ELECTRIC POWER RESEARCH INSTITUTE

TECHNOLOGY INSIGHTS

A Report from EPRI's Innovation Scouts

RENEWABLE ENERGY COUPLED WITH WATER DESALINATION

THE TECHNOLOGY

Renewable energy sources driving desalination technologies to produce fresh water.

THE VALUE

Using wind and solar power for desalinating water may have considerable potential to be cost effective where favorable site conditions exist.

EPRI'S FOCUS

Accelerate the development and deployment of renewable-energy powered desalination through collaboration with the electricity industry.

TECHNOLOGY OVERVIEW

Desalination is a water treatment process that separates salts from saline water to produce potable water that is low in total dissolved solids (TDS) (< 500 ppm). Desalination technology, developed extensively over the past 40 years, can now be reliably used to produce fresh water from saline sources. The cost for desalination can be significant because of its intensive use of energy. However, in many areas of the world, the cost to desalinate saline water is less than other alternatives that exist or that may be considered for the future. Desalinated water is used as the main source of municipal water supply in many areas of the Caribbean, North Africa, Southern Europe, and the Middle East. Using desalination technologies, especially for softening mildly brackish water, is increasing rapidly in various parts of the world.

As renewable energy (RE) technologies advance and environmental concerns are raised, these technologies are becoming more interesting partners for powering water desalination processes. This Technology Insights Brief analyzes the potential for and the viability of coupling wind energy and solar power with fresh water production through desalination.

Water desalination can be achieved through either thermal energy (using phase-change processes) or electricity (driving membrane processes), and these renewable sources are best matched to particular desalination technologies.

There is simply not one best method of desalination. Instead, the selection of a process should depend on a careful study of site conditions and the application at hand. Local circumstances may play a significant role in determining the most appropriate process for an application.

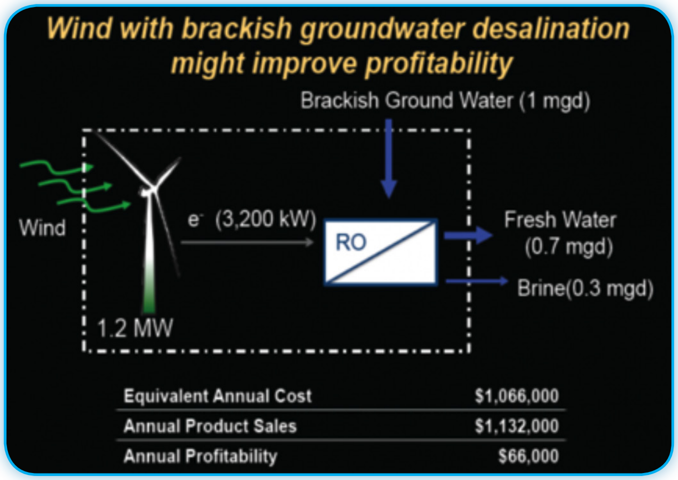

Figure 1 – Wind-brackish reverse-osmosis water desalination coupling [8]

RE can be coupled with desalination processes in rather conventional hybrid systems, such as solar-thermal with phase-changing processes and photovoltaic (PV) or wind power with membrane processes. These processes have been developed to be cost effective with conventional powered systems under favorable site circumstances.

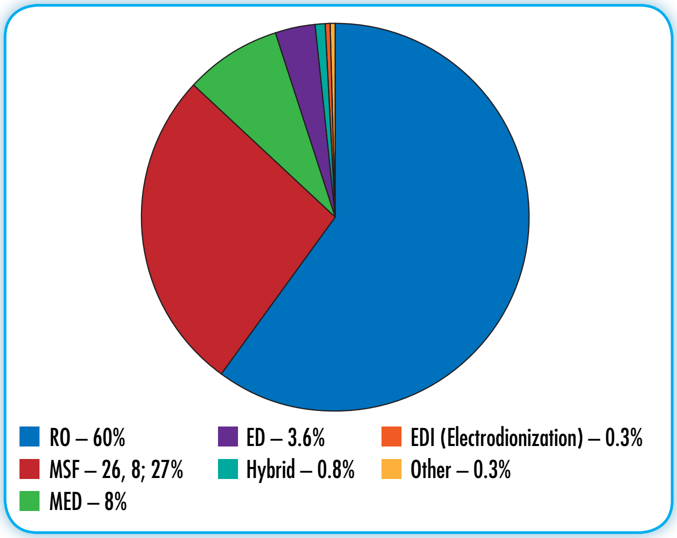

Figure 2 – Desalination technology market [1]

