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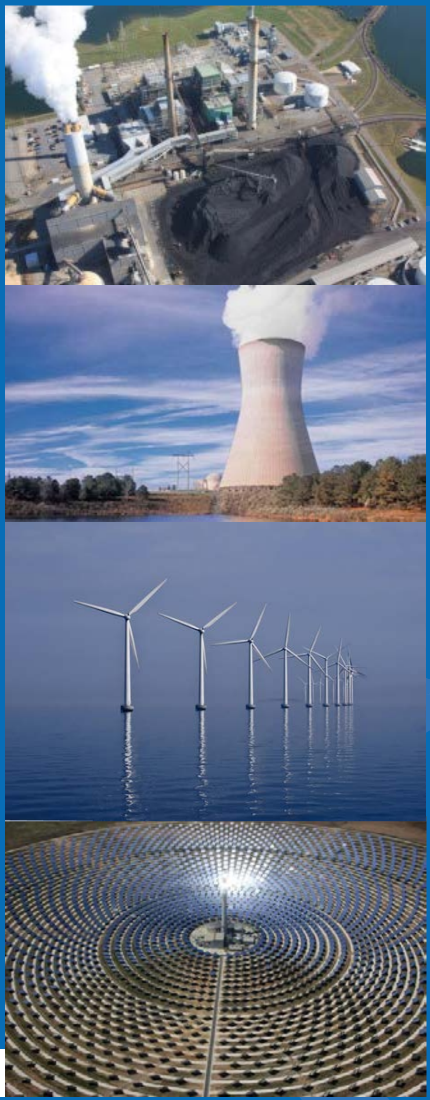

Water Use in the US Electric Power Sector: Energy Systems Level Perspectives

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2015 World Energy Engineering Congress
October 1, 2015

Overview and scope

- **The water-energy nexus in the electric sector**
- **Water demands of long-range electricity scenarios**
  - What are the aggregate water requirements of the U.S. electric power sector?
  - How could water requirements evolve under different long-range regional generation mixes?
- **Water demand from a life cycle perspective**
  - Beyond thermoelectric cooling water use
  - Water use for the fuel cycle: natural gas, coal, uranium, etc.
  - Water use for the materials/equipment/manufacturing of new power plants.

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Motivation and context

Growing attention to the water-energy nexus

- Thermoelectric power competes with irrigation for largest <u>total</u> water withdrawals, and <u>freshwater</u> withdrawals
  - Thermoelectric and irrigation comprise 45% and 32% of 2010 <u>total</u> withdrawals, respectively
- Freshwater consumption is small at 2-6% but possibly growing

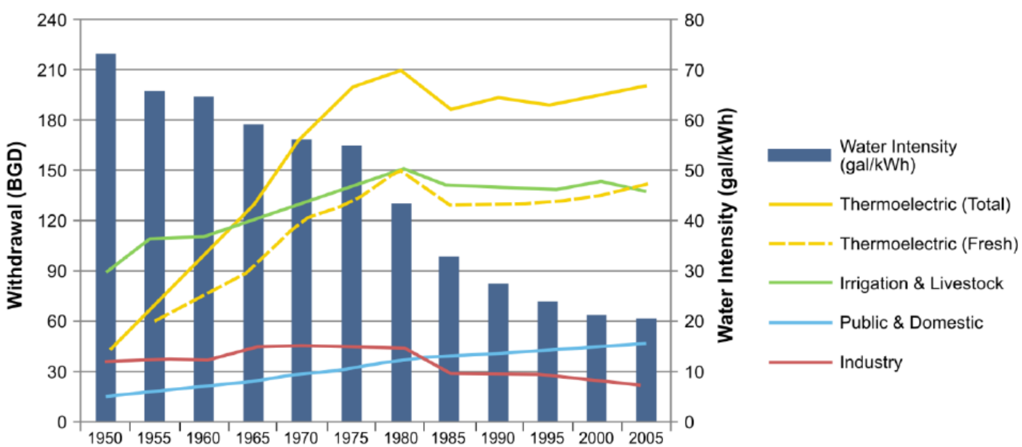

Figure 2. Water use for thermoelectric generation and other sectors.

Source: DOE (2014) The Water-Energy Nexus: Challenges and Opportunities

Increasing federal focus on need for better data and analyses, e.g.:

- Improvements in data on power plant water use
- Characterization of possible trends in water use into the future

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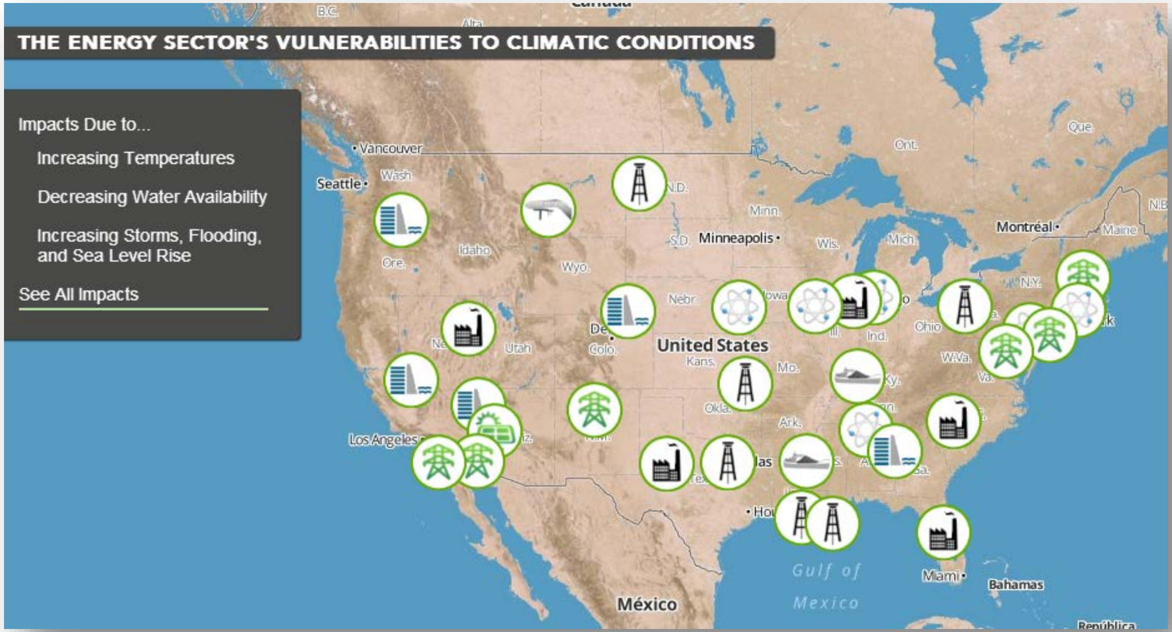
Water-energy-climate nexus

