

# Turning the Tide

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POLICIES TO ADVANCE SEAWATER DESALINATION IN THE UNITED STATES

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# PREFACE

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## About the WISE Program

The Washington Internships for Students of Engineering (WISE) program was founded in 1980 to engage engineering and computer science students in the legislative process. Participating professional engineering societies provide the opportunity for competitive students in the United States to spend nine weeks in Washington D.C. to independently research, write, and present a topical engineering-related public policy paper. Throughout the summer, the students have the opportunity to interact with elected-officials, federal agencies, and non-governmental organizations to observe the intersection between science, technology, and public policy. By the end of the summer, the students acquire a greater understanding of how engineers can contribute to regulatory public policy decision-making. For more information regarding the WISE program, visit [www.wise-intern.org](http://www.wise-intern.org).

## About the Author

Lauren Bartels is a fourth-year engineering student at Tulane University pursuing a Bachelor of Science degree in Chemical Engineering. She holds a leadership position in both Tau Beta Pi Engineering Honor Society and Theta Tau Professional Engineering Fraternity. Lauren has also remained an active member of the American Institute of Chemical Engineers and was awarded the Chevron Undergraduate Award for outstanding juniors. Alongside her studies, Lauren competes for Tulane's NCAA Division 1 cross country, indoor track, and outdoor track teams as one of the top distance athletes. Lauren spent her previous summer conducting materials synthesis and characterization research at the University of Delaware and will participate in similar research at Tulane her senior year.

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# LIST OF ACRONYMS

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<b>ADC</b>	Affordable Desalination Coalition
<b>AMO</b>	Advanced Manufacturing Office
<b>AWT</b>	Advanced Water Technology
<b>CWA</b>	Clean Water Act
<b>DWPR</b>	Desalination and Water Purification Research Program
<b>EPA</b>	Environmental Protection Agency
<b>EUWP</b>	Expeditionary Unit Water Purification Program
<b>FEWA</b>	Federal Electricity & Water Authority
<b>FY</b>	Fiscal Year
<b>I&amp;E</b>	Impingement & Entrainment
<b>ITC</b>	Investment Tax-Credit
<b>KSA</b>	Kingdom of Saudi Arabia
<b>MED</b>	Multiple Effect Distillation
<b>MSF</b>	Multistage Flash
<b>NF</b>	Nanofiltration
<b>NGO</b>	Nongovernmental Organization
<b>NPDES</b>	National Pollution Discharge Elimination System
<b>NRC</b>	National Research Council
<b>NREL</b>	National Renewable Energy Laboratory
<b>ONR</b>	Office of Naval Research
<b>OSTP</b>	Office of Science and Technology Policy
<b>PV</b>	Photovoltaic
<b>RO</b>	Reverse Osmosis
<b>SDWA</b>	Safe Drinking Water Act
<b>SWAQ</b>	Subcommittee on Water Availability and Quality
<b>TDS</b>	Total Dissolved Solids
<b>TWDB</b>	Texas Water Development Board
<b>UAE</b>	United Arab Emirates
<b>USBR</b>	United States Bureau of Reclamation
<b>WHO</b>	World Health Organization
<b>WIFIA</b>	Water Infrastructure Finance and Innovation Act
<b>WIIN</b>	Water Infrastructure Improvements for the Nation
<b>WMD</b>	Water Management District

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# EXECUTIVE SUMMARY

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Although water currently remains the world's most abundant resource, most of the water resides in the ocean. In addition to the already limited supply of freshwater, the global population is increasing at an unsustainable rate with regards to the current water resources. As the climate continues to change and droughts become more prevalent, further strain will be placed on the world's water supply. Currently, several regions of the United States are experiencing some level of water shortage, and although the majority of the affected states reside in the West, the effects are felt nationwide. Although both water conservation and reuse remain key components of the national water portfolio, these practices alone will not sufficiently accommodate future water demands. Thus, the United States must capitalize on alternative water sources to continue to sustain a growing population and stable economy.

Desalination, which removes salts and other suspended solids from seawater and brackish water, is a technique widely used around the world to convert high-salinity water sources into water suitable for human use. Despite the global preference for seawater desalination and the essentially unlimited supply of seawater, brackish groundwater, rather than seawater, remains the dominate desalination source in the United States. The unique benefits of seawater desalination remain to be recognized in the U.S., and since the options for augmenting the current water supply are limited, seawater desalination must hold a distinct place in the United States water portfolio.

To facilitate seawater desalination implementation, the United States has typically focused on advancing seawater desalination research rather than eliminating institutional barriers. The United States Bureau of Reclamation was tasked with addressing most of the challenges with seawater desalination technology, but several states have taken the lead in seawater desalination efforts. Even though many research initiatives are currently underway, the U.S. remains behind in seawater desalination implementation.

To maintain global competitiveness, the U.S. federal government must assume a larger role in seawater desalination developments by addressing the implementation challenges associated with the technology. The tedious permitting process, insufficient incentives, and the lack of desalination expertise exist as three of the biggest barriers to widespread adoption. Formulating national seawater desalination guidelines or creating a federal seawater desalination coalition would streamline the permitting process, while the creation of desalination tax-credit bonds or investment tax-credits would help spur more interest in the technology. In addition, encouraging interagency collaboration, promoting operator-regulator understanding, developing public awareness, and strengthening international partnerships would all aid in enhancing desalination expertise through elevated communication. Overall, the federal agenda must prioritize the implementation of seawater desalination to truly understand the best methods for successfully integrating the technique into the national water portfolio.

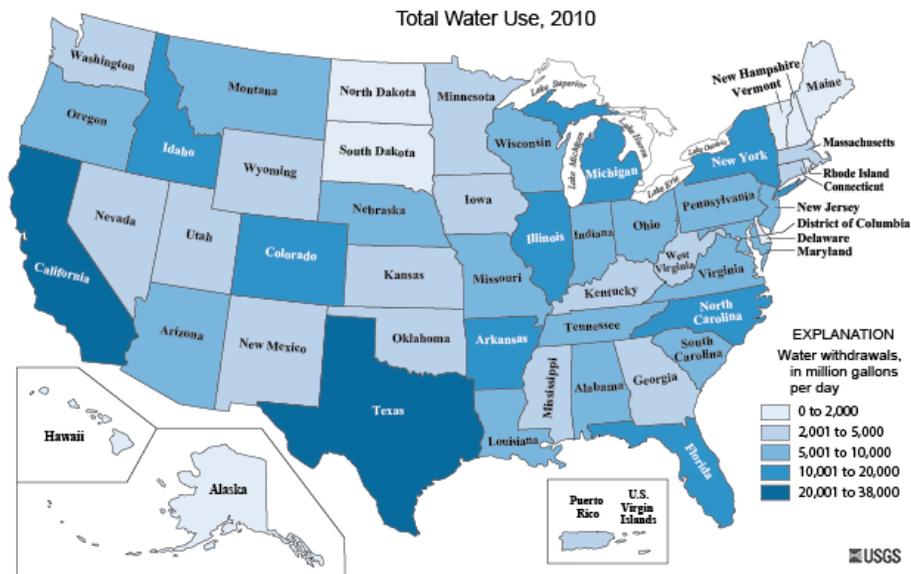
# BACKGROUND

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## UNITED STATES WATER SUPPLY

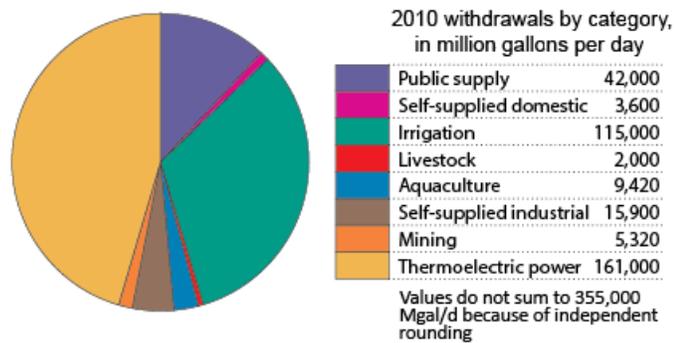
Water is one of the world's most abundant resources, covering about 71% of the earth's surface [1]. In addition, the existence of the water cycle allows the world's supply of freshwater to be naturally replenished. However, all of the global water reserves are not suitable for direct beneficial use, as 97% of earth's water resides in the ocean [1]. 2.5% of the remaining freshwater is inaccessible, leaving only 0.5% of the total water supply as freshwater available for human use [1]. Thus, useable freshwater reserves are extremely limited.

The sources of freshwater can be divided into two main categories: surface water and groundwater. Currently, 78% of United States water withdrawals come from surface sources, with the remaining 22% coming from ground sources [2]. As shown in Figure 1, the amount of water consumed varies by state, with California and Texas accounting for 18% of the total U.S. water withdrawals [2].



**Figure 1.** Total water withdrawals by state as of 2010 [2]

The U.S. water consumption by category is illustrated in Figure 2. Within the United States, the water required for thermoelectric power, irrigation, and public supply account for 90% of the total water consumption by category [2].

