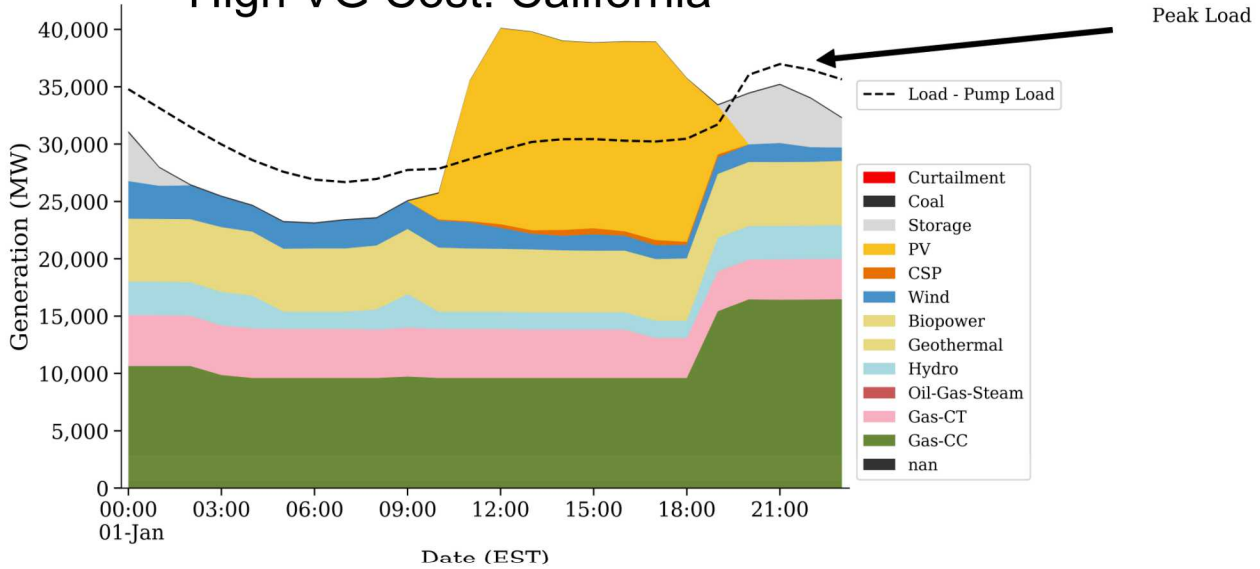
Example regional flows

Production Cost Modeling

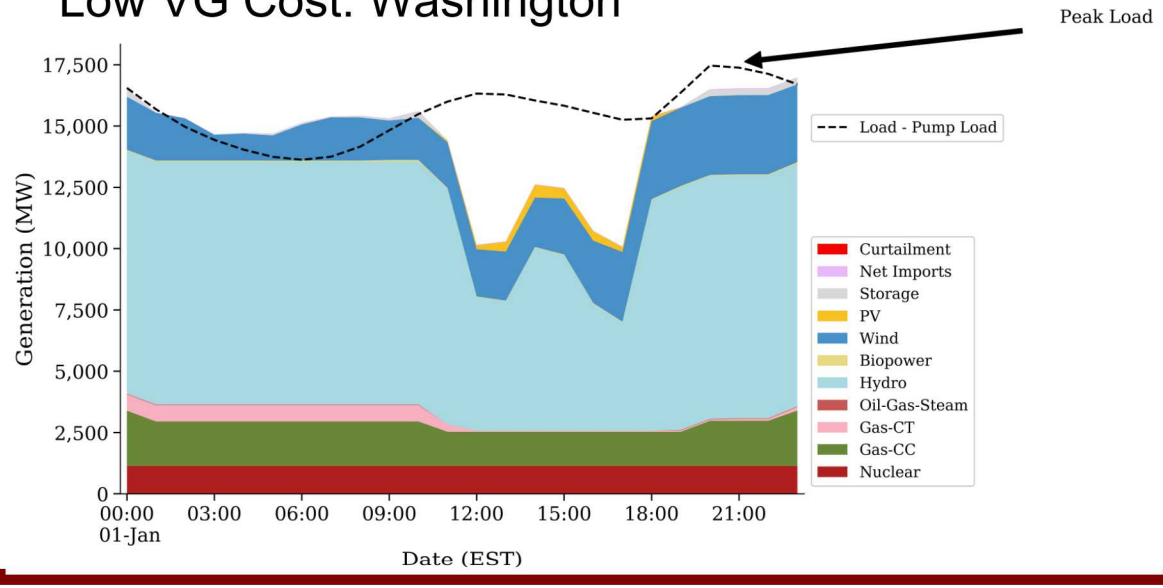
Low VG Cost: California



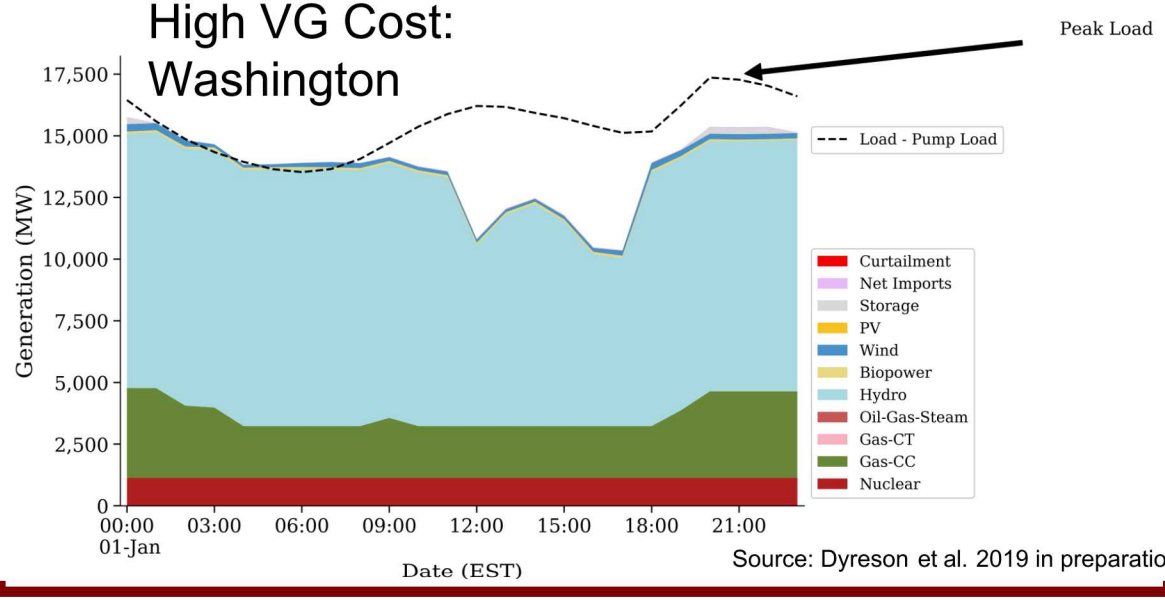
High VG Cost: California



Low VG Cost: Washington



High VG Cost: Washington



Source: Dyreson et al. 2019 in preparation

