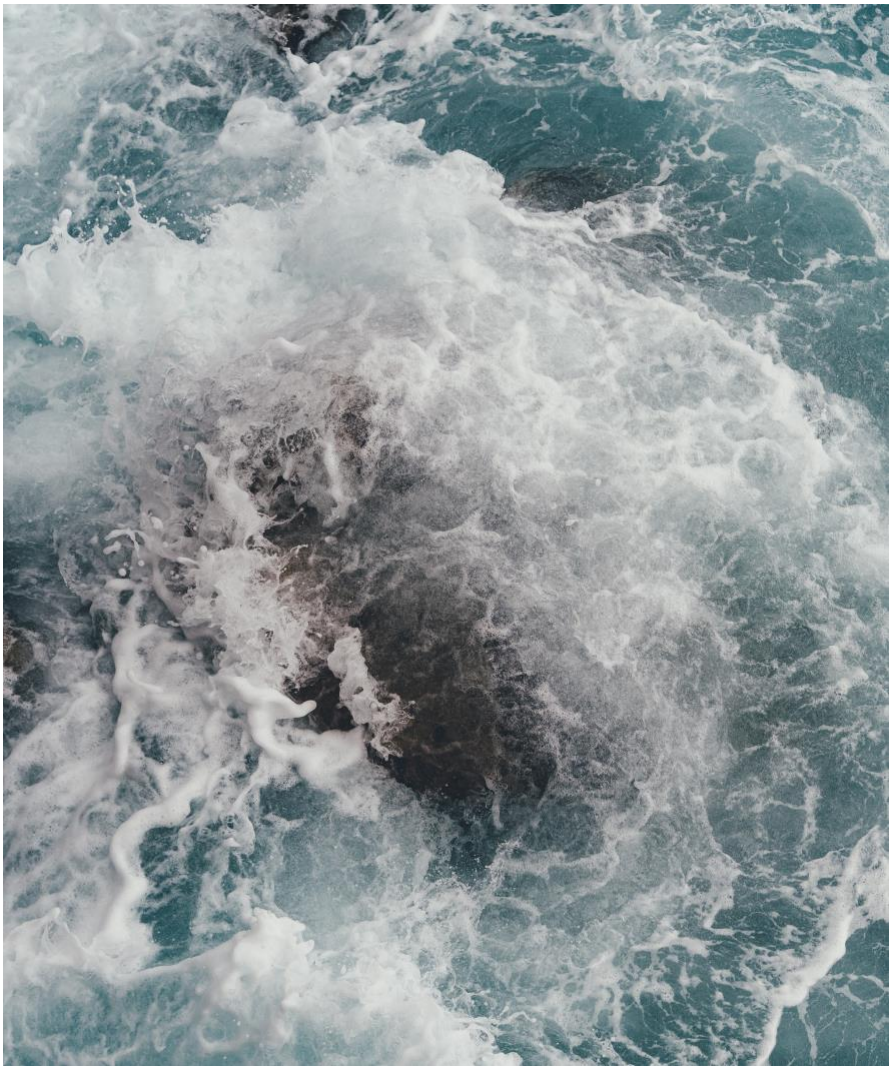
Desalination



https://unsplash.com/photos/3bduYlHnUll

By Karen Gomez
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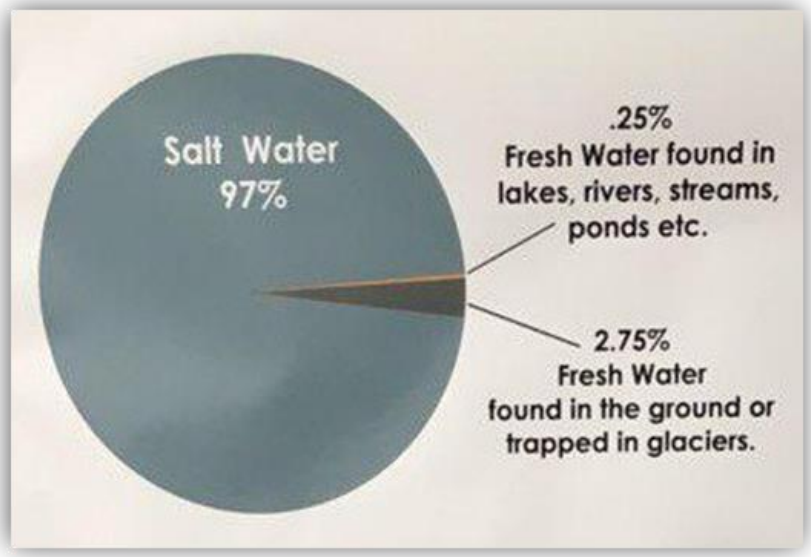
Desalination: From Poison to Potable

Water is one of the most important natural resources for all species on Earth. Without a stable supply of clean water, ecosystems can't survive. But beyond the most obvious importance, water is also crucial for sustainable development and critical for socio-economic growth, energy, and food production.

Earth is mainly composed of water, but only a small percentage of it is suitable for human consumption. Saltwater in the world's oceans and seas make up around 97% of the world's water. Only 2.75% of the world's water supply is freshwater, which is found under the ground and in glaciers. The other 0.25% of the world's water supply is freshwater found in lakes, rivers, streams, and ponds. At first glance, one can see that the planet's freshwater is not sufficient to supply the world's population, and that supply has been shrinking in recent decades due to a marked increase in the global population, growing consumption, unchecked land development, and the adverse effects of climate change.