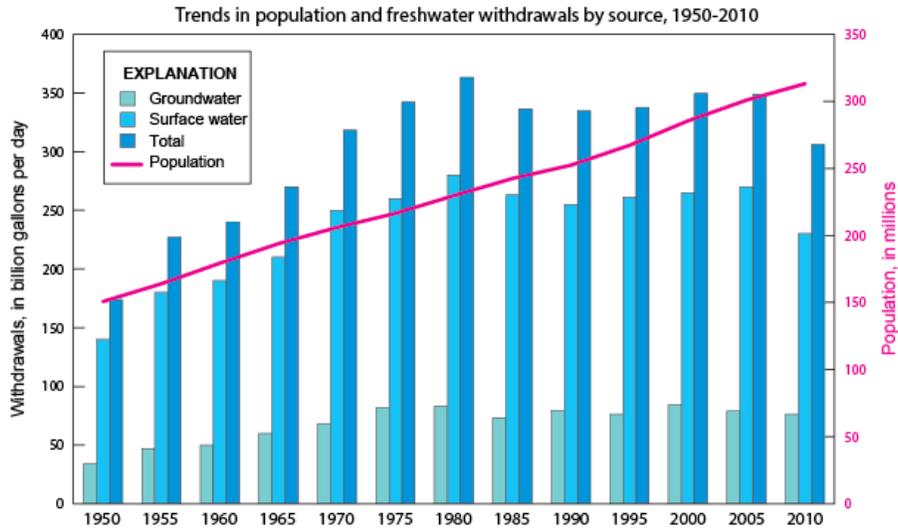


**Figure 2.** Total water withdrawals by category in the U.S. as of 2010 [2]

Although the quality and quantity of water varies by category, freshwater remains a vital resource for almost every sector of the U.S. economy.

Induced by the scarce supply of useable freshwater, the strain placed on U.S. water reserves will only be exacerbated by the growing U.S. population. Figure 3 illustrates the

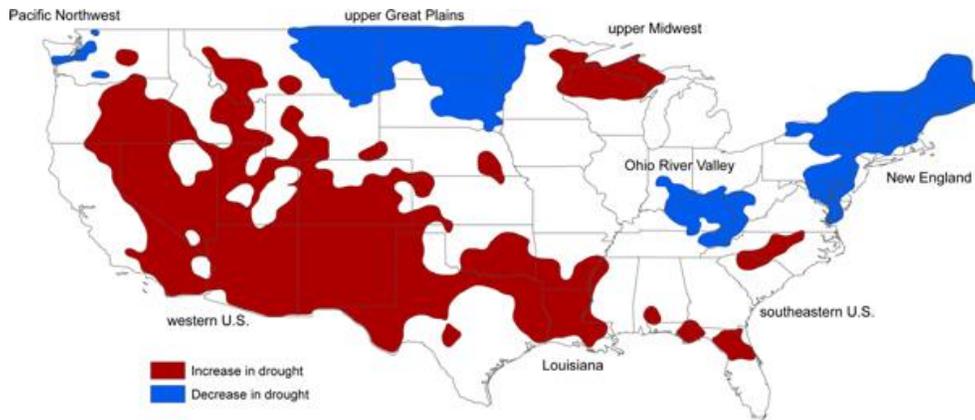
relationship between water withdrawals and population growth in the U.S. over the course of 60 years.



**Figure 3.** Trends in population and freshwater withdrawals by source in the U.S. from 1950-2010 [2]

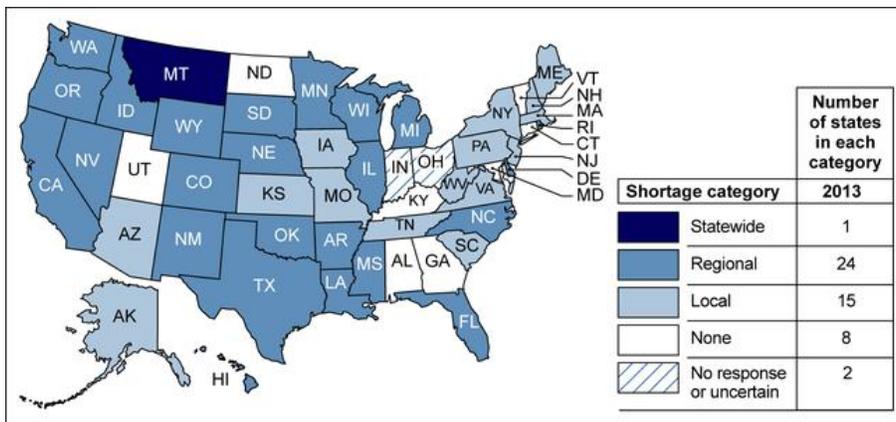
Although the water withdrawals peaked in the 1980's, the following decades saw a sustained volume of withdrawals considerably higher than the years prior to 1980. The decreases observed after 1980 and 2005 corresponded to years experiencing increased technological efficiencies and an emphasis on water reuse [2]. Disregarding these outliers, the overall amount of freshwater withdrawals trended upward with the population.

Aside from increasing water withdrawals, insufficient rainfall has greatly affected the water supplies of various regions of the United States [3]. These droughts have been increasing in severity over the years, and 40% of the continental U.S. experienced some level of drought conditions in 2016 [4]. Figure 4 illustrates the results of a recent study identifying the drought trends across the U.S.



**Figure 4.** U.S. regions of similarly increasing or decreasing drought trends [3]

As the figure shows, the southern and western regions of the U.S. are predicted to experience more instances of drought in the future. In addition, the U.S. Census Bureau anticipates over 40% increases in population in each of these regions by the year 2030 [5], ultimately placing an additional strain on the water reserves in these areas. The most recent GAO predictions for water shortages in each state can be viewed in Figure 5.



**Figure 5.** Extent of state shortages likely over the next decade under average water conditions

[5]

The number of states with regional water shortages increased from 16 to 24 between the 2003 and 2013 predictions [5], with the majority of the shortages occurring in the West. Although water conservation practices, along with other measures, have been implemented to reduce the

stress on water reserves, these tactics cannot increase water resources [6]. With freshwater constituting such a small portion of the world's water supply, the addition of an alternative water source remains necessary to sustain the current way of life.

## A BRIEF OVERVIEW OF DESALINATION

Due to the wide availability of saline water sources, the past decade has seen an increasing interest in the use of seawater and brackish groundwater as a means of augmenting the current supply of freshwater [7]. However, these sources cannot be utilized without advanced treatment, as the salinity levels exceed the recommended concentrations of total dissolved solids (TDS) for human use. Brackish groundwater is classified as having a salinity level between 1,000 and 10,000 mg/L TDS [8], while the salinity of seawater typically ranges from 33,000 to 42,000 mg/L TDS [7]. According to the World Health Organization (WHO), water with  $\leq 1,000$  mg/L TDS is usually acceptable for consumer use, but the United States Environmental Protection Agency (EPA) recommends  $\leq 500$  mg/L TDS for drinking water [9].

Desalination involves the separation of dissolved salts from seawater and brackish groundwater, generating both a low-salinity product water stream and a high-salinity waste stream [7]. The low-salinity product water can then be used as a source of freshwater for numerous applications where high-quality water is required, including municipal water use and agricultural irrigation.

Although multiple approaches to desalination exist, current large-scale technologies tend to utilize one of two methods: thermal desalination or membrane processes. Early desalination technology centered around thermal desalination, or distillation, which uses a heat source to produce freshwater through the evaporation and condensation of seawater [6]. On the other hand,

membrane processes rely on a semipermeable membrane designed to retain the salt [6]. Reverse osmosis (RO), a membrane process driven by a pressure gradient applied opposite of the natural osmotic pressure, prevails over all other technologies in terms of prominence and efficiency, as the flexibility to accommodate both brackish and seawater desalination facilities of any size remains an attractive quality [7]. However, most large-scale desalination facilities in the Middle East still operate using thermal desalination [6].

Only 14% of total U.S. water withdrawals use a saline-water source [2], with most of these withdrawals coming from brackish groundwater sources. Over 300 municipal brackish groundwater desalination facilities are currently operating in the U.S. [7], constituting more than 80% of the nation's municipal desalination plants [8]. In contrast to the U.S., 59% of the world's desalination capacity is devoted to desalting seawater [7]. Despite the global adoption of seawater desalination and widespread availability of the technology, seawater remains an underutilized water resource in the United States.

Seawater desalination holds the potential to provide a nontraditional water source capable of easing pressure on the existing water supply and mitigating future strains to U.S. water reserves. Many water conservation options exist, but only desalination and water reuse serve to increase the current supply of freshwater [6]. Support for water reuse, coupled with water conservation, remains popular across the U.S., and most regions evaluate these options before considering desalination [10]. Although these practices remain integral for ensuring a sustainable water supply, water reuse alone cannot support the growing demand [6]. The unique benefits of seawater desalination, including the resilience to drought and the production of high-purity water, reserve a distinct place for the technique in the U.S. water portfolio.

Water remains a vital component in many U.S. economic, social, and environmental sectors [11], and the impacts of water shortages extend far beyond a single state boundary. Due to the nationwide benefits of desalination and the national significance of sustaining ample water supplies, the development of seawater desalination into a feasible process necessitates support from the federal government. In addition, the desalination step represents only a portion of the entire process, and a comprehensive systems analysis requires collaboration between various entities. As previously mentioned, seawater desalination is not limited by water resources but rather by financial, social, and environmental factors [9]. The federal government tends to concentrate on the research and development of the technology, which remains an essential effort for achieving sustainability, but greater adoption of seawater desalination demands improvements to the non-technical aspects of the institutional system. Thus, updating and transforming the United States desalination implementation process through the formulation of desalination-specific guidelines, investment incentives, and educational campaigns remains imperative for the U.S. to significantly benefit from seawater desalination.

# UNITED STATES FEDERAL POLICY ON WATER DESALINATION

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## Saline Water Conservation Act of 1952

To address water shortages experienced across the nation, the Saline Water Conservation Act was passed in 1952. The Act instructed the Department of the Interior to work toward developing low-cost desalination operations to conserve and increase United States water resources [12]. The Interior gained authorization to fund and coordinate the research and

development of desalination technologies to gauge the viability of desalination as an alternative to the current water supply.

