Climate Impacts at the Nexus of Energy, Water, & Land Resources

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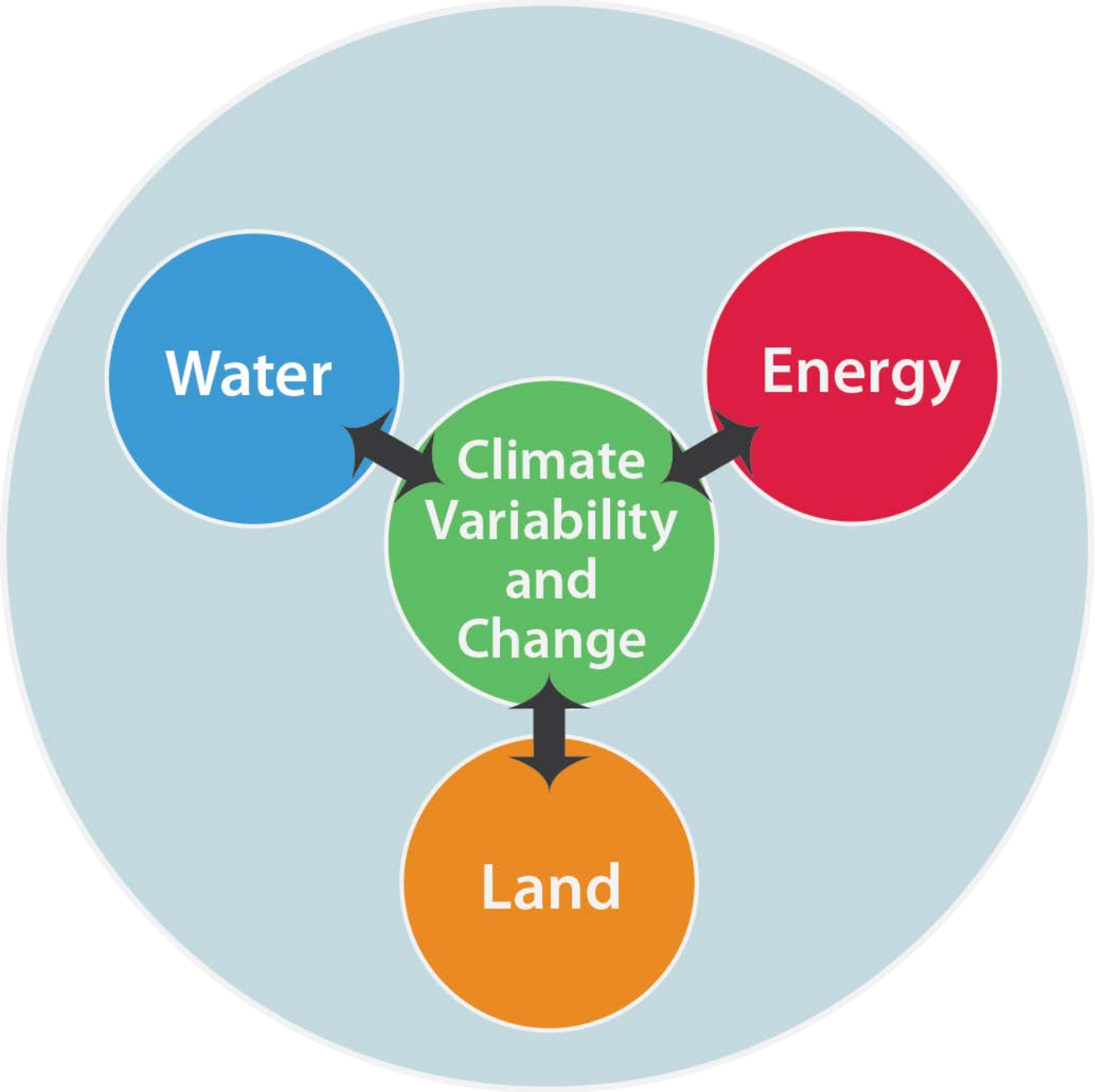
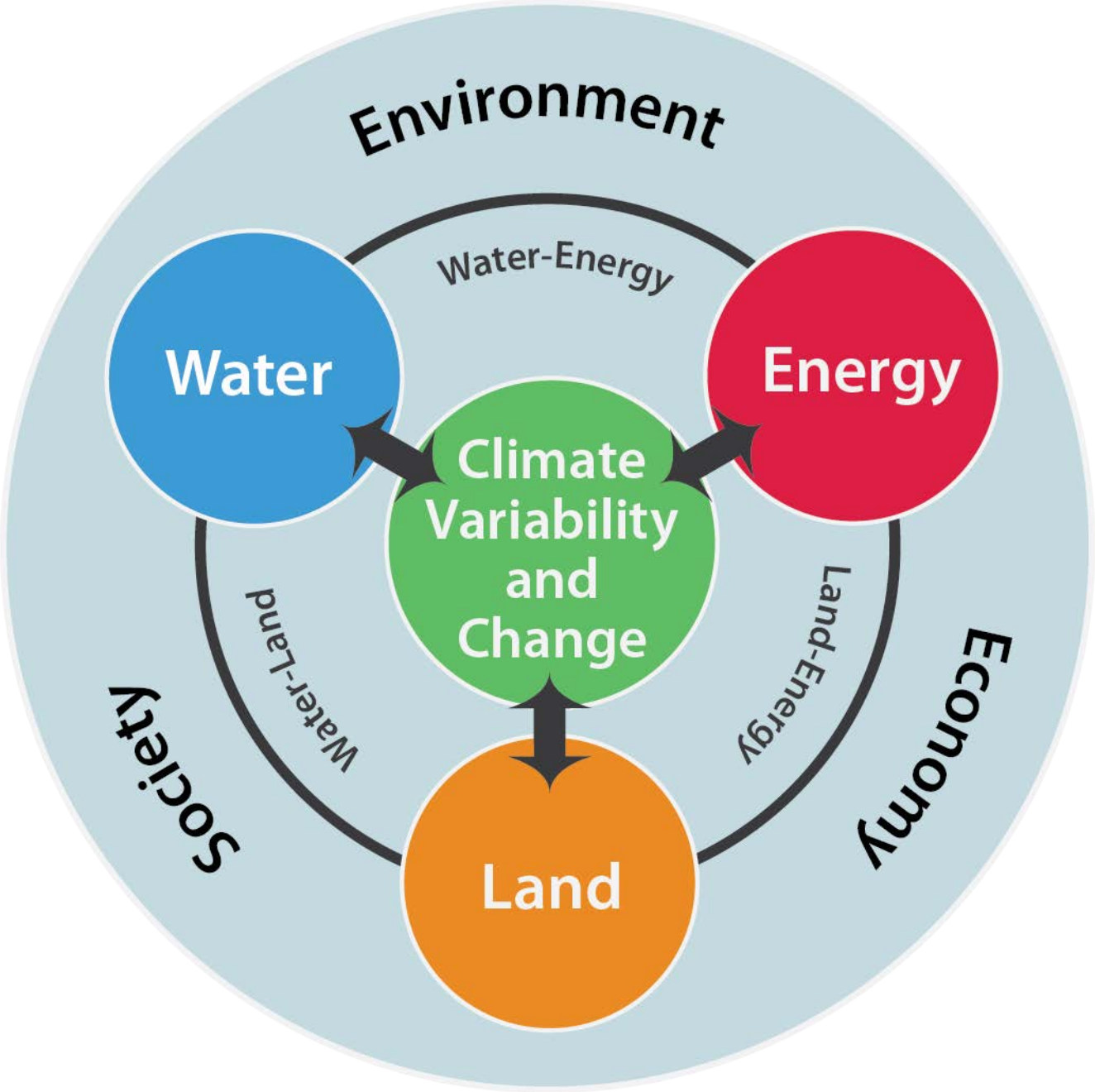
Sustainable Water Resources Roundtable • July 19, 2016