Vulnerabilities

- Water use by the electric sector has been identified by the DOE as a climate-related vulnerability
- Hydropower and thermoelectric cooling most impacted

Opportunities

- There are potential co-benefits for water use from changeover to higher efficiency power generation
- Renewables may offer benefits in terms of low operational water usage



Some specific impacts of temperature change

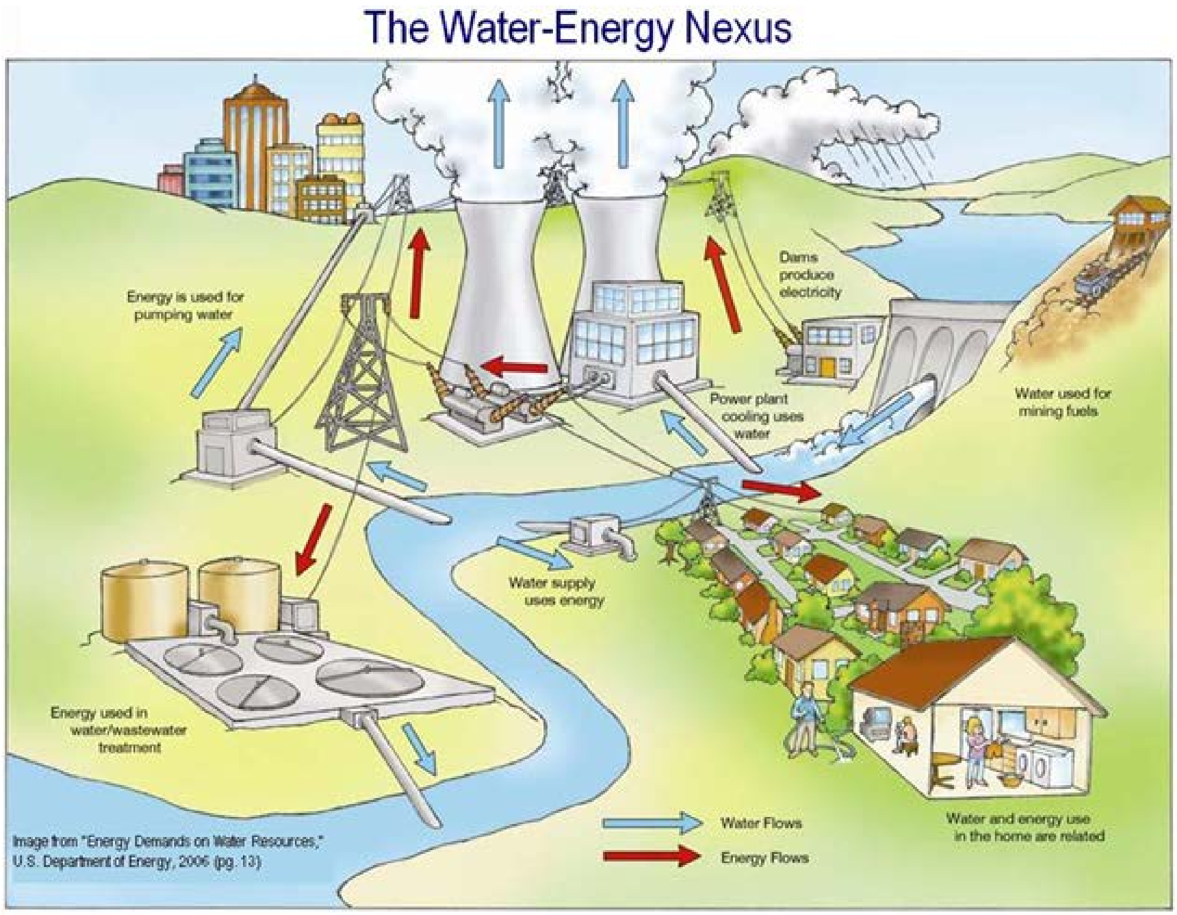
- Electricity demand side: changes in heating and cooling degree days will affect end-use electricity demands, both levels and timing
- Electricity supply side: changes in ambient air and surface water temperatures may affect cooling efficiency and even availability of generation capacity

Source: Jaglom et al. (2015)

Electric sector water use

Water withdrawal is the total amount of water diverted from nearby water bodies such as rivers and lakes.

Water consumption is the amount of water lost to evaporation as a result of the cooling process and emissions controls such as flue-gas desulfurization and carbon capture.

