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SAUDI DESAL MARKET EXPLODES

AWARDS IN SHOAIBA MARK A RETURN TO FORM FOR THE WORLD'S DESAL LEADER

THE NEW DESAL ENERGY REVOLUTION

GWI INVESTIGATES THE EMERGING WORLD OF LOW-ENERGY DESALINATION TECHNOLOGIES

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MARKET MAP

Renewing desalination's licence to operate

Improving the energy efficiency of desalination plants can reduce costs, not to mention their environmental impact. What can renewable energy and innovative solutions offer?

Solutions to lower the carbon footprint of desalination processes, including increased use of renewable energy sources, will become an important part of the mix if the industry is to be sustainable. In the past, the use of renewable energy has been hindered by its intermittency, and its economic benefits – mainly in the form of lower operating costs – have been somewhat neutralised due to its reliance on back-up energy from the grid and higher capital costs. However, there are a few upcoming projects where desalination systems have a high renewable energy mix in their power supply, sometimes up to 100%. Moreover, many opportunities for optimising existing desalination processes to enhance their energy efficiency, and by extension operating costs, already exist, and could save end-users significant sums of money. Alternative desalination technologies, such as forward osmosis (FO) and membrane distillation (MD), may also offer a strong hand in steering the industry away from high carbon emitting energy sources – linking them with renewable energy solutions can offer a double whammy in terms of clean energy and better efficiency.

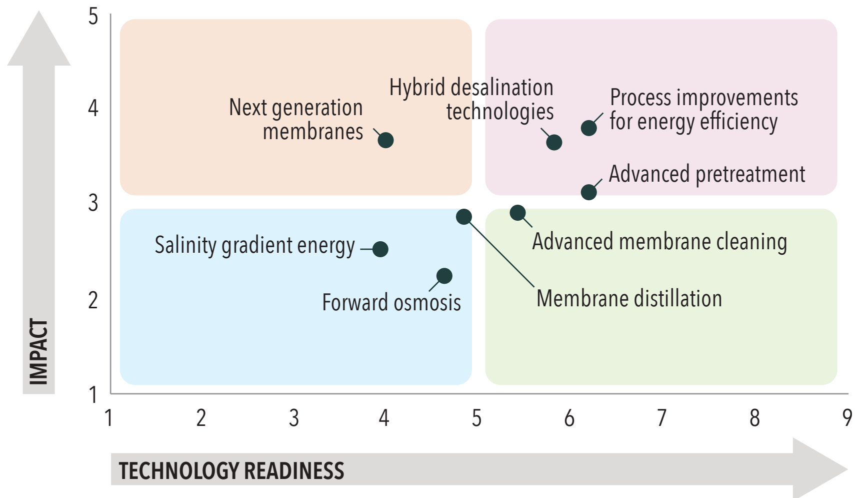
According to GWI's recent *Desalination & Water Reuse* report, installed capacity for seawater and brackish water desalination was a little over 62.5 million m³/d. This is projected to rise to nearly 80 million m³/d by 2020, and more measures towards the sustainability of the industry will be required.

The status of, and the requirements going forward for, a transition to lower carbon desalination were discussed by several prominent expert desalters at a workshop conducted by the Massachusetts Institute of Technology (MIT) in October 2016. The participants were asked to rank potential technology developments for reducing greenhouse gas emissions by the impact they could have versus technology readiness level (TRL), as well as the TRL and impact that low-carbon or renewable energy systems could have (*see figure, left*). The key suggestions were that focus should be put on improving the energy efficiency of existing processes, as well as more advanced pretreatment, rather than looking to less mature technologies such as membrane distillation and forward osmosis. In addition, connecting solar photovoltaic (PV) or wind power generation facilities to reverse osmosis (RO) plants was suggested as an immediate solution to help lower desalination's carbon footprint.