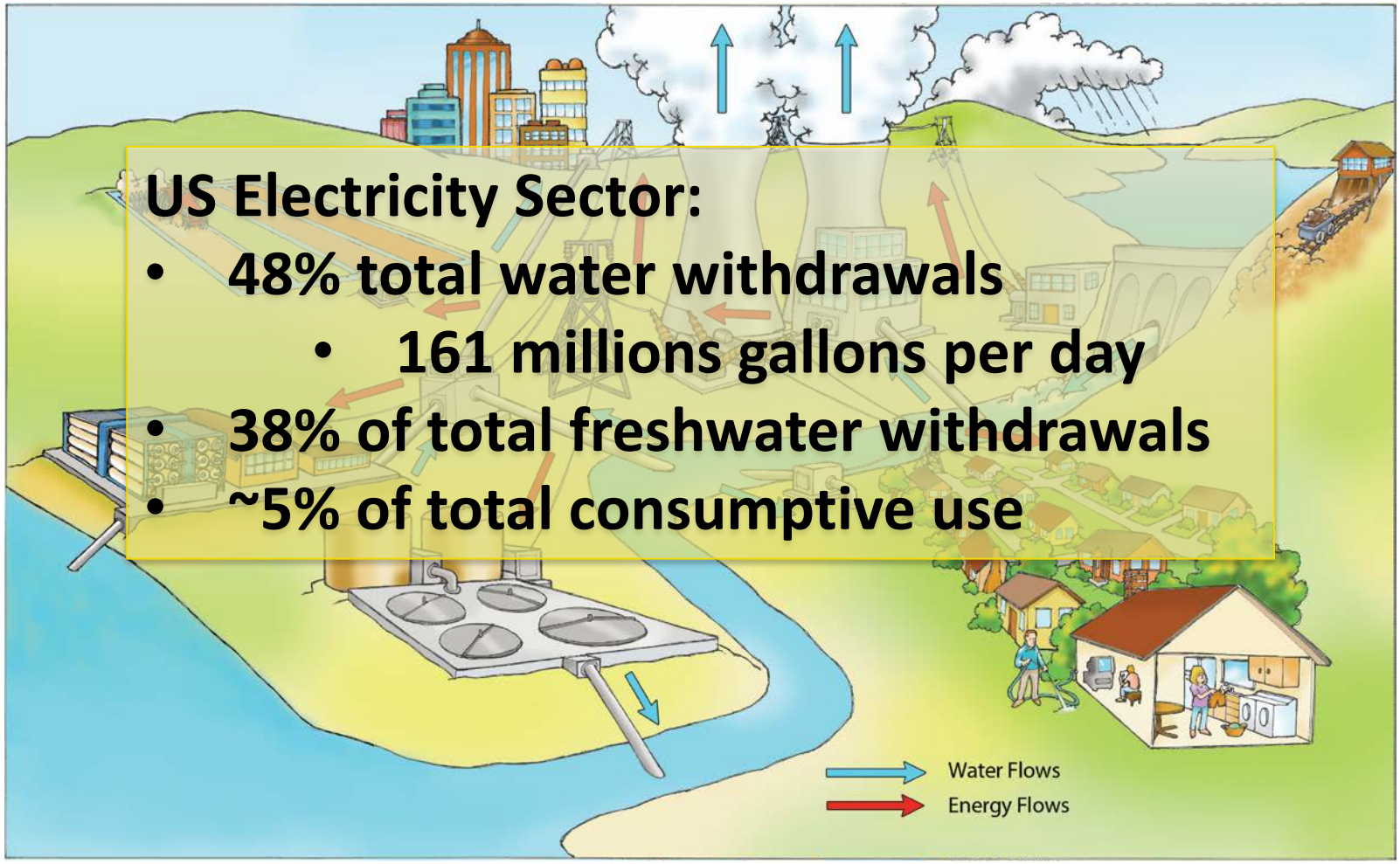


NCA, 2014


Environment
Water-Energy
Water
Energy
Climate Variability and Change
Water-Land
Land-Energy
Society
Economy
Land

NCA, 2014

The Energy-Water Nexus

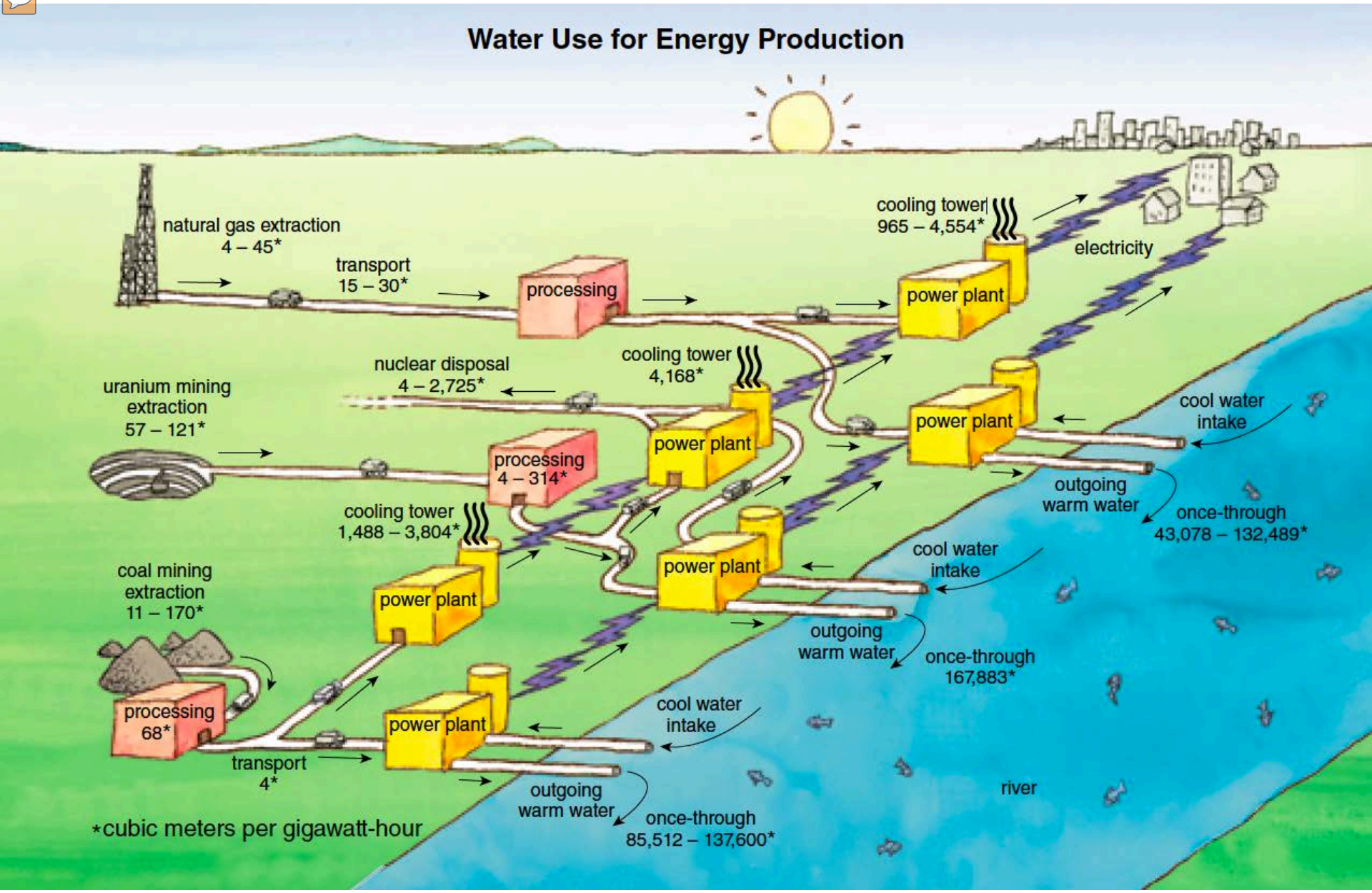


US Electricity Sector:

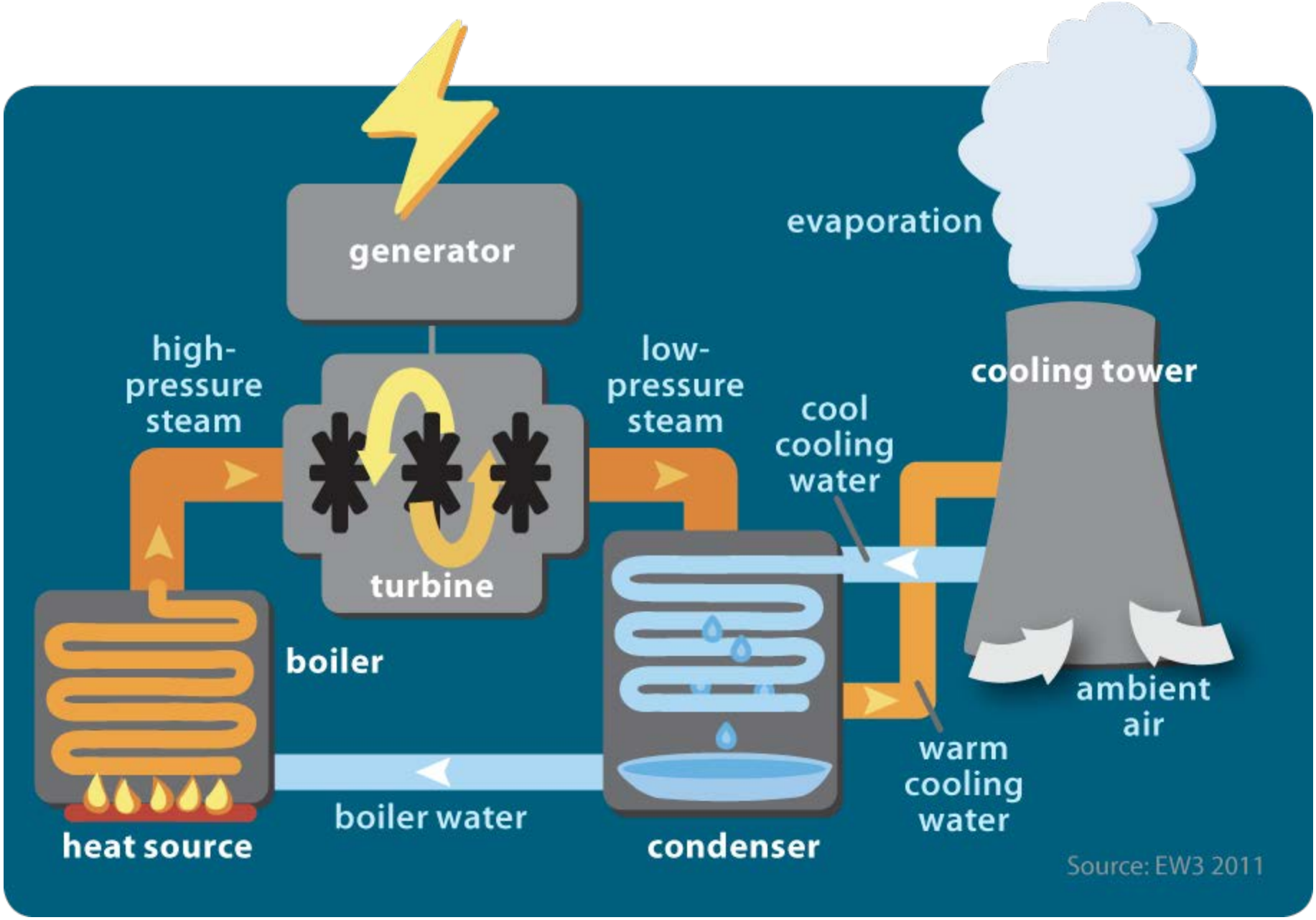
- **48% total water withdrawals**
  - **161 millions gallons per day**
- **38% of total freshwater withdrawals**
- **~5% of total consumptive use**

