Seawater Desalination Power Consumption

White Paper

November 2011

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WATEREUSE ASSOCIATION
DESALINATION COMMITTEE

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I Introduction

Virtually everything we do affects our ability to harness and expend energy. One simple, small-scale example is the energy expended by our bodies to fight the effect of gravity as salts and impurities are removed from our body. On a much larger scale, energy is necessary to meet the needs of society, which include obtaining, transporting, treating, and distributing potable water.

Access to clean, safe, and reliable sources of drinking water is a basic goal in today's world. As society has developed, so has our ability to transport water over great distances to meet that fundamental objective, as well as the ability to measure the quality of water to ensure that it is safe to drink. To a large extent, the advent of analytical techniques to measure contaminants, viruses, and pathogens in water paved the way for the US Environmental Protection Agency (US EPA) in the early 1970's to develop rules and regulations requiring drinking water to be treated, or "manufactured", to meet standards for the benefit and protection of public health. Rules and regulations have evolved since the 1970's, commensurate with our understanding of contaminants and ability to measure them. This "evolution" of standards led the US EPA to identify membrane filtration – including reverse osmosis desalination – as one treatment technology for drinking water supplies to meet increasingly difficult water quality challenges.

Today, virtually every drinking water supply is treated in some form or fashion, driven by a number of factors primarily associated with the discovery of new contaminants: advanced testing methods; public perception; verifiable health risks; and development of improved/new water quality standards. The extent of water treatment – and the energy and power needed to meet those requirements – can vary considerably, as expected, because of the accessibility and initial quality of a raw water supply.

Seawater desalination, like any other water treatment technology or separation processes, requires the use of energy to produce water. As a drinking water treatment technology, however, seawater desalination requires more energy than most other water treatment methods. Often, however, the power consumption associated with seawater desalination is exaggerated or inaccurately represented, particularly when compared to other treatment technologies or alternatives assuring safe, reliable public water supply.

This paper reviews and outlines the power requirements associated with seawater desalination, measures used to compare and offset seawater desalination power consumption to other water supply alternatives, and the opportunities for future reduced energy demand.

II Treated Water Power Consumption

A. <u>Water Project – Energy Requirements</u>

Every drinking water supply requires energy, and there are four principal areas consuming energy. These are:[1]

1. Source water extraction and delivery to the treatment plant (could be imported or nearby);
2. The treatment/purification process;
3. Distribution of drinking water; and
4. Residuals management, treatment, and discharge

Power costs associated with heating and cooling buildings and work spaces (HVAC), parking lot lighting, or other miscellaneous items are generally very small (compared to the total energy cost) and quite similar for comparable drinking water facilities of a similar size.

The hydraulics associated with transporting water requires pumps of varying capacity and pressure amongst each of the four power-consuming areas previously described. For illustrative purposes, individual factors that influence these areas are contained in Figure 1. Note that the actual percentage of energy contribution to the total can vary and is discussed later on in this document.

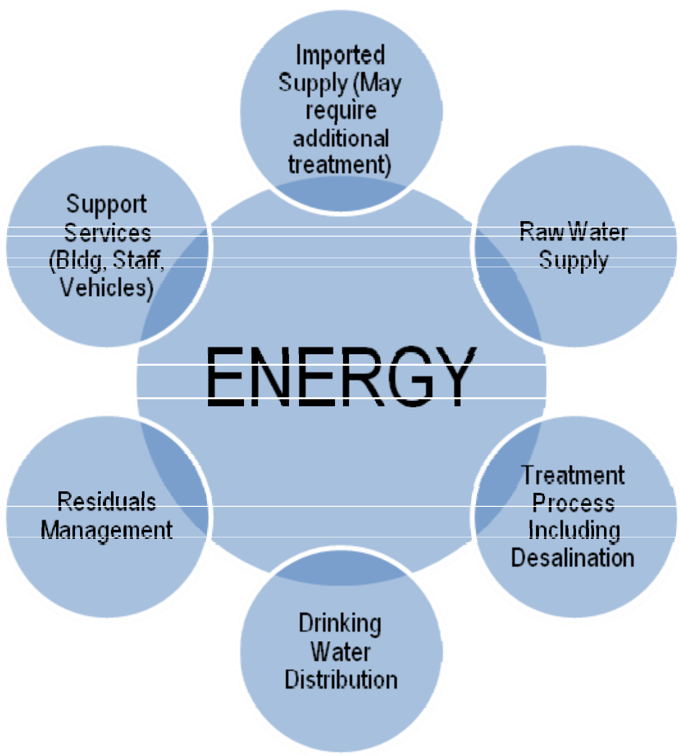


Figure 1
Areas Contributing to Energy Consumption for Water Projects[2]

1 Analysis of the Energy Intensity of Water Supplies for the West Basin Municipal Water District.
2 Graphic: Dietrich Consulting Group, LLC.

