Water Resource Challenges and Opportunities for Water Technology Innovation

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THE WHITE HOUSE
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Introduction

Whether through surging seas or parched landscapes, water is a common medium through which the impacts of climate change are felt. This document outlines the impact of climate change on already-strained water resources, actions by the Obama Administration to address water resource challenges, and an aggressive two-part water innovation strategy to accelerate ongoing progress with the goals of:

1) Boosting water sustainability through the greater utilization of water-efficient and water reuse technologies; and
2) Promoting and investing in breakthrough R&D that reduces the price and energy costs of new water supply technology.

Challenges to Water Resources

Climate-related stressors

Climate-related stressors pose significant challenges to our water resources, impacting both water supply and demand, and having significant implications on water management practices. Climate change affects water resources through changes in the form and timing of precipitation; droughts of increasing duration and severity; stresses on coastal freshwater aquifers and wetlands; decrease in quality and quantity of surface (e.g., rivers, lakes) and groundwater; and substantial impacts on ecosystem health and services. In particular, future short-term droughts (droughts within one season of the year) are expected to intensify in most regions of the United States, and longer-term droughts are expected to intensify in large areas of the Southwest, the southern Great Plains, and the Southeast.[1] Both kinds of drought pose significant challenges to water supplies; the drought in California, for example, already in its fourth year, has had multi-billion dollar impacts on agricultural production, has significantly stressed commercial and recreational fisheries, and has required significant municipal water use reductions.[2]

Further, climate change, acting concurrently with population growth, land use, energy use, and socioeconomic changes, increases water demand and exacerbates competition among uses and users of water.[3] The Third National Climate Assessment finds that U.S. water demand is projected to increase over the next several decades, rising by as much as 34 percent from 2005 levels by

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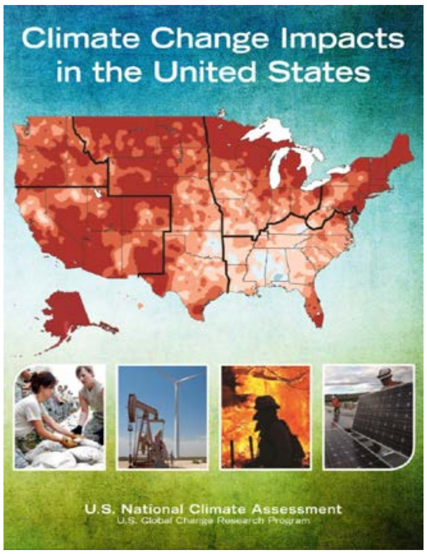
[1] Jerry M. Melillo, Terese (T.C.) Richmond, and Gary W. Yohe, eds., *Climate Change Impacts in the United States: The Third National Climate Assessment* [NCA3], Washington, D.C.: U.S. Global Change Research Program, 2014, 75.

[2] Richard E. Howitt, Duncan MacEwan, Josué Medellín-Azuara, Jay R. Lund, and Daniel A. Sumner, *Economic Analysis of the 2015 Drought for California Agriculture*, Davis: Center for Watershed Sciences, University of California - Davis, 2015.

[3] NCA3, 82.

2060 if global emissions of greenhouse gases continue.[4] Some of the largest water demand increases under climate change are projected in U.S. regions where groundwater aquifers are the main water supply source, including the Great Plains and parts of the Southwest.[5] This projected water demand increase, combined with potentially declining rates of groundwater recharge and changes in evapotranspiration due to climate change, will challenge the sustainability of the aquifers in these regions.[6] Administrative restrictions on water rights to both surface and groundwater further constrain how water is used and distributed.



The Third National Climate Assessment (2014) summarizes the impacts of climate change on the United States, now and in the future. A team of more than 300 experts guided by a 60-member Federal Advisory Committee produced the report, which was extensively reviewed by the public and experts, including Federal agencies and a panel of the National Academy of Sciences. The impact of climate change on water is detailed in this report and is the basis for the discussion of climate challenges in this section.