Energy for Water

Energy for Water Today

Irrigation Pumping

Source: Wisconsin Department of Natural Resources 2014

Water Sector Consumes 4-8% of Total U.S. Energy Consumption

Large Scale Conveyance

Source: Circle of Blue 2015

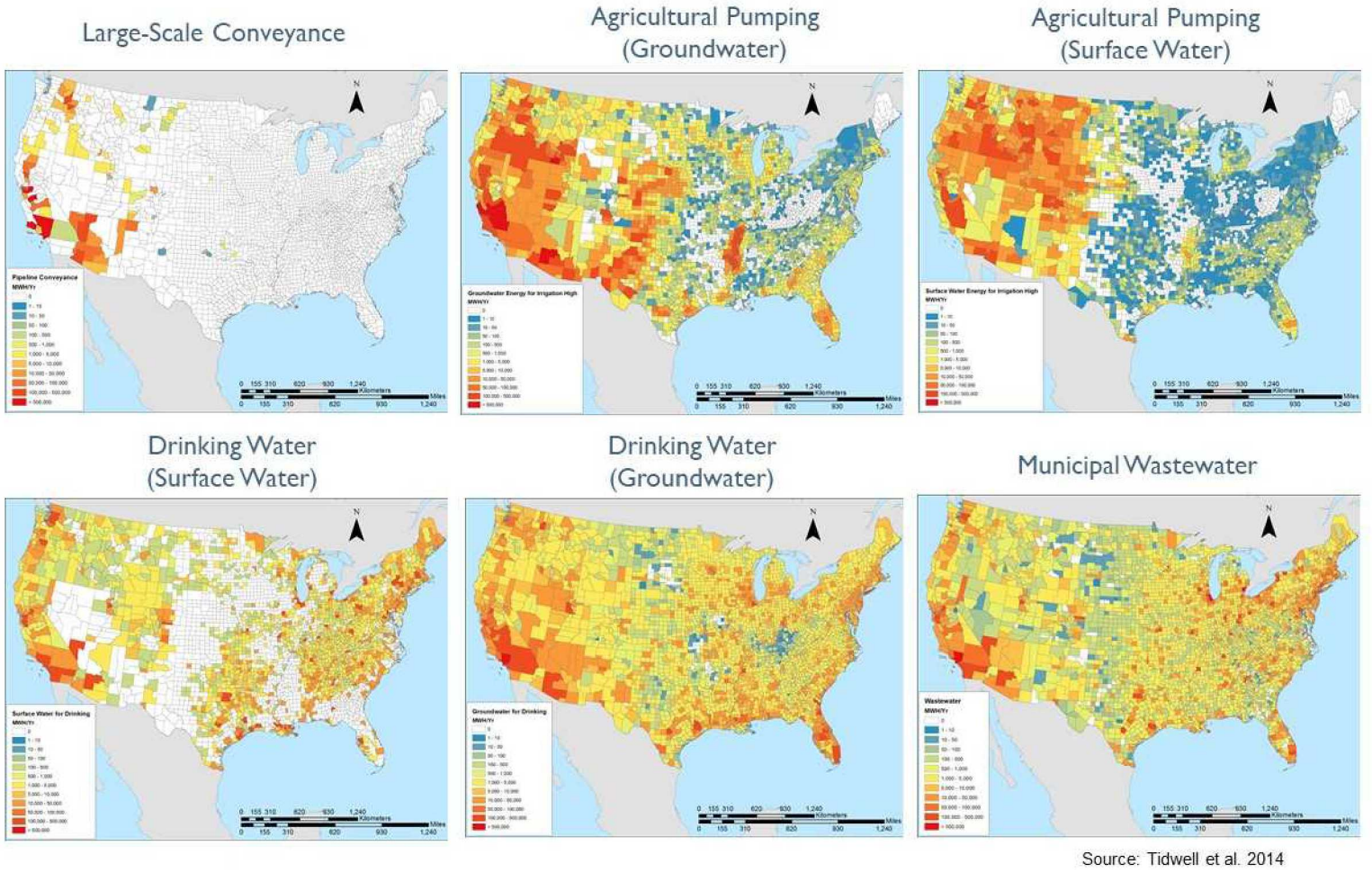
Waste Water Collection and Treatment

