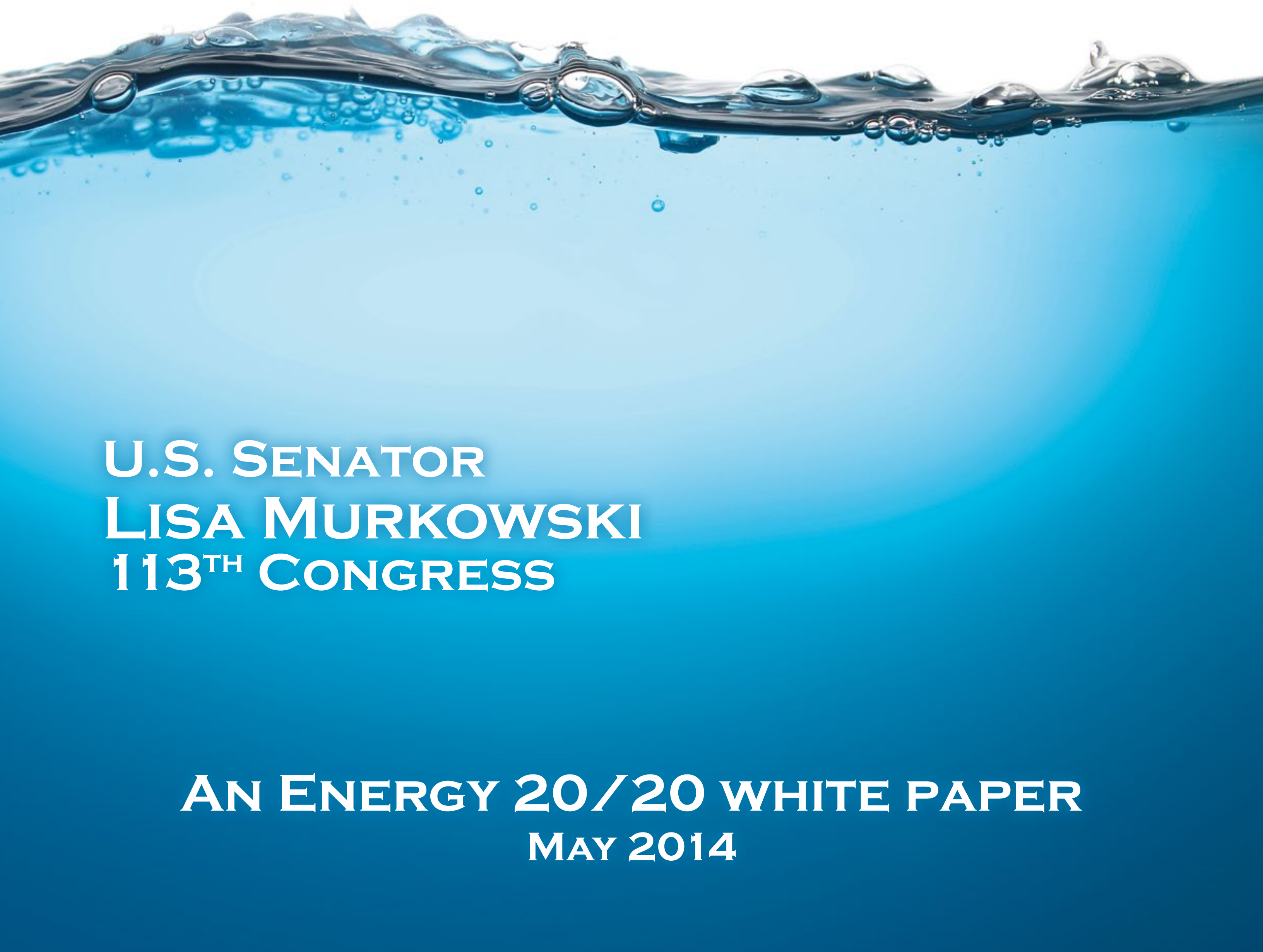
The Energy-Water Nexus

Interlinked Resources That Are Vital For Economic Growth and Sustainability



U.S. Senator
Lisa Murkowski
113th Congress

An Energy 20/20 white paper

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Energy-for-Water & Water-for-Energy

In many ways, energy and water resources go hand in hand. Water supports life while energy is the foundation of our economy and both are essential to our nation's future and security.

The Energy-Water Nexus

Source of the four images: http://www.epa.gov/microbes/research/drinkingwater.html; www.ferc.gov; http://www.energy4me.org/energy-facts/energy-sources/; http://abstract.desktopnexus.com/wallpaper/658658/

Providing affordable, secure, and sustainable[1] energy and water supplies are universal goals that are challenging to achieve.

[1] The Merriam-Webster Dictionary defines "sustainable" as: *of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged*. This definition recognizes that human

All forms of energy production, energy distribution, fuel extraction, and fuel refinement require water or affect water resources in some way. Every aspect of treatment, transport, and distribution of water, as well as the treatment and reuse of wastewater, is dependent on sufficient and reliable energy. Moreover, energy use by these systems is significant regionally. The interdependencies between the two are clear, though often tested during periods of water stress, as demonstrated presently by the ongoing western area drought, other extreme temperatures events, or prolonged electricity outages. It is in our own best interest to preserve, secure, and strengthen these critical energy and water resources.

To better understand how these energy-water resources can be improved, we must be better informed, and armed with better information; we must adopt more effective strategies for water and for energy. Moreover, many relevant technological advancements are well beyond the demonstration project stages and have been implemented in certain sectors. Still, enormous potential exists to increase the efficiency, conservation, and production of both energy and water and help achieve technological advancements.

This paper presents an overview of the interdependencies between energy and water, as well as key challenges and opportunities. It provides a series of recommendations on how the federal government, in partnership with external stakeholders, can take a leadership role in not only promoting a better understanding of this "energy-water nexus," but realizing its full potential.