Market Response

In some ways, the market has partially responded to these challenges through a number of water management activities in the private sector and policies aimed at increasing water use efficiency. Overall changes in the U.S. economy away from water-intensive manufacturing and other heavy industrial activities have helped to decrease U.S. per capita water use.[7] In addition, the U.S. electric power sector has seen dramatic changes in its patterns of water withdrawals, as older "once-through-cooling" power plants have been replaced by plants that recycle their cooling water or use air cooling technologies. Finally, shifts from flood irrigation to more efficient and innovative forms of irrigation in the western United States have contributed to trends in decreasing per capita water withdrawal and use. Despite this progress, persistent stress on water resources as a result of climate change, as well as continued growth in population and changes to land and water management to address environmental concerns, require continued investment in new technologies, climate science, hydrology, water use science, and water monitoring to help water resource planners and managers respond, especially

[4] NCA3, 84.
[5] NCA3, 84.
[6] NCA3, 84.
[7] NCA3, 84.

inasmuch as the market has failed to create the incentives for the use of water-efficient and cost-effective technologies.

Selected Administration Activities in Addressing Water Resource Challenges

Recognizing the primary role of states, tribes, and local communities in managing and allocating water, the Obama administration has taken significant steps to support these efforts to understand and address their water resource challenges, with drought being of particular focus.

Public and private sector decision-makers need science and decision-support tools to plan and adapt the infrastructure necessary for adequate water supplies to their communities. The Administration has supported research and data analysis responsive to these needs, and plans to continue investments in climate science, hydrology, and monitoring and data to make sure that the needed information and decision-support tools are accessible and useful to decision makers and the public. Beginning in 2006, the National Integrated Drought Information System (NIDIS), in the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce, began to develop a drought early-warning system in conjunction with other Federal agencies and partners at the regional, state, tribal, and local levels.

NIDIS has continued to work across agencies and sectors to link its drought monitoring, forecasting, and early warning with risk planning and management. This is accomplished through the U.S. Drought Portal as well as through various partnerships with other Federal agencies. The Administration's Open Water Data Initiative, which makes water use, water quantity, and water quality data publicly available will continue to work with stakeholders and decision makers to make available the science, data, and tools needed by states, local communities, tribes, and businesses as they prepare for drought and water reliability challenges.

In 2013, President Obama announced the formation of the National Drought Resilience Partnership (NDRP) to help communities better prepare for future droughts and reduce the impact of drought events on livelihoods, the economy, and the environment. Since then, the NDRP has responded to requests from communities, businesses, and farmers and ranchers, to make it easier to access Federal drought resources, and link information such as monitoring, forecasts, outlooks, and early warnings with longer-term drought resilience strategies in critical sectors such as agriculture, municipal water systems, energy, recreation, tourism, and manufacturing.

Building on these initiatives, the Federal government plans to continue to help states, tribes, and local communities tackle the challenges of stresses on water supplies by:

- Enhancing the coordination of data and information needed to strengthen and support policies and decision-making related to drought, water use, and water availability;

- Communicating targeted information about drought risks, including those specific to critical infrastructures;
- Assisting state, local, and tribal officials in building local capacity for drought preparedness and resilience to improve the effectiveness of drought planning;
- Enhancing the drought resilience impact of Federal programs and investments through improved coordination and integration of Federal agency activities;
- Promoting new investment models and market-based approaches to increase resilience, flexibility, and efficiency of water supply systems; and
- Improving water-use efficiency through research, innovation, and international engagement.

Water Infrastructure

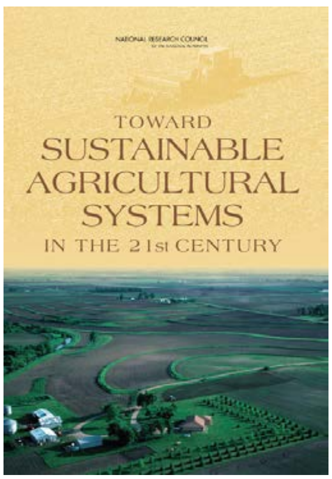
The Federal government has also had a long history of planning and financing water resources infrastructure critical to communities across the country. This has included investments in dams, canals, and other storage and conveyance facilities to manage water supplies. Today, largely through the Department of the Interior (DOI) and the U.S. Army Corps of Engineers (USACE), the Federal government manages a large number of water infrastructure assets in partnership with states, local agencies, and communities.

