Review of the Current State of Desalination

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1. Executive Summary

In search of new sources of water supply, saltwater desalination is increasingly recognized as a viable option. Costs of desalination have declined substantially throughout recent decades. In terms of cost competitiveness, desalination is catching up fast to alternative options for boosting water supply, namely water reclamation and water transport. This review on the state of desalination tries to provide a comprehensive insight into the main issues of desalination: differences in the processes, their respective costs, energy dependence, and environmental issues. In addition this paper compares the two dominant technologies for desalination, distillation and membrane processes, and assesses their respective potential.

Distillation or thermal processes on the one hand desalinate using the principle of evaporation. The membrane processes on the other hand employ the concept of filtration. Of the worldwide more than 15,000 industrial scale desalination plants that had been installed or contracted by the year 2002, reverse osmosis (RO), the leading membrane process, provides 44 percent of total capacity while the leading thermal process, multi stage flash (MSF), accounts for 40 percent. Both approaches still face considerable hurdles, such as high energy consumption and needed continuation of research in membranes at the molecular level, but the industry has demonstrated a strong commitment to addressing these challenges. The result has been a growing acceptance of desalination as a viable option for water supply augmentation.

Despite the many impressive achievements accomplished by the desalination industry, disadvantages in cost competitiveness relative to other sources of water supply still represent the most widely cited obstacle the desalination industry has to overcome. However, this argument may soon be rendered obsolete. The desalination industry shows an impressive record of lowering unit cost, reducing them by an average 44 percent per decade over the past fifty years[1]. This trend will continue to rapidly enhance the

[1] This statistic refers to the most widely used thermal process, multi stage flash, which has been in use the longest out of all desalination technologies.

industry's cost competitiveness relative to other prevailing water supply sources. In fact, an increasing number of large-scale plants with unit cost as low as $ 0.0017 per gallon begin to be considered legitimate competitors to conventional sources of water supply. This particularly holds true in places that are inclined to acknowledge the scarcity value of water due to competing demands for limited existing supplies. Planners and policy makers in populous and water scarce states like Texas and California have assigned a prime role to desalination in securing water supply for increasingly competing needs. A closer look at recent desalination initiatives in these states can be found in Appendix 1 of this paper. Appendix 2 provides a brief description of two very valuable sources of information found during this research. One source, the Desalination Economic Evaluation Program (DEEP) analyzes the feasibility of integrating desalination with nuclear power generation while the second source comprises the most comprehensive inventory assessment of global desalination infrastructure, composed by Wangnick Consulting.

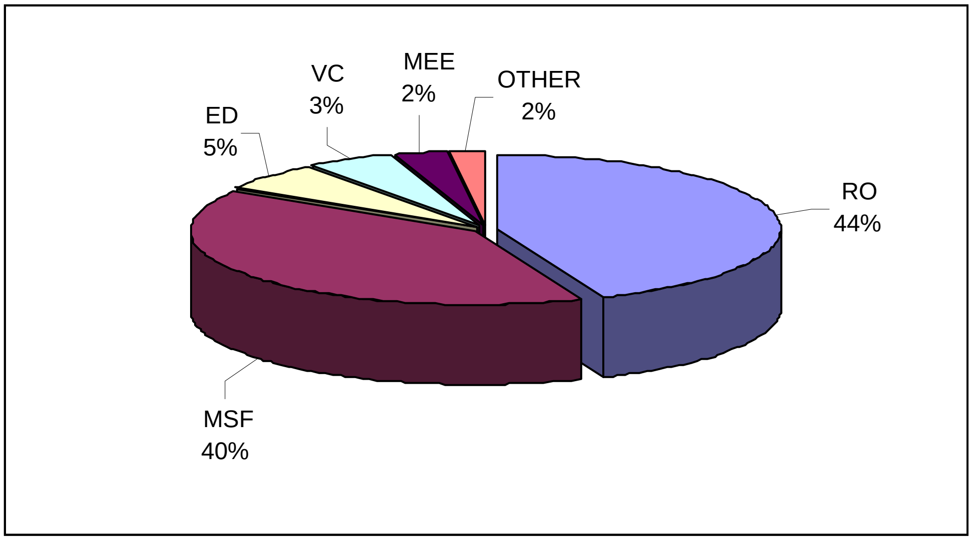
2. Introduction

With the need to fill present or future gaps between demand and supply of water, policymakers have traditionally chosen the approach that promises fewer objections: extending the available water supply. This kind of water policy has persisted despite readily attainable water savings on the demand side. From the small pool of options to increase water supply, desalination has moved to the forefront as its economic feasibility has improved radically in recent decades. Desalination produces potable water from desalinating brackish groundwater or seawater. Both exist in abundant amounts with seawater accounting for 97 percent of the world's water.

Worldwide more than 15,000 industrial scale desalination units had been installed or contracted by the year 2002. These plants account for a total capacity of 8.5 billion gallons/day. Total production capacity is split in non-seawater desalination and seawater desalination plants with a capacity of 3.5 billion gallons/day and 5 billion gallons/day respectively (IDA, 2002).

Both seawater and brackish groundwater are purified by use of two entirely different approaches. Distillation or thermal processes on the one hand desalinate through evaporation while membrane processes on the other hand employ the concept of filtration. In the market place, when judged by installed capacity, the membrane desalination process reverse osmosis (RO) leads with 44 percent of total capacity, closely followed by a thermal process called multi stage flash (MSF) with 40 percent of total capacity. The remaining 12 percent are divided between other thermal processes, such as electro dialysis (ED, 5%)and vapor compression (VC, 3%), a membrane process called multiple effect evaporation (MEE, 2%), and other partially new concepts. Figure 1 provides a graphical illustration of the process distribution.

