# Emerging Brine Management Approaches for Sustainable Desalination in the GCC Countries

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## Abstract

The major technologies employed in Gulf Cooperation Council (GCC) based commercial desalination facilities are classified into two categories: the membrane-based (mostly reverse osmosis (RO)) and thermal-based (primarily multi-stage flash distillation (MSF)). Currently, the GCC nations are in a process of changing the current desalination facility completely or partly by RO technology. In desalination facilities, 40 % of the feed water is fresh water and the balance 60 % is the discharged brine. For the Arabian Gulf, the brine disposal as well as wastewater disposal are important. This work examines trend in desalination capacity and electricity consumption in GCC nations, the Unified Water Strategy in GCC as well as examine the emerging technologies that show promise from an environmental standpoint. Several new brine management technologies, including pressure retarded osmosis system, greenhouse desalination, different hybrid technologies like reverse electrodialyzed-based and electrodialysed-based hybrid systems have been examined in this study. According to the results of our study, desalination plants' innovative strategies are suitable and advantageous for reducing energy consumption as well as for environmental sustainability. On a commercial level, we recommend that more research is necessary to evaluate the effectiveness, applicability, and sustainability of these solutions. Additionally, we encourage greater research to be done on approaches that have the least negative environmental effects and the most readily available renewable energy sources in the GCC countries, such as wind and solar energy.

**Keywords:** Desalination; Brine Management; Pressure Retarded Osmosis; Greenhouse Desalination; Electro-dialysis

## 1 Introduction

Because of the growing population and the excessive use of easily accessible freshwater supplies, the reliance on desalinated water has been steadily growing. The Arabian Gulf is enclosed by desalination plants with approximately 50% of global capacity for desalinating seawater. Commercial-scale desalination plants established in the Gulf Cooperation Council (GCC) primarily use two types of technologies: membrane-based (mainly reverse osmosis) and thermal-based (mostly multi-stage flash distillation (MSF) technologies. Currently, all the GCC countries are in a process of adjusting their existing desalination plant partially or completely by reverse osmosis (RO) process technology. Most of these desalination facilities discharge brine, or hypersaline wastewater, into the Gulf via nearshore and surface outfalls. Brine, also termed as concentrate, is the main seawater pollutant, and has an adverse effect on the surroundings because of its higher salinity and high temperature. The feed water used in desalination technologies will be converted to 40.0% potable water and the rest 60.0% discharge brine. For the Arabian Gulf, wastewater and brine disposal is crucial. The brine may also contain harmful pretreatment chemicals, heavy metals, and organics in addition to its greater salinity. Therefore, having affordable and practical brine management devices is crucial for lowering environmental pollution. This study analyzes the new technologies that show promise when taking the environment into account, as well as the trends in GCC desalination capacities, electricity consumption, and the GCC Unified Water Strategy. Several cutting-edge brine treatment technologies, including pressure retarded osmosis systems, greenhouse desalination, and various hybrid systems, including reverse electro-dialysed-based hybrid systems and electro-dialysed-based have been examined in this study.

## 2 GCC-Based Desalination Plants Capacity

In the GCC nations, a water shortage condition is expected with the water stress level considered as serious mainly because of the population growth rates, exhaustion of non-renewable subsurface water, high evaporation rates, low rainfall, and high industrial growth rate. The annual per capita renewable water obtainability in the GCC nations has reduced quickly during years 1962 - 2010. The stated annual per capita of renewable water changed from a lower value of 33 $m^3$ in Qatar, 20.0 $m^3$ in UAE, 7.3 $m^3$ in Kuwait, 92.0 $m^3$ in Bahrain to a greater value of 503.0 $m^3$ in Oman. Among the total 17346 online and contracted desalination plants across the world, 7499 of them are situated in the GCC nations. Out of the different GCC Countries, Saudi Arabia has the highest population and thus has the highest number of plants as well as total capacity followed by UAE. Figure 1 is the world and GCC desalination capacities trend during years 1985-2030. By 2030, installed desalination capacity is expected to doubled both globally and in the GCC. Figure 2 presents the GCC nations' electricity requirement trend from 2011 to 2050 in Terawatt-hour (TWh). The yearly electricity requirement in the GCC would rise from 467.0 Terawatt-hour in 2011 to almost 1,400 Terawatt-hour in 2030 and extending almost 2,000 TWh in the year 2040. Simultaneously, the requirement for potable water in the GCC would rise remarkably from 6,470 Gigaliter in 2011 to 16000 Gigaliter in 2030 as well as 21000 Gigaliter in 2040.