## Water Desalination Act of 1996

The Water Desalination Act of 1996 represented a renewed effort in desalination advancements, recognizing the need to develop more efficient and cost-effective desalination processes before further implementing the operation [12]. The bill authorized the Department of the Interior to finance desalination research projects as well as manage a desalination demonstration and development program. Until fiscal year (FY) 2002, \$5 million per year was to be allotted to research, while \$25 million was to be allotted to development projects. However, the Federal monetary contribution could not exceed 50 percent of the total project cost [13].

The appropriations authorized by the Water Desalination Act continued to be extended through FY 2002 by each subsequent Congress. The 112<sup>th</sup> Congress was the last to extend the Act but reduced the funding for development projects to \$3 million annually until FY 2013 [14]. Both the H.R. 745 bill and the Energy and Water Development and Related Agencies Appropriations Act introduced in the 113<sup>th</sup> Congress proposed extending the Act until FY 2018, but neither bill passed the House of Representatives. Despite the failure in extending the Water Desalination Act, Congress still allocated a portion of the requested funds for desalination research and development programs [15].

## WIFIA and WIIN Act

Chapter 52 of the Water Resources Reform and Development Act of 2014, commonly known as the Water Infrastructure Finance and Innovation Act (WIFIA), declared seawater

desalination projects eligible for financial assistance through loans and loan guarantees administered by the EPA [16]. The 114<sup>th</sup> Congress then passed the Water Infrastructure Improvements for the Nation (WIIN) Act, which reauthorized the Water Desalination Act of 1996 by extending the authorization of appropriations until FY 2021. The WIIN Act recognized the potential benefits of desalination and prioritized research involving the development of more sustainable desalination operations and technologies.

In addition to addressing funding for desalination research, the WIIN Act assigned the task of defining a coordinated strategic plan for desalination research and development to the White House Office of Science and Technology Policy (OSTP), who further delegated the task to the Subcommittee on Water Availability and Quality (SWAQ) [17]. SWAQ is currently working to frame a report detailing the appropriate level of federal government involvement for advancing desalination technology and improving the sustainability of the process.

## The Federal Budget

As part of the Department of Energy's FY 2017 Budget, the Advanced Manufacturing Office (AMO) requested \$25 million to establish the Energy-Water Desalination Hub. Congress granted the AMO \$20 million to establish the hub [18], which would focus on research to develop technologies to lower the cost and energy requirements of desalination [19]. The research would examine multiple uses for desalination, including both municipal drinking water and agricultural applications, as well as support collaboration between private and public entities interested in desalination [20]. The proposition to establish a desalination energy innovation hub represented the largest research and development effort in the U.S. for lowering the cost of desalination, demonstrating the growing federal interest in advancing the technology.

# SEAWATER DESALINATION EFFORTS

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## The United States

Although the commitment to seawater desalination integration in several other nations surpasses the efforts in United States, the changing climate and depletion of water resources have spurred both federal and regional investments in desalination research and development.

### State Initiatives

A substantial portion of the total water withdrawals in the U.S. comes from three states: California, Texas, and Florida. California and Texas are responsible for 11% and 7% of the total water withdrawals for all categories, respectively, while Florida maintains the largest saline withdrawals at 18% of the U.S. total [2]. Unsurprisingly, most of the desalination capacity in the United States is also concentrated in these three states [21]. Although each state experiences region-specific water challenges, a history of water shortages, growing populations, and recent increases in drought severity have spurred these states to invest in seawater desalination research, legislation, and adoption.

### California

California is leading U.S. efforts in seawater desalination development, housing two large and ten small seawater desalination facilities [22]. Due to limited water resources, Sand City began operating California's first full-scale seawater desalination facility in 2010 with the intent of providing the city with a long-term water supply [23]. Several years later, the Claude "Bud" Lewis Carlsbad Desalination Plant in Carlsbad, California, the largest desalination plant in the Western Hemisphere, began delivering water to San Diego County near the end of 2015 [24].

Santa Barbara saw the most recent development in California, as the Charles E. Meyer Desalination Plant started distributing desalinated seawater in May 2017 [25].

To sustain the operation of the existing facilities and provide a framework for future facilities, California has ratified laws mandating sustainable performance and development of seawater desalination plants. Chapter 9 of the California Water Code, known as the Cobey-Porter Saline Water Conversion Law, addresses the need to integrate seawater desalination into the water portfolio. The law acknowledges the interest in desalination implementation by both the citizens and government of California to assist in meeting the future water supply demands of the state. In addition, the law declares any desalination projects serving public water entities be given the same state funding opportunities as any other water supply project inasmuch as the operation abides by all relevant state environmental policies. The law also mandates continuing efforts to improve the efficiency and feasibility of desalination while encouraging collaboration between the federal government, state and regional governments, and various agencies [26].

Further interest in incorporating desalinated water into the public water supply arose in 2015 from the California Desalination Amendment, which amended the Water Quality Control Plan for the Ocean Waters of California. The amendment supports the supplemental use of seawater desalination for augmenting the existing water supplies while addressing potential environmental consequences of the operation. Specifically, the amendment works to protect marine life and water quality, requiring desalination plants be constructed and operated using the best available site, design, technology, and mitigation measures feasible [27]. The amendment identifies the preferred technologies for both water intake and concentrate disposal procedures and requires the operator to mitigate any environmental impacts to the best ability possible [28].

The Desalination Amendment is the first law to provide a consistent process for permitting seawater desalination facilities across California [27].

## **Texas**

Although ample groundwater and brackish water supplies have prevented any immediate developments of seawater desalination facilities in the state, Texas anticipates a growing drinking water shortage over the next 50 years. Due to this projection and the state's proximity to the Gulf of Mexico, the Texas Water Development Board (TWDB) acknowledged the importance of developing seawater desalination into a more cost-effective process. To address the diminishing water supply, the TWDB established the Seawater Desalination Initiative, providing funding to conduct feasibility studies for a large-scale desalination plant [29]. The TWDB also funded pilot-scale studies at the Brownsville Ship Channel and on South Padre Island, eventually concluding seawater desalination was feasible at both locations. Two more feasibility studies are currently being conducted in the Corpus Christi area [29].

The Texas Legislature passed House Bill 1370 in 2003, which focused on increasing the cost-effectiveness of seawater desalination by directing the TWDB to engage in research for advancing the process [30]. The TWDB is required to give a biennial report on the progress of seawater desalination in the state to keep the Legislature informed on the status of the technology. Since 2015, legislation has been passed to streamline the regulatory process of seawater desalination, resulting in a new permitting process developed by the Texas Commission on Environmental Quality. The most recent development appeared in Texas' 2017 State Water Plan, where four regional water planning groups in the state recommended seawater desalination as a water management strategy [29]. Although the contribution from seawater desalination

might not be effective until 2070, this recent legislation signifies Texas' growing interest in adding seawater desalination to their water portfolio [31].

## Florida

Similar to Texas, Florida relies on groundwater and inland water sources to sustain the current water demands of the state. Almost all of Florida's desalination interest focuses on brackish water desalination, but the state does operate three seawater desalination facilities. The Tampa Bay Seawater Desalination Plant is the largest of the three and satisfies up to 10% of the region's water demand [32]. The plant is co-located with Tampa Electric's Big Bend Power Station, which uses seawater from the Tampa Bay as cooling water. The desalination plant intakes the cooling water from the power station to produce drinking water. The concentrate reject stream is returned to the original cooling water stream, diluting the waste stream before returning the water to the Tampa Bay [32].

Even with the existence of the seawater desalination facilities, Florida's state policy encourages regional water supply development rather than supporting large-scale seawater desalination [21]. Due to variations in water resources across the state, Florida established Water Management Districts (WMDs) to administer water management programs in each specific region [33]. Each district holds authority over the water supply of the region, and three of the five districts are actively pursuing seawater desalination [21]. The WMDs submit region-specific water supply planning reports to the governor and legislature of Florida to monitor the progress of prospective seawater desalination projects. However, state funding for alternative water supplies has been inconsistent, and although laws were passed to streamline the permitting process for seawater desalination facilities, no mandate exists requiring the development or funding of seawater desalination plants [21]. These shortcomings, coupled with the practice of

exhausting local resources before relying on alternatives, hinder the growth of large-scale seawater desalination facilities in the state.

## Federal Initiatives

Florida, Texas, and California each demonstrate unique water supply challenges, yet despite the regional diversity, the interest in seawater desalination remains strong. The widespread impacts of regional water shortages emphasize the national significance of the country's limited water supply, justifying the need for reliable and meaningful engagement by the federal government to expand U.S. water resources through seawater desalination.

Historically, the federal government involvement in seawater desalination focused on research advancements, leaving the majority of the development decisions to the local and state governments [15]. However, the National Research Council's (NRC) Committee on Advancing Desalination Technology authored a report in 2008 analyzing the current state of desalination research and technology, the costs and benefits of desalination, and the implementation issues associated with the advancement of desalination in the United States. The committee anticipated greater integration of desalination into the nation's water management strategies and proposed a strategic research agenda for the federal government, providing an integrated direction to address the concerns of the technique. Since the report was published, several efforts have emerged to aid in more widespread development of seawater desalination.

### **United States Bureau of Reclamation**

The United States Bureau of Reclamation (USBR) remains at the forefront of seawater desalination research through the Desalination and Water Purification Research Program (DWPR). The objectives of the program align with the NRC's recommended strategic research agenda [34], examining an array of water treatment strategies to reduce the costs of desalination

and mitigate any environmental impacts [35]. The DWPR funds both reclamation researchers as well as any private entities who address the goals of the DWPR [34]. In addition, the DWPR owns and operates three major research facilities available to both USBR researchers and private organizations, highlighting the collaborative effort between the public and private sectors.

