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# Case History | Tapping the oceans

**Environmental technology: Desalination turns salty water into fresh water. As concern over water's scarcity grows, can it offer a quick technological fix?**

THERE are vast amounts of water on earth. Unfortunately, over 97% of it is too salty for human consumption and only a fraction of the remainder is easily accessible in rivers, lakes or groundwater. Climate change, droughts, growing population and increasing industrial demand are straining the available supplies of fresh water. More than 1 billion people live in areas where water is scarce, according to the United Nations, and that number could increase to 1.8 billion by 2025.

One time-tested but expensive way to produce drinking water is desalination: removing dissolved salts from sea and brackish water. Its appeal is obvious. The world's oceans, in particular, present a virtually limitless and drought-proof supply of water. "If we could ever competitively—at a cheap rate—get fresh water from salt water," observed President John Kennedy nearly 50 years ago, "that would be in the long-range interest of humanity, and would really dwarf any other scientific accomplishment."

According to the latest figures from the International Desalination Association, there are now 13,080 desalination plants in operation around the world. Together they have the capacity to produce up to 55.6m cubic metres of drinkable water a day—a mere 0.5% of global water use. About half of the capacity is in the Middle East. Because desalination requires large amounts of energy and can cost several times as much as treating river or groundwater, its use in the past was largely confined to wealthy oil-rich nations, where energy is cheap and water is scarce.

But now things are changing. As more parts of the world face prolonged droughts or water shortages, desalination is on the rise. In California alone some 20 seawater-desalination plants have been proposed, including a $300m facility near San Diego. Several Australian cities are planning or constructing huge desalination plants, with the biggest, near Melbourne, expected to cost about $2.9 billion. Even London is building one. According to projections from Global Water Intelligence, a market-research firm, worldwide desalination capacity will nearly double between now and 2015.

Not everyone is happy about this. Some environmental groups are concerned about the energy the plants will use, and the greenhouse gases they will spew out. A large desalination plant can suck up enough electricity in one year to power more than 30,000 homes.

The good news is that advances in technology and manufacturing have reduced the cost and energy requirements of desalination. And many new plants are being held to strict environmental standards. One recently built plant in Perth, Australia, runs on renewable energy from a nearby wind farm. In addition, its modern seawater-intake and waste-discharge systems minimise the impact on local marine life. Jason Antenucci, deputy director of the Centre for Water Research at the University of Western Australia in Perth, says the facility has "set a benchmark for other plants in Australia."

References to removing salt from seawater can be found in stories and legends dating back to ancient times. But the first concerted efforts to produce drinking water from seawater were not until the 16th century, when European explorers on long sea voyages began installing simple desalting equipment on their ships for emergency use. These devices tended to be crude and inefficient, and boiled seawater above a stove or furnace.

An important advance in desalination came from the sugar industry. To produce crystalline sugar, large amounts of fuel were needed to heat the sugar sap and evaporate the water it contained. Around 1850 an American engineer named Norbert Rillieux won several patents for a way to refine sugar more efficiently. His idea became what is known today as multiple-effect distillation, and consists of a cascading system of chambers, each at a lower pressure than the one before. This means the water boils at a lower temperature in each successive chamber. Heat from water vapour in the first chamber can thus be recycled to evaporate water in the next chamber, and so on.

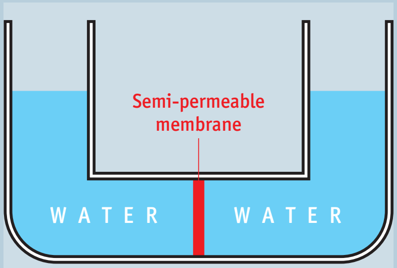
## No salt, please

This reduced the energy consumption of sugar refining by up to 80%, says James Birkett of West Neck Strategies, a desalination consultancy based in Nobleboro, Maine. But it took about 50 years for the idea to make its way from one industry to another. Only in the late 19th century did multi-effect evaporators for desalination begin to appear on steamships and in arid countries such as Yemen and Sudan.

