MEMBRANE DESALINATION

Power Usage in Perspective

OVERVIEW

Scientists have known that the Earth's natural hydrologic cycle continuously desalinates water using solar energy and evaporates water from oceans and lakes, leaving behind salt and mineral content. The resulting freshwater vapors form clouds, which produce rain and snow. This natural hydrological cycle continuously moves salt from land to the oceans and is the main reason why the oceans are salty.

Since the 4th century humans have tried to mimic this natural cycle and have learned that, with an energy input, "desalting" or "desalination" machines can be built to produce fresh water from brackish and seawater sources. In the Middle East, people have long evaporated brackish groundwater or seawater, then condensed the vapor to produce salt-free water. Over time the process has become more sophisticated.

Today, about 300 million people get drinking water from more than 17,000 desalination plants in 150 countries worldwide. The Middle East has dominated that market out of necessity and energy availability, but with climate change and freshwater shortages around the globe, many other countries are considering desalination.

Seventy percent of desalination plants in the world are located in the Middle East.

Although there are many different types of desalination techniques, the least energy intensive method currently in use is through a semi-permeable membrane process, referred to as reverse osmosis (RO). Since typical brackish water RO desalination uses just a fraction (10-30%) of the energy required for seawater desalination, this fact sheet focuses on seawater desalination utilizing RO technology.

ENERGY USAGE

Energy is the largest variable cost for seawater RO (SWRO) plant operation at approximately 60 to 70% of the cost of produced water, while all other operation and maintenance costs are less than 30 to 40% (**Figure 1**).

Energy costs for each plant depend on power pricing, type and degree of pretreatment, type of energy recovery devices, ocean salinity, concentrate disposal, regulatory requirements, land cost, and conveyance of seawater to and product water from the desalination plant.

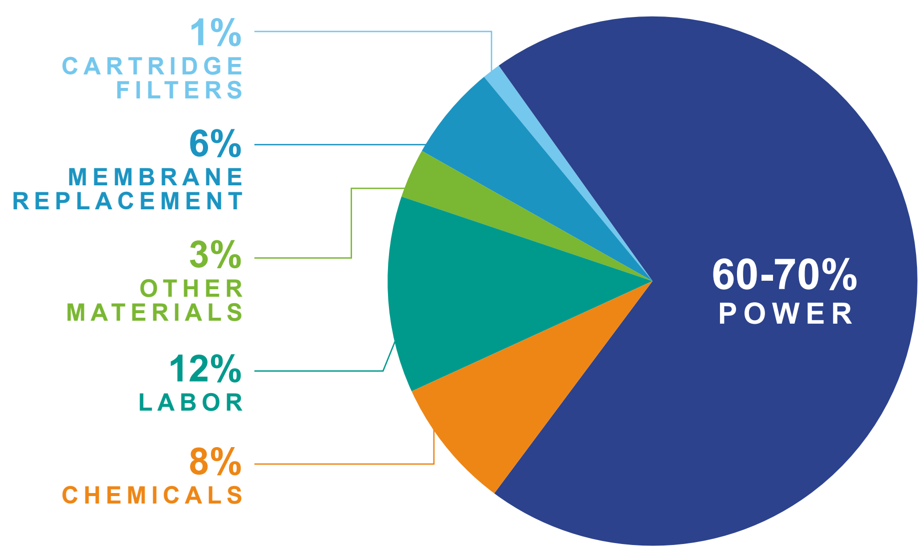


Figure 1: Typical Distribution of Costs for a Seawater RO Plant

SWRO ENERGY REQUIREMENTS EXPLAINED

The required energy to force water through SWRO membranes is a function of the salinity and temperature, due to natural osmotic pressure. The required driving pressure mandates the energy requirement. Colder ocean temperatures (such as Pacific Ocean) require more pressure, while higher salinity waters (such as the Persian Gulf) also require more pressure. A general "rule of thumb" is that the net driving pressure needed to produce an equivalent amount of desalinated permeate will increase (or decrease) by about 11 psi (0.76 bar) for each 1000 mg/L incremental change in feed water salinity (Total Dissolved Solids).

The theoretical absolute minimum amount of energy required by natural osmosis to desalinate average seawater is approximately 1.0 kilowatt-hour per cubic meter (kWh/m3) of water produced, or 3.8 kilowatt-hours per thousand gallons (kWh/kgal). The actual SWRO energy requirement in the 1970s was 7.0 to 9.0 kWh/m3 (26-34 kWh/kgal). With recent technological advancements and innovations in high efficiency pumps, energy recovery systems and overall higher efficiency plants, the actual expected consumed energy has decreased significantly to 3.0 to 4.0 kWh/m3 (11-15 kWh/kgal).

As an example, the Perth Seawater Desalination Plant in Australia, which utilizes wind power and advanced energy recovery systems, uses an average of 3.5 kWh/m3 (13 kWh/kgal) of produced water. This includes the total energy required from ocean intake to customer.

SWRO ENERGY IN PERSPECTIVE

No one will argue that seawater RO desalination consumes much higher energy than conventional freshwater treatment plants or water conservation. Desalination facilities should not be a primary option in locations where reliable fresh water sources are available and considerable cost-effective water conservation, efficiency improvements, and recycle and reuse are still possible.

