1828 L Street, N.W.
Suite 510
Washington, D.C. 20036

Tel 202.785.3756
Fax 202.429.9417
www.asme.org

ASME GENERAL POSITION PAPER

Energy Water Nexus

EXECUTIVE SUMMARY

Energy production and water use are intrinsically interdependent. Water is needed for energy production through thermal electric power plants, hydropower, and oil and gas extraction. Energy is needed to operate the public water supply and water infrastructure, for desalination and water reuse, irrigation, agriculture and food production. The industrial sector draws on both water and energy resources in myriad ways.

A shared challenge for improving the infrastructure for energy and water is the regulatory burden. Multiple agency reviews, duplicative requirements coupled with delays in decisions, provides little flexibility to encourage new technologies and hinders efficiency gains and infrastructure improvements. To assist technology development and infrastructure improvements, ASME recommends the following:

- Appropriating funds under the Water Resources Development Act, which will help public water systems upgrade aging water distribution systems to promote energy-water savings and efficiencies;

- Streamlining regulations and reducing the duplicative, multi-agency review processes in most sectors for water and energy will help reduce water usage to produce power and the amount of power required to move water and grow food;

- Providing funding for research, development and demonstration such that the various infrastructures can more quickly become cleaner and more efficient.

The private sector has demonstrated, through technology innovation that it is ready to make investments, but more certainty from regulators is needed to encourage the adoption of new technologies and invest in the high capital cost of some of the projects. Public private partnerships could also be an efficient means to improve the U.S. aging infrastructure while at the same time reducing water losses and energy required for clean water systems production.

Key factors in the Energy-Water Nexus that this paper will discuss include:

Thermal Electric Power Plants: Thermoelectric power plants that use heat to generate power are the largest users of water, as defined by total water withdrawals from water resources in the U.S.[Error! Bookmark not defined.] Most of the water withdrawn for cooling is returned to the source of the water. Water consumption (water that is not returned to the source) from thermal power facilities comprised 3% of the withdrawals. Several methods for cooling are used based on climate, water availability and regulatory requirements. Policies that promote water efficiency, such as, technology innovations in renewable energy that do not require cooling water (solar photovoltaics (PV), wind and hydro), hybrid-cooling systems, and higher efficiency thermal power systems (gas fired combined cycle power plants) help reduce water withdrawals. Currently, hybrid-cooling systems in a few thermal power plants are effectively striking a balance between plant efficiency technologies, cost-effectiveness, water usage and environmental impacts. A one-size fits all approach should be avoided as various regions and varied climates require different solutions.

Hydropower: Hydropower is a clean energy resource that draws on water but does not “consume” the water. Hydropower facilities, operate reliably and without greenhouse gas emissions for 75 to 100 years. Hydro facilities provide electric grid stability and can “load follow” thereby smoothing out the variability on the electric transmission system sometimes caused by more variable renewable sources. In the U.S., energy produced by hydroelectric technologies could be increased by as much as 10% with installation of hydro turbines at only the most ideal existing U.S. dams and conduit sites. Marine and hydrokinetic technologies offer tremendous potential and need more research and development funding. The current regulatory environment that governs the development of new hydropower is fragmented, varies from state-to-state, and requires significant investment of resources, with relatively little certainty that the process will result in an economically viable project. The regulatory hurdles for hydropower can require 10 years or more to overcome which are inconsistent with other renewable sources such as wind and solar power facilities which typically require only 1 to 2 years to obtain permits. The Water Resources and Development Act of 2018 takes significant steps to shorten the regulatory process at the Federal Energy Regulatory Commission, which when implemented should help reduce the regulatory burden.

Oil and Gas Extraction: The oil and gas industry is part of the mining industry, the USGS estimates that all mining activities constitute approximately 4% of the annual water withdraws in the United States (U.S. Department of Energy, Energy Information Administration, 2015). Because of the volumes of water involved and the nature of the exploration, development, and production activities which include drilling a large number of wells deep below the surface, particularly for unconventional well types. Considerations on water resources include source and volume requirements to supply initial development of the well, treatment and disposal of water during development and production, and potential impacts to groundwater aquifers and surface water systems. Whether a specific region or locale is suitable depends on local geology (stable low permeability vs. highly porous systems like limestone with highly connected aquifers and hydrology across zones), geography (plains areas versus coastal areas and peninsulas subject to saltwater intrusion) and current and projected adequacy of local water supplies (consider any existing stresses due to drought or usage exceeding availability).

Industrial Plant Usage: Industrial water usage comprises 4% of total water withdrawals in the U.S. In 2010, the total U.S. water withdrawals for industrial purposes were approximately 15.9 billion gallons per day. Due to increasingly efficient manufacturing practices, industry has reduced water use by 30 % since 1985. Advancements in process efficiency aim to reduce water consumption within the industrial processes and utilize water recycling within the facilities where possible. While the industries reduce water usage during the manufacturing processes, the end consumers are often less efficient at recycling or reusing products. Policies to improve water and energy efficiency should consider both the production facilities and end use of products in the industrial sector.

Public Water Supply and Urban Cycle: The urban water cycle consists of hydraulic systems that move water into, within, and out of defined boundaries and relies upon treatment facilities to modify water quality so it will meet the regulatory requirements of its intended uses. Potable water systems convey, store and extract raw water for treatment and distribution of drinking water to urban populations. Wastewater systems collect, convey, treat, and discharge or reclaim wastewater for suitable environmental applications. Stormwater systems protect water resources and minimize flooding through the removal of pollutants and reduction of flows. Many urban areas have aging and leaking water systems that need replaced but such projects are expensive. Additional funding sources are needed to meet the gap in infrastructure investment. Funding mechanisms such as The Water Resources Development Act (WRDA) are a possible funding source; however, appropriations need to be approved. The greatest opportunity for embedded energy reduction of public water supply and urban cycle lies in source location and proper design and operation of pumping systems for the conveyance and distribution of the water. Additional energy savings are possible through improved aeration systems in wastewater systems.

Desalination and Water Reuse: Desalination and water reuse are important current and future components of the water portfolio needed to meet growing population and water demands. Desalination has been commonly considered to be an energy intensive treatment in the water industry; however, more recent developments in energy recovery technologies, enhanced materials, and new membrane arrangements have helped reduce these energy related operating costs. Desalination has become an attractive option for coastal communities requiring a new water source or as a drought contingency. The potential to pair desalination plants with renewable resources and co-locate with power plants or wastewater treatment facilities may further reduce energy demands and permitting requirements.

Regulatory policies are needed to alleviate the challenges of brine disposal by streamlining permitting requirements and helping navigate the studies required to minimize impacts on marine life. Environmental impacts could be further reduced through partnerships with power plants. Water reuse for non-potable and potable uses can provide increased conservation and create a “new” water source for water constrained areas of the U.S., but also provides the potential to reduce energy consumption. Again, streamlined regulations are needed to expedite permitting of facilities and evaluate treatment processes with lower energy consumption for production of indirect and direct potable reuse.

Irrigation, Agriculture and Food Production: As of 2015, approximately 37% of the water withdrawal rates are for irrigation, animal husbandry and aquaculture. A concentration of irrigation implementation is focused on 17 Western States that cumulatively account for 93% of total surface-water irrigation withdrawals and 69% of total groundwater irrigation withdrawals. Further research and development of higher efficiency irrigation methods has the potential to significantly curtail water usage. Implementation of renewable energy sources may allow for distributed energy supplies in the agriculture sector.

