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Desalination and Membrane Technologies: Federal Research and Adoption Issues

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Summary

In the United States, desalination and membrane technologies are increasingly used to augment municipal water supply, to produce high quality industrial water supplies, and to reclaim contaminated supplies (including from oil and gas development). As of 2005, approximately 2,000 desalination facilities larger than 0.3 million gallons per day (MGD) were operating in the United States, with a total capacity of 1,600 MGD which represents more than 2.4% of total U.S. municipal and industrial freshwater use. At issue for Congress is what should be the federal role in supporting desalination and membrane technology research and facilities. Desalination issues before the 113th Congress include how to focus federal research, at what level to support desalination research and projects, and how to provide a regulatory context that protects the environment and public health without disadvantaging the technology.

Desalination processes generally treat seawater or brackish water to produce a stream of freshwater, and a separate, saltier stream of water that requires disposal (often called waste concentrate). In the last decade, many states (e.g., Florida, California, and Texas) and cities have actively investigated the feasibility of large-scale municipal desalination. Coastal communities look to seawater or estuarine water, while interior communities look to brackish aquifers. The most common desalination technology in the United States is reverse osmosis, which uses permeable membranes to separate the freshwater from the saline water supply. Membrane technologies are also effective for other water treatment applications. Many communities and industries use membranes to remove contaminants from drinking water, treat contaminated water for disposal, and reuse industrial wastewater (e.g., saline waters co-produced from oil and gas development). For some applications, there are few competitive technological substitutes.

Wider adoption of desalination is constrained by financial, environmental, and regulatory issues. Although desalination costs dropped steadily in recent decades, significant further decline may not happen with existing technologies. Electricity expenses represent from one-third to one-half of the operating cost of desalination. Its energy intensity also raises concerns about associated greenhouse gas emissions and its usefulness as a climate change adaptation measure. Substantial uncertainty also remains about the technology's environmental impacts, in particular management of the saline waste concentrate and the effect of surface water intake facilities on aquatic organisms. Desalination facilities require a significant number of local, state, and federal approvals and permits.

Emerging technologies (e.g., forward osmosis, nanocomposite and chlorine resistant membranes) show promise for reducing desalination costs. Research to support development of emerging technologies and to reduce desalination's environmental and social impacts is particularly relevant to the debate on the future level and nature of federal desalination assistance. The federal government generally has been involved primarily in desalination research and development (including for military applications), some demonstration projects, and select full-scale facilities. For the most part, local governments, sometimes with state-level involvement, are responsible for planning, testing, building, and operating desalination facilities. Some states, universities, and private entities also undertake and support desalination research. While interest in desalination persists among some Members, especially with drought concerns high, efforts to maintain or expand federal activities and investment are challenged by the domestic fiscal climate and differing views on federal roles and priorities.

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A Primer on Desalination

Interest in desalination technologies for seawater, brackish water, and contaminated freshwater has increased globally and in the United States, as costs have fallen and pressure to develop drought-proof water supplies has grown. Adoption of desalination, however, remains constrained by financial, environmental, regulatory, and social factors. At issue is what role Congress establishes for the federal government in desalination, particularly in desalination research and development and the federal regulatory environment related to desalination. Also of congressional interest is what role desalination may play in meeting future water supply needs. Desalination processes generally treat seawater, brackish water,[1] or impaired waters to produce a stream of freshwater, and a separate, saltier stream of wastewater, often called *waste concentrate* or *brine*. The availability and regulation of disposal options for the waste concentrate can pose issues for desalination's adoption in some locations.

Desalination's attractions are that it can create a new source of freshwater from otherwise unusable waters, and that this source may be more dependable and drought-proof than freshwater sources that rely on annual or multi-year precipitation, runoff, and recharge rates.[2] Another significant application of desalination technologies is for treatment of contaminated waters or industrial water or wastewater. Some communities and industries use technologies developed for desalination to produce drinking water that meets federal standards, to treat contaminated water supplies to meet disposal requirements, or to reuse industrial wastewater (e.g., saline waters co-produced from oil and gas development). Many of the technologies developed for desalination also can produce high-quality industrial process water. For many of these applications, there may be few technological substitutes that are equally as effective and reliable as the desalination technologies.

There are a number of desalination methods. Two processes, thermal (e.g., distillation) and membrane (e.g., reverse osmosis), are the most common, with reverse osmosis dominating in the United States. For more information on the traditional and emerging desalination technologies, see **Appendix A**.

Desalination treatment costs have dropped steadily in recent decades, making it more competitive with other water supply augmentation and treatment options. Electricity expenses vary from one-third to one-half of the cost of operating desalination facilities.[3] A rise in electricity prices could reverse the declining trend in desalination costs; similarly, drops in electricity costs (e.g., due to falling costs associated with natural gas-fueled electric generation) improve desalination's competitiveness. Costs and cost uncertainties remain among the most significant challenges to implementing large-scale desalination facilities, especially seawater desalination plants.[4]

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[1] For more information on what is brackish groundwater, see National Ground Water Association, *Brackish Groundwater*, NGWA Information brief, Westerville, OH, July 21, 2010, http://www.ngwa.org/Media-Center/briefs/Documents/Brackish_water_info_brief_2010.pdf.

[2] For more on drought, see CRS Report RL34580, *Drought in the United States: Causes and Issues for Congress*, by Peter Folger, Betsy A. Cody, and Nicole T. Carter.

[3] S. Chaudry, "Unit cost of desalination," California Desalination Task Force, California Energy Commission, 2003.