But let's put seawater RO desalination power requirements into perspective:

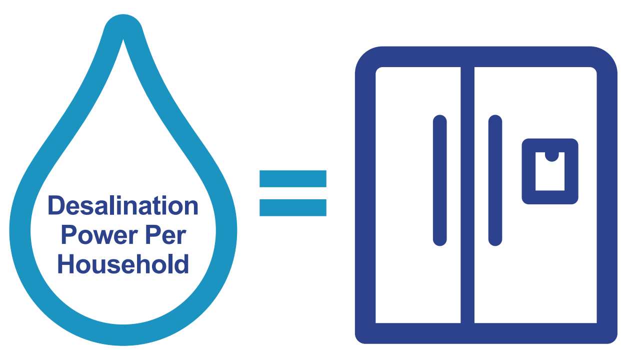
- In 2019, the U.S. Environmental Protection Agency estimated that a typical household in the U.S. uses 300 gallons of water per day (0.3 kgal/day). Using the Perth desalination plant numbers referenced above, energy consumption utilizing desalinated water per household can be calculated:

13 kWh/kgal x 0.3 kgal/day x 365 days = 1,423 kWh/year, or 1.423 megawatts/year (MW/year)

- Based on the 2019 report from the Energy Information Administration, the average U.S. household power consumption was 10.65 MW/year.

This means, if a community was served solely by desalinated seawater, energy consumption would increase by 13% (1.423/10.65).

- If we assume this same community was previously served by fresh water, which also consumes energy (approximately 3% of total power), one can estimate that a typical U.S. household served entirely by desalinated seawater will have a 10% increase in energy consumption.
- In most cases, desalinated water is used to augment existing traditional fresh water sources. If we assume 40% from fresh water and 60% from desalinated seawater, the percent increase in power consumption is between 5 and 7%.
- Based on nationwide data from the Energy Information Administration, the average annual energy usage of a typical refrigerator is about 7% of total energy used by a household. Therefore, the energy requirement for supplying a U.S. household with desalinated water (to augment existing traditional supplies) is the same as the power use of a refrigerator.



ADVANCES TO REDUCE SWRO ENERGY REQUIREMENTS

There is considerable focus on the energy consumption of seawater desalination and the climate impacts associated with increased power generation. However, this important technology is helping many areas throughout the world that are facing freshwater shortages or where supplies are limited. The desalination industry and these communities are actively innovating and seeking solutions to increase efficiency and reduce environmental impacts, including:

- Improving desalination technology design and methods of operation to further reduce power requirements.
- Recapturing energy from RO systems by utilizing Energy Recovery Devices (ERDs), which have reduced typical SWRO energy consumption by as much as 40%. ERDs are now an integral part of most modern desalination plants. The leading ERD manufacturers are continuing to develop more efficient devices.
- Utilizing graphene membranes, which are extremely durable, incredibly thin and, unlike polyamide, are not sensitive to chlorine. Chlorination upstream of SWRO can reduce pretreatment and fouling concerns. Some of these innovative membranes are only one atom thick with holes small enough to trap salt and other minerals, but that allow water to pass.
- Incorporating other popular nanomaterial solutions such as carbon nanotubes, which are attractive for the same reasons as graphene (strong, durable material packed in a tiny package) and can absorb more than 400 percent of their weight in salt.
- Looking beyond RO to another process known as forward osmosis (FO). In FO, seawater is drawn into the system by a solution that includes salts and gases, which creates a high osmotic pressure difference between the solutions. The solutions pass through a membrane together, leaving the salts behind. As a pretreatment, FO can extend the lifespan of RO membranes by reducing the needed disinfectants and other pretreatment options.
- Reducing the energy cost of desalination through reverse osmosis pressure retarded osmosis (RO-PRO). RO-PRO works by passing an impaired freshwater source, such as wastewater, through a membrane into the highly saline solution leftover from RO, which would normally be discharged to the ocean. The mixing of the two produces pressure and energy that is used to power an RO pump.
- Incorporating renewables (wind and solar) into the energy input side of SWRO, which is a particularly promising approach to enhancing the sustainability of desalination. Currently, only 1 to 2% percent of desalinated water comes from renewable sources of energy and mainly in small-scale facilities, although larger plants are starting to add renewables to their energy portfolio. The United Arab Emirates energy company, for example, is working on the world's largest solar powered desalination plant.

Incorporating renewables is a promising approach to enhancing the sustainability of desalination.

- Co-locating desalination and power plants to reuse and recycle thermal energy, reduce burdens on the power grid, and make use of lower off-peak power costs.

Water agencies can also incorporate the value of the reliability and water quality advantages of membrane desalination when comparing traditional supplies (if available) to desalination. With recent concerns over the discovery of pharmaceuticals and personal care products in drinking water supplies, it makes sense to include values and advantages of membrane technologies in such comparisons.

Additionally, the value of seawater desalination should be carefully considered when comparing desalination to other alternatives. When traditional supply sources are not feasible or available, seawater desalination can be achieved in an environmentally friendly manner, without aggravating climate change or land use concerns, while being 100% drought-proof.

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This material has been prepared as an educational tool by the American Membrane Technology Association (AMTA). It is designed for dissemination to the public to further the understanding of the contribution that membrane water treatment technologies can make toward improving the quality of water supplies in the US and throughout the world.