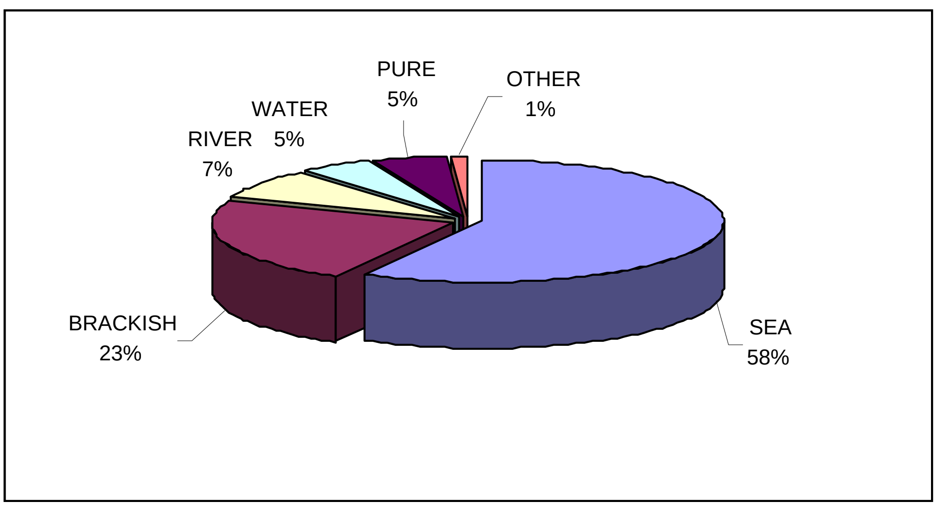
Figure 1. Installed Desalting Capacity by Process.



Source: IDA, 2002.

The main sources of feed water for desalination are seawater at 58 percent and brackish groundwater, which accounts for 23 percent. Figure 2 illustrates the distribution of feed water sources.

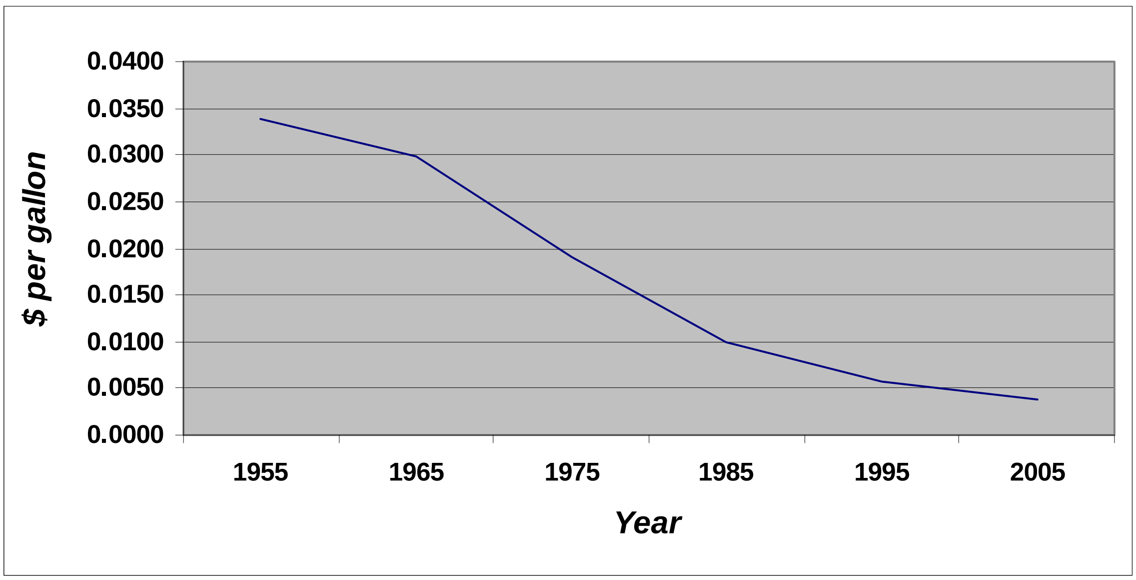
Figure 2. Installed Capacity by Raw Water Quality.



Source: IDA, 2002.

The cost of obtaining potable water by using desalination processes has decreased substantially and at a consistently fast annual rate throughout recent decades. Over the past 50 years, per unit cost of MSF, a distillation desalination technology that has used for centuries in one way or another, have decreased by an average of 44 percent per decade as shown in Figure 3 below.

Figure 3. MSF Product Unit Cost Over Time



In addition to lower unit cost of desalination, increasing cost of conventional water supplies due to overexploitation and scarcity have aided desalination in becoming one of the top options for boosting potable water supply.

The following discussion provides insights into the various aspects of desalination. A brief outline of the main desalination processes' technical side is followed by an assessment of their respective advantages and disadvantages. The text then delineates a general economic assessment of desalination which includes a range of cost estimates of competing processes as stated in the literature and how they compare to alternative sources of water supply. In addition, this text attempts to give an idea of the broad scientific opinion regarding the potential of desalination in general and versus other sources of water supply. It also includes a brief synopsis of potential environmental issues, for which only limited research is available due to the industry's infant stage. Furthermore, this discussion entails a brief description of actual experiences made with the largest ever US desalination project, the Tampa Bay seawater reverse osmosis plant.

3. Discussion

3.1 Operational Concept and Technology of Main Desalination Processes

3.1.1 Terse Technical Description: Membrane Desalination

The fastest growing desalination process is a membrane process called reverse osmosis (RO). Apart from RO, there is no other membrane based process installed at a large enough capacity to be relevant for this discussion. RO employs dynamic pressure to overcome the osmotic pressure of the salt solution, hence causing water-selective permeation from the saline side of a membrane to the freshwater side (Faller, 1999). Salts are rejected by the membrane, which is how the separation of saltwater and fresh water is accomplished. The RO membranes used are semi-permeable polymeric thin layers, which hold on to a thick support layer. Membranes are usually made of cellulose acetates, polyamides, polyamides, and polysulfones. They differ between symmetric, asymmetric, and thin film composite membranes (Zhou, 2004).