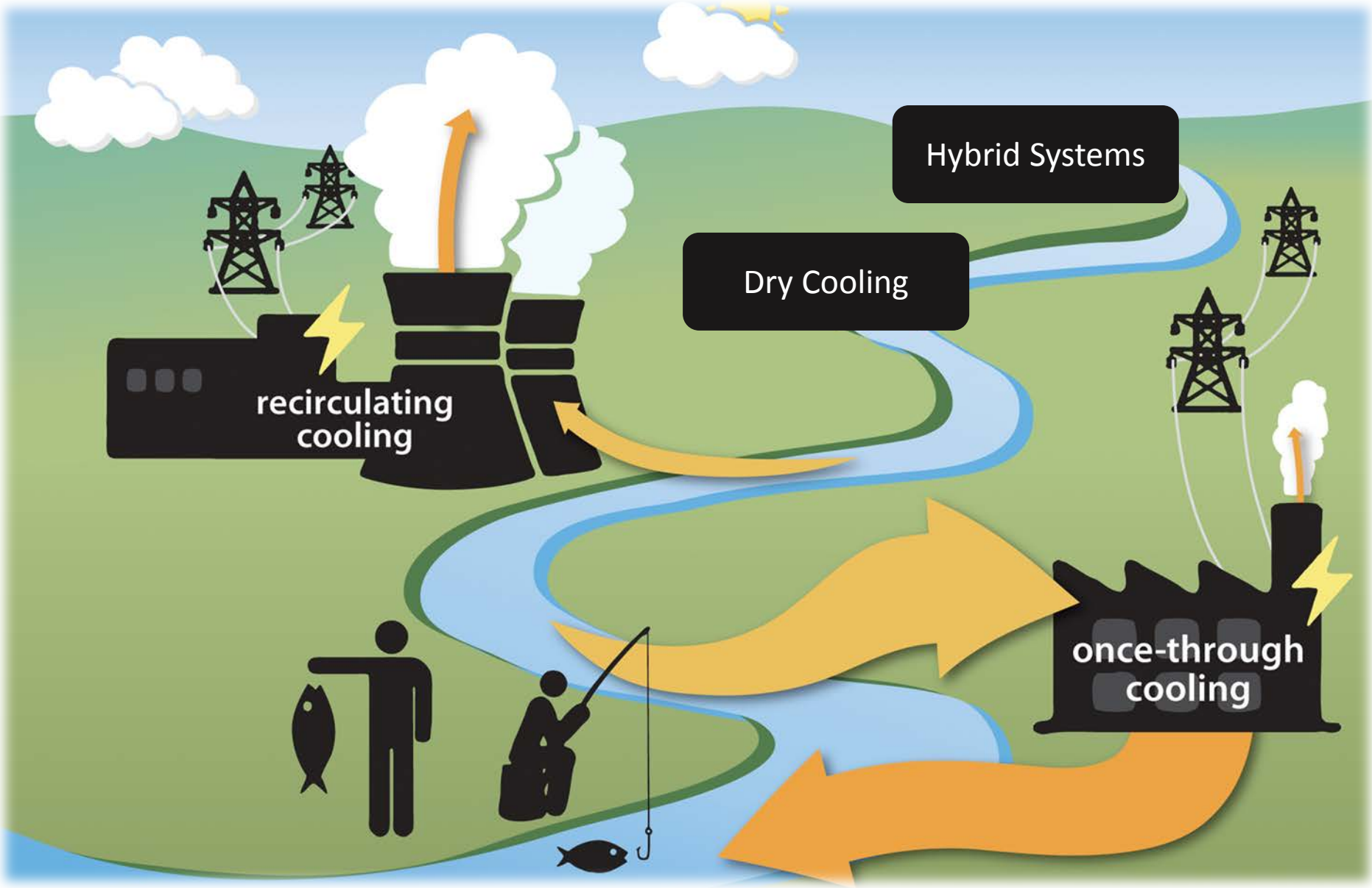
Source: DOE 2006

Diehl & Harris, 2014; Maulpin, 2014; Kenny, 2009

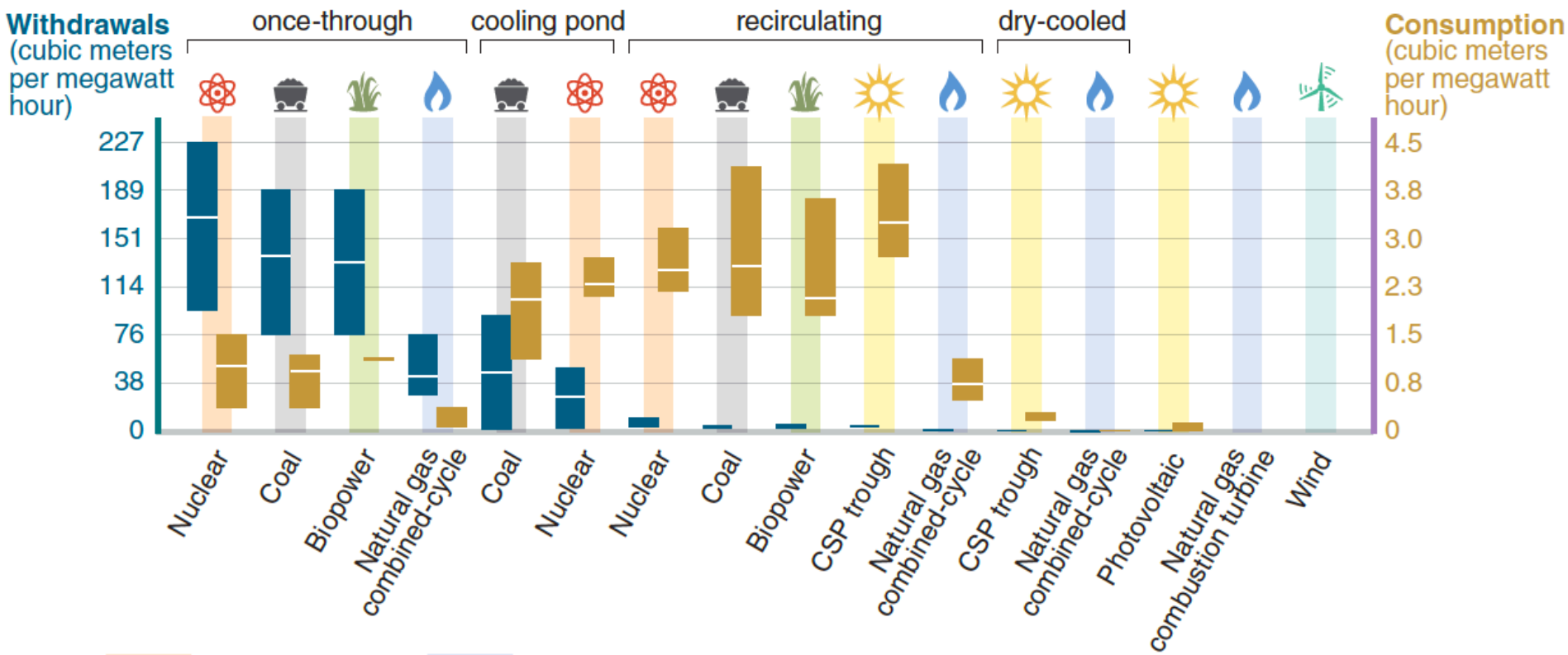


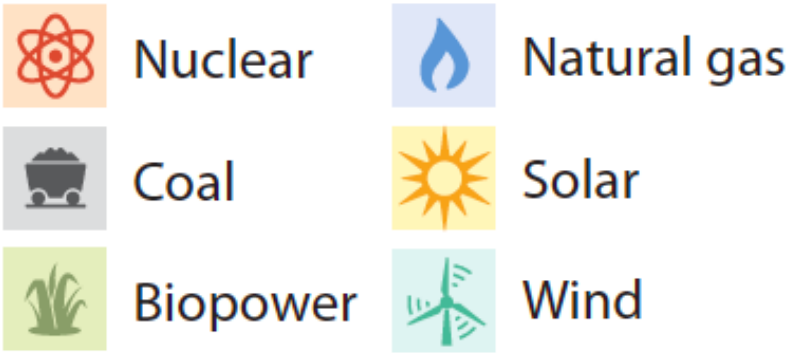
Data from Macknick et al., 2012; Meldrum et al. 2013
Graphic from Averyt, 2016


generator
evaporation
high-
pressure
steam
low-
pressure
steam
cool
cooling
water
cooling tower
turbine
boiler
ambient
air
warm
cooling
water
boiler water
heat source
condenser
Source: EW3 2011


