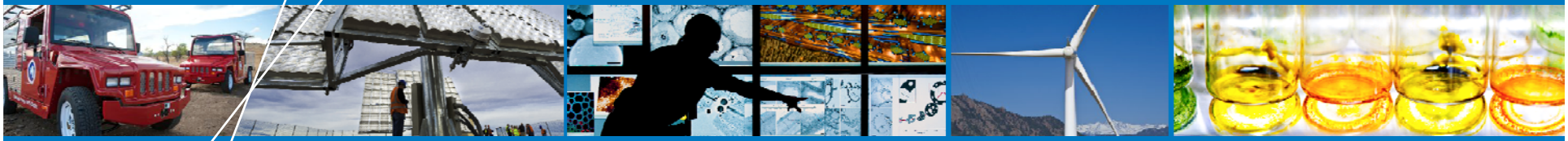
Framing the Energy-Water Nexus: a US perspective



National Academies Board on Energy & Environmental Systems
Energy-Water Nexus Forum

Robin L. Newmark

April 3, 2013

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Energy and Water are linked:

Energy for water and water for energy

Energy production requires water

- Thermoelectric cooling
- Hydropower
- Extraction and mining
- Fuel Production
- Emission controls

Water production and distribution require energy

- Pumping
- Treatment
- Transport (End use)

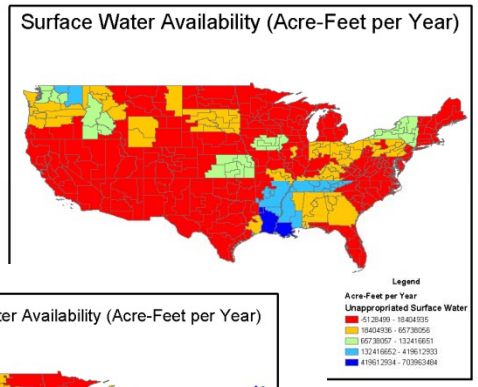
What are the different sources of water in the US and how much is there of each? How much water do different end use sectors use, and of what kinds? How and how much water is used to produce different kinds of energy? How much energy is used to move water, and for what purposes? How do droughts and extreme weather events affect these patterns?
How do we expect climate change to affect these patterns? How much real data exist and where are there holes or obsolescence in the data?

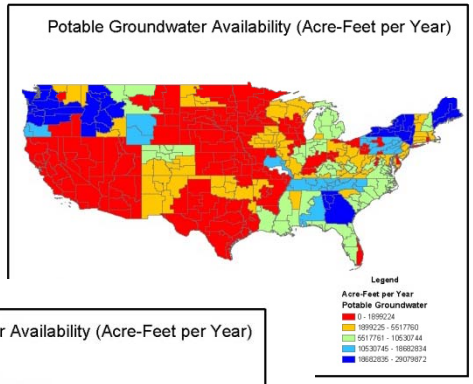
A seemingly simple question

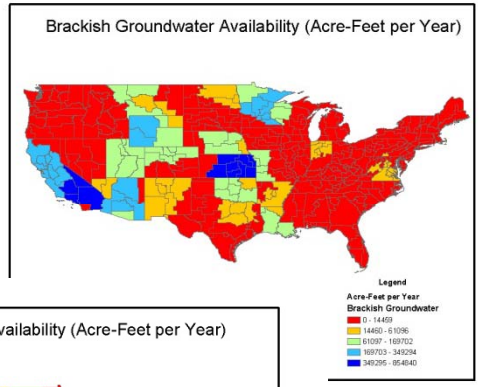
How much water is there, of what type?

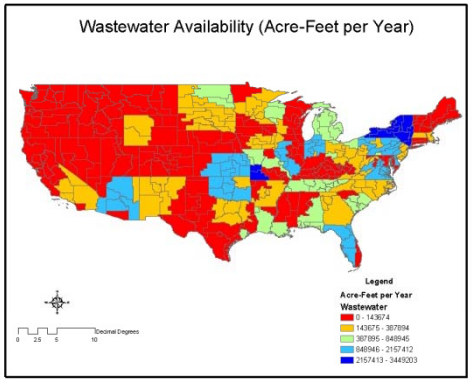
New: a concerted effort to gather consistent data regarding availability and costs for multiple water sources

Unappropriated surface water	Total unappropriated surface water
Appropriated surface water	Appropriated surface water
Potable groundwater	Potable groundwater use - calculated using state-specific pumping data
Brackish groundwater	Brackish groundwater in MGD; calculated using combination of state inventories, USGS reported use and presence of brackish wells
Wastewater	Net wastewater effluent available; plants discharging to reuse or those discharging to a perennial stream (in western states only) are excluded.
Appropriated surface water cost	Cost per AF - based on UCSB Water Strategist data at state level
Potable groundwater cost	Cost per AF - well field and pumping costs only
Brackish groundwater cost	Cost per AF - includes extraction, treatment, disposal and associated capital costs
Wastewater treatment cost	Cost per AF - includes transportation, treatment, and lease/purchase of water from utility







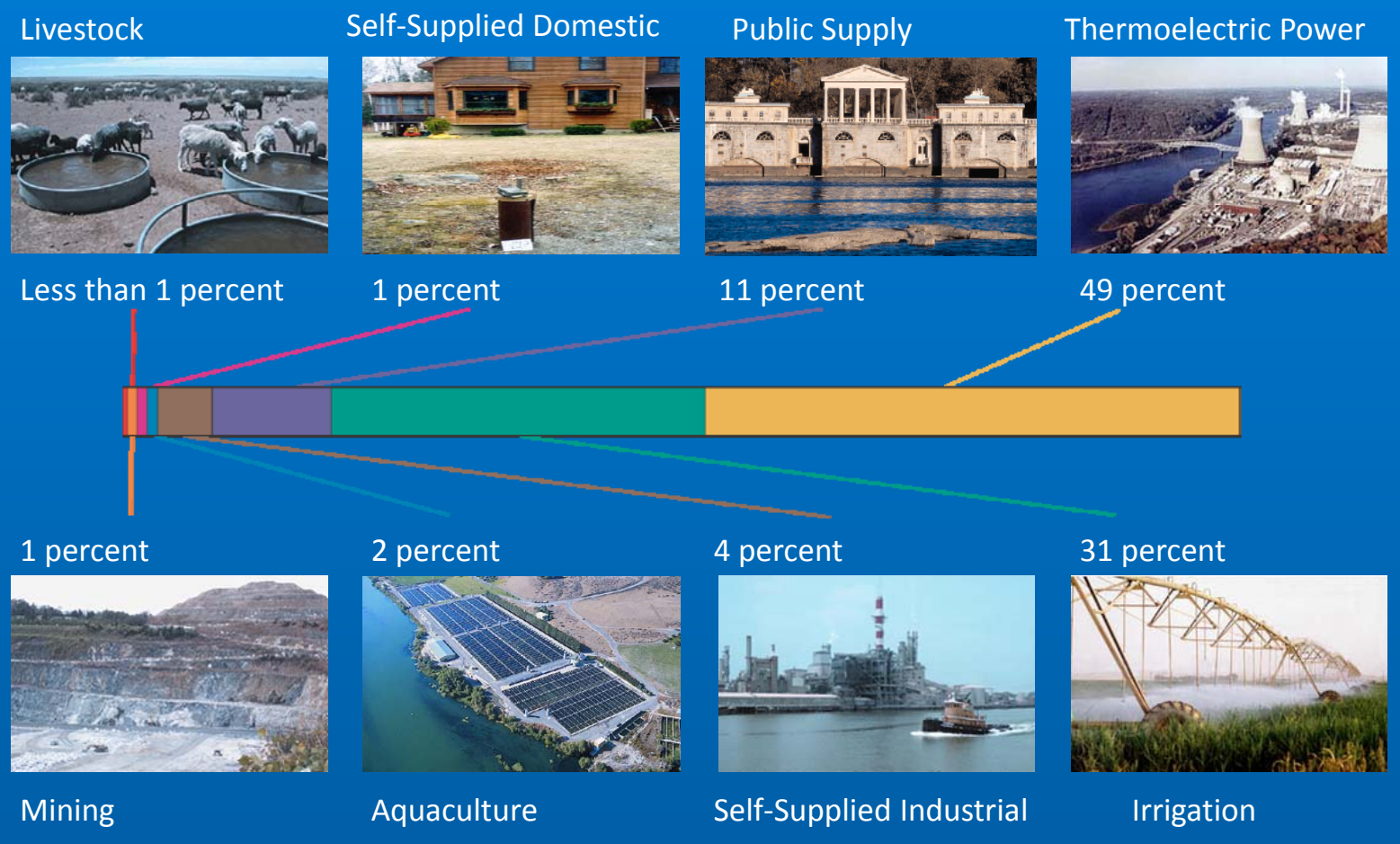


Western US will be available at the Western States Water Council's WaDE site

Source: Tidwell et al (forthcoming)

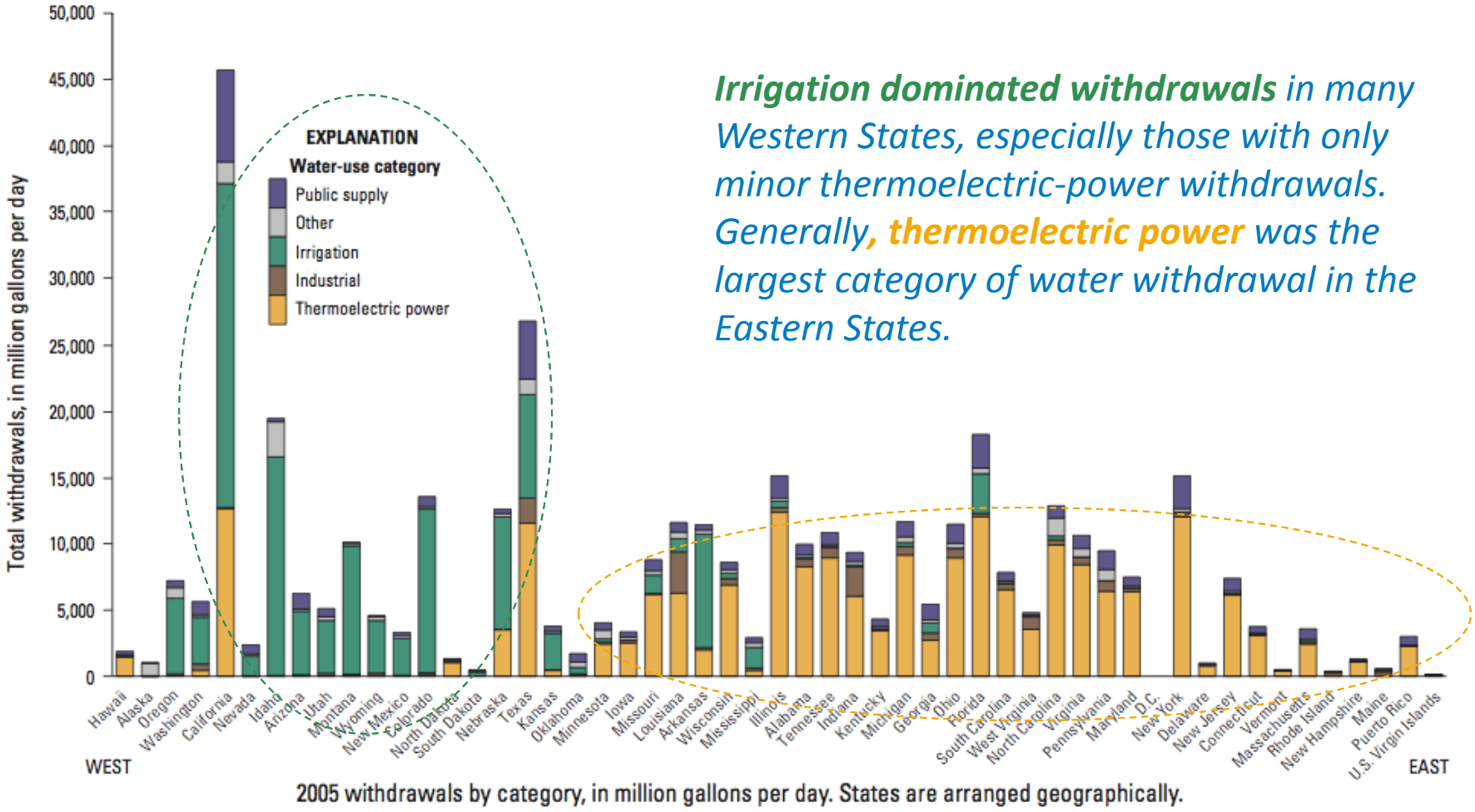
U.S. water withdrawals by category: 2005

