MORA ASSOCIATES
CLEAN ENERGY | CLEAN TECHNOLOGY

Water desalination – Tap into the liquid Gold

Research report
December 2007

Analyst
Leonard Wagner, leonard@moraassociates.com

Table of Contents

Water industry – At a glance

Introduction to H_2O

Water is a common chemical substance that is essential to all known forms of life. In typical usage, water refers only to its liquid form or state, but the substance also has a solid state, ice, and a gaseous state, water vapour. About 1,460 teratonnes (Tt) of water cover 71% of Earth's surface, mostly in oceans and other large water bodies, with 1.6% of water below ground in aquifers and 0.001% in the air as vapour, clouds (formed of solid and liquid water particles suspended in air), and precipitation.

Saltwater oceans hold 97.0% of surface water, glaciers and polar ice caps 2.4%, and other land surface water such as rivers and lakes 0.6%. Water in these forms moves perpetually through the water cycle of evaporation and transpiration, precipitation and runoff usually reaching the sea.

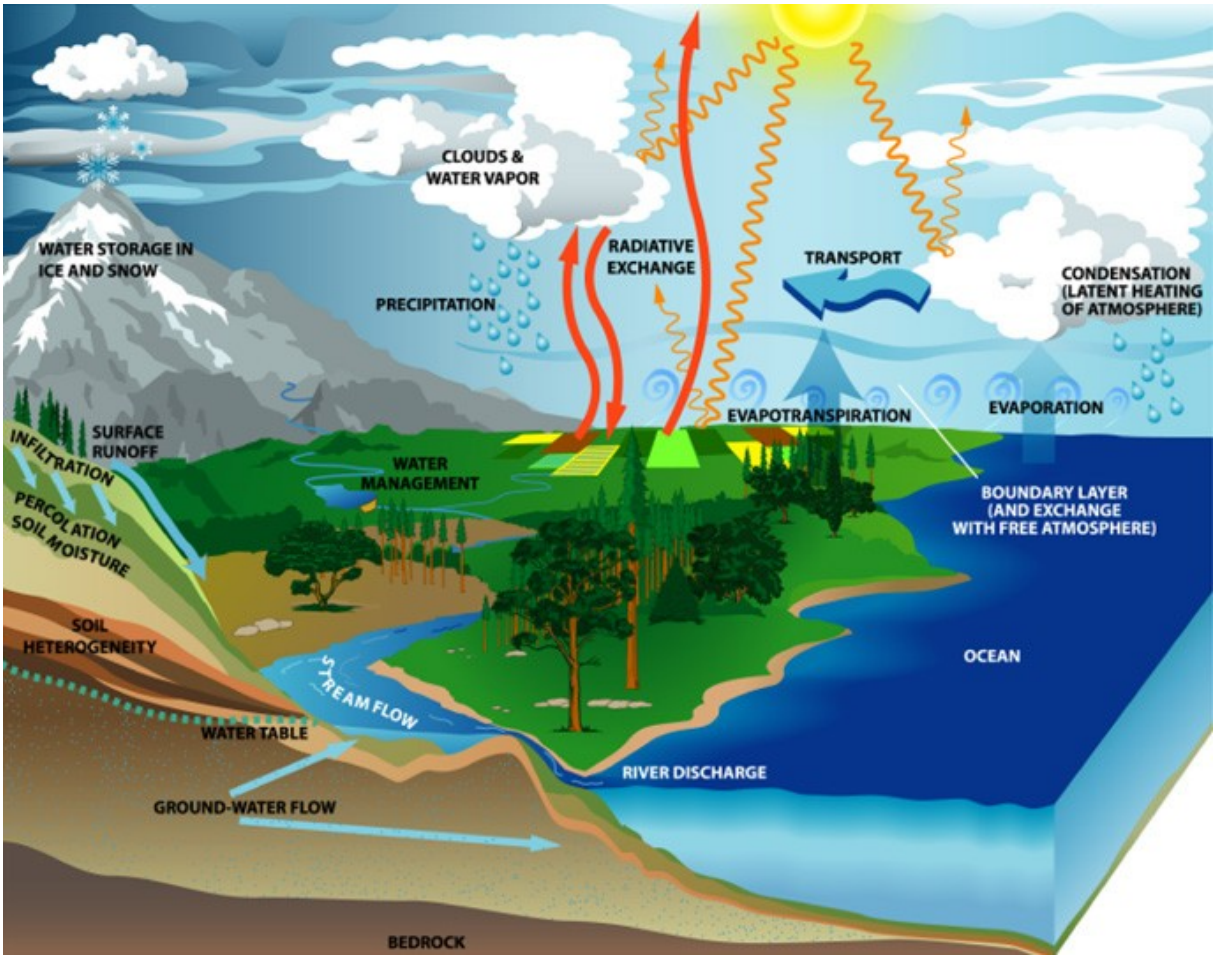


Figure 1 - Conceptualization of the Water Cycle (*Source: US Global Change Research Program)*

Fresh water – a precious commodity