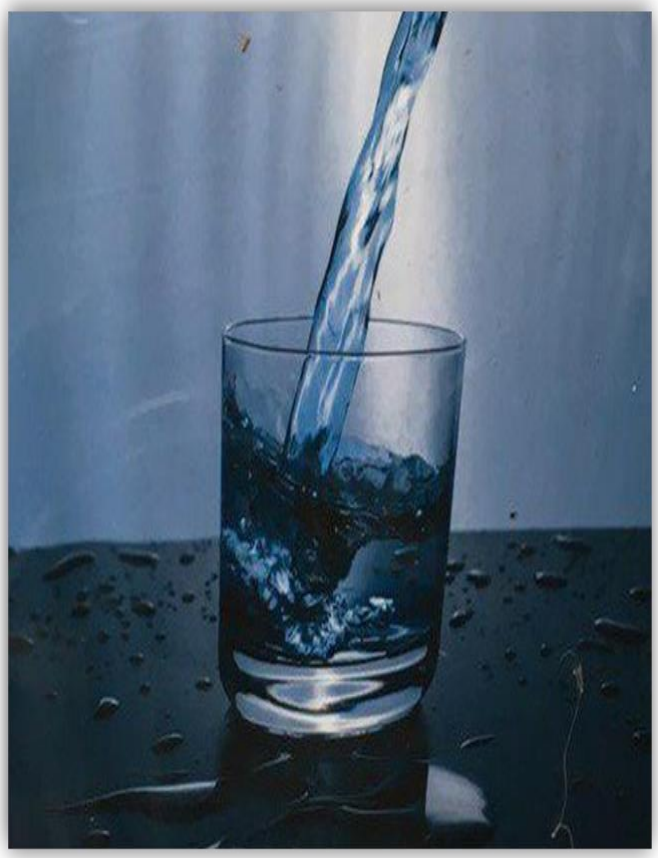
https://blog.dhigroup.com/2020/01/28/an-expert-perspective-discovering-the-importance-of-early-warning-systems-in-drought-management/

Devastating meteorological phenomena are among the worst consequences of climate change. Hurricanes, cyclones, rainstorms, floods, and droughts are more common, longer-lasting, and more severe than in previous centuries. In recent years, historic droughts have devastated various regions of the world. For example, in 2018, Afghanistan suffered a prolonged drought that destroyed crops in much of the country. According to data from the United Nations, this drought forced about 260,000 Afghans to flee their homes. In the Horn of Africa, four periods of extreme drought have been reported since the beginning of this century,

The Oxford Committee for Famine Relief (Oxfam) reports that the last drought, which occurred in 2017, left around 7.6 million people at risk of extreme hunger and endangered the lives of 15 million of the region's citizens. In 2018, an unprecedented drought in Australia caused massive crop die-offs. Kangaroos,

the country's national symbol, invaded agricultural farms in search of food and water. The Australian government had no choice but to authorize farmers to shoot the animals if necessary. That same year, droughts also occurred in the less arid areas of Europe. While the rain caused an unusually humid summer in the Mediterranean, high temperatures parched much of Northern Europe.

In the United States, significant dry spells have also been reported. In 2011, Texas had its driest year since 1985. From 2012 to 2016, California had the lowest period of rainfall in recorded history. Experts say that it was the most serious drought in the last century. The drought caused significant economic losses to the agricultural sector, drastically reduced the state's supply of drinking water, and reduced California's capacity to generate electricity.



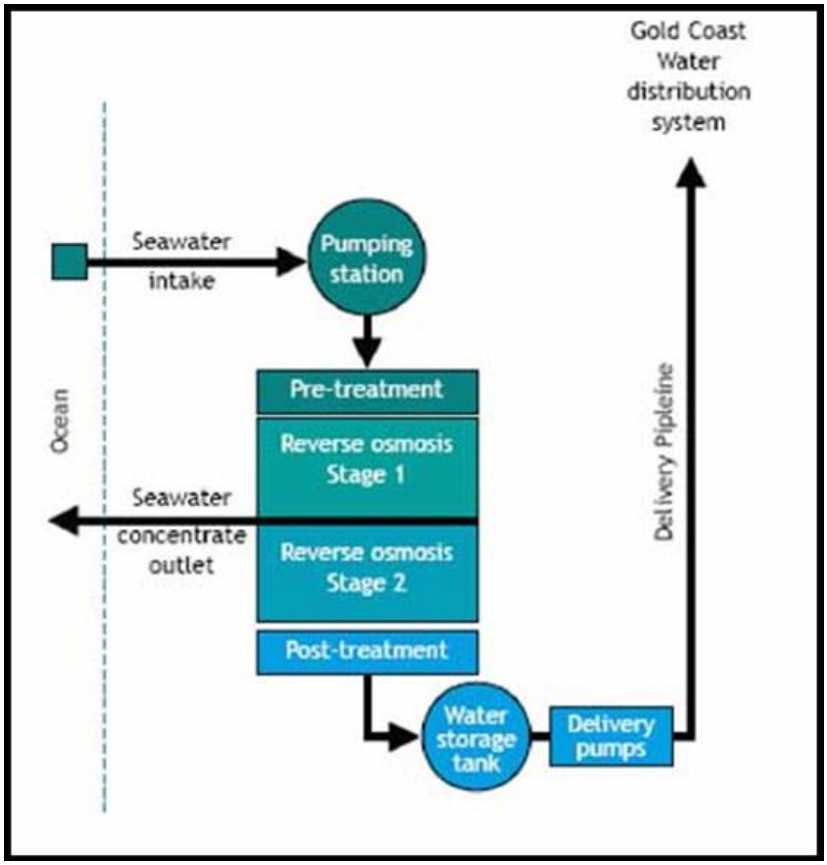
Water scarcity is a global issue. A shortage of drinking water affects approximately 40% of all inhabitants. According to United Nations and World Bank predictions, a lack of water could worsen by 2030 and leave 700 million people at risk of displacement. According to the UN, insufficient access to quality drinking water causes 780,000 global deaths annually. Water demand will increase 20% to 30% by 2050 due to population growth, economic development, and increased consumption. These water shortages could exacerbate political conflicts, and the third world war could be fought over water.

To avoid these dire possibilities, we must find alternative sources of water. Our priority must be avoiding a shortage of drinking water and preventing crises in industrial sectors and ecological ecosystems.