DWPR funding facilitates the transition of an idea from the lab to the demonstration level through the cost-sharing of full and pilot testing projects [34]. The funding serves to encourage private entities to engage in research addressing issues of national concern and with outcomes supplying widespread benefits [34]. The highly-integrated research efforts have led to major advancements in the seawater desalination industry, such as lowering the energy requirements for RO desalination systems [36].

## **United States Office of Naval Research**

Although the U.S. Navy began investigating RO desalination in the 1970's, the Navy's desalination research capabilities escalated in the early 2000's due to a renewed federal interest in seawater desalination. Through the Expeditionary Unit Water Purification Program (EUWP), a Congressional Interest Program managed by the Office of Naval Research (ONR) from FY 2003 to FY 2007, the Navy worked to reduce the costs and energy requirements associated with seawater desalination. Beginning with basic research in 2005, the ONR studied various pretreatment methods and desalination techniques by administering desalination testing, demonstration, and EPA environmental technology verifications at the Naval Seawater Desalination Test Facility at Port Hueneme, California [37]. The development and operation of the demonstration plant was made possible through the Affordable Desalination Coalition (ADC), which provided necessary funds from both public and private financial resources [15].

Up until 2010, funding from EUWP allowed the ONR to move from basic research to applied research and development. The results of the studies indicated reverse osmosis with an energy recovery pump tended to be the most efficient desalination technology, and additional recommendations were made to further develop the various existing desalination technologies [37]. Although the Navy has unique requirements for shipboard desalination, the research considered municipal water purification applications. Collaboration between various agencies, including the USBR and National Science Foundation, contributed to the success of the research, emphasizing the benefits of an integrated and involved approach to seawater desalination advancement.

## **National Renewable Energy Laboratory**

As renewable energy technologies become more prevalent in society, these technologies provide feasible alternatives for generating the electricity or thermal energy needed to power desalination processes. The National Renewable Energy Laboratory (NREL), which is the only federal laboratory dedicated to the advancement of renewable energy technologies, has managed projects focusing on optimizing the energy requirements of desalination processes using different renewable sources [38]. The laboratory partners with both private industries and government agencies to integrate sustainable energy resources into preexisting desalination operations [39].

The commercialization of renewable energy technologies has spurred the interest in integrating photovoltaic (PV) and wind technologies with seawater desalination facilities [40]. In 2009, the NREL evaluated the potential for solar and wind technologies to power water desalination projects in the Arab region, matching the different desalination methods to the most effective energy sources [41]. The continuation of collaborative efforts in renewable energy

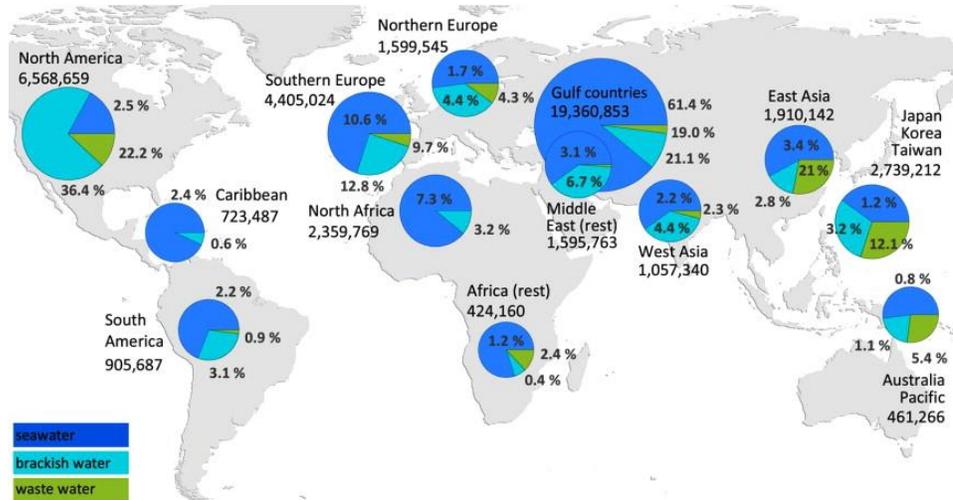
technologies remains imperative for further developing the sustainability of seawater desalination.

## **Sandia National Laboratories**

Since 2000, Sandia National Laboratories maintained a program focused on the implementation of desalination technologies [42]. The Advanced Concepts Water-Treatment Program works toward developing cost effective and efficient technology through pilot-testing and long-range research programs [42]. Sandia National Laboratories exemplifies the success obtained in advancing seawater desalination through public-private partnerships, and the ability of Sandia to objectively evaluate both the advantages and limitations of the seawater desalination process has led to novel developments in membrane technologies and desalination systems.

## International

Despite the fact brackish water desalination dominates the desalination market in North America, most of the recent growth in the technology has taken place in the seawater sector [43]. Currently, seawater desalination constitutes about 59% of the worldwide desalination capacity, with the Gulf region accounting for over 60% of the installed capacity [43]. Figure 6 summarizes the desalination capacities for various regions across the globe by water source.



**Figure 6.** Global desalination capacities in cubic meters per day [43]

Within the Gulf region, the largest producers of desalinated seawater are the Kingdom of Saudi Arabia (KSA) and the United Arab Emirates (UAE), respectively [44]. However, nations in other regions of the world, including Spain, Algeria, and Australia, continue to demonstrate the potential to make considerable progress [44].

## Saudi Arabia

As a result of the arid climate and proximity to the sea, the largest seawater desalination market in the world emerged in the KSA [45]. Currently, 30 government-operated desalination plants produce 24 million cubic meters of water per day for the KSA [46], with thermal desalination techniques dominating the market over reverse osmosis desalination. However, advancements in membrane technologies have generated membranes less susceptible to fouling and more capable of handling the high salinity of the Gulf and Red Sea [47].

Utilizing these recent membrane advancements, the KSA began working to improve the sustainability of the seawater desalination process. As of 2010, 90% of all desalination plants in the KSA ran on fossil fuels, requiring 1.5 million barrels per day [46]. Recognizing the

unsustainable nature of this water production method, the KSA acquired an interest in renewable energy-powered seawater desalination. In early 2015, Advanced Water Technology (AWT) and Abengoa, two groups dedicated to sustainable technologies, agreed to jointly develop a solar-powered RO seawater desalination plant in Saudi Arabia. The facility, set to begin operation in 2017, will be the world's largest solar-powered desalination plant, designed to treat 60,000 cubic meters of water per day. Using PV solar cells connected to both the desalination plant and the national grid, all the power needed to support the energy requirements of the plant will be sustainably obtained [48]. Once operating, the plant will provide a stable water supply to northern Saudi Arabia at a reduced operational cost and with fewer greenhouse gas emissions, extending the available water resources while diversifying the nation's economy [49].

## **United Arab Emirates**

Similar arid conditions in the UAE drove the nation to become the second largest producer of desalinated seawater in the world. Two major cities in the UAE, Abu Dhabi and Dubai, heavily rely on seawater desalination to supply nearly all of their water for municipal and industrial uses [50]. The city of Ghalilah also began benefitting from seawater desalination in 2015 when Aquatech, a U.S.-based water purification technology provider, partnered with the Federal Electricity & Water Authority (FEWA) in the UAE to help construct a seawater RO plant [51]. The facility won Desalination Plant of the Year at the 2016 Global Awards due to the high-performance operation with a low energy consumption [52].

Emulating the efforts of other Middle Eastern nations, the UAE looks to transition to more sustainable seawater desalination production. Masdar, the Middle East's largest exporter of renewable energy, developed a pilot program in 2013 to research and develop cost-competitive and energy-efficient desalination technologies. Four commercial partners were chosen to operate

pilot-scale seawater desalination plants, encouraging the implementation of renewable energy-powered desalination facilities in the UAE [53].

## **Future Leaders**

Spain, who already boasts the largest municipal desalination plant in Europe, is working to increase their seawater desalination capacity [54]. Currently, the Barcelona-Llobregat Desalination Plant, which was initially designed in response to a severe drought in the early 2000's, has successfully served to increase Spain's water security [55]. The construction of the plant was co-financed by the European Union and is currently administered by the renewable energy company Acciona [54]. As a result, the facility utilizes a hybrid RO system and incorporates several sustainable features, including a deep intake system, a wind power generator, and PV solar panels, to purify water from the Mediterranean Sea [56].

The continuing shift toward a hotter and drier climate forced the Water Corporation of Western Australia to adopt the strategy of 'security through diversity'. The Perth Seawater Desalination Plant began operating near the end of 2006, becoming the first Australian facility utilizing desalinated water as a major public water source. The plant also remains the largest seawater desalination facility powered by renewable energy in the southern hemisphere, as all the electricity for the plant comes from the Emu Downs Wind Farm [57]. In addition, operators practice comprehensive marine monitoring and organize rehabilitation projects to protect the ocean environment [58], further enhancing the sustainability of the plant. The facility supplies 17% of Perth's water demands, and the annual running costs of the plant are less than \$1 per week per household [57].

The United States holds the potential to accelerate developments in desalination over the next decade, as desalination research is expected to receive \$10 billion of investments between 2016 and 2021 [59]. However, the most recent comprehensive data on federal funding indicated a decreasing trend in federal spending on seawater desalination, and the USBR desalination funding declined by \$8 million from FY 2006 to FY 2015 [15]. Verifying the decline of U.S. global competitiveness in implementing this promising technology, a group of researchers in Asia compared the leading institutes publishing desalination articles, concluding the U.S. to be less prolific in desalination research than other nations [60].

## CURRENT STATUS OF SEAWATER DESALINATION TECHNOLOGY

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Physically desalting seawater is only one aspect of desalination, as the entire desalination process exists as an integrated system. Prior to any application of the desalination technology, the feedwater must be first be obtained and pretreated. After the salt removal, the product water goes through a post-treatment step while the concentrate stream is properly disposed. Due to the complexity of the operation, each step requires individualized attention to optimize the desalination process and successfully implement the technology [61].