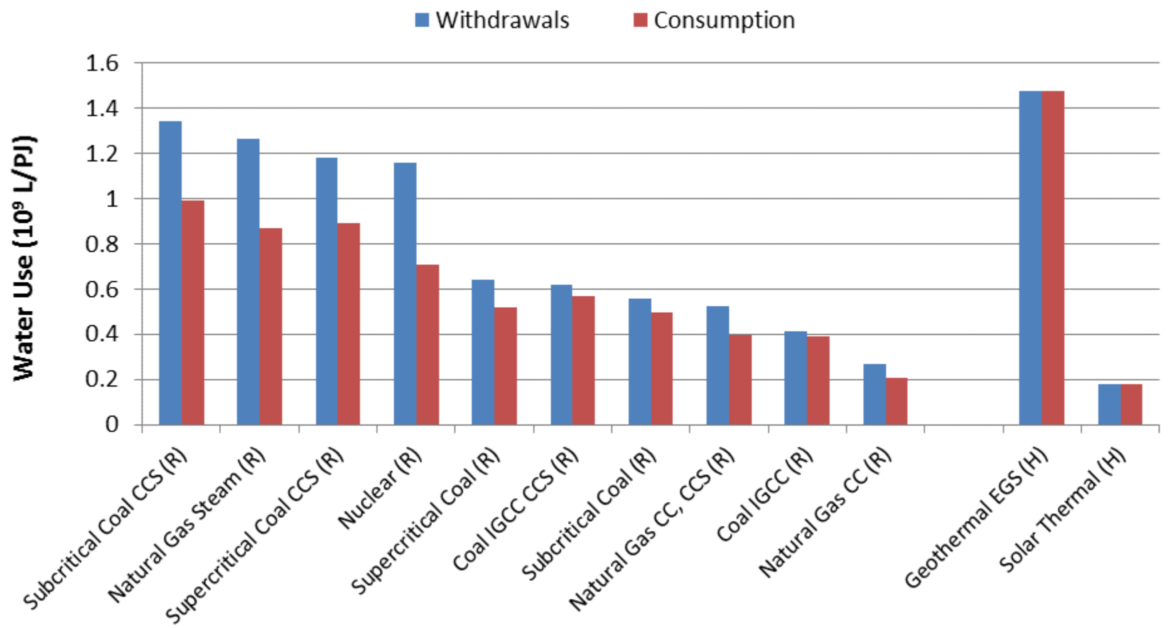


Source: U.S. DOE (2006) Energy Demands on Water Resources

Operational water use by technology/generation and cooling type

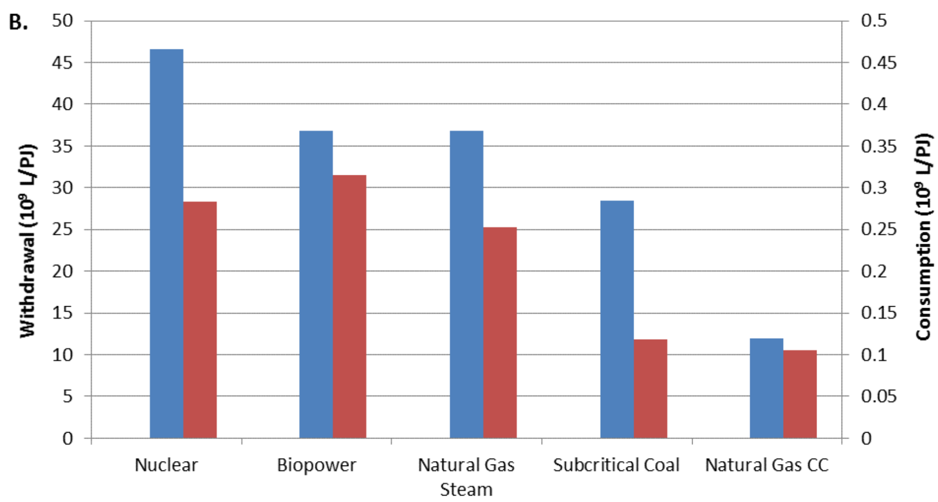
Water factors for **recirculating** cooling systems

Consumption is on the same scale, but slightly lower than withdrawals



Water factors for **once- through** cooling systems

Note the difference in scale for withdrawals compared to consumption



Source: Cameron et al. (2014), based on data from Macknick et al. (2011, 2012)

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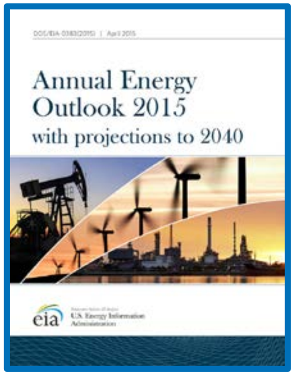
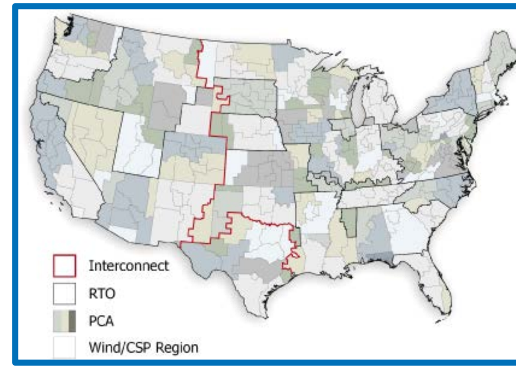
Water demands of long-range electricity scenarios

An active area of research: and many energy models



EIA's Annual Energy Outlook (AEO)

AEO is a key reference and data source for many energy models. Earlier AEO projections were used by a number of researchers to calculate water use based on scenarios

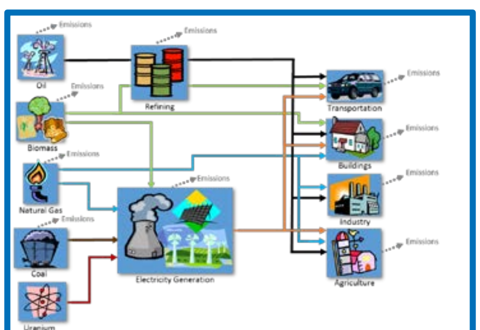


Pacific NW National Laboratory

PNNL are more recent entrants to the water-energy modeling literature. Their Global Change Assessment Model (GCAM) has global coverage and multiple economic sectors (incl. land use) beyond the electric power sector.

DOE's National Renewable Energy Laboratory (NREL)

Comprehensive analysis with ReEDS model, also same group that developed widely-used water factors. Part of a large multi-institution research effort: Energy and Water in a Warming World (EW3) Initiative.



U.S. EPA's Office of Research and Development (ORD)

Using MARKAL energy systems database and analysis, with a strong existing air component. Coverage is full US energy system.