Surface water 328,000 Mgal/d (80%), 82% freshwater
Groundwater: 82,600 Mgal/d (20%), 96% freshwater
Total: 410,000 Mgal/d



Source: Kenny et al., *Estimated Use of Water in the United States in 2005: U.S. Geological Survey Circular 1344, 2009*

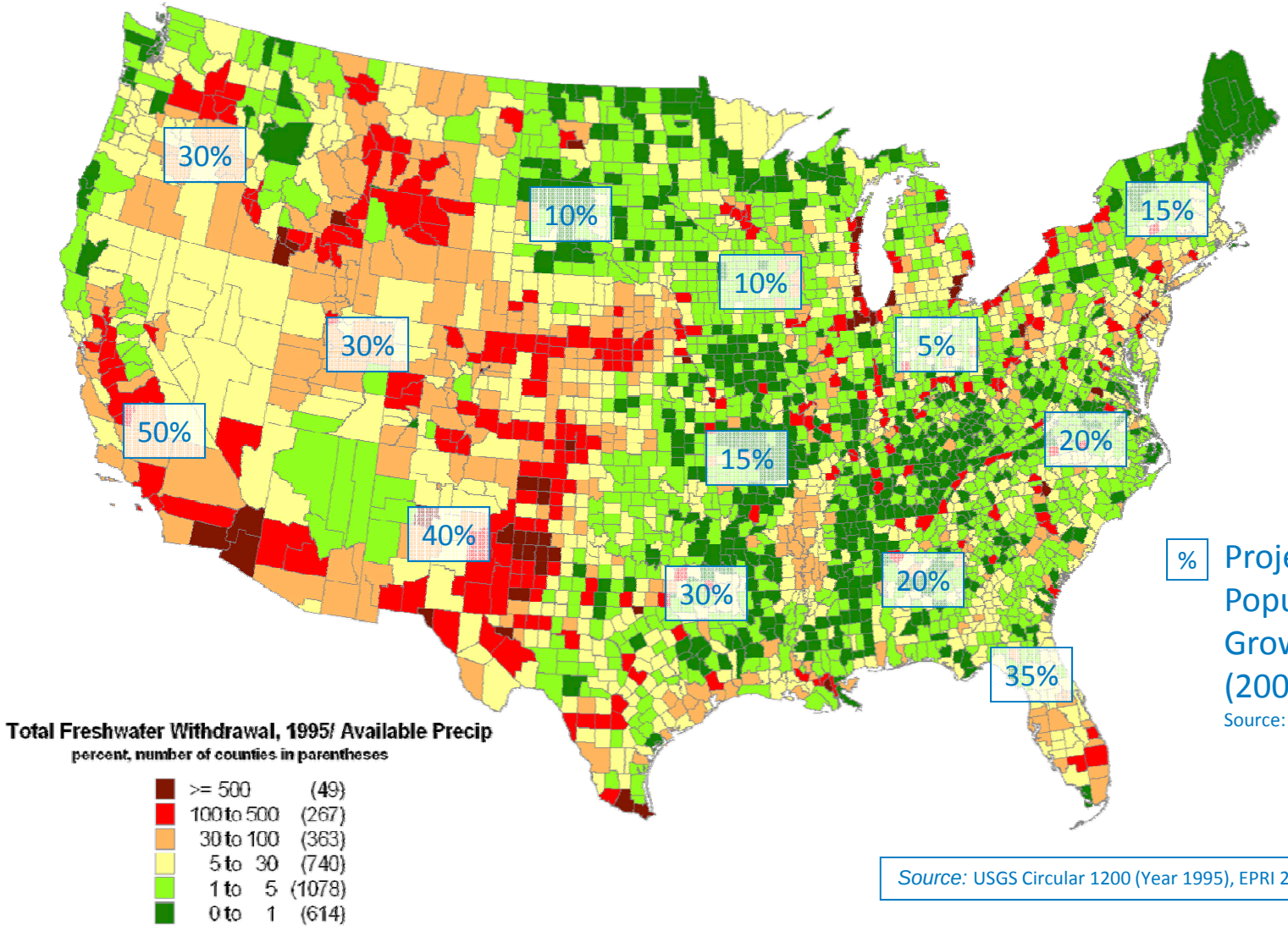
US water withdrawals by category and State: 2005



Irrigation dominated withdrawals *in many Western States, especially those with only minor thermoelectric-power withdrawals. Generally,* ***thermoelectric power*** *was the largest category of water withdrawal in the Eastern States.*

Source: Kenny et al., *Estimated Use of Water in the United States in 2005: U.S. Geological Survey Circular 1344, 2009*

Water challenges are nationwide

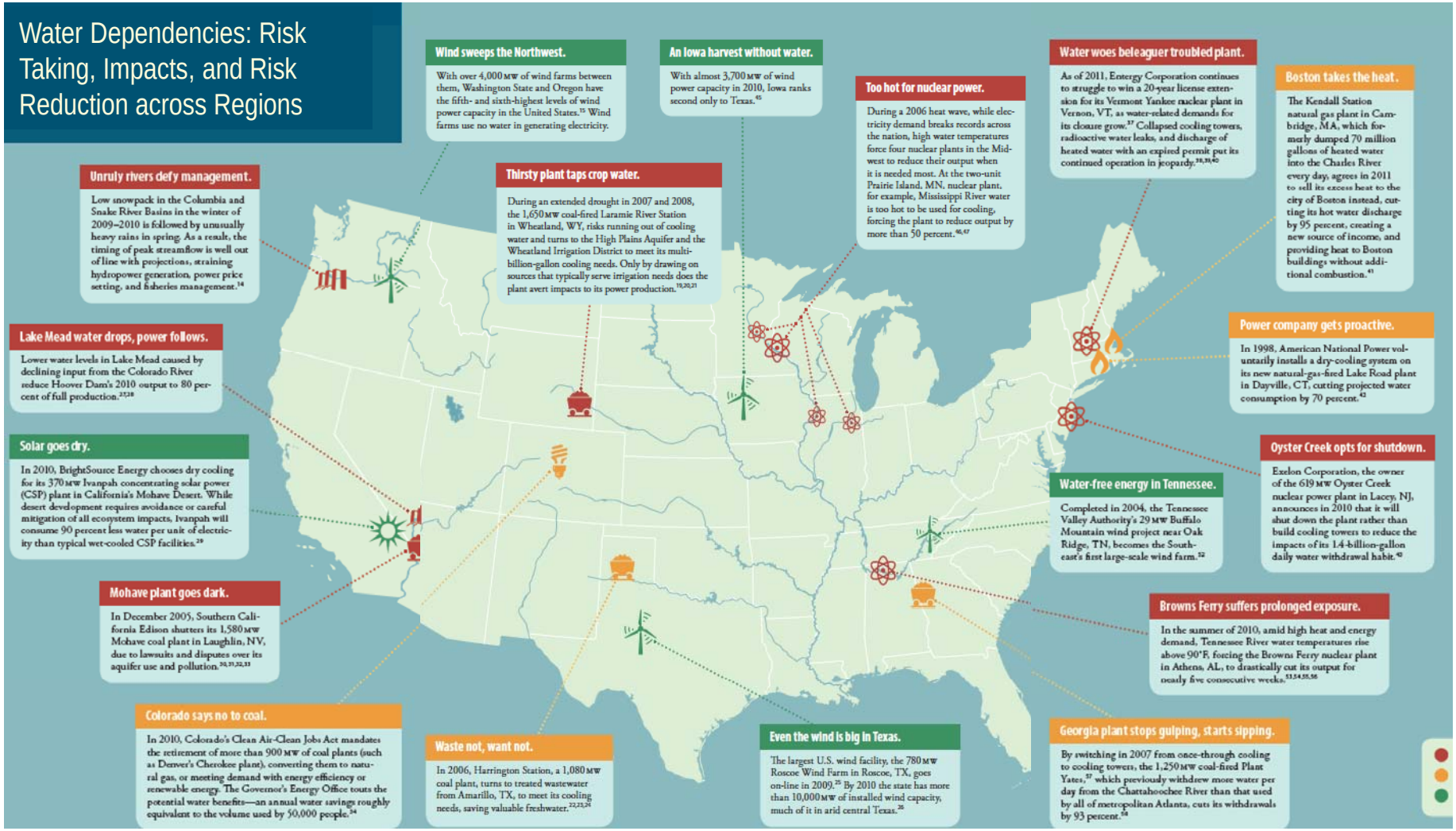


% Projected Population Growth (2000-2020)

Source: NETL (2002)

Source: USGS Circular 1200 (Year 1995), EPRI 2003

Multiple examples of current or emerging impacts at the energy-water nexus



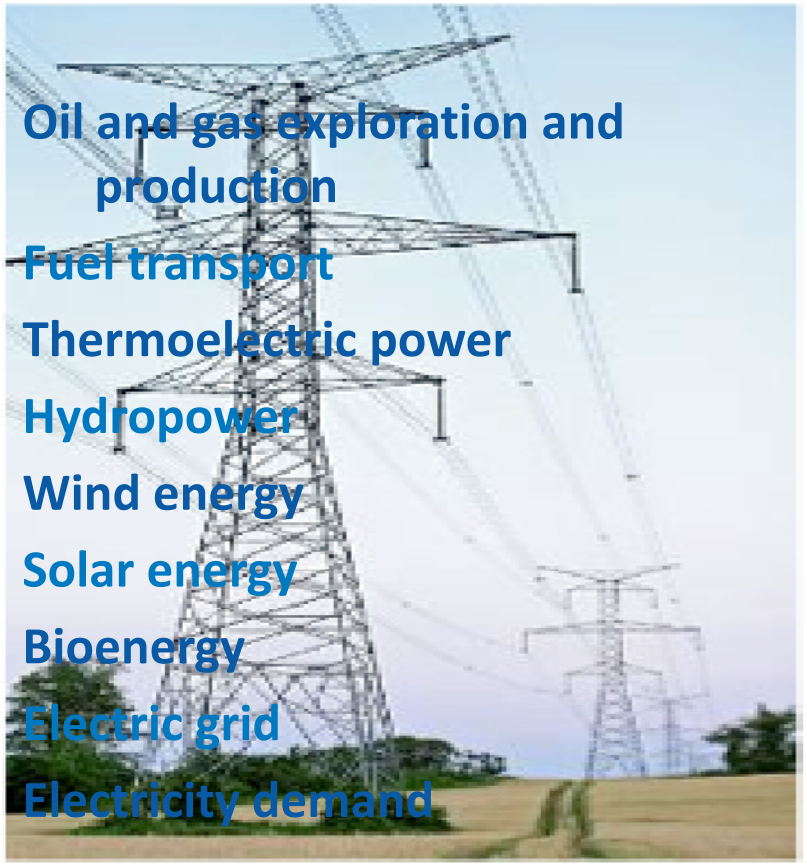
Source: **Power and Water At Risk:** The Energy-Water Collision, UCS, 2012

See also Averyt et al., 2011, Freshwater Use by U.S. Power Plants, Electricity's Thirst for a Precious Resource

A new DOE effort focuses on the implications of climate change projections on specific elements of the energy system