### Source Water Intake

Seawater can be obtained through two methods: surface intakes or subsurface intakes. Surface intake structures, which encompass all structures above the seafloor, are commonly employed by thermal desalination and large seawater RO facilities [9]. On the other hand,

smaller seawater desalination systems typically utilize subsurface intakes, which include all structures installed beneath the seafloor [9].

Advantages and disadvantages exist with both intake methods, but due to geographical variances between regions, the unique conditions surrounding a specific plant will ultimately determine the most suitable structure. Thus, advancements must be made to each type of intake technology to ensure a sustainable method for every location.

The main concern with surface intakes revolves around the impingement and entrainment (I&E) of marine life. Impingement refers to the trapping of larger organisms against the intake screens, while entrainment refers to the passage of smaller organisms into the intake structure and desalination system [61]. In addition, these open intake systems allow the passage of undesirable particles through the screen, requiring significant pretreatment of the seawater before the desalination step [62]. General guidelines exist for reducing the harmful effects to marine life from I&E, including setting a low-approach water velocity, designing escape or diversion channels for the organisms, and utilizing fine-mesh screens in the design [62].

In comparison, subsurface intakes avoid direct contact with the open ocean and thus eliminate any concerns regarding I&E. Subsurface intake wells also eliminate the need for a pretreatment step, as the design of an underground well integrates a natural filtration system by utilizing coastal aquifer deposits. However, construction-related issues arise during the installation of the wells, raising concerns regarding land erosion and habitat destruction. Furthermore, seawater intake wells usually increase the unit cost for producing water [62].

Other than concentrating on advancements to intake technology, recent studies have also focused on the potential for co-locating new desalination facilities with existing power plants. Since a power plant must intake seawater for cooling water, the desalination facility could

repurpose the plant's cooling water into feedwater for the process, eliminating the need to construct additional intake structures [9]. However, co-location is not always feasible or available, so new structures are installed outside highly productive regions or further from shore to minimize harmful marine impacts and ensure more reliable water quality [63]. Either way, the desalination facility design plan evaluates the best available locations for intake structure installment.

## Pretreatment

Depending on the intake method and the desalination technology, the raw seawater may be subjected to a pretreatment step to increase the quality of the feedwater [64]. As previously mentioned, open seawater intake systems provide lower quality water in need of pretreatment before the desalination step. A pretreatment operation is especially necessary if the facility utilizes a reverse osmosis desalination system. Due to membrane sensitivity, particles which facilitate fouling of the membrane must be removed to preserve membrane life and performance capabilities [64].

The conventional pretreatment technique exists as a combination of a physical and chemical process. The physical process is purely mechanical, utilizing devices such as cartridge filters to remove the particles capable of blocking the membrane [64]. On the other hand, the chemical process involves the use of additives to adjust the pH, disinfect the water, or prevent membrane fouling and corrosion [64]. Issues with conventional pretreatment arise in terms of the reliability and sustainability of the step, as the specifics of the method vary with seawater quality and can significantly contribute to the overall cost and energy consumption of the desalination process [65].

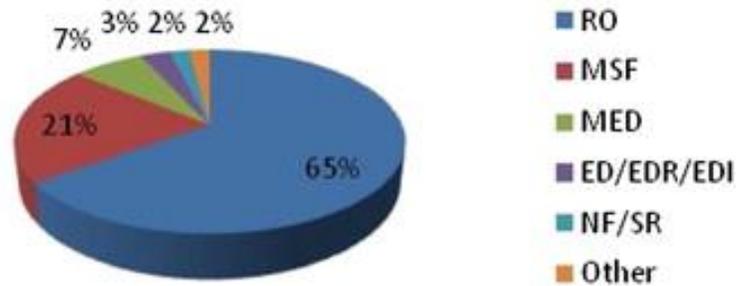
Advancements to pretreatment methods have emerged in the form of pressure driven membrane processes, including microfiltration, ultrafiltration, and nanofiltration [65]. The implementation of these technologies has indicated trends of higher feed water quality, reduced membrane fouling, less chemical additives, and lower system costs [64]. Nanofiltration has proven the most effective membrane pretreatment method, allowing the desalination units to operate at a considerably higher recovery while also preventing membrane fouling [66].

Due to the close relationship between the source water intake system and the pretreatment technology, the most feasible pretreatment method will also depend on site-specific conditions. However, recent developments in membrane filtration systems continue to increase the sustainability of a membrane-based pretreatment step. Furthermore, improvements to both the source water intake method and desalination technology could eliminate the need for a pretreatment step.

## Desalination

A variety of technologies currently exist to remove the majority of dissolved salts and other solids from the source water [9]. As previously discussed, desalination technologies typically fall into one of two main categories: thermal desalination or membrane desalination. Other than the Middle East, membrane technologies dominate the seawater desalination market, with RO systems constituting about 65% of the global desalination capacity [67]. Figure 7 illustrates the global prevalence of each major desalination technology.

### Distribution of total world installed capacity by technology



**Figure 7.** Total capacity installed by technology [68]

The earliest desalination methods utilized thermal desalination, and facilities in the Middle East continue to incorporate these technologies. Among the commercially developed thermal desalination processes, multistage flash (MSF) and multiple effect distillation (MED) have sustained a presence in the global seawater desalination market. The two techniques are similar in principle: a series of stages or chambers utilizes steam as a source of thermal heat to extract pure water from the feed stream by vaporization and subsequent condensation. Due to the robust nature of the technology and the large production capacity, MSF is typically preferred over MED. However, MED requires less power input than MSF [9].

Despite the durability of thermal desalination technology, high energy requirements and limited water recovery prevent widespread installation. However, co-locating new seawater desalination facilities with existing power plants would reduce the cost of heat energy needed for desalination, as low-grade heat from the power plant could be harnessed as a less-expensive energy source [9].

For seawater desalination applications, membrane processes typically require lower energy than thermal desalination methods [7]. Two main types of membrane systems at the focus of commercial seawater desalination include RO and nanofiltration (NF). Both RO and NF rely

on a semipermeable membrane and a pressure gradient to drive the seawater through the membrane while blocking the passage of suspended solids. RO remains more prevalent than NF on the commercial scale, and most research over the past couple of decades has been directed toward advancements in RO membranes. However, the energy consumption for NF is generally less than RO [9].

Due to the recent developments in RO membrane technology, current RO membranes can operate near the thermodynamic minimum energy required for seawater desalination [7]. In turn, seawater desalination has seen steadily decreasing costs, making the process competitive with some traditional water sources [7]. However, the initial capital expenses and total energy costs of membrane seawater desalination still create a barrier to implementation. In addition, the energy is typically supplied with nonrenewable fossil fuel sources, intensifying climate change through the emission of greenhouse gases [6].

The maturity of membrane technology makes advancements in the permeability of membranes unlikely to significantly reduce the overall cost of membrane seawater desalination [7]. However, more resistant membranes or membranes constructed using novel materials could increase membrane lifetimes and reduce the footprint of the desalination facility [7]. Graphene-based membranes have emerged as a promising technology for the commercial desalination industry and hold the potential to reduce the plant footprint [69].

To observe significant reductions in the overall cost of seawater desalination, the energy requirement for the process, which typically accounts for the majority of the cost of seawater desalination, must be minimized [7]. Although dramatic increases in energy-efficiency emerge with the incorporation of energy recovery devices [9], significant improvements remain possible. Recent studies have examined options to integrate renewable energy sources, rather than relying

on thermoelectric energy, to power seawater RO facilities [6]. Currently, solar-powered seawater desalination is the most prevalent renewable energy-powered desalination system, but the increasing widespread interest in renewable energy continues to spur developments by both federal and private research groups in high-efficiency desalination systems [70].

In addition to improving existing technology, the focus of recent studies has also revolved around the development of new desalination techniques. Hybrid systems, which integrate multiple desalination technologies into a single technique, have resulted in reduced costs and enhanced performances of seawater desalination processes. The Water Research Foundation conducted a study regarding a forward osmosis-reverse osmosis system, declaring the system to be both technically and economically feasible. Furthermore, the hybrid system decreased the overall production cost of the desalinated water, demonstrating the potential for seawater desalination to become a practical alternative water source [71].

## Post-Treatment

The ability of current technologies to produce high-purity water with extremely low TDS concentrations remains one of the attractive qualities of seawater desalination. However, the thorough stripping of solids alters the composition of the water, and additional treatment remains necessary to either remineralize or disinfect the desalinated product stream [72]. Not only do the water parameters and pH levels need to be adjusted to adhere to drinking water standards, but the permeate must also be re-hardened to prevent corrosion of the system infrastructure [64]. Current post-treatment technologies add chemicals to the desalinated water stream, including calcium hydroxide, sodium hydroxide, and carbon dioxide, while membranes are typically used to remove any boron remaining after the desalination step.

Although water chemistry, and thus the post-treatment process, is well-understood, concerns still arise regarding the quality of the chemicals introduced, the accuracy of the dosages, the presence of any manufacturing contaminants, and the occurrence of unwanted chemical reactions [73]. However, these issues stem from the operation of the plant rather than a need for advanced technology. To ensure regulatory compliance and a high-quality product, the facility administrators must constantly monitor the operational controls of the plant and regularly conduct water tests [74]. The post-treatment step generally contributes the smallest portion to the overall cost of desalination [75], so as long as the public remains informed on the improbability of contamination, post-treatment can be classified as a mature technology.