I. Background

The ASME provides insights on the intrinsic connection between energy and water. There is an inverse relationship in that to clean and distribute water requires large amounts of energy, and to produce energy typically requires large amounts of water. Technology policy and decisions regarding energy and water cannot be separated. The ASME members focus on specific areas including; electricity production, oil & gas extraction, industrial plant usage, the public water supply and distribution system.

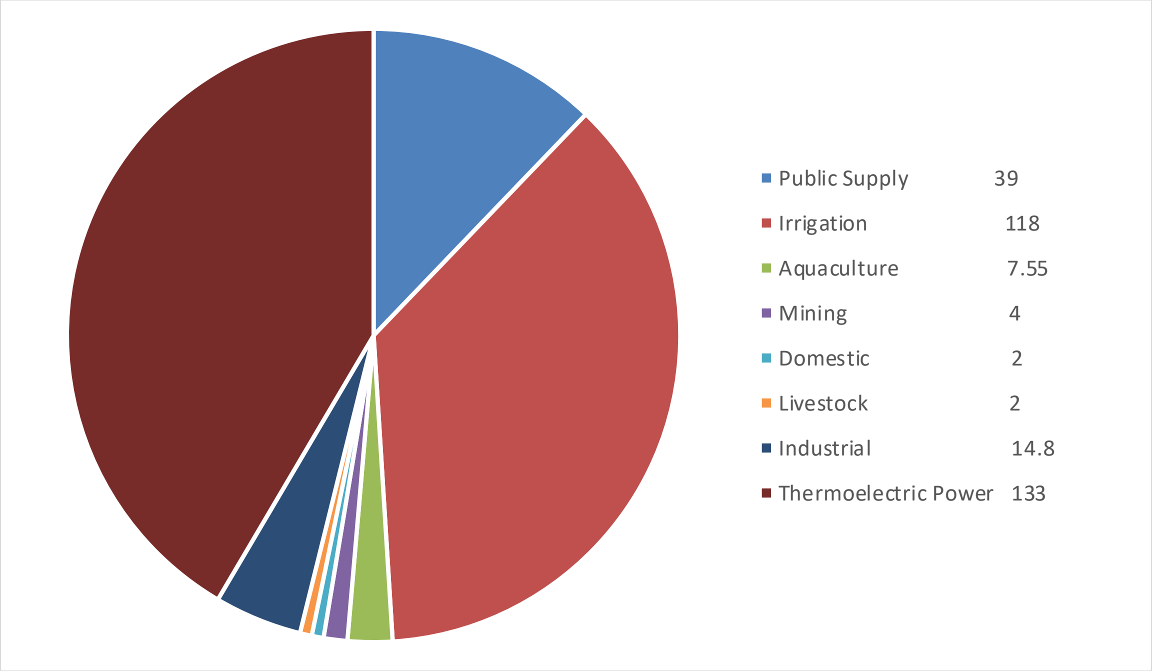
Mechanical engineers build, design, install and innovate to improve critical energy and water systems so that they are more robust, efficient and cost effective. From a technical perspective, mechanical engineers recognize that different regions of the U.S. have varied resources and terrain, which limits the practical choices of certain technologies

Water consumption in the United States is dominated by three main categories; thermoelectric power, irrigation and public water supply based on data gathered by the U.S. Geological Survey**Error! Bookmark not defined.**, see Figure 1. These three categories comprised over 90% of the water withdrawn in the United States in 2015.**Error! Bookmark not defined.** Many of these uses are directly or indirectly connected.

Energy is required for a variety of public and industry activities. As it relates to the energy-water nexus, energy is used for pumping water resources, potable water treatment and wastewater treatment facilities to ensure that discharged water meets the local and federal regulations. The amount of energy or electricity required to operate water systems depends on the location, terrain, proximity of available water sources and discharge receiving water bodies.

Figure 1 draws on the U.S. Geological Survey estimated water use in 2015. Approximately 41 % of the water withdrawn relates to thermoelectric power production. Water for thermoelectric systems is required for steam generation and more significantly for cooling systems. It should be noted the amount of water depends on the source of the water as well as the thermoelectric system and cooling system used.

Figure 1 - U.S. Water Withdrawals (estimated) in 2015 in billions of gallons/day[1]



Climate change may have started to affect precipitation and temperature patterns across the United States. The overall security, reliability, and resilience of energy and water systems is a national issue and will become further problematic as the impacts of climate change accumulate. These intertwined systems will require specific attention and combined policy development to enable continued reliable operation. While there is significant uncertainty regarding the magnitude of the effects, water availability and predictability may be altered by shifting precipitation patterns, increasing variability, and more extreme weather. Shifts in precipitation and temperature patterns, including changes in snowmelt, will likely lead to more regional variation in water availability for energy generation by hydropower and thermoelectric generation, posing challenges for energy infrastructure resilience.

Decision making related to the energy-water nexus is shaped by political, regulatory, economic, environmental, and social factors, as well as available technologies. Incentive structures are overlapping, inconsistent, and constantly changing, based on state and local government budget conditions. Water is inherently a multi-jurisdictional management issue and is primarily a state and local responsibility. The following sections describe some of the major components of the energy-water nexus and, where appropriate how policy related improvements may assist future implementation and operations.

---

[1] Dieter, Cheryl, Maupin, Molly, et al. Estimated Use of Water in the United States in 2015, U.S. Department of the Interior, U.S. Geological Survey, Circular 1441, 65 p. 2018.

II. Water Use in Thermal Power Plants

In 2015, approximately 67% of the electricity generated in the US was from fossil fuels (coal, natural gas, and petroleum) and 20% from nuclear for a total of 87% from thermal generation.[2] All thermal power plants (including certain biomass, geothermal and concentrated solar thermal plants that currently constitute <1% of total electricity mix) operate on the thermodynamic principal of the Rankine steam cycle. Thermal energy is used to generate steam or other fluids (e.g. ammonia, pentene) at a high temperature and pressure which passes through a steam turbine to generate electricity. The exhaust from the steam turbine is cooled and the condensate is returned to the thermal energy source to again make steam in a cyclical process.

The "working" fluid, most frequently steam, is heated to high pressures and temperatures and then passes through the turbine to generate electricity. The steam is cooled and then reheated in a continuous, closed loop cycle. The steam, or other working fluid, needs to be very pure to not to ruin the turbine. The steam coming out of the turbine is cooled and condensed in a cooling condenser that uses water or air as the cooling medium. In thermal power plants, cooling condensers are the primary draw of water.