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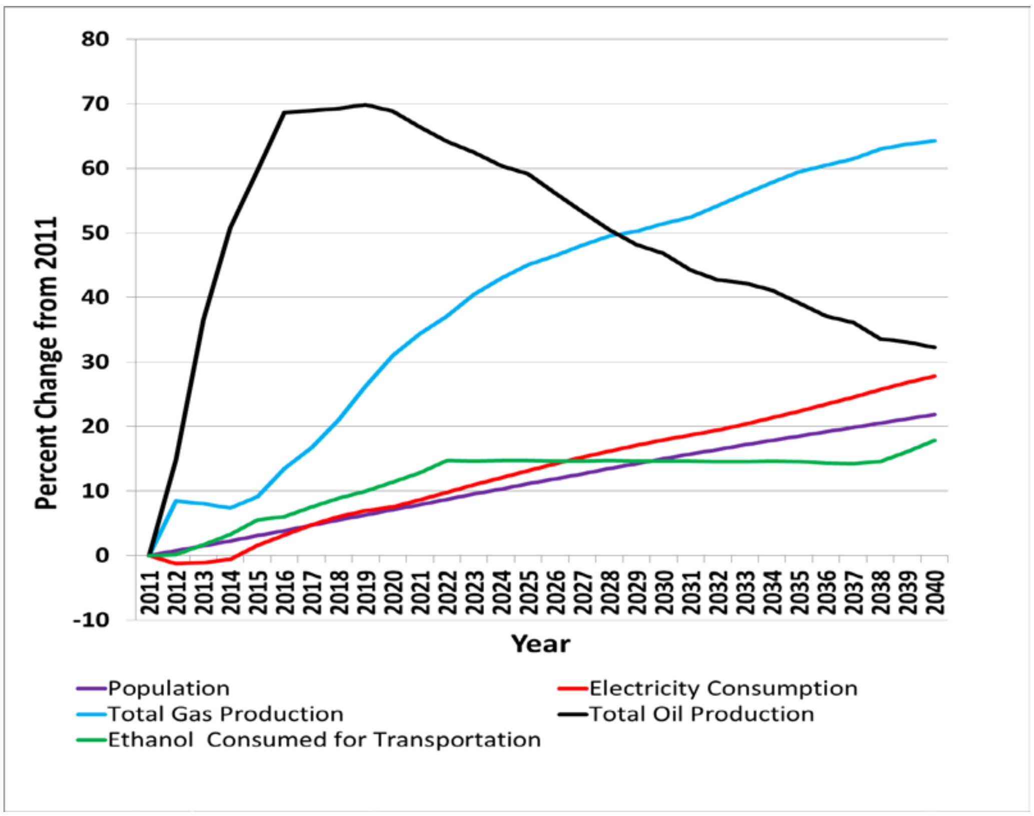
wellbeing is the preeminent value. Intensifying energy insecurity to meet environmental goals cannot be a feature of "sustainability."

Numbers & Trends

Water-for-Energy: Fueling Our Nation

Our nation's appetite for both energy and water continues to grow. As depicted in Figure 1, between 2011 and 2040 it is estimated that the U.S. population will grow by 22 percent; electricity consumption will increase by 28 percent; natural gas production will expand by 67 percent; oil production will be 32 percent higher than the 2011 level; and ethanol consumption for transportation fuel will increase by 18 percent.[2] Water is crucial in supporting growth in all

Figure 1: Growth in Population and Key Domestic Energy Indicators (2011-2040)



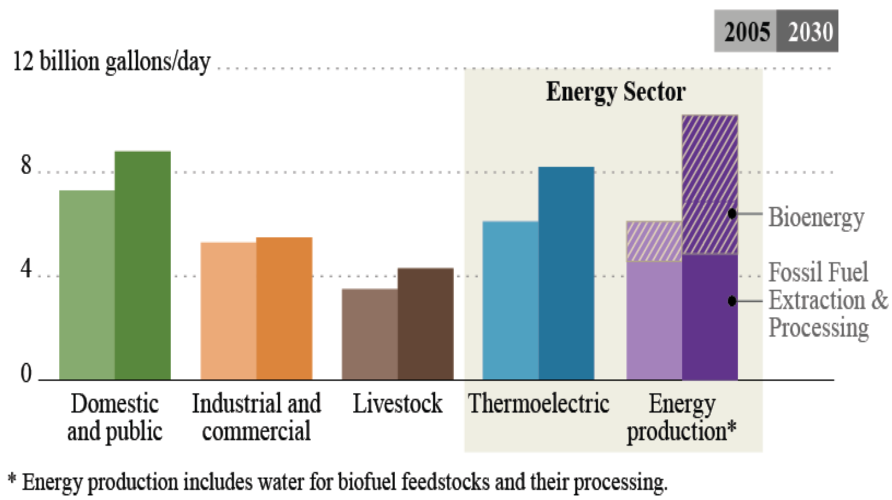
Source: EIA, "Annual Energy Outlook" (2014)

[2] Despite its eventual decrease, oil production is still predicted to nearly double by 2020 and remain higher than the 2011 level through 2040.

of these areas. The ensuing discussion highlights the degree to which our economy depends on its sustained supply. [3]

By One Projection, the Energy Sector[4] May be the Sector of our Economy With the Fastest Growing Freshwater Consumption through 2030[5]

Figure 2: Estimated and Projected Water Consumption for Select Sectors



Source: CRS, "Energy's Water Demand: Trends Vulnerabilities, and Management" (2010)

Based on 2005 U.S. Geological Survey (USGS) estimates, 349 billion gallons of freshwater are withdrawn each and every day in the U.S.; [6] of that, about 31 percent (or 108 billion) is

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[3] At the outset, the reader should note that the discussion and analyses of energy and water issues is too often based on sparse, scarce and sometimes unavailable data. This lack of data is one of the main underlying problems that hinder a complete and accurate quantification of data and trends in the energy-water nexus and forms the basis for one of the paper's main recommendations.
[4] The energy sector, as it pertains to water withdrawals and consumption, includes electricity generation and the production of a range of fuels, such as transportation fuels (i.e., oil, natural gas, and biofuels) that provide essential energy to both industry and households across the country.
[5] Water consumption for irrigation purposes (other than for biofuels) is actually projected to slightly decrease from an estimated 80.0 bdg in 2005 to 78.4 bdg due to continued improvements in water efficiency in that sector. CRS Report, "Energy's Water Demand: Trends Vulnerabilities, and Management," *R41507* (2011)
[6] These 2005 estimates are the latest comprehensive data that are currently available, demonstrating the lack of recent, updated data; USGS, "Estimated Use of Water in the United States in 2005," *U.S. Geological Survey Circular 1344* (2009). Water consumption refers to water that is not immediately available for subsequent use, while water withdrawals represent water removed from a water source. Withdrawn water is temporarily not available for other uses.

consumed and taken out of the water supply cycle.[7] According to the one government estimate, for freshwater *withdrawals*, the energy sector leads with 41 percent of the total and withdrawals for irrigation purposes are a close second at 37 percent. As shown in Figure 2, irrigation exceeds the energy sector for water *consumption*. Roughly 11 percent (about 12.2 billion gallons per day [bgd]) of total freshwater *consumption*[8] in 2005 was energy-related, while 74 percent (80 bgd) of all freshwater consumption was attributed to irrigation activities.[9] While agricultural water consumption is anticipated to be relatively steady or declining slightly in the coming decades, according to one estimate that takes into account biofuels production (largely ethanol from corn), the energy sector's water consumption is projected to lead the way in water consumption growth through 2030.[10]

Water Use for Electricity Generation Can be Significant

According to the Energy Information Administration (EIA), more than 86 percent of the electricity in the U.S. – over 3.4 trillion kilowatt hours (kWh) – is produced using steam turbines in thermoelectric power generating stations.[11] The vast majority of these plants are powered by coal, natural gas or nuclear fuel to generate the heat that is then used to boil water and produce the steam that drives the turbines. These steam-generating systems require significant amounts of water for cooling purposes.[12] Nationwide, thermoelectric cooling accounted for 41 percent (or 154 bgd) of water withdrawals[13] and 6 percent (or 6.1 bgd) of water consumed.[14]

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[7] D. Elcock; "Future U.S. Water Consumption: The Role of Energy Production," *Journal of the American Water Resources Association*, 46.3 (2010): 447-480.