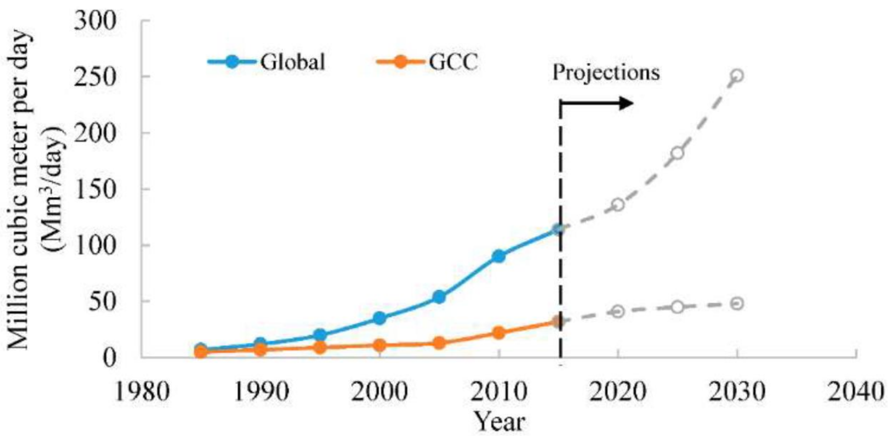


**Fig. 1:** World and GCC desalination capacities trend from the years 1985 to 2030

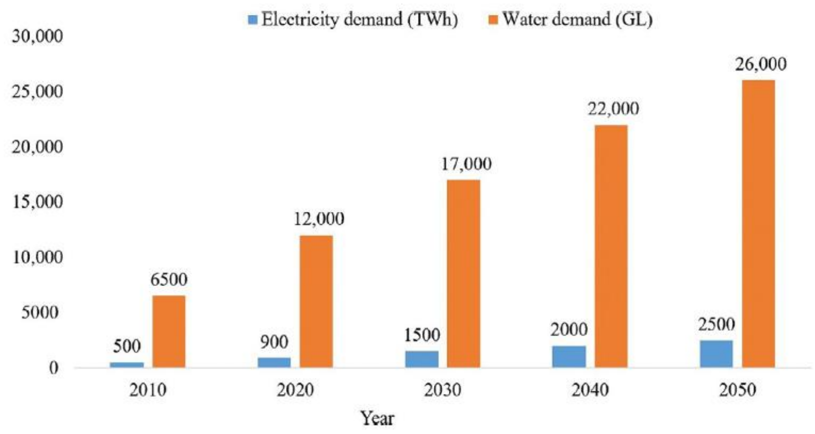


**Fig. 2:** Trend of GCC electricity demand in the years 2011- 2050 (TWh)

## 3 Unified Water Strategy in Gcc

The Gulf Cooperation Council Supreme Council and the GCC Secretariat General confirmed and endorsed a GCC Unified Water Strategy, 2016-2035, in 2016. The establishment of this strategy signifies a key breakthrough for the intricate as well as long path for dealing with the water shortage in the water stressed Gulf Cooperation Council countries. The goal of the general strategy is to launch a "sustainable water sector management system" in all the GCC nations while preserving long-term water supplies and adhering to stringent public health and environmental sustainability standards.

The programs, objectives, and policies of the strategy are steered by the succeeding principles:

- Achievement of highest international standards of service delivery in water supply as well as sanitation to the Gulf Cooperation Council growing population;
- Implementation of applicable water governance (legislation, transparency, participation, institutions, accountability and decentralization);
- Enhancing water awareness of the Gulf Cooperation Council societies;
- Implementing integrated supply as well as demand driven approach in entire water consuming sectors as well as concentrating on demand management, water efficiency, as well as conservation;
- Water valuation in the Gulf Cooperation Council nations;
- Integrating upcoming effects of climate variation by combining proper adaptation measures in water resources planning as well as management;
- Encouraging research as well as development, and groundbreaking technological solutions in the water sector;
- Employing a water, energy, and food nexus strategy to plan as well as manage the water sector;
- Improving national and institutaional human resources;
- Effective collaboration on the regional as well as global water agenda.

The Gulf Cooperation Council countries execution of the strategic objectives as well as policies set in the strategy will lead to several succeeding advantages in addition contributes to the developmental goals of the Gulf Cooperation Council nations, will support for ensuring the consistent water supplies nowadays and for upcoming generation, and improve the overall level of water security.