There are four steam exhaust cooling technologies currently used in the thermoelectric plants:

- <u>Direct or once-through cooling (from lakes, rivers, or oceans)</u> - If the power plant is in close proximity to the sea, a big river, or large inland water body, cooling is performed simply by running a large amount of water through the condensers in a single pass and discharges the cooling water back to the source a few degrees warmer and with little loss of water from evaporation. The water may be brackish (high chloride content; almost salt water) or fresh. A small amount of evaporation will occur off site due to the water being a few degrees warmer. Once-through systems are the simplest method of cooling and require low capital and operating costs. The drawback of once through systems pertain to the slightly warmer water on marine and estuarine life and future once through cooling applications will require extensive review. In California, the State Water Resource Control Board has proposed technology-based standards to implement federal Clean Water Act section 316(b) to eliminate once through cooling for power plants by 2024.[3]

- <u>Recirculating, closed-loop or wet cooling (with mechanical, forced draft, natural draft cooling towers or cooling water reservoirs and spray ponds)</u> - If the power plant does not have access to abundant water, cooling may be performed by passing the turbine exhaust steam through the condenser and utilizing a cooling tower to cool water using an updraft of air through water droplets. In some cases, an on-site pond or canal may be sufficient for cooling the water. The cooling is normally achieved through evaporation, with thermal heat transfer to ambient air resulting in little to no environmental impact. The cooling tower evaporates up to 5% of the cooling water flow through the steam condenser in a cyclical process. The evaporated water in the cooling tower must be continually

---

[2] What is U.S. electricity generation by energy source? U.S. energy information agency – EIA https://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3

[3] Cooling water intake structures once-through cooling water policy - official policy documentation - http://www.waterboards.ca.gov/water_issues/programs/ocean/cwa316/policy.shtml

replenished. Evaporation can lead to an increase in the total dissolved solids (TDS) that can result in scaling of the heat transfer surfaces and reduced cooling efficiency. Blow down is performed to prevent scale build-up and maintain a concentration of TDS below 5 parts per million (ppm); however, the blow down process requires fresh water makeup. New chemical treatment of cooling water is being evaluated to allow concentrations up to the 10-15 ppm TDS level to accumulate, resulting in a reduction of 1/3 to 1/2 the required water makeup for blow down in a conventional cooling tower.

- Dry (air) cooling - A small number of power plants are cooled simply by air, without evaporation. This may involve an air cooled condenser with a closed circuit, or high forced draft air flow through a finned assembly similar to a radiator. Air cooled condensers for large power plants do not require the high water usage of other evaporation systems, but have a high capital cost and performance is very dependent on ambient temperature that can vary +/-30^{o}F (+/-16^{o}C) during a day. Ambient temperatures above 85^{o}F (30^{o}C) can significantly reduce cooled condenser performance; therefore, implementation of dry cooling systems are limited by the local climate.

- Hybrid cooling – a combination of wet and dry cooling. Advantages of the hybrid cooling towers include plume abatement limiting environmental impacts, significant water savings over traditional water-cooled equipment, and suitability for high temperature cooling. The design features of hybrid cooling address environmental concerns, minimize installation costs over dry air cooled condensers, maximize year-round operating reliability, and simplify maintenance requirements. Only a few hybrid-cooling systems have been installed but are demonstrating an effective balance of plant efficiency, cost-effectiveness, water usage and environmental impacts. Additional test plants are needed to demonstrate the benefits of these systems.

According to the U.S. Energy Information Agency (US EIA), thermal electric cooling system usage in the U.S. includes 43 % once-through cooling, 42% wet recirculating cooling, 14% cooling ponds and 1% dry (air) cooling or hybrid, which can switch between dry and a type of wet cooling depending on the ambient temperature and availability of water.[4] Table 1 provides estimates of water used, or consumed, in power plants for cooling in gallons/MWh and water withdrawal rates.[5] The water withdrawal rate value in Table 1 is the amount of water a power plant takes in from a source such as a river, lake, or ocean for the purpose of cooling steam. Consumption, is the amount of water lost through evaporation and other uses during the power generation and cooling process. According to the USGS, the total consumption of water for the thermoelectric sector in 2015 was 4.31 Bgal/day, which was 3% of the total thermoelectric water withdraw.

---

[4] US Energy Information Agency US EIA - http://www.eia.gov/todayinenergy/detail.php?id=14971

[5] Union of Concerned Scientists, 2012- UCS EW3 Energy-Water Database V.1.3. www.ucsusa.org/ew3database

Table 1 – Use and Water Withdrawal Rates for Thermal Power Plants

Generation Technology	Estimated Water Consumption by Cooling Method				Estimated Water Withdrawal Rate
	Once Through	Cooling Tower	Pond	Dry Cooling	
	Estimates in gallons/MWh				
Nuclear	100-400	581-845	560-720	N/A	800-2600
Coal	100-317	480-1100	300-700	N/A	500-1200
Gas - Combined Cycle	20-100	130-300	240	0-4	150-283

The water required for the non-cooling requirements in power generation is-significantly lower than required by the cooling systems and can be further reduced by recycling boiler blowdown water for dust control, and boiler sluicing.

Table 2 provides an estimate of other water use in thermal power plants as % of cooling water requirements.[6]

Table 2 - Water Withdrawal Rates for Thermal Power Plants

Process	Percentage of water use in thermal power plants
Boiler/Steam Generation and Blowdown	1% of total water
Boiler sluicing and dust control	<1% of total water
Wet FGD	~5-10% of total water

Another factor that has impacted the energy-water nexus is energy efficiency standards at the Federal and the State levels. The combination of energy efficiency, Renewable Portfolio Standard (RPS) implementations and the 2008-2009 recession resulted in a flat demand for ~~the~~ power generation over the 10 year period of 2005 to 2015. Between 2010 and 2015, water use for thermal power generation decreased 9% (Dieter, C, et al.). It is expected that with economic recovery, the demand for power generation will increase, but major utilities forecast a growth rate 2-2.5% or less annually due to increased adaptation of energy efficiency and distributed self-generation, resulting in lower demand for water for thermal power generation.

The National Renewable Energy Laboratory (NREL) and the Lawrence Berkeley Laboratory (LBL) have jointly estimated water savings from renewable energy penetration (RE) under a no RPS, existing RPS and high RPS scenarios..[7] Under the Existing RPS scenario, water consumption is 4% lower in 2030 and 7% lower in 2050 relative to the No RPS baseline. Greater impacts could be seen in the High RPS scenario compared to the No RPS baseline, where water consumption is 20% lower in 2030 and 25% lower in 2050. The NREL/LBL projections through

---

[6] U.S. Department of Energy, "Water Requirements for Existing and Emerging Thermoelectric Plant Technologies," DOE/NETL-402/080108, Pittsburgh, PA, April 2009

[7] "A Prospective Analysis of the Costs, Benefits, and Impacts of U.S. Renewable Portfolio Standards", National Renewable Energy Laboratory and Lawrence Berkeley Laboratory - Technical Report; NREL/TP-6A20-67455 LBNL-1006962; December 2016

2050 under the three RPS scenarios for water consumption and water withdrawal rate for power generation are shown in Figures 2 and 3 respectively. The study assumes that power generation through renewable energy sources, primarily wind and solar will continue to grow with or without the RPS standards due to economic competitiveness and favorable tax incentives for these renewable energy technologies.