3.1.2 Terse Technical Description: Thermal Desalination

In MSF, MEE, and MVC there are three advanced thermal processes. In MSF and MEE, steam extracted from low- and medium-pressure turbine lines provides the heat necessary for flashing or evaporation. In MSF, pressurized seawater flows through closed pipes in which it exchanges heat, with vapor condensing in the upper sections of the flash chambers. Water is then heated to a high temperature level, using burnt fuel or external steam, which allows flashing along the lower part of the chambers, from chamber to chamber under reduced pressure conditions. The vapor that is generated flows through a mist eliminator to meet the condensing tubes, where heat is transferred to the heating feed seawater. The condensate drips into collectors and is pumped out as the plant product. Exhausted brine, concentrated in salt, is pumped out and rejected to the sea (Semiat, 2002).

In MEE, the heating steam is routed to the first evaporating effect. The MSF process operates with a top brine temperature in the range of 90–110°C while the MEE and MVC processes are operated with lower top brine temperatures in the range of 64–70°C. MVC is distinguished from the other processes by the presence of a mechanical vapor compressor, which compresses the vapor formed within the evaporator to the desired pressure and temperature. The system also includes plate heat exchangers for preheating the feed water using heat recovered from the brine lowdown stream and the distillate product.

3.2 Feasibility Match Up of Main Desalination Processes

This section discusses the main aspects and issues involved with various desalination processes, but remains mostly limited to the two dominant desalination concepts membrane and thermal desalination. Analogous to comparisons of most other commercially employed competing processes or concepts, much of this discussion pertains to differences in cost of production. It will nevertheless cover other critical issues, such as product quality or environmental issues to the appropriate extent. A general economic assessment of desalination follows in section 3.2.

3.2.1 Energy

Comprising the main cost driver for both processes, energy consumption is probably the most crucial criterion on which membrane and thermal desalination processes are compared. Due to the nature of its membrane filtration concept, RO uses considerably less energy than thermal processes. In turn, energy accounts for a much higher percentage of total operating cost for thermal desalination plants than for plants using membrane technology. Comparing the cost composition of two seawater desalination plants of almost equal capacity of roughly 10 million gpd, a MSF plant called Tripoli West II in Libya and a RO plant called Sabha A in Israel, shows energy’s share of total operating cost at 41 percent for the former and only 26 percent for the latter facility. Related figures for these statistics can be found in section 3.2. The main reason for this discrepancy is due to the fact that thermal processes require a much higher operating temperature.

Based on the specific thermal process employed temperatures ranging from 40 ° to 120 ° Celsius are required for distillation desalination while temperatures necessary for membrane desalination processes range between 0 ° and 40 ° Celsius. Hence, steam production represents the main energy consuming factor in thermal processes. Many MSF desalination plants are therefore located near power plants supplying waste heat to enhance energy efficiency. The large consumption of energy makes the economic feasibility of thermal processes extremely contingent upon energy prices or the availability of waste heat from thermal power plants (Lahmeyer, 2004). Membrane desalination plants on the other hand do not need to be linked to power plants for energy efficiency reasons for they have no use for purged steam. Most of their energy consumption is attributable to the high pressure pump required to generate saltwater permeation through the membrane elements.

3.2.2 Maintenance and Operation

Maintenance and feed water treatment constitute another important cost driver for all desalination approaches. Membranes' pronounced sensitivity to their environment, such as changes in pH level, small concentrations of oxidized substances like chlorine and chlorine oxides, a wide range of organic materials, and the presence of algae and bacteria require careful feed water pretreatment in order to prevent membrane contamination and fouling (Zhou, 2004). The extensive pre treatment required to make membranes compatible with the site and situation specific feed water conditions translates into significantly higher cost of chemicals, (membrane) maintenance, cleaning, and ultimately replacement as is incurred with thermal processes. There are, however, ways to curb the extent of pretreatment efforts and associated expenses for seawater desalination plants. Collocation with power plants using seawater for cooling purposes constitutes one such solution. Since power plants have to treat the water they use for cooling to avoid pipe congestion, feed water cleaning expenditures can be shared by the two facilities. The Big Bend Power Station adjacent to one of the potential locations of the Tampa Bay RO plant was a major determinant in the final decision making on where to construct the facility. Now, the feed water taken into the desalination plant has already gone through a cleaning process conducted by the power plant. This convenient efficiency-enhancing arrangement could not, however, prevent the occurrence of a number of significant deficiencies that still exist in dealing with membrane sensitivity. A more detailed discussion of the Tampa Bay experience is provided in subsequent section 3.3. Higher complexity of maintenance tasks requires membrane desalination plants to shut down more frequently than their thermal counterparts further adding to the cost of maintenance. Thermal processes on the other hand have to apply significantly less treatment to the feed water intake due to the nature of the distillation concept. Also, lack of replaceable material keeps maintenance cost at comparatively lower levels.

Start and stop operation of membrane desalination processes is less costly and more immediate than for thermal processes. This explains the frequent use of RO on stand by mode to enhance water supply during periods of drought. An example of such a plant is the Key West, FL, plant with a capacity of 3 million gpd, which is turned on and off frequently throughout the year depending on the magnitude of demand. Membrane technology has also accomplished tremendous success in improving membrane material. Productivity has increased by 94 percent between 1990 and 2000 while costs have declined by 86 percent over the same period (Chaudhry, 2004).

3.2.3 Output Quality

Thermal processes perform better than membrane processes when it comes to the product's purity. While RO's output can be considered fair at values between 100-600 ppm of total dissolved solids (TDS), thermal processes are capable of producing much purer water at values between 5 and 50 ppm of TDS. A great deal of purity variation in RO's output is highly correlated to feed water quality. A costly, hence infrequently implemented option for improving output quality of RO consists of using a secondary stage at considerable additional cost. However, it is important to note that in contrast to its comparatively meager performance in salt removal, the membrane process allows for removal of unwanted contaminants, such as pesticides and certain bacteria.