As climate change results in shifts in water supply and demand, communities will need to expand, reduce, or reconfigure their water infrastructure systems, including through innovative public-private partnerships, bringing together the Federal government with local, tribal, and state governments, special authorities like irrigation districts, and the private sector. In recent years, the Federal government has explored ways to expand financing options for public sector infrastructure through increased private investment, such as through its Build America Investment Initiative established by President Obama in July 2014. As the largest Federal investors in water infrastructure, the Department of Agriculture (USDA) and the Environmental Protection Agency (EPA) have opened Build America finance centers. These centers – USDA's Rural Opportunity Investment Initiative and EPA's Water Infrastructure and Resiliency Finance Center – are staffed with financial experts and focus on outreach to the private sector and developing new ways to leverage the Federal government's existing investments in water projects.

The Administration will also work to facilitate market mechanisms that enable water management flexibility and create incentives for investment in water efficiency. In particular, through the new Natural Resource Investment Center at the DOI, the Administration will encourage the development of water exchange and transfer in the western United States. By opening up regional water markets, establishing water banks, and facilitating exchange through Federal water assets, the Department of the Interior will begin laying the foundations for a broader voluntary water market that has, and will continue to drive, additional investment in conservation technologies.

The Water Innovation Strategy

Recognizing the complex and evolving challenges facing water users and water resource planners and managers in the United States, the Administration has an opportunity to build on its work in partnership with regional, state, tribal, and local officials by promoting more integrated water resource management strategies and formulating and carrying out a water innovation strategy. Through research, development, and deployment of clean water technologies and promoting reuse opportunities, we can improve the efficient use of existing supplies, and we can lower the cost and increase the availability of new fresh water supplies from marginal and non-traditional sources. Together, this will spur the development of water technologies and infrastructure projects by the public and private sectors, as well as creating new opportunities for water-sharing arrangements between water users. The following sections discuss this two-pronged innovation strategy by highlighting previous Administration successes and suggesting metrics to guide progress.



According to the National Research Council's report "Toward Sustainable Agricultural Systems in the 21st Century," as water is critical for food production, research in water-efficient agricultural practices and technology will be critical in maintaining and improving agricultural productivity in water stressed regions.

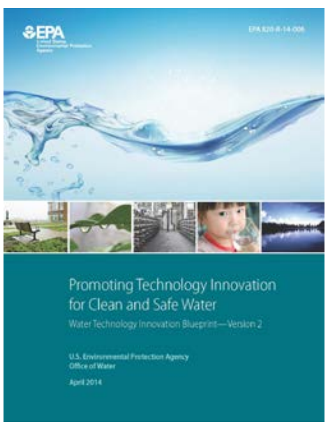
Successes in Water Use Efficiency

While the United States still has a per capita water footprint higher than other industrialized nations, tremendous advances have already been made to improve our efficient use of water and the potential to further improve by as much as a third exists. [8,9,10] Sustained investment in research and development for technologies and improved practices for agriculture, for example, can help to build on the significant improvements in water-use efficiency that have occurred in the agricultural sector over the past 50 years. Over this time, water-use efficiency has increased by 32 percent for chicken-egg production, 41 percent in the

[8] Arjen Y. Hoekstra and Mesfin M. Mekonnen, "The water footprint of humanity," *Proceedings of the National Academy of Sciences*, 109(9), February 28, 2012.
[9] Matthew Heberger, Heather Cooley, Peter Gleick, "Urban Water Conservation and Efficiency Potential in California," NRDC and The Pacific Institute, June 2014.
[10] Dean D. Steele, Earl C. Stegman, and Raymond E. Knighton, "Irrigation management for corn in the northern Great Plains, USA," *Irrig. Sci.*, 19:107-114, 2000.

pork industry, 65 percent in the dairy industry, and 75 percent in the cotton industry.[11]

There is still considerable opportunity for innovation and wider adoption of technologies for more-efficient water use. Fewer than 10 percent of irrigated farms use advanced tools and technologies, such as soil- or plant-moisture sensing devices, commercial irrigation-scheduling services, or computer-based crop-growth simulation models to assist with water-management decisions. Groundwater extraction should also be optimized to better monitor water levels and extraction volumes, pump efficiencies, reduce well interference, and reduce energy costs (*e.g.*, optimizing pumping rates, optimizing pumping times to lower energy costs, utilizing alternative energy sources such as solar power or other energy sources to reduce emissions). An optimized groundwater extraction system integrated with surface water and recharge activities can result in increased water efficiencies and increasing water supply reliability.