Fresh water refers to bodies of water containing low concentrations of dissolved salts and other total dissolved solids. Fresh water is an important renewable resource, necessary for the survival of most terrestrial organisms, and required by humans for drinking and agriculture, among many other uses.

Fresh water bodies include icecaps, glaciers, and some bodies of ground water. The ultimate source of fresh water is the precipitation of atmosphere in the form of rain and snow.

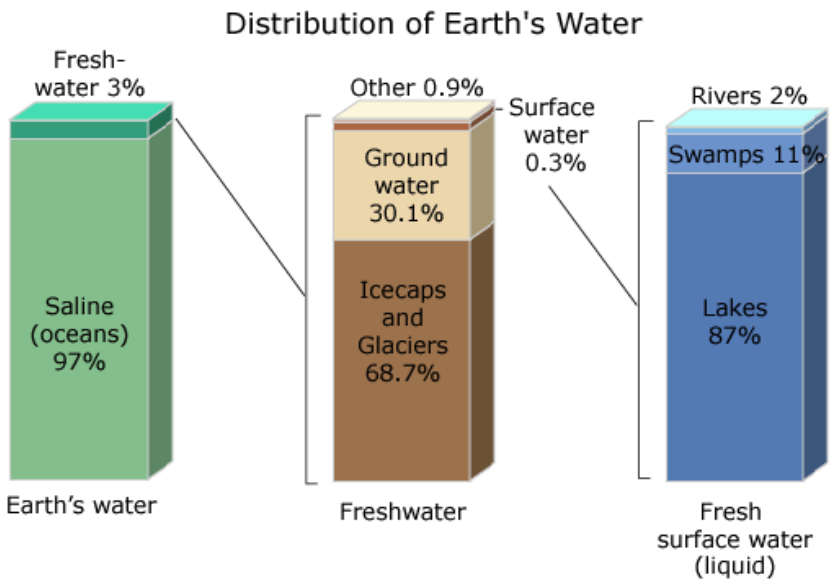


Figure 2 – Distribution of Earth's Water (Source: U.S. Geological Survey)

Although the earth has plenty of water, clean and potable water is becoming increasingly scarce. And while energy security is currently capturing the media's attention and attracting significant pools of capital, water will not be far behind. [7]

Utilities and infrastructure

Worldwide water infrastructure is completely outdated. The outsourcing megatrend of all water services, an increasing demand for water worldwide and a natural monopoly in the industry lead us to forecast above average growth prospects for water investments.

The diagram below outlines the key drivers in the development and investment in the water industry in the forthcoming years.