Most impacts reside at the energy-water nexus

Energy Sector Impacts



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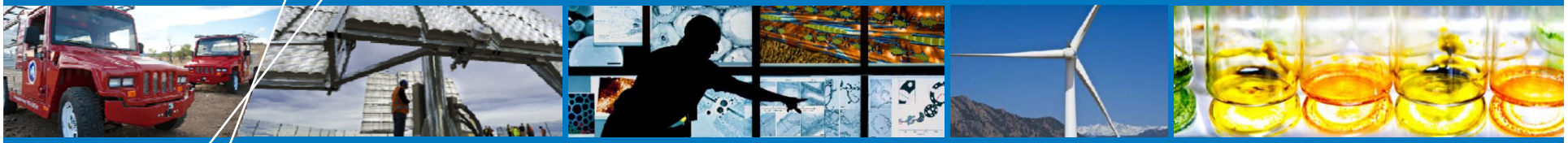
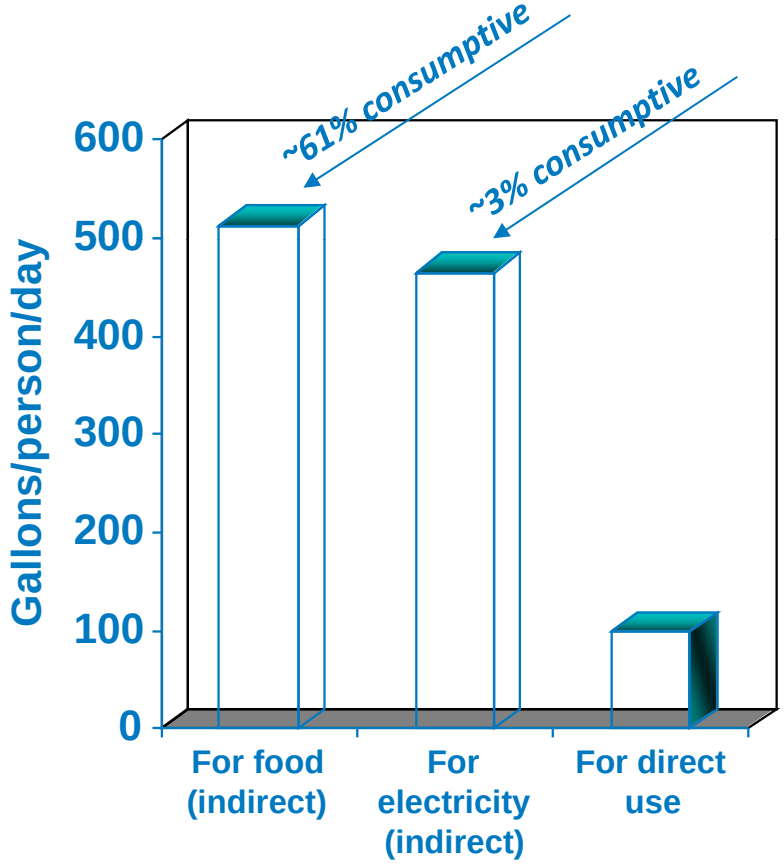


Water for Energy

Water for Energy

Water needed to produce household electricity exceeds direct household water use



GALLONS PER PERSON PER DAY

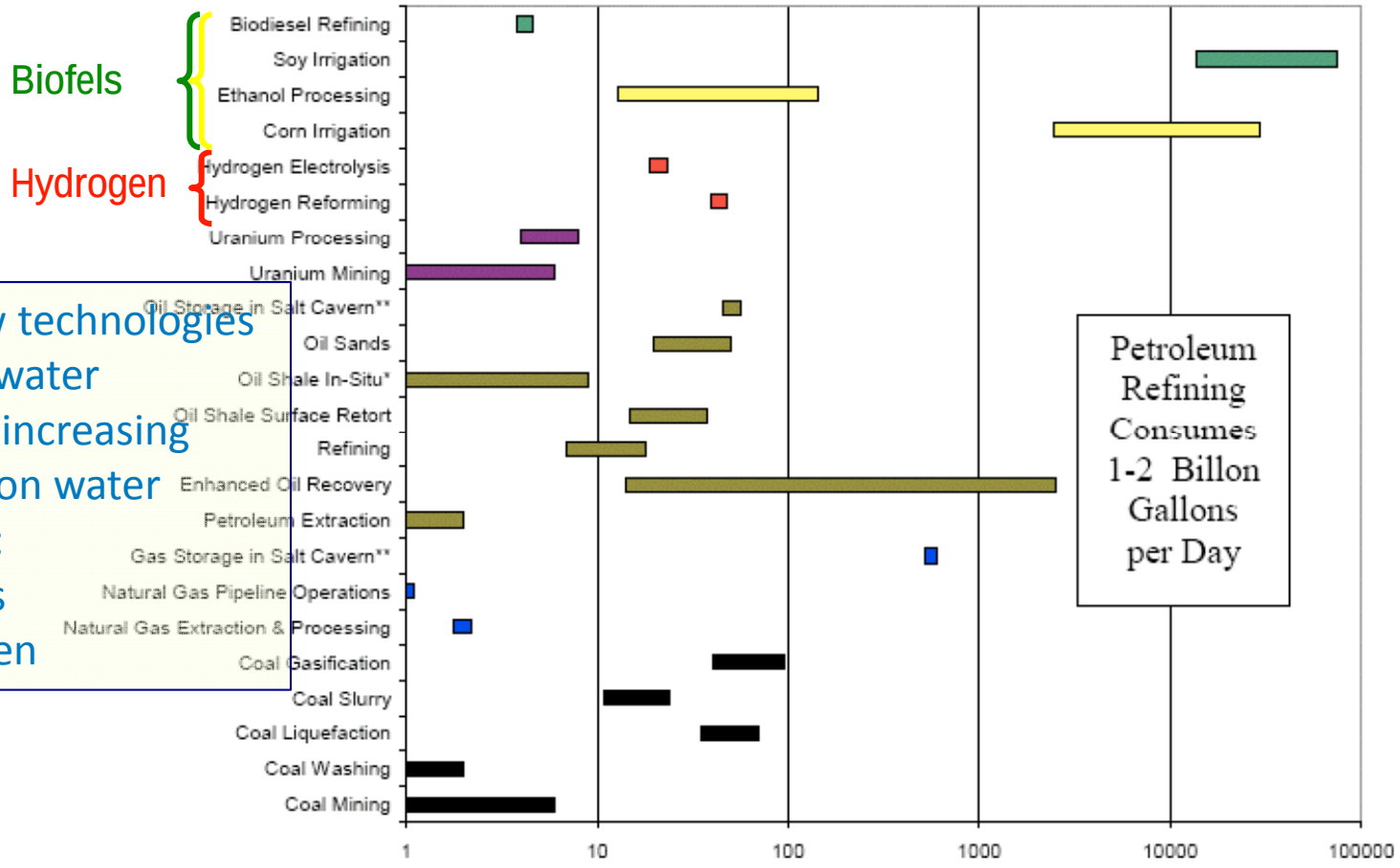
- **510 for food production**
  - includes irrigation and livestock
- **465 to produce household electricity**
  - Range: 30 to 600 depending on technology
- **100 direct household use**
  - includes bathing, laundry, lawn watering, etc.

Source: derived from Gleick, P. (2002), *World's Water 2002-2003*.

Substantial amounts of water are used in fuel extraction/processing

Future energy development will put new demands on water resources

Water Used for Fuel Extraction and Processing

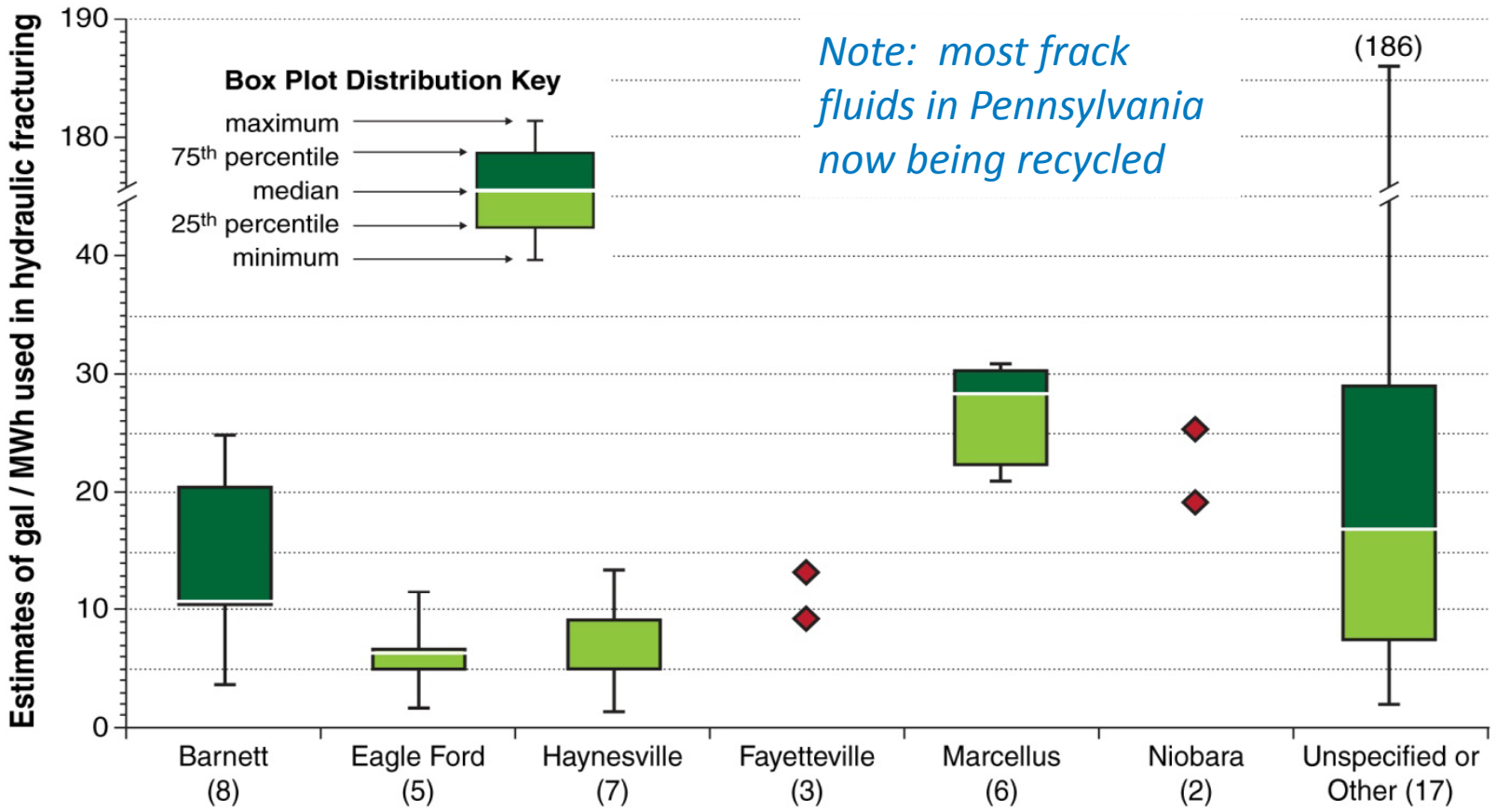


Many new technologies are more water intensive, increasing demands on water resources:
- Biofuels
- Hydrogen

Source: DOE Report to Congress (2007)

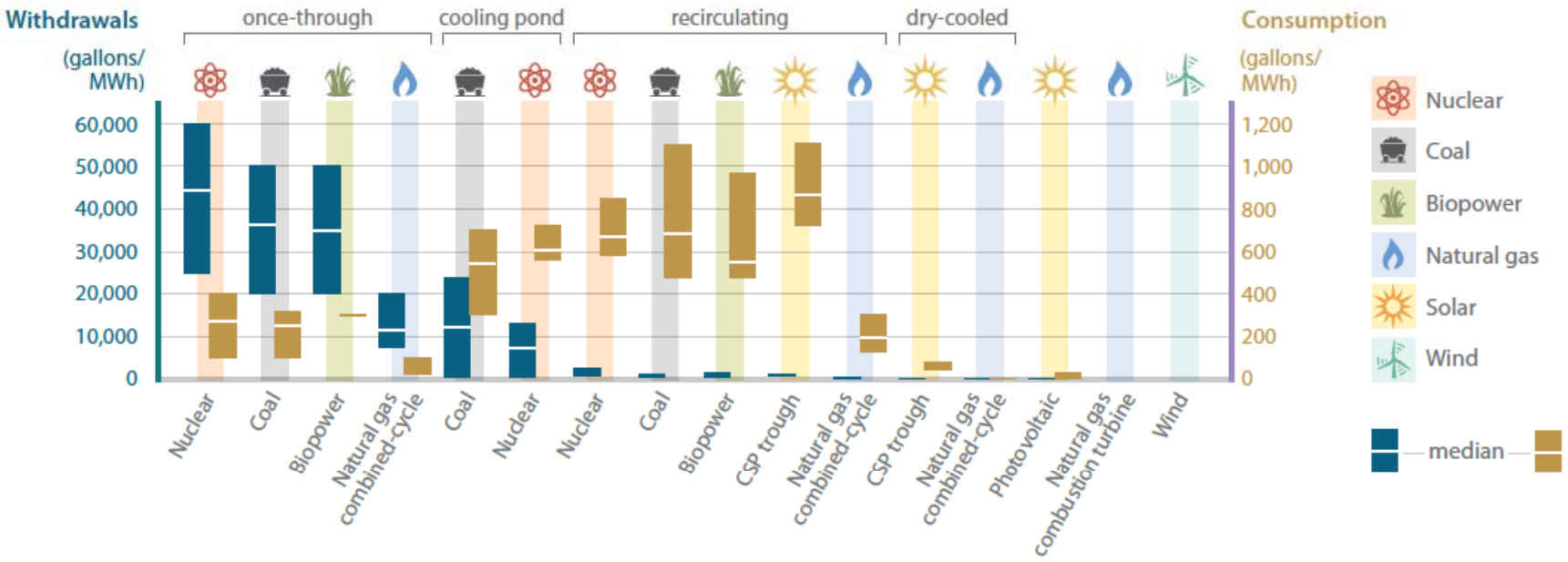
Substantial amounts of water are used in fuel extraction/processing