EPA Administrator Gina McCarthy released *Promoting Technology Innovation for Clean and Safe Water, Water Technology Innovation Blueprint* - *Version 2* on April 7, 2014 to demonstrate the extent of risks to water resources, frame ten "market opportunities", and identify actions that EPA will take to foster technology and innovation across the water sector.

There are a number of successful models within the Federal government dedicated to increasing water efficiency. USDA's Environmental Quality Incentives Program (EQIP), for example, has been instrumental in financing advanced irrigation systems, and the Department's Natural Resources Conservation Services (NRCS) has made significant progress in building soil resilience to drought through enhanced soil health.[12] Similarly, since 2009, the WaterSMART program at the DOI has facilitated the conservation of over 1 million acre-feet of water to augment western water supplies on an annual basis, a majority of that in the agricultural sector. More widespread adoption of water-efficient technologies can lower costs of agricultural production while enabling other productive uses including aquifer recharge of the conserved water.

The EPA has outlined a blueprint for Promoting Technology Innovation for Clean and Safe Water and captures the innovations into three major categories: new technologies; new management approaches (*e.g.*,

[11] Charles Parrott, "Conservation and Innovation Preserve Water Resources for Generations to Come," May 2014. <http://blogs.usda.gov/2014/05/29/conservation-and-innovation-preserve-water-resources-for-generations-to-come/>
[12] Glenn D. Schaible, and Marcel P. Aillery, "Water Conservation in Irrigated Agriculture: Trends and Challenges in the Face of Emerging Demands," Sept. 2012. <http://www.ers.usda.gov/media/884158/eib99.pdf>

regional coordination); and techniques that increase the efficiency of existing systems (*e.g.*, sensors and controls). The Blueprint frames ten "market opportunities" for technology and innovation to accelerate progress to clean and safe water. Illustrative market opportunities include: resource recovery (i.e., energy, nutrients, clean water), green infrastructure, enhanced water monitoring techniques, climate resilience, and performance of small water utilities.[13] In particular, municipal water systems could benefit from technologies and approaches that already exist but are not widely deployed. Improved sensor networks and metering technologies can enable better management of water distribution networks and identify leaks and system inefficiencies that can result in average losses of about 16 percent of clean and treated water in public water systems, allowing for preventative and rapid response to water-infrastructure problems.[14]

In the commercial and residential sector, there are also many opportunities for water use efficiency gains. The EPA WaterSense partnership promotes products and services that use at least 20 percent less water and has helped save 1.1 trillion gallons of water and $21.7 billion in water and energy bills since the program began in 2006.[15] The Department of Energy (DOE) Better Buildings Challenge also works to promote the use of water efficient technologies to conserve and stretch water supplies in the commercial sector. In the energy sector, the DOE's *Water-*

DOE's International Energy-Water Programs

DOE has several international collaborations to address the energy-water nexus that will bring existing best practices and technologies to the United States from experienced partners and accelerate the pace of innovation to drive down the cost of new technologies. For example:

- The U.S.-China Clean Energy Research Center (CERC) added a new technical track to address water-related aspects of energy production and use through innovative technologies, modeling, and analytical research. The joint effort will utilize the unique technical knowledge and opportunities for demonstration of each country and further accelerate the development and deployment of these critical technologies.

- DOE has ongoing collaboration with Israel on a variety of joint research projects to address the challenges of the energy-water nexus. DOE and Israel jointly fund the United States-Israel Binational Industrial Research and Development (BIRD) Foundation Energy Program with projects developing energy-efficient waste water treatment systems and floating solar technology. Israel provides deep technical expertise in the field which will help develop technology that benefit both the United States and other countries.

- DOE is providing advice to Masdar in the United Arab Emirates (UAE) for the development of energy-efficient water desalination plants which will demonstrate superior processes that can be powered by renewable energy. This collaboration leverages Emirati resources while utilizing U.S. technical expertise to demonstrate new systems that will reduce costs for further applications in the United States and abroad.

[13] Environmental Protection Agency, *Promoting Technology Innovation for Clean and Safe Water: Water Technology Innovation Blueprint – Version 2*, April 2014.
[14] Julian Thornton, Reinhard Sturm, and George Kunkel, *Water Loss Control*, 2nd ed., New York: McGraw-Hill, 2008.
[15] Environmental Protection Agency, Office of Wastewater Management, "2015 WaterSense Award Winners Make a Difference Every Day," *The WaterSense Current* (Fall 2015). <http://www3.epa.gov/watersense/our_water/fall2015.html>.