Generally, the power costs associated with elevation changes, piping distance, and pressure requirements can be easily estimated (area numbers 1, 3, and 4). Understanding the energy associated with the treatment/purification such as the seawater desalination process – area number 2 identified above – is fundamental and the primary topic of this paper.

B. Desalination Energy - Osmotic Driver

Within the "fenceline" of a seawater desalination plant, feed water salinity has the most significant impact on power consumption. Why? Compared to brackish water or other alternative surface water supplies, seawater contains a greater quantity of dissolved salts. The desalination process must overcome osmotic pressure to reverse the flow, forcing water from the "salty" feed side of a membrane to flow to the "purified" water (also known as permeate, or product water) side of the membrane (Figure 2); hence, "reverse osmosis desalination."

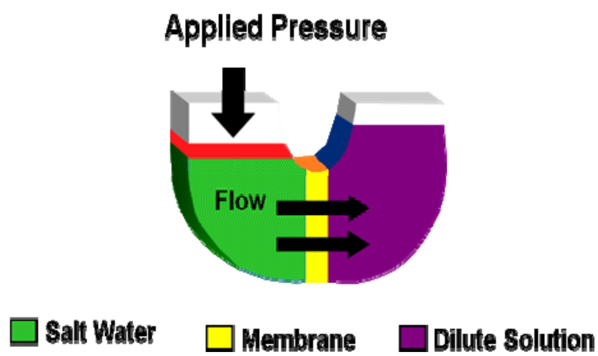


Figure 2
Producing Drinking Water by Applying Pressure[3]

A fresh, non-seawater surface water supply may not require desalination treatment if the salinity is already within secondary US EPA water quality guidelines. However, in an increasing number of utilities, brackish water desalination is utilized for targeted reduction of undesirable parameters (and in some cases, even removal of TDS to for existing distribution system compatibility). Fresh surface water – just like seawater – is associated with containing viruses and pathogens. Therefore, microfiltration (MF) or ultrafiltration (UF) are membrane-based alternatives to conventional granular media or other similar treatment processes to meet US EPA drinking water quality standards if desalination is not needed. Because of this, MF and UF are frequently utilized as low-pressure membrane pretreatment alternatives for removal of non-ionic species such as suspended matter or viruses and pathogens.

Table 1 (below) contains the range of typical pressures associated with feed water salinity. As such, it is clear to see that as feed water salinity increases, so does the requirement for an increase in membrane feed pressure (and associated energy) until the practical limitation of 1200 psi (82.7 bar) for drinking water

3 Southeast Desalting Association (SEDA): www.southeastdesalting.com.

production is reached; at which point the actual feed water recovery is typically decreased to stay within design pressure limitations.

Table 1
Source Water Quality and Pressure Requirements[4]

Source	Associated Salinity, (mg/L)	Typical Pressure Range, psi (bar)
Surface (Fresh) Water (MF/UF)	<500	15 – 30 (1 – 2)
Brackish Water (RO)	500 – 3500	50 – 150 (3.4 – 10.3)
Brackish to Saline (RO / SWRO)	3500 – 18,000	150 – 650 (10.3 – 44.8)
Seawater, typical range[5] • USA • Middle East	18,000 – 36,000 18,000 – 45,000+	650 – 1200 (44.8 – 82.7)

The viscosity of water changes with temperature. A change of one degree Centigrade in the temperature of the feed water results in a 3% rate of change (increase/decrease) in membrane throughput[6]. Throughput, or flux, describes the hydraulic capacity of water produced by the desalination membrane. Therefore, to achieve an equivalent production value or throughput, more pressure is applied (in varying increments), additional reverse osmosis capacity is brought on line, or production decreases. The relative influence that feed water temperature has on required seawater reverse osmosis (SWRO) pressures, at a fixed average seawater salinity of 34,000 mg/L (34 parts per thousand, ppt) and a SWRO recovery of 50%, is illustrated in Figure 3.

4 Dietrich Consulting Group, LLC.
5 Ranges can vary widely and are site specific. For illustrative purposes only.
6 This is corrected from another published document “An Investigation of the Marginal Cost of Seawater Desalination in California”; Fryer, James; March 18, 2010, R4RD.