## 4 Emerging Technologies for Brine Treatment

### 4.1 Greenhouse desalination

The present dependence of the GCC countries on fossil oil as well as gas is imprudent with respect to economic and environmental sustainability. The renewable energy use in the desalination field is an inspiring concept for reducing the enormous energy costs related to the desalination process. GCC countries should consider the use of renewable energy to deal with the price variations of oil and gas in the global market and for lowering the emission of greenhouse gases. The newly developed seawater greenhouse technology demonstrates a potential source of clean water for irrigation purpose in locations where just seawater or saline ground water are available. In greenhouse desalination, it is possible to decrease the brine volumes using the evaporative coolers in seawater greenhouses, therefore facilitating the high-value crop cultivation and sea salt production. The seawater greenhouse technology recreates the "hydrologic cycle" by the evaporation of water from saline water sources such as seawater and recovers it as pure water by a condensation process (Figure 3). This renewable energy based technology has experienced numerous stages of developments and exhibited a favourable practical solution in regions having a shortage of fresh water for the purpose of irrigation. In a study by Ismaili et al. (2016), the team provided an up-to-date and comprehensive review on what have been published on seawater greenhouse technology. Moreover, the study also investigated the efficiency in using the seawater greenhouse technology in Oman as a case study.

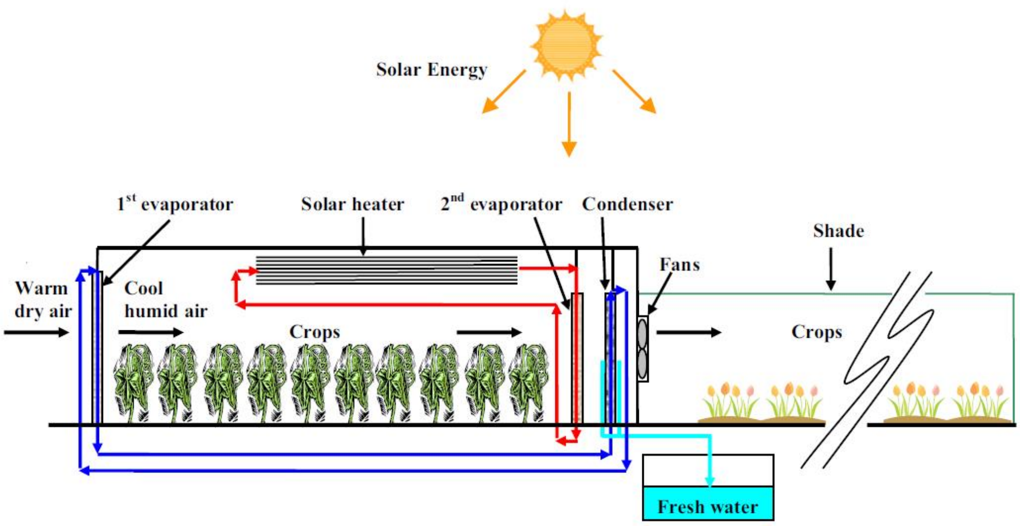


**Fig. 3:** Diagrammatic representation of the seawater greenhouse system in Oman

On the other hand, an obvious knowledge gap was noted in the financial attributes of seawater greenhouse because of the lack of research focus in this field. The primary trial of an understanding at the seawater greenhouse economics was performed in the work by (Ismaili et al., 2016). The major finding from the study was to decrease the capital expenses of the dehumidification units. Considering the technical aspects, the seawater greenhouse technology can be considered as a water conservational tool, due to the fact, that it decreases the water requirement of crop by practically 67.0 percent, as compared to the standard open-field cultivation. The generation of fresh water from the Oman seawater greenhouse unit was varying between 300.0 to 600.0 Litres/day, with almost zero-salinity. Even though this quantity is considered to be half of the requirement of irrigation water, it is feasible to raise the volume of freshwater by combining with raw sea water or brackish ground water. Due to the fact that the freshwater production of seawater greenhouse unit in Oman was below the required demand and various research works confirm the prospect for progress, additional research and development works are crucial. On technical aspects, these efforts should have to be together with the efforts on the financial aspects.