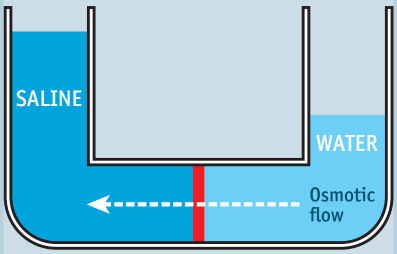
A few multi-effect distillation plants were built in the first half of the 20th century, but a flaw in the system hampered its widespread adoption. Mineral deposits tended to build up on heat-exchange surfaces, and this inhibited the transfer of energy. In the 1950s a new type of thermal-desalination

**Under pressure**

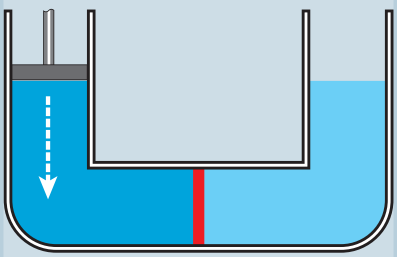
How reverse osmosis works



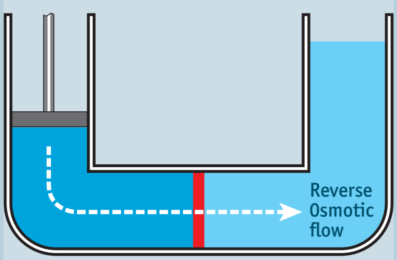

**1.** Two vessels are separated by a semi-permeable membrane that allows water to diffuse from one side to the other, but restricts the passage of dissolved salts.




**2.** When the liquid on one side of the membrane is saltier than on the other side, water diffuses through the membrane from the less concentrated to the more concentrated side. This process, which tends to equalise the saltiness of the two solutions, is called osmosis, and the flow is called osmotic flow.



**3.** The process of osmosis can be stopped by applying pressure to the saltier solution to stop the influx of water molecules. The pressure required (which is equal and opposite to the pressure exerted, in effect, by osmosis) is known as the osmotic pressure.




**4.** Applying pressure greater than the osmotic pressure does not simply stop the osmosis, but forces it into reverse. The salty liquid becomes even more concentrated, and pure water builds up on the other side of the membrane. This is called reverse osmosis.

Source: *The Economist*

process, called multi-stage flash, reduced this problem. In this, seawater is heated under high pressure and then passed through a series of chambers, each at a lower pressure than the one before, causing some of the water to evaporate or "flash" at each step. Concentrated seawater is left at the bottom of the chambers, and freshwater vapour condenses above. Because evaporation does not happen on the heat-exchange surfaces, fewer minerals are deposited.

Countries in the Middle East with a lot of oil and a little water soon adopted multi-stage flash. Because it needs hot steam, many desalination facilities were put next to power stations, which generate excess heat. For a time, the cogeneration of electricity and water dominated the desalination industry.

Research into new ways to remove salt from water picked up in the 1950s. The American government set up the Office of Saline Water to support the search for desalination technology. And scientists at the University of Florida and the University of California, Los Angeles (UCLA) began to investigate membranes that are permeable to water, but restrict the passage of dissolved salts.

Such membranes are common in nature. When there is a salty solution on one side of a semi-permeable membrane (such as a cell wall), and a less salty solution on the other, water diffuses through the membrane from the less concentrated side to the more concentrated side. This process, which tends to equalise the saltiness of the two solutions, is called osmosis. Researchers wondered whether osmosis could be reversed by applying pressure to the more concentrated solution, causing water molecules to diffuse through the membrane and leave behind even more highly concentrated brine.

Initial efforts showed only limited success, producing tiny amounts of fresh water. That changed in 1960, when Sidney Loeb and Srinivasa Sourirajan of UCLA hand-cast their own membranes from cellulose acetate, a polymer used in photographic film. Their new membranes boasted a dramatically improved flux (the rate at which water molecules diffuse through a membrane of a given size) leading, in 1965, to a small "reverse osmosis" plant for desalting brackish water in Coalinga, California.

The energy requirements for thermal desalination do not much depend on the saltiness of the source water, but the energy needed for reverse osmosis is directly related to the concentration of dissolved salts. The saltier the water, the higher the pressure it takes (and hence the more energy you need) to push water through a membrane in order to leave behind the salt. Seawater generally contains 3,337 grams of dissolved solids per litre. To turn it into drinking water, nearly 99% of these salts must be removed. Because brackish water contains less salt than seawater, it is less energy-intensive, and thus less expensive, to process. As a result, reverse osmosis first became established as a way to treat brackish water.