3.2.4 Environmental Impacts

Absolute environmental impacts of desalination plants and the respective processes are largely unknown due to still sporadic application and limited public attention. Since this lack of public exposure is in the process of changing considerably, more information will be available soon with regard to environmental impacts. Most environmental concerns that are raised relate to both air and saltwater emissions. Air emissions are due to the desalination industry's heavy energy consumption and involve the commonly named pollutants carbon dioxide and sulfur dioxide. In light of their substantially higher energy consumption, thermal processes are inferior to membrane processes when it comes to air pollution.

The other form of emission from desalination raising environmental concerns comprises the discharge of concentrated saltwater after the desalination process is completed. The effluent is approximately twice as concentrated as the original sea water solution. Additionally, it contains chemicals used in the pretreatment of feed water, such as anti-scalants, surfactants, and acid. Speed of dilution, once brine is released into the ocean, depends largely on depth and flow rates at the release location. To our knowledge, no empirical results from comprehensive studies investigating the impact on sea life around the brine outlet have been published. Many experts argue that the amount of brine release is too insignificant to pose a burden on ocean ecology against prevailing opinion among environmental activists.

The left-over concentrate from desalinating brackish groundwater appears to pose greater disposal problems. Without access to the sea the brine may significantly augment groundwater salinity once released into the ground. Storage of the concentrate on the other hand requires large amounts of space and measures to prevent saltwater penetrating the earth. Compliance with environmental standards for inland disposal of brine may entail substantial expenses for the desalination industry. A similar outcome in terms of extra cost could arise for seawater desalination if results of pending scientific studies find detrimental effects on ocean ecology from brine release.

The third critical environmental concern pertaining to desalination besides air emissions and brine discharge consists of the use of valuable coastal lands (These areas are extremely valuable from both an economic and environmental perspective). Membrane processes take up less surface area than distillation plants.

3.3 General Economic Assessment of Desalination

The economies of desalination and the decision as to which approach to select are contingent on situation-specific parameters. Since energy is the main cost driver in the cost of operation, economic feasibility of either approach to desalination is highly correlated to the location specific-cost and availability of energy. Figures 4 and 5 provide a comparative illustration of energy's share of total operational cost for two desalination plants of comparable capacity. Figure 4 illustrates the cost composition of an average sized 10 mgpd seawater RO plant. Cost of energy make up 26 percent of total operating cost, which is second to fixed charges that are mainly composed of the cost of capital. Figure 5 illustrates the cost composition of a seawater MSF plant producing approximately 10 mgpd shows energy's share of total operating cost at 41 percent, roughly equal to the main cost driver capital cost.

Figure 4. Cost Composition for a Typical Seawater RO Plant[1]

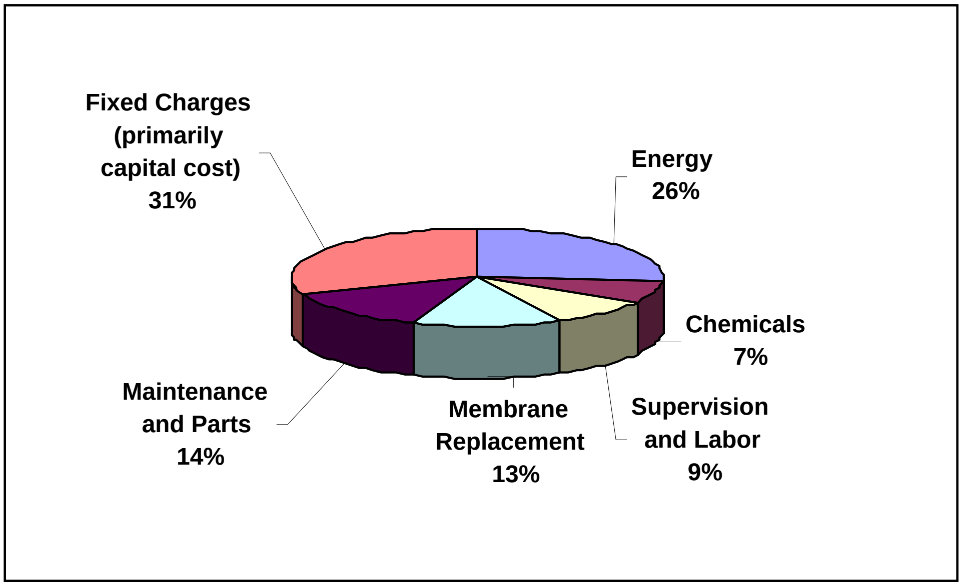
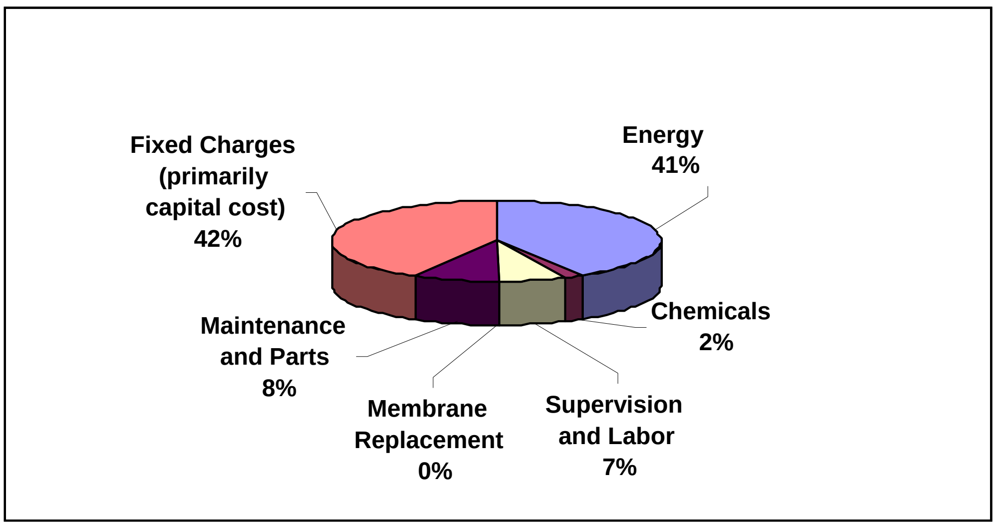


Figure 5. Cost Composition for a Representative Seawater MSF Plant[2]



Based on a seawater MSF plant located in Libya.