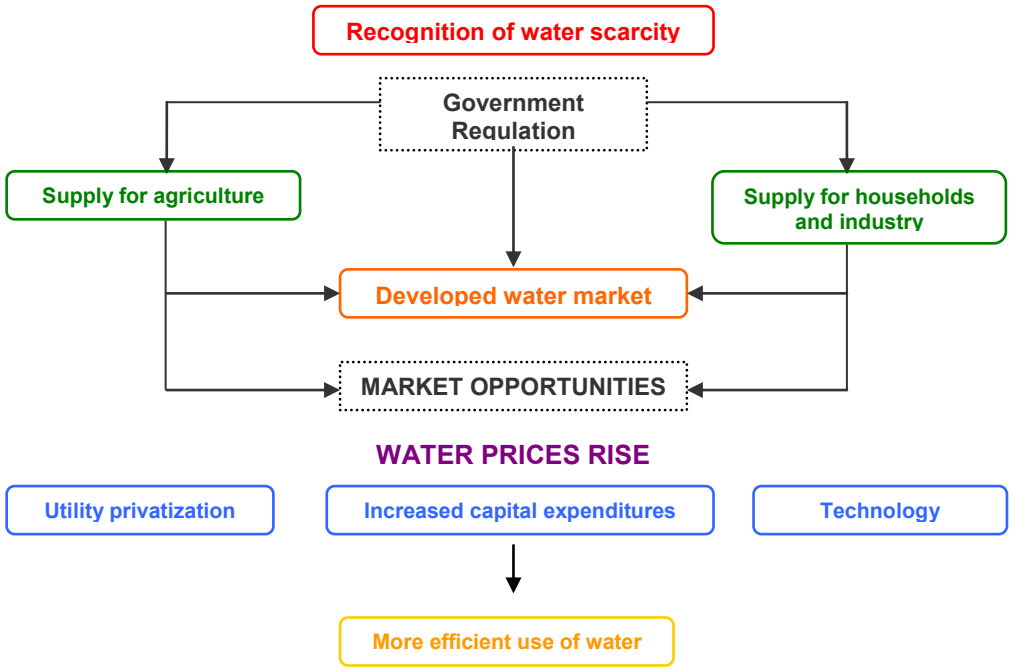


Figure 3 – Turning on the tap: Opportunities in Water. (Source: Citigroup Economic Research)

Water desalination

How does it work?

Water is desalinated in order to obtain fresh water suitable for animal consumption or irrigation, or, if almost all of the salt is removed, for human consumption. Sometimes the process produces table salt as a by-product. **Most of the modern interest in desalination is focused on developing cost-effective ways of providing fresh water for human use in regions where the availability of water is limited.**

Large-scale desalination typically requires large amounts of energy as well as specialized, expensive infrastructure, making it very costly compared to the use of fresh water from rivers or groundwater. The large energy reserves of many Middle Eastern countries, along with their relative water scarcity, have led to extensive construction of desalination in this region.

There are more than 7,500 desalting plants in operation worldwide producing several billion gallons of water per day. 57% are in the Middle East and 12% of the world capacity is produced in the Americas, **with most of the plants located in the Caribbean and Florida. Saudi Arabia's desalination plants account for about 24% of total world capacity.** However, as drought conditions continue and concerns over water availability increase, desalination projects are being proposed at numerous locations.

World economics aside, the market demand still exceeds the industries' capacity to produce fresh water. In fact, attempts to reclaim arid areas combined with increased population growth, industrial and economic development, signal a strong and continued market need.

Important economic factors [10]

- Industrial expansion or development is impossible without water in large quantities.
- Unless the water can be obtained at a lower cost per unit than all the other materials involved in an industrial product, industrial production will be expensive and impractical.

Desalination compared to other water supply options

Increased water conservation and water use efficiency remain the most cost effective priority for supplying water. While comparing ocean water desalination to wastewater reclamation for drinking water shows desalination as the first option, using reclamation for irrigation and industrial use provides multiple benefits.

Overview of most common desalination techniques

Distillation

- **Multi-stage flash distillation (MSF)**
- **Multiple-effect evaporator (MED|ME)**
- **Vapor-compression evaporation (VC)**
- **Evaporation/condensation**

Membrane processes

- **Electrodialysis reversal (EDR)**
- **Reverse osmosis (RO)**
- **Nanofiltration (NF)**
- **Forward osmosis (FO)**
- **Membrane distillation (MD)**

See table below for advantages and disadvantages of the desalination techniques listed above.