Another important distinction is that reverse osmosis, unlike thermal desalination, calls for extensive pre-treatment of the feed water. Reverse-osmosis plants use filters and chemicals to remove particles that could clog up the membranes, and the membranes must also be washed periodically to reduce scaling and fouling.

## Getting better all the time

In the late 1970s John Cadotte of America's Midwest Research Institute and the FilmTec Corporation created a much-improved membrane by using a special cross-linking reaction between two chemicals atop a porous backing material. His composite membrane consisted of a very thin layer of polyamide, to perform the separation, and a sturdy support beneath it. Thanks to the membrane's improved water flux, and its ability to tolerate pH and temperature variations, it went on to dominate the industry. At around the same time, the first reverse-osmosis plants for seawater began to appear. These early plants needed a lot of energy. The first big municipal seawater plant, which began operating in Jeddah, Saudi

**Sometimes, using desalination within water management may be the only way to ensure supply.**

Arabia, in 1980, required more than 8 kilowatt hours (kWh) to produce one cubic metre of drinking water.

The energy consumption of such plants has since fallen dramatically, thanks in large part to energy-recovery devices. High-pressure pumps force seawater against a membrane, which is typically arranged in a spiral inside a tube, to increase the surface area exposed to the incoming water and optimise the flux through the membrane. About half of the water emerges as freshwater on the other side. The remaining liquid, which contains the leftover salts, shoots out of the system at high pressure. If that high-pressure waste stream is run through a turbine or rotor, energy can be recovered and used to pressurise the incoming seawater.

The energy-recovery devices in the 1980s were only about 75% efficient, but newer ones can recover about 96% of the energy from the waste stream. As a result, the energy use for reverse-osmosis seawater desalination has fallen. **The Perth plant, which uses technology from Energy Recovery, a firm based in California, consumes only 3.7kWh to produce one cubic metre of drinking water, according to Gary Crisp, who helped to oversee the plant's design for the Water Corporation, a local utility.** Thermal plants suck up nearly as much electricity, but also need large amounts of steam. "A thermal plant only is practical if you can build it in such a way that it can take advantage of very low-cost or waste heat," says Tom Pankratz, a water consultant based in Texas, who is also a board member of the International Desalination Association.

Economies of scale, better membranes and improved energy-recovery have helped to bring down the cost of reverse-osmosis seawater-desalination. Although the cost of desalination plants and their water depends on where they are, as well as the local costs of capital and operations, prices decreased from roughly $1.50 a cubic metre in the early 1990s to around 50 cents in 2003, says Mr Pankratz. As a result, reverse osmosis is preferred for most modern seawater-desalination (though rising energy and commodity prices mean the cost per cubic metre has now risen to around 75 cents). Experts reckon that further gains in energy efficiency, and hence cost reductions, will be increasingly difficult, however. According to a recent report on desalination from America's National Research Council, energy use is unlikely to be reduced by much more than 15% below today's levels—though that would still be worthwhile, it concludes.

To achieve these reductions, researchers want to find better membranes that allow water to pass through more easily and are less likely to get clogged up. Eric Hoek and his colleagues from UCLA, for example, have developed a membrane embedded with tiny particles containing narrow flow channels, producing a significant increase in water flux. The membrane's smooth surface is also expected to make it harder for bacteria to latch onto. Depending on a plant's design, the new membranes could reduce total energy consumption by as much as 20%, reckons Dr Hoek. The technology is being commercialised by NanoH2O, a company on UCLA's campus.

Meanwhile, the possibility of making membranes out of carbon nanotubes, which consist of sheets of carbon atoms rolled up into tubes, has also garnered attention. A study published in the journal Science in 2006 demonstrated unexpectedly high water-flow rates. But insiders think it will be a decade before the idea is ready for commercialisation.

As desalination becomes more widespread, its environmental impacts, including the design of intake and discharge structures, are coming under increased scrutiny. Some of the damage can be mitigated fairly easily. Reducing the intake velocity enables most fish species and other mobile marine life to swim away from the intake system, though small animals, such as plankton or fish larvae, may still get caught in the intake screens or sucked into the plant.