The High Costs of Desalination

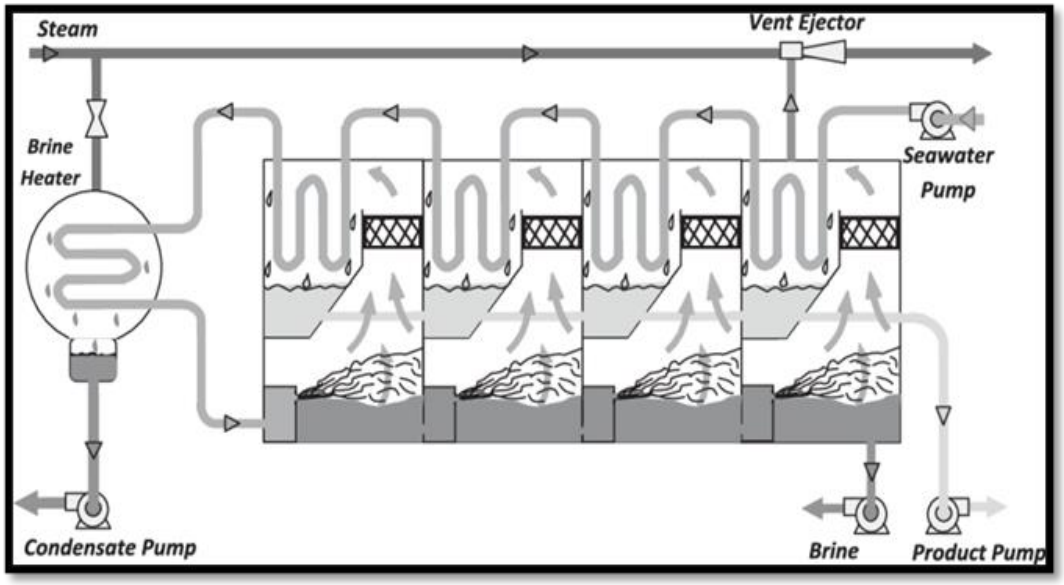
One of the most promising methods to address these potential crises is seawater desalination, which involves removing the mineral salts from the water, making it suitable for human consumption. Several processes have been explored, including:

- Reverse osmosis (RO): This process is the most widespread and advanced. It involves using pressure to force the water through a membrane, moving the water from a high salt concentration to a low salt concentration.



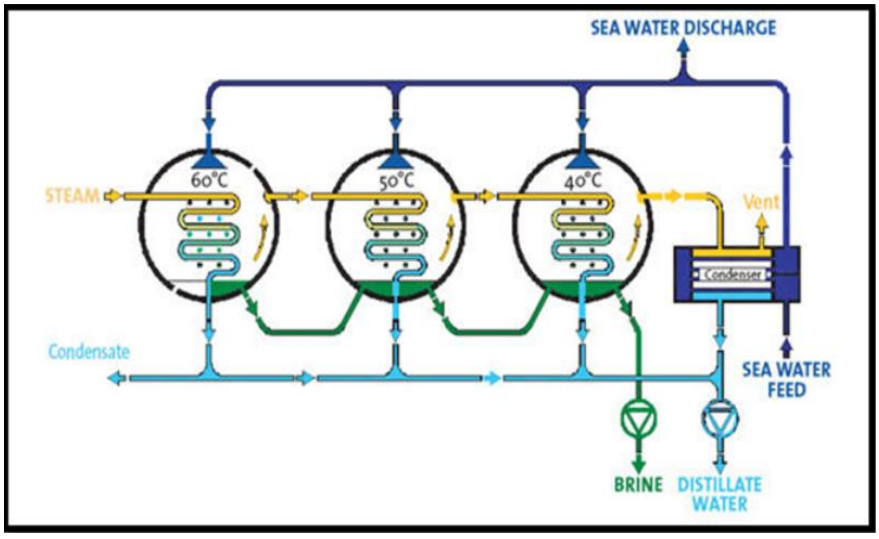
Seawater Reverse Osmosis Desalination Process
Source: https://www.interempresas.net/Quimica/Articulos/23632-La-importancia-de-la-seguridad-en-desalacion.html

- Multi-stage flash distillation (MSF): This process is carried out in successive stages. Seawater is first distilled, and the resulting steam is condensed. Latent heat evaporates the water, which is then desalinated.



Sea Water Multi-Stage Flash Distillation Process
Source: https://www.researchgate.net/figure/The-principle-of-the-multi-stage-flash-distillation-MSF-adapted-from-Ref-21_fig3_223107551

- Multi-effect thermal distillation (MED): This process uses the same principle as multi-stage flash distillation (MSF). The fundamental difference lies in the evaporation process, which involves evaporation in successive stages. In the first stage, evaporation is fed by external steam. In the rest of the stages, the heat of the condensation used in the previous stage is re-used, and the temperature of the seawater rises to the temperature of the feed steam.



Multi-Effect Thermal Distillation Process
Source: https://www.veoliawatertechnologies.com/en/technologies/multiple-effect-distillation-med

Although desalination looks like a promising way to supply cities with potable water, this process has some downsides that can't be ignored. It's expensive to build and operate desalination plants, the process is energy-intensive, the salt byproduct must be disposed of, and the required regulations and permits can be onerous (Lee, 2019).

Source: https://time.com/3625511/this-plant-in-dubai-makes-half-a-billion-gallons-of-fresh-water-a-day/