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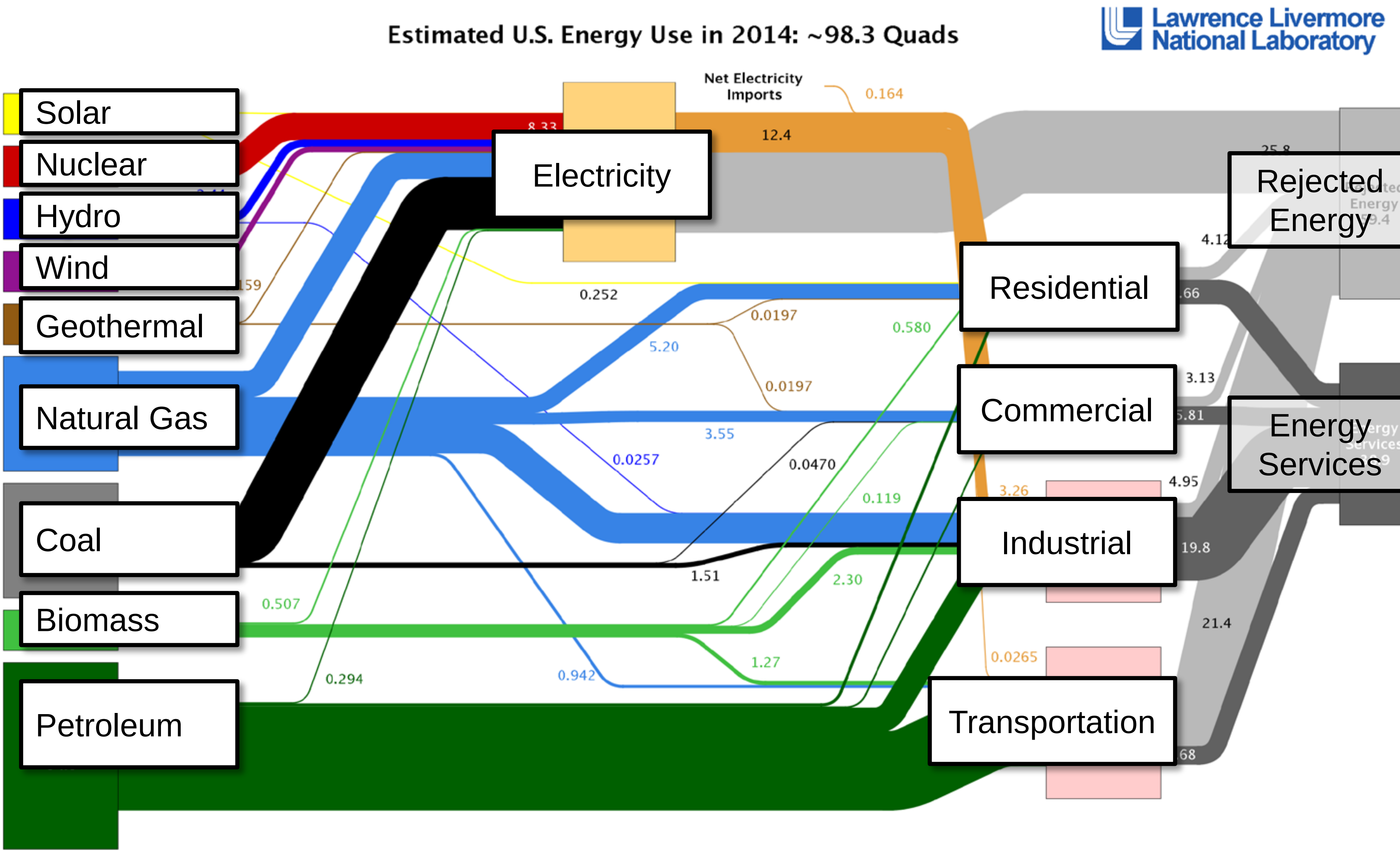
Energy systems perspective



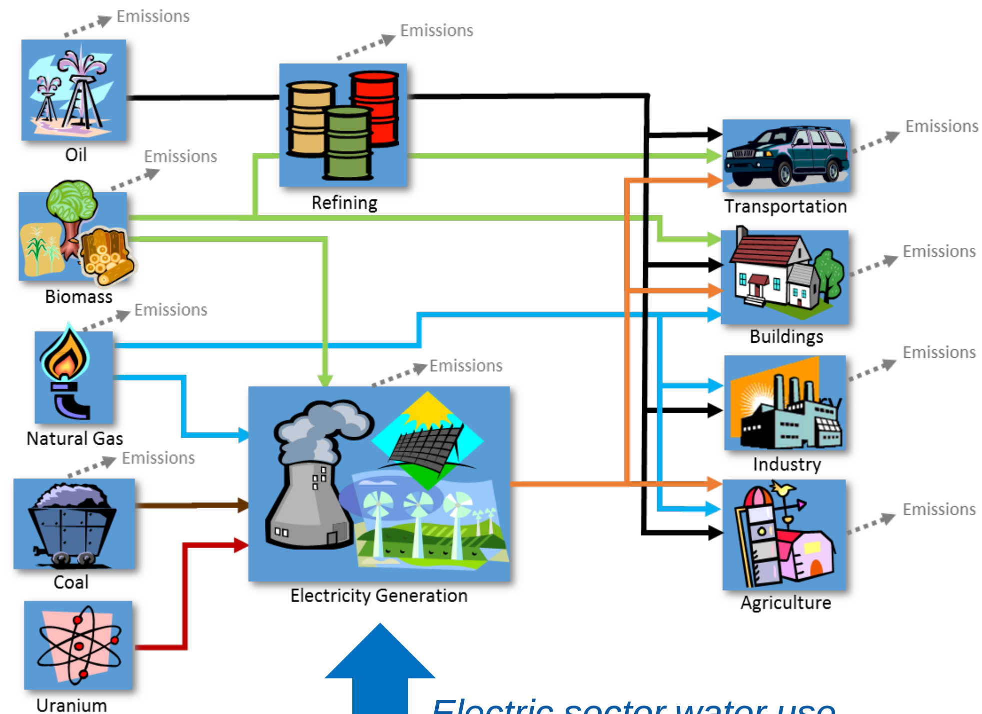
Source: LLNL 2015. Data is based on DOE/EIA-0035(2015-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Background on methods

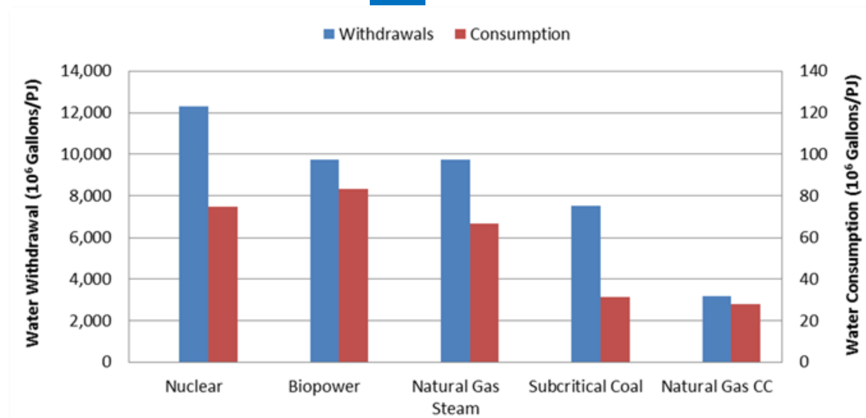
Energy systems modeling in ORD

- MARKAL (MARKet ALlocation) model is an energy modeling platform used internationally
- ORD has developed & maintains a publicly available database
  - Regional model at Census Divison level (EPAUS9r_14)

- Optimizes fuel and technology choices to minimize total system cost
  - Primary resources
  - Conversion technologies
  - End-use demands
- Most applications have been focused on air and climate
- Have incorporated water withdrawals and consumption