Drinking Water Treatment and Distribution

Source: Green Prophet 2014

Varies by Sector and Location

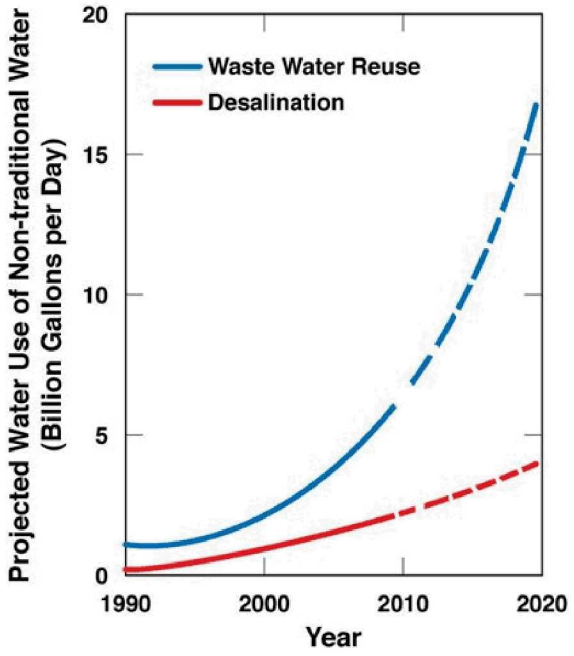
- Map electricity use for water services at the county level, distinguishing between four sectors:
  - Large-scale conveyance,
  - Irrigation,
  - Drinking water, and
  - Wastewater.