## Concentrate Management

Since a typical seawater desalination process only recovers about 40-50% of the intake water in the product stream, a second stream, known as brine, contains the remaining water, salts, and process chemicals [7]. Managing the brine remains one of the biggest and most controversial issues associated with seawater desalination, as the concentrate can have up to twice the salinity of typical seawater [7]. Many different discharge methods exist, but the disposal of a stream with elevated salinity must abide by all relevant environmental regulations as well as avoid any disruptions to marine life and habitats.

Despite the rather limited experimental data assessing the environmental impacts of brine disposal, the biggest concern revolves around the effects of the high-salinity concentrate on marine life [6]. As these concerns persist, seawater desalination facility operators strategically evaluate the site of discharge to minimize any potential hazards. Surface water discharge remains the most commonly practiced discharge method in both the U.S. and the world due to the low

energy and technology requirements of the method [9]. A common sustainable discharge practice via surface water disposal involves the dilution of the brine with other waste streams before disposing the concentrate in a location suited for natural mixing and away from vulnerable habitats [6]. Individual states have passed regulations mandating both best-use practices and mitigation efforts to minimize any potential negative consequences of brine disposal. In addition, recent studies have analyzed alternative uses for the concentrate byproducts, including the recovery of salts from the seawater concentrate [76]. Although the best practices remain site-specific, enough sustainable technologies exist to accommodate different regions.

# INSTITUTIONAL BARRIERS TO SEAWATER DESALINATION IMPLEMENTATION IN THE UNITED STATES

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## Environmental Regulations and Permits

A seawater desalination facility must abide by a wide variety of existing regulations, and a comprehensive list of relevant regulations ultimately depends on the location, technology, and concentrate management method of a particular plant. However, two national regulations, the Clean Water Act and the Safe Drinking Water Act, operate as the main legal framework for any seawater desalination facility [9].

The Clean Water Act (CWA), which was enacted in 1948 but significantly restructured in 1972, represented the first federal action addressing water pollution issues. The CWA establishes effluent discharge limits of certain pollutants and requires any discharges to obtain permits from

the EPA under the National Pollutant Discharge Elimination System (NPDES) [77]. However, desalination waste is not specifically addressed in the CWA, so the brine from a seawater desalination facility must follow the same parameters as industrial waste. In addition, specific regulations vary by region, as programs can be supervised by the states themselves [9].

Enacted in 1974, the Safe Drinking Water Act (SDWA) operates as the federal law protecting the nation's drinking water supply. The law applies to every public water system in the nation, defining a maximum contaminant level standard for over 90 contaminants [78]. In terms of seawater desalination, the facility must operate under the same regulations as any other water supplier.

Although both the CWA and the SDWA address contaminated industrial effluent rather than a high-salinity waste stream [10], these regulations ultimately dictate the necessary permits to be obtained by a desalination facility. The site-specific applications of these regulations, coupled with unique state requirements, creates variations in the type and complexity of permits required for each facility. In addition, individual permit approvals typically involve some interaction between federal, state, and local agencies [9].

Rather than the volume of permits required for each facility, the permit process itself acts as the greatest barrier to seawater desalination development. Multiple agencies may need to approve a single permit, and the relative novelty of seawater desalination in the U.S. makes regulators hesitant to issue permits. The permitting process can range anywhere between 3-8 years and cost between \$3-\$12 million [9], significantly obstructing widespread adoption of the technology. Regulations remain vital for ensuring minimal environmental harm, but the process of obtaining a permit has evolved into a tedious and complex procedure.

## Lack of Incentive

Although future water shortages are expected to affect the majority of the United States to some extent, the current water supplies of many states do not face immediate threats. Thus, these regions experience no urgent concerns and do not see a need to invest in desalinated water as a means to augment water resources. On the other hand, states foreseeing an imminent water crisis may actively pursue more cost-effective alternatives before even considering seawater desalination. The high-cost of seawater desalination remains a significant deterrent for poorer regions of the U.S., prohibiting some water-stressed districts from adopting the technology. Without some form of incentive to invest in seawater desalination, states will forgo proactive policies pursuing the integration of the technology into the water portfolio.

The research and development tax credit, which helps companies offset research and development expenditures, was recently made permanent in 2015 [79]. However, the tax policy strictly applies to research initiatives and does not aid in the construction of projects. WIFIA provides credit assistance in the form of low-cost loans for the construction of large water infrastructure projects, including desalination facilities, helping to incentivize seawater desalination implementation [80]. However, the WIFIA loan program does not incentivize the construction of smaller regional desalination facilities, as the program only funds projects surpassing a set project cost. The Drinking Water State Revolving Fund also supplies loans to help drinking water suppliers comply with the SDWA, but similar to the research and development tax credit, these loans do not help finance construction costs [81]. Thus, the United States needs to institute more diverse incentives to encourage the implementation of desalination facilities of any scale.

## Public Perception

The implementation challenges of seawater desalination extend beyond technical barriers, as the success of a desalination facility relies heavily on public opinion. A negative perception of the project can severely hinder the permitting process, and even if the concerns lack scientific support, active stakeholders maintain a strong influence over development initiatives [9]. Environmental advocacy groups and anti-growth organizations tend to function as the strongest opponents to seawater desalination. Specific concerns vary between stakeholders, but water quality, environmental impacts, and operation costs remain some of the major uncertainties [10]. Without widespread public approval, successful adoption of seawater desalination in the U.S. remains challenging.

In addition to the concerns held by the affected citizens and stakeholders, many individuals located in inland regions with ample water supplies remain unaware of the existence and potential of seawater desalination. Although these individuals are not directly influenced by seawater desalination developments, the nation's water resources operate as a highly interconnected system. Without sufficient knowledge of seawater desalination, individuals cannot voice strong opinions regarding to the implementation of the technology. Any issue impacting an entire population deserves national attention, and by not providing pertinent information to all citizens, the technology cannot be successfully incorporated into the water portfolio of the United States.

# LEGISLATIVE PROPOSALS TO FACILITATE SEAWATER DESALINATION IMPLEMENTATION

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The potential for innovative technologies to improve the overall performance of seawater desalination still exists, and the federal government must continue to support strong desalination research initiatives. To sustain a level of global competitiveness, the U.S. cannot entirely rely on other nations for novel technological achievements. However, the timeframe and overall costs associated with desalination implementation remain two of the biggest deterrents to innovation. If advancements in seawater desalination are to be recognized, then the U.S. must maintain a welcoming environment for creative ideas. Recent desalination research continues to unveil the unique potentials of seawater desalination, providing reason for the federal government to embrace new responsibilities for advancing the process. By addressing the most significant implementation barriers, the role of the federal government can realign with the strategy most effective and beneficial to the growth of the operation.

## Streamline Permitting Process

Neither the CWA or the SDWA, the two main federal water regulations, directly address desalination-specific issues. Water utilities may have to prove the facility adheres to certain standards not entirely relevant to seawater desalination, as the regulatory procedures were originally designed to monitor toxins found in municipal wastewater and industrial discharge rather than high-salinity waste streams [10]. These regulations create impediments to the permitting process, ultimately hindering the adoption of seawater desalination. However, the

CWA and SDWA, both well-established federal regulations, do not lend themselves for easy amendment. Rather than updating the existing regulations to specifically address desalination, streamlining the current permitting process exists as a more realistic solution offering timely results.

When compared to other nations actively pursuing seawater desalination, obtaining desalination permits in the U.S. remains an inefficient process. Although the regulatory systems of nations such as Israel, Australia, and Spain operate in a similar manner to the U.S. regulatory system, a study published by the Water Environment & Reuse Foundation discovered these nations demonstrated significantly shorter timeframes for issuing permits [82]. The report concluded the approaches to the permitting process, rather than the specific regulatory framework, accounted for the discrepancies in implementation success [82]. Whereas other nations operate under a streamlined process in which permit authorization involves only one or two agencies, the U.S. procedures require approval from multiple federal and state agencies to issue a single permit [83]. In turn, the length of the permitting process typically exceeds the length of construction [82]. Outlining and clarifying the current U.S. regulatory system would work to reduce the time and cost of seawater desalination development without compromising safety.

## Formulate Seawater Desalination Guidelines

Since adjustments to the legal framework are both unviable and unnecessary, improvements to the current permitting system could be achieved by developing specific seawater desalination guidelines under the existing regulations. By providing national guidance for seawater desalination practices, the government could help encourage science-based decision-making, as utilities could reference this resource during the design and planning

process. Although some general federal guidelines currently exist, no documents include any specific details to aid in successful project completion and operation [82].

All proposed seawater desalination projects in the U.S. must obtain the permits mandated by federal regulations. Due to this nationwide requirement, all utilities interested in seawater desalination would benefit from a compilation of federal desalination regulations and permits. Benefits would also arise from a description of the permit application process, the federal agencies involved, and the common issues associated with the process. However, region-specific permits must also be obtained, necessitating a section dedicated to pertinent state and local regulations, permits, and case studies.

As the research on seawater desalination technology continues to advance, the guidelines could also recommend the optimal operational practices and designs. Aside from citing the best available technology, these recommendations could also summarize the most effective monitoring procedures, including the devices to use, the chemicals and contaminants to regulate, and the frequency of testing. Parameters for analyzing the composition of desalination waste streams could outline a set of performance-based standards for desalination plants, facilitating both desalination plant design and regulatory approval by establishing general maximum limits based on salts and other contaminants typically present in the brine. Systematized monitoring protocol and reports could then allow facilities across the U.S. to be evaluated and compared in terms of ability to meet the predetermined TDS requirements.

Unofficial standards for marine salinity testing, which studies the maximum tolerance levels of the organisms in the affected ecosystems, would help ensure facilities conducted proper evaluations of the potential environmental impacts prior to plant construction. By identifying the most vulnerable organisms, specifying salinity testing equipment and procedures, and defining a

safe range for TDS concentrations in the brine, the potential impacts of a particular project could be assessed and compared to existing facilities [82]. Although marine habitats vary by region, explicit testing methodology would establish fundamental safeguards to minimize harm to marine ecosystems and ultimately facilitate the permitting process.