Detailed estimates of hydraulic fracturing for specific plays reveal a wide range of water intensities



Source: Meldrum , J., Nettles-Anderson, S., Heath, G., and J. Macknick. Life Cycle Water Use for Electricity Generation: A Review and Harmonization of Literature Estimates." (*2013)*

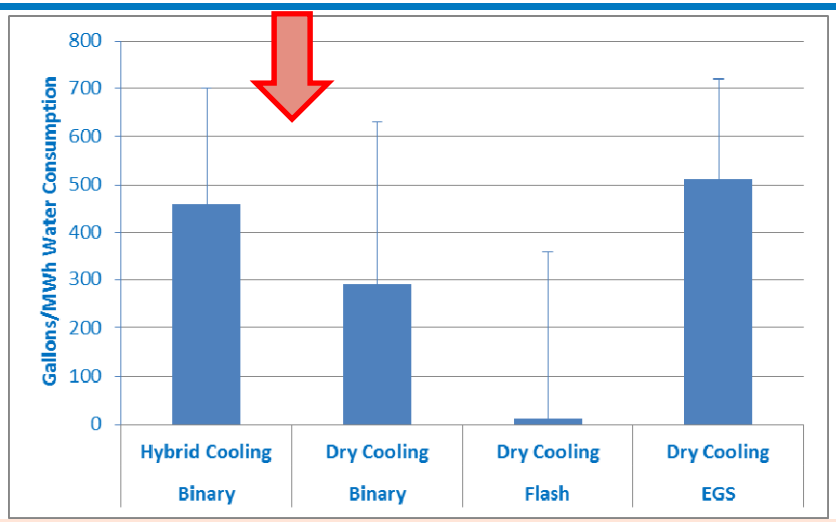
Operational water use varies by both generation and cooling technology



Operational withdrawal and consumption factors for electricity generating technologies

(UCS presentation of data from Macknick et al., 2011)

High uncertainties and site-specific variability for water usage rates at Geothermal and Hydropower facilities



Site preparation water use (drilling, cementing, pipeline and plant construction) varies depending on:

- Geothermal resource
- Geothermal technology
- Number of wells (~1 well for every 2 MW)
- Depth of wells

Operational water use varies depending on:

- Geothermal resource
- Geothermal technology
- Cooling system
- Water source (geothermal fluids/external water source)

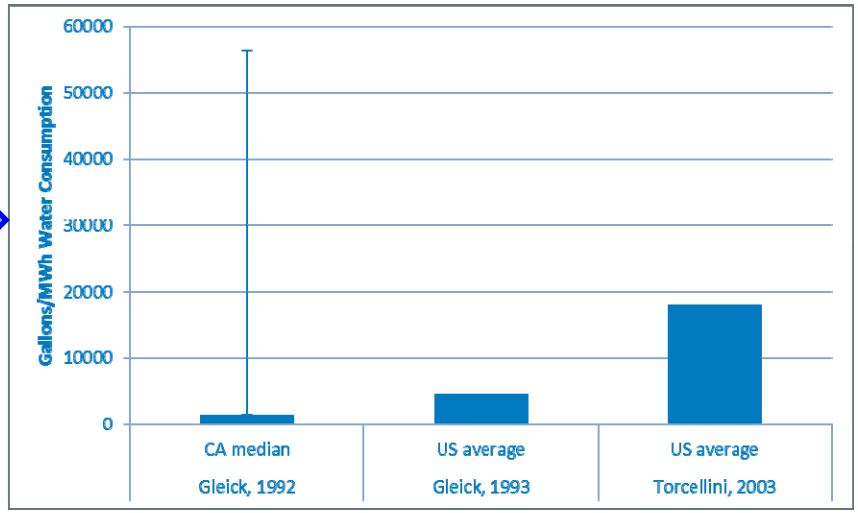
Sources: Meldrum , J., Nettles-Anderson, S., Heath, G., and J. Macknick. Life Cycle Water Use for Electricity Generation: A Review and Harmonization of Literature Estimates." (2013) Clark, C., C. Harto, J. Sullivan, and M. Wang. Water use in the development and operation of geothermal power plants. *Argonne National Laboratory Report* (ANL/EVS/R-10/5) (2011)

Substantial amounts of water can evaporate from reservoirs that support hydropower production

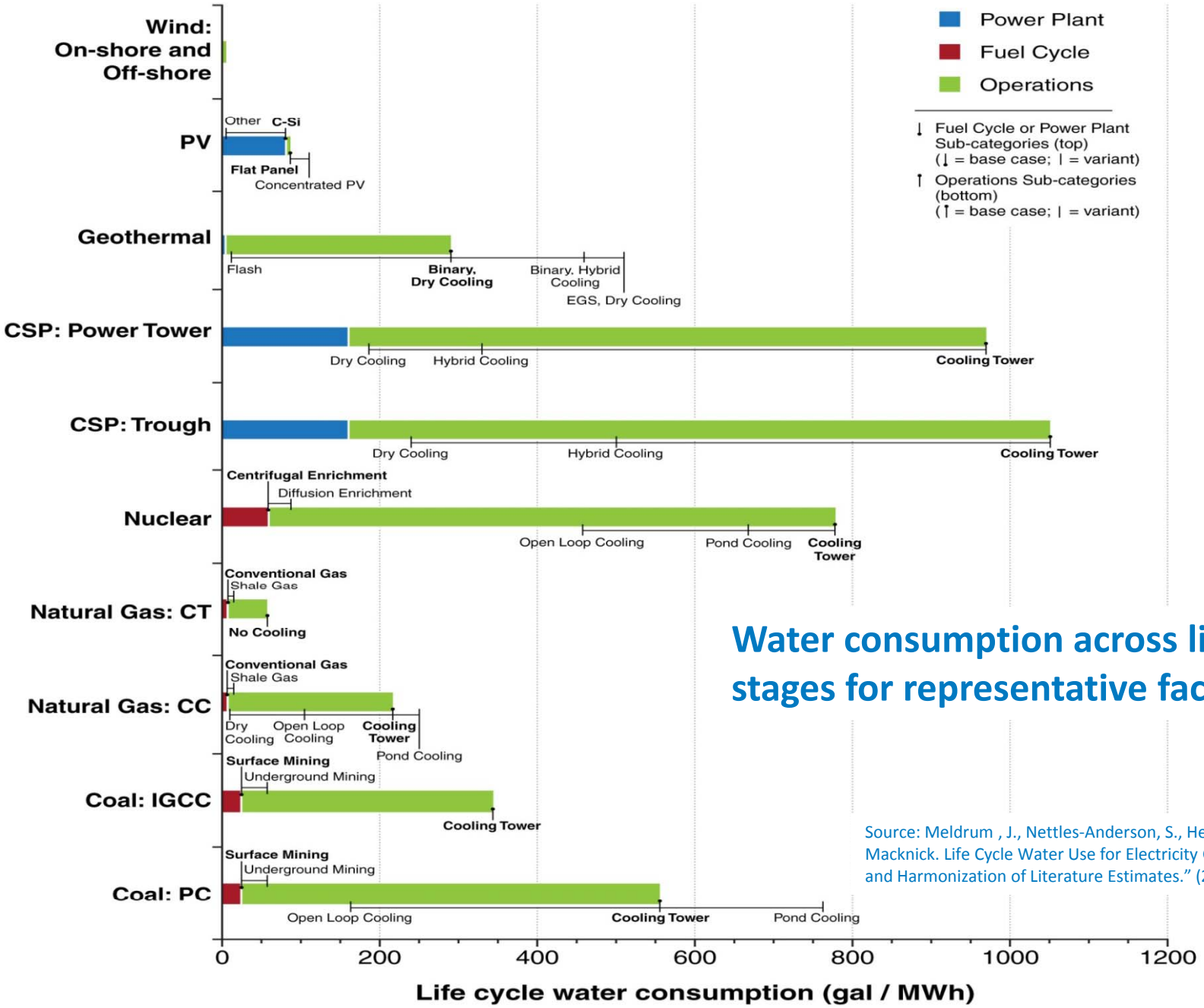
Factors influencing reservoir evaporation include:

- Reservoir depth, shape, surface area
- Temperature
- Size of inlet body of water
- Climatic conditions

Many reservoirs that generate hydropower have multiple uses (e.g., water supply, flood control, recreation), making allocating water consumption to hydropower activities challenging.



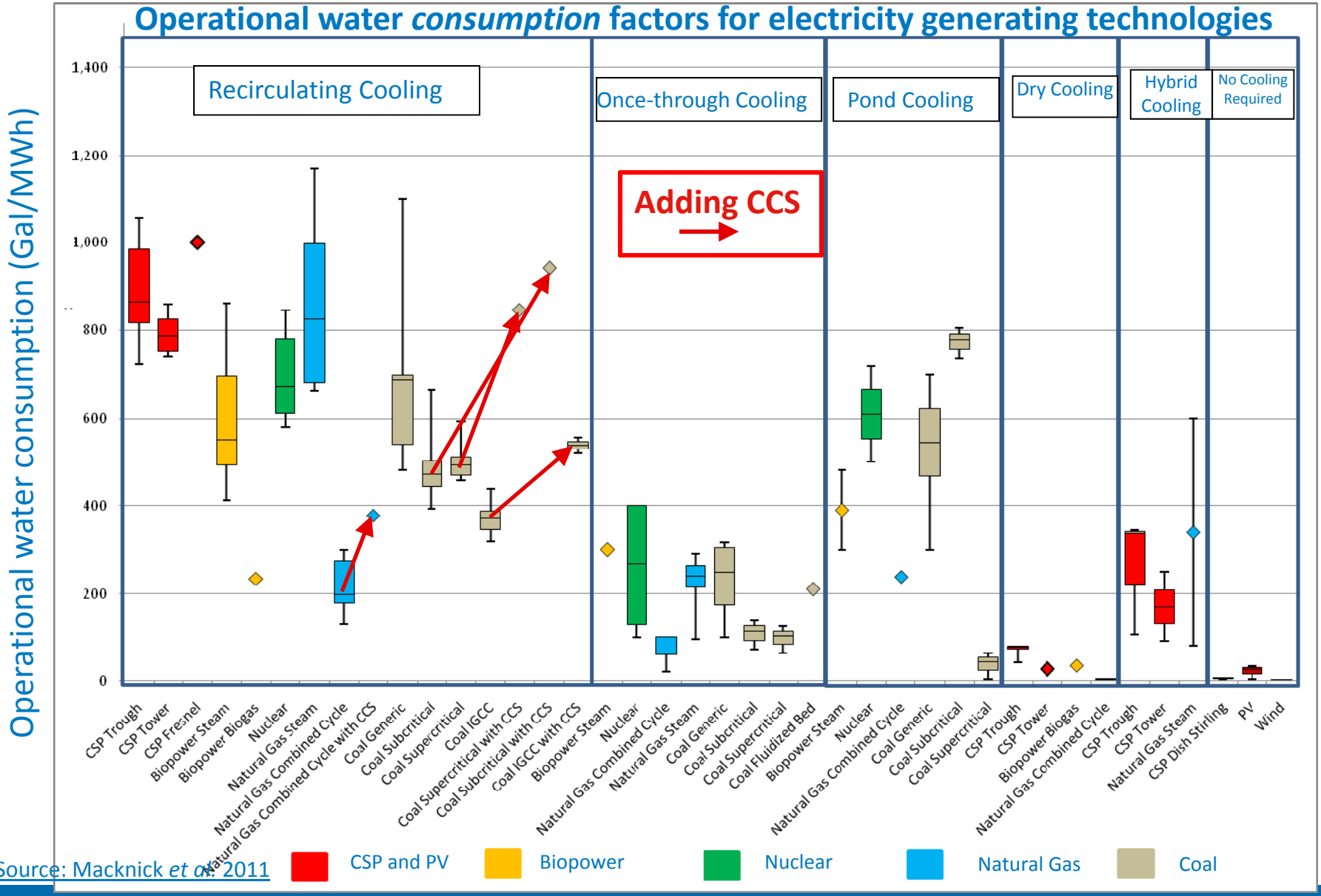
Sources: Gleick, P. "Environmental Consequences of Hydroelectric Development: The Role of Facility Size and Type." *Energy; Vol. 17 (8), 1992; pp. 735–747.* Gleick, P. *Water in Crisis: A Guide to the World's Fresh Water Resources. New York: Oxford University Press, 1993.* Torcellini, P., N. Long, and R. Judkoff, 2003: Consumptive Water Use for U.S. Power Production. *NREL Technical Report-TP-550-33905*