[4] A survey of municipal desalination facilities in Texas found the cost for brackish desalination ranged from $410 to $847 per acre-foot, and for seawater desalination ranged from $1,168 to $1,881 per acre-foot. (J. Arroyo and S. Shirazi, *Cost of Water Desalination in Texas*, Texas Water Development Board, Austin, TX, October 2009, p. 6, http://www.twdb.texas.gov/innovativewater/desal/doc/
(continued...)

Desalination's energy intensity also raises concerns about the greenhouse gas emissions emitted and its usefulness as part of a climate change adaptation strategy.[5] Substantial uncertainty also remains about the environmental impacts of large-scale desalination facilities. Social acceptance and regulatory processes also affect the technologies' adoption and perceived risks. Research and additional full-scale facilities may resolve uncertainties, alleviate concerns, and contribute to cost reductions and options for mitigating environmental impacts.

To date, the federal government has been involved primarily in research and development, some demonstration projects, and select full-scale facilities (often through congressionally directed spending). The federal government also may support construction of municipal desalination facilities through loans provided to these facilities through the U.S. Environmental Protection Agency's (EPA's) Drinking Water State Revolving Loan Funds. For most municipal desalination facilities, local governments or public water utilities, sometimes with state-level involvement and federal construction loans, have been responsible for planning, testing, building, and operating desalination facilities, similar to their responsibility for treating freshwater drinking water supplies. During recent Congresses, legislative proposals have identified a range of different potential federal roles in desalination. The most recent fiscal years have seen a decline in federal support for desalination research and desalination facilities.

Recent Congressional Consideration

Desalination issues before the 113th Congress include how to focus federal research to produce results that provide public benefits, at what level to support desalination research and projects, and how to provide a regulatory context that protects the environment and public health without unnecessarily disadvantaging these technologies. In a provision in the Consolidated Appropriations Act of 2012 (§204 of Division B of P.L. 112-74), the 112th Congress extended through 2013 the Water Desalination Act, which authorizes appropriations for the main desalination research and demonstration outreach program of the Department of the Interior program which is carried out by the Bureau of Reclamation. The extension was for an annual authorized level of $3 million. The act also appropriated $2 million for the program in FY2012; the President had requested $2 million. Authorization of the program beyond 2013 was the subject of a House Natural Resources Water and Power Subcommittee hearing in April 17, 2012, and was the subject of H.R. 2664 (112th Congress), Reauthorization of Water Desalination Act of 2011. The bill as introduced (which was prior to the extension in P.L. 112-74) would reauthorize the program for $2 million annually for FY2012 to FY2016. The April 2012 hearing illustrated the range of opinions on the federal role in desalination research, with one witness arguing against further federal support for this type of a research[6] while other witnesses discussed research areas warranting the federal program's extension.[7]

(...continued)

Cost_of_Desalination_in_Texas.pdfhttp://www.twdb.state.tx.us/iwt/desal/docs/Cost_of_Desalination_in_Texas.pdf.) Water produced from proposed seawater desalination facilities in California is estimated to range from $1,900 to $3,000 per acre-foot (H. Cooley and N. Ajami, *Key Issues for Desalination in California: Cost and Financing*, Pacific Institute, November 2012, p. 5, http://www.pacinst.org/reports/desalination_2013/financing_final_report.pdf).

[5] J. McEvoy and M. Wilder, "Discourse and desalination: Potential impacts of proposed climate change adaptation interventions in the Arizona-Sonora border region," *Global Environmental Change*, vol. 22 (2012).

[6] U.S. Congress, House Committee on Natural Resources, Subcommittee on Water and Power, *Testimony of Wayne* (continued...)

Congress in recent years also supported the Department of the Interior's construction of the Brackish Groundwater National Desalination Research Facility.[8] A provision in S. 1343 (112th Congress), the Energy and Water Integration Act of 2011, would have directed the Secretary of the Interior to operate, maintain, and manage the facility and authorize appropriations of $2 million annually through 2016. The provision also would have directed that the facility conduct research, development, and demonstration activities to promote brackish groundwater desalination, including the integration of desalination and renewable energy technologies, and outreach programs with public and private entities and for public education. The facility's mission also includes managing the waste concentrated from desalination, desalinating waters produced during oil and gas production, and small-scale desalination systems.

H.R. 5826 (112th Congress), the Coordinating Water Research for a Clean Water Future Act of 2012, would have formally established a National Water Research and Development Initiative through the National Science and Technology Council (NSTC). The council would have been required to develop, within a year of enactment, and updated every three years thereafter, a five-year plan to guide federal water research aimed at enhancing reliable and clean water supply systems. Although the bill did not specifically list desalination or membranes, the scope of the initiative appeared to include these treatment technologies.

Federal Desalination Research

Research Agenda

Several reports in the last decade have aimed to inform the path forward for U.S. desalination research. The first was the 2003 *Desalination and Water Purification Technology Roadmap* produced by the Bureau of Reclamation and Sandia National Laboratories at the request of Congress. The National Research Council reviewed the roadmap in a 2004 report, *Review of the Desalination and Water Purification Technology Roadmap*, which called for a strategic national research agenda. To this end, the National Research Council convened a Committee on Advancing Desalination Technology. That NRC committee published a report in 2008, *Desalination: A National Perspective*. It concluded that research should focus on reducing the cost of desalination and that substantial further cost savings are unlikely to be achieved through incremental advances in the commonly used desalination technologies, like reverse osmosis. Consequently, the report recommended that federal desalination research funding be targeted at long-term, high-risk research not likely to be attempted by the private sector that could

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Crews, Competitive Enterprise Institute, Hearing on H.R. 2664, 112th Cong., 2nd sess., April 17, 2012, http://naturalresources.house.gov/UploadedFiles/CrewsTestimony04.17.12.pdf.