Electric sector water use



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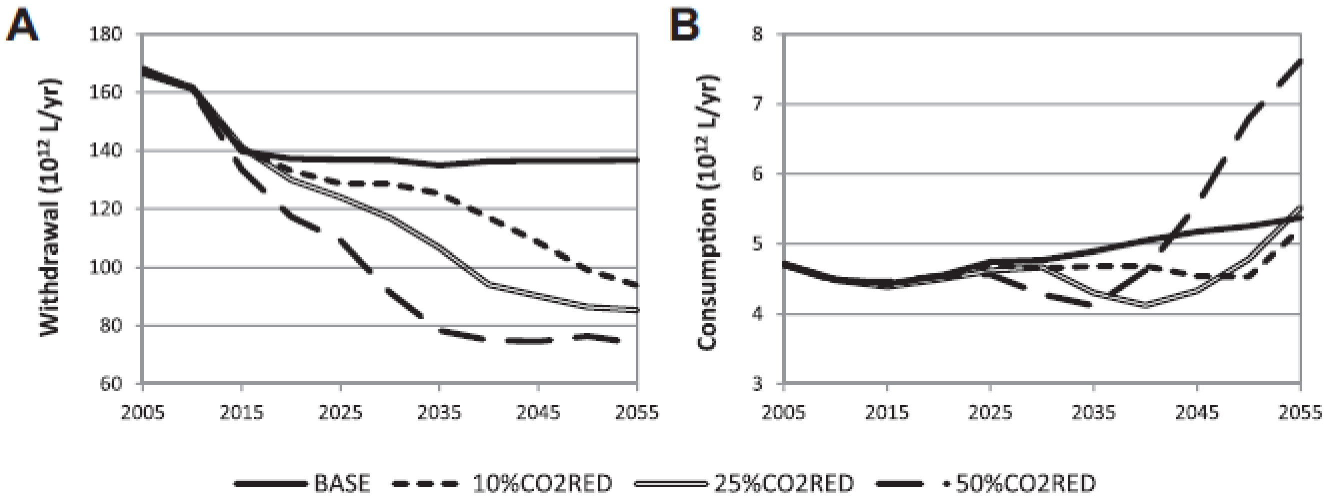
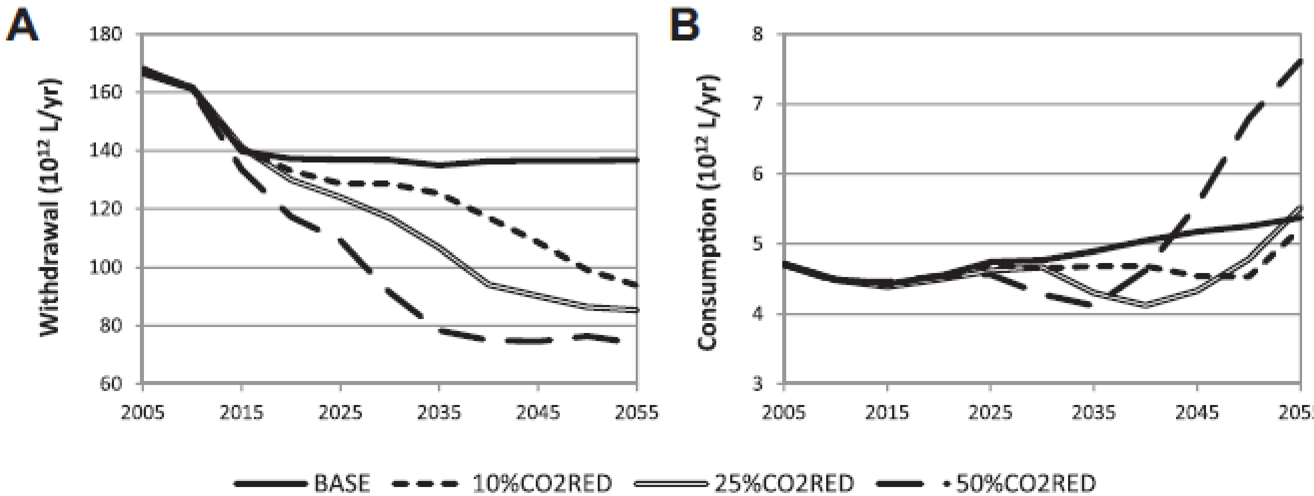
What were the impacts on overall water withdrawals and consumption?



- **Withdrawals (A)** were lower than 2005 levels for all scenarios, including baseline
  - Lower withdrawals as CO_2 reductions were more stringent (scenarios include a Base and 10%, 25% and 50% reduction in energy system-wide CO_2 levels from 2005)
  - Driven by replacement/retirement of existing thermoelectric power, primarily coal-fired, with once-through cooling systems
  - Share of total once-through systems fell to 5% of total generation capacity under the 50% reduction scenario (relative to 19% in base), which has implications for heat discharge

Source: Cameron et al. (2014)

What were the impacts on overall water withdrawals and consumption?



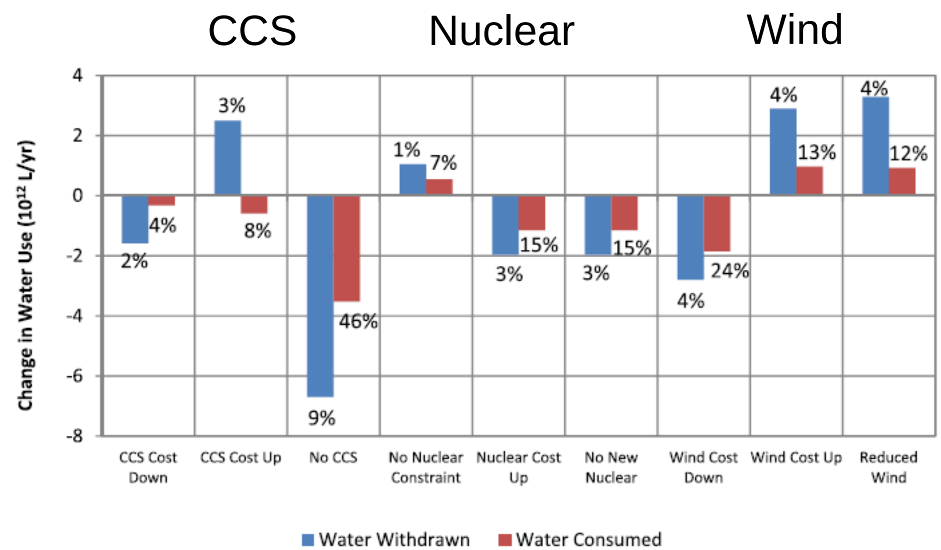
- **Consumption (B)** was higher than 2005 levels for all scenarios, including baseline
  - All except the 50% CO_2 reduction scenario were at or below the 2055 baseline consumption levels
  - Replacement/retirement of existing once-through systems leads to decreases in middle years for 10%, 25%, 50% reduction scenarios
  - In later years, increases water-intensive CCS technologies and increases in electricity demand bring consumption levels back up