Additional economic research could also lend the ability to devise a comprehensive set of cost analysis criteria. The reputedly high price tag of seawater desalination remains one of the main deterrents of U.S. adoption. However, no current system exists to accurately evaluate and compare the feasibility of seawater desalination project proposals. The exact price of each facility depends heavily on the specific region, but an outline of the components warranting consideration in the cost analysis would allow seawater desalination to be compared to other water supply options. Direct costs, such as capital and operation and maintenance, represent only a portion of the complete cost-evaluation, and the product-quality, reliability, and other environmental and social factors significantly influence the feasibility of a plant. Considering both the internal and external costs of desalination plants using standardized cost analysis criteria remains vital for justifying seawater desalination adoption in a region, and evaluation of the costs in a consistent manner is crucial for legitimate comparisons and profitable conclusions.

## Create a Federal Seawater Desalination Coalition

Whereas world leaders in seawater desalination engage only a few agencies per project review, permit approval for seawater desalination facilities in the U.S. requires an extensive independent multiagency review process [82]. Either a single permit needs approval from several agencies, or multiple permits with different requirements regulate a single operation [10]. Not only do severe limitations to the rate of the permitting process occur without simultaneous

interagency collaboration, but increased difficulties with the operation and monitoring of the facility arise as a result of the various evaluation criteria.

To decrease the timeframe for permit approval, a distinct coalition could be created by assembling a set number of representatives from federal agencies, research laboratories, state water districts, nongovernmental organizations (NGOs), and various advocacy groups. The goal of the coalition would focus on facilitating communication between all relevant parties while serving as a resource for the industrial, private, and governmental sectors when issues and setbacks arise during the desalination permitting process. Communication could also be enhanced between the regulators and the applicant, as the coalition could serve to inform a specific utility of the unique permit requirements, provide site-specific design strategies to expedite the application process, and address any questions and concerns held by the utility or agencies. Fostering close collaboration between utilities, regulators, and public officials serves as a feedback loop, further encouraging more active engagement from policymakers to streamline the permitting process.

The federal coalition could also maintain the authority to approve concurrent permit applications when deemed appropriate and safe. Rather than waiting for the approval from one agency before applying for a subsequent permit, multiple permits could be sent to various agencies simultaneously. Thorough evaluation of each permit would not be compromised, but the timeframe for project approval could be substantially reduced.

## Advantages and Disadvantages

The existence and success of an efficient seawater desalination permitting process in nations with similar regulatory systems holds promise for improvements to U.S. procedures. Organizing the required permits and delineating the permitting process, a responsibility

appropriate for the EPA, would not only clarify the procedure for both regulators and utilities but also instill confidence in the individuals involved with the design and review stages of facility development. The guidelines could also establish a sense of regulatory uniformity across states, allowing for objective comparisons of facilities in terms of performance, feasibility, and sustainability. In response to these national guidelines, states may be more inclined to formulate region-specific permitting process plans to further facilitate project review. Since the guidelines would remain unbinding, the suggestions refrain from limiting the ability of states to develop site-specific regulations. Furthermore, streamlined permitting could lower costs for concentrate management practices as well as prevent legal challenges regarding data acquisition and systems analysis tactics [10].

With the existence of a federal coalition, measures could be taken to mitigate any concerns between relevant parties before the issues escalated into serious conflicts. In addition, the coalition could oversee essential research projects deemed necessary for further progress. The ADC serves as one example of the success of collaborative efforts. The coalition contributed funds and resources to a demonstration project at the Naval Desalination Research Test Facility, which ultimately recorded a record low for seawater desalination energy consumption [84]. The existence of a permanent federal coalition could foster similar achievements through the allocation of resources while also financing educational campaigns to publicize the advancements in desalination research.

Despite the appeal of a streamlined process, many challenges associated with this proposal remain. The necessary site-specific considerations produce the most challenging barrier to providing national guidelines, as the best available technologies and practices for each desalination facility will ultimately depend on the characteristics of the region. In general, more

quantitative environmental data is needed to evaluate the long-term environmental impacts of seawater desalination and provide accurate, instructive recommendations. In turn, this lack of research requires designing a strategic research plan, conducting appropriate studies, and allocating funds to the relevant research groups and organizations. Once sufficient data becomes available, reasonable operational recommendations would need to be presented as flexible guidelines compatible with existing state-specific regulations. Thus, generating a comprehensive set of information and publishing overarching guidelines becomes a time-intensive task.

Some proposed aspects of the guidelines, such as the environmental and social costs, become difficult to accurately predict and monetize. Although some methods exist for estimating the monetary values of these factors, a systemic cost analysis may still remain unfeasible [10]. Additionally, the need to develop greater desalination expertise remains before creating an effective desalination-specific coalition. Not only would experts from a wide array of professions and organizations be required to develop a working group dedicated to the operation, but a large amount of funding would be needed to support the new coalition.

Ideally, a streamlined permitting process would serve to ensure a basic level of safety and performance without altering the regulatory framework of the nation. The successful execution of a streamlined process in the advanced seawater desalination nations can largely be attributed to their immediate need for an additional water source. The potential benefits from seawater desalination integration remain less obvious in the United States, delaying any initiatives addressing the inefficiencies of the permitting process. In addition, extensive collaboration between federal agencies would be necessary to avoid jurisdictional boundary issues [10], and the degree of agency participation depends on the value placed on seawater desalination. The discrepancy in desalination priority levels between the U.S. and other nations, coupled with

intense U.S. environmental regulations, could lead to additional permitting challenges not faced by the nations operating under a more efficient system. Although the immediate creation of a permanent federal desalination coalition would not be easily justifiable, the EPA is currently equipped to handle the task of formulating national seawater desalination guidelines. However, the intimidating size and time-commitment of these guidelines deters any federal action until seawater desalination is designated as a national priority.

## Stimulate an Interest in Desalination Investment

The federal government typically chooses between two options when promoting the adoption of a technology or process: establish a mandate or provide incentives. A federal law instructing states to obtain a certain percentage of their water portfolio from seawater desalination would ensure cooperation, but the lack of seawater desalination experience in the U.S. constitutes a need for incentives, rather than mandates, to stimulate more widespread adoption.

### Tax-Credit Bonds

Infrastructure developments typically qualify as large expenditures, requiring a significant amount of funds to initiate and support the projects. When banks cannot finance the entirety of the enterprise, bonds can be issued by governments or corporations involved in the development. A bond essentially operates as a means for these institutions to borrow money; the borrowing entity issues a bond, individual investors lend their money by purchasing the bond, and the issuer provides interest payments to the investor in return for the borrowed money [85].

Tax-exempt bonds constitute the conventional bond in which the issuer pays interest to the investor [86]. The construction cost of the Carlsbad Desalination Plant in California, in

conjunction with assistance from a private investor, was financed with tax-exempt bonds issued by state and regional water authorities [87]. Although the tax-exempt bonds contributed to the successful construction of the facility, tax-credit bonds could also prove useful for encouraging desalination adoption. Rather than the issuer paying interest, the federal government would pay a tax-credit to the investor, directly reducing federal taxes for the bondholder [86].

During the 111<sup>th</sup> Congress, the New Water Supply Coalition, a national organization focused on the development of desalination plants and other water projects, proposed the Clean Renewable Water Supply Bonds bill. The legislation granted local government agencies the ability to sell tax-credit bonds to finance construction of water infrastructure developments [88]. Although the bill never passed, the legislation outlined a potential incentive for stimulating investments in seawater desalination implementation.

## Investment Tax-Credits

Instead of issuing tax-credits in the form of bonds, the federal government could also provide investment tax-credits (ITCs) to incentivize investments in the seawater desalination industry. Whereas tax-credit bonds would be issued to acquire the necessary funds for the construction of the desalination plant, investment tax-credits would work to stimulate private-sector financing by providing a tax-credit to entities who invest in desalination projects [87], ultimately reducing the amount of taxes owed by the investor.

An ITC for solar energy is already in place and grants a 30% federal tax credit for solar systems on residential, commercial, and utility properties. This ITC applies to entities who invest in solar technologies as well as businesses who develop and finance solar projects [89]. A similar incentive system could be applied to desalination developments, attracting private investors to the desalination industry and encouraging investments in desalination technologies.

## Advantages and Disadvantages

Providing investment incentives remains a viable approach to stimulate the implementation of seawater desalination in coastal states not experiencing an immediate water crisis. Tax-credit bonds would help offset the intimidating construction costs of a seawater desalination facility, encouraging state and local water authorities to consider seawater desalination as a practical option for supplementing the current water supply. In addition, poorer districts facing impending water shortages could formulate plans to integrate seawater desalination into their future water portfolios. In agreement with the legislation proposed by the New Water Supply Coalition, the regional organizations would hold the authority to sell the tax-credit bonds and thus directly obtain the necessary funds. Both the states and the citizens would benefit from tax-credit bonds, as the states would retain control of the project development while the citizens received the federal tax reductions.

Although the idea of tax-credit bonds warrants some merit, passing bond legislation remains a timely and arduous process. In addition, public bonds typically must finance the entire process, as the constraints of the policies usually do not allow for assistance from private investments [87]. Consequently, tax-credit bonds may not be the most efficient means of incentivizing seawater desalination implementation.