[8] As a comparison, this amount would be enough to provide the daily freshwater needs of about 150 million Americans (assuming a daily water consumption of 100 gallons per person).

[9] The combined water consumption of domestic, public, industrial and livestock represented the remaining 15 percent (16.1 bgd) Note: Current water consummation data in this paper are calculated from best available data, mostly from 2005. (D. Elcock; "Future U.S. Water Consumption")

[10] Most of this increase is attributed to biofuels production (largely ethanol from corn). Also, the projected values take into account future potential increases in water efficiencies due to technological improvements. (D. Elcock; "Future U.S. Water Consumption")

[11] Energy Information Administration, "Electricity Explained: Electricity in the United States," www.eia.gov/energyexplained (2013)

[12] Open loop type cooling systems withdraw 10 to 100 times more water per unit of electric generation than closed loop type systems. However, closed loop type systems consume roughly twice the amount of water as open loop systems. Consumption rates depend on multiple factors, such as fuel type, power plant efficiency, power generation technology, cooling technology, and plant location. For more detailed information, see: National Renewable Energy Laboratory Technical Report: NREL/TP-6A20-50900 (2011)

[13] USGS, "Estimated Use of Water in the United States in 2005"

[14] D. Elcock, "Future U.S. Water Consumption"

Renewable forms of electric power generation also require water. Concentrated solar power farms need water for washing and cooling the apparatus, especially in desert locations. Hydroelectric power generation, accounts for 7.9 percent of U.S. electricity generation according to EIA's Annual Energy Outlook for 2014, provides an inexpensive, renewable and clean source of base load power across the U.S. with the potential to increase capacity even further. Although some argue that flow patterns through dams and reservoirs introduce evaporative losses, any such losses very much depend on the specific site, climate and water conditions.[15]

While geothermal electric generation currently accounts for only 0.26 percent of U.S. electric generating capacity, it is yet another example of a renewable energy resource with enormous potential that also requires water for cooling purposes.[16] Alaska, Hawaii, and other western states, are seeking to take advantage of this clean and plentiful energy source.

Large Volumes of Water are Consumed in the Production of Fuels

Water is essential to extract and process the fuels that power the economy, providing most of its industrial and residential energy needs (Table 1). Current water consumption rates for the main fuels produced in the U.S. can be ranked according to the estimated ranges (in rough orders of magnitude) of their respective water intensities (often expressed as gallons per million British thermal units [MMBtu]).[17] These water intensity values range from the lowest for conventional natural gas (at less than one gallon per MMBtu); followed by coal, unconventional natural gas, and uranium mining and enrichment (at one to 10 gallons per MMBtu); oil (at 10 to 100 gallons per MMBtu); to the highest for irrigated biofuels (at 100 to 1000 gallons per MMBtu).[18] Based on available data, overall water consumption by the combined production of fuels is roughly the same as the water consumed by thermoelectric cooling, which amounts to just over 6 bgd.[19]

[15] Pumped hydro storage plants are typically excluded from conventional hydroelectric power generation considerations. Additional water withdrawals and consumptions may be associated with evaporative losses from pumped storage water reservoirs but to date these have not been evaluated. (CRS Report, "Energy's Water Demand)
[16] EIA, "Annual Energy Outlook for 2014"
[17] One Btu is the amount of heat energy needed to raise the temperature of one pound of water by one degree Fahrenheit and is a typical unit used to quantify the energy content of fuels. For example, 1000 cubic feet of natural gas contain about 1 MMBtu of heat energy.
[18] CRS, "Energy-Water Nexus: The Energy Sector's Water Use," R43199 (2014).
[19] D. Elcock, "Future U.S. Water Consumption: The Role of Energy Production"

Table 1: Water Uses in Fuel Production

Fuel Type	Key Uses of Water in Fuel Production[20]
Oil and Gas	Drilling; hydraulic fracturing; enhanced oil recovery; processing and refining.
Coal	Drilling/mining; dust suppression in mines and transport; washing.
Uranium	Mining, ore processing, conversion and enrichment, chemical processes in nuclear fuel fabrication.
Biofuels	Irrigation for feedstock crop; refining and processing.

The Ongoing Oil and Gas Resurgence Presents Issues About Associated Water Needs

The rapid expansion of U.S. unconventional oil and natural gas production has presented tremendous economic growth opportunities in recent years. Production is projected to continue expanding, with vast amounts of technically recoverable reserves: 223 billion barrels of oil (of which 26 percent is shale oil) and some 2,431 trillion cubic feet of gas (of which 27 percent is shale gas). [21] Combined oil and gas production provides over 60 percent of the nation's total energy demand, with an expectation that this share will increase in the future. It is indeed prudent to assess the impact the production boom may have on freshwater resources.

Water is necessary in the widely used process of hydraulic fracturing with horizontal drilling to extract unconventional oil and gas resources that are locked in rock formations.[22] Water use for hydraulic fracturing is the highest in early stages of well development, typically in the first few

[20] BP has recently released a report that provides a comprehensive description of these uses and additional information on various aspects of the energy-water nexus (BP, *Water in the energy industry*: *An introduction* (2013).
[21] Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States: http://www.eia.gov/analysis/studies/worldshalegas/pdf/overview.pdf, p.3.
[22] Hydraulic fracturing involves the injection of large volumes of water, sand (or other propping agents), and specific chemicals under pressure into a well in order to fracture the rock formations and release trapped oil or natural gas. Water is also used in enhanced oil recovery to release heavy oil from formations and stimulate its flow upward to the surface. The older the oil or gas well, the more water will be needed to stimulate production.

weeks. Once the well is producing oil or gas, little or no water is needed unless additional fracturing is subsequently required. [23]

Because much of the current unconventional oil and gas development occurs on private lands, water use data is sparse. Increasingly, however, some states are collecting data on this type of water use.[24] According to the Congressional Research Service (CRS), the average water use for a hydraulically fractured well ranged from 2.7 million to 3.9 million gallons of water.[25] Although water use may be high at the onset, the overall water consumption intensity value for some unconventional gas production wells is on the low or middle end of the scale compared with the development of other fuels like biofuels. Still, when water supplies are constrained in areas that contain such considerable resource potential, availability of water for hydraulic fracturing may pose a challenge, especially for production from new wells. In recent years, much of the growth in unconventional oil and gas development has been concentrated in regions that have already been experiencing competition over freshwater (e.g., Colorado, Eagle Ford shale gas and oil in south Texas, and the Bakken oil development in North Dakota). Some producers in these regions have therefore been using brackish water supplies and recycled produced water (see below) that can significantly reduce freshwater requirements. For example, recent data from Texas shows that freshwater volumes can be as low as 20 percent of the total required water.[26]