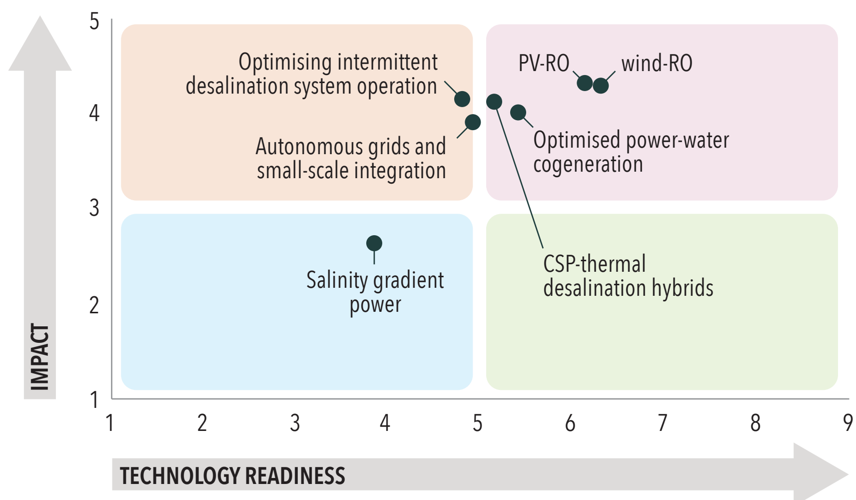
PLOTTING DESAL'S LOW-CARBON FUTURE

There are a plethora of ways to improve the sustainability of the desalination industry, some more immediately deployable than others. Wind- and PV-RO can have an immediate impact.

GHG reduction versus technology readiness level for desalination technologies



GHG impact versus technology readiness level for several low carbon desalination systems



Source: MIT

Renewable desalination landscape

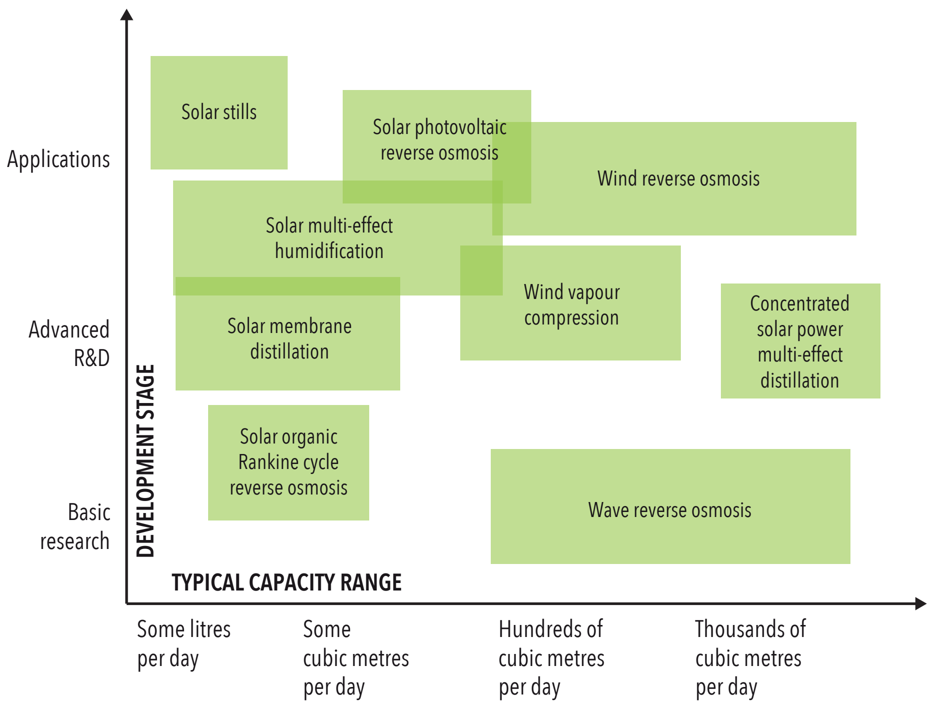
Renewable energy, unless subsidies are in place, is more expensive than conventional energy, and without improvements in energy storage, it will remain expensive. Another barrier it faces is the fact that there is no inherent advantage for a desalina- ▶

tion plant to receive its energy from renewable sources, and it can in fact be hindered by the intermittency of such a source.