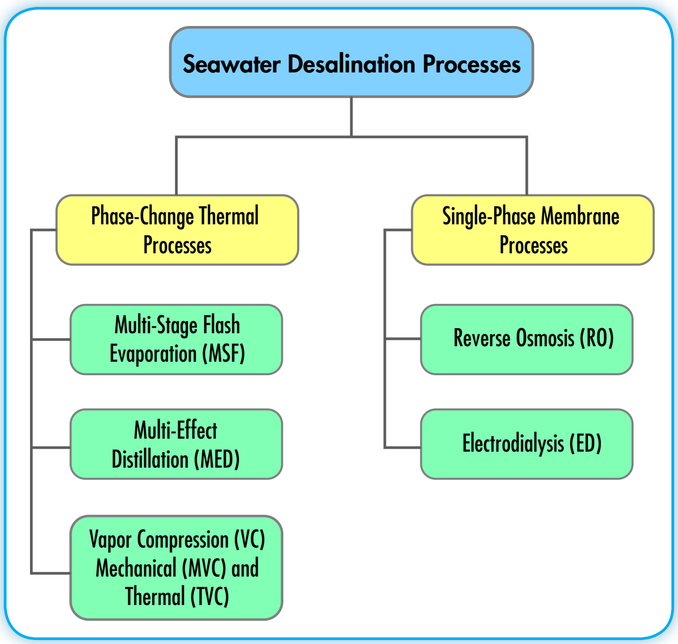

Figure 3 – Main desalination processes [7]

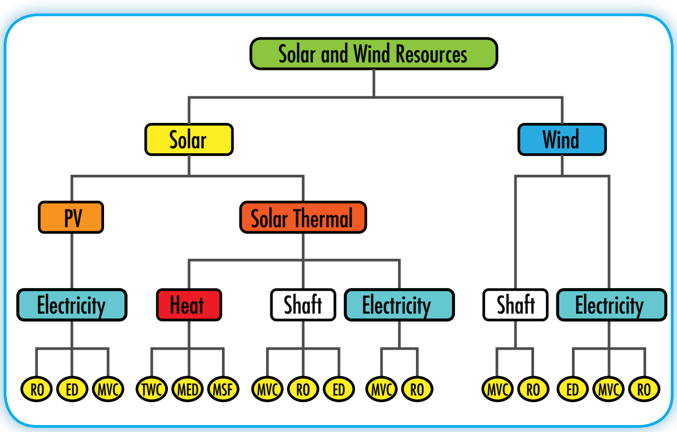

Figure 4 – Possible combinations of solar-wind and desalination processes [7]

BASIC SCIENCE

Desalination is provided by a set of mature commercial technologies that remove salt and other minerals from feedwater such as seawater, underground brackish water, or industrial waste water. Desalination is currently the most reliable and cost-effective means of producing fresh water in many Persian Gulf countries and other parts of the world. Desalination technologies (see Figure 3) include:

- ***Phase-changing processes*** involve liquid to vapor phase change, such as in multistage flash (MSF) evaporation, multi-effect distillation (MED), and vapor compression (VC) distillation processes. Phase-change distillation (MSF, MED) processes are viable only for high-salinity feedwater (~35,000 TDS) and are used in large-capacity plants.
- ***Membrane processes*** use a membrane either to allow fresh water to pass through and reject the salt as a concentrate, such as in the reverse-osmosis (RO) process, or to allow certain ions to pass through, as in the electrodialysis (ED) process. Membrane processes can be used for both high-salinity water and brackish water (1,000–10,000 ppm TDS) and in both large- and small-capacity plants.