### 4.2 Pressure Retarded Osmosis

The conventional energy production methods of using the non-renewable fossil fuels have many drawbacks. Power plants operated by fossil fuels generate greenhouse gases and cause environmental damage. For overcoming the problems associated with the standard fossil-fuel system, the requirement for eco-friendly as well as sustainable energy production systems is rising. The requirement for renewable energy sources for meeting the global energy demand and progressively substitute for fossil fuels is growing. Hence, several research studies are concentrating on developing effective alternate energy sources such as wave, tidal, solar and biomass, and are being comprehensively studied for providing sustainable and secure energy sources. However, the high installation costs, irregular availability of energy sources, or complex logistics, are still preventing these energy sources from being extensively used. Pressure retarded osmosis (PRO) is an alternate source of renewable energy presently in the advanced stage of development: and it is part of the salinity gradient energy or osmotic power sources, which employ the energy produced by salt concentrations differences between two solutions, generally freshwater and salt water. In the PRO concept (Figure 4), electrical power is generated by means of water flux brought about by the osmotic pressure difference between two different solutions.

The process employs the Gibbs' free energy of mixing of the saline solution (on the semipermeable membrane draw solution (DS) side) and the drawn solution from the feed solution (FS) (on the semipermeable membrane feed side). In this process, water will permeate through a semipermeable membrane from a lower concentration feed side into a higher concentration, moderately pressurized, brine (DS). The DS will have a lower hydraulic pressure than osmotic pressure even when it is considerably pressured. As a result, the flow of the permeate stream from the FS to the DS is still being driven by the net osmotic force. It turns out that the permeate is pressured, which weakens the DS. A turbine-generator set might then transform the energy in the pressured permeate solution into mechanical or electrical energy. Water producing from a sewage treatment facility could be used as the dilute solution (feed solution), whereas the brine discharging from a desalination facility can be employed as the concentrate (draw solution), thus being efficiently diluted before release into the sea. Correspondingly, PRO can generate energy from the salinity gradient generating from the salt concentration differences between the two different water solutions. This PRO technology is getting research attention due to its exclusive benefits:1) It will not produce hazardous waste to the environment, 2) this membrane-based packed system decreases the ecological damage caused by plant construction, 3) this is a sustainable energy production method using saline water sources, 4) PRO unit has application as a high-efficiency hybrid system, while used with commercial RO, forward osmosis (FO), and membrane distillation (MD), 5) this system has wide range of uses, in that different sources of water on the earth might be used.

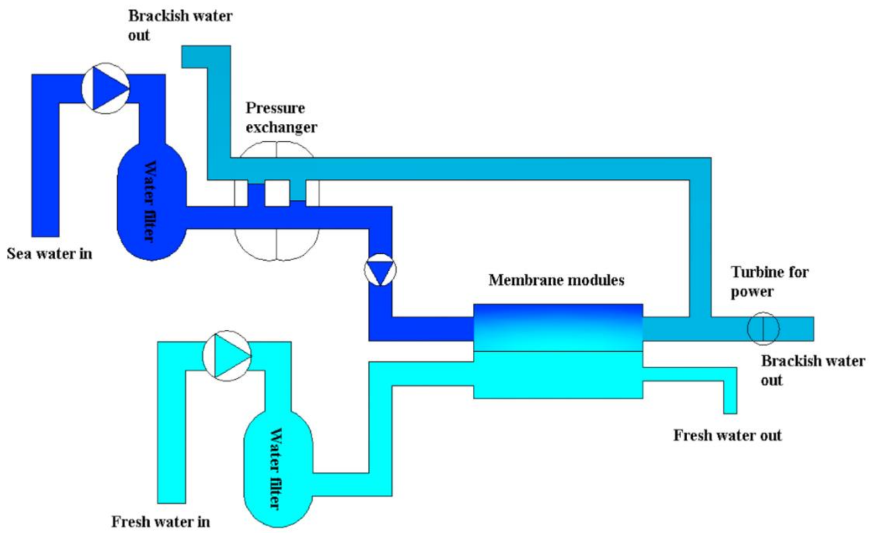


**Fig. 4:** Process outline for a standard osmotic power plant

The application of PRO to the seawater reverse osmosis desalination plant can simultaneously solve the issue of higher energy use and the high-salinity brine production of these plants. Subsequent to the pressure retarded osmosis process, the brine is diluted and thereby the ecological impact of the brine can be reduced. The PRO economic feasibility is extremely affected by the choice of selecting the hydroturbine or pressure exchanger for converting the resultant power to electricity. Sarp and Saththasivam recommended that employing a pressure exchanger instead of a hydroturbine for seawater reverse osmosis-PRO hybrid system might increase the rate of using the hydraulic pressure up to 97%. Therefore, this reduces the energy use of the seawater reverse osmosis desalination process by 25%. The study by Al-Anzi et al. (2018) discusses the use of 1-D analytical expressions for a parallel flow configuration in PRO exchangers by employing the real brine as well as feed TDS values from a Kuwait-based desalination facility. The results from this study confirmed that a maximal power of 2.6 kJ and 0.28 kJ could be generated by the pressure retarded osmosis system employing treated wastewater effluent or seawater as the FS, respectively. The authors confirmed that this might be definitely able to decrease the power utilization of the desalination sector in Kuwait.