Advantages and disadvantages of desalination techniques

Desalination type	Usage	Advantages	Disadvantages	Companies
Distillation				
Multi-stage flash distillation (MSF) Desalination process that distills seawater by flashing a portion of the water into steam in multiple stages of what are essentially regenerative heat exchangers.	Accounts for 85% of all desalinated water; used since early 1950s	MSF plants, especially large ones, produce a lot of waste heat and can therefore often be paired with cogeneration	High operating costs when waste heat is not available for distillation. High rates of corrosion	Doosan Heavy Industries (South Korea)
Multiple-effect evaporator (MED|ME) Using the heat from steam to evaporate water. In a multiple-effect evaporator, water is boiled in a sequence of vessels, each held at a lower pressure than the last.	Widely used, since 1845	High efficiency, while relatively inexpensive	A large heating area is required	Niro (United States)
Vapor-compression evaporation (VC) Evaporation method by which a blower, compressor or jet ejector is used to compress, and thus, increase the temperature of the vapor produced.	Mainly used for wastewater recovery	Technique copes well with high salt content in water	-	Vacom, Water Desalination International (United States)
Evaporation/condensation Evaporation of seawater or brackish water and consecutive condensation of the generated humid air, mostly at ambient pressure.	Widely used	Easiest method of distillation	Time-consuming and inefficient in comparison to other techniques	-
Membrane processes				
Electrodialysis reversal (EDR) Electrochemical separation process that removes ions and other charged species from water and other fluids.	Widely used, since early 1960s	Long membrane lifetime and high efficiency (up to 94% water recovery, usually around 80%)	High capital and operational costs	General Electric (GE), Ryan Herco Flow Solutions (United States)
Reverse osmosis (RO) Separation process that uses pressure to force a solvent through a membrane that retains the solute on one side and allows the pure solvent to pass to the other side.	Widely used, first plant installed in Saudi Arabia in 1979	In water purification, effectively removes all types of contaminants to some extent	Requires more pretreatment of the seawater and more maintenance than MSF plants	Multiplex-Degremont Joint Venture (Australia) Consolidation Water (Cayman Islands), GE
Nanofiltration (NF) Nanofiltration membranes have a pore size in the order of nanometers and are increasingly being used for water desalination.	Emerging technology	Very high efficiency	High capital cost, unknown lifetime of membrane, no large-scale plant built yet	Stoneybrook Purification (United States)
Forward osmosis (FO) Osmotic process that, like reverse osmosis, uses a semi-permeable membrane to effect separation of water from dissolved solutes.	Emerging technology	Low or no hydraulic pressures, no energy needed for seperation	Cannot produce pure water, only concentrated solutions	Apaclara (United Kingdom)
Membrane distillation (MD) In membrane distillation, the driving force for desalination is the difference in vapor pressure of water across the membrane, rather than total pressure.	Widely used	Low energy consumption, low fouling	-	KeppelSeghers (Belgium)

Sources: European Desalination Society (www.edsoc.com), International Desalination Association (www.idadesal.org), Universities Council on Water Resources (www.ucowr.siu.edu).

More technical details and information about these desalination techniques can be found in the report "*Overview of Desalination Techniques*" published by Tamim Younos and Kimberly E. Tulou (Virginia Polytechnic Institute and State University) in December 2005. [16]

Experimental technologies

In the past many novel desalination techniques have been researched with varying degrees of success. Some are still on the drawing board now while others have attracted research funding.

Geothermal desalination

Geothermal desalination is a proven process under development for the production of fresh water using heat energy. Claimed benefits of this method of desalination are that it requires less maintenance than reverse osmosis (RO) membranes and that the primary energy input is from geothermal heat, which is an source of energy with a low environmental footprint.

Around 1995, several entrepreneurs came together with an idea to use geothermal water directly as a source for desalination. About 1998 several individuals began working with evaporation/condensation air loop desalination about 1998. The experiment was moderately successful and a proof of concept, proving that geothermal waters could be used as process water to produce potable water in 2001. [12]

Passarell Process [19]

As an example of newer theoretical approaches for desalination, focusing specifically on maximizing energy efficiency and cost effectiveness, we may consider the “Passarell” Process.

The "Passarell" process has had a considerable amount of due diligence performed by both the US Department of Commerce and the US Department of Energy, as well as United States and Korean companies. Both have verified its commercial viability. This process is based upon earlier processes of desalination, which have been used for many years: the process combines accelerated distillation with efficient vapor compression (VC). [12]

Nanofiltration / Nanotube membranes

Recent research in the United States indicates that nanotube membranes may prove to be extremely effective for water filtration and may produce a viable water desalination process that would require substantially less energy than reverse osmosis in the near future.