Distillation processes are a very established technology and are characterized by high-quality-product water production; they are less impacted by the quality of feedwater and have lower maintenance costs than membrane processes.

Compared to distillation, membrane processes have lower capital costs, less energy consumption, a higher recovery ratio, a higher space-to-production ratio, and less corrosion and scaling due to ambient temperature operation.

POTENTIAL IMPACT

Using desalination technologies driven by renewable energy sources (RESs) is a viable way to produce fresh water in many locations today. As the technologies continue to improve and as fresh water and cheap conventional sources of energy become scarcer, RES desalination will become even more attractive. Fortunately, RE has unique synergies in regions where desalination is most needed. Figure 4 shows possible combinations of solar and wind systems with desalination processes.

Proper matching of desalination systems with stand-alone power supplies has been recognized as being crucial if the system is to provide a satisfactory supply of power and water at a reasonable cost. Selecting the appropriate RES desalination technology depends on a number of factors, including the amount of water needed (plant size), feedwater salinity, remoteness, availability of grid electricity, technical infrastructure, and the type and potential of the local RE resource.

If a RE resource is available at the desalination site, experience has shown no significant technical problems in combining RE systems and desalination units. The only current limitation is the economic factor. Especially during the last two decades, numerous desalination systems using RE have been constructed. Many of these plants have been research or demonstration projects with small capacity.

Hybrid desalination systems are independent and incorporate more than one power source. One important application is the use of PV and wind generators to drive RO desalination units. Diesel generators are used mainly as backup; however, fuel transportation to remote areas poses the same difficulties as water transportation. Nevertheless, there are hybrid desalination plants operating in Greece and many isolated islands.

VALUE TO THE INDUSTRY

The technical feasibility of desalination systems that are powered by renewables should be accompanied by economic feasibility to justify the implementation of the technology. Despite the free nature of RESs, their collection systems are not always viable or affordable. Therefore, it is important to look at the economic aspects of desalination systems powered by various RE systems. Typically, when comparing cost distribution for conventional systems and plants driven by RE systems, investment costs are higher for RE-powered plants, but the energy costs are the lowest.

There are locations, such as West Texas in the United States, where windy nights, copious brackish groundwater, high levels of drought, and a strained electric grid provide the perfect setting for alternative energy and water production opportunities that make economic and environmental sense. Brackish groundwater desalination is a very energy-intensive process. Wind-generated electricity is available there primarily at night when it is not needed; therefore, an attractive alternative to storage would be to use the power locally for groundwater desalination. By selling the excess energy for fresh water production, the economics of both wind farms and water production would be improved while reducing emissions, compared to the use of fossil fuels. This model may be applicable to many other locations worldwide.

The techno-economic viability of operating either solar-thermal or solar-PV desalination units tends to be related to the cost of producing energy with these alternative energy devices. At this time, the cost is high, but it is expected to decline as further development reduces their capital costs. Using solar power for desalinating water may have a considerable potential to be cost effective where favorable site conditions exist.