### 4.3 Hybrid Systems

Furthermore, the hybrid systems such as electrodialysis-based and reverse electrodialysis-based hybrid systems also support in reducing the energy use and minimizing the environmental effect of the reverse osmosis brine.

#### 4.3.1 Electrodialysis-based Hybrid Systems

Electrodialysis is an economical, feasible, as well as eco-environmentally friendly process for treating the reverse osmosis effluent, which is extensively used in water treatment. In this process, ions are carried through semipermeable membranes under the impact of an electric field driving force generated by an applied direct current (DC) voltage source. Numerous studies confirmed the capability of electrodialysis technique for treating the extremely high saline water. Casas et al. (2012) as well as Reig et al. (2014) used electrodialysis as a technical solution for recovering sodium chloride from the reverse osmosis brines, which has been subsequently employed as a raw material in the chloralkali process. In two different studies, Korngold et al. (2005, 2009) employed electrodialysis technique for reducing the reverse osmosis brine effluent volume as well as its disposal cost. In a work by Nayar et al. (2019), the team examined the possibility of completely hybridizing reverse osmosis with electrodialysis, together with optimizing electrodialysis current densities for producing brine with a salt concentration of 120.0 g/kg. This study demonstrated that the optimization assisted for reducing the brine concentration expenses by 33.0-70.0 %, as compared to a standalone electrodialysis system. The possibility of developing salt and low salinity water by the treatment of synthetic brine was examined by Al-Anzi et al. (2021) in a pilot-scale electrodialysis-evaporator hybrid system for brine management. Presently, the desalination facilities in Kuwait release the brine effluents subsequent to combining it with seawater in which the bathymetry (bathymetry is the measurement of the depth of water in sea or rivers) is very shallow. The selected synthetic brine concentration was between 65,000–68,000 mg/L to mimic reject brine from Kuwait desalination plants. The concentrated brine effluent from electrodialysis process was taken to an evaporator for producing coarse salt with 84.75 percent salt recovery as well as less salinity water with TDS concentration of 1526 ppm. Therefore, the electrodialysis-evaporator hybrid system was noted to be a safe choice for treating the reject brine from desalination facilities.

### 4.3.2 Reverse Electrodialysis-based Hybrid Systems

Reverse electrodialysis is a developing membrane technology that gets electrical power from the salinity differences between two solutions. In this reverse electrodialysis technique, the fundamental ions present in the solutions will be powered by means of ion-exchange membrane by a salinity difference. In the work by Li et al. (2013), the RO and reverse electrodialysis processes have been integrated for designing an advanced hybrid process that used the synergy of reverse osmosis and reverse electrodialysis processes. From the perspective of the reverse electrodialysis process, the reverse osmosis process could offer the concentrated brine as the higher salt concentration FS for a high power density. Also, the environmental impact of the reverse osmosis brine can be reduced by reducing the salt concentration of the discharged brine by means of the reverse electrodialysis process. Conversely, the energy usage of the reverse osmosis process could be decreased by pretreating the FS by the reverse electrodialysis process; that is., the feed solution osmotic pressure will be reduced and transformed into electrical energy. Such complementary impacts turn reverse osmosis and reverse electrodialysis processes a perfect combination for low energy seawater desalination as well as brine management.

## 5 Discussion and Conclusion

The two important factors that influence the production of brine are the feed water type and the purification technology used in the desalination facilities. Thus, our study demonstrated that the advanced techniques analyzed here are advantageous and suitable for decreased energy utilization as well as ecological sustainability of desalination plant. Currently, due to the fact that the crude oil is a restricted energy resource, the thermal-based desalination techniques would not be practical for the prospect of the Gulf Cooperation Council nations. Majority works should be concentrated on employing the extremely accessible renewable energy in the Gulf Cooperation Council nations, like solar energy, wind energy etc., and for techniques that result in minimal influence on the ecosystem. Generally, the emergent technologies discussed in this study are very promising for the brine volume reduction of effluent volume, on the other hand, majority are just on a lab/pilot scale and it very hard to examine their applicability on a commercial scale. Several studies have confirmed that the suitable usage of extremely concentrated brine solution with diluted treated wastewater or seawater by means of PRO can not only reduce the serious environmental impacts caused by the brine discharge to the surroundings, but also can produce considerable energy output from the feed and draw salinity gradient. The electrodialysis-based and reverse electrodialysis-based hybrid systems also proved to be ideal solutions for the brine management. Further studies are necessary on a higher scale for assessing the effectiveness and sustainability of these technologies. Numerous problems must be properly addressed for the practical application of the high salinity PRO technique for the seawater RO desalination facility. In the water sector, to ensure that the desalination processes are successfully employed and performed in a favorable manner, it is needed to have a proper structured system governed by objectives and laws. The GCC nations along with their resemblances in geography, and conditions of water constraints could be the world leaders in bringing up advanced approaches in the desalination sector.