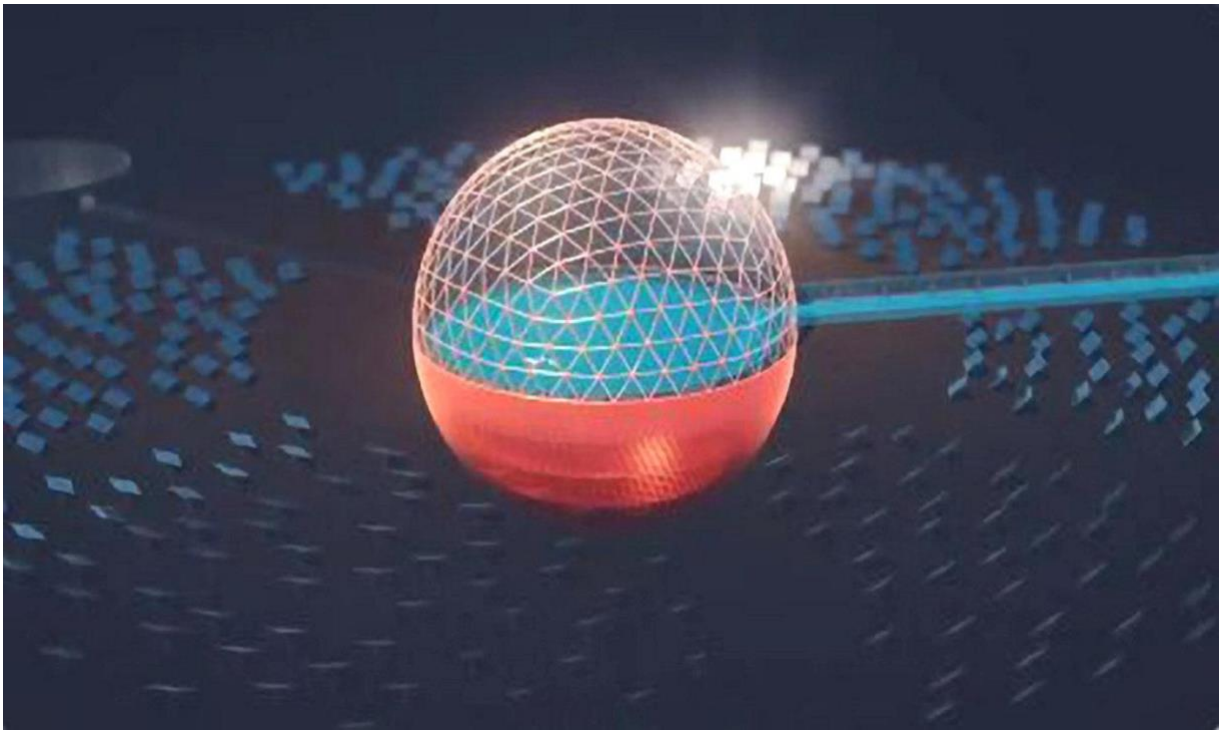
Because the initial costs for building desalination plants are quite high, this isn't a feasible solution for many countries. Most reverse osmosis plants take three to ten kilowatt-hours of energy to produce one meter of freshwater from seawater. Traditional drinking water treatment plants typically use well under one kWh per cubic meter (Bienkowski, 2015). The energy needed to create the electricity for this process mainly comes from fossil fuels, which contributes to climate change.

A desalination plant's energy consumption depends on many factors, including the desalination technique, the concentration of salt in the water, the temperature of the feedwater, the plant's capacity, the location of the source water, and the concentration of the salt in the discharge. Many are trying to improve the energy consumption required for the desalination process. Co-located plants, co-generation plants, and hybrid plants could increase the efficiency of desalination (Lee and Younos, 2019).

Solar Powered desalination plant by thermosolar in Oman
Source: http://www.climasouth.eu/en/node/448

Various organizations around the world are developing desalination plants that are powered by renewable energy. Australia and some countries in the Middle East are already using large-scale solar-powered desalination plants, the most widely explored renewable energy option. Organizations are also exploring renewable energy sources like wind, wave, and geothermal energy, but solar power is widely regarded as the most promising long-term option for sustainable desalination.

Studies in France have demonstrated that photovoltaic-powered desalination plants without storage are the cheapest option, and they will likely remain so until at least 2030. But photovoltaic-concentrated solar power technologies may play an important role in the construction of RO desalination plants in the near future (Hutchings, 2020).



South Arabia Solar Dome to desalinate water in Neom
Source: https://www.thenationalnews.com/business/energy/saudi-arabia-plans-to-use-solar-dome-to-desalinate-water-in-neom-1.971945

The most innovative solar-powered desalination plant is the prototype solar dome, announced in Saudi Arabia in 2020. The process used at the plant promises to be more environmentally friendly than reverse osmosis and other methods. This pioneering plant is composed of a glass dome surrounded by reflectors that focus the solar radiation around it. The heat is transferred to the seawater that flows into the dome, and after the water evaporates, it condenses as freshwater. This technology requires less money and time for carbon-neutral construction, and it doesn't require fibers that take 400 years to decompose (CNN, 2021).