STATE OF THE TECHNOLOGY

- ***Desalination systems driven by solar-thermal.*** The best known solar-thermal distillation combination is a solar-thermal MED. From an energy perspective, the main supply to the desalination plant is a large thermal input from the solar field, as well as some auxiliary electricity required for pumping. Research has shown that the combination of solar-thermal distillation seems best suited for medium-high (>10,000 m^3/day) production capacities. There are a few of these plants in Spain, Tunisia, and Oman that have been operating since the early 2000s. The Technical Readiness Level (TRL) of this RE and desalination coupling is 8.
- ***Desalination systems driven by wind.*** Wind turbines can be used to supply electricity or mechanical power to desalination plants. Few applications have been implemented using wind energy to drive a mechanical vapor compression unit. A number of wind energy and RO combination systems have been designed and tested in France, Greece, and Spain. A combination of wind coupled with RO has been commercially developed by the German company ENERCON. This company provides modular and energy-efficient RO desalination systems driven by wind turbines (grid-connected or stand-alone systems) for brackish and seawater desalination. Amounts of water desalinated per day range from 175 to 1,400 m^3 for seawater and 350 to 2,800 m^3 for brackish water. The present TRL of this RE and desalination coupling is 7–8.
- ***Desalination systems driven by PV.*** The main advantages of coupling PV with RO desalination are the ability to develop small desalination plants, the ease of transportation and installation of PV, and the limited maintenance costs of PV. RO pumps usually employ ac motors, which means that either dc-to-ac inverters or dc motors would be required to enable these systems. Energy storage is again a matter of concern, and batteries are used for PV output power smoothing or for sustaining system operation when solar energy is insufficient. Typical PV-coupled RO applications are standalone. There are a number of these small plants operating in desert areas of Australia and Indonesia. The present TRL level is ~7.

NEXT MILESTONE

The feasibility of RE coupled with desalinated water production is highly related to the cost of the energy produced from these systems, which reflects, in many cases, a higher water cost. The capital costs, as well as the operation and maintenance costs, can be reduced if a hybrid energy source comprising both fossil and renewable energy is considered. Such a hybrid energy source can reduce the production cost of desalinated water along with the additional benefits of lower emissions of CO_2 and lower electricity consumption.

Figure 2 shows the desalination technologies market. A breakdown of desalination processes driven by RE worldwide is as follows: RO 62%; ED 5%; MSF 10%; MED 10%; VC 5%; and others 4%, out of which 43% of desalination processes are powered by solar PV, 27% by solar thermal, 20% by wind, and 10% by RE hybrid combinations. Recently, PV panels and wind turbine generators have experienced sharp cost reductions, opening promising opportunities for applications in combination with RO desalination systems.

The value of fresh water continues to increase, especially in areas where the scarcity for both water and energy is highly pronounced. Installing RE-driven desalination will ensure the supply of fresh water, but it may also bring down the cost for fresh water production. Use of RE will bring environmental benefits as well.

The next milestones will be pilot tests, demonstrations, and commercial deployment of:

- Hybrid RE systems in combination with fossil energy to optimize the cost of water production (evolving from TRL 7, System Prototype Demonstration in an operational environment, to 8–9, System Completed and Qualified Through Test and Demonstration – System Proven Through Success Operation)
- Co-generation systems that produce water and power (evolving from TRL 7, System Prototype Demonstration in an Operational

- Environment, to 8–9, System Completed and Qualified Through Test and Demonstration – System Proven Through Success Operation)
- New desalination plant components that are designed to allow robust, smoother, more efficient coupling with RE and that can operate in harsh environments (evolving from TRL 6, System Prototype Demonstration in a Relevant Environment, to 7–8, System Prototype Demonstration in an Operational Environment – Completed and Qualified Through Test and Demonstration)

COLLABORATION

CURRENT COLLABORATORS

Numerous institutions are currently fostering the application of renewables to the production of fresh water including:

- International Renewable Energy Agency (IRENA)
- Promotion of Renewable Energy for Water Production Through Desalination (PRODES)
- International Energy Agency-Energy Technology Systems Analysis Program (IEA-ETSAP)
- Fraunhoffer Institute (Germany)
- CIEMAT (Spain)
- LNEG (Portugal)
- National Renewable Energy Laboratory (NREL) (United States)

Additionally, there are companies in the market commercializing turnkey systems with different levels of maturity, such as ENERCON (Germany). BEFESA (Spain), GE (United States), and Fitchner (Germany).

The coupling of RE and desalination technologies are the subject of numerous R&D projects by universities and research institutes worldwide.

EPRI ENGAGEMENT

The Electric Power Research Institute (EPRI) is not currently engaged with any technology developer that is coupling RE with water desalination.

The main interest of most developers is to obtain funding of the substantial investments required to build and test pilot programs and small prototypes during extended periods in order to assess the system's performance reliability and production costs.