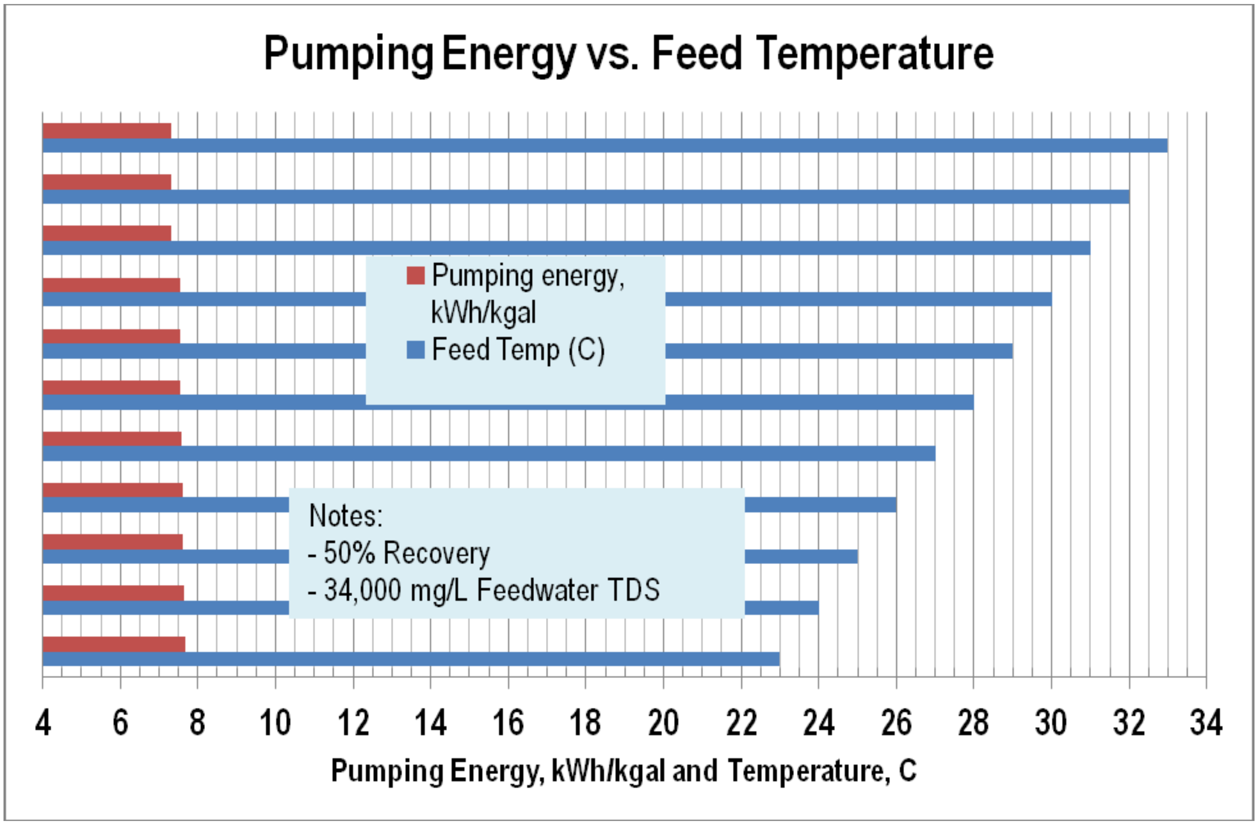


Figure 3[7]
Effect of Feed Water Temperature on Pumping Energy

The example in Figure 3 is for seawater with a salinity of 34,000 mg/L. Because salinity is variable around the coastal United States (and around the rest of the world), the required driving pressure and associated energy needed to produce the same throughput (flux) for different salinities will vary accordingly. A general "rule of thumb" is that the net driving pressure needed to produce an equivalent amount of permeate will increase (or decrease) by about 11 psi (0.76 bar) for each 1000 mg/L (1 ppt) incremental change in feed water salinity. Figure 4 illustrates how salinity varies around the coastal United States.

According to the National Oceanic and Atmospheric Administration (NOAA), the 3-Zone Average Annual Salinity Digital Geography in Figure 4 was developed using geographic information system (GIS) technology, and are the average annual salinities found in certain estuaries along the coastal United States. The mapped areas include the entire Atlantic, Gulf of Mexico, and Pacific coasts of the United States.