Energy Nexus: Challenges and Opportunities report outlines a robust focus and need on developing and demonstrating technologies to reduce water withdrawals needed for energy production. In April 2015, DOE's Advanced Research Projects Agency-Energy (ARPA-E) announced $30 million in awards under the Advanced Research in Dry-Cooling (ARID) program to fund transformative new power plant cooling technologies that enable high thermal-to-electric energy conversion efficiency with zero net water dissipation to the atmosphere.

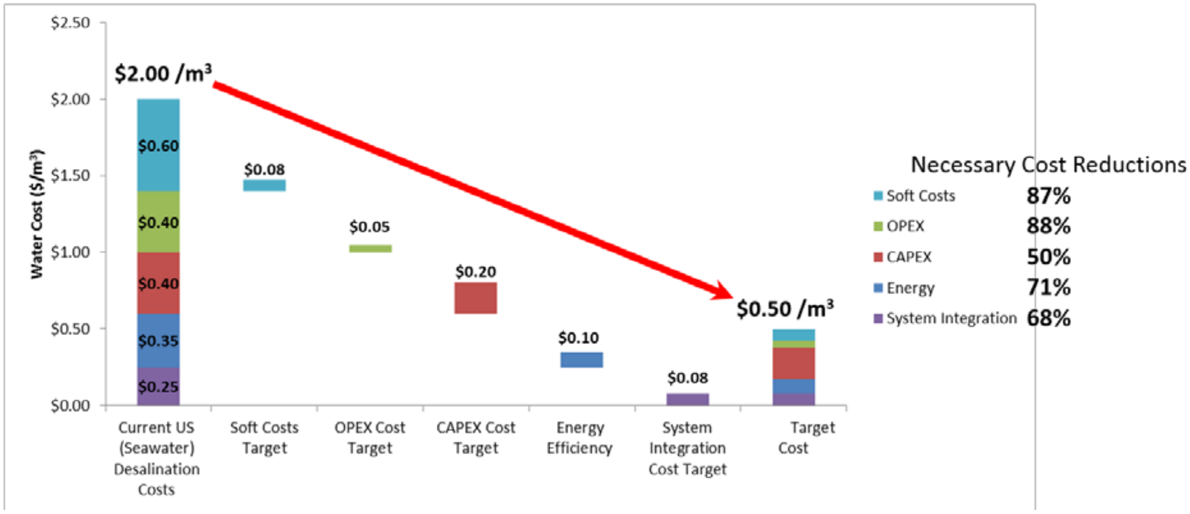
As being more efficient with our energy resources is critical to reducing our carbon dioxide (CO_2) emissions, improving our water use through water efficient technologies, management practices, and conservation can also contribute to CO_2 emissions reductions. It has been estimated that the carbon footprint currently associated with moving, treating, and heating water in the United States is at least 290 million metric tons a year, meaning even a 33 percent improvement could result in about 90 million metric tons of CO_2 savings, or about 1.5 percent of total annual emissions.[16, 17] Through sustained Federal investment in research and development, the Federal government can foster an innovation ecosystem of researchers, industry, and water utilities to discover new ways of improving the use of existing water supplies and contribute to these potential savings.

Technology Innovation Potential for New Sources of Water

Water-stressed regions are increasingly supplementing conventional water sources with marginal sources of water such as brackish or sea-water, or through water reuse from municipal reclaimed water, storm water or other sources. For the first two identified sources, desalination offers an opportunity to convert previously unusable saline water to freshwater. A number of government-issued reports have identified challenges and research opportunities in desalination of brackish and seawater, the most energy intensive of the non-traditional supplies and also an area that is underexplored compared to that of water efficient technologies.[18,19,20] At present, the cost and energy intensities of desalinated water are prohibitive for most communities, and particularly high for seawater which is higher in salinity than brackish water. For desalination to reach "pipe parity" with delivered potable water, lower levels of total cost, energy input, and carbon emissions – equal to those from current processes for delivering water – would be needed. To achieve pipe parity, an ambitious set of target levels would stand at less than $0.50 spent in total cost, 1 kWh_e of energy consumed, and less than 1 pound of carbon dioxide generated over the course of producing 1 cubic