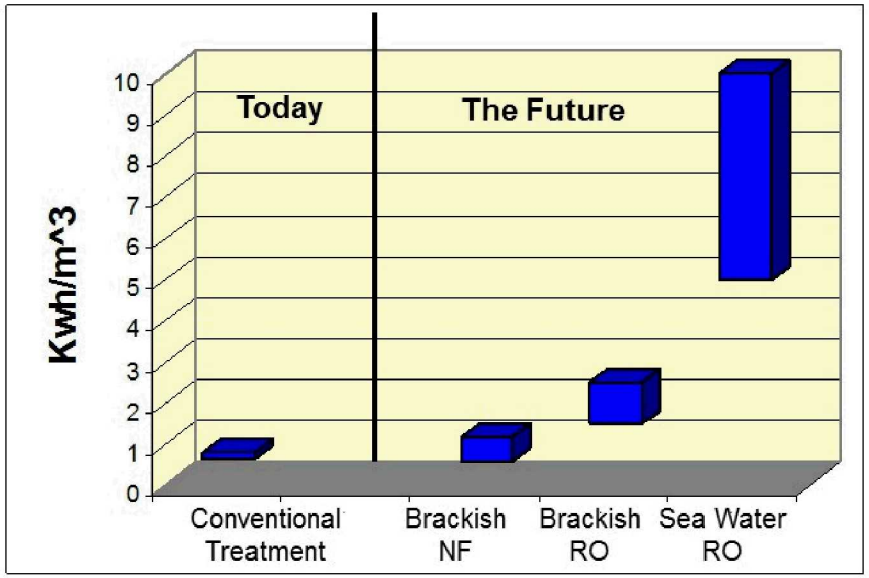


Source: Tidwell et al. 2014

Intensifying Nexus

Power Requirements For Treatment

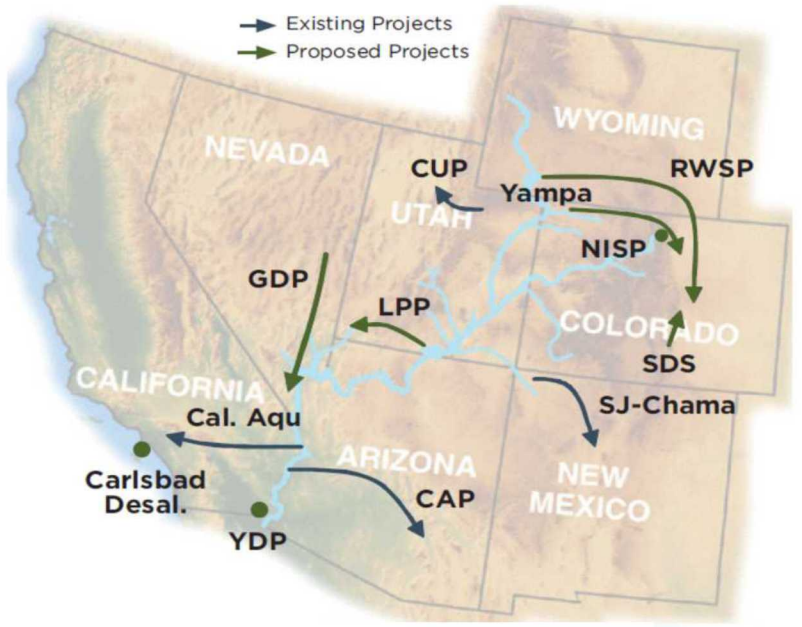