Water consumption across life cycle stages for representative facilities

Source: Meldrum , J., Nettles-Anderson, S., Heath, G., and J. Macknick. Life Cycle Water Use for Electricity Generation: A Review and Harmonization of Literature Estimates." (2013*)*

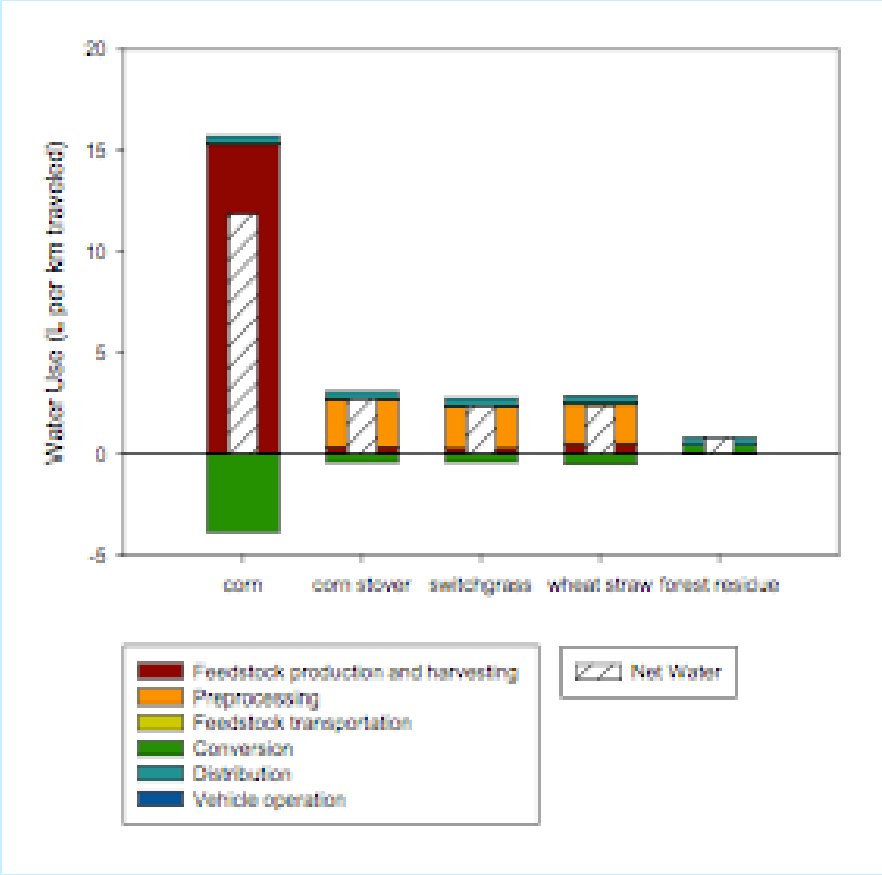
Some advanced technologies are even more water-intensive



Source: Macknick *et al.* 2011

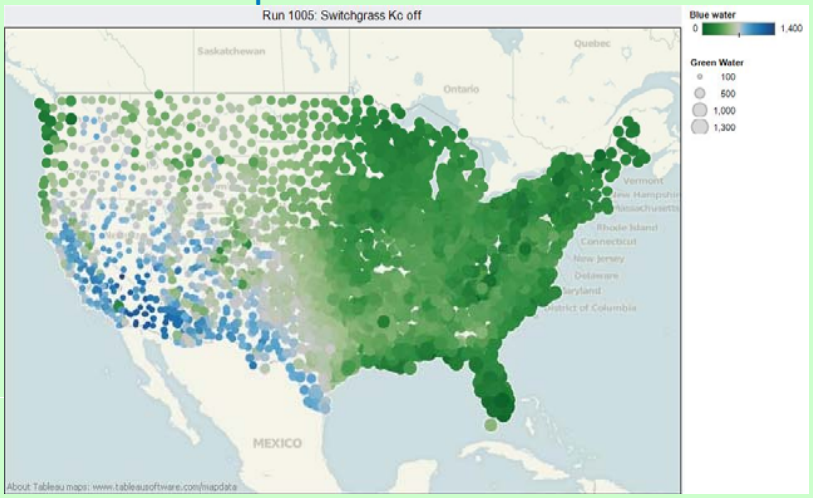
Water intensity of transportation fuels is likely to increase

TOTAL LIFE CYCLE WATER USE FOR 2022 E85

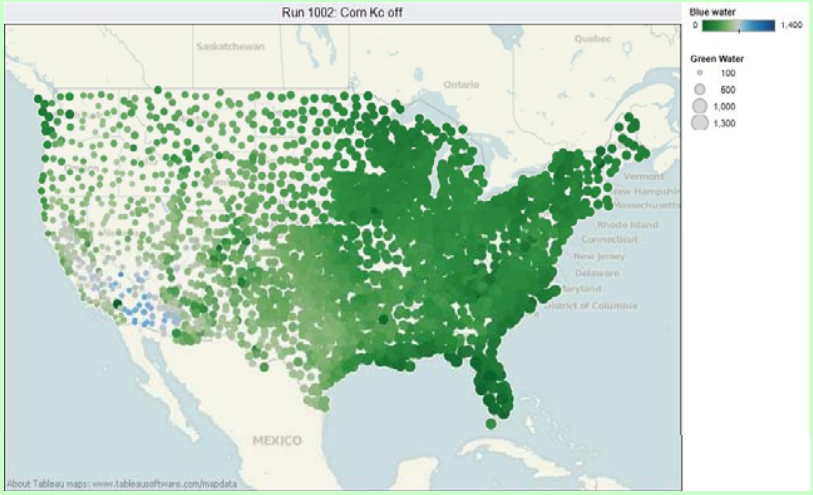


Source: Heath et al., Life Cycle Assessment of the Energy Independence and Security Act of 2007: Ethanol - Global Warming Potential and Environmental Emissions, 2009

Water Footprint for Corn



Water Footprint for Switchgrass



Source: Inman *et al., (forthcoming);* Gerbens-Leenes *et al., 2009;* Singh and Kumar, 2011, Inman *et al., (forthcoming);*

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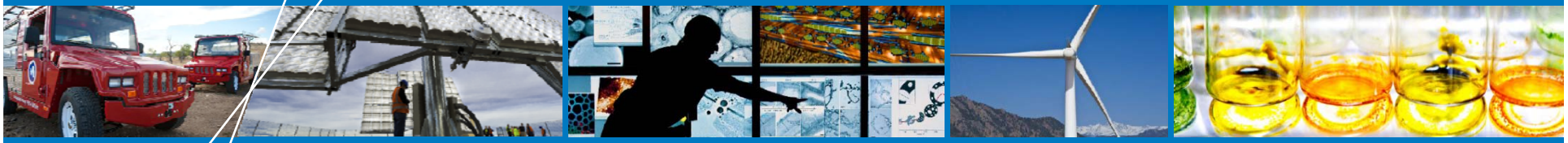


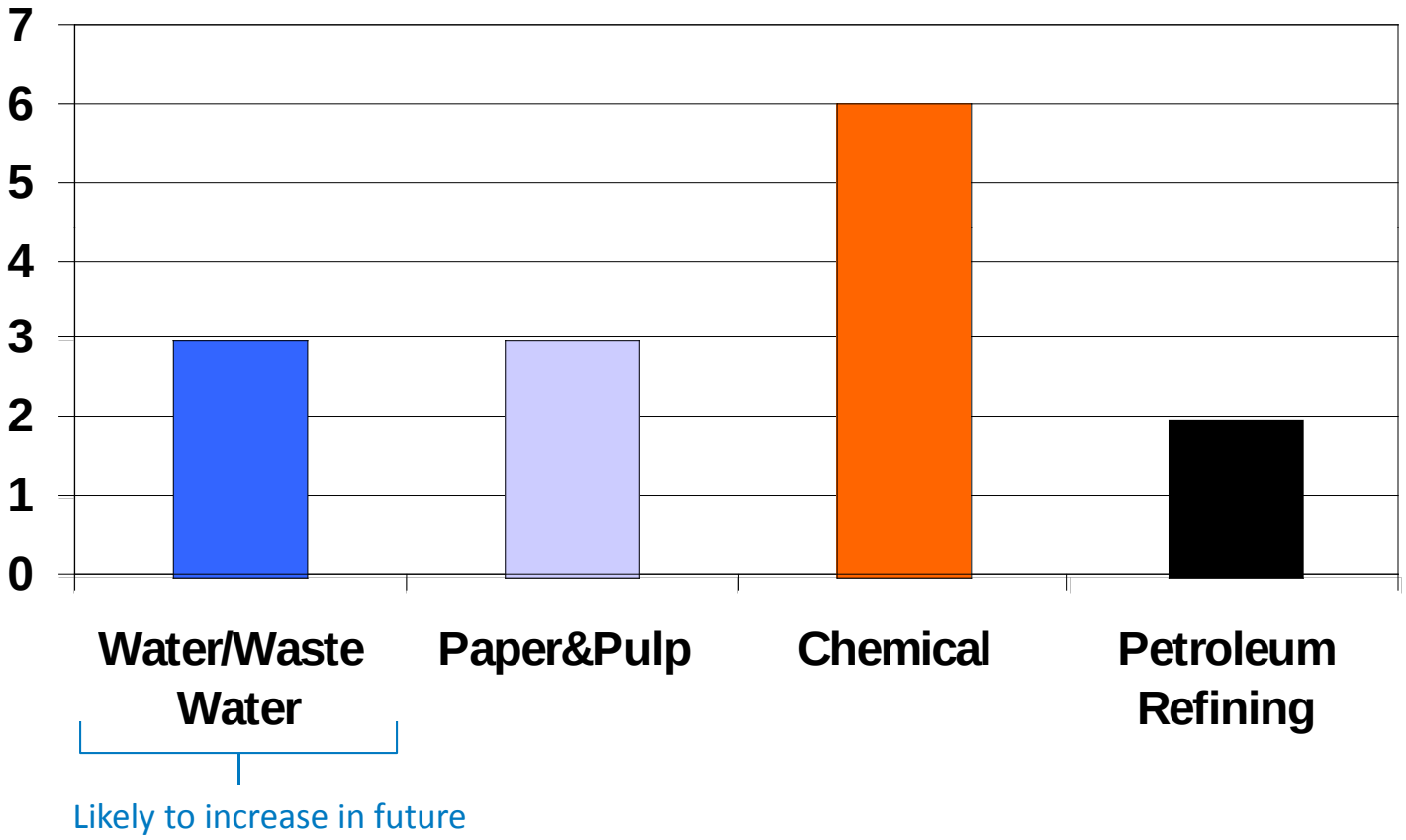
Energy for Water

Energy for Water

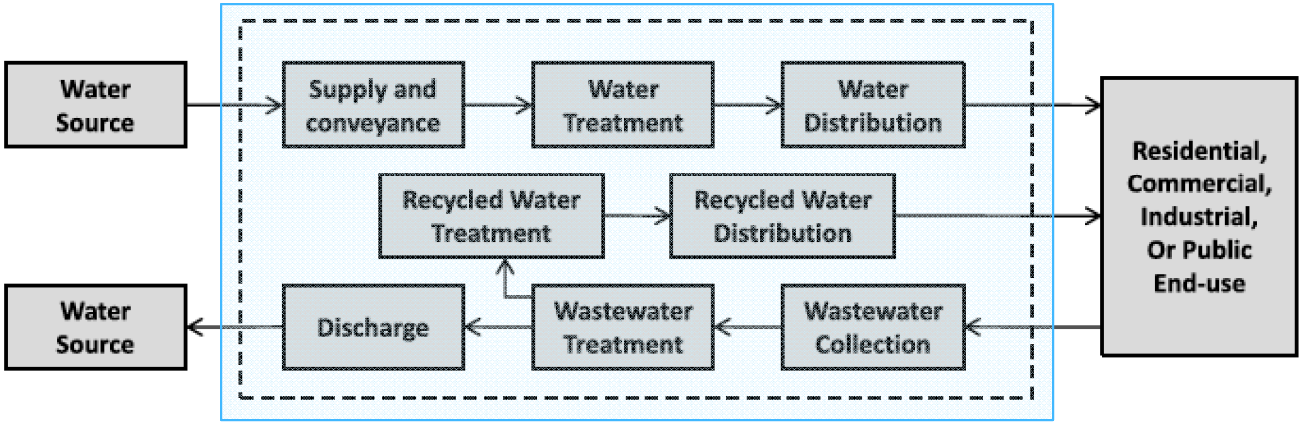
The water/wastewater industry is a significant user of electricity