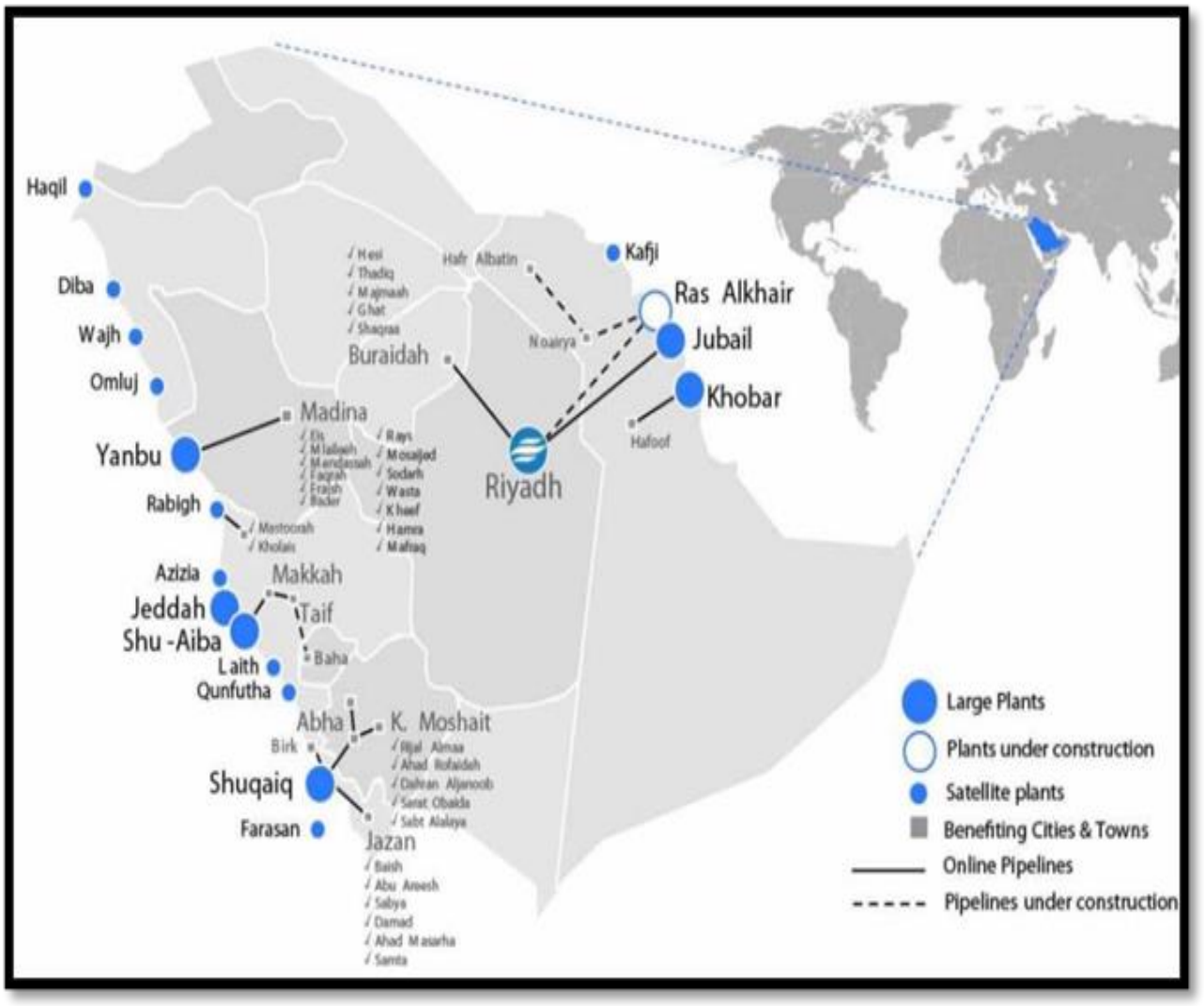
Saudi Arabia

The kingdom of Saudi Arabia is the largest country on the Arabian Peninsula. Considerably more than half of its territory is arid, and the country has no permanent rivers. Its lakes, oases, and underground water sources aren't sufficient to supply the country's population with drinking water. Precipitation is also low throughout the year, and temperatures can rise to 130° F in the summer.

Source: https://www.britannica.com/place/Saudi-Arabia

These harsh conditions pose significant challenges for supplying the population with a stable source of drinking water. The country has one of the world's lowest per-capita supplies of drinking water, but it is also one of the wealthiest nations in the world, and it has the resources necessary to become a pioneer in seawater desalination.

Saudi Arabia has thirty-five desalination plants around the country to supply its population. These plants supply the country with 6.85 million cubic meters of water every day, which represents 18% of the world's production of desalinated water, making Saudi Arabia the world's leader in desalination. The most widely used technology is reverse osmosis, employed in fourteen of the plants. Multi-stage flash distillation (MSF) technology is used in thirteen plants, and multi-effect (MED) is used in eight plants (Iagua, 2020).



Source: https://twitter.com/FirasMaksad/status/1141549399841095680/photo/1

Los Cabos

Located in Baja California Sur Mexico, Los Cabos is a paradise with amazing beaches, deserts, and mountains. Los Cabos is made of two cities: San Jose del Cabo and Cabo San Lucas, which are connected by the tourist corridor. It's a tourist destination that boasts luxurious resorts surrounded by the Pacific Ocean and Mar Cortes. It's a semi-dry desert with an average annual temperature of 78.8° F (26° C). Rainfall is scarce in the region.

Source: https://www.visitloscabos.travel/industry/tools/maps-and-directions/

Los Cabos has a limited source of drinkable water, and as the economy of Los Cabos grows, so does the scarcity of water. To address the problem, the water authority has adopted intermittent restrictive measures to ensure that it can continue supplying its population with drinking water. But the cities have access to a significant amount of saltwater, and desalination is a possible solution to the region's water scarcity. There are few desalination plants in the region, however.

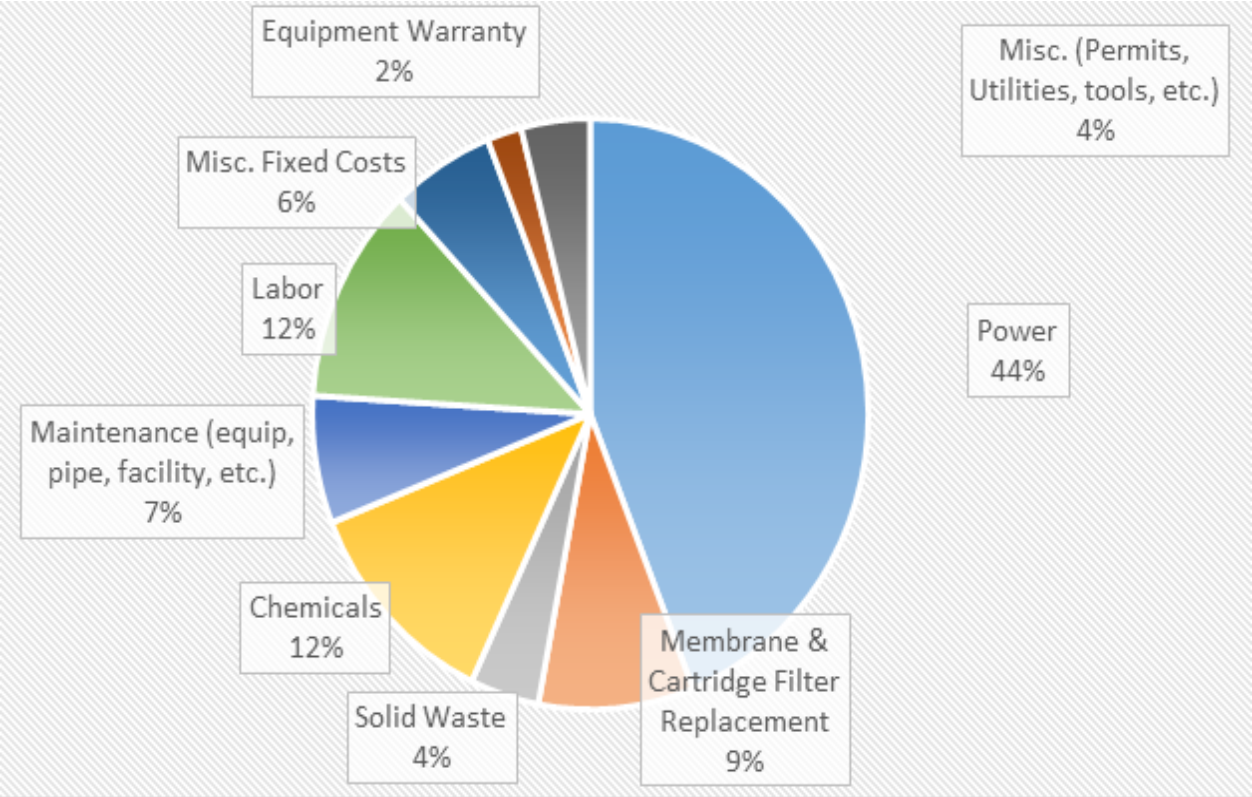
Source: https://gringogazette.com/wp/2021/05/los-cabos-new-desal-plant-bid-awarded/