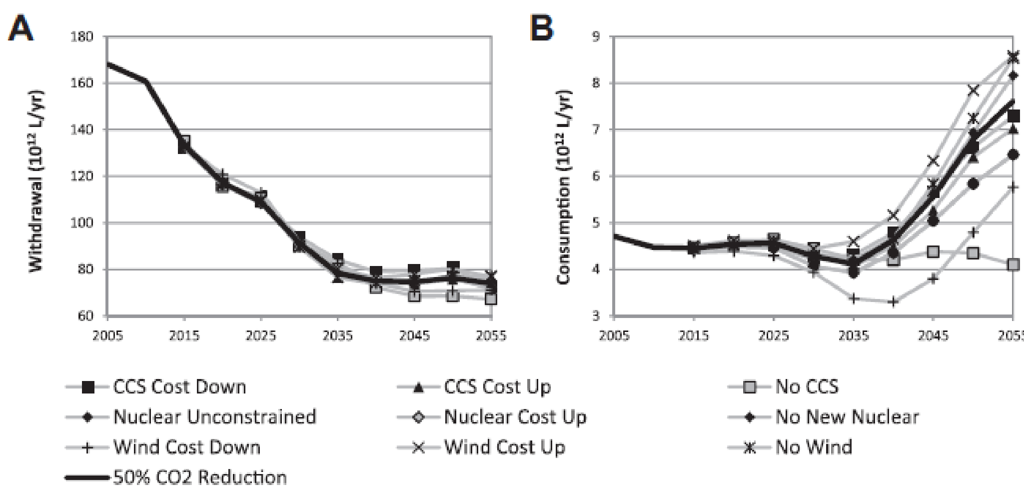
Source: Cameron et al. (2014)

Robustness: how sensitive are the results to technology assumptions?

Restrictions or higher investment cost assumptions for nuclear and CCS will generally bring water use down

Optimistic cost assumptions for wind will lower water use, restrictions and higher wind costs will increase water use





Withdrawals (A) varied relatively little (13%) for the 50% CO2 reduction scenario

Consumption (B) was more sensitive to assumptions regarding technology cost or availability

Source: Cameron et al. (2014)

Different models, similar trends

NREL modeling results have similar general trends to Cameron et al. (2014) for national consumption and withdrawals

Results from GCAM by PNNL also show withdrawals falling due to carbon constraints

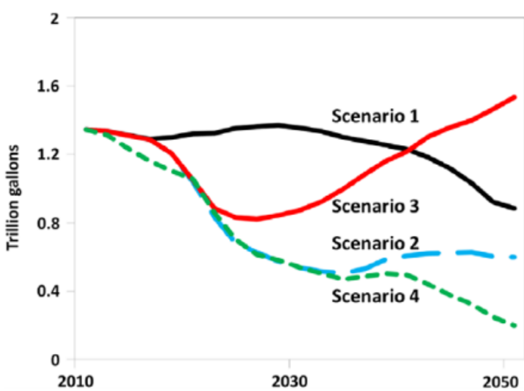


Figure 5. National-level water consumption results for four electricity scenarios. Scenario 1, reference case; scenario 2, carbon budget, no technology targets; scenario 3, carbon budget with coal with CCS and nuclear targets; scenario 4, carbon budget with efficiency and renewable energy targets.

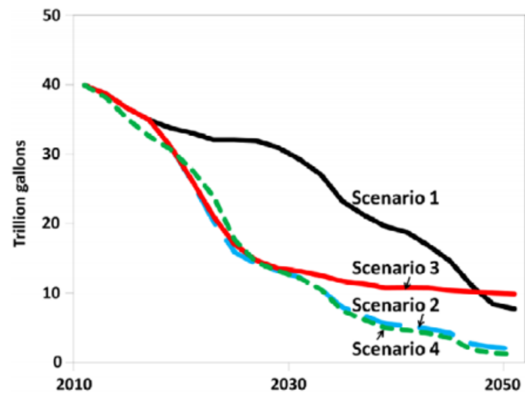


Figure 3. National-level water withdrawal results for four electricity scenarios. Scenario 1, reference case; scenario 2, carbon budget, no technology targets; scenario 3, carbon budget with coal with CCS and nuclear targets; scenario 4, carbon budget with efficiency and renewable energy targets.

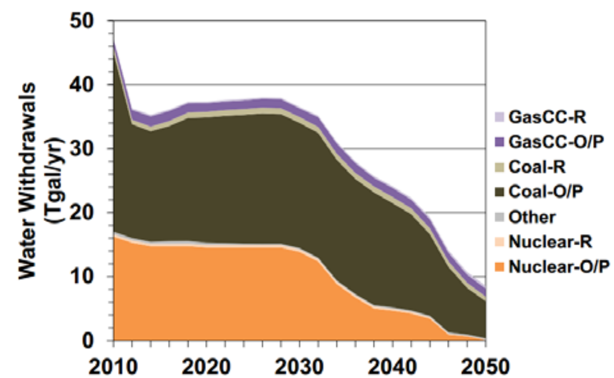


Figure 8: Water withdrawals fall over time as retired once-through cooled systems are replaced by GasCC with recirculating cooling.