EPRI's potential role could be as a provider of independent technology and prototype test result assessments. Combining variable renewable technologies and desalination processes involves technical, economic, and organizational challenges. Technical developments include significant availability of low-cost RE and energy storage technologies in order to address the variable nature of RE. Another key issue is the disposal of brine, that is, minimizing the impact on ecosystems of its disposal and/or recycling.

OPPORTUNITIES FOR COLLABORATION

EPRI's role regarding this technology could be as an observer of the development and testing of the integrated RE and desalination component prototypes being developed for different key technologies.

Independent assessment of the first pre-commercial units, monitoring the "as-built" long-term reliability, efficiency, and operation and maintenance costs versus design targets, may be of interest in order to reduce the risk and financial cost of subsequent large-scale applications by early adopters.

NEXT STEPS

For the most part, RE and desalination technologies have developed along independent paths with no consideration as to how the two technologies may be integrated.

Wind and solar sources are variable energy resources; that is, the wind does not always blow and the sun does not always shine. The design of conventional desalination plants, however, is based on a constant supply of energy, so there is typically a mismatch between energy supply and demand. Therefore, either the RE or the desalination plant is underutilized. Operations under variable conditions also lead to increased maintenance requirements and costs, making RE-desalination plants less commercially attractive.

Key technological strategies to overcome barriers associated with poor reliability, increased water costs, and increased capital and maintenance costs include:

- Better seawater- and brackish water–resistant materials
- Better control systems to optimize performance and minimize maintenance requirements
- Development of standardized, reliable, robust systems integrating RE energies with desalination units offered to the end user with comprehensive performance guarantees
- A supply of energy made more constant by hybridization (that is, wind coupled with PV) and RE integrated through the electricity grid, with tailor-made control systems to guarantee continuous operation
- Alternatively, minimization of the impact of a variable energy supply on desalination plant operation (that is, development of RO membranes that are less sensitive to variable pressure and flow)

EPRI may contribute to accelerating the development and deployment of RE-powered desalination, for instance, through collaboration with the electricity industry by funding selected pilot projects. In addition, EPRI could perform independent performance assessments of the first commercial units as they are deployed.

REFERENCES

A number of independent assessments, reports, and articles address the issue of watch desalination using RE. See the references below:

1. "Water Desalination Using Renewable Energy," International Renewable Energy Agency, http://www.irena.org/DocumentDownloads/Publications/Water_Desalination_Using_Renewable_Energy_-_Technology_Brief.pdf
2. "Roadmap for the Development of Desalination Powered by Renewable Energy," http://wrri.nmsu.edu/conf/conf11/prodes_roadmap_online.pdf
3. De La Nuez Pestana et al. "Optimization of RO Desalination Systems Powered by RE," http://www.desline.com/articoli/5287.pdf
4. "Seawater Desalination Systems: An Application Example," http://www.wwindea.org/technology/ch05/en/5_2_1.html
5. "Additional Documents for Modeling Results of Wind/Diesel Retrofit Options for Santa Cruz, Galapagos," http://wind.nrel.gov/public/Corbus/Galapagos%20Homer/Additional%20Documents%20for%20prefeasibility%20analysis%20of%20wind%20Systems%20on%20Santa%20Cruz%20Final%20Report.pdf
6. Renewable and Sustainable Approaches for Desalination. Veera G. Gude and alts. 2010. http://ases.conference-services.net/resources/252/2859/pdf/SOLAR2012_0591_full%20paper.pdf
7. "Solar and Wind Opportunities for Water Desalination in the Arab Regions," Ali Al- Karaghouli, David Renne, Lawrence L. Kazmerski, Renewable and Sustainable Energy Reviews.13 (2009) pp. 2397–2407. http://wrri.nmsu.edu/conf/conf11/solar_wind_desal_arab.pdf
8. "How Wind Energy Can Power Desalination in Texas," http://www.scoop.it/t/sustainable-technologies/p/2314047848/how-wind-energy-can-power-desalination-in-texas.

1026887 March 2013

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