[16] Bevan Griffiths-Sattenspiel and Wendy Wilson, "The Carbon Footprint of Water," The River Network, 2009.
[17] Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013*, 2015.
[18] Department of Energy, *The Water-Energy Nexus: Challenges and Opportunities*, June 2014.
[19] National Science Foundation, *Food, Energy, and Water: Transformative Research Opportunities in the Mathematical and Physical Sciences*, July 2014.
[20] National Research Council, *Desalination: A National Perspective*, Washington, D.C.: National Academies Press, 2008.

meter of water. [21,22] *Achieving these targets would require approximately a 4-times improvement in cost, a 3-times reduction in electricity usage, and a 2-times reduction in carbon dioxide emissions over existing seawater desalination technologies to achieve cost-competitive pipe parity.* [23, 24]



Estimated current cost elements for desalination of seawater (including capital expenses (CAPEX), operating expenses (OPEX), energy costs, and costs for the balance of the system and systems integration containing the desalination process), compared to the estimated target cost elements needed to achieve "pipe parity" with other water treatment technologies. While the current costs are based on Reverse Osmosis, alternative approaches to reach the cost goal should also be considered. The costs of seawater desalination in other countries may differ significantly due to differences in the costs of energy as well as soft costs.[18]

Aside from coastal areas, there are also innovation opportunities with inland desalination utilizing previously unusable brackish water supplies. For example, in El Paso, Texas, at the world's largest inland desalination plant, 27.5 million gallons of fresh water are made daily, making it a critical component of the region's water portfolio. [25]

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[21] From EPRI *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries* (2013), the annual electricity demand is 39.2 Billion kWh (134 TBTUs) for public water supply and treatment. From the DOE *Water Energy Nexus* report, the US annual water consumption for clean municipal water supplies is 16,060 Billion gal (60.8 billion m^3). This corresponds to National Average Electric Energy Intensity of 0.645 kWh_e/m^3 for the supply of clean municipal water. While this is a national average, the energy intensity may vary widely depending on location, topology, and source of water.

[22] Environmental Protection Agency, *GHG Equivalencies Calculator*, 2010. <http://www2.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references>.

[23] T. Parantz, *Desalination Markets*, Global Water Intelligence, 2015.

[24] Mark Johnson, "Energy Optimized Desalination Technology Development Workshop," Department of Energy, November 5, 2015. <http://energy.gov/sites/prod/files/2015/11/f27/Desalination%20Workshop%202015%20 Johnson.pdf>.

[25] El Paso Water Utilities, Water, 2015. <http://www.epwu.org/water/desal_info.html>.

Seawater that is treated using current commercialized reverse osmosis (RO) systems—the most common desalination method—is significantly higher in cost than water from traditional sources because RO systems require large amounts of electricity (typically >3 kWh_e/m^3). Although state-of-the-art RO efficiency is approaching fundamental and practical limits, the cost of freshwater produced by RO can still be reduced through advances in membrane manufacturing methods as well as a focus on balance of systems costs. Furthermore, alternatives to RO may offer additional opportunities for cost, energy, and carbon emission improvements. Technologies such as forward osmosis, multi-effect distillation, multi-stage flash distillation, membrane distillation, freeze separation, and capacitive deionization potentially can be used in commercial desalination of both brackish and sea-water, but will require research advances to achieve pipe parity (detailed technical information on these technologies can be found in the Appendix). The use of renewable power or waste heat offers opportunities to reduce energy costs. For example, several of these emerging technologies can already deliver fresh water at electrical usage of less than 1 kWh_e/m^3 by making use of lower-grade thermal energy.

The environmental impact of desalination of both seawater and brackish water need to be considered and research into technologies and approaches to reduce those impacts will be critical to greater adoption of desalination for new supplies of water. The intakes for seawater desalination can significantly impact coastal ecosystems through entrainment and entrapment of marine organisms and the brine discharge can impact sensitive species unless sufficiently diffused. Inland, the disposal of brine from brackish water desalination presents technical and environmental challenges that need to be addressed.