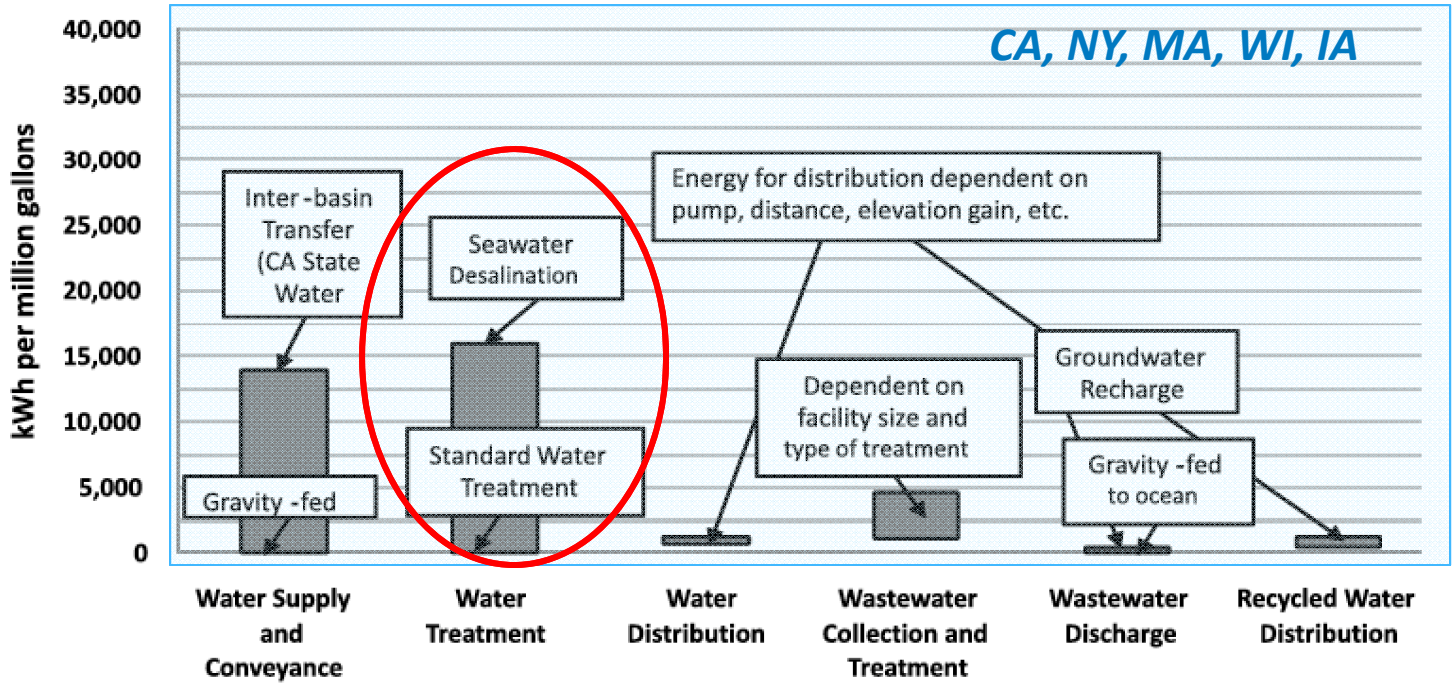
Percent of U.S. Electricity Generation Used by Industry

Source: DOE, 2004



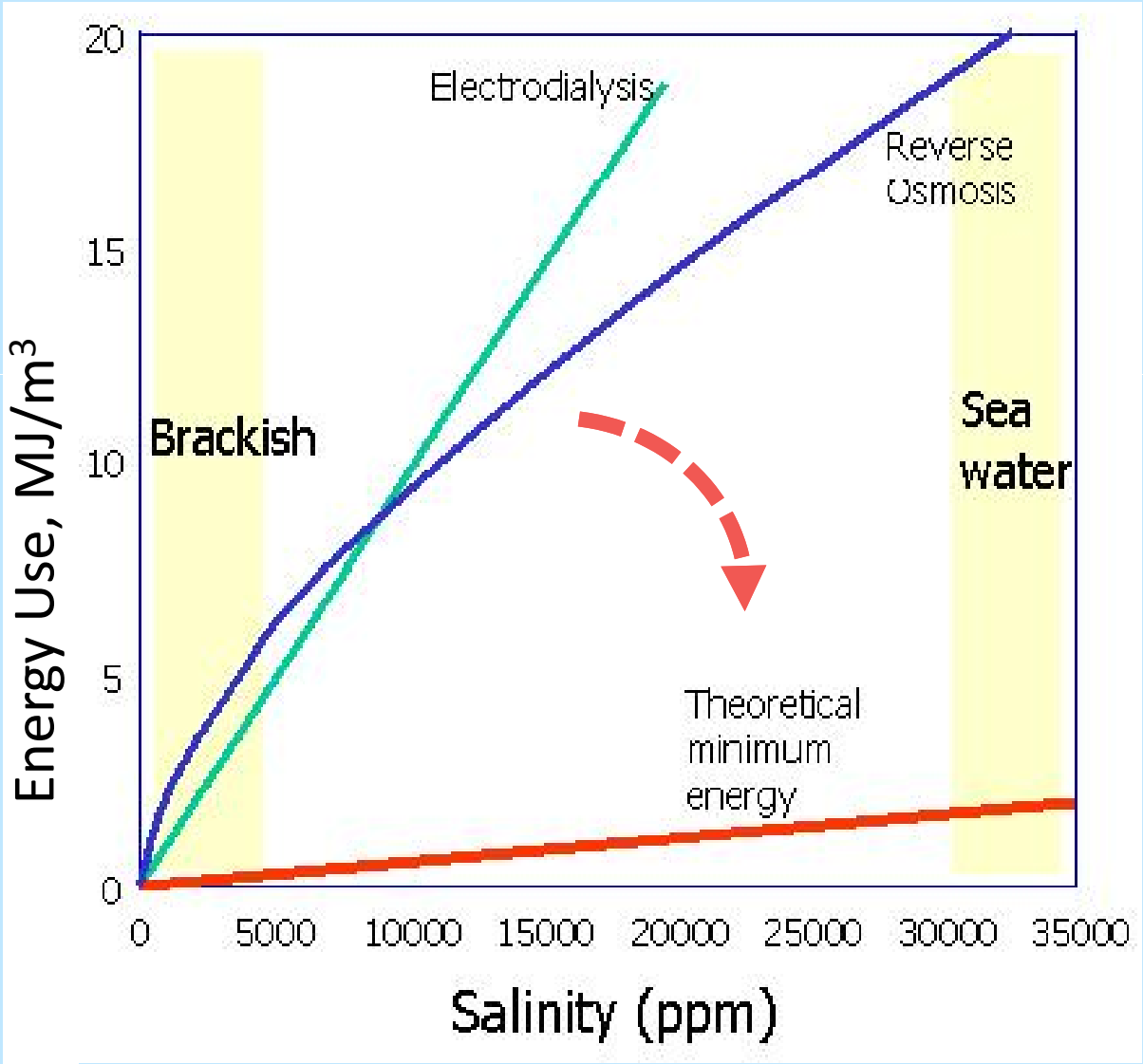
The energy intensity of each stage of the public water supply life-cycle varies according to regional topography, climate, and policy framework





Source: Sanders and Webber, 2013

Use of non-traditional water resources is growing



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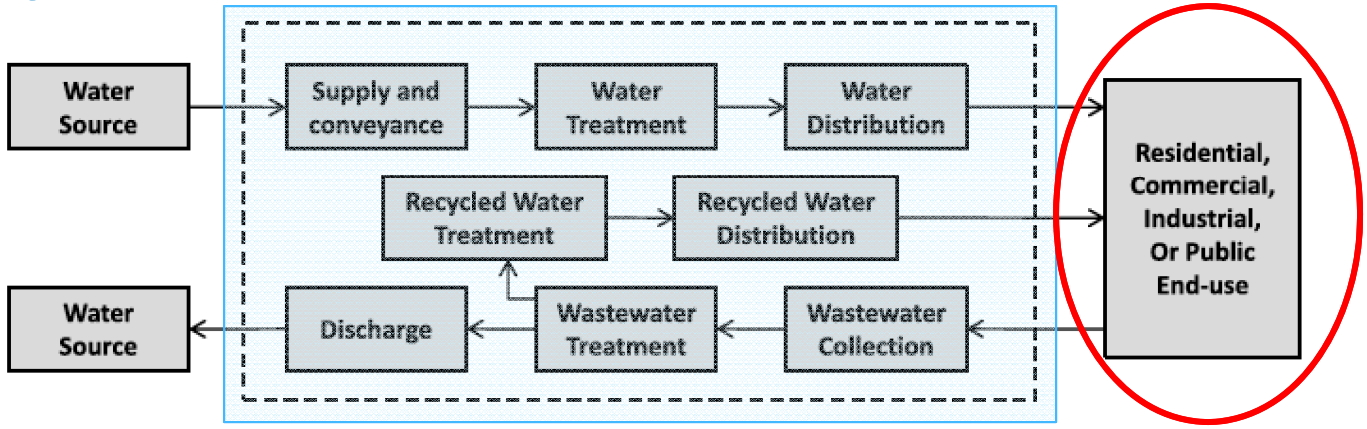
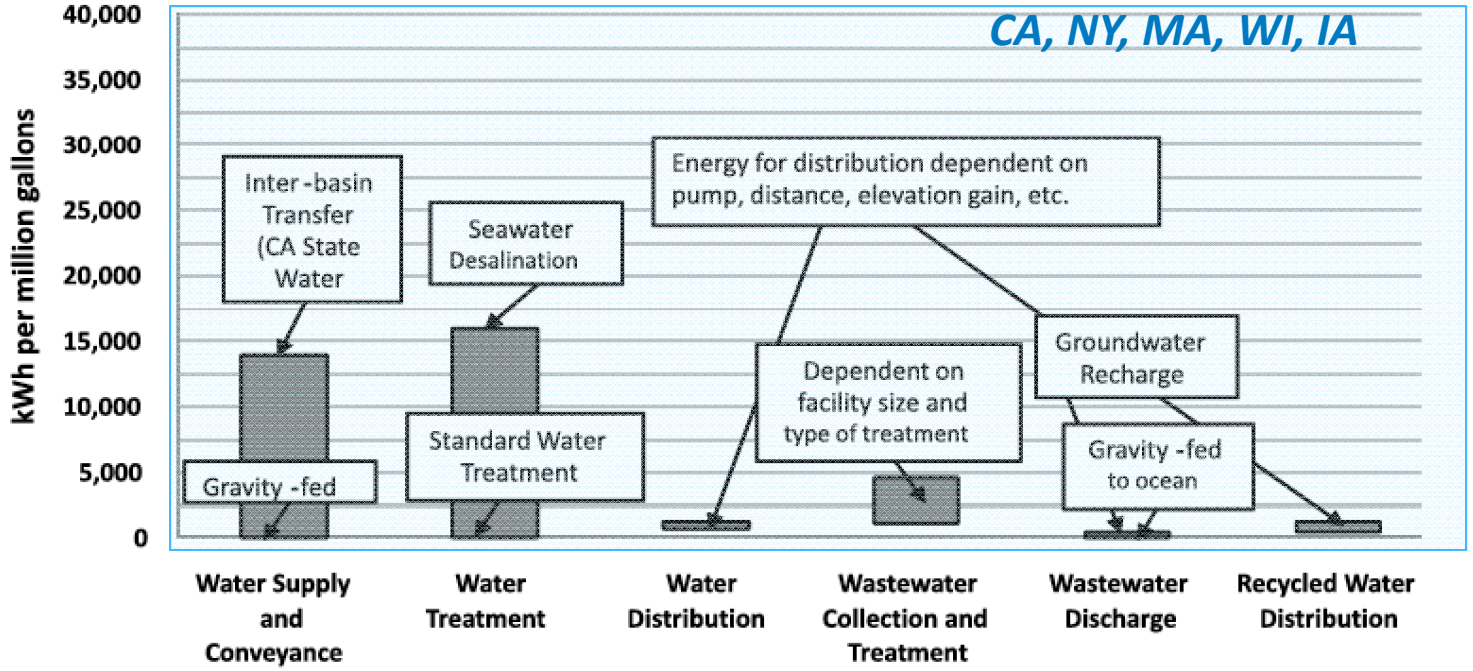