7 Source: Dietrich Consulting Group, LLC.

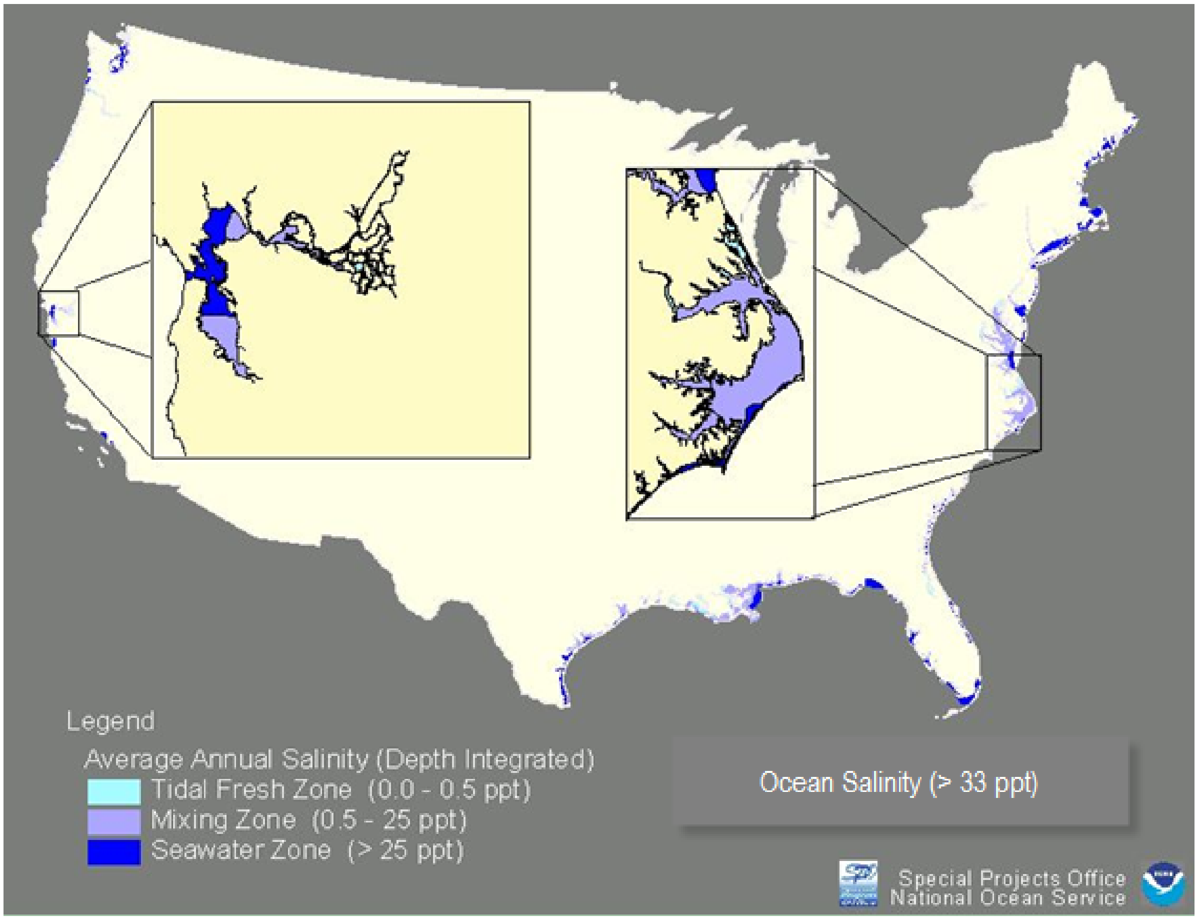


Figure 4
United States Coastal Salinity Zones[8]

III Power-Contributing Components of the Desalination Process

Figure 1 contains the individual areas of a water supply project that contribute to the total energy. The impact, range, and percentage each of these areas are further illustrated by breaking out each area individually for discussion purposes.

Because the seawater desalination treatment process is typically associated with being the most energy-intensive, it is a convenient starting point. The remaining areas identified in Figure 1 are discussed below. It is important to note that the power consumption costs utilized throughout this document are relative to each treatment process. The sum of the components with respect to the quantity of water produced is also called specific power[9]. This paper discusses each of the individual components of the water treatment process which add up to the total.

8 NOAA's Coastal Geospatial Data Project; http://coastalgeospatial.noaa.gov.
9 33,000 mg/L feed water salinity; 25 deg. C; 9 GFD flux.

The seawater desalination treatment process includes:

- Pretreatment, or pre-filtration;
- SWRO (membrane) desalination; and
- Post-treatment of permeate

Pretreatment

Reverse osmosis membranes are subject to fouling or plugging on the membrane surface. This can decrease the permeate production capacity of the membrane or require an increase in operating pressure (and subsequent energy) to overcome the fouling effect. As a result, virtually every membrane desalination facility in the world (including SWRO) requires properly pretreated seawater. The pretreatment equipment used in SWRO facilities is similar to what you would find at any other drinking water treatment facility elsewhere and incorporates, individually or in combination: flocculation / sedimentation to remove suspended material; dissolved air flotation (DAF) to remove potential algal biomass or potential hydrocarbons; granular media filtration (GMF); and/or low-pressure UF or MF to remove suspended particulate matter. The pretreatment energy requirements are comparable to any other surface water treatment plant, and range from 0.9 to 1.5 KWh/kgal (293 – 489 kWh/AF). When compared to the energy costs associated with the rest of a typical SWRO facility, pretreatment accounts for 8 to 12% of the total.