[7] U.S. Congress, House Committee on Natural Resources, Subcommittee on Water and Power, *Testimony of Ian C. Watson, American Membrane Technology Association*, Hearing on H.R. 2664, 112th Cong., 2nd sess., April 17, 2012, http://naturalresources.house.gov/UploadedFiles/WatsonTestimony04.17.12.pdf; and *Testimony of David Murillo, Bureau of Reclamation,* ,http://naturalresources.house.gov/UploadedFiles/MurilloTestimony04.17.12.pdf.

[8] The Brackish Groundwater National Desalination Research Facility is a federally constructed research facility focused on developing desalination technologies for brackish and impaired groundwater found in inland states. It is located in Alamogordo, Otero County, NM. The facility opened in August 2007 and is integrated into Department of the Interior's existing desalination research and development program at the Bureau of Reclamation. It brings together researchers from other federal agencies, universities, the private sector, research organizations, and state and local agencies.

significantly reduce desalination costs. It also recommended a line of research on minimizing or mitigating the desalination's environmental impacts of desalination. NRC specifically identified research relevant for federal investment because of its benefits being widespread and little willingness to undertake the research by the private sector. (See "National Research Council 2008 Desalination Research Recommendations" box for more details on the research recommendations in the report.)

National Research Council 2008 Desalination Research Recommendations

The NRC in 2008 identified topics for a research agenda of interest both for public and private sector investment. The topics considered by NRC to be the most appropriate for the federal support are identified below in italics.

The NRC recommended steps to reduce the financial cost of desalination with research to

- Improve pretreatment for membrane desalination
- Improve membrane system performance
- Develop improved energy recovery technologies and techniques
- Reduce existing desalination approaches' primary energy use by integrating desalination and renewable energy, understanding energy pricing impacts, and identifying opportunities to use low-grade and waste heat.
- Develop novel desalination processes or approaches that reduce primary energy use

The NRC identified the following priority research areas to address environmental concerns:

- Assess environmental impacts of desalination intake and concentrate management approaches, and synthesize results in a national assessment;
- Improve intake methods at coastal facilities to minimize harm to organisms;
- Develop cost-effective approaches for concentrate management that minimizes environmental impacts; and
- Develop monitoring and assessment protocols for evaluating the potential ecological impacts of surface water concentrate discharge.

Additionally the NRC identified the following cross-cutting research activities:

- Develop cost-effective concentrate management that minimizes environmental impacts

Source: NRC, *Desalination: A National Perspective*, 2008.

In 2010, the Water Research Foundation, WateReuse Foundation, and Sandia National Laboratories published a report on how to implement the 2003 roadmap.[9] The report identifies research agendas for a range of topics—membrane technologies, alternative technologies, concentrate management, and institutional issues such as energy cost reduction and regulatory compliance.

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[9] Water Research Foundation, WateReuse Foundation, Sandia National Laboratories, *Implementation of the National Desalination and Water Purification Technology Roadmap*, January 2010, http://www.sandia.gov/water/docs/DesalImplementRoadmap1-26-2010_c_web.pdf.

Federal Research Funding

No one federal agency has responsibility for all federal desalination and membrane research; instead numerous agencies and departments are involved in promoting related research based on their specific missions. In FY2005, FY2006, and FY2007, federal desalination research totaled $24 million, $24 million, and $10 million, respectively.[10] (These are the most recent comprehensive data on federal desalination funding.) The Bureau of Reclamation was responsible for half or less of that spending at $12 million, $11 million, and $4 million, respectively. Other agencies and departments with spending on desalination research included the Army, National Science Foundation, Office of Naval Research, U.S. Geological Survey, and four of the Department of Energy's National Laboratories. Sandia National Laboratory has had the largest role among the national laboratories. In FY2005 and FY2006, much of the federal desalination research was congressionally directed to specific sites and activities. The level of funding fell after FY2006, when the appropriations process began to include less congressionally directed spending.

The optimal level and type of federal support for desalination research is inherently a public policy question shaped by factors such as fiscal priorities and views on the appropriate role of the federal government in research, industry development, and water supply.[11] Federal support for desalination research raises questions, such as what should be the respective roles of federal agencies, academic institutions, and the private sector in conducting research and commercializing the results, and should federal research be focused on basic research or promoting the use of available technologies? In addition to federal and private research activities, some states, such as California and Texas, also have supported desalination research.[12]

In 2008, the National Research Council recommended a federal desalination research level of roughly $25 million, but recommended that the research be targeted strategically, including being directed at the research activities described above.[13] The NRC drew the following conclusion:

> There is no integrated and strategic direction to the federal desalination research and development efforts. Continuation of a federal program of research dominated by congressional earmarks and beset by competition between funding for research and funding for construction will not serve the

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[10] National Research Council, *Desalination: A National Perspective*, 2008, p. 228. Hereafter referred to as NRC 2008.

[11] For more information on the general discourse about federal funding for research and development, see CRS Report R42410, *Federal Research and Development Funding: FY2013*, coordinated by John F. Sargent Jr. Part of the debate about the level of desalination research to support in the United States is related to how much desalination research is occurring outside of the United States. While the U.S. research previously was significant in the development of desalination especially membrane desalination, the United States now is less prolific than other nations. For example, In a 2011 article analyzing the research institutes producing journal articles on desalination, no U.S. entity was in the top 10; the leading institutes in terms of publications were in Australia (1), China (3), India (1), Jordan (1), Kuwait (2), Oman (1), Poland (1), and Singapore (1) (H. Tanaka and Y. Ho, "Global trends and performance of desalination research," *Desalination and Water Treatment*, vol. 25 (January 2011). Whether this shift signals a reason for more support for U.S. desalination research or for less since other nations are investing depends on one's views on research to support industry and whether the internationally conducted research is meeting U.S. needs.