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## References

Achilli, A. & Hickenbottom, K. L. (2016). Pressure retarded osmosis: Applications. In Sustainable Energy from Salinity Gradients (pp. 55-75). Woodhead Publishing.

Al-Anzi, et al. (2021). Brine management from desalination plants for salt production utilizing high current density electrodialysis-evaporator hybrid system: A case study in Kuwait. Desalination, 498, 114760.

Al-Anzi, B. S. & Thomas, A. (2018). One-Dimensional Analytical Modeling of Pressure-Retarded Osmosis in a Parallel Flow Configuration for the Desalination Industry in the State of Kuwait. *Sustainability, 10*(4), 1288.

Al-Ismaili, A. M. & Jayasuriya, H. (2016). Seawater greenhouse in Oman: A sustainable technique for freshwater conservation and production. *Renewable and Sustainable Energy Reviews, 54*, 653-664.

Al-Zubari, et al. (2017). An overview of the GCC Unified Water Strategy (2016–2035). *Desalination and water treatment, 81*(s 5).

Casas, et al. (2012). Seawater reverse osmosis brines as a new salt source for the chlor-alkali industry: integration of NaCl concentration by electrodialysis. *Solvent Extraction and Ion Exchange, 30*(4), 322-332.

Douani, et al. (2011). Modeling heat exchange in the condenser of a seawater greenhouse in Oman. *Chemical Engineering Communications, 198*(12), pp.1579-1593.

Jia, et al. (2014). Blue energy: Current technologies for sustainable power generation from water salinity gradient. Renewable and Sustainable Energy Reviews.31: 91-100

Korngold, et al. (2005). Electrodialysis with brine solutions oversaturated with calcium sulfate. *Desalination, 172*(1), 63-75.

Korngold, E., Aronov, L. & Daltrophe, N. (2009). Electrodialysis of brine solutions discharged from an RO plant. *Desalination, 242*(1-3), 215-227.

Li, et al. (2013). A novel hybrid process of reverse electrodialysis and reverse osmosis for low energy seawater desalination and brine management. *Applied energy, 104*, 592-602.

Nayar, et al. (2019). Cost and energy needs of RO-ED-crystallizer systems for zero brine discharge seawater desalination. *Desalination, 457*, 115-132.

O. Ellabban, H. Abu-Rub & F. Blaabjerg (2014). Renewable energy resources: current status, future prospects and their enabling technology, Renew. Sustain. *Energy Rev. 39*, 748-764.

Post, et al. (2007). Salinity-gradient power: evaluation of pressure etarded osmosis and reverse electrodialysis, *J. Membr. Sci*. 288 (2007) 218-230

Reig, et al. (2014). Concentration of NaCl from seawater reverse osmosis brines for the chlor-alkali industry by electrodialysis. Desalination, 342, 107-117.

Sarp, S. & Hilal, N. (2018). Membrane Modules for Large-Scale Salinity Gradient Process Applications. In Membrane-Based Salinity Gradient Processes for Water Treatment and Power Generation (pp. 223-242). Elsevier.

Sarp, S., Li, Z. & J. Saththasivam. (2016). Pressure Retarded Osmosis (PRO): Past experiences, current developments, and future prospects. Desalination. 389: 2-14.

Shahzad, et al. (2018). Adsorption desalination—principles, process design, and its hybrids for future sustainable desalination. In Emerging technologies for sustainable desalination handbook (pp. 3-34). Butterworth-Heinemann.

Shahzad, et al. (2019). Desalination processes' efficiency and future roadmap. *Entropy*, *21*(1), 84.

Weinstein, J. N. & Leitz, F. B. (1976). Electric power from differences in salinity: the dialytic battery. *Science*, *191*(4227), 557-559.

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