Other byproducts of the fracturing process are flowback and produced waters. These are fluids that rise to the surface with the oil and gas. Approximately 2.3 billion gallons are produced daily from onshore oil and gas production.[27] Over 90 percent of the onshore produced water is disposed of by carefully controlled injection into deep wells, but there is an increased interest in recycling and reusing produced water, especially in water constrained areas. Access to better

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[23] CRS, "Energy-Water Nexus: The Energy Sector's Water Use," R43199 (2014).
[24] See http://fracfocus.org/regulations-state for information on latest regulations by state.
[25] CRS, Energy's Water Demand: Trends Vulnerabilities, and Management," Report R41507 (2011). Not all of the water used is freshwater. In fact, some of it is treated and recycled industrial wastewater and recycled produced water from the fracturing process.
[26] BP, *Water in the energy industry*: *An introduction* (2013), p. 32.
[27] CRS, "Energy-Water Nexus: The Energy Sector's Water Use," R43199 (2014).

data and technological advancements in water use and reuse would be instrumental in facilitating better water management practices.[28]

Other Emerging Water-For-Energy Trends and Related Water Constraints Can Be Identified

The significance of emerging trends in water-for-energy, highlighted in Table 2, is clearly dependent on the location of the energy production facilities and on the actual water demands by the various operations. In the U.S., growth in energy sector water use and consumption is expected in already water-stressed regions and areas experiencing open disputes and competition over water resources. States currently participating in the unconventional oil and gas boom – such as Colorado, West Virginia, North Dakota, Wyoming, and Texas – are important examples of areas with both increased water usage and vulnerability to shortages. However, as depicted in Figure 3, no region in the U.S. will escape some type of water shortages.

In the Southwest, concentrating solar power (CSP) systems[29] (which generally use thermoelectric generation) and some fossil-fueled thermoelectric power plants have been hindered by regional water conditions and shortages. Regional water shortages can in fact occur anywhere in the U.S., at any given time. Periods of drought and increased water stress have been regularly occurring in other regions across the country, including in locations that traditionally have not been associated with water shortages like Alaska and the Northeast.

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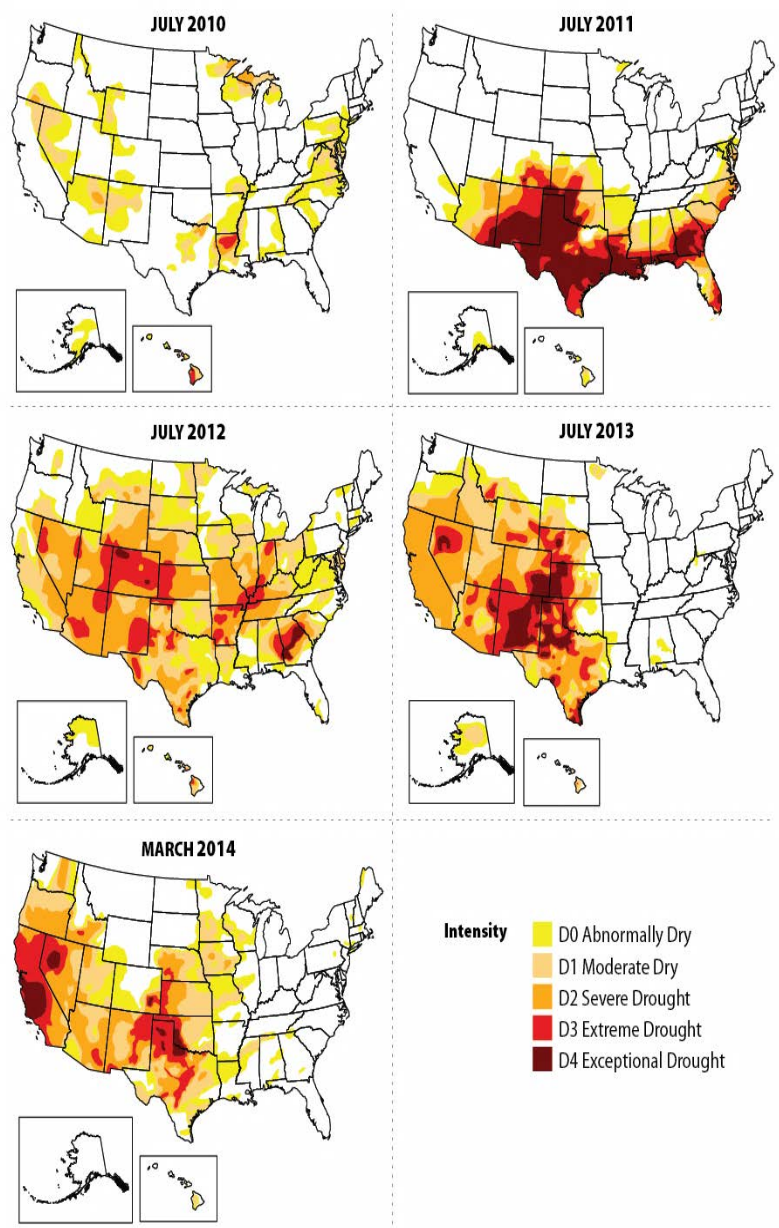
[28] GAO, "Energy-Water Nexus:Information on the Quantity, Quality, and Management of Water Produced during Oil and Gas Production," GAO-12-156 (2012). In Texas, for example, there is an increased interest in produced water reuse by oil and gas developers because of recent droughts and overall freshwater constraints (CRS, Report R43199 (2014)).

[29] Most CSP projects consist of ground-based mirrors that concentrate the sun's heat; the heat then is used in a thermoelectric process to generate electricity (in the U.S. this accounts for 0.14 percent (1.35 gigawatts) of power generation (EIA, Annual Energy Outlook for 2014).