Hybrid Systems
Dry Cooling
recirculating cooling
once-through cooling

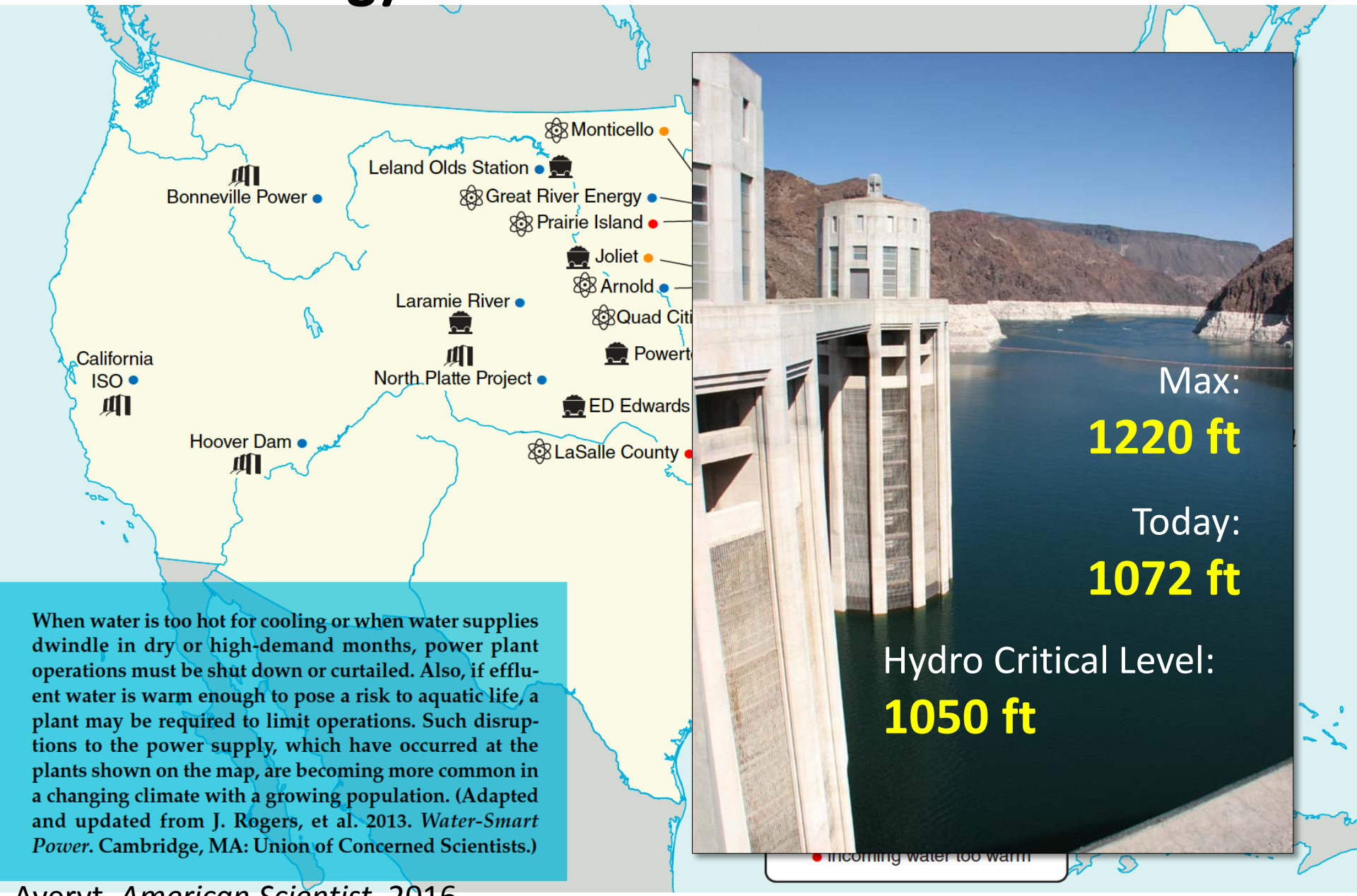
Water Requirements for Electricity Generation





Data from Macknick et al., 2012
Graphic from Averyt, 2016

Energy-Water Collisions: 2006–2015



When water is too hot for cooling or when water supplies dwindle in dry or high-demand months, power plant operations must be shut down or curtailed. Also, if effluent water is warm enough to pose a risk to aquatic life, a plant may be required to limit operations. Such disruptions to the power supply, which have occurred at the plants shown on the map, are becoming more common in a changing climate with a growing population. (Adapted and updated from J. Rogers, et al. 2013. *Water-Smart Power*. Cambridge, MA: Union of Concerned Scientists.)

Averyt, *American Scientist*, 2016

Energy-Water-Heat Collisions

Heatwave hits French power production

2003: France
50,000 heat-related deaths

Agencies

Tuesday 12 August 2003 12.21 EDT

France has shut down the equivalent of four nuclear power stations as the heatwave eats into the country's electricity generating capacities. With temperatures in French rivers hitting record highs, some power plants relying on river water to cool their reactors have been forced to scale back production.

The French nuclear safety authority has given others permission to return the river water at a higher temperature than is normally allowed.

The precise consequences of higher river temperatures are not known, but it is thought that they could endanger fish. French meteorologists are calling this summer the country's hottest since 1947.

The chief executive of state-owned Electricité de France did not rule out further cuts, but said that the company would do all it could to maintain supplies