Consumption can go up or down relative to 2010

Withdrawals are lower than 2010 in all scenarios, but the rate of change and levels differ

Assumptions about key technologies, like **nuclear**, are critical and can vary widely between models

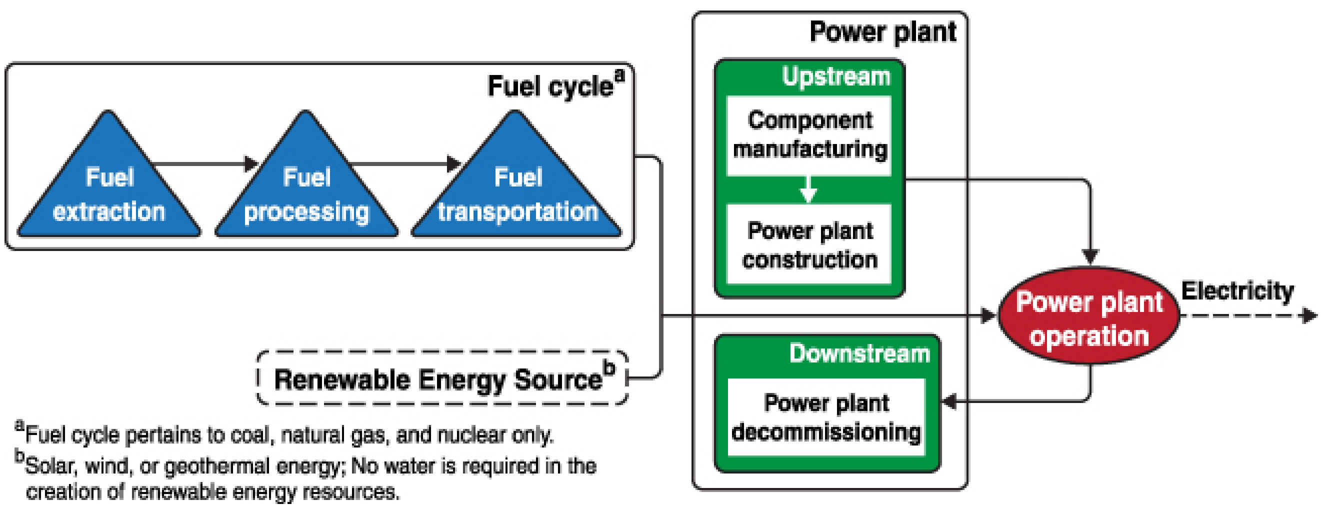
Source: Macknick et al. (2012)

Source: Cohen (2014)

Water demand from a life cycle perspective

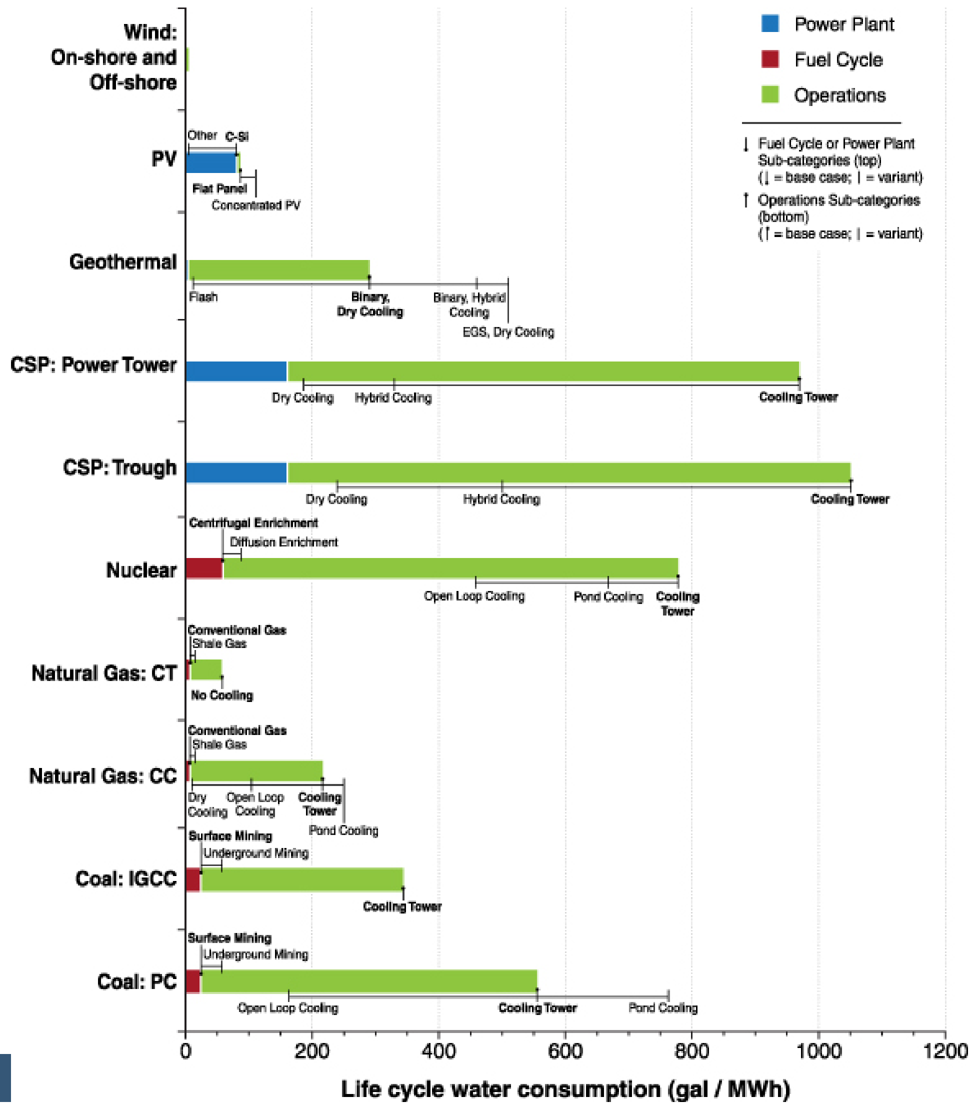
Water demands for the full electricity generation pathway

- We have focused on power plant operational water use, primarily for cooling
- What is the contribution of the fuel cycle and power plant manufacturing, construction, and decommissioning?
- How does this differ for renewables and non-renewable energy sources?



Source: Meldrum et al. (2013)

Water demands for the full electricity generation pathway



Source: Meldrum et al. (2013)

- Operational water use still dominates
- Fuel cycle can contribute to total life cycle water demands
    - Coal
    - Natural gas
    - Uranium
- Power plant manufacturing & construction water use can be a significant contributor for renewable pathways
    - PV
    - Concentrating Solar Power (CSP)

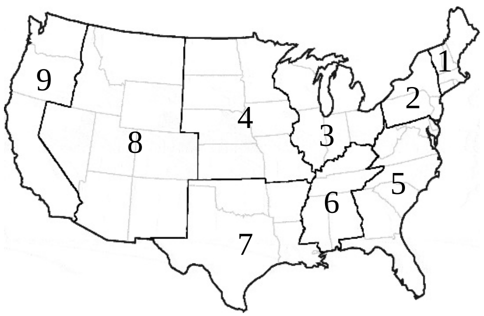
- Missing from this list, biomass fuel cycle water use
- We know this can be substantial based on studies for biofuels for transportation