For more detailed information on nanotechnology and nanomaterials, you may consult the forth-coming research report by Mora Associates Ltd. “Nanotechnology in the cleantech sector”.

Recent developments in desalination

Veolia awarded huge desalination contract in Saudi Arabia (June 2007) [6]

“Veolia Water Solutions & Technologies has been chosen to design and build one of the world’s largest desalination plants in Saudi Arabia. The plant is to provide 800,000 m^3 per day of desalinated water to Jubail Industrial City and the Eastern Province of Saudi Arabia—a desert region facing massive industrialization and a growing population.

The contract is worth approximately €702 million. It is part of a long-term expansion Independent Water and Power Production Project (IWPP) plan for power and desalination capacities in the Eastern Province of Saudi Arabia. The overall IWPP Project was won by a Consortium of developers composed of Suez Energy International in partnership with ACWA Power and Gulf Investment Corporation. The members of the consortium include General Electric (United States), Hyundai Heavy Industries (Korea) and SIDEM (France). Veolia's thermal desalination units will recuperate the heat from the power station to be built by General Electric. Hyundai will assure the construction of the seawater intake and outlet units. [...] The project is to be completed by 2010.”

Consolidated Water wins new desalination plant in Caymans (July 2007) [5]

“Consolidated Water announced on July 11th, 2007 a ten-year contract for a new seawater desalination plant on Grand Cayman Island. The company says it will guarantee under delivery of 2.14 million gallons per day to its customer, the Water Authority of the Cayman Islands. [...] Consolidated Water develops and operates seawater desalination plants and water distribution systems in areas of the world where naturally occurring supplies of potable water are scarce or nonexistent.”

Acciona ventures get desalination contracts (August 2007) [3]

"On August 6th, 2007 Spain's Acciona announced that two of its joint ventures have made deals for desalination plants in Algeria and the United Arab Emirates. Acciona said its water division Acciona Agua signed a contract to build a $184.9 million plant in Algeria. The venture will also operate the facility for 25 years in a deal worth a total of $799.9 million. [...] In the United Arab Emirates, Acciona said it plans to build a desalination plant and operate it for 10 years in a joint deal with local partners."

Aqua Engineering to build water desalination plant in UAE (August 2007) [4]

"Aqua Engineering announced on August 6th, 2007 it would lead a consortium to build a large desalination plant in the United Arab Emirates. Aqua, a unit of Austria's Christ Water Technology, will get $84 million of the $121 million contract in Sharjah in the UAE. [...] Aqua will be responsible for the delivery and assembly of the seawater reverse osmosis membrane plant. [...] The company said the plant will produce 91,000 m^3 of drinking water per day when complete."

Major players in water desalination

- Austria, Aqua Engineering GmbH, www.aqua-eng.com – *owned by Christ Water Technology Group*
- Cayman Islands, Consolidated Water, www.cwco.com
- France, Suez Environnement, www.suez-environnement.com
- France, Veolia Water Solutions & Technologies, www.veoliawaterst.com/en/
- Spain, Acciona Agua, www.acciona.es
- United States, General Electric (GE), www.ge.com
- United States, Ionics, www.ionics.com – *acquired by GE in 2004*
- United States, Zenon Environmental, www.zenon.com – *acquired by GE in 2006*

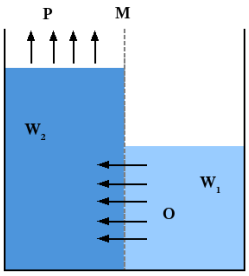
As part of *Ecomagination* programme, General Electric is currently building up a portfolio of companies specialized in water treatment and desalination technologies.

Salt concentration in water as energy source

How does it work?

Osmotic energy (sometimes referred to as 'blue energy') is the energy retrieved from the difference in the salt concentration between seawater and river water with the use of reverse electrodialysis (RED) (or osmosis) with ion-specific membranes. The waste product in this process is brackish water.

The technology of reversed electrodialysis has been confirmed in laboratory conditions. As in common technologies, the cost of the membrane is an obstacle. The possibility to use the salinity gradient in the ocean for power lies within the technology that needs to be developed.