SWRO Process

Seawater RO membrane energy consumption is related to site-specific salinity and temperature (as previously discussed) and other design-specific characteristics such as hydraulic loading rates (flux) and the percentage of feed water recovered. The primary power-consuming devices are the pumps required to achieve the feed pressure needed to facilitate the reverse osmosis process. The range of pressures listed in Table 2 is typical for the United States. Elsewhere in the world – for example, in the Middle East, where salinity can be significantly higher – the net energy required (including recovered energy) will increase 15 to 20% above those values contained in Table 2. For lower salinity applications, there is an associated decrease in power demand. Coastal embayment areas under the influence of river or other surface water runoff will require, at a minimum, 15 to 20% less power.

Any processes or practice that can reduce power consumption will, by definition, decrease the costs associated with operating a SWRO plant (or any plant, for that matter). For this reason – and because of the potential to recover the power necessary for the reverse osmosis process – energy recovery systems are almost always a part of the mechanical equipment incorporated into the desalination process. The principle behind an energy recovery device is to use the energy of the concentrate, which is about 1 to 2% less than the feed pressure energy, and transfer this energy back into the system to cause a net decrease in overall power consumption.

Energy recovery devices offer significantly improved efficiencies compared to equipment utilized decades ago. Energy recovery devices can operate at an efficiency of 85 to 95% and hydraulically recapture a portion of the power consumed by the high-pressure SWRO pump.

Engineers, designers, and operators also pay serious consideration to power savings with adjustable frequency drives (AFD). For example, a coastal upper bay experiencing a relatively wide salinity range of 20,000 mg/L to 32,000 mg/L (such as in Tampa Bay, FL), must meet a SWRO feed water pressure differential of up to 400 psig (27.6 bar) to desalinate the seawater. An AFD allows for operation of a pump on a practically "infinite" number of speed curves depending on the required operating conditions, in lieu of "burning off" excess pressure (and power cost) that may not be necessary during certain times when salinity is lower, and yet still allow production of the required volume of water. Ultimately, the choice of energy recovery devices and/or AFDs is site specific and depends on the configuration of the membrane system, pressure requirements, and budget.

The Affordable Desalination Collaboration (ADC) Project

The ADC is a non-profit organization comprised of government and state agencies such as the California Department of Water Resources, California Energy Commission, City of Santa Cruz/Soquel Creek Water District, Metropolitan Water District of Southern California, Marin Municipal Water District, Municipal Water District of Orange County, Naval Facilities Engineering Service Center, San Diego County Water Authority, Sandia National Laboratories, and the West Basin Municipal Water District. The organization's members also include leading equipment manufacturers and consulting engineering firms with seawater desalination experience. Work accomplished by the ADC towards assisting water industry professionals in understanding the energy associated with desalination, as well as the costs associated with desalination processes, is significant. The ADC established the lowest energy use and costs that were obtained by applying modern desalination technology and equipment. The ADC has since achieved its goals including demonstrating very low energy consumption for the desalination process, and discontinued testing in 2010.

In 2008, after two years of extensive testing of various membrane manufacturers' products using "off the shelf" modern technology, including the aforementioned adjustable frequency drives, the ADC concluded that the range of energy requirements for the SWRO process (including energy recovery) is 6.8 – 8.2 kWh/kgal (2216 kWh/AF – 2672 kWh/AF) depending upon the type of manufacturers' membranes tested during the study[10]. Figure 4 shows how the power costs varied with membrane type and feed water recovery (%). In the figure, "Total Treatment Energy" is calculated in the upper curves and includes power estimates for the rest of the plant treatment equipment and components.

When compared to the total energy costs associated with a modern SWRO facility, the SWRO component (not including feed conveyance or finished water distribution) ranges from 65 to 85% of the total energy cost. Accordingly, within the fence line of the desalination facility, the SWRO process itself consumes the greatest percentage of total power.

10 MacHarg, J., Seacord, T., Sessions, B., "ADC Baseline Tests Reveal Trends in Membrane Performance", *Desalination and Water Reuse*, Vol 18/2, 2008.