Figure 3: Drought Intensity across the U.S. for the Past 4 Years Shows that Few have Escaped Droughts and Water Shortages



Source: U.S. Drought Monitor (http://droughtmonitor.unl.edu/)

Table 2: Water-for-Energy Emerging Trends

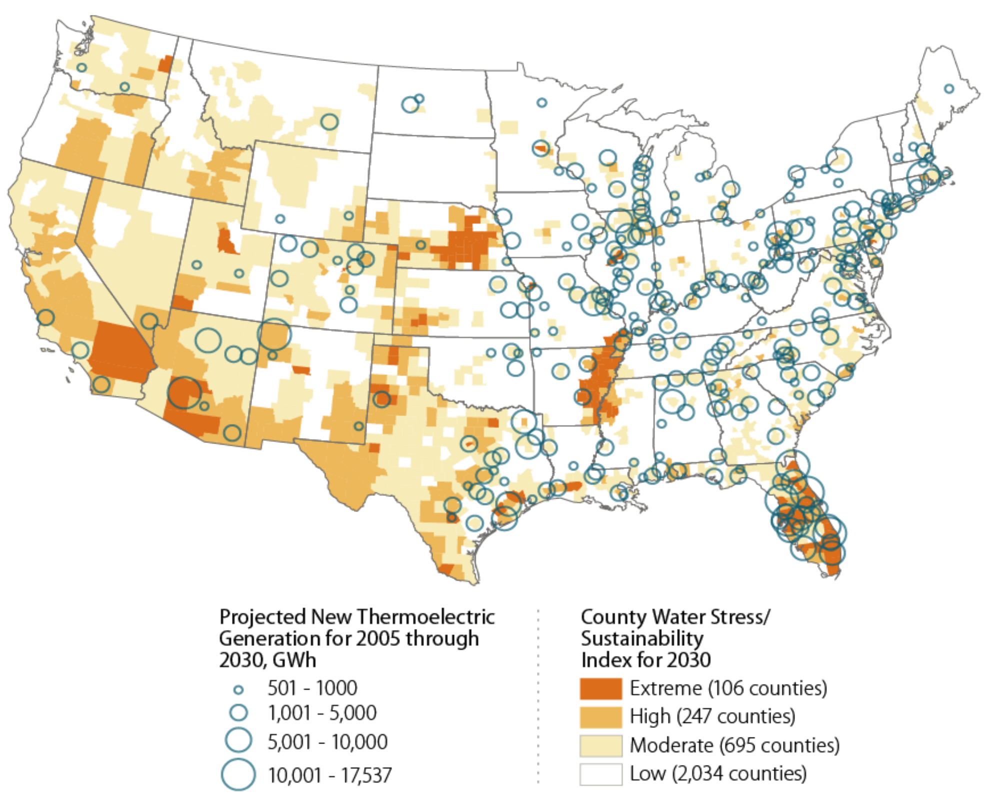
General Energy Trends	Corresponding Water Use Trends
Shift to shale oil and gas	Natural gas and oil from hydraulically fractured shale formations may raise water quantity concerns if well development is geographically concentrated in areas with water constraints, as well as water quality concerns and wastewater disposal (or reuse) challenges. However, natural gas from fracturing consumes less U.S. freshwater than current domestic ethanol production or many onshore conventional oil practices (e.g., well flooding).
Shift from foreign oil to biofuels	Increases energy's water consumption if domestic agricultural irrigation water (and other inputs) is needed for fuel production and processing.
Growth in domestic electricity demand	More water consumed during electricity generation; how much more depends on how the electricity is produced.
Shift to renewable electricity	Renewable technologies, such as photovoltaic solar and wind, use little water. Concentrating solar power technologies, on the other hand, can use more water to produce electricity than coal or natural gas; these solar facilities are likely to be concentrated in water-constrained areas. Technologies are available to reduce this water use.
Use of carbon mitigation measures	Current carbon capture and sequestration technologies may double water consumption for fossil fuel electric generation.

Source: Adapted from CRS Report R41507, "Energy's Water Demand: Trends, Vulnerabilities, and Management, (2011).

Region-Specific Water Issues Highlight the Energy Sector's Vulnerabilities to Freshwater Related Constraints

- **Electricity Generation:** Many of the planned thermoelectric generation stations are projected to be located in water-stressed areas as shown in Figure 4. This may pose a challenge in securing cooling water for these power plants if these facilities use freshwater (which is likely to depend in part on state law and policies, as well as federal and state permitting and regulations). At times, existing plants have already been forced to reduce power production or even stop output altogether due to constrained water

Figure 4: Projected New Thermoelectric Generation and Water Stress in the U.S.



Source: Adapted from data in EPRI Technical Report (2011) supplies.[30] And plant operations regularly experience additional challenges during exceptionally warm weather periods when cooling water temperatures exceed intake requirements or when surface water temperatures are too high to receive warm discharge cooling water.[31]

Significant water consumption increases associated with thermoelectric power generation by 2030 could also be attributed to additional deployments of closed loop cooling systems – one of the unintended consequences of regulations, such as EPA's proposed power plant cooling water intake modifications in Section 316(b) of the Clean Water Act.[32]

Naturally, hydroelectric generation is also sensitive to water availability. According to the EIA, "[s]ince 1989, hydroelectric dams have accounted for varying portions of electricity generated within California, from 11 percent in 1992 (reflecting a low water year) to 28 percent in 1995 (a high water year)."[33] The EIA further noted that hydroelectric generation in California during the past two dry summers was well below levels attained in the summers of 2010 and 2011. The situation is likely to persist this year with the current drought conditions in California and other Western states.

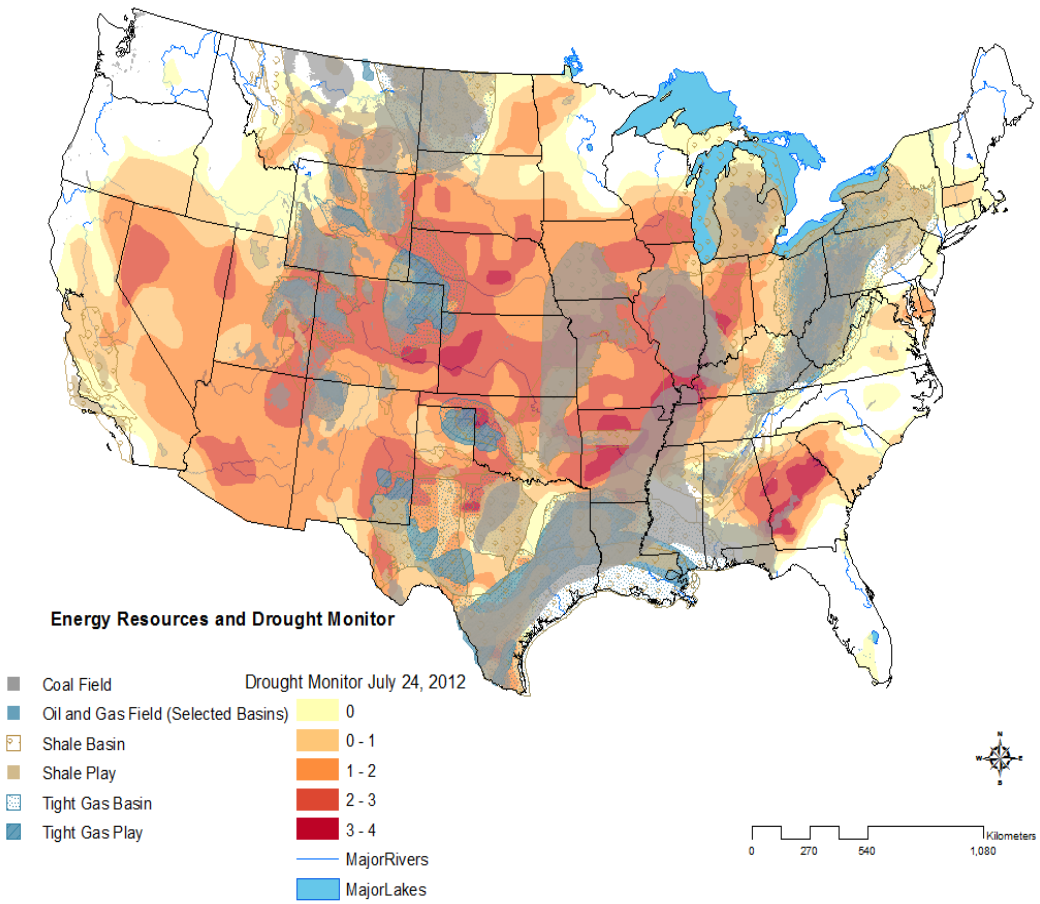
- **Biofuels:** As the drought map in Figure 5 illustrates, a significant portion of the Midwest and Great Plains regions – where the vast majority of corn is grown – have been subjected to drought conditions in recent years. Ethanol producers have cut back on production because of shortages in, and prices of, corn feedstock. For instance, ethanol production fell from 920 thousand barrels per day (bbl/d) in early June 2012 to 809