Figure 2 – Water Consumption Estimate for Power Generation

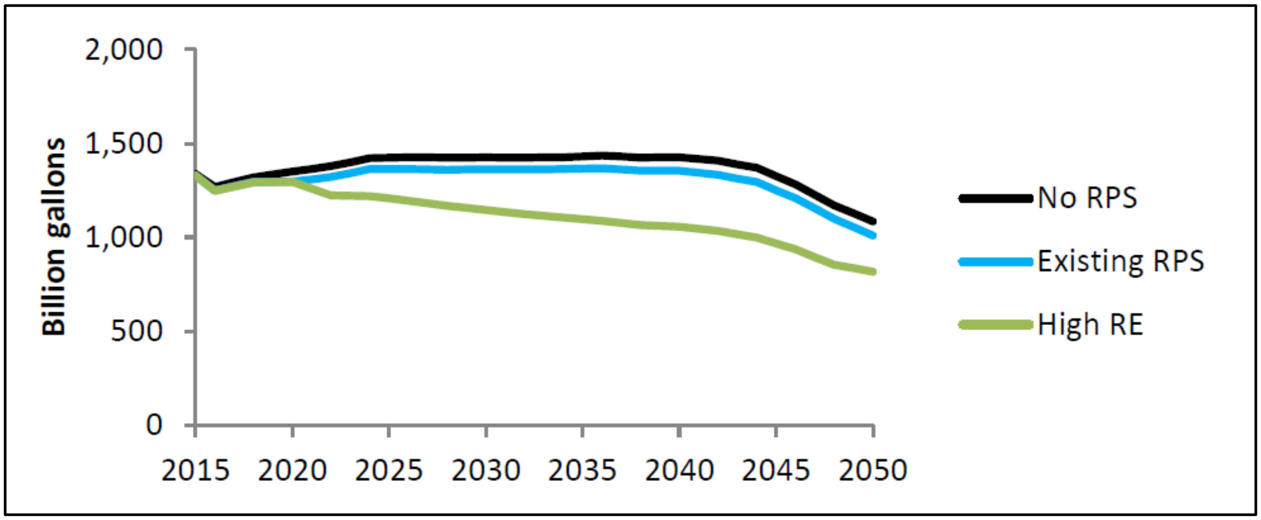
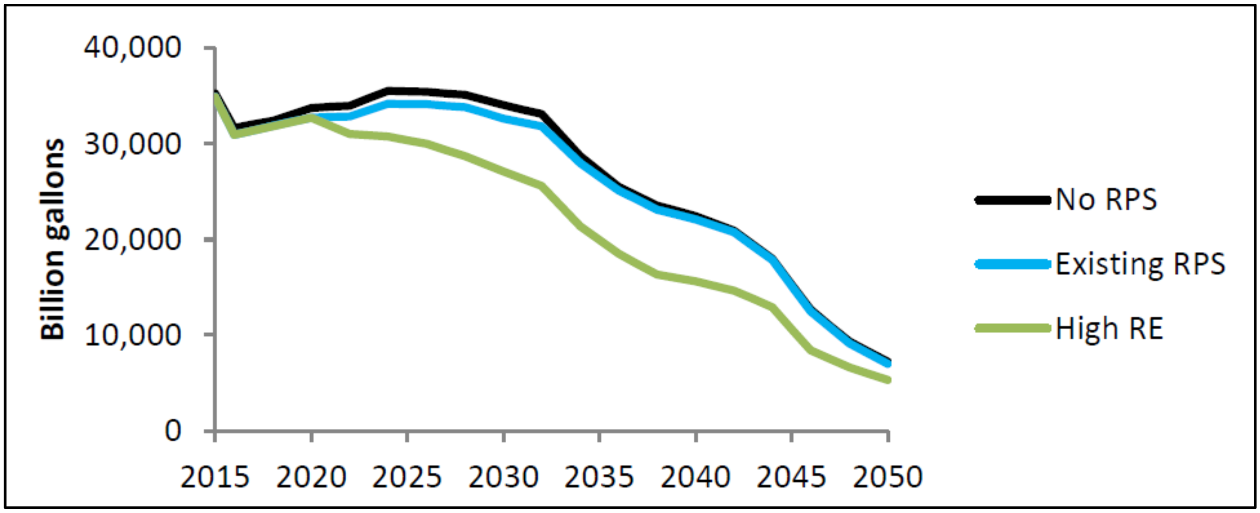


Figure 3 – Water Withdrawal Rate Estimates for Power Generation



The power generation industry continues to move toward reducing greenhouse gas emissions despite on again off again policy requirements. The increase in natural gas as a fuel source in combined cycle power plants, replacing older, less efficient coal fired power plants has been the largest contributor to reducing greenhouse gas emissions in the United States (Taylor, 2017). While reductions in greenhouse gas emissions have been also been achieved through the increase in renewable energy technologies, many provide intermittent power from wind and solar resources. There is a need for more baseload power generation that can help stabilize the grid and/or for more energy storage such as large-scale batteries or pumped storage hydro. Pumped storage hydro continuously transfers water from a lower elevation storage pool to an upper storage pool. The water is not consumed and the system is operational for 50 to 100 years, significantly longer than battery storage facilities. Baseload power could be achieved through CO_2 capture and sequestration from fossil fuel plants, currently only in demonstration projects. Policy decisions regarding greenhouse gas emissions and incentives for technology development will direct water use in the energy sector.

III. Hydropower

Hydropower is driven primarily by the hydrologic cycle that is responsible for the movement and distribution of water that supports all life. The potential energy of water can be harnessed as it returns to the sea via lakes and rivers in the U.S. and the majority of countries around the world. Hydropower generation does not release carbon dioxide, or criteria pollutant gases into the atmosphere. Hydropower is generally a more constant and dependable source of renewable energy, when compared to more intermittent sources of wind and solar technologies. Hydropower systems are typically very flexible and can help with grid stability especially where a high percentage of solar and wind powered systems are installed. Unlike thermoelectric power and agriculture, water used for hydropower generation is completely non-consumptive. The water used for energy generation passes through a hydroturbine and is returned to the river and may be used again for power generation downstream, as long as an adequate drop over dams or similar structures is available.

Hydropower currently provides about 17% of the world's electricity production, and about 7% of the production in the U.S., utilizing advanced turbine, generator, and control system technologies. In many cases turbine efficiency values may be as high as 95% and overall system efficiencies are in the 90% range. The theoretical potential of hydropower worldwide is estimated to be about five times the output currently installed. Environmental and social impacts will likely preclude the development of significant portions of new hydropower, even on the existing 80,000[8] (Hadjerioua, 2012) dams in the U.S. that do not have installed hydropower. The scarcity of capital investment due to environmental and regulatory uncertainty is a limiting factor in the implementation of hydropower potential projects in addition to no long-term tax incentives that are in place for solar and wind power technologies.

There are many diverse types of hydropower facilities and applications including:

- **Reservoirs:** Dams or natural impoundments are used to store water that is then released through the turbines to produce hydropower when needed. The reservoir may also be used for other purposes like flood control, irrigation, recreation and water supply.

---

[8] Hadjerioua, b. Wei, Y. and Kao, S.C., An Assessment of Energy Potential at Non-Powered Dams in the United States. A Report Prepared for the U.S. Department of Energy Wind and Water Power Program. Prepared by Oak Ridge National Laboratory, Oak Ridge, Tennessee. April, 2012.

- **Run-of-River:** Flowing water is passed through a turbine. The water flow is not stopped behind a dam or other structure. Water that is not passed through the turbine passes around the turbines over a spillway.
- **Pumped Storage:** Water is pumped from a lower reservoir or river up to an upper reservoir (usually man-made) using energy generated during the low demand periods, mostly evenings and weekends. This water is then run through turbines to generate power during high demand periods. Both pumping and generating is accomplished using a reversible type pump/turbine connected to a reversible type generator/motor. The water goes back to the lower reservoir to start the cycle over again.
- **Marine and Hydrokinetic:** The motion of ocean waves, tides, currents, the natural flow of water in rivers, and marine thermal gradients can also be used to produce hydropower, although is it not as well developed as the prior described systems.