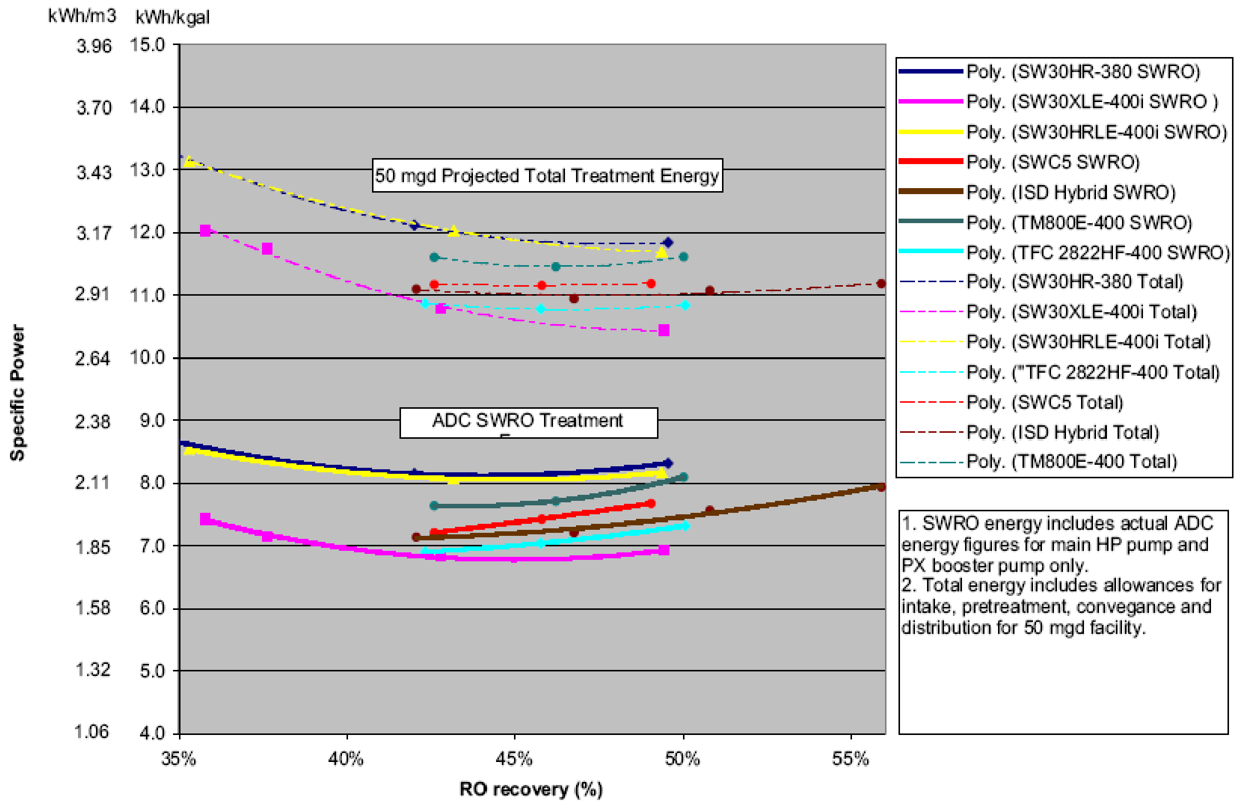


Figure 4

SWRO+Energy Recovery – Energy Consumption vs. Recovery at 9 GFD[11]

<u>Post Treatment Conditioning</u>

The next treatment step in a SWRO facility is post-treatment conditioning of the permeate. Permeate produced by the desalination process requires the addition of conditioning chemicals for buffering and stabilization prior to entering a drinking water distribution system. Buffering and stabilization requires very little energy; most of the power is associated with pumping SWRO permeate high enough (e.g., 30 feet (10m)) to trickle-down through limestone (calcite) reactors for buffering or the minute energy associated with a lime slaking system. These energy expenditures are less than 2% of the total power requirement for a typical seawater desalination facility.

Additional methods of drinking water post treatment, and the energy associated with such treatment, are common among virtually all other treatment processes in the US. These include (but are not limited to) disinfection with chlorine and/or chloramination, fluoridation, addition of corrosion inhibitors, and blending.

IV Remaining Areas Contributing to Energy Consumption for Water Projects

Any water supply project also considers how the available supply (to be treated or otherwise consumed) is transported and pumped through pipelines to the treatment site, and, after treatment, how the potable water

11 Ibid; MacHarg, J.

will be pumped and conveyed through pipelines to the public. As one can imagine, the energy costs associated with these two components can range in significance, depending upon how far the facility is from the source and distribution area.