One particularly important project in progress promises to supply fresh water to a significant percentage of the region's population. This new facility will use efficient reverse osmosis technology that will be less energy intensive and will emit 6.5 times less greenhouse gases than conventional thermal desalination. Once completed, the facility will have the capacity to desalinate 250 liters of saltwater per second or 7.9 million cubic meters per year.

Smart Solutions

Hoping to streamline the desalination process to make it economically feasible for a greater number of cities and countries, industry leaders are exploring solutions to the most vexing challenges, including the high cost of facility construction and operation, the high energy consumption, the disposal of the salt byproduct, and the burdensome regulation and permitting process. These difficulties could act as barriers to desalination, and industry leaders must address each one to meet the water needs of a growing global population.

The operational costs for most desalination plants typically fall into one of nine categories: power consumption, consumables, solid waste disposal, purchase of chemicals, labor, maintenance, equipment warranty, the balance of the plant and utilities, and other fixed costs (e.g., administration expenses, spare parts, contingencies.)



Typical seawater reverse osmosis (SWRO) plant operation costs breakdown
Source: https://www.advisian.com/en/global-perspectives/the-cost-of-desalination

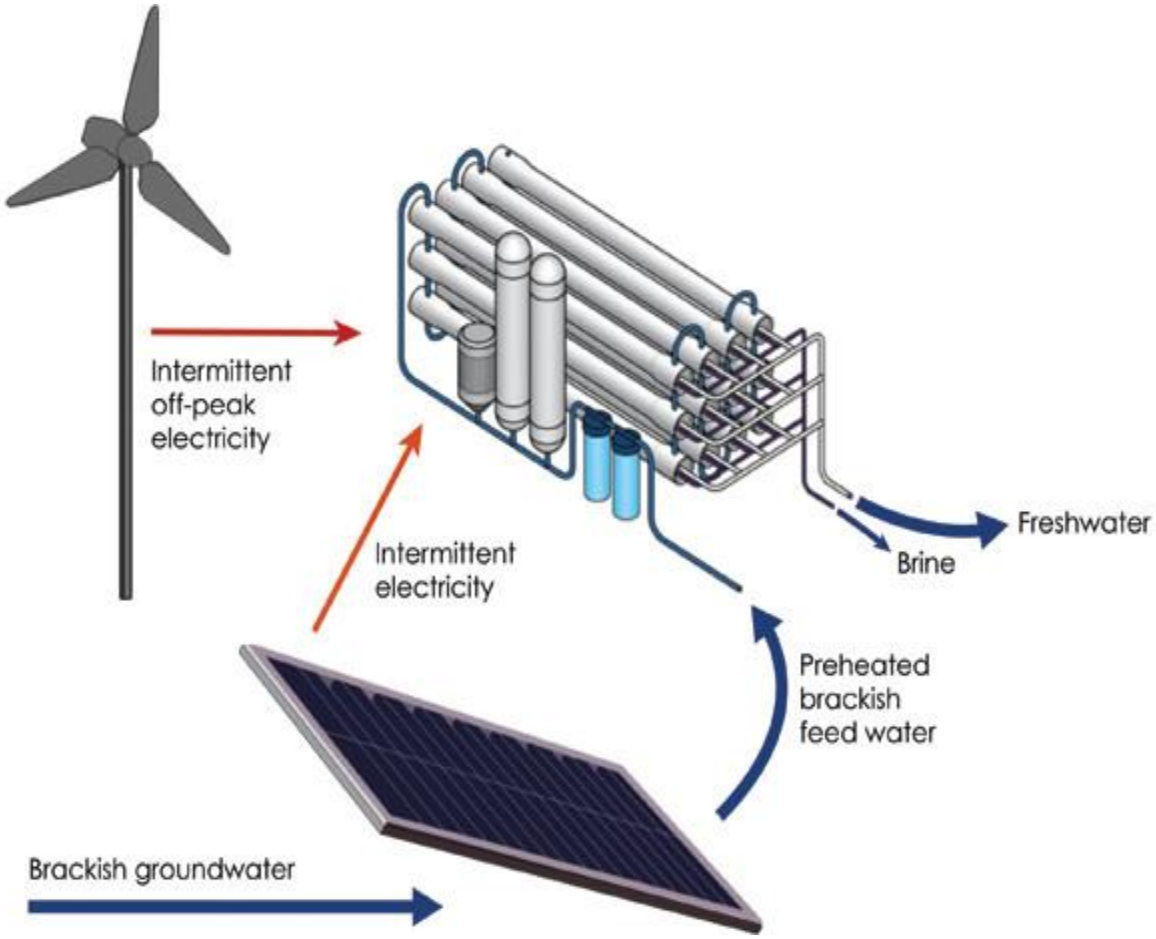
Generally speaking, desalination costs are impacted by the type of technology, the quality of the saltwater and the final product, the type of intake and outfall, the location of the plant or project, the type of energy recovery, the price of electricity, post-treatment needs, storage, distribution, local infrastructure costs, and environmental regulations. The technology that the plant's builders select will also determine the type of chemicals that they will use for pretreatment and post-treatment, which impact operational costs.