Wind, wave and geothermal are all competing as renewable energy sources for desalination, but it is solar that is making the most headway, principally because the most water-stressed areas of the world are in the sunniest climes, as well as the sharp decline that has been seen in recent years of PV costs. Solar-powered desalination systems generally divide into two types: direct or indirect systems. A direct system comprises a closed system where the heat of solar radiation directly activates the desalination process. The most common type is a solar still, which works as a greenhouse, trapping radiation and heating up water that evaporates and condenses on a glass surface. In indirect systems, the two processes of solar concentration and desalination take place in two distinct units. Concentrated solar power technologies – which can take the form of parabolic trough, linear Fresnel or a solar tower – use the heat from solar radiation to power thermal desalination processes such as MSF, MED, VC and MD. Another, more common, indirect solar energy source are PV panels generating electricity to power an RO or electrodialysis (ED) process. Generally, indirect systems are better used for larger scale applications.

HOW TO USE RENEWABLES FOR DESAL

Solar stills are most prevalent in the industry from a renewables point of view, but limited to small-scale systems. The typical desalination capacities for RE sources are displayed, but there are exceptions.



Source: Adapted from ACWA Power

When comparing solar PV and solar thermal, the latter has a disadvantage in terms of capital costs, but makes up for it in terms of storage, which is often cheaper than using PV (where energy is stored in a battery). “With solar PV you can use it in the day time, but with solar thermal coupled with thermal storage you can potentially use it on a 24/7 basis giving you a better return on the capital expenditure,” explained Manoj Divakaran, President of renewable energy desalination project developer Empereal Energy. A solar thermal plant needs to be close to the desalination plant, unlike a PV plant which could be located off-site. Both PV and solar concentrators collect solar radiation better inland however, which can make situating them on the coast in proximity to desalination plants an issue.

Wind turbines can generate electricity for use by RO or ED technologies. Two combinations of wind power and desalination are possible: either the coupling of a wind turbine system and desalination plant on a small size autonomous electricity grid; or the direct coupling of a wind turbine system and desalination plant solely to produce water. The most prominent examples of desalination plants using energy produced in wind farms are the Kurnell (Sydney) and Kwinana (Perth) plants in Australia.

Certain renewable energy sources are better suited to certain desalination technologies, and that suitability becomes even more notable when it comes to capacities of a desalination plant (*see figure, above*). For reverse osmosis, wind power is better suited to larger capacity RO plants, because less flexible desalination capacity is required.

As an example, if a wind turbine with 1MW of generation capacity is installed to power a desalination plant, given that weather conditions are changeable, the power output over a year may average out at around 300kW. As this is about 30% of capacity, it means that a connected desalination plant would require three times the capacity of one being run on conventional energy sources in order to ensure that the same amount of desalinated water would be produced. This clearly creates a disadvantage in terms of initial capital outlay, with the benefits emphasised on the operational side as electricity would not need to be purchased from the grid. This “capacity factor” plays an important part when considering renewables as an energy source – the closer the average capacity to the peak capacity, the less flexible desalination capacity is required.

Cost-competitive use of wave energy for desalination likely remains a long way off. Several start-ups claim they are looking into using electricity generated by the kinetics of the waves for powering the desalination process. Though some trials have been completed, the production of water solely using electricity generated by wave energy has yet to be commercialised. “High capital costs and the issue of maintaining wave energy devices that stretch many metres ▶

> “From a technology point of view, everything’s very simple except for maintaining simultaneous connections and optimising the switch over from grid to solar – that’s where the trick is.
>
> Todd Leyland, Advanced Water Technology

below the sea will likely inhibit the uptake of this energy source," Neil Palmer, principal water engineer at Tonkin Consulting, told GWI.

Geothermal offers obvious advantages over solar and wind, with it not being weather dependent but being a steady source of energy. Some have proposed the combination of geothermal energy with an MED process because MED can operate at relatively low temperatures, but, realistically in the future, deploying thermal technology would need compelling reasons because it is inherently much more energy demanding than membrane processes. A thermal process with an exothermic reaction to release energy could be an option.

Sun shines on large-scale solar

Large scale solar PV desalination is receiving most attention in the sunlight rich Middle East. One of the largest plants will be Advanced Water Technology's 60,000m^3/d solar RO plant at Al Khafji, which is being built close to Saudi Arabia's Kuwaiti border. The Saudi kingdom has been very keen to explore new ways to reduce its reliance on fossil fuels for powering its extensive network of seawater desalination plants. Solar energy is a natural choice to come into the mix, but is not the only solution. "Whether [reduced reliance on fossil fuels] comes from a direct connection to renewable energy, or it is an offset arrangement, in Saudi Arabia it doesn't really matter, as long as you are reducing the overall use of carbon fuel," Todd Leyland of Advanced Water Technology told GWI.