Modified from Water Reuse 2007, EPA 2004, Mickley 2003

Source: Einfeld 2007

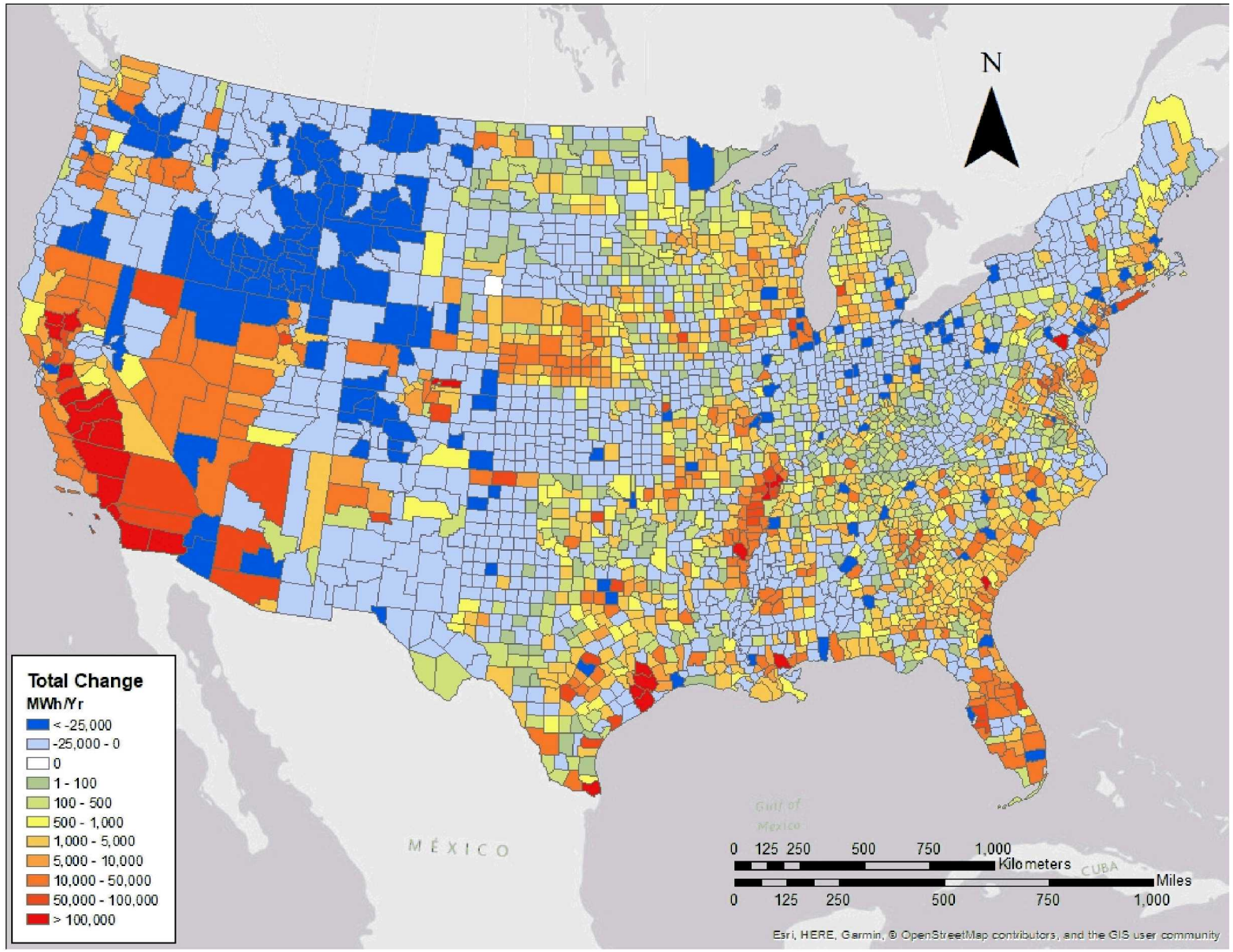
Existing and Proposed Western Water Supply Projects