[30] GAO, "Climate Change: Energy Infrastructure Risks and Adoption Efforts," GAO-14-74 (2014).
[31] For example, in 2007, 2010 and 2011 the Tennessee Valley Authority reduced electricity generation output of its Browns Ferry Nuclear Plant in Alabama because the temperature of the local river was too high to receive discharged cooling water. This cost the Authority about $50 million (Ibid.).
[32] EPA has initiated an Endangered Species Act Section 7 consultation with the Fish and Wildlife Service and the National Marine Fisheries Service on the proposed rule regarding Section 316(b) of the Clean Water Act governing power plant cooling water intake structures. The energy industry has raised concerns about the potential for the rule to be applied in an overly broad manner such that it could require facilities to install cooling towers or stop operations if a threatened or endangered species is located in a water body from which the facility draws water from, even if there is no evidence of impact to that species.
[33] Source: EIA, http://www.eia.gov/todayinenergy/detail.cfm?id=14911

thousand bbl/d by the end of July 2012.[34] As a result, ethanol prices increased significantly for that period.

- **Oil, Gas, and Coal:** The production of fossil fuels is not limited to any one region in the U.S. There have been several instances of low freshwater flows or drought conditions that have reduced the availability (and hence increase the cost) of freshwater for fuel

Figure 5: Energy Resources around the U.S. and Drought Conditions



Source: EIA (http://www.eia.gov/state/maps.cfm) and U.S. Drought Monitor (http://droughtmonitor.unl.edu/)

production (e.g., Colorado, North Dakota's Bakken Formation, Texas' Eagle Ford Formation, and Susquehanna River Basin in Virginia, West Virginia, and Pennsylvania).[35]

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[34] Source: EIA, http://www.eia.gov/todayinenergy/detail.cfm?id=7770

Energy-for-Water: The Water Sector's Energy Concerns

Energy is required to move, treat, and distribute about 410 billion gallons of water daily in the U.S., of which nearly 350 billion gallons are freshwater.[36] This type of energy use is referred to as the "embedded energy in water."

In 2000, 3.7 percent of the nation's electricity, or about 123 billion kilowatts per hour (kWh), was used to treat and transport water and wastewater for both residential and commercial use.[37] Some regional, state-specific data show an even greater share of electricity consumption by the water sector. For example, as illustrated in Figure 6, the seminal 2005 study by the California Energy Commission found that "water-related energy use [in California] consumes 19 percent of the state's electricity, 30 percent of its natural gas, and 88 billion gallons of diesel fuel every year – and this demand is growing."[38]

A 2012 analysis examined broader energy needs for water supply, including water required by industry and thermoelectric power plants.[39] The analysis concluded that direct water-related energy consumption was 12.6 percent of national primary energy consumption in 2010. This amount of energy – 12.3 quadrillion BTUs – is equivalent to the annual energy consumption of 40 million Americans. Notably, it appears that inaccurate or unavailable data often lead to the exclusion of some important water-related energy consumption values, such as privately operated water supply wells, the bottled water industry, agricultural use of water for irrigation and other purposes.

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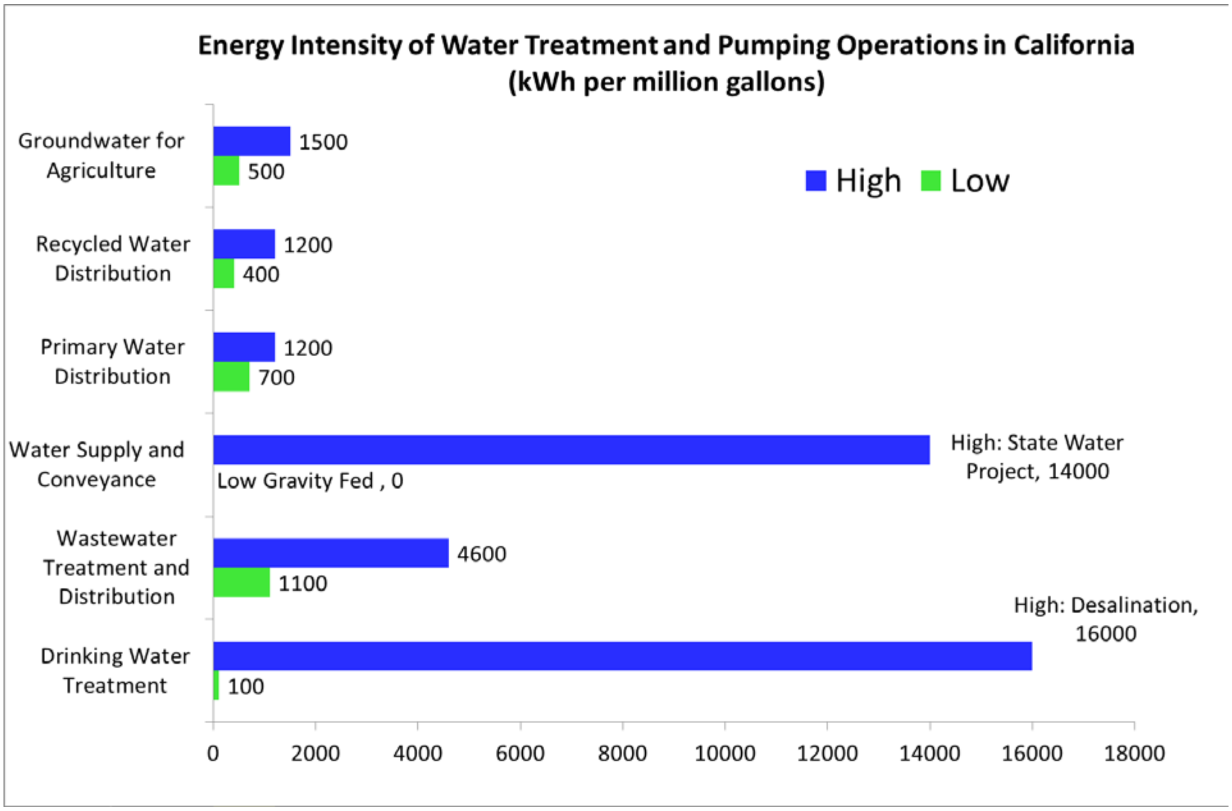
[35] CRS, "Energy-Water Nexus: The Energy Sector's Water Use," R43199 (2014).
[36] USGS, "Estimated Use of Water in the United States in 2005"
[37] Electric Power Research Institute (EPRI), *Water & Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply & Treatment – The Next Half Century*, 1006787 Topical Report, 2002. Note: A more recent report by EPRI, "*Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*, 3002001433, Final Report, November 2013," introduced some updates to water consumption estimates in publicly owned water treatment facilities but did not contain updates for all other privately run facilities. Hence for the sake of consistency, the 2002 report was used in the current discussion.
[38] California Energy Commission, *California's Water-Energy Relationship, Final Staff Report*, CEC-700-2005-011-SF, November 2005, p. 1. The study examined energy required to pump, treat, transport, heat, cool, and recycle water.
[39] Kelly T. Sanders and Michael E. Webber, "Evaluating the Energy Consumed for Water use in the United States," *Environmental Research Letters*, vol. 7, 034034 (2012).