[12] For example in 2003, House Bill 1370 of the 78th Texas Legislature directed the Texas Water Development Board to participate in research, studies, investigations and surveys to further the development of cost-effective water supplies from seawater desalination. As of May 2012, the Board has spent $4.2 million on 18 brackish and seawater desalination demonstration projects and related activities since 2004.

[13] NRC 2008. According to the 2004 NRC report, *Confronting the Nation's Water Problems: The Role of Research*, in the past the federal government invested more in this area; in the late 1960s, federal research in desalination and other saline water conversion activities exceeded $100 million annually.

> nation well and will require the expenditure of more funds than necessary to achieve specified goals.[14]

The Bureau of Reclamation's desalination and membrane research spending has declined since FY2005 and FY2006. It ranged from $3.7 million and $4.0 million between FY2009 and FY2011; for FY2012, the bureau received $2.0 million for this work, and the Administration requested $3.0 million for FY2013.

In the 2008 NRC report, the Office of Naval Research followed the Bureau of Reclamation in spending on desalination research. In FY2010, FY2011, and FY2012, desalination research by the office was funded at $2.6 million, $4.4 million, and $5.3 million, respectively.[15] The Administration requested $4.5 million for FY2013 and shifted the research to a new program, Future Naval Capabilities.[16]

While some of the traditional avenues for federal desalination research are receiving less support, some new avenues may be opening. Two of these are the Advanced Research Projects Agency-Energy (ARPA-E) and the National Science Foundation's Urban Water Engineering Research Center that was initiated in 2011.

Desalination Adoption in the United States

Desalination and membrane technologies are increasingly investigated and used as an option for meeting municipal and industrial water supply and water treatment demands. The nation's installed desalination capacity has increased in recent years, reflecting the technology's growing competitiveness and applications and increasing demands for reliable freshwater supplies. As of 2005, approximately 2,000 desalination plants larger than 0.3 million gallons per day (MGD) were operating in the United States, with a total capacity of 1,600 MGD.[17] This represents more than 2.4% of total U.S. municipal and industrial freshwater withdrawals, not including water for thermoelectric power plants.

Florida, California, Texas, and Arizona have the greatest installed desalination capacity. Florida dominates the U.S. capacity, with the facility in Tampa being a prime example of large-scale desalination implementation (see box); however, Texas and California are bringing plants online or are in advanced planning stages. Several other efforts also are preliminarily investigating desalination for particular communities, such as Albuquerque. Two-thirds of the U.S. desalination capacity is used for municipal water supply; industry uses about 18% of the total capacity.[18]

The saline source water that is treated using desalination technologies varies largely on what sources are available near the municipalities and industry with the demand for the water. In the United States, only 7% of the existing desalination capacity uses seawater as its source. More than half of U.S. desalinated water is from brackish sources. Another 25% is river water treated

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[14] NRC 2008.

[15] Personal communication with CRS by email from Navy Office of Legislative Affairs, June 8, 2012.

[16] Ibid.

[17] H. Cooley et al., *Desalination, With a Grain of Salt: A California Perspective*, Pacific Institute (June 2006).

[18] Ibid.

for use in industrial facilities, power plants, and some commercial applications. Globally, seawater desalination represents 60% of the installed desalination capacity.[19]

While interest in obtaining municipal water from desalination is rising in the United States, desalination is expanding most rapidly in other world regions, often in places where other supply augmentation options are limited by geopolitical as well as natural conditions, such as arid conditions with access to seawater. The Middle East, Algeria, Spain, and Australia are leading in the installation of new desalination capacity,[20] with Saudi Arabia and the United Arab Emirates leading in annual production of desalinated water.

Tampa's and San Diego's Desalination Experiences and Lessons

Tampa's planning of the first large-scale (25 MGD) desalination plant in the late 1990s ignited interest in large-scale desalination as a municipal water supply source elsewhere in the United States. The facility was thought of as a signal of desalination becoming a cost-effective supply option, However, the Tampa plant, a facility to desalinate heavily brackish estuarine water, encountered technical and economic problems (e.g., less freshwater produced than anticipated, fouling of reverse osmosis membranes, financing issues) during construction and start-up, driving up the cost of the freshwater produced. For some observers, a lesson from the Tampa plant experience is one of caution; before proceeding to full-scale implementation, large-scale desalination requires careful investigation. In the view of industry observers, the lessons to be learned from Tampa are that (1) good design suited to the local conditions and (2) a thorough pilot-study are critical for a desalination facility to function properly. For other observers, the Tampa project illustrates some of the risks of working with private water developers and lowest-bid contracts without sufficient external review and accountability mechanisms. Private developers, however, remain attractive for some communities because of their role in financing the capital cost of constructing a large-scale desalination facility.

In 1998, just north of San Diego in Carlsbad, California, a private joint venture, Poseidon, initiated its effort to build a 50 MGD seawater desalination facility to sell water to San Diego's water system, In November 2009, Poseidon received all of the permits for the Carlsbad project. In November 2012, the San Diego County Water Authority approved the purchase of the desalinated water for thirty years. The project costs in 2012 were estimated at close to $1billion, which represents a significant increase from estimates a decade earlier at $270 million; the cost for delivered desalinated water from the plant is estimated at $1,600 per acre-foot. The plant is expected to complete construction and begin water deliveries in 2016. The extended negotiation and approval process illustrated some of the tensions and concerns that arise during private-sector engagement in provision of municipal water. While Poseidon owned a prime location site for a desalination facility, the water authority and public were hesitant about the arrangement because of concern over profit-taking by a private entity engaged in the provision of a public service. After more than a decade, this concern and other concerns (e.g., environmental impacts) were overcome and mitigated. The Poseidon Carlsbad experience has yielded lessons about the public's expectations for transparency and protections when the private sector is involved in desalination or other aspects of public services and infrastructure. Desalinations stakeholders are anticipated to continue to watch the Poseidon Carlsbad facility and arrangement for lessons and precedents as implementation proceeds.