In order to make desalination affordable, industry leaders must consider all these factors together, but some of them have more workable solutions than others. The location of the facility can have a major impact on the overall cost of the plant, and the plant should be located as close to the seawater intake source as possible to avoid higher costs for the construction of intake pipelines and complex intake structures.

Source: https://idadesal.org/saudi-arabias-mobile-desalination-plants-achieving-a-new-world-record-2-27-kw-per-cubic-meter-lowest-energy-consumption/

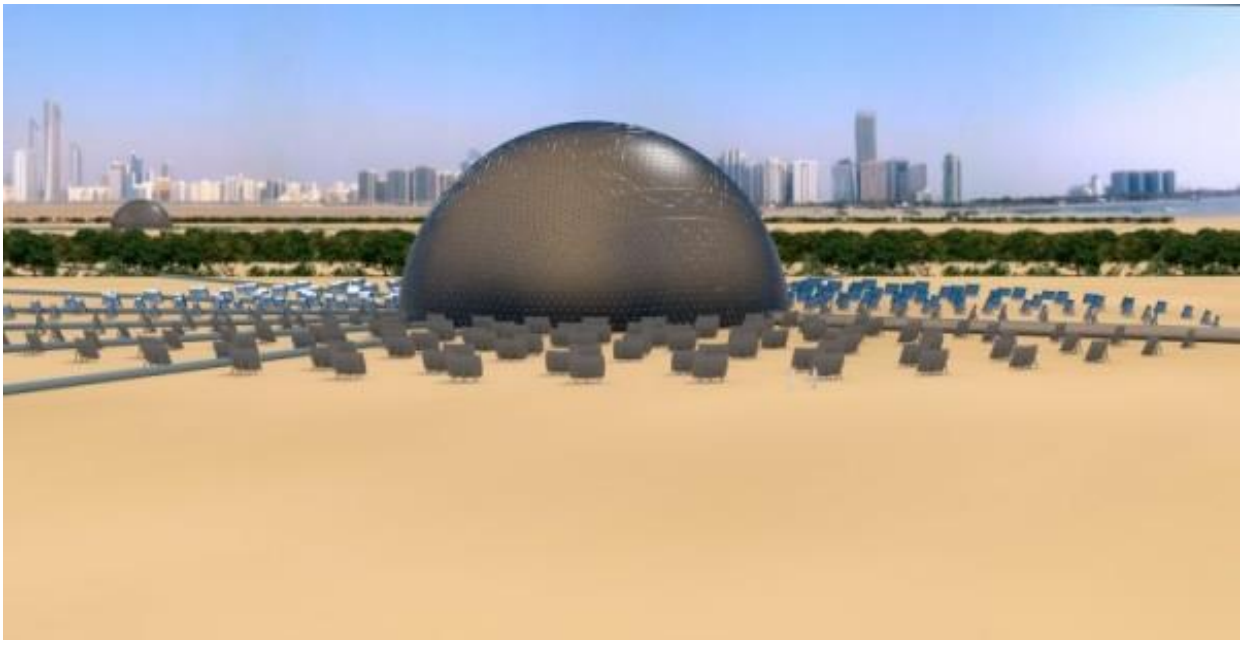
Desalination costs are directly linked to a plant's energy use, but reverse osmosis technology promises to make desalination more affordable because it reduces the amount of energy required for the process. The type of membrane used in the process determines how much energy a plant must use. Improved seawater reverse osmosis (SWRO) membranes reduce costs through high-fouling resistance, increased productivity and rejection, and improved cleanability (Markus & Mikols, 2014).

One of the most promising proposed solutions is focused on reducing energy losses associated with feeding the pump and motor, permeating the water through the membrane, and pressurizing the brine. SWRO plants can reduce their energy consumption and costs by using energy-efficient equipment that meets the combined needs for energy efficiency, reliability, and performance (Flowserve, 2020).



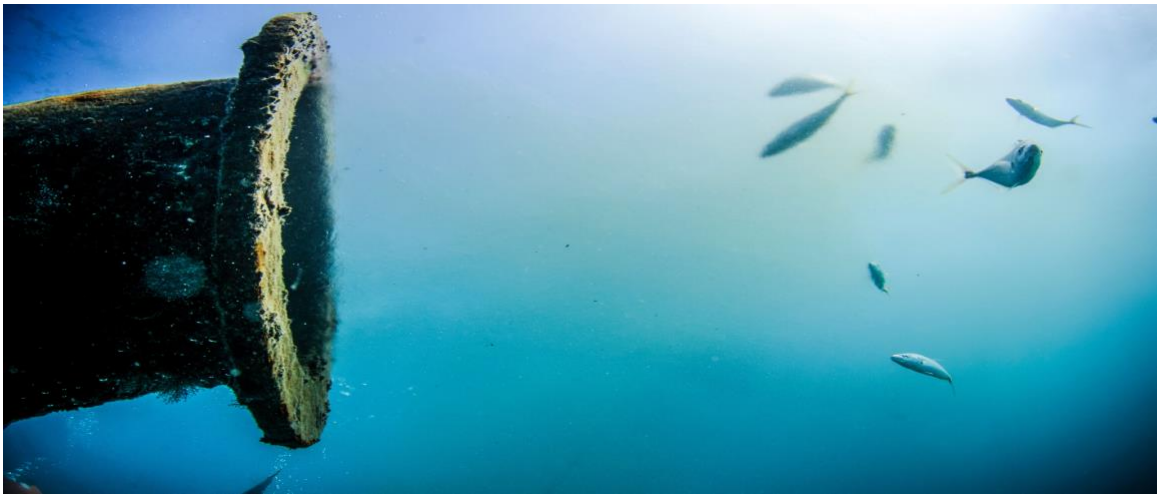
Renewable energy presents an opportunity to reduce off-peak electricity and waste heat
Source: Ccsf.edu/myccsf/can renewable energy and desalination tackle two problems at once?

Hybrid plants are another solution for reducing costs and energy usage. Such plants combine desalination with renewable energy sources that allow operators to produce drinking water without increasing our dependence on fossil fuels. One important advantage of these hybrid plants is that they can resolve the intermittency issues of wind and solar because the consumption can be dialed up or down to match the supply of electricity.