Hydropower is very often one component included in the comprehensive development of water resources, which frequently includes dams for storage of water supply or diversion for irrigation, sediment control, flood control and damage reduction/mitigation, as well as providing navigation and recreational opportunities.
An "Assessment of Energy Potential at Non-powered Dams in the United States", compiled by the Department of Energy's Oak Ridge National Laboratory (ORNL), assesses the ability of existing non-powered dams across the country to generate electricity. The 80,000+ non-powered dam facilities represent most of the dams in the country; more than 90% of dams are used for services such as regulating water supply and controlling inland navigation, and lack electricity-generating equipment. The study found that the nation has over 50,000 suitable non-powered dams with the technical potential to add about 12 gigawatts (GW) of clean, renewable hydropower capacity. Considering only the 100 largest capacity facilities - primarily locks and dams on the Ohio, Mississippi, Alabama, and Arkansas rivers operated by the U.S. Army Corps of Engineers - these existing dams could provide 8 GW of power combined. These existing dams can likely be retrofitted at a lower cost than creating new powered dam structures without impacting critical habitats, parks, or wilderness areas. Together, these facilities could power millions of households and avoid millions of metric tons of carbon dioxide emissions each year. Hydropower provides electric grid stability due to its flexibility to load follow, thereby allowing a larger percentage of wind and solar power into the electrical system.

To enable the development of hydropower at the best existing dam sites, policy changes are necessary. The licensing process for new hydropower, including on long standing existing dams, can take up to 7 or 8 years, and requires an investment of several million dollars. Even near the end of the process, several uncertainties persist, particularly related to water use and water quality. Duplicative studies are frequently required by different agencies, complicating the permitting process. In October 2018, Congress passed the Water Resources Development Act of 2018 that included several provisions requiring two year licensing processes for powering non-powered dams and closed loop pumped storage hydro. The regulatory implementation of the changes made by the law will help provide some certainty for these types of hydropower projects going forward. Further reforms eliminating duplicative efforts at multiple agencies are still needed.

The Department of Energy (DOE) estimates that drawing on all the marine and hydrokinetic resource potential energy in the United States could produce 1700 terawatt hours per year, almost half of the nation's total annual electricity usage (U.S. Depeartment of Energy, Office of Energy Efficiency & Renewable Energy, Wind and Water Power Technologies Office, 2016). Not all of the potential from the waves, tides, ocean currents, and natural water flows can be developed, but the potential demonstrates the need for further government support for research and development.

IV. Oil and Gas Extraction

Approximately 63% of U.S. primary energy consumption is in the form of oil and gas, with nearly all transportation fuels from petroleum products. As of July 2015, natural gas fueled 35% of U.S. electricity generation by surpassing coal[9]. Oil and gas production have a substantial interdependency with water, in terms of water withdrawal and return of water used in the process to the environment. Further water interdependencies pertain to the impact of exploration and production activities on groundwater and surface water systems.

Major increases in U.S. domestic oil and gas production have been achieved with "unconventional" oil and gas production with enhanced recovery methods that include hydraulic fracturing and horizontal drilling. There are over 100,000 unconventional well sites in the U.S.[10], with water usage per well ranging from 2 million to 13 million gallons[11]. The trend has resulted in an increase in water usage. By 2014, median annual water volume estimates for hydraulic fracturing in horizontal wells were more than 4 million gallons per oil well and 5.1 million gallons per gas well[12].

Water is used in the well development stage of hydraulic fracturing as the medium to pressurize the rock and prop it open, involving large volumes of water delivering various chemicals down into the formation. At depths of thousands of feet or miles below the surface, wells penetrate through many subsurface geological and hydrological structures and systems to reach oil and gas formations. Water is used in the process of releasing oil and gas from the formation and, then, during production, large volumes of water come to the surface from the formation. This "produced water", globally, amounts to 3 or more barrels of water for every barrel of oil[13]. Water from oil and gas wells, associated with development of the well or ongoing production must be managed, which includes treatment and disposal processes. Some amounts of the water coming out of a well are re-injected deep below the surface.

---

[9] "Form EIA-923 detailed data", U.S. Department of Energy, Energy Information Administration (EIA), Dec. 2015.

[10] Groundwater Protection Council (GWPC), 2014. FracFocus Chemical Disclosure Registry. <http://fracfocus.org> (visited 22 January 2016).

[11] Rodriguez, R.S., Soeder, D.J., "Evolving water management practices in shale oil & gas development", Journal of Unconventional Oil and Gas Resources, 10 (2015) 18-24, March 2015.

[12] Wade, A.B., Cooper, L., Gallegos, T., "Water used for hydraulic fracturing varies widely across the United States", U.S. Geological Survey (USGS), June 2015, http://www.usgs.gov/newsroom/article.asp?ID=4262&from=rss&utm_source=dlvr.it&utm_medium=twitter#.VqJlBFIiZl2

[13] Arnold R., et al, "Managing water – from waste to resources", Oilfield Review, Summer 2004.

The energy and water link in oil and gas development and production is crucial. Because of the volumes of water involved and the nature of the exploration, development, and production activities which include drilling a large number of wells deep below the surface, particularly for unconventional well types, the potential interdependencies and impacts are numerous. Considerations include source and volume requirements to supply initial development of the well, treatment and disposal of water during development and production, and potential impacts to groundwater aquifers and surface water systems. Considerations are inherently regional and local. Whether a specific region or locale is suitable depends on local geology (stable low permeability vs. highly porous systems like limestone with highly connected aquifers and hydrology across zones), geography (plains areas versus coastal areas and peninsulas subject to saltwater intrusion) and current and projected adequacy of local water supplies (consider any existing stresses due to drought or usage exceeding availability). Exploitation of the oil and gas resource is precluded where there are excessive risks to water resources due to the interdependencies.

V. Industrial Plant Usage

Industry uses water for various purposes including steam production, fabricating, processing, washing, diluting, cooling, transporting a product, incorporating into a product, and sanitation/cleaning needs within the manufacturing facility. Several industries that use large amounts of water to produce commodities such as food, paper, chemicals, refined petroleum, or primary metals. Water for industrial use may be delivered from public water supplies or be self-supplied either from groundwater or surface water. In 2015, the total U.S. water withdrawals were approximately 14.8 billion gallons per day for industrial purposes, a 9% reduction since 2010. Due to increasingly efficient manufacturing practices, industry has reduced water use by 30% since 1985. While many industries are reducing their waste and conserving water. American consumers are often less efficient. In 2008 for example, Americans threw out approximately 34.5 million tons of paper and 27.9 million tons of plastic — both of which are water-intensive materials that could be re-used or recycled to reduce industrial water and energy usage.[14]

Water usage in industrial processes fall into two main categories: fresh water usage and recycled water.

Freshwater is used by most industrial facilities for a variety of different purposes depending upon the industrial process and the facility. The usage is dependent on location, water needs and regulatory constraints. Some of the general categories include:

- **Steam production** – similar to thermoelectric plants, industrial plants use freshwater as makeup for several uses including boiler feed water to produce steam that is either used in the process for heating, electric generation or power (turbine drive) use, cooling on the

---

[14] Grace Communications Foundation http://www.gracelinks.org/285/the-hidden-water-in-everyday-products

exhaust system and intermediate process equipment in the power cycle, and cleaning of plant equipment (e.g., steam drums) during outages

- **Fabricating** – water is used in fabricating both as a cleaning agent and as a coolant. Examples include the rinsing of metal parts after degreasing, plating or painting and used during the tempering process. For the automotive industry, it requires approximately 75,000 gallons to produce 1 ton of steel. The average car contains about 2,150 pounds of steel which translates into 80,000 gallons of water.[1414]
- **Processing** – within the food, paper, chemical, refining and pharmaceuticals industry water is used for a variety of purposes including as a carrier or solvent of raw materials and intermediates, washing/cleaning of process equipment, as a diluent of raw materials/products, as a catalyst, as well as for cooling and steam production.
- **Incorporation into a product** – within the food, chemical and pharmaceutical industries water is added to products during or after production depending upon the concentration needed. Some examples include:
  - Sodium hypochlorite is produced at approximately 35% but when sold, the product is diluted by water to 8% - 17% depending upon the customer need.
  - Intravenous (IV) solutions are predominately water with minimal amounts of active pharmaceuticals added.
  - Soft drinks, teas and other beverages are produced through the addition of water to manufactured syrups.
  - Sanitation at industrial facilities use water for cafeterias/lunchrooms, bathrooms and laundry facilities for uniforms/work clothes.