Heatwave shuts down nuclear power plants

2006: Spain, Germany, France, UK

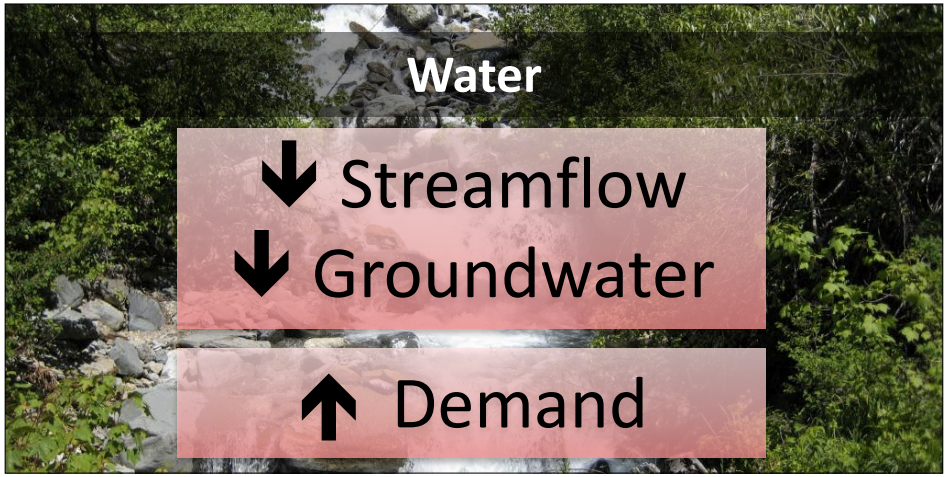
Juliette Jowit and Javier Espinoza

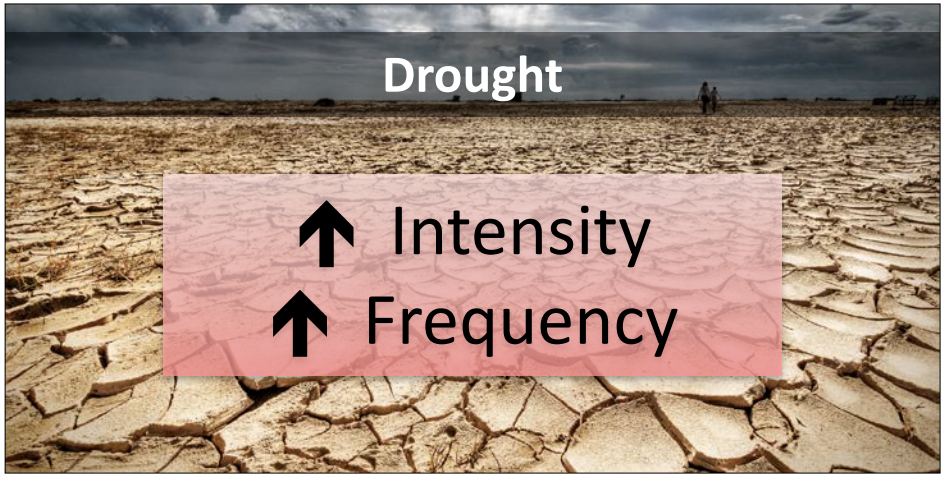
Saturday 29 July 2006 19.57 EDT

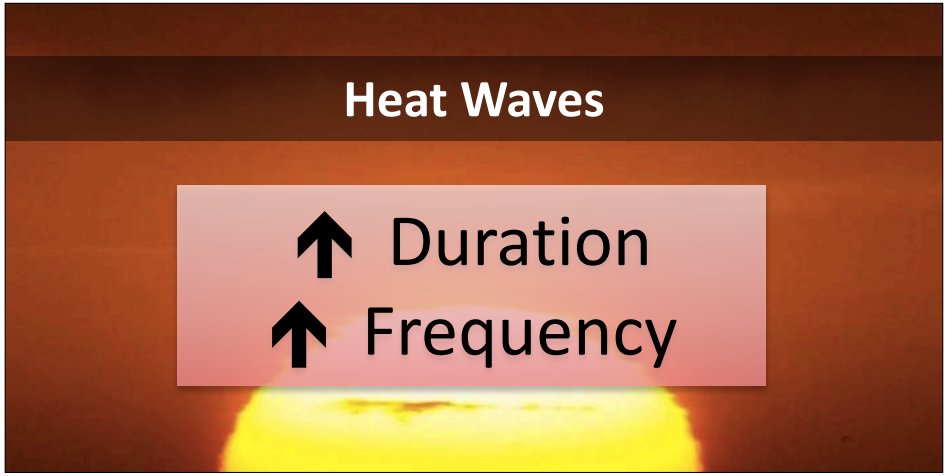
The European heatwave has forced nuclear power plants to reduce or halt production. The weather, blamed for deaths and disruption across much of the continent, has caused dramatic rises in the temperature of rivers used to cool the reactors, raising fears of mass deaths for fish and other wildlife.

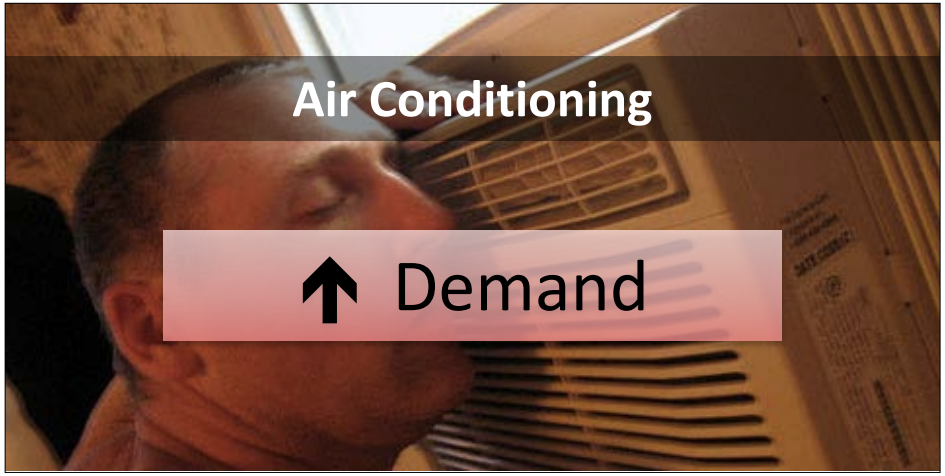
Spain shut down the Santa Maria de Garona reactor on the River Ebro, one of the country's eight nuclear plants which generate a fifth of its national electricity. Reactors in Germany are reported to have cut output, and others in Germany and France have been given special permits to dump hot water into rivers to avoid power failures. France, where nuclear power

Climate Change: General US Trends



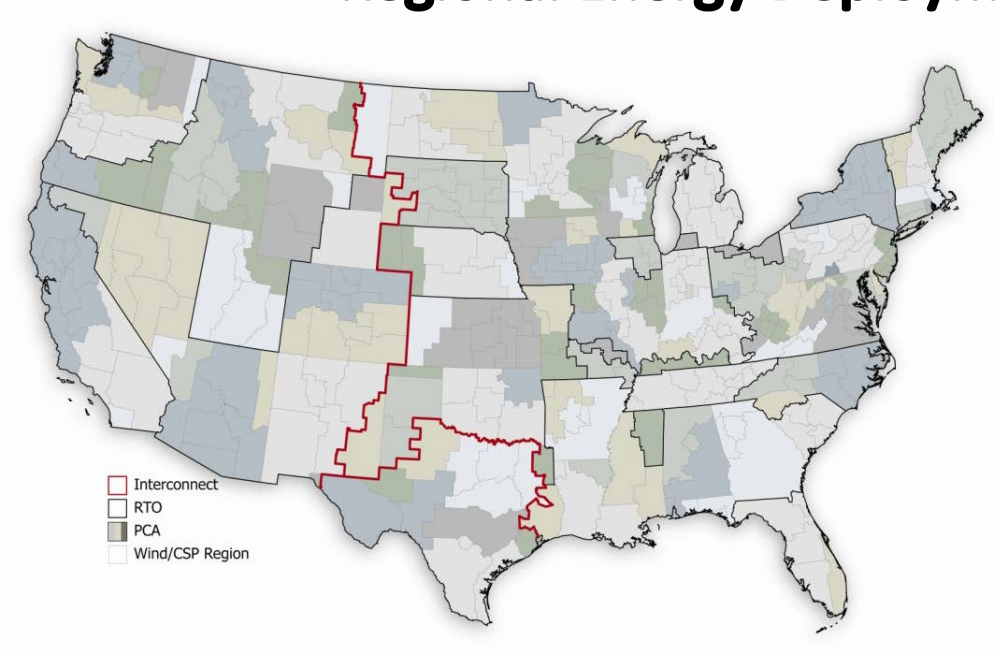






How will climate, weather, and changing population shift the dynamics of the energy-water nexus?

Regional Energy Deployment Model (ReEDS)



Generation technologies

- ✓ Coal (pulverized, IGCC, & IGCC-CCS)
- ✓ Nuclear
- ✓ Natural Gas (combustion turbine(NGCT), combined cycle(NGCC), & CC-CCS)
- ✓ Biomass (dedicated, cofired with coal, landfill-gas/MSW)
- ✓ Geothermal (hydrothermal & EGS)
- ✓ Hydropower, Marine Hydrokinetic
- ✓ Solar (concentrating solar power & PV)
- ✓ Wind (onshore & offshore)

Storage: pumped hydropower storage, CAES, batteries

Demand-side technologies: plug-in hybrid/electric vehicles (PHEVs), thermal energy storage in buildings, interruptible load

- **Spatially resolved into 356 wind/solar regions, 134 balancing areas (BAs) for demand and other renewables**
- **Serves load, meets planning and operating reserves requirements, and obeys physical constraints**
- **Policy & regulatory considerations**
- **Water availability constraint**

See also: Short, W.; Sullivan, P.; Mai, T.; Mowers, M.; Uriarte, C.; Blair, N.; Heimiller, D.; Martinez, A. (2011). Regional Energy Deployment System (ReEDS).NREL Report No. TP-6A20-46534.

Climate Scenario Selection

Scenario Selection: CMIP5

- Temperature (Reclamation, 2013)
- Hydrology (Wood & Mizukami, 2014)
- Colorado River Basin
- Summer/Fall Months (June–September)

Scenarios (2040–59)

- Hot-Dry, Hot-Wet, Mod Hot

Data Input

- Humidity, CDD, HDD, Water Availability
- Population: Ag, Municipal Water

Model Name	CMIP5 Scenario
Hot/Dry Scenario	
ACCESS1.0	RCP 8.5
CCSM4	RCP 6.0
HadGEM2-AO	RCP 8.5
HadGEM2-ES	RCP 8.5
MIROC-ESM-CHEM	RCP 4.5
Moderately Hot Scenario	
BCC_CSM1.1	RCP 8.5
CESM1(CAM5)	RCP 8.5
FGOALS-G2	RCP 4.5
INM-CM4	RCP 8.5
MPI-ESM-LR	RCP 4.5