Source: Sanders and Webber, 2013

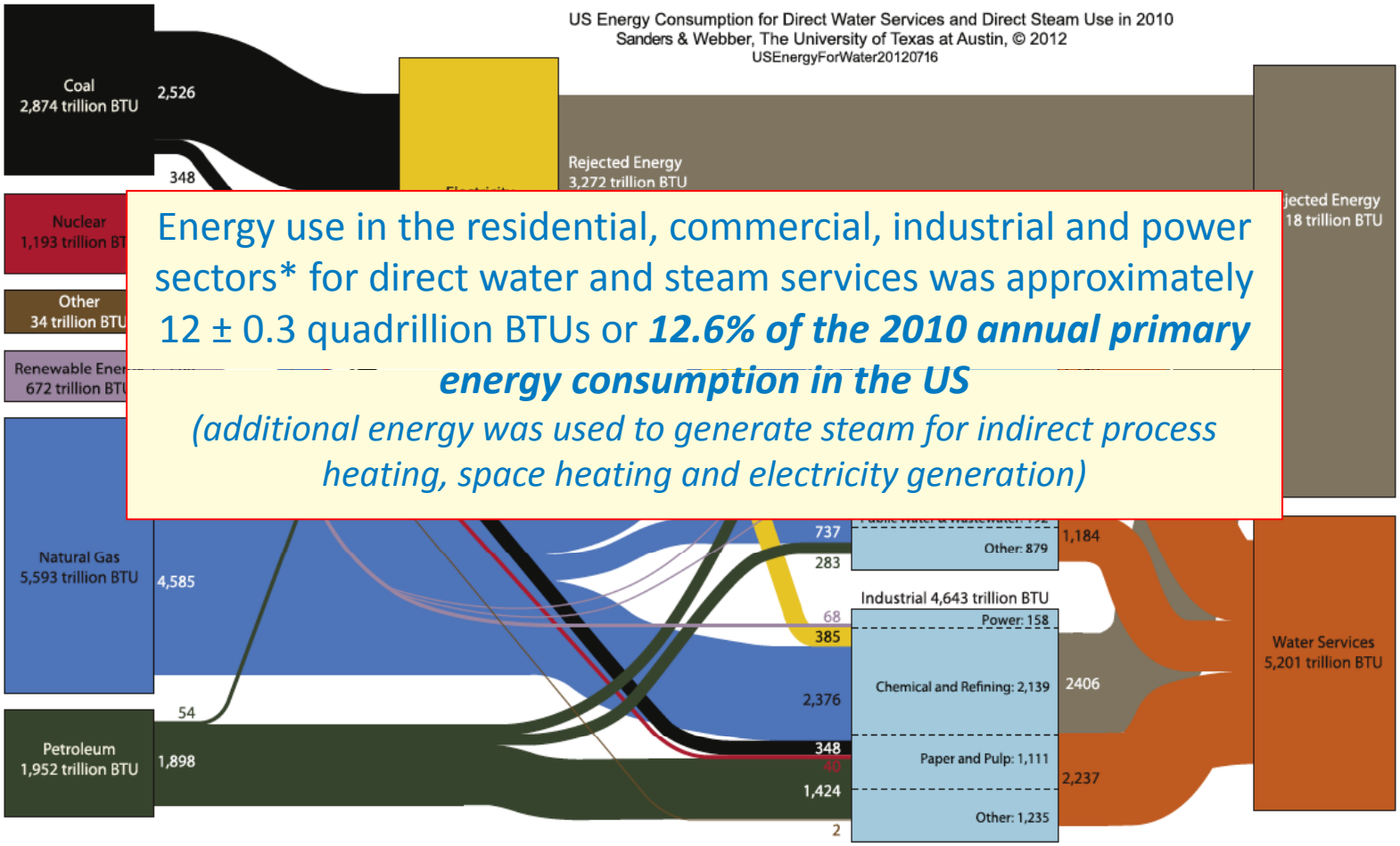
Energy intensity of end use: California's surprise

Table 3: 2001 Water-Related Energy Use in California

	Electricity (GWh)	Natural Gas (Mill. Therms)	Diesel (Mill. Gallons)
Water Supply and Treatment			
Urban	7,554	19	?
Agricultural	3,188		
End Uses			
Agricultural	7,372	18	88
Residential	27,887	4,220	?
Commercial			
Industrial			
Wastewater Treatment	2,012	27	?
TOTAL	48,012	4,284	88
2001 Consumption	250,494	13,571	?
Percent of Statewide Energy Use	19%	32%	?

Source: IEPR, 2005, CEC-100-2005-007-CTD

Primary energy embedded in water*: US national-level



Energy use in the residential, commercial, industrial and power sectors* for direct water and steam services was approximately 12 ± 0.3 quadrillion BTUs or ***12.6% of the 2010 annual primary energy consumption in the US***

(additional energy was used to generate steam for indirect process heating, space heating and electricity generation)

*Residential, Commercial, Industrial and Power sectors, (~70% of total US primary energy consumption). Transportation sector not included.

Source: Sanders and Webber, 2012

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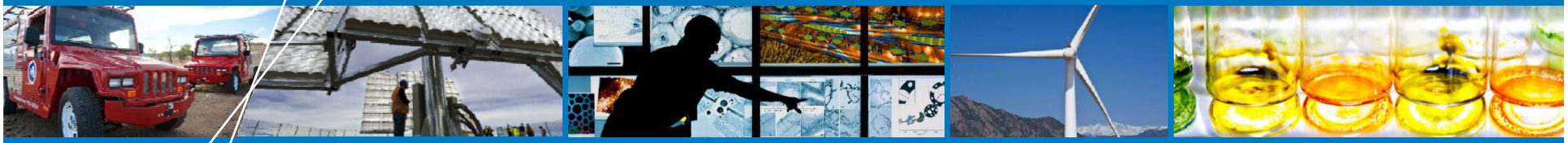
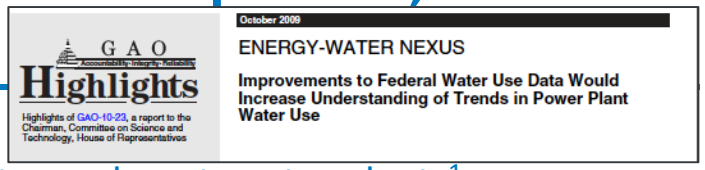


Data Gaps

Recent studies have highlighted data gaps and discrepancies, *primarily regarding water needs for energy**


GAO
Highlights
Highlights of GAO-10-23, a report to the Chairman, Committee on Science and Technology, House of Representatives

October 2009

ENERGY-WATER NEXUS

Improvements to Federal Water Use Data Would Increase Understanding of Trends in Power Plant Water Use

Data Gaps

- Outdated national-level data on energy consumption by water and wastewater plants[1]
- Incomplete data for water-related end-uses (especially in non-residential sectors) [1]
- Poor accounting for losses and leaks (state public use and losses report 3-41% of the total public supply) [1]
- Power plants not reporting their water use to the EIA (including nuclear plant water use) would account for 28 - 30 % of freshwater withdrawals by the electricity sector, and at least 24 - 31 % of freshwater consumption by the sector. [2]

Discrepancies

- Reported freshwater use by power plants across the country fell outside the technology-based bounds, including plants in 22 states for withdrawal, and 38 states for consumption.[2] *(Discrepancies especially large in the Lower Colorado River and Southeast Gulf regions, where plant operators reported consumption five times greater and withdrawals 30% less—than the median NREL values would suggest)*
- Multiple causes:
  - Some power plant operators are exempt from reporting their water use based on plant size or technology.
  - Many operators appeared to report peak rates of water use rather than the requested annual average rate, leading to overestimates.
  - Some operators reported zero water use.

Other

**This may in itself reflect an opportunity or gap*

- Very limited nature by which water and energy planning is done in an integrated fashion (few local/regional efforts, plus WECC/ERCOT study.[3]

[1]Sanders and Webber, 2013 [2] Averyt et al., 2011 [3]Tidwell (pers comm.)

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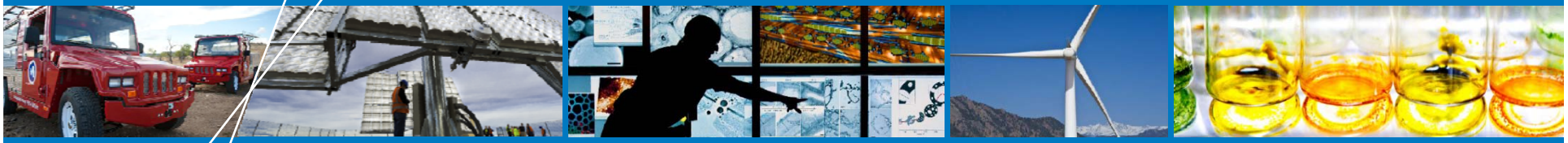


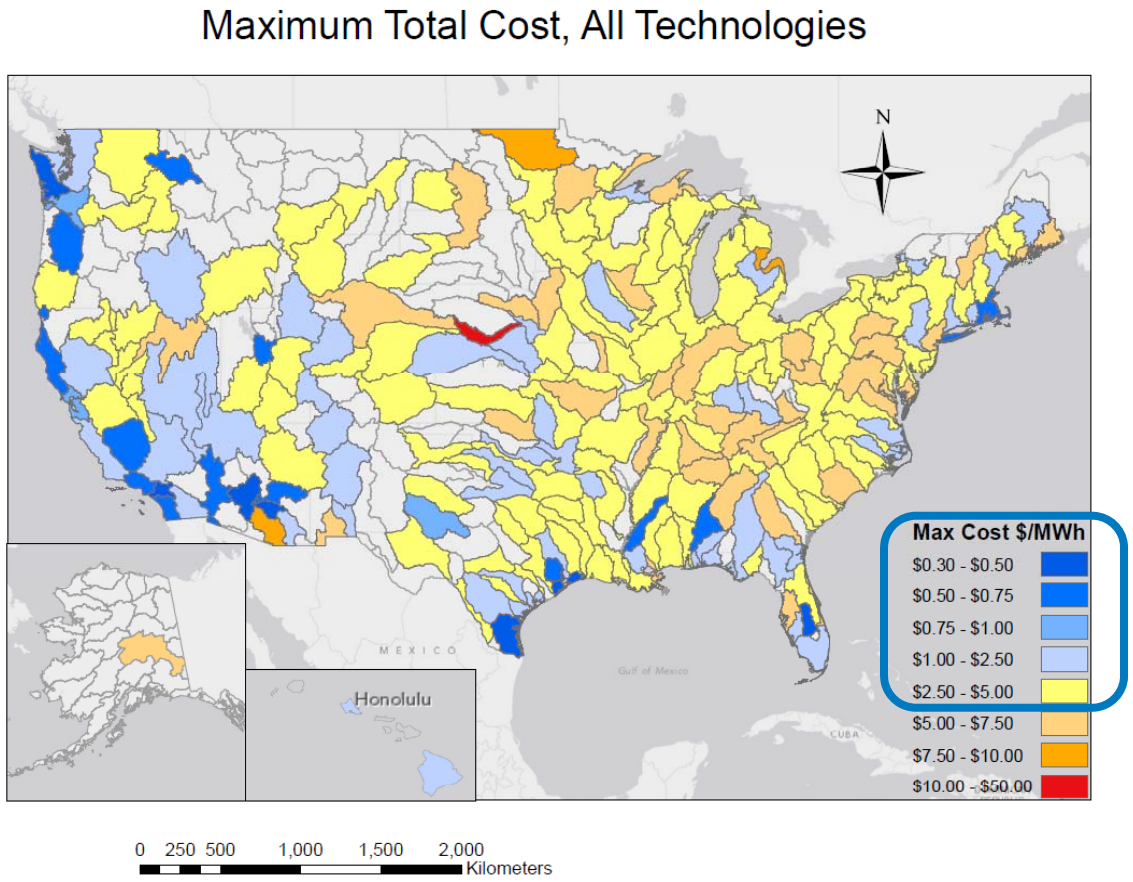
Going forward

Transitioning to Zero Freshwater Withdrawal for Thermoelectric Generation: ΔLCOE associated with retrofit