At Al Khafji, the desalination plant is anticipated to come online in summer 2017 and the solar array is expected by early 2018. The goal is to create a surplus of energy during the day to put into the grid, and then draw from the grid during hours of darkness. The project will act as a pathfinder for future solar energy desalination plants, and cement the fact that the best way forward for renewable energy in Saudi Arabia will be to link up with the grid, rather than going towards off-grid systems directly powering a desalination plant. "Even remote parts of the Kingdom have decent access to the grid," said Leyland.

Connecting solar PV to an RO system is not taxing from an engineering point of view, but optimising the solar potential can be tricky. "From a technology point of view, everything's very simple except for maintaining simultaneous connections and optimising the switch over from grid to solar – that's where the trick is, the only complication," Leyland told GWI.

In the United Arab Emirates meanwhile, private developer Utico has begun the construction of a 100,000m^3/d SWRO plant which it expects to run off solar PV in the future. However, the procurement of the solar plant has been delayed.

Away from the Middle East, German renewable energy desalination developer Synlift is planning a solar PV desalination project in Chile, where there is strong solar irradiation. Several seawater desalination plants have been constructed for mining clients, where the product water has to be pumped dozens of miles into the mountains where mining operations are located. The company is designing an 86,400m^3/d SWRO, which is anticipated to be 80% fed by solar energy with 20% of energy taken from the grid. Because the power output of the solar system fluctuates, Synlift adopts a load management system which adapts to both parts of the process depending on the power output. The transport system is also planned to be flexible, with greater pumping capacity used when the sun is at its most potent in order to adapt the network to match the availability of solar power. Synlift Managing Partner, Joachim Kaeufler, told GWI that the environmental impact assessment had been carried out and front-end engineering design has been completed, ▶

PLAYERS FOR A RENEWABLE FUTURE

Numerous companies are exploring coupling desalination technologies with renewable energy. Concentrated solar power can be coupled with both membrane and thermal technologies, but the jury remains out on the merits of the process. It should be noted that the majority of companies listed are the renewable energy providers working with desal system suppliers, rather than vice versa. WaterFX meanwhile had a high profile project in California that has failed to take off.

Company	RE Technology Type	Desalination technology	Company	RE Technology Type	Desalination technology
Sundrop Farms	CSP	MED	Elemental Water Makers	PV	RO
Empereal	CSP - Linear Fresnel	MED/FO	Monsson	PV	RO
Frenell	CSP - Linear Fresnel	MED	Synlift	PV	RO
Trevi	CSP - Linear Fresnel	FO/RO/MED	Carnegie Wave Energy	-	RO
D&D Manufacturing	CSP - Parabolic	MSF	EcoH2O (SAROS)	-	RO
Epiphany Water Solutions	CSP - Parabolic	MED	Havkraft	-	RO
WaterFX	CSP - Parabolic	MED	Resolute Marine Energy	-	RO
eSolar	CSP - Tower	RO/MED	Seatricity	-	RO
Advanced Water Technology	PV	RO	Solteq Energy	-	RO
Hitachi	PV	RO	Colorado School of Mines	-	MD
Mascara	PV	RO	Xenesys	-	-
MegaEngineering	PV	RO			
Sisyan LLC	PV	RO			
Sojitz	PV	RO			
SolarWave	PV	RO			

Type of RE: Solar Solar/Wind Wave Wind Geothermal Ocean thermal

Source: GWI

and the project is going into an approval procedure that will last at least 12 months.

Decentralised renewable solutions

For areas with the combination of high electricity costs and a lack of freshwater alternatives, notably island communities, off-grid solar or wind plants directly connected to small-scale desalination plants can make sense. Dutch company Elemental Water Makers (EWM) recognised the limitations that off-grid systems have in providing a 24/7 energy supply for the desalination process. "Because renewable energy sources fluctuate, existing sources up until now were very expensive because they either operated discontinuously or they incorporated batteries," said Sid Vollebregt, Managing Director of EWM. If an SWRO plant does not run on a continuous basis, it can potentially increase the risk of the membranes succumbing to biofouling, which would result in either costly cleaning procedures or extensive membrane replacement. Furthermore, membrane providers are more reluctant to give guarantees because the operation of the system may not fall under usual standards.