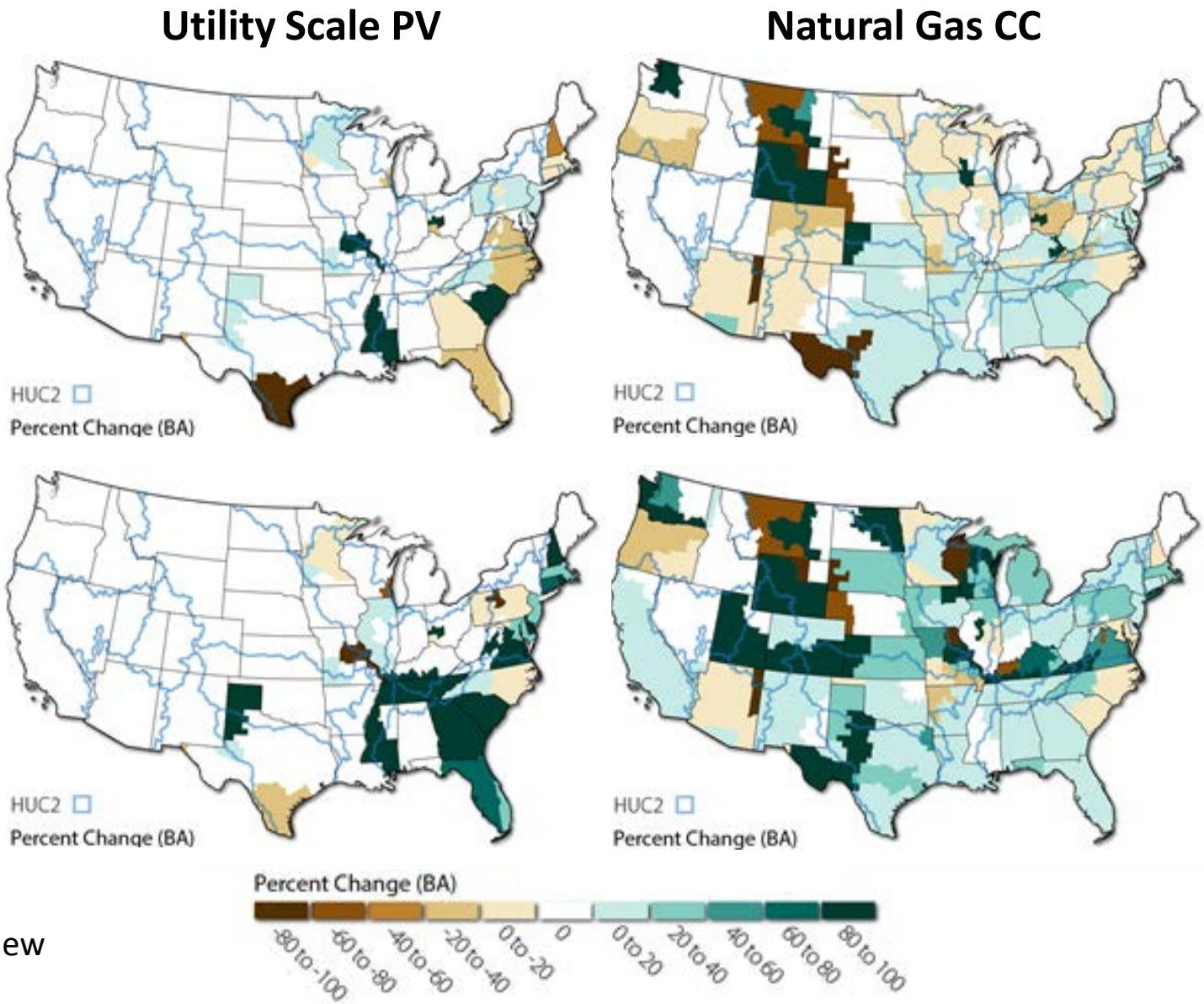
Cohen et al., Under Review

Electricity Generation (2050)

Increased water demand; current water supply

Hot & Dry Climate Scenario

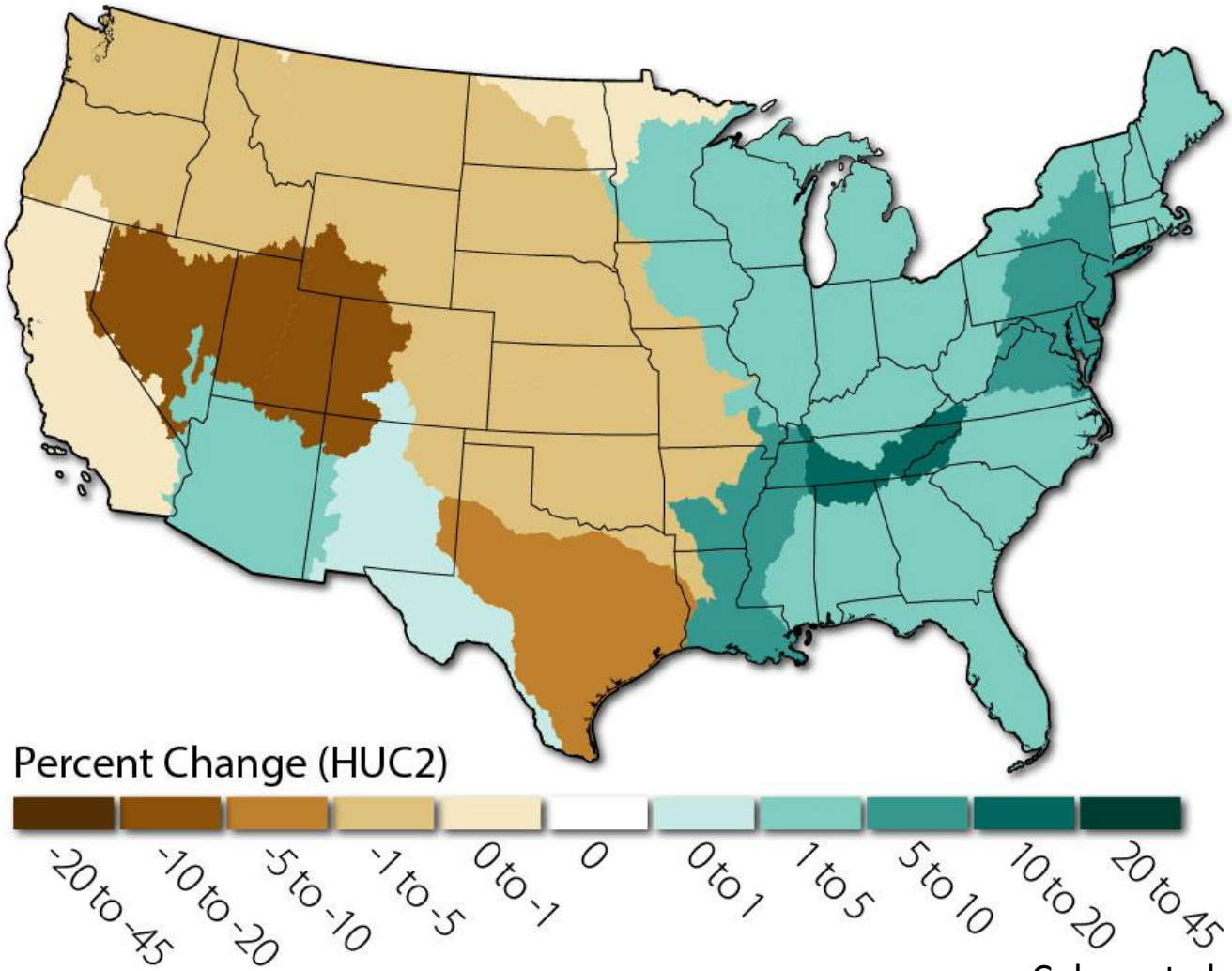
Water supply
Air temperature
Water temperature
Humidity



Cohen et al., Under Review

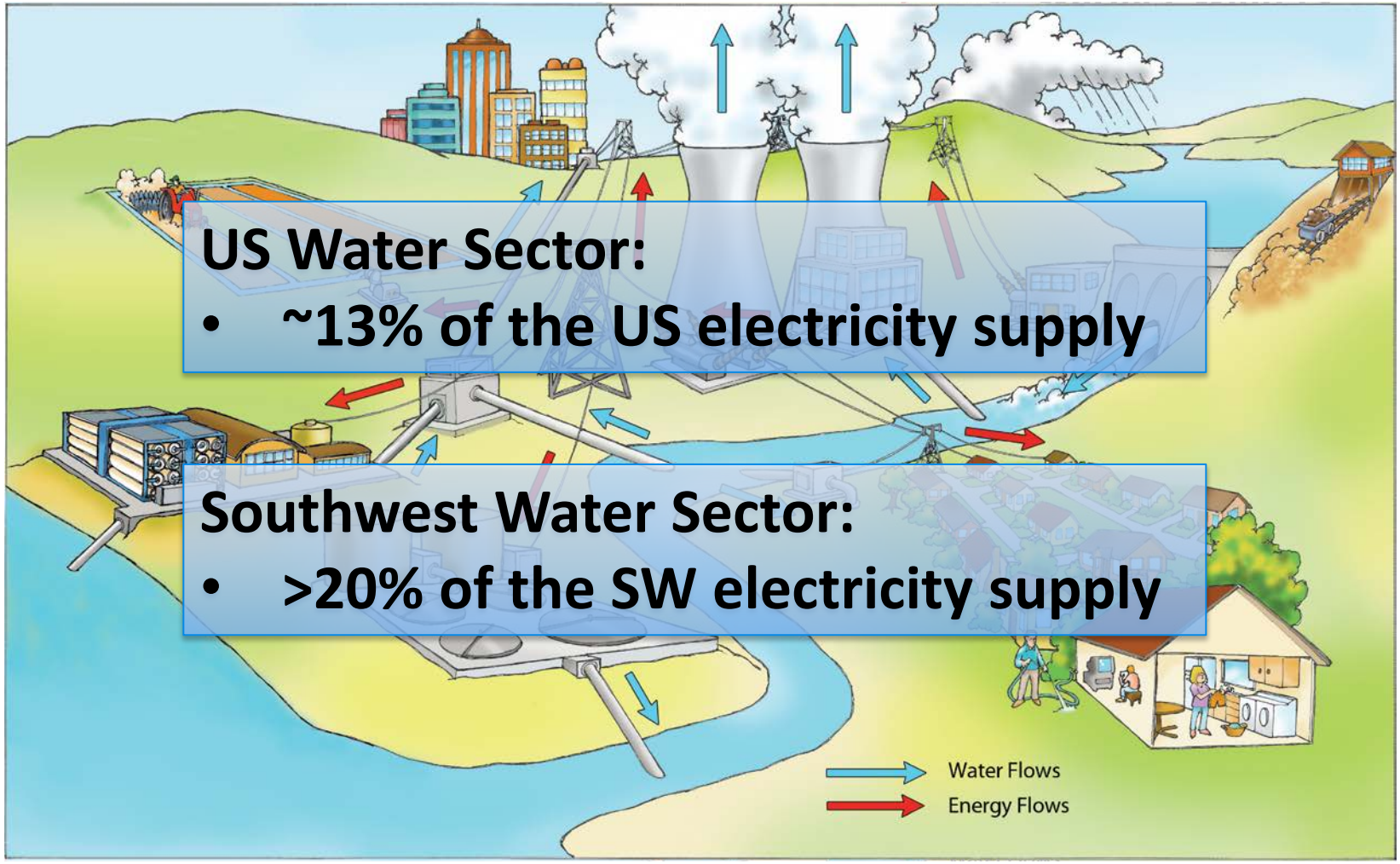
Water for Electricity (2050)

