Framing the Energy-Water Nexus: a US perspective

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

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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)

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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

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

Source: Tidwell et al (forthcoming)

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

US water withdrawals by category and State: 2005

\[\text{Irrigation dominated withdrawals} \text{ in many Western States, especially those with only minor thermoelectric-power withdrawals.} \]

Generally, \textit{thermoelectric power} was the largest category of water withdrawal in the Eastern States.

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


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*

**Climate Change**

- Increasing temperature
- Limited water availability
- Sea level rise
- Increasing frequency and intensity of storms and flooding

**Energy Sector Impacts**

- Oil and gas exploration and production
- Fuel transport
- Thermoelectric power
- Hydropower
- Wind energy
- Solar energy
- Bioenergy
- Electric grid
- Electricity demand
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.

Substantial amounts of water are used in fuel extraction/processing

*Future energy development will put new demands on water resources*

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

![Water Used for Fuel Extraction and Processing](chart)

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

Note: most frack fluids in Pennsylvania now being recycled

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

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.

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:
Water consumption across life cycle stages for representative facilities

Some advanced technologies are even more water-intensive

Operational water consumption factors for electricity generating technologies

Operational water consumption (Gal/MWh)

Adding CCS

Source: Macknick et al. 2011
Water intensity of transportation fuels is likely to increase

TOTAL LIFE CYCLE WATER USE FOR 2022 E85

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);
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

Likely to increase in future
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

- Desalination is growing at 10% per year,
- Waste water reuse is growing at 15% per year,

Energy Use, MJ/m³ vs. Salinity (ppm)

- Brackish Water
- Sea Water
- Reverse Osmosis
- Electroosmotic

Courtesy, Mike Hightower
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
Energy intensity of end use: California’s surprise

Table 3: 2001 Water-Related Energy Use in California

<table>
<thead>
<tr>
<th></th>
<th>Electricity (GWh)</th>
<th>Natural Gas (Mill. Therms)</th>
<th>Diesel (Mill. Gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Supply and Treatment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>7,554</td>
<td>19</td>
<td>?</td>
</tr>
<tr>
<td>Agricultural</td>
<td>3,188</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>End Uses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural</td>
<td>7,372</td>
<td>18</td>
<td>88</td>
</tr>
<tr>
<td>Residential</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>27,887</td>
<td>4,220</td>
<td>?</td>
</tr>
<tr>
<td>Industrial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wastewater Treatment</strong></td>
<td>2,012</td>
<td>27</td>
<td>?</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>48,012</td>
<td>4,284</td>
<td>88</td>
</tr>
</tbody>
</table>

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

Data Gaps
- Outdated national-level data on energy consumption by water and wastewater plants
- Incomplete data for water-related end-uses (especially in non-residential sectors)
- Poor accounting for losses and leaks (state public use and losses report 3-41% of the total public supply)
- 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.

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. (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
- Very limited nature by which water and energy planning is done in an integrated fashion (few local/regional efforts, plus WECC/ERCOT study. *This may in itself reflect an opportunity or gap

--Sanders and Webber, 2013
--Averyt et al., 2011
--Tidwell (pers comm.)
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

<table>
<thead>
<tr>
<th>Technology</th>
<th>Number of plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste water</td>
<td>823</td>
</tr>
<tr>
<td>Brackish water</td>
<td>109</td>
</tr>
<tr>
<td>Dry cooling</td>
<td>246</td>
</tr>
</tbody>
</table>

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 affects national trends in power sector water intensity.

Consumption decreases to different extents.

Regional impacts vary.

Climate change may enhance impacts locally and regionally.

A low-carbon future may also require less water.

Source: Newmark et al., 2011
The Balancing Act...

Interdependence

Global governance failures

Economic disparity

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

The Changing Climate

Food security
- Food crisis
- Social unrest

Water intensity of food production

Water security
- Chronic shortages
- Drag on growth
- Water crisis
- Social unrest

Energy intensity of water production

Energy security
- Chronic shortages
- Drag on growth
- Energy crisis
- Economic damage
- Social unrest

Energy intensity of food production

Population and economic growth

Environmental pressures

Demographics
Social Media
Public Perceptions

Source:
World Economic Forum
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