In the representative example given above, cost of capital is considerably higher for the thermal than for the membrane process. This reflects the prevailing situation in the desalination industry in which

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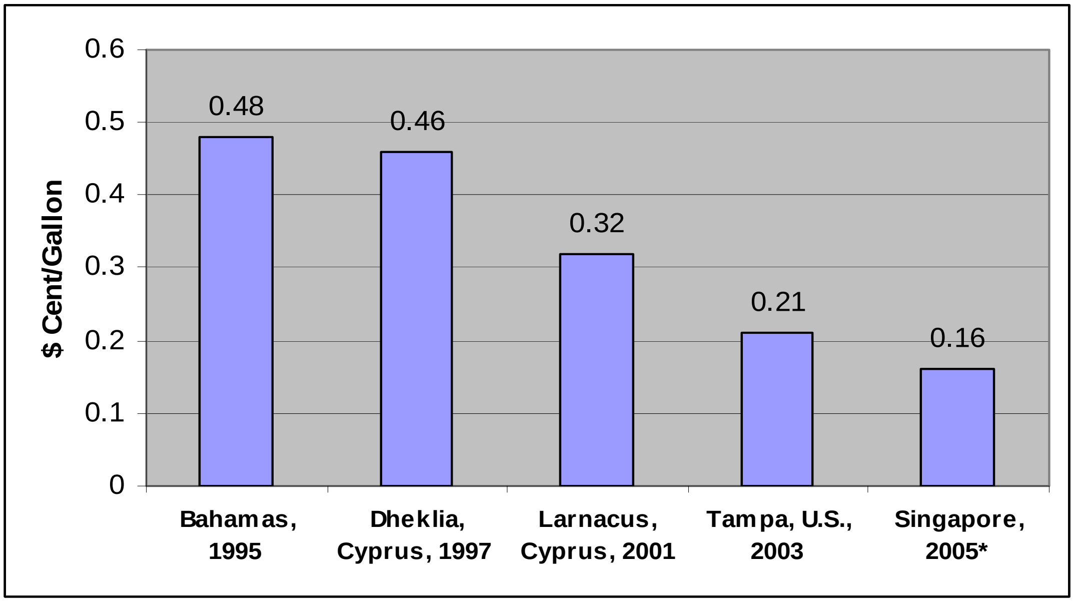
[1] SWRO plant Sabha A, Israel.
[2] SWMSF plant Tripoli West II, Libya.

construction cost of thermal desalination plants exceed those of membrane plants. All other main cost related to operating a desalination plant are usually higher for membrane processes due to the greater complexity of maintenance tasks and operation. Accordingly, cost of chemicals are 7 versus 2 percent, maintenance and parts are 14 versus 7 percent, and labor cost are 9 versus 7 percent of total operating cost for the representative RO and MSF plants respectively. Membrane replacement, which is listed separately in Figure 4, adds further to maintenance cost for RO while this cost is obviously absent for thermal processes.

Strong inter-firm competition and advances in technology have resulted in average annual unit cost reductions of close to 6 percent for MSF processes since 1970. In addition, many MSF desalination plants, which are mostly located in the Middle East, have increasingly taken advantage of economies of scale. RO, which has been used commercially only since 1982, has seen even steeper cost declines since its beginning. Membrane costs have fallen by 86 percent between 1990 and 2002 (Chaudhry, 2004). Steeply declining maintenance cost in combination with relatively low capital cost have contributed much to the rapidly growing success of membrane technology. In fact, as Figure 6 shows for select plants, 2005 unit cost of SWRO are only about a third of 1995 unit cost.

Figure 6. Cost Evolution of the SWRO Process



Source: Estimates prepared from various sources by CRWPPC

* Projected estimate

Of course, the decrease in unit cost shown in Figure 5 is not only due to the rapid advancement in membrane technology. Economies of scale also contribute considerably to cutting unit cost. The magnitude of the respective effects of improved membranes and economies of scale are difficult to measure as they take place concurrently. With respect to Figure 5, as unit cost drop to one third between 1995 to 2005, plant capacity of the particular plants shown increases by a factor of 10.

While in Figure 6 the effect of economies of scale on cost is rather implicit and largely dominated by the effect of improved membrane technology over time, it can be clearly identified in Table 1 below. It displays unit cost of desalination for various processes when conducted at different plant capacities. All data shown pertain to plants operating in the year 2001, which reduces the diminishing effect on unit cost exerted by rapid improvements in membrane technology. Again, plants for which numbers are shown are not representative for all plants using their desalination approach or operating at their capacity and their unit cost are highly contingent upon location-specific factors, such as cost of energy or capital. Nonetheless, the inverse relationship between capacity and unit cost can easily be identified, particularly for processes, such as RO for which a wide range of data is available. While unit cost for a plant with a capacity of 1 mgpd are 0.75 US cents/gallons, they fall to about a third of that cost for a 12 mgpd plant and by another 20 percent for a 30 mgpd plant. The reader should also note the efficiencies attained from integrating power production by some desalination facilities. These plants, called dual purpose plants, manage to cut unit cost by about 50 percent as can be seen for three types of distillation processes.

Table 1. Unit Product Costs for Conventional and Novel Desalination Processes by Capacity, Plants Operating in 2001.