In addition to freshwater supplied by either public water or self-supplied, industrial facilities recycle large quantities of water within the manufacturing facility. Water recycling is reusing treated wastewater for beneficial purposes and offers resource and financial savings. General applications include cooling water for industrial plants and oil refineries, industrial process water for such facilities as paper mills and carpet dyers, toilet flushing, dust control, construction activities, and concrete mixing. Recycled water can satisfy a great many water demands, as long as it is adequately treated to ensure water quality appropriate for the use. In some cases, the treatment process is regulated by U.S. EPA or States.

VI. Public Water Use and Systems Cycle

Population and urban boundary growth dramatically increase energy and water consumption. The public water cycle consists of hydraulic systems that move water into, within, and out of defined boundaries for public use and relies upon treatment facilities to modify water quality so it will meet the regulatory requirements of its intended uses. Potable water systems extract raw water for treatment, store and distribute drinking water to the general public. Wastewater systems collect, convey, treat, and discharge or reclaim wastewater for suitable environmental applications. Storm water systems protect water resources and minimize flooding through removal of pollutants and reduction of flows. In drought-stricken regions, storm water and wastewater are also being considered as potential potable supply sources. Water reuse helps to reduce pumping requirements although the water would require more energy intensive treatment.

Energy needed for potable water treatment facilities vary from 10.78 to 144 kWh per one million gallons depending on plant size, water source and type of treatment.[15] Increasing energy costs are problematic for potable water production as well as sewage treatment facilities. Growing water distribution systems require energy for pipe manufacturing and construction.

Water treatment and delivery systems constitute critical infrastructure which are aging and need updating. The drinking water crisis in Flint, Michigan underscores the challenges that municipalities and local governments face in addressing water infrastructure issues. Many cities are heavily reliant upon pipeline infrastructure that was built in the nineteenth century.[16] An analysis by the EPA estimated a 20-year capital gap for clean water infrastructure spending of $122 billion ($6 billion per year) in 2001 dollars.[17] In 2010 alone the total water funding gap was $55 billion and expanding rapidly.[18]

Unrestricted urban growth could eventually reach a point where water consumption exceeds the water supply replenishment rate especially in areas of drought unless other distant potable or non-potable water sources that require energy intensive filtration methods are available. For example, saltwater desalination using reverse osmosis plants uses about 11,240 kWh per one million gallons of fresh water produced according to the National Renewable Energy Laboratory studies. Careful urban planning and establishing growth boundaries could further reduce energy and water consumption by creating denser urban areas. Energy savings can be designed into municipal systems by proper placement of water treatment and waste water treatment systems through proper sizing of pumping equipment, pipelines and site locations. Designing piping systems that are gravity fed instead of pumped systems (when possible) will also reduce energy costs.

Waste water treatment facilities need to design systems to reduce energy costs associated with pumping systems and aeration needed for the biological waste treatment. More advanced technologies like membrane bioreactors use more energy than activated sludge or extended aeration.

Good water system design practices can lower energy usage with water infrastructure designs that reduce friction losses, improved control systems and utilizing energy efficient electrical motors for pumps. Hydraulic modeling using quality data can prevent oversizing or under sizing a piping system. Additional water and energy savings are attainable with elimination or control of water leakage in public water system infrastructure, power plants, industrial processes, commercial activities, agricultural and even domestic plumbing fixtures. Pipe leakage can result from corrosion, aging pipe joints, poor maintenance, and poor pipe installation. For instance, a dripping faucet at 0.03 gallons per minute equals 15,768 gallons per year in water losses with the added repercussion of energy losses.

---

[15] Pacific Gas and Electric August 28, 2006; EPRI CR-106941 (2013)

[16] Drinking Water Infrastructure Key Points

[17] U.S. Water Infrastructure Needs & the Funding Gap http://water.epa.gov/infrastructure/sustain/infrastructureneeds.cfm

[18] GAO Energy-Water Nexus, Amount of Energy Needed to Supply, Use, and Treat Water Is Location-Specific and Can be Reduced by Certain Technologies and Approaches http://www.gao.gov/assets/320/316893.pdf

Public Water Supply and Recommendations

Potable water facilities can minimize energy requirements through consideration of four key strategies:

- Implementation of water-use efficiency programs through promotion of demand-side conservation or supply-side facility enhancements.
- Avoidance of higher embedded energy supplies due to pumping demands (e.g., groundwater or imported supplies) or treatment requirements (e.g., desalination) when possible
- Adaptation of distribution-system energy water quality management systems (EWQMS), particularly in regions with flat tariff rates and systems with high storage capacities.
- Increased reliance on energy from renewable fuel sources through direct and indirect strategies.

Five key strategies can assist wastewater facilities in minimizing their energy requirements:

- Restricting collection system infiltration and inflow through detection of structural failures
- Optimizing activated sludge aeration systems through off-gas monitoring with mathematical modeling
- Optimizing ultraviolet disinfection systems through flow-pacing or utilization of low-pressure lamps when appropriate;
- Capitalizing on combined heat and power installation opportunities to use biogas to simultaneously generate electricity and heat with a prime mover that drives the overall system
- Capturing latent energy in digested biosolids through capture of methane from aqueous anaerobic digestion of the wastewater treatment facility sludge.

The Water Resources Development Act of 2016 (WRDA) authorizes funding for upgrading public water systems and creates an Innovative Water Technology Grant Program to support research for innovative water technologies. However, Congress must appropriate funding for these authorizations; funds allocated could not only help create jobs but save millions of gallons of lost water and reduce unnecessary energy consumption. Public-Private Partnerships (PPP) may be another approach to encourage private sector investments with a possibility of low interest government financing and/or the creation of Water Savings contracts, whereby the savings in reduced water and energy consumption could pay for the upgraded infrastructure. However, the financial feasibility of the PPP approach may vary by project type.

VII. Desalination and Water Reuse

Desalination and water reuse are critical technologies in the U.S. Water portfolio to meet future population water demands. While these systems are typically more expensive than traditional water sources and treatment methods, they will inevitably be required to meet future water needs in certain coastal communities.

Desalination is the process of removing salinity from water, most commonly by pumping water at high pressures through semi-permeable reverse osmosis membranes. Water sources treated by desalination may be defined as either brackish water (typically under 10,000 parts per thousand of salinity) or seawater (typically 35,000 parts per thousand of salinity). The energy costs for desalination are proportionally related to the salinity in the water, therefore, seawater desalination has been considered one of the costlier water treatment options in the water industry. Desalination has been utilized in the U.S. for decades for both industrial needs and public drinking water, but only recently have large-scale desalination water treatment plants been installed. The recent large desalination plants include the 25 MGD seawater desalination plant in Tampa Bay, FL, the 27.5 MGD inland brackish desalination plant in El Paso, TX, and the 50 MGD seawater desalination plant completed in Carlsbad, CA in 2016. While these plants represent a small fraction of the total water supply treated in the United States, these projects are critical in providing reliable water resources to the communities where they have been constructed.