The water potential between fresh water and sea water corresponds to a hydraulic head of 270 metres.

W1: fresh water
W2: sea water
M: membrane
O: osmosis process
P: pressure obtained

Advantages

There are many attractive features about using salt for power. A big advantage is that **osmotic energy is a renewable energy source**. There is no risk what so ever to run out of salt because of osmotic produced power. The process creating energy, does not consume the salt, it only utilises it to force water to move.

Another advantage is that osmotic-produced energy has a **minimal environmental impact**. The amount of heat that occurs in the process would raise the temperature less than half a degree Celsius, which is not harmful to the marine organisms.

Disadvantages

Compared to other processes of producing energy osmotic energy is **extremely expensive, about 36 times as expensive as a conventional power plant**. There are also engineering problems to be overcome. It is difficult to build a large plant and lower it in the sea as deep as 110 meters.

Bibliography

1. "*Water - Wikipedia, the free encyclopaedia*" published by Wikipedia. Retrieved on July 28th, 2007 from http://en.wikipedia.org/wiki/Water

2. "*Fresh Water / Salt Water*" by Geotechnical, Rock, Water Resource Library. Retrieved on November 19th, 2007 from http://www.grow.arizona.edu/water/freshsaltwater.shtml

3. "*Acciona ventures get desalination contracts*" published by Inside Greentech. Retrieved on August 7th, 2007 from http://www.insidegreentech.com/1573/acciona-venture-gets-184-9m-desalinati

4. "*Aqua Engineering to build plant in UAE*" published by Inside Greentech. Retrieved on August 7th, 2007 from http://www.insidegreentech.com/1574/aqua-engineering-to-build-plant-in-uae

5. "*Consolidated wins new desal plant in Caymans*" published by Inside Greentech. Retrieved on August 7th, 2007 from http://www.insidegreentech.com/1450/consolidated-wins-new-desal-plant-in-c

6. "*Veolia awarded huge desalination contract in Saudi Arabia*" published by Inside Greentech. Retrieved on August 7th, 2007 from http://www.insidegreentech.com/1392/veolia-awarded-huge-desalination-contr

7. "*The Clean Tech Revolution: The Next Big Growth and Investment Opportunity*" by Ron Pernick and Clint Wilder (p. 23). Published by HarperCollins in 2007.

8. "*How does it work? Osmotic power in brief.*" published by Statkraft. Retrieved on November 9th, 2007 from http://www.statkraft.com/pub/innovation/osmotic_power/osmotic_power_in_brief/osmotic_power_in_brief.asp

9. "*Osmotic Energy*" published by Tomas Harrysson, David Lönn and Jesper Svensson. Retrieved on November 9th, 2007 from http://exergy.se/goran/cng/alten/proj/97/o/

10. "*WDI Water Desalination International: Introduction*" published by WDI. Retrieved on November 9th, 2007 from http://www.waterdesalination.com/introduction.htm

11. "*Where is the Earth's water located?*" published by U.S. Geological Survey. Retrieved on November 16th, 2007 from http://ga.water.usgs.gov/edu/earthwherewater.html

12. "*Geothermal desalination - Wikipedia, the free encyclopaedia*" Retrieved on November 17th, 2007 from http://en.wikipedia.org/wiki/Geothermal_desalination

13. "*Solar humification - Wikipedia, the free encyclopaedia*" Retrieved on November 19th, 2007 from http://en.wikipedia.org/wiki/Solar_humidification

14. "*Water Technology – Industry Projects*" published by SPG Media. Retrieved on November 27th, 2007 from http://www.water-technology.net/projects/

15. "*Energy Efficiency of Evaporation Plants*" published by Niro Inc. Retrieved on December 2nd, 2007 from http://www.niroinc.com/evaporators_crystallizers/energy_evaporation_plants.asp

16. "*Overview of Desalination Techniques*" published by Universities Council on Water Resources in December 2005. Retrieved on December 2nd, 2007 from http://131.230.120.111/updates/132/2.pdf

17. "*WDI Water Desalination International: The Passarell Process*" published by WDI. Retrieved on December 2nd, 2007 from http://www.waterdesalination.com/technica.htm