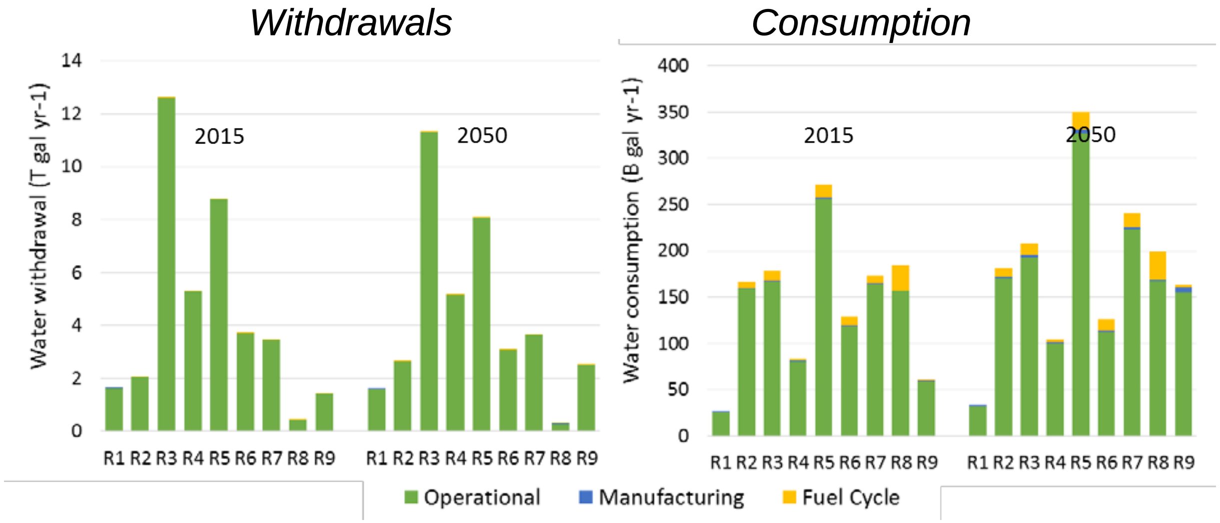
Life cycle water demands under different mix of generation types

Preliminary Results

- Coupling an energy system model (EPA's US 9-region (EPAUS9r) MARKAL model) with life cycle water use factors (Meldrum et al. 2013)

MARKAL EPAUS9r regions





Source: Dodder et al. (preliminary results)

- Under a business as usual (BAU) scenario, for most regions, *consumption* is up, *withdrawals* are down
- The relative shares of life cycle water use do not vary considerably

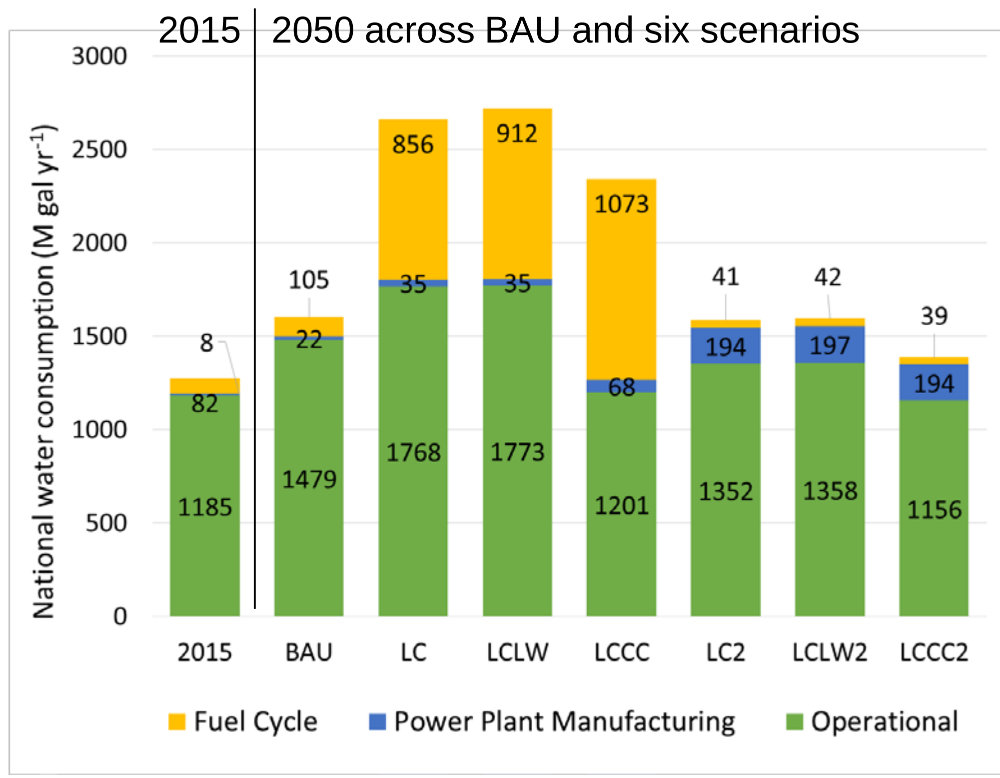
Different scenarios, different demands and life cycle impacts

Alternative scenarios

- We modeled a range of scenarios (see table)
- Included both carbon reductions and water use limits
- Incorporated biomass fuel cycle water demand for biopower options

Preliminary results

- Scenarios that lead to high use of biomass for electricity substantially increased the fuel cycle water use
- Scenarios with increased solar, particularly CSP, increase manufacturing relative to operational water use



Dodder et al. (preliminary results)

	w/ biomass-CCS	w/o biomass-CCS
Business as usual	BAU	
Low carbon (↓ 50% between 2005-55)	LC	LC_2
Low carbon + low withdrawal (↓ 50%)	LC+LW	LC+LW_2
Low carbon + constant consumption (= 2005)	LC+CC	LC+CC_2

Summary

- The water-energy nexus is critical and has key climate linkages

- Systems-based modeling of water demands for electricity production have substantially advanced our understanding of the water-energy nexus
  - withdrawals are generally falling while consumption trends are more scenario dependent

- Scenarios of limiting CO_2 from the electric sector show that how we decarbonize the electric sector has a substantial influence on water demands
  - Impacts on operational water use can be significant
  - Wind and solar PV shift system to lower operational water use
  - Retirements of once-through facilities speed withdrawal decreases
  - CCS, nuclear and CSP can drive consumption higher

- Both energy system modeling and life cycle approaches are key to understanding potential trade-offs and co-benefits between CO_2 and water
  - Biomass fuel cycle water use and CSP manufacturing water demand merit additional study