## Measuring the impact

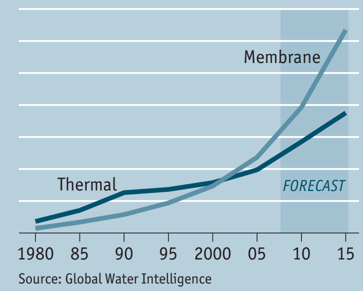
A bigger problem may be the leftover brine, which typically contains twice as much salt as seawater and is discharged back into the ocean. So far little scientific information exists about its long-term effects. In the past, most big seawater-desalination plants were built in places that did not conduct adequate environmental assessments, says Peter Gleick, president of the Pacific Institute, a think-tank based in California that published a report on desalination in 2006. But as plants are built in areas with tighter environmental restrictions, more information is becoming available.

Some recent measurements from Perth are encouraging. Initially scientists from the Centre for Water Research feared that the brine discharge from the plant would increase the saltiness of the coastal environment. But a monitoring study found that salinity returns to normal levels within about 500 metres of the plants' discharge units. "The brine discharge is a prob-

**Membrane gain**

Worldwide installed desalination capacity

Millions of cubic metres per day




Source: Global Water Intelligence

lem that can be overcome with good design," says Dr Antenucci.

A separate problem may be that some metals or chemicals leach into the brine. Thermal-desalination plants are prone to corrosion, and may shed traces of heavy metals, such as copper, into the waste stream. Reverse-osmosis plants, for their part, use chemicals during the pre-treatment and cleaning of the membranes, some of which may end up in the brine. Modern plants, however, remove most of the chemicals from the water before it is discharged. And new approaches to pre-treatment may reduce or eliminate the need for some chemicals.

Based on the limited evidence available to date, it appears that desalination may actually be less environmentally harmful than some other water-supply options, such as diverting large amounts of fresh water from rivers, for example, which can lead to severe reductions in local fish populations. But uncertainties over the environmental impacts of desalination make it hard to draw definite conclusions, the National Research Council concluded. Its report suggested that further research on the environmental impacts of desalination, and how to mitigate them, should be a high priority.

The reverse-osmosis process is increasingly being used not just for desalination, but to recycle wastewater, too. In Orange County, California, reclaimed water is being used to replenish groundwater, and in Singapore, it is pumped into local reservoirs, which are used as a source for drinking water. In both cases, the treated water is also available for tasting at local water-recycling facilities. This "toilet-to-tap" approach may leave some people feeling queasy, but wastewater is a valuable resource, says Sabine Lattemann, a researcher at the University of Oldenburg, Germany, who studies the environmental impacts of desalination. "Energy demand is lower compared to desalination," she explains, "and you can produce high-quality drinking water."

As water becomes more scarce, people will want to find several ways to secure their supplies. Many parts of the world also have enormous scope to use water more efficiently, argues Dr Gleick—and that would be cheaper than desalination. But sometimes, making desalination part of the approach to water management may be the only way to ensure a steady supply of drinking water.

In drought-ridden Western Australia, which ordered conservation years ago, the Water Corporation has adopted what it calls "security through diversity", otherwise known in the industry as the "portfolio" approach. At the moment, Perth's residents receive about 17% of their drinking water from seawater desalination. Desalination makes sense as one of several water sources along with conservation, agrees Dr Antenucci. But, he adds, "to say it is the silver bullet is wrong." ■



## About ERI®

Energy Recovery, Inc. (ERI) is a leading manufacturer of energy recovery devices, which by drastically reducing energy consumption is helping make desalination affordable and enabling the rapid expansion of desalination plants worldwide. ERI's PX Pressure Exchanger® technology (PX®) is a rotary positive displacement pump that recovers energy from the high pressure waste stream of SWRO systems at up to 98% efficiency with no downtime or scheduled maintenance. With over 6,000 PX devices installed or contracted in plants worldwide, PX technology is reducing the cost to produce over 5.2 million cubic meters (1.4 billion US gallons) a day of fresh water and saving customers an estimated 500 MW of energy, or $352 million a year in operating costs. The company has research, development and manufacturing facilities in the San Francisco technology corridor as well as direct sales offices and technical support centers in key desalination hubs such as Madrid, UAE, Shanghai and Florida; including service representatives in Algeria, Australia, China, India, Mexico, Spain and Taiwan.

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