Energy Concerns and Responses

Reducing Energy Intensity To Reduce Cost Uncertainties

The cost of desalination for municipal water remains a barrier to adoption. Like nearly all new freshwater sources, desalinated water comes at substantially higher costs than existing municipal water sources.

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[19] Ibid.

[20] J. Hughes, "Seawater Desalination Leads Response to Global Water Crisis," *AWWA Streamlines*, Nov. 10, 2009.

Much of the cost for seawater desalination is for the energy required for operations; in particular, the competitiveness of reverse osmosis seawater desalination is highly dependent on the price of electricity. Reverse osmosis pushes water through a membrane to separate the freshwater from the salts; this requires considerable energy input. Currently the typical energy intensity for seawater desalination with energy recovery devices is 3-7 kilowatt-hours of electricity per cubic meter of water (kWh/m^3).[21] The typical energy intensity of brackish desalination is less than seawater desalination, at 0.5-3 kWh/m^3, because the energy required for desalination is a function of the salinity of the source water.[22]

Uncertainty in whether electricity prices will rise or fall creates significant uncertainty in the cost of desalinated water. If electricity becomes more expensive, less electricity-intensive water supply options (which may include conservation, water purchases, and changes in water pricing) become comparatively more attractive. Recent drops in natural gas prices and little to no growth in electricity demand has increased the cost competitiveness of existing desalination technologies in recent years.

Cost-effectively reducing desalination's energy requirements could help reduce overall costs. In recent decades, one of the ways that desalination cost reductions were achieved was through reduced energy requirements of reverse osmosis processes. Now the energy used in the reverse osmosis portion of new desalination facilities is close to the theoretical minimum energy required for separation of the salts from the water.[23] Therefore, although there still is some room for energy efficiency improvements in using desalination as a water supply, dramatic improvements are not likely to be achieved through enhancements to standard reverse osmosis membranes. Instead energy efficiency improvements are more likely to come from other components of desalination facilities, such as the pretreatment[24] of the water before it enters the reverse osmosis process, enhanced facility and system design, or the use and development of a new generation of technologies (see **Appendix A**).

For example, energy efficiency advances in the non-membrane portions of water systems and the use of energy recovery technologies are reducing energy use per unit of freshwater produced at desalination facilities. Pumps are responsible for more than 40% of total energy costs at a desalination facility.[25] Energy efficiency advances in a type of pump that is useful for smaller applications (called a positive displacement pump) have made desalination more cost-effective for some applications and locations and less sensitive to electricity price increases.[26]

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[21] NRC 2008, pp. 74-75, and 77.

[22] Ibid., p. 77.

[23] M. Elimelech and W.A. Phillip, "The Future of Seawater Desalination: Energy, Technology, and the Environment," *Science*, vol. 333 (August 5, 2011), pp. 712-717.

[24] Pretreatment is necessary in order to avoid fouling and harm to the reverse osmosis membranes.

[25] A. Subramani, "Energy minimization strategies and renewable energy utilization for desalination: a review," *Water Research*, vol. 45, no. 5 (February 2011), pp. 1907-1920.

[26] A. Bennett, "Innovation continues to lower desalination costs," *Filtration+Separation*, July/August 2011. Packaging of pre-engineered membrane-based desalination plants also have reduced the upfront capital costs for some desalination applications.

Emissions Concerns and Renewable Energy Opportunities

Desalination's electricity consumption has greenhouse gas and other emissions associated with it if the electricity is generated using fossil fuels. The use of desalination as a climate change adaptation strategy is questioned because of its potential fossil fuel intensity relative to other adaptation and water supply options.[27] Electricity price uncertainty and emissions considerations have driven many desalination proponents to investigate renewable energy supplies and co-location with power plants.[28]

The extent to which desalination technologies can be coupled with intermittent renewable or geothermal electric generation,[29] use off-peak electricity, and operate in areas of limited electric generation or transmission capacity but with renewable energy resources is increasingly receiving attention. Desalinating more water when wind energy is available (which requires facilities that can operate with a variable water inflow) and storing the treated water for when water is demanded can almost be viewed as a means of electricity storage and reduction of peak demand.[30] Efforts to jointly manage water and energy supply and demand and to integrate renewable energy with desalination may bolster support for desalination.

Health and Environmental Concerns

From a regulatory, oversight, and monitoring standpoint, desalination as a significant source of water supply is new in the United States, which means the health and environmental regulations, guidelines, and policies regarding its use are still being developed. Existing federal, state, and local laws and policies often do not address unique issues raised by desalination. This creates uncertainty for those considering adopting desalination and membrane technologies.

Environmental and human health concerns often are raised in the context of obtaining the permits required to site, construct, and operate the facility and dispose of the waste concentrate. A draft environmental scoping study for a facility in Brownsville, TX, identified up to 26 permits, approvals, and documentation requirements for construction and operation of a seawater desalination facility.[31] According to the Pacific Institute's report *Desalination, With a Grain of Salt*, as many as 9 federal, 13 state, and additional local agencies may be involved in the review or approval of a desalination plant in California. For example, during the Corps' process for issuing a seawater desalination facility permits for placing structures in waterways and dredging and filling in navigable waters, the U.S. Coast Guard would consult with the Army Corps of Engineers on whether an intake facility would be a potential navigation hazard and the National

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[27] J. McEvoy and M. Wilder (2012).