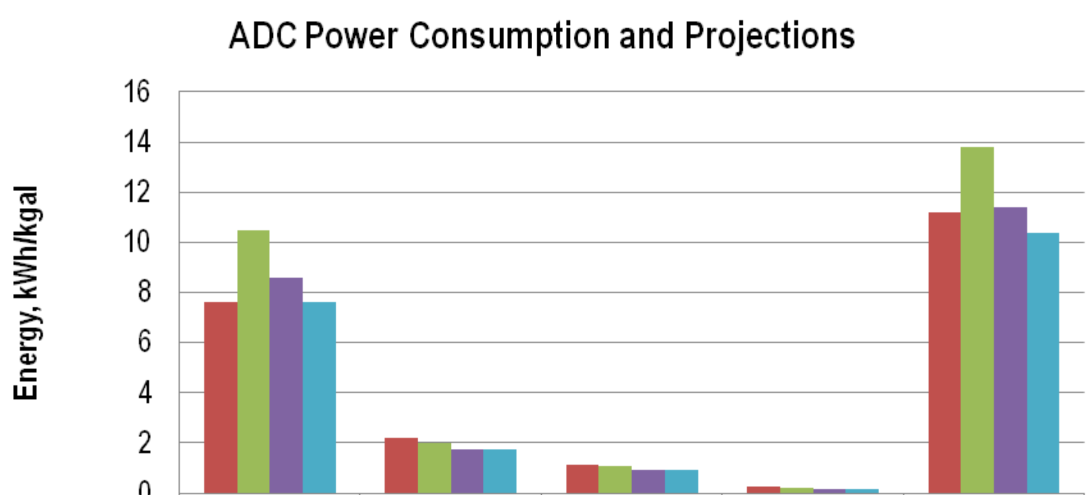
Energy Associated with Supply

This area might be one of the most understated or overlooked components of water projects. Perhaps this is because in coastal areas where a seawater desalination facility is located next to the ocean, the power cost to pump seawater to the facility are usually associated with overcoming a short distance and relatively short elevation to reach the treatment facility. Close proximity to the ocean makes economic sense, if at all feasible. However, when evaluating the total energy equation, such as comparing one water supply versus another, the power costs for supplying inland conventional water supplies to coastal areas can be greater than a coastal desal facility.

For example, the bulk of Southern California drinking water comes from the Colorado River via massive aqueduct and conveyance systems. This involves pumping (and re-pumping) raw water through a wide variety of elevations (hillsides and mountains) to ultimately reach the Southern California consumer. The energy costs associated with supplying this water is a major element of the typical southern Californian's consumption of energy – about 14% to 19% of the total residential energy demand (which includes air conditioning)[12].

For a conventional intake system where the supply source is nearby the SWRO facility, power consumption will range from 15% to 20% of the total power consumed by the water treatment process. Figure 5, developed by the ADC, shows a comparison of energy requirements for the different treatment components of a SWRO facility producing 0.3, 10, and 50 million gallons per day. An additional benefit of the ADC chart is the effect economies of scale have on power cost.

12 Wilkinson, Robert C, Ph.D., Analysis of the Energy Intensity of Water Supplies for West Basin Municipal Water District, March 2007.



	SWRO Process	Intake	Prefiltration	Permeate Treatment	Total Treatment
ADC MAP	7.6	2.19	1.15	0.25	11.2
0.3 MGD	10.5	2.01	1.06	0.23	13.8
10 MGD	8.6	1.74	0.91	0.17	11.4
50 MGD	7.6	1.72	0.9	0.16	10.4

Figure 5

ADC – Energy Consumption and Projections[13]

Energy Associated with Distribution

Just as the feed water source to a water treatment facility has an energy impact, so too does the energy associated with pumping drinking water from the treatment facility to the consumer. Local terrain, elevation, subsurface impediments (geologic or man-made), required delivery pressure, and accessibility all factor in into the power cost.

For example, the West Basin Municipal Water District (WBMWD), located near Los Angeles in Southern California, evaluated a scenario incorporating both the imported water and distribution energy cost. Figure 6 displays a comparison of the costs. As the figure demonstrates, power consumption associated with seawater desalination (including the feed water conveyance and distribution) are competitive with other current, alternative sources of supply.

13 "Affordable Desalination Profiles State of the Art SWRO", www.affordabledesal.com , March 27, 2008. Test conditions: (excluding ADC Record): 885 psi feed pressure, 9.0 gfd, 48% recovery, 156 mg/L permeate TDS, 0.8 mg/l Boron, feed TDS 31,742 mg/L, 60˚F.