Solar dome desalination system – Neom, Saudi Arabia
Source: https://www.thecivilengineer.org/news-center/latest-news/item/1465-the-solar-dome-desalination-system

Solar desalination is another innovative technology that promises not only to reduce costs but also to decrease the environmental impact caused by the use of fossil fuels. Saudi Arabia is already constructing plants that use the technology, and when the facility is finished, it will be able to provide drinking water that requires almost no energy besides solar radiation. The energy required for maintenance and operation will be significantly lower than other technologies, but the facility needs an ideal environment and much space to be efficient.



Source: https://chinadialogueocean.net/6347-waste-brine-ecological-problem-economic-opportunity/

The brine discharge produced at the end of desalination is one of the most harmful byproducts of the process. It has a profound impact on marine life. The International Center for Biosaline Agriculture in Dubai has researched alternatives to reduce this impact of the brine. The researchers discovered that brine can be used in some industrial sectors. Agriculture and aquaculture industries can use brine to irrigate salt-tolerant plants such as sea beet and *Salicornia bigelovii*, a multi-purpose halophyte that can be used to feed animals for biofuel production (Early, 2019).

Ancient Roman concrete
Source: https://www.asme.org/topics-resources/content/ancient-roman-concrete-stands-test-time

In addition to the agriculture industry, brine can be used in the process of concrete production, which is responsible for roughly 5% of global carbon dioxide emissions. In the United Arab Emirates, most of the water used in concrete production comes from desalination plants. An experimental investigation suggests that using brine as a source of water in the production process can improve the strength of concrete, and it has the potential to reduce 176 kg of carbon dioxide and 1.7 kg to 3.4 kg of carbon dioxide equivalents per cubic meter of concrete (Fattah et al., 2020).

Pantheon, Rome
Source: https://www.planetware.com/rome/pantheon-i-la-rp.htm

It's interesting to note that archeological evidence suggests that the ancient Romans used saltwater to produce concrete. The Pantheon in Rome was built 2,000 years ago, and it's still the world's largest concrete dome. Roman concrete contained an aggregate of sand and rock, just like modern concrete, and it was bound together with volcanic ash, lime, aluminum tobermorite, and seawater.

While it's true that seawater on its own isn't suitable for making concrete, it allows a chemical reaction between the minerals contained in the mixture and the volcanic rock aggregate, which develops resistance in the concrete (Jenkins, 2017).

The regulatory and permit requirements for developing desalination plants are time-consuming. For most plants, the permitting process takes more time than the construction of the facility. There are two major regulatory permitting issues related to planning and implementing desalination projects: developing the saline water source and managing the concentrated byproducts.

Several federal regulations govern the desalination process, including the Clean Water Act, the Safe Drinking Water Act, the Resource Conservation and Recovery Act, the Superfund Amendments and Reauthorization Act, the Endangered Species Act, and the Water Desalination Act.

In the U.S., only a handful of states have regulations and/or permitting requirements for the desalination process: California, Texas, Florida, and Virginia. The Environmental Protection Agency has, however, created state regulations to control the discharge of water with high concentrations of salt.

The management of the saline discharge at the end of the desalination process is the main obstacle for the approval of a desalination project. The regulations worldwide don't have specific limits for brine discharges as they do for other forms of waste like suspended solids or biological oxygen demand. Instead, environmental laws regulate the concentration of the discharges by establishing limits for project-specific acute and chronic whole effluent toxicity (WET).

While it is undeniably difficult to acquire permits to build a desalination plant, this is one challenge that shouldn't have an easy solution. The federal and state regulations are meant to mitigate against further ecological damage. The solutions to the problems produced by climate change shouldn't worsen the crisis, otherwise we risk creating a runaway feedback loop that makes life harder and harder for humans every year.

Source: https://unsplash.com/photos/3gUg8zuIKEE

The Future of Drinking Water

Seawater desalination technologies are without a doubt a reliable option to address the scarcity of freshwater around the world. Some technologies offer a more viable solution. One of those is reverse osmosis, a process that is poised to become less expensive, more energy efficient, and more reliable in the coming years.

Other options still in development include hybrid plants that combine current technologies with renewable energy sources like solar power, which can desalinate seawater strictly with radiation from the sun. These technologies still need further development, but eventually they will be able to generate significant amounts of drinking water without contributing to climate change.

https://unsplash.com/photos/YpZ2cj4s0oo

Saudi Arabia and Los Cabos are perfect examples of countries using desalination to supply freshwater to populations in coastal and desert areas. In both regions, desalinated water is the main source of drinking water, and they're examples to people in other water-insecure regions.

Although desalination has many benefits, it also has serious downsides. Researchers are developing technologies that can reduce the impact of those disadvantages. For example, saline concentrated byproducts can be used in some industrial sectors such as agriculture, aquaculture, and cement production. Energy-efficient equipment can also significantly reduce the process's high energy consumption.

The most onerous part of desalination is the regulation and the permits required to build desalination plants. The majority of these projects take longer to gain approval than to build due to the plants potential environmental impacts. To project aquatic and terrestrial ecosystems during and after construction, the plants must adhere to stringent government regulations.

Research

Here's an article (in Spanish) about the process of desalination using multistage flash evaporation:

https://ecoagua.com/wp-content/uploads/2016/12/Art_tecnico_ecoagua_4.pdf

Here you can read more about the process of multiple effect distillation:

https://economictimes.indiatimes.com/news/international/saudi-arabia/inside-the-worlds-biggest-water-desalination-plants-in-saudi-arabia/articleshow/78639741.cms?from=mdr

Here's an article about desalination in California, which studied desalination methods developed in Saudi Arabia:

https://www.arabnews.com/node/1275981/saudi-arabia

Here's an article that talks about the importance of early warning systems in drought management:

httphttps://blog.dhigroup.com/2020/01/28/an-expert-perspective-discovering-the-importance-of-early-warning-systems-in-drought-management/

Here's a graphic that shows the desalination of seawater through evaporation, a process known as multiple effect distillation (MED):

https://www.sulzer.com/es-es/spain/shared/applications/multi-effect-distillation-med

Here's another article (in Spanish) about MED:

https://www.scribd.com/document/319918350/Destilacion-Multi-Efecto