Type of System: Capacity, in millions of gallons per day	**Unit Product Cost, $ Cent / gallon**
Novel Processes	
MEE-VS, 30eftects,Aluminum alloy, Fluted tubes: 90.53	0.182
MEE-ABS, Absorption heat pump and gas turbine: 2.5	0.133
Mechanical Vapor Compression (MVC)	
0.03	1.894
0.13	1.220
1.06	0.939
1.20	0.920
5.28	0.174
Reverse Osmosis	
5.28 (single stage)	0.242
5.28 (two stage)	0.288
0.03	0.898
1.06	0.750
1.20	0.489
9.99	0.413
10.56	0.314
12.00	0.258
30.00	0.208
Multistage Flash Desalination (MSF)	
7.13 (Dual-purpose)[1]	0.292
7.13 (Single-purpose)	0.621
8.45 (Gas turbine, waste-heat boiler)	0.545
7.13	0.595
9.99	0.473
Multiple-Effect Evaporation (MEE)	
6 (Dual-purpose)	0.330
6 (Single-purpose)	0.739
6	0.529
6	0.470
9.99	0.409
9.99 (Gas turbine, waste-heat boiler)	0.496
MEE-TVC	
5.85 (Single-purpose)	0.886
5.85 (Dual-purpose)	0.496
5.85	0.587

Source: Ettouney, 2002.

Product unit prices shown generally take into account all relevant cost originating from direct capital, indirect capital, and annual operating cost.

[1] A dual-purpose plant provides both water desalination and electric power generation, whereas a single-purpose plant produces only desalinated water (its boiler is used to generate only heating steam).

Table 2 breaks down cost figures for various plant sizes by major cost components capital, energy, and chemical cost. While estimates within each category vary significantly with plant capacity and characteristics, the processes' respective overall cost advantages and disadvantages become clear upon closer examination. Of the two main processes employed worldwide, RO and MSF, the former is more competitive in both capital and energy cost while the latter involves lower chemical and maintenance cost.

Table 2. Capital, Energy and Chemical Costs for Various Desalination Processes.

Process	Capacity	Total Capital Cost	Unit Cost of Capital	Annual Energy Cost	Unit Cost of Energy	Unit Cost of Chemicals	Total Unit Cost
	million gpd	$ / yr	cent / g / day	Cost, $ / yr	cent / g / day	cent / g / day	cent / g / day
RO	0.3	924,000	0.048	1,710,000	0.018	0.042	0.107
RO	8.4	53,300,000	0.086	6,261,000	0.002	0.125	0.213
RO	10.0	49,700,000	0.068	4,300,000	0.001	0.027	0.096
RO	25.0	98,000,000	0.054	5475000	0.001	0.020	0.074
MVC	0.3	894,000	0.046	152,000	0.002	0.008	0.056
MVC	0.3	1,586,000	0.069	140,000	0.001	0.008	0.078
MVC	5.3	56,000,000	0.145	2,690,000	0.001	0.019	0.166
MSF	8.4	72,600,000	0.118	11,539,000	0.004	0.078	0.200
MSF	10.0	60,500,000	0.083	4,300,000	0.001	0.009	0.093
MSF	12.0	76,817,000	0.088	12,453,000	0.003	0.022	0.112
MEE	6.0	35,050,000	0.080	3,719,000	0.002	0.023	0.105
MEE	8.4	67,200,000	0.109	12,059,000	0.004	0.078	0.191
MEE	10.0	70,400,000	0.097	1,000,000	0.000	0.009	0.106
MEE- TVC	6.0	34,650,000	0.079	5,658,000	0.003	0.022	0.104
MEE-VS	90.0	187,100,000	0.028	13,650,000	0.000	0.015	0.044

Source: Ettouney, 2002.

3.4 Experiences with the Tampa Bay Desalination Project

With a planned initial output of approximately 25 million gpd, the Tampa Bay desalination project, a seawater reverse osmosis plant, is the largest desalination project of its kind in the United States. Construction of the project, which was started in 1997, was taken up in August 2001 and water was first produced in March 2003. Unit cost were projected to be the world's least expensive for desalinated water at $ 0.0025/gallon, dropping even lower to $0.0017/gallon once initial problems were eliminated. Desalination cost projections of ultimately roughly $ 0.0019/gallon compare to Tampa Bay Water's groundwater costs of about $ 0.001/gallon.

The various contractors ran into a number of difficulties both during the construction period and the project's initial operating phase. These issues were of technical as well as financial nature. In fact, three firms were forced to declare bankruptcy and cease involvement in the project. In May 2003, two months after production had started, a performance test uncovered 31 deficiencies in the plant allowing the plant to run only "intermittently" (Tampa Bay Water, 2004) since then. Publicized major problems involve the cartridge filters used to catch large particles before the water permeates the delicate reverse-osmosis membranes. These were clogged after just a week - instead of the expected 90 days. Also, the 10,000 reverse-osmosis membranes, used in the final steps of water treatment to filter out the finest of salts and minerals, had to be cleaned of algae and bacteria every two weeks compared to an anticipated cleaning interval of two to six times a year (St. Petersburg Times, 2004). The current time table projects the plant to be fixed and taken off its current stand-by mode by spring 2006, roughly three years after the plant's first run.

3.5 How Desalination Compares to Alternative Sources of Water Supply

Continued demographic and economic growth result in increasingly strong competition for the available water supply. Making matters worse, water supply is shrinking for reasons like surface water pollution, groundwater depletion, or saltwater intrusion. Out of the two options to deal with the problem, increasing supply or curtailing demand, the former is pursued with much greater intensity. But, the array of means to enlarge the amount of drinking water for public use is fairly limited in scope and in some cases not practicable; for instance, it is not feasible to deplete ground or surface water reservoirs above the rate of natural replenishment for years and decades to come without a readily available alternative at hand that could reliably sustain entire region's demographic and economic needs. Thus enhanced depletion of existing reservoirs does not represent a prudent option to increase water supply.

This leaves two alternatives against which desalination can be compared. Practiced since thousands of years, predominantly in arid regions, water transport from places with excess supply to places in need represents the first alternative. Relatively little empirical work has been published on this subject although water transport is undertaken in many locations all over the world (Zhou, 2004). Cost vary enormously and are highly dependent on case specific conditions.