In some places, more water will be required for power generation in order to meet the electricity demands of a growing population in a hot climate.



Cohen et al., Under Review

Water Requires Power



US Water Sector:

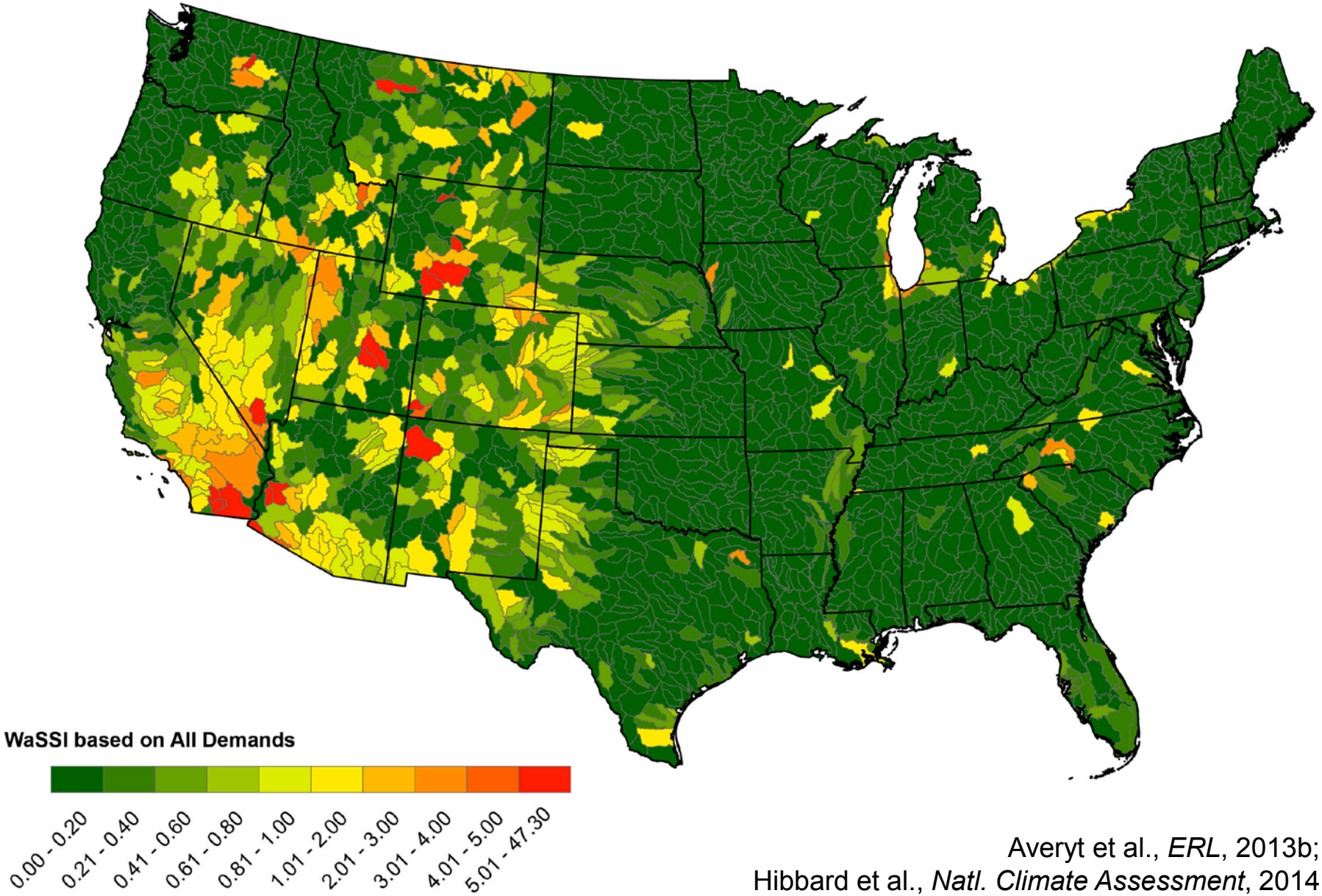
- ~13% of the US electricity supply

Southwest Water Sector:

- >20% of the SW electricity supply

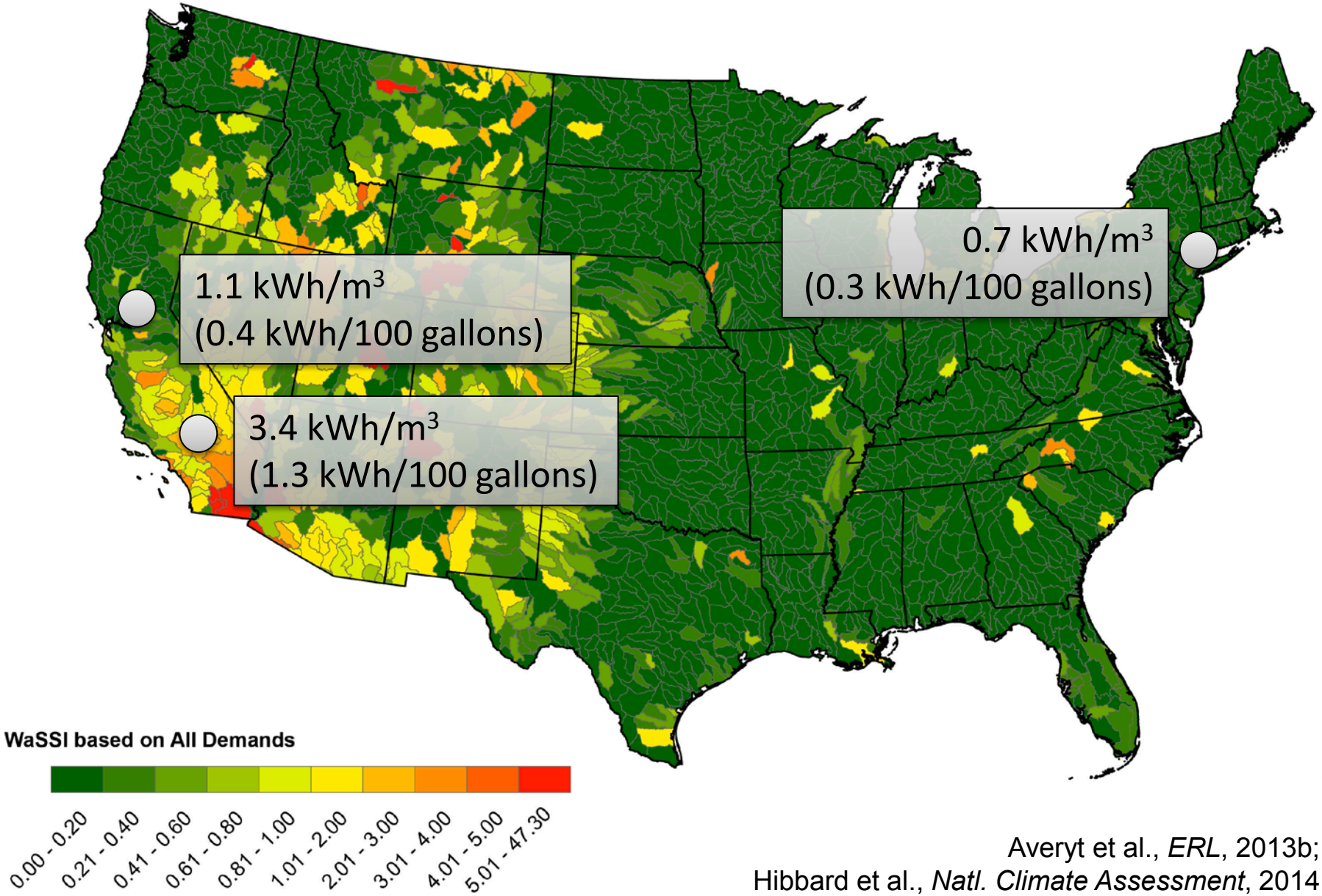
Source: DOE 2006

Water Supply Stress Index (WaSSI) (1999–2007)