Figure 6: Embedded Energy in Water: The California Example



Source: California Energy Commission, "California's Water-Energy Relationship, Final Staff Report, CEC-700-2005-011-SF", November 2005

The most energy-intensive activities are the transport, conveyance, and desalination of water. These all require large quantities of energy for pumping water. The need for more stringent drinking water and wastewater treatment requirements due to a variety of potable water standards and discharge regulations has also contributed to the increase in the energy required to power these often more advanced water treatment processes.[40]

With freshwater withdrawals in water-stressed regions that are projected to remain strained, and increasing demands in states even where freshwater is generally considered abundant, the public is looking for solutions. These factors provide a major incentive to conserve water and invest in efficient water treatment and conveyance technologies. An obvious solution is to minimize the

[40] Electric Power Research Institute, *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*, 3002001433, Final Report, November 2013, pp. 1-1 and 3-17.

embedded energy in water conveyance and treatment processes since population growth, land use, and aging water infrastructure are fueling ever-increasing demands for water.[41]

Recommendations

There are opportunities and solutions for sustainable energy and water use in the U.S. The keys to success will be technological innovations and advancements as well as better-informed decision making processes for all stakeholders

Energy and water conservation efforts can significantly reduce the amounts of energy or water needed for a specific application. But conservation alone cannot sustain steady population growth and robust economic activity. A key advancement will be reducing the costs and improving the performance of already-available technological solutions, such as dry or hybrid cooling.[42] Other examples of "game changing" technologies include advanced and cost-effective water treatment options for recycling and reusing produced water as well as new biofuel feedstocks that do not require large quantities of freshwater. In the energy-for-water domain, improved desalination technologies are needed to reduce the often prohibitive operating costs.[43] Another example is the innovative use of biogas generation from residuals of municipal wastewater streams to supply on-site power to the wastewater treatment plant and perhaps to external users as well.[44] Advanced modeling and simulation efforts can also assist water and

[41] Alliance for Water Efficiency and the ACEEE, "Water-Energy Nexus Research: Recommendations for Future Opportunities," GEI Consultants (2013).
[42] In dry cooling, only air is used for cooling purposes. Hybrid cooling systems combine dry cooling and wet cooling to reduce water use relative to wet systems while improving hot-weather performance relative to dry systems (U.S. Department of Energy, "Energy Demands on Water Resources, Report to Congress on the Interdependency of Energy and Water," 2006).
[43] The design of more efficient membrane separation systems is a typical example of such technological advancements. Cogeneration of water and power using desalination, especially in water-stressed coastal regions, could be optimized for specific locations around the country.
[44] CRS, "Energy Water Nexus: The Water Sector's Energy Use," R43200 (2014).

energy resource planning and resource-use decision making, particularly when specific data on water and energy use is unavailable.[45]

To unleash the solutions, five key recommendations would enable innovation and its optimal application to energy-water nexus activities:

1. **Address Data Gaps:** There is a clear need to obtain reliable, current, and comprehensive data on energy-for-water and water-for-energy use by all stakeholders, both public and private. Examples include data on water use by power plants, water for liquid fuel production, energy use by water utilities, and water reuse and replacement.[46] More accurate data can improve informed decision making; help prioritize investments in energy-water related infrastructure; and lead to better water and energy use practices (e.g., state-of-the-art water treatment and transport systems and reduced water needs for fuels production).[47]

   As noted in a recent report on water-energy nexus research activities, "[m]ultiple research papers, reports, and best management handbooks recommend that improved data collection and auditing of water and wastewater utilities is integral for determining appropriate actions they can take to improve operations, lower costs, and reduce their energy footprint."[48] The key word in this quote is "*they.*" It should always be stakeholders' decision to adopt the practices and technologies that are *best suited to their specific operations*. An opportunity thus exists to create a well-defined data warehouse, through which stakeholders – both public and private – can share the latest water-for-energy and energy-for-water data. Such dissemination would help in decision making

[45] Alliance for Water Efficiency and the ACEEE, "Water-Energy Nexus Research: Recommendations for Future Opportunities," GEI Consultants (2013).
[46] Here "replacement" refers to the substitution of water of greater quality (e.g., freshwater) with water of potentially lesser quality (e.g., reclaimed water).
[47] There are a variety of current and relevant data collection efforts. These, however, tend to focus on separate data sets for energy and water uses. Examples of such efforts are: the EIA data on energy consumption by sector; the Army Corps of Engineers' Watertoolbox.us website with information and data on integrated water resource management tools; and other government efforts on water use data at the U.S. Geological Survey, the U.S. Department of Agriculture and the U.S. Bureau of Reclamation. The Department of Agriculture provides web access to its lifecycle assessment (LCA) tool. The California Public Utilities Commission collects specific data on energy-water related activities.
[48] Alliance for Water Efficiency and the ACEEE, "Water-Energy Nexus Research: Recommendations for Future Opportunities," GEI Consultants (2013).

about water and energy resource utilization and for planning of future activities, as well as technological research, development, and demonstration (RD&D) investments. Many stakeholders such as utilities, service companies, and technology developers are reluctant to share operational data on water and energy usage due to proprietary concerns. Yet the facilitation and encouragement of data collection, sharing, and dissemination, while being mindful of industry's concerns, will help inform future RD&D needs, as well as new and robust energy-water nexus decision-making tools.