It is critical to keep in mind when comparing water transport and seawater desalination that the latter actually augments total available supply of freshwater whereas the former only shifts water from a location with excess supply to a location in need of water. Thus in the long run only desalination can be considered a viable source of additional fresh water in contrast to the intermediate solution water transport.

The other more promising option to augment the available water supply consists of wastewater reclamation. As with water transportation, published empirical data is limited. A current high-profile case of wastewater reclamation is the Orange County, California, Regional Water Reclamation Project. The project's unit cost of water supply is estimated to be slightly lower at $ 0.0015/gallon than those of large scale desalination projects. The majority of studies on wastewater reclamation pertain to reclamation of water withdrawn by the largest water user, agriculture. Haruvy et. al. (2001) estimate the direct cost of agricultural effluent reuse at $

0.001/gallon. Interestingly, there are substantial synergies between wastewater reclamation and the RO desalination process because both use membrane technology. Both approaches also increase total available water supply.

3.6 Outlook

Rising water scarcity in many parts of the United States have begun to expose the potential of desalination to a larger audience. The 2004 Desalination Energy Assistance Act proposal entails incentive payments for qualifying desalination facilities to partially offset the cost of electricity. Despite its considerable energy dependence, desalination, particularly of seawater, is backed by a number of strong arguments. Seawater is available in sheer limitless supply, which is in stark contrast to ground and surface water supplies in many regions. Supported by the evidence of declining criticism regarding the industry's cost competitiveness in producing additional water supplies, the desalination industry is capable of producing water on a commercial basis even at the industry's still early development stage. Finally, planners and policy makers are in the process of acknowledging that existing water supplies in most places do not suffice to sustain robust population and economic growth in the long run, particularly in light of numerous scientific studies stating that not even current withdrawal rates are long-term sustainable.

On the other hand, the case of the Tampa Bay plant shows that at the cutting edge of implementing new technologies many deficiencies still remain to be overcome. For instance, the mechanism of water transfer and salt rejection in RO membranes is not clearly understood. Better understanding at the molecular level, however, will lead to new membranes that may show higher fluxes and better salt rejection for it is critical to improve both water recovery and quality.

For both membrane and particularly for thermal processes, it is crucial to enhance energy efficiency and create partnerships with power plants. By using heat recovery from a nearby power plant, energy consumption of thermal desalination processes is reduced by a factor of eight compared to a single stage process without heat recovery.

However, the feasibility of partnerships between power plants and desalination plants presently faces major obstacles. First, presently in the US, facilities are typically owned and operated by separate entities contrary to Saudi Arabia, the country with the world's largest desalination capacity. Second, power plants typically purge waste heat at temperatures of 30 degree Celsius, well below the temperatures required for thermal processes. However, Semiat (2000) has called for an entirely different approach. He suggests the construction of desalination dedicated power plants as energy sources. The heat produced would be used by thermal processes while electricity would be employed by membrane processes. This hybrid approach is very similar to hybrid processes already employed in the chemical industry. While this solution would clearly enhance efficiency, it would not solve the problem that volatile energy prices pose for long term desalination planning.

4. Conclusion

The desalination industry has aggressively sought to implement more efficient technologies with the result that the cost of desalination is declining rapidly while the value of water is slowly but steadily increasing. In addition, the industry can claim the unmatched benefit of a seemingly limitless and cost free input: seawater. These two arguments make for a strong case to declare desalination the main option for boosting water supply in the future. This holds true despite the strong dependence on energy. In fact, some Arab countries already supply 90 percent of their water needs through desalination (Lahmeyer, 2004). Although it currently appears to be thermal processes that have the upper hand in seawater desalination, RO is progressing fast. It has the advantage of consuming substantially less energy. Hence, after reducing energy dependence, the second highest priority for the desalination industry is the advancement of membrane technology to make it more compatible with seawater desalination. Generally speaking, all desalination approaches need to become more independent of situation-specific characteristics, which will ultimately have the beneficial effect of fueling competition between the membrane and thermal approaches and stimulating innovation.

States like Florida, Texas, and California facing rapid population growth with ready access to seawater have clearly committed to the pursuit of desalination options to augment water supplies. From the industry side there is also a substantial commitment to aggressive research and development. This has produced rapidly declining prices despite rising energy costs.

Georgia shares with Florida, Texas, and California the need to supply a rapidly growing population. Between 1980 and 2000 the state grew by 50 percent from 5.5 to 8.2 million people. Over the same time period population in Coastal Georgia grew by 40 percent[1]. Counties in neighboring

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[1] By our definition Coastal Georgia comprises nine counties: Bryan, Bulloch, Camden Chatham, Effingham, Glynn, Liberty, Long, McIntosh.

states South Carolina and Florida exhibited substantial growth as well with three neighboring South Carolina counties growing 66 percent[1] between 1980 and 2000. Population in Florida Counties Nassau and Duval in the South has increased by a combined 38 percent. Projections for Coastal Georgia predict its population to reach 664,000 by 2020 and 732,000 by 2030, increases of 22 and 34 percent over the baseline year 2000. Population forecasts for bordering counties in South Carolina are 237,500 by 2020 and 279,000 by 2030, projected increases of 45 and 70 percent on the year 2000. Florida's Duval and Nassau Counties are forecast to grow from 780,000 and 58,000 respectively in 2000 to 1.1 million and 101,000 in 2030, reflecting increases of 42 and 76 percent. The combined increase in population is projected at 29 percent for the twenty year period between 2020 and 2030[2] and 44 percent by 2030.