Beyond desalination, water reuse can provide additional benefit, including water conservation opportunities for areas with limited water resources. Water reuse and recycling can span many uses including agriculture, irrigation, industrial processing and cooling, ecosystem restoration, and potable and non-potable municipal purposes. The National Research Council has estimated that reuse of municipal reclaimed water has the potential to increase the equivalent of up to 27 percent of the public supply of fresh water.[26] To provide information on water reuse practices and key implementation considerations, the EPA and the U.S. Agency for International Development developed the *Guidelines for Water Reuse* in 2012. [27]

Soft Cost Challenges

Once technology costs have been addressed for innovative new water supply technologies, the development of any large-scale water infrastructure project requires navigating a multi-jurisdictional regulatory framework that spans local, tribal, state, and Federal governing bodies.

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[26] National Research Council, *Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater*, Washington, D.C.: National Academies Press, 2012.

[27] Environmental Protection Agency, *Guidelines for Water Reuse*, 2012. <http://nepis.epa.gov/Adobe/PDF/P100FS7K.pdf>.

The cost of delivering fresh water in the United States is often dominated by "soft costs" associated with project financing, permitting, and environmental mitigation rather than the "hard costs" of water treatment and transport. Hence, the viability of advanced technologies as a method for unlocking "new" sources of fresh water depends not just on technology costs, but also reducing soft costs and project development times, which currently can be as long as a decade or more. For desalination, research and development of cost-effective intakes that minimize entrainment and entrapment of marine organisms, as well as research and development on methods for brine disposal, are critical to minimize both impacts to the natural ecosystem and total costs to communities that are interested in deploying these technologies.

Conclusions

Through research, development, and deployment of clean water technologies, we can improve the efficient use of existing water supplies, and lower the cost, electricity use and carbon emissions of technologies that would act to increase our overall supply of freshwater. Making these technologies at cost, electricity and emissions parity with the average price of municipal water today would open up new options for communities and can provide reliable supplies even through periods of drought. Since it can be a decade or more before research in laboratories can reach commercialization and similar time scales for more widespread adoption of infrastructure technologies, achieving these cost reductions in the 2020-2030 timeframe will be critical to our ability to adapt to stresses to our water supply in the latter half of this century. The Federal government has a unique role to share some of the risk at the levels of research, development, demonstration scale, and/or implementation of new technologies that industry is not willing to take or that municipalities are not financially able to take in the development of new processes for treatment of water. The Federal government also has a unique role supporting private and public sector investments in the early stages of these innovations, developing them through new and existing Federal partnerships and programs, and promoting them through their local, tribal, and state counterparts. This document and the White House Roundtable lay out the strategy Administration will pursue over the next year to develop a cohesive foundation for fostering innovation on these water resource challenges.

APPENDIX

Overview of technical metrics and potential for technological advances for selected desalination technologies. (Source: Department of Energy, 2015)

Technology	Current Operating Temperature Range	Current Power Consumption	Current State of the Art Costs	Potential 'Game-Changing' Technology Advances
Reverse Osmosis (RO)	ambient	~3 kWh/m^3	$2.00/$m^3$	• Long-lifetime membranes (high-durability, low-fouling) • Integration with renewable primary energy sources
Multi-effect Distillation / Multi-stage Flash Distillation (MED/MSF)	70 – 110 °C	• 15 – 20 kWh_t/m^3 • 1 – 2kWh_e additional	$2 – $3/$m^3$	• Low-cost, high-flux heat exchanger materials • Integration with waste/renewable sources of heat
Forward Osmosis (FO)	• Thermal FO: 80 – 100 °C • Non-thermally-driven FO is also being explored	• 0.5 – 1.5 kWh_e/m^3 • Thermal FO: additional 10 – 16 kWh_t/m^3	No commer-cial data	• New membranes designed for FO (currently using RO membranes) • Materials discovery for draw solutes
Membrane Distillation (MD)	40 – 100 °C	• 1 – 30 kWh_t/m^3 • Current wide range due to no large-scale projects	No current commercial data	• Thermally insulating membranes that preserve selectivity • Low-cost, high-flux heat exchanger materials
Dewvapora-tion	120 °C	6 kWh_e/m^3 – 407 kWh_t/m^3	$80/$m^3$	• Low-cost, high-flux heat exchanger materials • Integration with waste/renewable sources of heat • Optimized system configuration
Capacitive Deionization	ambient	0.11kWh_e/m^3	No current commercial data	• Hybridization with other desal technologies • Novel electrode materials