For off-grid systems to run on a continuous basis, energy generated during the day needs to be stored, but for solar PV it is usually in the form of batteries, which remain costly. EWM's proposal is to pump seawater up a hill to a storage tank during the day, and then at night, or in especially overcast conditions, use the force of gravity to cascade the seawater back down the hill into an RO process, which consequently gets the required pressurised seawater feed. "If we make sure the water tank contains enough seawater to ensure 24/7 production, then we can realise the 24/7 operation while using only off-grid solar energy," said Vollebregt. The 50-60 bar pressure requirement for RO equates to around 500–600m of elevation for a water tank, but EWM says they have managed to reduce the elevation to 90m through the use of energy recovery devices. Naturally, the use of gravity is severely limited by topography of the site.

There is also the option to have no storage at all. French company Mascara, also targeting off-grid, remote communities, has developed a technology where a reverse osmosis unit system is operated on variable solar power for 7 to 10 hours a day, delivering a variable flow of permeate during the day, ostensibly reducing energy consumption in the process. The system takes electricity from the grid at night. Mascara was the fifth – and latest – entrant at UAE renewable energy company Masdar's Ghantoot pilot site, beginning piloting of its OSMOSUN40 product (which produces 40m³/d of desalinated water) in September 2016. Since 2015, Veolia Sidem, Suez, Abengoa and Trevi Systems have been demonstrating pilot membrane desalination systems (in addition to other innovative technologies such as membrane distillation and liquid-liquid separation) that take energy from the grid but mimic the conditions of renewable energy sources. Mascara was the only company testing renewable energy desalination, before some of the pilots – including Trevi's forward osmosis and Abengoa's MD units – recently started to use a solar thermal system deployed at the site. "Since the success of the acceptance test when we exceeded the announced performance with 3.19kwh/m³ of seawater with a salinity of 46 g/L, we received the agreement from Masdar to qualify smaller units of our product line producing 10 and 1m³/d" said Maxime Therrillion, Business Developer at Mascara. Mascara is also pursuing opportunities in Francophone countries such as Tunisia and Morocco, which is promoting the use of renewable energy for desalination purposes due to high energy costs there. Morocco recently called for expressions of interest for a 36,000m³/d seawater desalination plant for irrigation purposes; it will be integrated with a 26MW wind farm in the region of Dakhla, Western Sahara.

> "In terms of raw reduction of energy consumption of RO, the most promising innovations that have emerged are semi-batch or batch operation of RO systems
>
> Professor John Lienhard, J-WAFS

Prospects for renewables

Piloting desalination systems powered by renewable energy sources can help prove their case, but in the near to medium term their uptake will be inhibited by higher upfront costs for the client. This is recognised as the most significant barrier and vendors need to ensure a short payback period. The best business model is yet to be determined, particularly in the decentralised solutions space.

"We are initially aiming for EPC contracts, but going for a BOO or BOT approach would be effective to display the system is actually working," said Mascara's Therrillion. EWM meanwhile is implementing a privately financed 50m³/d project in Cabo Verde which will include a water purchase agreement (WPA), unprecedented in the small scale desalination market. "The smallest water purchase agreements are a few thousand cubic metres a day and this is only 50m³/d, so it will be a very unique showcase in terms of financing but also [for an] off-grid, independent WPA," noted Vollebregt.

Synlift offers both solar and wind systems, but in larger projects sees the benefits of wind power due to a higher capacity factor. Kaeufler explained to GWI: "A high penetration system that is using 80%-plus of solar or wind technology will need more flexible capacity on the desalination side for a solar system compared to a wind system." However, solar has a cost advantage. "The prices for solar [per kWh] have not bottomed out. Wind technology is very material intensive and we do not see cost reductions in the coming years in wind technology," Kaeufler added.

Optimising current desal technologies

Away from renewables, reducing the carbon footprint of desalination can be achieved by optimising mature technologies. This entails improving the energy efficiency of existing desalination processes through solutions such as incremental improvements in membrane processes, energy recovery devices or deploying hybridised desalination plants – those that use both MED and RO technology. In these plants the aim is to reduce energy consumption as the RO portion is generally operated at lower than normal pressure because optimal TDS removal is not required. The permeate is blended with the much purer distillate from the MED stage, producing a water that would not be as pure as that from an MED plant, but still meets WHO drinking water standards.