[28] A major benefit of co-location is using the cooling water from the power plant for desalination; this water has been warmed by the power plant which reduces the energy requirements for desalinating it. Also, the desalination facility may avoid construction costs by sharing intake and discharge facilities.

[29] Ibid.

[30] For example, M.S. Miranda and D. Infield, "A wind-powered seawater reverse-osmosis system without batteries," *Desalination*, vol. 153 (2002); D. Weiner et al., "Operation experience of a solar- and wind-powered desalination demonstration plant," *Desalination*, vol. 137 (2001).

[31] Texas Water Development Board, *The Future of Desalination in Texas: 2010 Biennial Report*, Austin, TX, Dec.2010, p. 8, http://www.twdb.state.tx.us/innovativewater/desal/doc/2010_TheFutureofDesalinationinTexas.pdf. The report includes a table listing the permits, approvals, and environmental documentation compliance requirements, and estimates of the cost for obtaining each. To reduce the time and expense of the project development process, the Board has supported a study to develop a permitting and decision model for desalination projects in Texas.

Oceanic and Atmospheric Administration would consult on whether intake facilities and discharge of waste concentrate may affect marine resources. Some of the regulatory hurdles are not particularly onerous; others may be particularly challenging depending on the location and size of the facility. In California in 2012, Assembly Bill 2595 was introduced; it would require California's Ocean Protection Council to create a task force to study how to streamline the state permitting process for seawater desalination facilities. No similar legislation for the federal process has been proposed during the 112th Congress.

Some stakeholders view the current permit process as a barrier to adoption of desalination. Other stakeholders argue that rigorous permitting is necessary because of the potential impact of the facilities on public health and the environment. Particular attention is often paid to the impingement and entrainment of aquatic species by intake structures of coastal and estuarine facilities and the disposal of waste concentrate.

Evolving Drinking Water Guidelines

While the quality of desalinated water is typically very high, some health concerns remain regarding its use as a drinking water supply. The source water used in desalination may introduce biological and chemical contaminants to drinking water supplies that are hazardous to human health, or desalination may remove minerals essential for human health.

For example, boron, which is an uncommon concern for traditional water sources, is a significant constituent of seawater and can also be present in brackish groundwater extracted from aquifers comprised of marine deposits. Boron levels after basic reverse osmosis of seawater commonly exceed current World Health Organization health guidelines and the U.S. Environmental Protection Agency (EPA) health reference level.[32] While the effect of boron on humans remains under investigation, boron is known to cause reproductive and developmental toxicity in animals and irritation of the digestive tract, and it accumulates in plants, which may be a concern for agricultural applications.[33] Boron can be removed through treatment optimization, but that treatment could increase the cost of desalted seawater.

EPA sets federal standards and treatment requirements for public water supplies.[34] In 2008, EPA determined that it would not develop a maximum contaminant level for boron because of its rare occurrence in most groundwater and surface water drinking water sources; EPA has encouraged affected states to issue guidance or regulations as appropriate.[35] Most states have not issued such

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[32] The EPA Longer Term Health Advisory level for boron is 2.0 milligram-per-liter (mg/L). Boron occurs in oceans at an average concentration of 4.5 mg/L. Concentrations in water derived from basic reverse osmosis of seawater often are near but necessarily below the EPA Advisory level (NRC 2008). A second pass through reverse osmosis membrane with a pH adjustment can effectively remove the boron; boron removal increases with pH. Some states have drinking water standards or guidelines for boron (California, Florida, Maine, Minnesota, New Hampshire and Wisconsin); these range from 0.6 to 1 mg/L. (USEPA, *Summary Document form the Heath Advisory for Boron and Compounds*, Doc. No. 822-S-08-003, 2008.)

[33] According to the NRC 2008*, w*hile boron is recognized to have a beneficial role in some physiological processes in some species, higher exposure levels may cause adverse human health effects. EPA has concluded there is inadequate data to assess the human carcinogenicity of boron. Most of the boron toxicity data come from studies in laboratory animals.

[34] For more information on EPA's role in protecting drinking water, see CRS Report RL31243, *Safe Drinking Water Act (SDWA): A Summary of the Act and Its Major Requirements*, by Mary Tiemann.

[35] EPA, *Regulatory Determinations for Priority Contaminant s on the Second Drinking Water Contaminant Candidate List*, available at http://www.epa.gov/OGWDW/ccl/reg_determine2.html.

guidance. Therefore, most U.S. utilities lack clear guidance on boron levels in drinking water suitable for protecting public health. The National Research Council recommended development of boron drinking water guidance to support desalination regulatory and operating decisions; it recommended that the guidance be based on an analysis of the human health effects of boron in drinking water and other sources of exposure.

Similarly, the demineralization (particularly the removal of the essential minerals calcium and magnesium) by desalination processes also can raise health concerns.[36] This has prompted researchers to promote the remineralization of desalinated water prior to the water entering the distribution system in communities that are highly dependent on desalinated water.[37] Another health-related concern is the extent to which microorganisms unique to seawater and algal toxins may pass through reverse osmosis membranes and enter the water supply, and how facilities may need to be operated differently when these organisms and algal toxins are present. Algal toxins are a consideration for desalination facilities in locations affected or potentially affected by harmful ocean algal blooms that can produce a range of substances ranging from noxic to neurotoxic (e.g., domoic acid). How to effectively manage desalination facilities in order to avoid public health treats from algal blooms is an emerging area of interest and research.[38]

Some of the coastal facilities contemplated in the United States would treat estuarine water. Estuarine water, which is a brackish mixture of seawater and surface water, has the advantage of lower salinity than seawater. The variability in the quality and constituents in estuarine water, as well as the typical surface water contaminants (e.g., infectious microorganisms, elevated nutrient levels, and pesticides), may complicate compliance of desalinated estuarine water with federal drinking water standards.