Coastal Georgia is facing a near term need to decide how to meet the growing demand for water in the region. It is expected that the Sound Science study, due out in 2005, will recommend decreased dependence on groundwater, particularly in the Savannah and Brunswick areas. While it would seem that the region's rivers would make surface water an easily accessible option, the coastal geography actually makes surface water a relatively complicated option. For example, salinity levels in the Savannah River only drop to approximately 0.5 ppt at a distance of roughly 20 river miles upstream[3]. Therefore, surface water intake for treatment and release into public drinking water supply occurs roughly 25 miles upstream or approximately 20 miles away from the center of population. In the Brunswick area the Satilla River is subject to a great deal of variability of saltwater propogation due to the river's specific flow characteristics. Lower flow coastal plain rivers are generally more susceptible to large upstream migration of salt, which can, for instance, vary significantly between dry and wet periods. Saltwater penetration for the coastal rivers Ogeechee and Altamaha under normal conditions is estimated at 22 and 7 miles

[1] These counties are Beaufort, Hampton, and Jasper.
[2] Projections are based on Woods and Poole economic and demographic forecasting.
[3] Information provided by John Sawyer with the City of Savannah's Water and Sewer Bureau

respectively. In any case, surface water sources for water supply in Coastal Georgia entail substantial transportation cost to deliver the water to the population centers as intakes have to be located sufficiently far upstream to evade salty surface water.

This begs the question, with declining costs from the increasing economies of scale and rapidly falling prices for desalination of saltwater, might desalination be a competitive water supply augmentation.

Appendix 1

A Look at Developments in States Leading the Way in Seawater Desalination

Even with the challenges faced by those implementing desalination, new large scale projects are in the process of being launched in Florida, Texas, and California[1].

California

Agencies throughout California are planning to make seawater desalination part of a diversified water supply portfolio. As of March 2004, the Seawater Desalination and California Coastal Act lists 11 seawater desalination plants in operation producing a combined 3 mgpd. Meanwhile, 21 seawater desalination facilities are proposed and expected to generate a combined production of 240 mgpd upon completion. The San Diego County Water Authority, which sells about 600,000 acre-feet of water each year, has been working on a 2030 Regional Water Facilities Master Plan that has seawater desalination as its preferred supply alternative. The Authority plans to obtain from 50,000 acre-feet per year to as much as 140,000 acre-feet per year from desalinated seawater by 2020. This range would provide between 6 and 15 percent of the region's water supply in 2020. The entire Coastal Southern California region is expected to serve 3-4% of total water supply from desalinated seawater by 2020.

Texas

Texas currently has 80 brackish water desalination plants while it does not have any seawater desalination operations. It is, however, aggressively pursuing this additional source of water supply as a viable option to counteract shrinking ground and surface water supplies. In 2003, the state legislature directed the Texas Water Development Board (TWDB) to allocate $ 1.5 million for feasibility studies to determine the technical and economic

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[1]It is estimated that 50 percent of the future population growth will occur in the coastal states of California, Texas, and Florida. These three states are leading the nation in pursuing seawater desalination.

viability of three proposed desalination projects. In 2004, the TWDB issued a two volume report “The Future of Desalination in Texas.” The report outlines comprehensive policies and strategies to further the development of desalination in Texas. Among the key findings and recommendations are:

- desalination is technically viable but projects will require considerable financial assistance;
- that $ 2.4 million be provided for advancing proposed large-scale seawater desalination pilot plant studies;
- that research will continue to play a vital role in developing efficient, cost-competitive, and environmentally sound seawater desalination projects in Texas;
- that $ 900,000 be provided for technical assistance and outreach for developing demonstration brackish desalination projects for small to medium size communities; and
- that the legislature considers the benefits to the state of demonstrating the feasibility of a new, substantial, sustainable, and drought-proof water supply.

Currently, there are two seawater desalination projects that have already gotten far into the planning process. On the Texas Gulf Coast near Freeport, two private companies collaborate on a 25 mgpd seawater desalination plant, which is planned to be upgradeable to 100 mgpd. Another plant presently in the planning process near Brownsville, TX, is designed to produce 25 mgpd from seawater desalination.

Florida

Of the three states discussed here Florida appears to have the most extensive experience with desalination. According to the last comprehensive publicly accessible survey on desalination plants in the United States, conducted by the Bureau of Reclamation in 1997, Floridian desalination plants accounted for about half of the total number of plants surveyed and more than two thirds of total capacity. Presently, the Tampa Bay desalination plant represents the largest US saltwater desalination facility in operation by a wide margin.

Appendix 2

Valuable Informational Resources on Desalination

Desalination Economic Evaluation Program (DEEP)

SINCE 1989, the International Atomic Energy Agency (IAEA) has been exploring the possibilities of large and small seawater-desalination plants powered by nuclear reactors. One of the most important issues for large-scale implementation of nuclear desalination is the need to demonstrate its economic competitiveness with alternative energy supply options. To this end, the IAEA has developed the Desalination Economic Evaluation Program (DEEP). DEEP is based on a hybrid Microsoft Excel spreadsheet and Visual Basic methodology, and is suitable for economic evaluations and screening analyses of various desalination and energy source options. It comprises simplified models of several types of nuclear and fossil-fuel power plants, nuclear and fossil-fuel heat sources, and both thermal and membrane desalination plants. Current cost and performance data are incorporated. The output of DEEP includes per unit cost of water and power, breakdowns of cost components, energy consumption and net saleable power for each selected option. Specific power plants can be modeled by adjusting input data such as design power, power cycle parameters and costs. Version 2.0 of the DEEP software (issued in 2000) is available from the IAEA on CD-ROM, with an upgrade to Version 2.1 (issued in 2002) on a floppy disk. The software is free, but each institutional or individual user needs to establish a license agreement. (IAE, 2004)

Wangnick Global Assessment

Wangnick Consulting GMBH is a private consulting firm providing consulting services for seawater and brackish water desalination. It compiles on regular basis the most comprehensive inventory assessment of global desalination infrastructure. The database is called PAM. It supplies information on more than 16,000 land-based desalting units rated at more than 26,400 gpd per unit and contracted, delivered or under construction, with a total capacity of more than 9,250 million gpd. The data is as recent as December 2003.

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