The energy consumption and costs of desalination are cost prohibitive in regions where abundant water resources exist and are in proximity to the populations and industries that they serve. However, in coastal regions with limited water resources (California and Texas) or environmental drivers (Florida), desalination has become a significant consideration in the water portfolio. Drought preparedness in the southwest and western United States is a key driver for identifying "new" water sources for water contingency. In Texas and California, some communities rely on water pumped hundreds of miles to supply the industries and growing population demands. The capital investment for water transmission, operational pumping and maintenance costs approach the capital costs and energy requirements for desalination projects. Coastal desalination requires less water transmission because water resources and disposal locations are proximate to consumer demand and power.

Desalination in the U.S. has predominately been achieved using reverse osmosis membranes. Energy reduction in the desalination market continues to develop. Alternative designs with 16 inch diameter membrane elements instead of the traditional 8 inch diameter elements can reduce the ancillary piping and equipment required and minimize capital costs.[19] Energy recovery turbochargers have been incorporated into modern designs to reduce energy consumption. Researchers are continuing to evaluate nanotechnology materials to improve flux rates and alleviate the pumping energy requirements for membrane treatment. Furthermore, the locations where desalination appears to be most viable from a water resources perspective are in warmer coastal regions and may be able to draw on renewable energy resources to power the desalination facilities.

A key barrier to entry and energy cost for desalination projects is the disposal of concentrated brine generated during the treatment process. The capital investment of pumping waste brine to off-shore ocean outfalls can be an economic and energy challenge depending on terrain, elevation changes, and proximity to appropriate discharge locations. To mitigate costs and environmental impacts, desalination plants may co-locate with power plants to utilize existing intakes and outfalls and blend brine discharge with power plant discharge waters.

---

[19] Water Desalting Planning Guide for Water Utilities By American Water Works Association.

A more uncertain challenge for future desalination facilities are the requirements to obtain an outfall permit to discharge waste brine without impacting marine habitats. The recent Carlsbad Desalination Plant completed in 2016 required over 7 years of permitting, which extended the planning, design, and construction period.[20] Legislation and regulations should consider the need for streamlined, consistent, and expedited evaluations for permitting. Regulatory certainty would allow critical projects to be implemented efficiently to meet growing population demands, changing availability of water supplies, and drought preparedness. Where possible, opportunities and incentives to use existing intakes and outfalls and co-locate with power plants or wastewater treatment facilities should be encouraged to expedite projects and minimize energy costs for disposal.

Water reuse may be defined as non-potable or potable. Non-potable reuse encompasses land application of treated wastewater or use of grey water in homes or building applications. Potable reuse is the application of wastewater treated to a sufficient quality for consumption as drinking water. Reusing water, minimizes reliance on the energy requirements to convey water sources from distant reservoirs or deep groundwater wells. Within potable reuse, the level of treatment required and energy costs differ depending on if it is intended for indirect potable reuse (conveyed to a groundwater or surface water source) or direct potable reuse (conveyed directly into the water distribution system). Indirect potable reuse provides an additional natural "buffer" for water before being consumed as drinking water. Additional pumping energy is required to first convey the water to the aquifer or other storage source, secondly pump the water from that source to the drinking water treatment plant, and thirdly re-treat the water to potable drinking water standards. Direct potable reuse can eliminate the pumping energy and treatment energy needed for indirect potable reuse; however, the treatment process by which water has been treated for this application is more complex than conventional treatment and requires additional energy.

The regulatory requirements for potable reuse are at a nascent stage, federal standards are needed. Currently, the State of California follows a potable reuse treatment process referred to as Full Advanced Treatment (FAT), which has been modified for limited implementation in Texas. The process includes a multi-barrier treatment that incorporates microfiltration/ultrafiltration (MF/UF), reverse osmosis (RO), ultraviolet (UV) light disinfection, and advanced oxidation (AOP) technologies. The treatment process is considerably more energy intensive than conventional treatment processes, but research continues to demonstrate the efficacy of alternative treatment processes such as ozone followed by biologically active filtration (BAF) that may replace the energy intensive RO process and still achieve properly treated, potable water.

VIII. Irrigation, Agriculture, and Food Production

As of 2015, approximately 37% of the water withdrawal rates are for irrigation, agriculture and aquaculture (USGS, 2018). Irrigation water use includes water that is applied by an irrigation system to sustain plant growth in all agricultural and horticultural practices. Irrigation also

---

[20] Carlsbad Desalination Plant: http://carlsbaddesal.com

includes water that is used for pre-irrigation, frost protection, application of chemicals, weed control, field preparation, crop cooling, harvesting, dust suppression, and leaching salts from the root zone. Estimates of irrigation withdrawals include water that is lost in conveyance prior to application on fields as well as water that may subsequently return to a surface-water body as runoff after application, water consumed as evapotranspiration (ET) from plants and ground surfaces, or water that recharges aquifers as it seeps past the root zone.

Surface water was the primary source of water in the arid West, except in Kansas, Oklahoma, Nebraska, Texas, and South Dakota, where more groundwater was used, with 17 Western States cumulatively accounting for 93% of total surface-water irrigation withdrawals and 69% of total groundwater irrigation withdrawals. The major irrigation methods include sprinkler systems (51 %), surface or flooding (41%), and micro-irrigation systems (7%).**Error! Bookmark not defined.** Irrigation of golf courses, parks, nurseries, turf farms, cemeteries, and other self-supplied landscape-watering uses also are included in the estimates. The national average application rate for 2010 was 2.07 acre-feet per acre (1 acrefoot=325,851 gallons). Irrigation water use includes self-supplied withdrawals and deliveries from irrigation companies or districts, cooperatives, or governmental entities. Some irrigation water is reclaimed wastewater from nearby treatment facilities or industries. All irrigation withdrawals are considered freshwater.

Livestock water use is water associated with livestock watering, feedlots, dairy operations, and other on-farm needs. Livestock includes dairy cows and heifers, beef cattle and calves, sheep and lambs, goats, hogs and pigs, horses, and poultry. Other livestock water uses include cooling of facilities for the animals and products, dairy sanitation and wash down of facilities, animal waste-disposal systems, and incidental water losses. The livestock category excludes on-farm domestic use, lawn and garden watering, and irrigation water use. Withdrawals for livestock use were an estimated 2,000 Mgal/d for 2010, about 1 % of total freshwater withdrawals. Groundwater was the source for 60 % of total livestock withdrawals. **Error! Bookmark not defined.**

Aquaculture water use is water associated with raising organisms that live in water—such as finfish and shellfish— for food, restoration, conservation, or sport. Aquaculture production occurs under controlled feeding, sanitation, and harvesting procedures primarily in ponds, flow through raceways, and, to a lesser extent, cages, net pens, and closed-recirculation tanks. Total withdrawals for aquaculture during 2010 were 9,420 Mgal/d, about 81 % from surface water. Much of the surface water was used for flow through raceways and was returned to the source after use. Aquaculture withdrawals were 3 % of total withdrawals for 2010.**Error! Bookmark not defined.**

Affordable solar panels could be employed to produce electricity and hot water for farms. There are commercial organic solar panels that are less expensive than the silicon crystal type, though with a shorter life. Reasonably sufficient areas to capture the sunlight should not be problematic in rural areas, as compared to urban areas that hinder the solar radiation from being efficiently tapped. Energy from the sun, wind, and water (mini-water turbines) should be employed for the electricity needs of a farm.