Concentrate Disposal Challenges and Alternatives

For inland brackish desalination, significant constraints on adoption of the technologies are the uncertainties and the cost of waste concentrate disposal. For coastal desalination projects, the concentrate management options are often greater because of surface water disposal opportunities. EPA is authorized to manage the disposal and reuse of desalination's waste concentrate.[39] The disposal option selected largely is determined by which alternatives are

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[36] Fluoride is low in seawater and is further depleted by desalination; communities can choose to add fluoride to treated water consistent with their health goals.

[37] J. Cotruvo, "Health Aspects of Calcium and Magnesium in Drinking Water," *Water Conditioning and Purification*, June 2006. Remineralization would also help reduce the corrosivity of desalinated water on piping.

[38] According to a 2009 article, "there are no published reports on the effectiveness of reverse osmosis for removing dissolved algal toxins from seawater. Some of these toxin molecules (e.g., domonic acid) are near the theoretical molecular size of molecules rejected by reverse osmosis membranes, but experimental studies are required to validate the effective (sic) of this process on toxin removal" (D.A. Caron et al., "Harmful algae and their potential impacts on desalination operations off southern California," *Water Research*, (2009). Coastal algal blooms known as red tides were the subject of a 2012 expert workshop ("Red Tide and HABs: Impact on Desalination Plants," Expert Workshop, Muscat, Sultanate of Oman, Feb. 2012, http://www.medrc.org/index.cfm?area=about&page=expert_workshop_download.

[39] EPA's authority is derived primarily from the Safe Drinking Water Act and the Clean Water Act. For a CRS report on the Safe Drinking Water Act, see CRS Report RL31243, *Safe Drinking Water Act (SDWA): A Summary of the Act and Its Major Requirements*, by Mary Tiemann. The sections of the act most significant to disposal of waste concentrate create the underground injection control (UIC) program; this is in Part C, Protection of Underground Sources of Drinking Water, §§1421-1426 (42 U.S.C. §§300h-300h-5). The Clean Water Act establishes the federal standards for surface water disposal and requirements for obtaining permits for these discharges. For more on the Clean (continued...)

appropriate for the specific characteristics of the concentrate and the cost-effectiveness of the alternatives, which is largely shaped by the proximity of the disposal option and the infrastructure, land, and treatment investments required. Disposal options typically include land application, evaporative ponds, surface water disposal, or deep well injection.

Land application can include spraying concentrate on salt-tolerant plants or infiltration; land application typically is used for small volumes of brackish water concentrate. Evaporation ponds use solar radiation to precipitate salt crystals, which are then harvested and typically disposed; in some cases the salts or other constituents may be beneficially reused. Surface water disposal of waste concentrate is permitted on a project-specific basis based on predicted acute and chronic effects on the environment.[40] Inland surface water disposal is particularly challenging because of the limited capacity of inland water bodies to be able to tolerate the concentrate's salinity. In some cases a limited amount of concentrate can be sent to a large-volume wastewater treatment facility. For injection purposes, EPA generally classifies waste concentrate as an industrial waste, thus requiring that the concentrate be disposed of in deep wells appropriate for industrial waste. Desalination proponents argue that desalination's concentrate is sufficiently different from most industrial waste that it should be reclassified to increase the surface and injection well disposal opportunities. Some states (e.g., Texas) have made efforts to promote the beneficial use of waste concentrate (e.g., use as liquids in enhanced oil and gas recovery) and facilitate its disposal including land application techniques.[41] While states can have such policies and programs in place, federal environmental regulations administered by EPA for the most part define the regulatory context of concentrate disposal.

Concluding Remarks

Desalination and membrane technologies are playing a growing role in meeting water supply and water treatment needs for municipalities and industry. The extent to which this role further expands depends in part on the cost-effectiveness of these technologies and their alternatives. Desalination's energy use, concentrate disposal options, and environmental and health concerns are among the top issues shaping the technology's adoption. How to focus federal research to produce results that provides public benefits, at what level to support it, and how to provide a regulatory context that protects the environment and public health without unnecessarily disadvantaging these technologies are the three most significant desalination issues before the 113th Congress.

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Water Act, see CRS Report RL30030, *Clean Water Act: A Summary of the Law*, by Claudia Copeland.

[40] N. Voutchkov, *Management of Desalination Plant Concentrate*, SunCam, 2011, http://s3.amazonaws.com/suncam/npdocs/113.pdf.

[41] For example,, House Bill 2654 passed by the 80th Texas Legislature provided for a general permit for Class I injection wells that can be used to dispose of brine concentrate from a municipal desalination plant. Also, the Texas Water Development Board undertook a study with the intent of showing that oil and gas fields can physically and chemically accept desalination waste concentrate and to recommend changes to statutes and rules to facilitate waste concentrate disposal in oil and gas fields (R. E. Mace et al., *Please Pass the Salt: Using Oil Fields for the Disposal of Concentrate from Desalination Plants*, Texas Water Development Board, Austin, TX, April 2006, http://www.twdb.state.tx.us/publications/reports/numbered_reports/doc/Report366.pdf). Since publication of that report, more questions have arisen related to induced seismic activity from deep well injection; these concerns may affect how the risks and attractiveness of concentrate brine injection as a disposal method among some stakeholders.