2. **Promote Federal Leadership and Public-Private Partnerships:** Several states are actively engaged in energy-water nexus issues, but there has been little clear federal leadership in the energy-water domain. [49] The benefits of public-private partnerships to promote collaboration and elevate research and information are well known. The Administration should seize this opportunity by advancing such an effort aimed at improving knowledge and reducing barriers to adoption of more water and energy efficient technologies and practices.

3. **Document and Publicize Best Practices:** There appears to be no compilation of best practices in the energy-water domain. Such a compilation would highlight innovative methods for collecting and interpreting data, proven as well as advanced technologies, roadmaps for RD&D activities, modeling and simulation tools, and overall resource utilization. It is important to note that the adoption of best practices should be done on a voluntary basis and not lead to new regulations.

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[49] The Department of Energy has recently established The Energy-Water Tech Team to explore how DOE can play a more active role in the energy-waster nexus domain. The DOE and its National Labs have been closely examining water for energy uses for quite a while (e.g., improved technologies for thermoelectric cooling; biofuels production) as well as some aspects of energy efficiency of water treatment systems (e.g., water desalination). DOE also published a report in 2006 on a wide variety of issues related to the energy-water nexus (Department of Energy, "Energy Demands on Water Resources, Report to Congress on the Interdependency of Energy and Water," 2006) and a much more recent report on the freshwater needs for thermoelectric generation (DOE/NETL, Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements *2010 Update*, DOE/NETL-400/2010/1339, September 30, 2010). The Department of Interior has unique capabilities to understand and address the energy-water nexus, including USGS monitoring systems and research programs (including the National Water Census), energy resource assessments, Reclamation Basin Studies, and WaterSMART research and grants. Also, the Environmental Protection Agency hosts an energy data information tool known as Portfolio Manager on the Energy Star website where water and wastewater treatment facility users can store energy data and develop energy benchmarks.

4. **Encourage Generation and Adoption of More Efficient Technologies and Practices:** The federal government should encourage the development of new technologies and practices through its activities in the energy-water domain.[50] Improved energy-water data will assist in identifying energy and water processes and applications that represent particularly attractive innovation opportunities and may help to encourage such innovation. Barriers to adoption of new technologies and practices can take many forms. Improved management and dissemination of existing information and knowledge can alter perceptions and increase confidence in adopting more water- and energy-efficient practices and technologies. Reducing the risks and costs of adoption and furthering understanding of the benefits are central to creating more sustainable energy and water sectors. All stakeholders should be encouraged to adopt best practices and to invest in future RD&D. After all, it is in every stakeholder's interest to optimize the use and conservation of energy and water resources, and, by doing so, to also reduce overall production costs.

   Synergies between different stakeholders' needs and interests should be identified and collaborative work encouraged and supported. The federal government is uniquely positioned to facilitate multiparty RD&D activities from industry, academia, and government, in order to leverage each other's expertise for achieving common goals.

5. **Federal Coordination:** The executive branch must be mindful of Congress as it seeks to advance energy and water nexus technologies. The energy-water nexus federal initiative should be coordinated at the highest level of science and research policy making, such as the National Science and Technology Council (NSTC) housed in the Office of Science and Technology Policy (OSTP) to enable crosscutting and multiagency coordination and to avoid duplicative efforts. [51]

[50] Incentives to overcome barriers need not be of a monetary nature. At times, incentives could be offered by industry rather than the federal government. Trade organizations, for example, could survey members without revealing proprietary data in order to leverage the information more broadly (Summary Report on the Roundtable on the Energy-Water nexus with Governmental Organizations, Committee on Energy and Natural Resources, August 14, 2013).

[51] A similar recommendation, among others, was given during two recently-held roundtable meetings with government and non-governmental organizations by the joint staff of the Energy and Natural Resources Committee

In January 2014, I introduced S. 1971, *The Nexus of Energy and Water for Sustainability (NEWS) Act of 2014*, to task the Departments of Energy and the Interior with the day-to-day responsibility for managing and implementing needed interagency coordination. This legislation directs the OSTP to establish a committee or a subcommittee under the NSTC to coordinate and streamline the energy and water nexus activities of all federal departments and agencies. Specifically, this new panel will identify all relevant energy-water nexus activities across the federal government; enhance the coordination of effective research and development activities (both on-going and in the future); work to gather and disseminate data to enable better practices; and explore relevant public-private collaboration.[52] The bill also calls for the Office of Management and Budget to submit to Congress a "cross-cut" budget soon after enactment. The cross-cut budget will detail various expenditures across the federal government related to energy-water activities and will greatly assist in these streamlining efforts.

Apart from this pending legislation, it has also been suggested that a national platform be established for exchanging information, data collection, dissemination and standardization; identification of innovative technologies and methodologies, including best practices and deployment incentives; and innovative RD&D projects. This platform could reside inside or outside of government and should include all key stakeholders, from both the public and private sectors. Finally, it is important to ensure that any new organization or initiative examine how to incentivize active participation of the various stakeholders, as well as adoption of existing or new innovative energy and water practices and other recommended actions that would result from the collaborative activities.

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in July 2013 (meeting reports are available on the Committee on Energy &Natural Resources website's under Republican Documents, http://www.energy.senate.gov/public/index.cfm/documents-republicans. Similar recommendations were also made in a GAO report on "Energy-Water Nexus: Coordinated Federal Approach Needed to Better Manage Energy and Water Tradeoffs", GAO-12-880 (2012).

[52] Work on many innovative technologies and related RD&D is being done overseas (e.g., in the Middle East and Asia; countries such as Australia, the Gulf countries, Israel, and Singapore); opportunities for international collaborations should be considered

Conclusion

Vast amounts of water are used every day to produce vital fuels, cool power plants, produce hydropower, irrigate the nation's crops, provide clean drinking water, and support recreational activities. Without a reliable water supply, most of our electricity and fuel systems are at risk, which has significant economic and national security implications. At the same time, a great deal of electricity is needed to treat, transport and convey water across the country, not only to support economic growth and well-being, but also to sustain life and public health.

The energy-water nexus is comprised of these inseparable linkages of "water for energy" and "energy for water." Federal agencies can and must do more to ensure that the U.S. has the best possible data, technology, and expertise so that this nexus is not only well understood but continuously improving. The government must also seek to establish productive public-private partnerships. These partnerships can leverage private sector and other external stakeholders' interests and resources to advance effective and efficient resource use.

Every American benefits from increasing the efficiency and availability of these energy and water resources while also reducing the associated costs. A focused and well-coordinated public-private approach to the energy-water nexus issues can promote economic growth and lead to new breakthrough technologies in water and energy resiliency. It is truly a "win-win" proposition for the American people.