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

Preliminary results

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



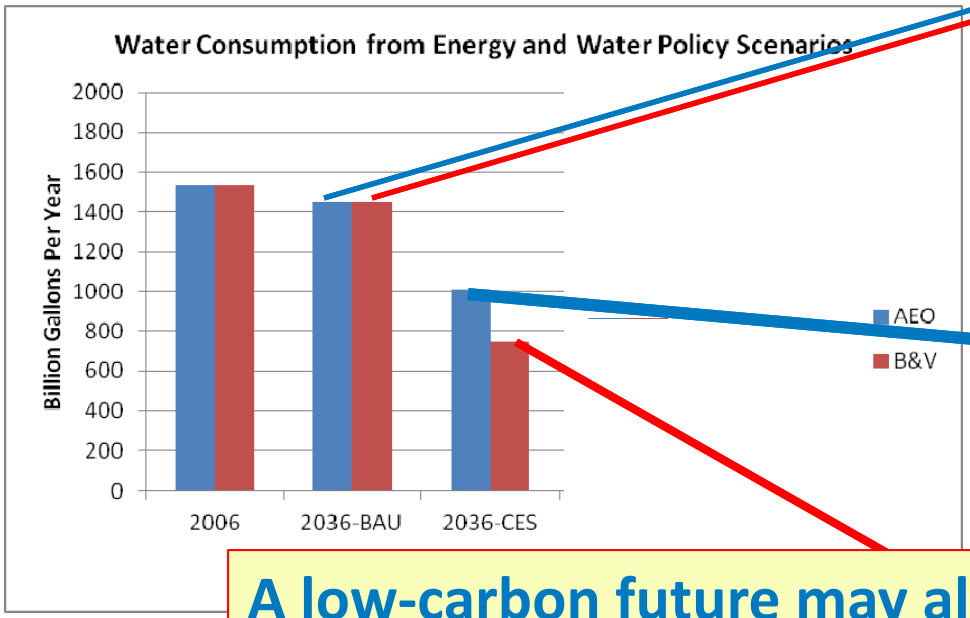
With wholesale cost of electricity about $40/MWh, many retrofits could be accomplished at levels that would add less than 10% to current power plant generation expenses.*

Source: DOE, in review

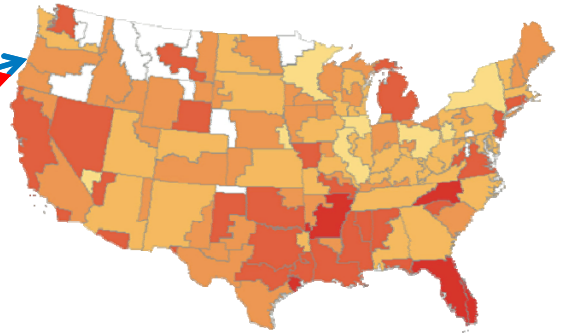
*average 2012 wholesale cost over 3 US trading hub regions

80% CES scenario: Technology choice affect national trends in power sector water intensity

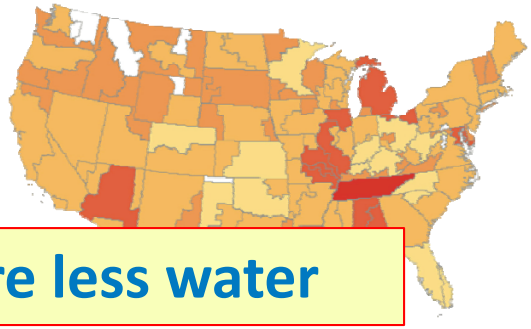
Consumption decreases to different extents



BAU 2036 vs 2006



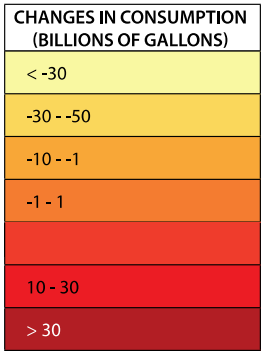
CES AEO 2036 - 2006



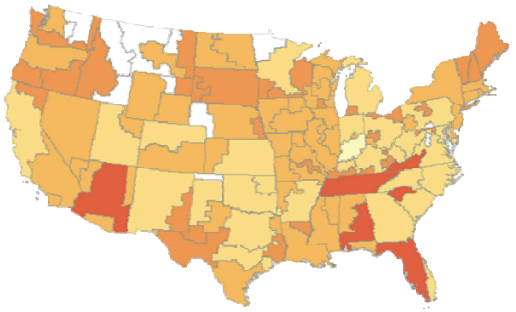
A low-carbon future may also require less water

Regional impacts vary

Climate change may enhance impacts locally and regionally



CES B&V 2036 - 2006

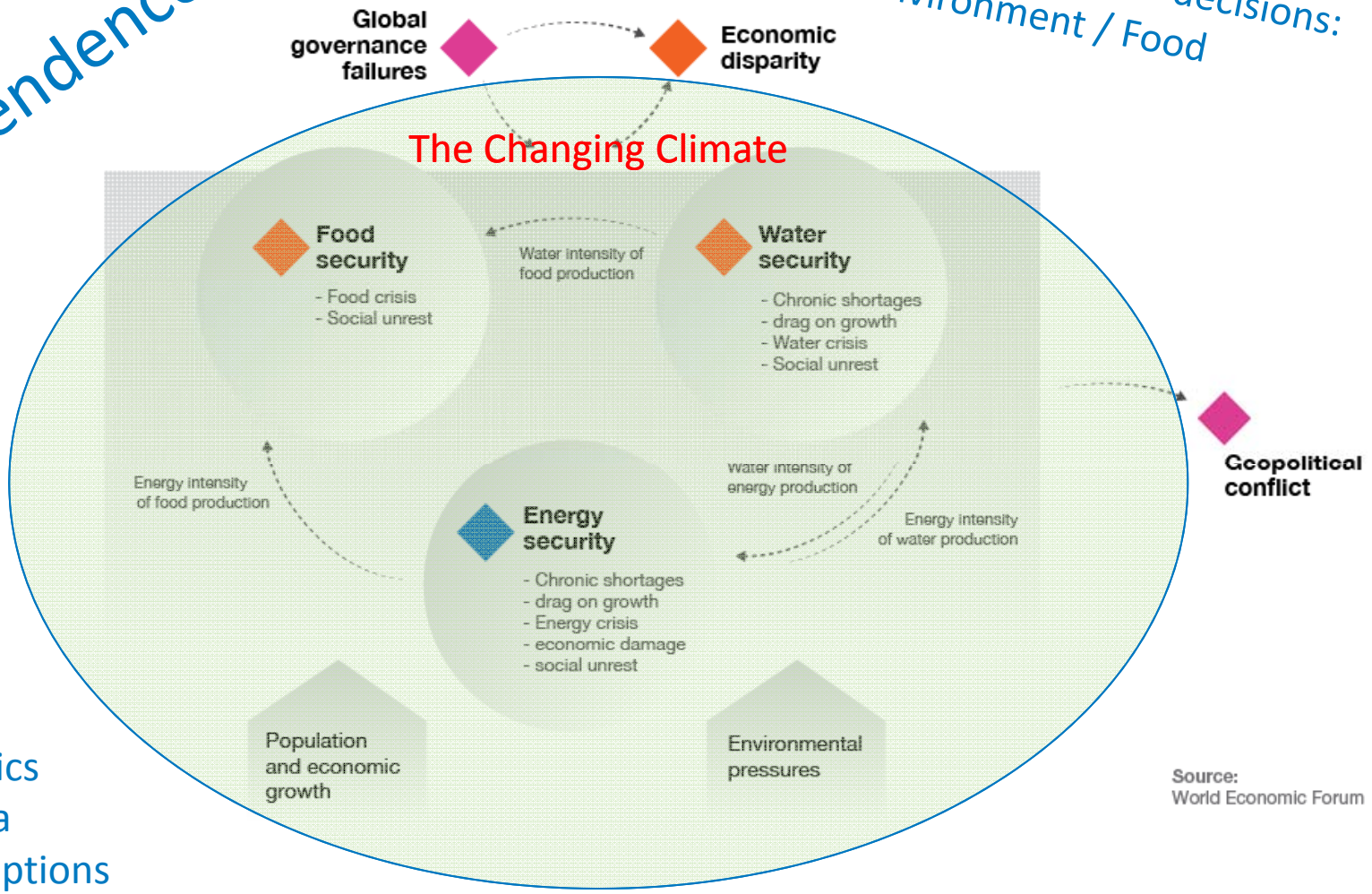


Source: Newmark et al., 2011

The Balancing Act…

Interdependence

Tradeoffs playing out in our decisions:
Energy / Environment / Food



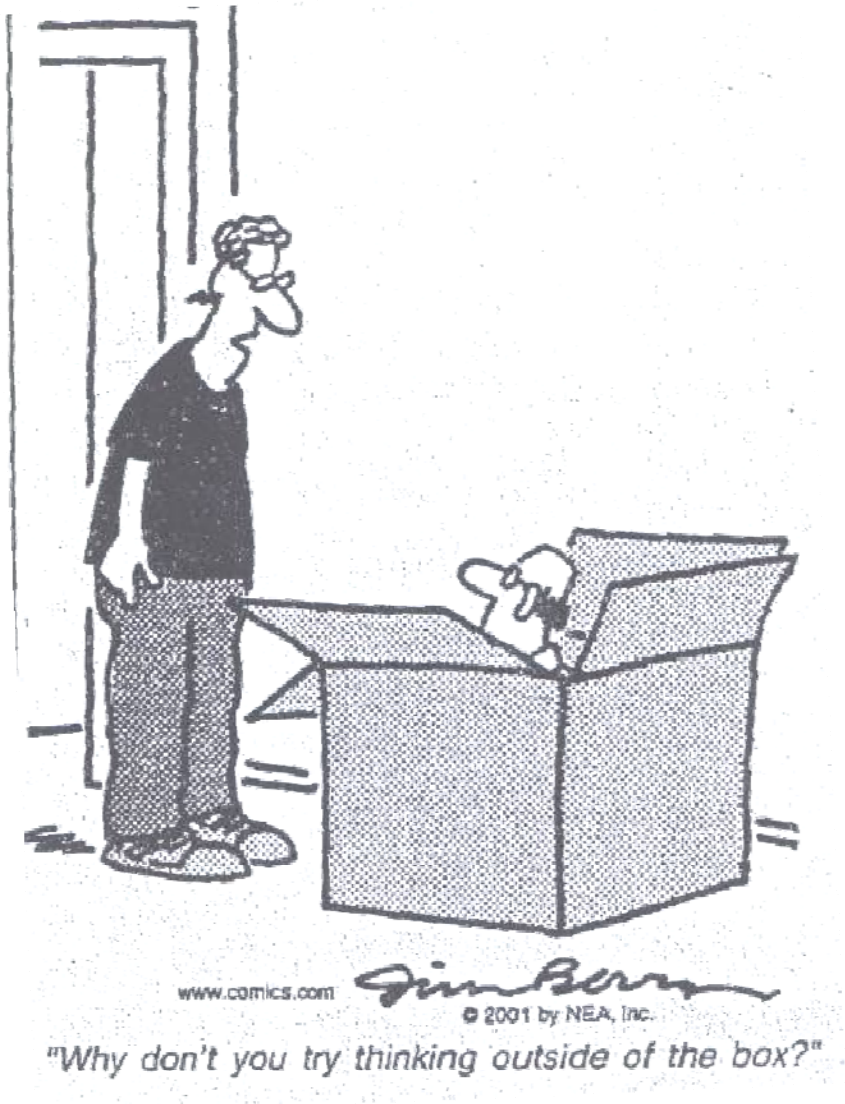
Source:
World Economic Forum

Demographics
Social Media
Public Perceptions

Opportunities exist for creative solutions to move us beyond current approaches

"Insanity is doing the same thing
over and over again
and expecting different results."

--Albert Einstein



"Why don't you try thinking outside of the box?"

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