When considering water for irrigation, the solar drip irrigation system should be investigated for use in dry areas. It has been successfully carried out in many parts of the world. Drip irrigation is known for being successful in agricultural areas with dry climates. Additional technologies such as infiltration trench irrigation methods could be implemented instead of traditional lawn with sprinklers, which would assist in groundwater recharge. The technology has been shown to have a recharge efficiency of 58 to 79% was achieved by the infiltration trench, as compared to 8 to 33 % achieved by a regular lawn.[21] These kinds of low-impact development (LID) methods and best management practices may be followed to assist in the urban, water-stressed areas.

Mechanical Engineers have minimal involvement with water usage in agricultural systems. This is predominately the purview of, among others, Agricultural Engineers, hydrologists, agronomists, farmers, State Cooperative Extension Services, and manufacturers of irrigation, drainage and erosion control equipment, components and systems.

IX. Conclusion

Energy and water are intrinsically dependent. As engineers and the technical communities who operate in energy-water industries strive to develop new technologies and upgrade the existing infrastructure, government can assist by:

- Appropriating funds under the Water Resources Development Act, which will help public water systems upgrade aging water distribution systems to promote energy-water savings and efficiencies;
- Streamlining regulations and reducing the duplicative, multi-agency review processes in most sectors for water and energy will help reduce the amount of water to produce power and the amount of power required to move water and grow food;
- Providing funding for research, development and demonstration such that the various infrastructures can more quickly become cleaner and more efficient.

The private sector has demonstrated, through technology innovation that it is ready to make investments, but more certainty from regulators is needed in order to encourage the adoption of new technologies. Public private partnerships could also be an efficient means to improve the U.S. aging infrastructure while at the same time reducing water losses and the energy required for the water systems.

***

---

[21] Newcomer. Et al. Urban Recharge beneath low impact development and effects of climate variability and change. Water Resources Research

I. References

Atkinson, C. E. (2010). *Energy Choices.* New York: ASME.

Crawford G. and Sandino, J. (2010). *Energy Efficiency in Wastewater Treatment in North America: A Compendium of Best Practices and Cases Studies of Novel Approaches.* Water Environment Research Foundation. London: IWA Publishing.

Elliott, T. Z. (2003). *Energy Center of Wisconsin.* Retrieved August 2013, from Www.ecw.org: Www.ecw.org/prod/222-1.pdf

EPRI. (2002). *Water and Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply and Treatment – The Next Half Century.* Technical report .

GWRC. (2008). Retrieved August 2013, from www.iwahq.org.

Hadjerioua, B. W. (2012). *An Assessment of Energy Potential at Non-Powered Dams in the United States.* Wind and Water Power Porgram. Oak Ridge: U.S. Department of Energy.

Maupin, M. K. (2014). *Estimated Use of Water in the United States in 2010.* Reston: U.S. Geological Survey.

NYSERDA. (2008). *Statewide Assessment of Energy Use by the Municipal Water and Wastewater Sector.* New York State Energy Research Development Authority. Albany: NYSERDA.

Senon, C. B. (2013). *Drinking Water Pump Station Design and Operation for Energy Efficiency.* Water Research Foundation, Denver, Denver.

Taylor, J. (2017, September 12). *Climate Group: Natural Gas, Not Renewables, Is Largest Factor In Emissions Decline*. Retrieved from Forbes: www.forbes.com

U.S. Department of Energy, Energy Information Administration. (2015). *EIA-923 Detailed Data.* Washington.

U.S. Depeartment of Energy, Office of Energy Efficiency & Renewable Energy, Wind and Water Power Technologies Office. (2016). *Marine adn Hyrokintic Energy Projects.* Wasington: Department of Energy.

U.S. EPA. (2008). *Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities.* U.S. EPA Office of Water and Global Environment and Technology Foundation, Arlington, VA, Office of Water. Washington: U.S. Environmental Protection Agency.

WEF. (2009). *Energy Conservation in Water and Wastewater Treatment Facilities. Manual of Practice No. 32.* World Environment Federation. Alexandria: WEF Press.

Wilkinson, R. (2000). *Wilkinson, R.C. (2000) Methodology for Analysis of the Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits through Integrated Water-Energy Efficiency Measures. Exploratory research project.* Research Project, Santa Barbara.

Wolff, G. G. (2004). *www.pacinst.org.* Retrieved August 2013, from www.pacinst.org/publicaton/water-to-air-models/: www.pacinst.org/publicaton/water-to-air-models/

APPENDIX A – Water Leakage Case Study - Forrest Kemp

Population and urban boundary growth dramatically increase energy and water consumption as illustrated with an example in the Forest Kemp, a residential neighborhood of Houston, Texas. This subdivision's estimated water consumption and distribution piping serving it are summarized in the following tables:

ESTIMATED FOREST KEMP SUBDIVISION WATER CONSUMPTION

Parameter	Units	Comments and Source
Subdivision Area	0.18-square miles	Goggle Earth Photo
Subdivision Perimeter Distance	1.9-miles	Google Earth Photo
Number of Residences in Subdivision	429-each	Goggle Earth Photo
Number of Swimming Pools	86-each	Goggle Earth Photo
Average Residential Water Usage	101-gallons per residence per day	DOE Bldgs. Energy Data Book
Average Swimming Pool Evaporation	120-gallons two day or 3.6-gpm	Lone Star Chapter Sierra Club
Daily Residential Water Consumption	30.1-gpm or 43,330-gallons	gpm equals gallons per minute
Daily Swimming Pool Evaporation	5,160-gallons	86 swimming pools
Total Daily Water Consumption	33.7-gpm or 48,490-gallons	Residential and Swimming Pools
Total Annual Water Consumption	17,698,500-gallons	

ESTIMATED FOREST KEMP WATER DISTRIBUTION PIPING

12 inch Diameter Pipe	3,620 feet	*Ductile Iron buried–4 feet
6-inch Diameter Pipe	4,130-feet	*Ductile Iron buried–4 feet
Fire Hydrants and Valves	39-each	*1,500-gpm fire flow residential
Residential Water Meters	429-each	1-inch
Cross Tees 6" X 12" X 6"	13-each	*Ductile Iron
Isolation Gate Valves 6 inch	26-each	
Isolation Gate Valves 12 inch	13-each	
1 inch Diameter Copper Pipe	5,150-feet	Assumed average 12-feet distance from water main connection to meter box

***Source: City of Houston Infrastructure Manual**
Note: According to Houston Public Works Department statistics, the Houston metropolitan area with a 2.2 million population uses 392 million gallons per day that requires a water supply system with over 7,000 miles of pipe including pump stations, wells, treatment plants, control center and storage tanks.

Furthermore, pipe friction losses, elevation differences and leakage increases the amount of electricity a pump needs to deliver water as shown in the following equation.

$$Pumping\ Cost\ \$\ =\ 1.65 \times H_L \times Q\ \times \left(\frac{a}{E}\right)$$

Where:
H_L = Hydraulic gradient or head loss that includes pipe, valve and fitting friction losses.
Q = flow, gallons per minute or gpm
a = unit cost of electricity, $/ kW-hr
E = total efficiency of pump system (pump, motor, transmission), %/100
Source: American Water Works Association Ductile-Iron Pipe and Fittings AWWA M41 page153

A Pacific Gas and Electric report titled “Municipal Water Treatment Plant Energy Baseline Study” August 28, 2006 and Electric Power Research Institute report CR-106941 stated that water distribution pumping uses about 1,000 kWh per one million gallons. Annual water supply for Forest Kemp example would need approximately 17,700 kWh of electricity where Houston electrical rates equal $0.082 to $0.091 per kWh.