The existence of the solar ITC provides promise for desalination ITCs. Since the creation of the solar ITC in 2005, the U.S. has seen a significant increase in solar energy installments at both the residential and utility scale [89]. The success of this tax policy instills a sense of optimism for the formation of a similar desalination tax policy to spur private-sector financing of desalination projects, especially for smaller facilities not eligible for WIFIA loans. Water infrastructure projects will remain large endeavors, so successful developments necessitate

assistance from private investors. A diverse investment portfolio would then minimize the risks associated with projects funded by one main entity.

Although the need for an additional water supply is an indisputable and nonpartisan issue, the tactics used to address the situation will be favored by different political ideologies. A more liberal approach would prefer government actions to mandate and regulate the installment of desalination facilities, while a more conservative approach would prefer to incentivize development and spur private investments. Thus, the feasibility of instituting an investment tax-credit for desalination projects largely depends on the majority party.

## Enhance Expertise and Foster Communication

The relative novelty of seawater desalination in the United States and the lack of initiatives to facilitate adoption of the technology have resulted in a deficit of desalination experts engaged in the implementation process [82]. In addition, many advocacy groups and affected stakeholders still hold invalid concerns regarding the impacts of seawater desalination. Advancing seawater desalination in the U.S. remains a collaborative process between public officials, NGOs, regulators, and stakeholders, and strengthening the relationships between all levels of the desalination community enables more opportunities for success.

## Interagency Collaboration

Many distinct federal agencies engage in desalination regulation, funding, and research, and benefits would accrue by mandating interagency collaboration. Through regularly scheduled conferences, relevant parties could remain educated on recent studies and findings, eliminating any research redundancies. In turn, each agency capable of supplying funding could better

inform research groups and independent scientists about available funding opportunities, current research initiatives, and the most promising design, management, and operation practices.

## Operator-Regulator Understanding

In addition to a federal desalination coalition, professional workshops and conferences could help enhance the overall understanding of the challenges faced by utilities and regulators. Rather than focusing on a specific seawater desalination project, the assemblies would work to eliminate any misconceptions held by the two communities, informing regulators about the technical aspects of desalination and utilities about the permitting process. Encouraging proactive and direct interactions would elevate the general desalination expertise within these two different industries and facilitate the adoption process.

## Public Awareness

As previously mentioned, public support for desalination remains crucial for a successful project. Although the wide variety of stakeholders inevitably leads to a myriad of concerns, the key issues typically stem from only a few major themes [10]. Public forums, focusing on either a specific facility and the general desalination process, would allow affected citizens to effectively voice concerns to both elected officials and utilities from the onset of development. In turn, desalination proponents would have the opportunity to refute any unsupported claims, reassure the public of the measures taken to minimize costs and environmental impacts, and emphasize some of the less obvious benefits of seawater desalination. Justifying the need for a diverse water portfolio would garner public support, and open communication between producers and consumers provides an opportunity for elected-officials to articulate this point. Rather than solely

educating the public, forums would serve to build relationships with stakeholders, creating opportunities to advance seawater desalination implementation.

## International Partnerships

Advanced seawater desalination nations, including Australia, Spain, and Israel, exhibit a level of desalination expertise unparalleled in the United States, and the persistent promotion of seawater desalination in these nations has been responsible for much of the experienced success. The accomplishments extend past the implementation of large-scale seawater desalination facilities, as these nations all took unprecedented steps to ensure sustainable operational practices. Many similarities exist between the regulatory systems of Australia, Europe, and the United States; however, the permitting process in Australia and Europe functions with much higher efficiency [82]. Initiating interactions between these nations to learn from their success could inform the U.S. of methods for reducing the time and cost of seawater desalination implementation and operation. The federal government maintains both the extensive network and necessary resources to foster communication on an international-scale, and since the U.S. does not currently spearhead the seawater desalination movement, recognizing and evaluating the achievements of allies remains imperative to ensure global competitiveness.

## Advantages and Disadvantages

As previously mentioned, instilling a positive public image of seawater desalination better ensures the success of a project, and individuals remain more likely to display support once issues are well-understood. The federal government maintains the necessary resources to provide outreach opportunities and foster communication on both a national and international scale. Through community-engagement programs, the undervalued and overlooked benefits of

seawater desalination, such as drought resilience and reliability, can be reinforced to the public [10]. Aside from fostering a greater appreciation for seawater desalination, enhanced communication between federal agencies, utilities, citizens, and elected officials would indirectly aid in streamlining the permitting process by instilling a deeper understanding of the technological and institutional considerations. Thus, a high-level of expertise remains desirable among all parties affiliated with the planning, construction, and operation of a desalination facility.

To maximize the success of these efforts, the relevant parties cannot demonstrate resistance to the educational opportunities. Individuals and agencies must recognize the importance of seawater desalination before the entities allocate time for workshops and forums. The severe water shortages experienced in the advanced seawater desalination nations led to the prioritization of the technique, eventually cultivating the necessary level of expertise. Thus, the current lack of interest in seawater desalination in the U.S. could create some resistance to collaborative efforts.

Even if seawater desalination gains notable recognition, substantial time and money must be allocated to establish a desirable level of expertise. Agencies will demand funding to arrange the opportunities for information exchange, and professional workshops require both financial resources and collaborative planning. Elected-officials, regulators, or utility managers may not be willing to sacrifice time to attend educational meetings if the assemblies do not possess any obvious benefits. Similarly, citizens or other stakeholders may not attend the public forums if they believe their opinions and concerns will remain insignificant or unaddressed. Thus, resource limitations and negative preconceptions hinder the success of educational gatherings and awareness campaigns.

The desire to educate the national population justifies a level of involvement from the federal government. Again, the ability to list seawater desalination among the national priorities remains imperative for success. In addition, agencies, utilities, and stakeholders must demonstrate a commitment to collaboration, as a complete investment in seawater desalination would require input and assistance from all sectors. Transforming seawater desalination into a priority would be driven by the spread of information about the operation through meaningful interactions between various parties.

## CONCLUSIONS AND RECOMMENDATIONS

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Ultimately, the efficiency and sustainability of seawater desalination technology must improve to allow widespread commercialization of the process. However, promising advancements in both U.S. desalination research and global desalination developments indicate a promising future for greater integration of the technology. As the price of conventional water resources continues to increase, some regions of the U.S. have already incorporated the technique into their water portfolios [10]. While continuing support and focus should remain largely devoted to basic research and environmental assessments, comprehensive evaluations of the technology require full-scale applications. Thus, measures must be taken to facilitate the implementation of seawater desalination facilities in the United States.

Unlike the advanced seawater desalination countries in the Middle East and other regions of the world, the U.S. does not immediately need widespread implementation. Many regions currently experience an adequate supply of water, and some efforts have been directed toward water reuse and recycling. However, climate change and a growing population will continue to

strain the national water supply, placing a large burden on the current water resources and creating a need to augment the freshwater reserves. While seawater desalination technology continues to mature, initiatives must be enacted to facilitate the incorporation of seawater desalination into the water portfolio of the United States.

First and foremost, prioritizing seawater desalination implementation remains the most valuable and efficient means of ensuring success. The nationwide benefits of the technology need to be articulated by stressing the realities of a future without any contribution from seawater desalination. Recognizing the vital role of seawater desalination in the water supply begins with developing a level of desalination expertise in the agencies involved with implementation as well as among the general stakeholders directly impacted by the technology. Weaknesses arise from a lack of true understanding of the process, limiting the potential for desalination to serve as a solution to the water crisis. Once seawater desalination becomes recognized as a necessary component of the water portfolio, the heterogeneity of the technique needs to be reduced within the United States. Although seawater desalination will likely always remain highly site-specific, adequate research will allow for standardization of some core elements of the process.

A nationwide appreciation for seawater desalination will most likely come in the form of incentives. States currently experiencing strains on traditional water resources, such as California, Texas, and Florida, have already begun to invest in diverse water portfolios. Thus, these initiatives must receive federal encouragement through improvements to the seawater desalination institutional system. However, states lacking interest in desalination implementation need to be incentivized to invest in the technology. One of the most reasonable options would be to provide a desalination ITC. In order to initiate an ITC policy, the federal government must first incorporate desalination equipment and projects into the Internal Revenue Code's

investment credit category [87]. The desalination ITC could then be formed and enacted using the solar ITC as an outline. As previously mentioned, the U.S. is not currently equipped to handle a desalination-related mandate, but once the technology develops greater maturity, the federal government may find imposing water portfolio mandates appropriate.

To successfully incorporate seawater desalination into the national water supply, both general guidelines and greater overall expertise must be developed. In the long-run, enough information may exist to formulate comprehensive federal seawater desalination guidelines that work to streamline the permitting process while maintaining regulatory measures. Until the necessary information is obtained, the federal government should work to encourage various states to develop region-specific guidelines to aid the areas actively pursuing seawater desalination. Eventually, a compilation of these guidelines could be condensed and summarized in the federal seawater desalination guidelines.

Reaching the level of seawater desalination expertise apparent in advanced seawater desalination countries will take time, but an extensive familiarity with the technique should be viewed as the ultimate goal. Although not every stakeholder can be educated immediately, the federal government should begin to take measures toward the desired objective. By suggesting regional governments hold public forums, the most affected citizens can begin to become better informed on desalination. In addition, a national workshop for all affiliated parties should be initiated to assess the current state of the technology and identify the most problematic aspects of implementation. As these forums become more popular, federal government personnel can engage in both the local and national discussions.

Waiting for a crisis to ensue is not a sustainable management practice, and the need for a consistent and reliable water supply will not disappear. The impending water shortage must be

addressed, and the U.S. could significantly benefit from utilizing the ocean as a supplemental resource. As various states begin to express interest in seawater desalination, the federal government must assume a greater role in the development and integration of the technology into society. Freshwater will always remain integral to every functioning civilization, and greater diversity within the national water portfolio ensures a more stable water supply and a more stable future.

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