Another optimisation technique is to increase and decrease the pressure of an RO system depending on the time of day, to coordinate higher energy usage with periods when electricity tariffs are lower. This is widely practised by IDE Technologies on plants in Israel, and could be replicated in a system powered by solar energy: when the sun disappears, the operating pressure is reduced until high solar energy returns. ▶

The RO process can be further optimised in different ways. "In terms of raw reduction of energy consumption of RO, the most promising innovations that have emerged are semi-batch or batch operation of RO systems," said Professor John Lienhard, director of MIT's Abdul Latif Jameel World Water and Food Security Lab (J-WAFS), and co-ordinator of the October 2016 workshop. An example of a semi-batch system is the Closed Circuit Desalination (CCD) technology from Desalitech, which has driven the energy consumed in desalination towards the thermodynamic minimum. The CCD technology was originally developed for the seawater desalination market, but has found its niche in high recovery of brackish water, most likely because concentrating seawater takes more energy due to its higher salinity. Batch operation could take energy efficiency even further, however it is still some years from deployment, according to Lienhard. "There is more work that needs to be done, and we're actively engaged in that," he added.

Trevi Systems, which has traditionally specialised in forward osmosis, has been trialling renewable energy with improvements in RO membrane system topology that will lower operating power through pressure reduction. "We foresee RO systems operating at 40 bar in the near future that will better allow them to couple to solar PV systems," Trevi CEO John Webley told GWI. Trevi has ambitions to take the pressure down further. "The system could go to 30 bar, where the entire RO system could be built out of plastic piping, providing a nice capex advantage," Webley added.

Improved pretreatment can also potentially lower the energy consumption of an RO process, and hence the operating costs. At Masdar's Ghantoot pilot site, Veolia Sidem has deployed its Spidflow filter, a combination of its Spidflow flotation system and Filtraflo TGV, a gravity multimedia filter, in one process unit, upstream of an RO unit, to tackle biofouling. "The Spidflow filter tackles biofouling molecules by allowing biomass development in the media of the filter," explained Nelly Pitt, Head of Process Department at Sidem. "We like to highlight that compared to ultrafiltration, with the Spidflow filter there is a lower biofouling potential with the pretreated seawater for RO membranes, which is really critical." The harsh waters of the Gulf region have not been conducive to RO processes because of high salinities and constant threat of algal blooms. They need extensive pretreatment, usually in the form of a DAF and media or membrane filtration system.

ED, which fell out of favour in the water treatment business in the 1970s following the development of RO has seen an uptick in interest as an alternative to RO. It is understood that Evoqua's trial of its NEXED technology with PUB in Singapore resulted in promising energy consumption figures, however the cost benefits are yet to be adequately demonstrated. ED is also gaining increasing interest for brine concentration applications. "We've done a lot of work to show that ED has potential for high salinity waters, basically because at higher salinity you have more charge conductors in the water, so the electrical resistance is not as high," Lienhard told GWI. However, valuable though this research is, it is some years away from commercialisation.

The European Union-funded Horizon 2020 REvivED project can build on MIT research, having the bold ambition of establishing ED as the "new standard for desalination of seawater", extolling reduced energy consumption compared to RO technology. Running between May 2016 and April 2020, the REvivED consortium of companies will run pure ED systems as well as the integration of ED-RO in one application and ED-reverse electrodialysis (RED) in another – RED has the potential to produce clean energy from the use of salinity gradients.

The hybridisation of thermal desalination processes can lead to thermodynamic synergies when using low grade heat sources, meaning that more water can potentially be produced with the same energy input. Singapore start-up MEDAD Technologies is employing IP from the National University of Singapore (NUS) and Saudi Arabia's KAUST to couple MED with an adsorption desalination (AD) step, which can run on either waste heat (from industrial exhausts for example) or solar thermal energy. The theory is that the AD step enables the output temperature of the water from the MED stage to be much lower than the ambient temperature and expands the operating ▶

Terminology

Concentrated solar power (CSP): generation of solar power that uses contraptions such as mirrors and lenses to concentrate sunlight or solar thermal energy onto a particular area and heat fluid in a receiving tube. Arrangements include linear Fresnel, parabolic troughs or towers.