Averyt et al., *ERL*, 2013b;
Hibbard et al., *Natl. Climate Assessment*, 2014

Power Intensity of Water Supplies



Averyt et al., *ERL*, 2013b;
Hibbard et al., *Natl. Climate Assessment*, 2014

Power Intensity of Major Water Projects

Water Deliveries: 14.8 km^3 (11.9 million acre-ft)

Pipelines & Canals: 4900 km (3000 miles)

Averyt, *American Scientist*, 2016

Navajo Generating Station

- 17,000,000 T of Carbon each year
- 24% of electricity generated is used by CAP

Central Arizona Project
US Bureau of Reclamation

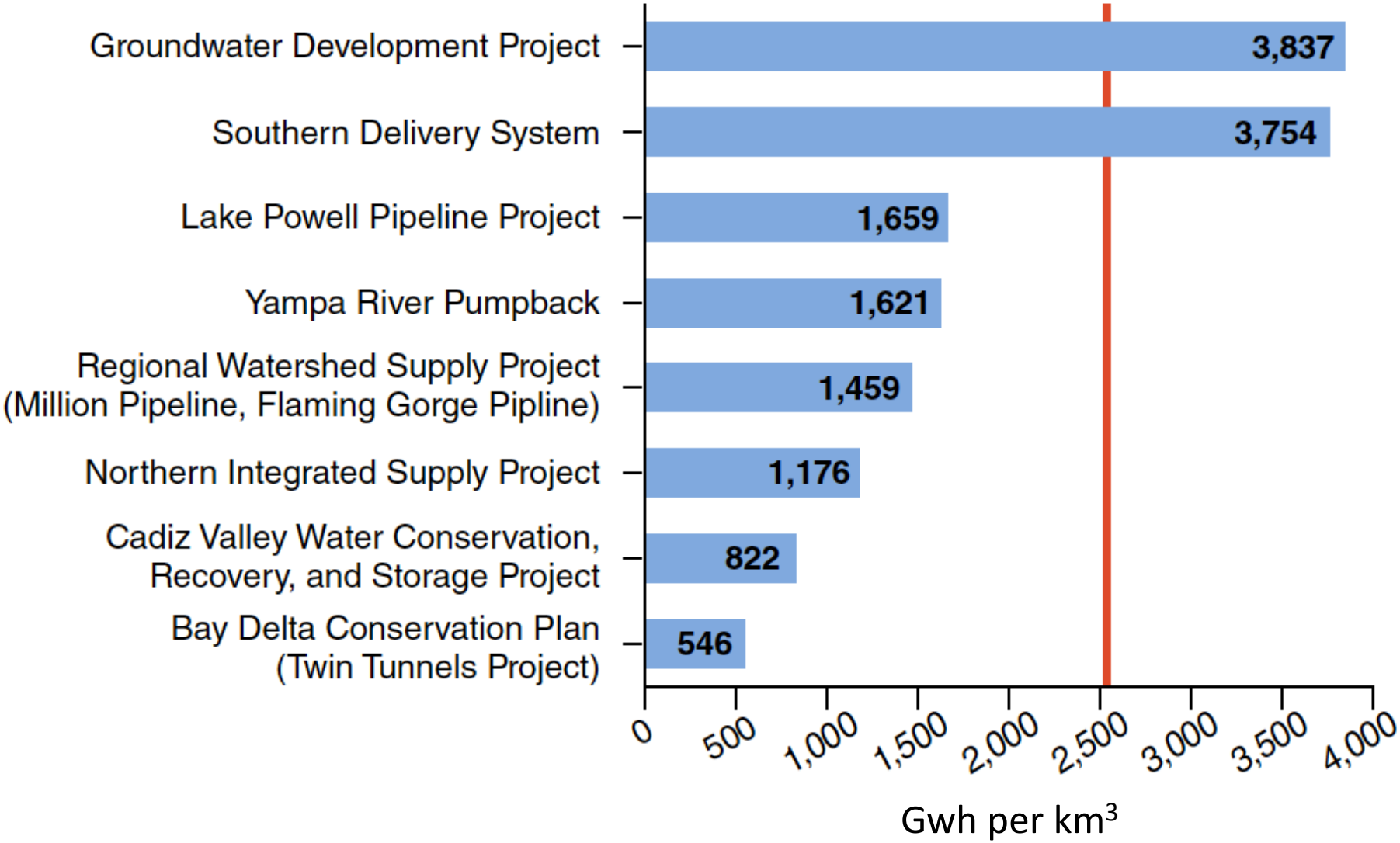
Power Intensity of Major Water Projects

Water Deliveries: 14.8 km^3 (11.9 million acre-ft)

Future Water Deliveries: 5.4 km^3 (4.5 million acre-ft)

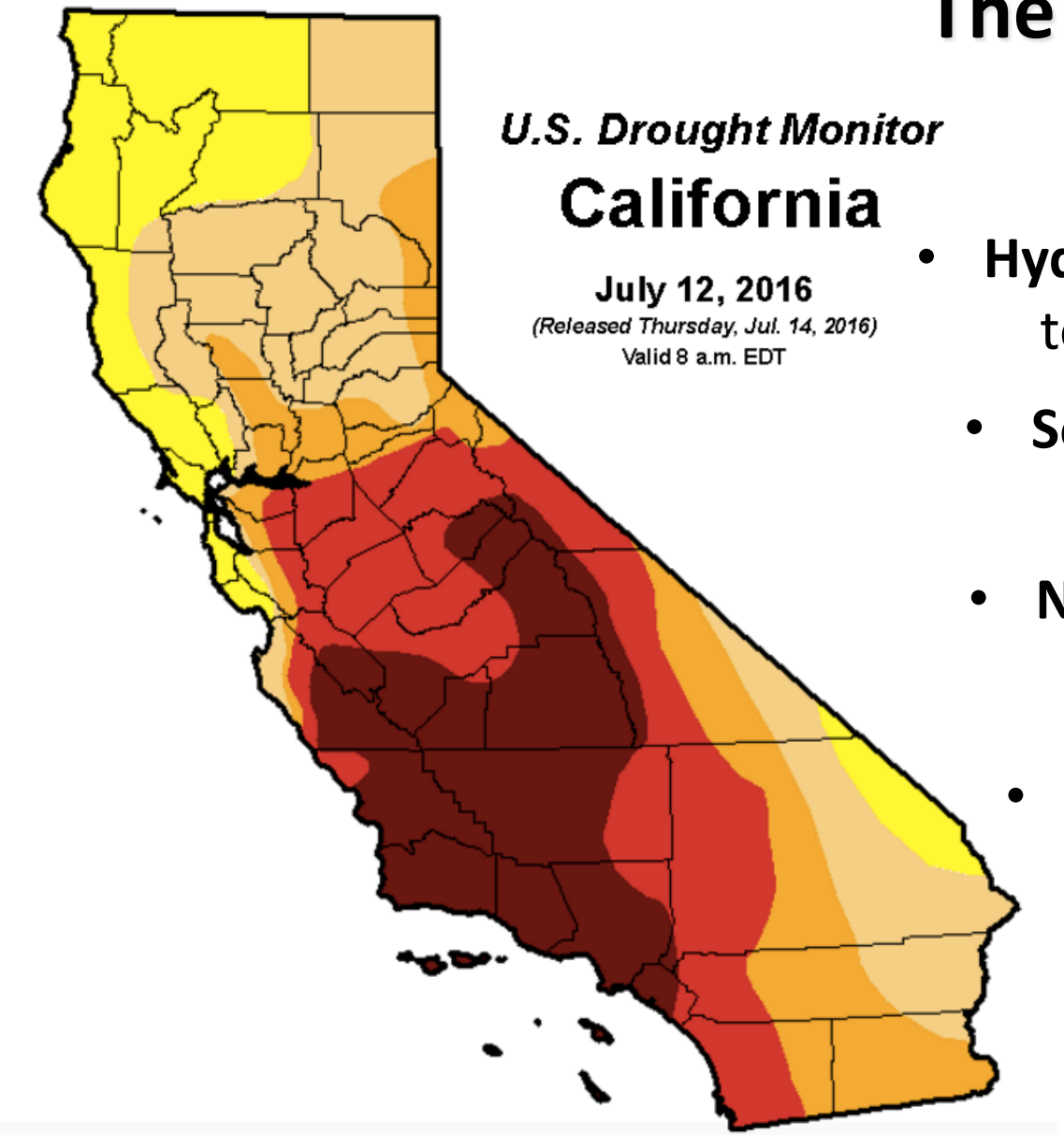
Averyt, *American Scientist*, 2016

(Gross) Power Intensity of Proposed Projects



Averyt, *American Scientist*, 2016; Averyt & Meldrum, unpublished data

The California Example 2011–15



- **Hydropower** decline from 20% to 12% of total generation
- **Solar and wind** increase to 30% of total generation
- **Nat gas** increase by 16% & C emissions by 8%
- **Agriculture (est. 2015):**
  $2.7B revenue loss
  $0.6B in pumping costs

Gleick et al., 2015; Howitt et all., 2015

Thank You!