Source: Western Resource Advocates 2010

Source: detoxifynow.com

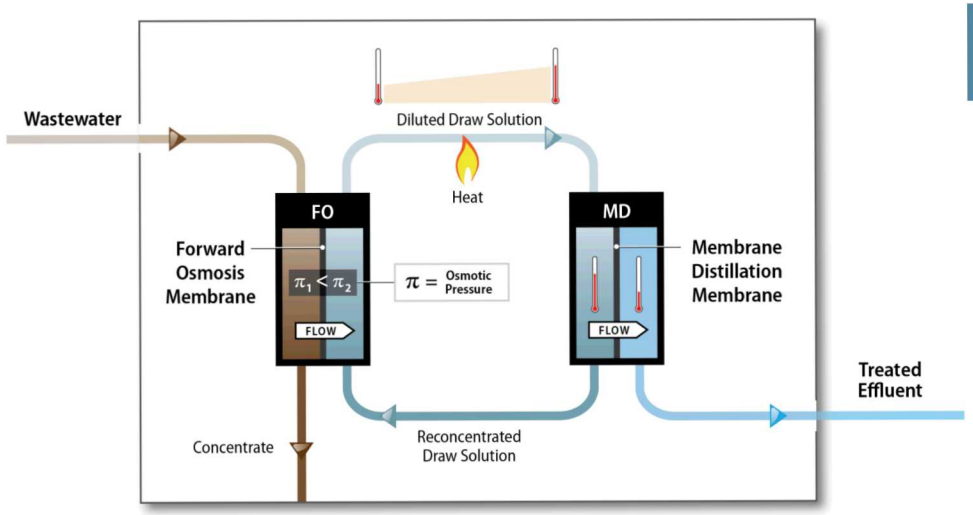
Changing Landscape



- Projected change in electricity use ranges from 1% to 18%.
- Significant changes in electricity use could occur within sectors.
- Largest increases likely in CA, TX, AR and FL.

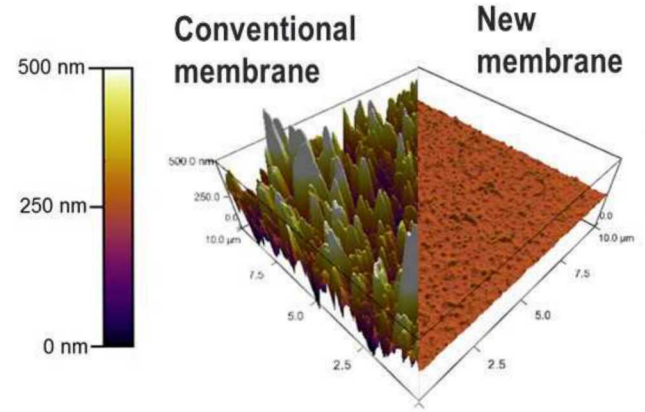
Advanced Treatment Technologies

Provide a public-private partnership framework for the development, testing and scaling of innovative water treatment technologies

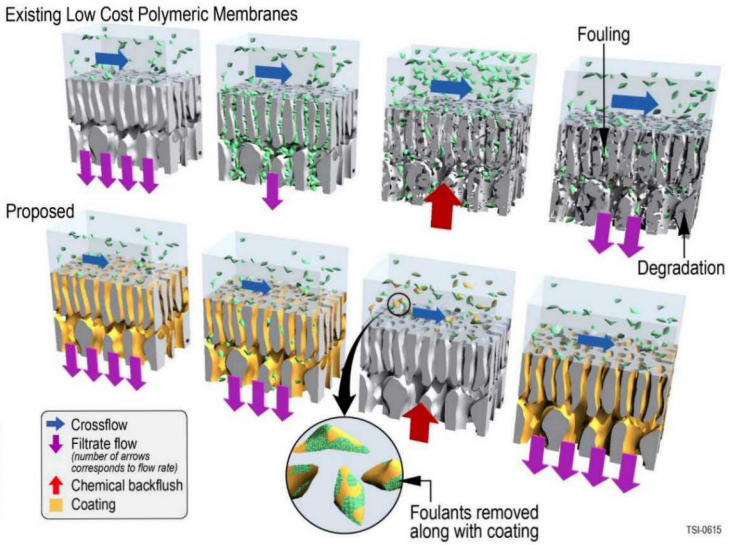


Hybrid Membrane System for Industrial Water Reuse

Novel membranes and Systems



Sacrificial Protective Coating Materials



Key Points

1. Energy-Water-Climate issues are affecting energy production today.

2. Without attention these issues will intensify.

3. Changes in the energy sector are affecting climate vulnerabilities.

4. Options are available to adapt to a changing and uncertain future.

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