Appendix A. Traditional and Emerging Desalination Technologies

There are a number of methods for removing salts from seawater or brackish groundwater to provide water for municipal and agricultural purposes. The two most common processes, thermal distillation and reverse osmosis, are described below; their descriptions are followed by descriptions of some of the more innovative and alternative desalination technologies. The earliest commercial plants used thermal techniques. Improvements in membrane technology have reduced costs, and membrane technology is less energy-intense than thermal desalination (although it is more energy-intense than most other water supply options). Reverse osmosis and other membrane systems account for nearly 96% of the total U.S. desalination capacity and 100% of the municipal desalination capacity.

Reverse Osmosis

Reverse osmosis forces salty water through a semipermeable membrane that traps salt on one side and lets purified water through. Reverse osmosis plants have fewer problems with corrosion and usually have lower energy requirements than thermal processes.

Examples of how research advances in the traditional desalination technologies of reverse osmosis have the potential for improving the competitiveness and use of desalination are: nanocomposite and nanotube membranes and chlorine resistant membranes. Nanocomposite membranes appear to have the potential to reduce energy use within the reverse osmosis process by 20%, and nanotube membranes may yield a 30%-50% energy savings.[42]

Membranes are susceptible to fouling by biological growth (i.e., biofouling), which reduces the performance of the membranes and increases energy use. The most widely used biocide is chlorine because it is inexpensive and highly effective. The most common membranes used in reverse osmosis, however, do not hold up well to exposure to oxidizing agents like chlorine. Advancements in chlorine resistant membranes would increase the resiliency of membranes and expand their applications and operational flexibility.[43]

Distillation

In distillation, saline water is heated, separating out dissolved minerals, and the purified vapor is condensed. There are three prominent ways to perform distillation: multi-stage flash, multiple-effect distillation, and solar distillation. In general, distillation plants require less maintenance and pretreatment before the desalination process than reverse osmosis facilities.

While solar distillation is an ancient means for separating freshwater from salt using solar energy, research into improving the technology is increasing.[44] In large part the interest stems from the

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[42] A. Subramani (2011).

[43] H,B. Park et al., "Highly Chlorine-Tolerant Polymers for Desalination," *Angewandte Chemie*, vol. 120 (July 2008), pp. 6108-6113.

[44] H. Tanaka and Y. Ho, "Global trends and performance of desalination research," *Desalination and Water Treatment*, (continued...)

potential application for the technology to supply freshwater to small remote settlements where saline supplies are the only source and power is scarce or expensive.

Innovative and Alternative Desalination Processes

Capacitive Deionization

Capacitive deionization desalinates saline waters by absorbing salts out of the water using electrically charged porous electrodes. The technology uses the fact that salts are ionic compounds with opposite charges to separate the salts from the water. The limiting factor for this technology is often the salt absorption capacity of the electrodes. The technology shows promise for energy-efficient desalination using electrodes of optimized pore size.

Electrodialysis

Electrodialysis and capacitive deionization technologies depend on the ability of electrically charged ions in saline water to migrate to positive or negative poles in an electrolytic cell. Two different types of ion-selective membranes are used—one that allows passage of positive ions and one that allows negative ions to pass between the electrodes of the cell. When an electric current is applied to drive the ions, fresh water is left between the membranes. The amount of electricity required for electrodialysis, and therefore its cost, increase with increasing salinity of feed water. Thus, electrodialysis is less economically competitive for desalting seawater compared to less saline, brackish water.

Forward Osmosis

Forward osmosis is an increasingly used but relatively new membrane-based separation process that uses an osmotic pressure difference between a concentrated "draw" solution and the saline source water; the osmotic pressure drives the water to be treated across a semi-permeable membrane into the draw solution. The level of salt removal can be competitive with reverse osmosis. A main challenge is in the selection of a draw solute; the solute needs to either be desirable in the water supply, or be easily and economically removed. Research is being conducted on whether a combination of ammonia and carbon dioxide gases can be used as the draw solution. The attractiveness of forward osmosis is that its energy costs can be significantly less than for reverse osmosis when combined with industrial or power production processes.[45] A disadvantage of this technology is that it yields a lower quantity of freshwater per unit of water treated and a larger quantity of brine that requires disposal.[46]

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[45] R. L. McGinnis, and M. Elimelech. "Energy requirements of ammonia carbon dioxide forward osmosis desalination," *Desalination* (2007) 207, pp. 370-382.

[46] A. Bennett, "Innovation continues to lower desalination costs," *Filtration+Separation*, July/Aug. 2011.

Freezing Processes

Freezing processes involve three basic steps: (1) partial freezing of the feed water in which ice crystals of fresh water form an ice-brine slurry; (2) separating the ice crystals from the brine; and (3) melting the ice. Freezing has some inherent advantages over distillation in that less energy is required and there is a minimum of corrosion and scale formation problems because of the low temperatures involved. Freezing processes have the potential to concentrate waste streams to higher concentration than other processes, and the energy requirements are comparable to reverse osmosis. While the feasibility of freeze desalination has been demonstrated, further research and development remains before the technology will be widely available.

Ion Exchange

In ion exchange, resins substitute hydrogen and hydroxide ions for salt ions. For example, cation exchange resins are commonly used in home water softeners to remove calcium and magnesium from "hard" water. A number of municipalities use ion exchange for water softening, and industries requiring extremely pure water commonly use ion exchange resins as a final treatment following reverse osmosis or electrodialysis. The primary cost associated with ion exchange is in regenerating or replacing the resins. The higher the concentration of dissolved salts in the water, the more often the resins need to be renewed. In general, ion exchange is rarely used for salt removal on a large scale.

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