Electrodialysis: an electrodialysis stack consists of alternating cation- and anion-permeable membranes. An electric potential is applied which makes ions in the water migrate towards electrodes of the opposite charge.

Forward osmosis (FO): water molecules from a feed solution are naturally transported across a membrane by osmosis into a concentrated draw solution with an osmotic pressure higher than that of the feed. The osmotic driving forces in FO can be significantly greater than the hydraulic driving forces in RO, leading to potentially higher fluxes and recoveries.

Linear Fresnel: flat or curved mirrors attached to the ground are configured to reflect sunlight onto a receiving tube that contains fluid which heats up to create thermal energy or electricity.

Membrane distillation (MD): a low temperature, thermally driven desalination process that employs a porous, hydrophobic membrane to separate heated feedwater from a cool distillate. Pure water vapour passes through the membrane due to the difference in feed/product water temperature, condensing as distillate on the cooler side.

Multiple effect distillation (MED): thermal desalination technology where cool feedwater is sprayed over heat exchange tubes, causing steam flowing through the tubes to condense into pure product water.

Parabolic trough: the receiver tube is placed in a parabola shaped reflector which receives the sunlight. The heat transfer fluid flows out to create steam or is sent to a turbine.

Reverse electrodialysis: solutions of different salinities are passed through a stack of alternating anion and cation exchange membranes, using the salinity gradient to generate clean energy.

Solar photovoltaic (PV): solar panels absorb sunlight to generate electricity before the current is inverted from DC to AC. Can feed the electricity grid which is powering a desal plant, or sit on the roof of a much smaller system.

Solar still: distillation of water using the sun's heat to evaporate water, which then condenses again for collection. Stills can go up to significant scale.

temperature range of that stage, increasing the number of recoveries for the MED system. However, the MEDAD system currently carries significantly high capex and physical footprint, and will require some upstream hardness removal to limit scaling that could be a problem when operating at higher temperatures. Following a 2–5m^3/d pilot plant at KAUST, MEDAD has built a 700m^3/d AD desalination plant in Riyadh that will use solar thermal energy, hybridised with an MED plant to treat RO reject brine.

> “It is extremely promising to couple solar energy with a forward osmosis (FO) system, because the promise of more energy efficiency is very high in FO.
>
> Manoj Divakaran, Empereal Energy

Impact of emerging desal technologies

The use of mature RO or thermal technologies for connecting to a renewable energy or waste heat source has been well explored. But what of emerging desal technologies?

Forward osmosis has made some headway into the brine concentration market and shows some promise as a pretreatment for RO systems, diluting seawater in order to reduce the energy requirement of the RO system. It is conducive to using solar thermal as an energy source because it is a low temperature process. Trevi Systems is developing several FO projects using solar thermal technology in Kuwait, Saudi Arabia, and for the US Navy. “We use solar thermal because we can store the hot water in a tank, and it is 10 times cheaper than storing energy in a battery,” Webley explained. All the projects are currently less than 100m^3/d, but Webley told GWI that the Saudi project will soon be scaled up to 500m^3/d, and if that is successful, then a 10,000m^3/d plant is on the cards. For thermal storage, Webley added that “for large size systems, higher temperature molten salt is also more economical to store than battery storage.” Molten salt has been identified as a low-cost medium to store solar thermal energy.

Pairing forward osmosis with solar thermal technology has excited Empereal Energy, which is teaming up with Trevi to undertake a pilot in the state of Tamil Nadu in India. “It is extremely promising to couple solar energy with a forward osmosis system, because the promise of more energy efficiency is very high in FO,” Manoj Divakaran told GWI. “That may allow more of these 24/7 solar desal systems to work if you can couple a good FO system with a solar energy generation system.” Empereal and Trevi are currently drawing up the design for a 20m^3/d FO system, and will aim to demonstrate the ability of the system to operate 24/7 on solar energy alone.

Membrane distillation (MD) is also a low temperature process that operates at near-ambient pressure, which makes it conducive to the use of renewable sources of energy. For example, it could operate with low-grade heat obtained from geothermal energy sources. The US Department of Energy’s Geothermal Technologies Office is supporting a project for the production of freshwater via MD. However, the MD process has faced significant scaling up challenges, even with conventional energy sources, and a geothermal source would need to be stable and close to a population centre if MD is to be used for municipal purposes. ■