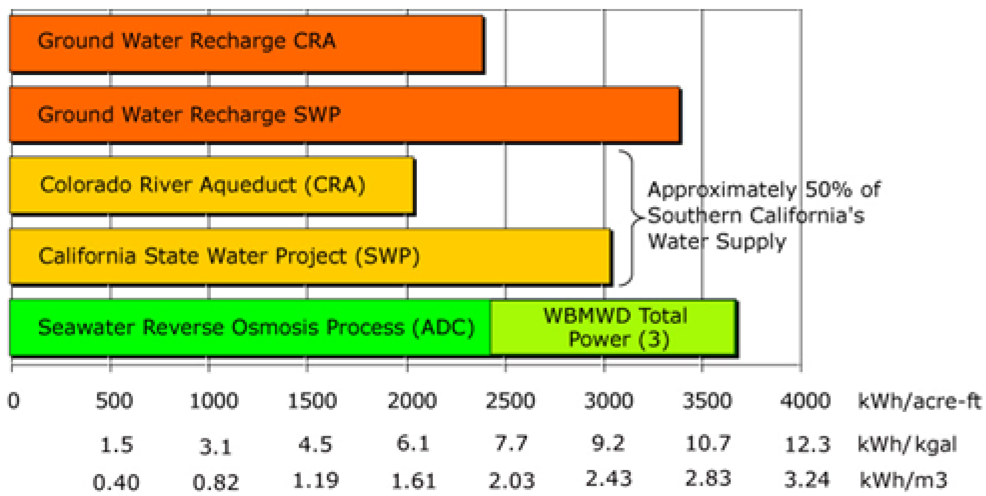


Figure 6

Water Supply Energy Consumption Comparison at West Basin[14]

<u>Residuals Management and Support Services</u>

This energy component of a seawater desalination facility includes the remaining items that support the proper function and operation of the plant excluding the treatment process itself. For example, similar to a commercial park or residential household, typical support services would include building lighting and air conditioning. Because pretreatment requires occasional backwash and cleaning, and RO membranes also require periodic cleaning, energy associated with pumps, heaters, blowers, and chemical feeders are accounted for. Figure 7 shows a typical breakdown of ancillary support power associated with a typical desalination facility.

14 Wilkinson, Robert C, Ph.D., <u>Analysis of the Energy Intensity of Water Supplies for West Basin Municipal Water District</u>, March 2007.

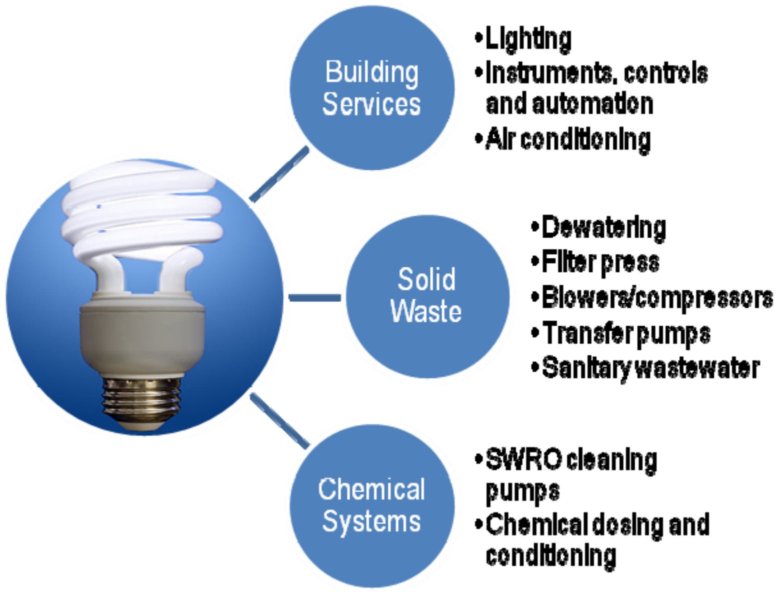


Figure 7[15]
Ancillary (Facility) Components of SWRO Energy

These components, when added together and compared to the rest of the facility, account for between 10 and 15% of the total power consumption. Many of the services attributed to power consumption are similar to any other conventional drinking water facility, with the exception of the membrane cleaning system(s). Note that the actual value can vary among differing facilities based on the specific needs of the plant and personnel.

V Rolled-Up Power Costs for Seawater Desalination Facilities

Although the basic application of membrane technology is the same among seawater desalination plants, published reports on the total (rolled-up) power consumption of SWRO facilities vary significantly. This is because SWRO projects are specifically designed for the locale, accounting for energy costs associated with changes in feed water salinity and temperature, changes in elevation, the local cost of power and fuel, degree of pretreatment, distance to feed water supply source, and the distribution point. The pie chart in Figure 8 contains a range of costs for the various components of a SWRO facility, based on actual costs at operational SWRO facilities. The energy "slice" is 28% to 50%, which can approach (or exceed) the capital recovery. A range is provided because the specific technical components factoring into the range will vary by project, and the capital recovery cost is driven by many factors such as interest, bond cost, payment time frame, and other financing schemes.

15 Dietrich Consulting Group, LLC.

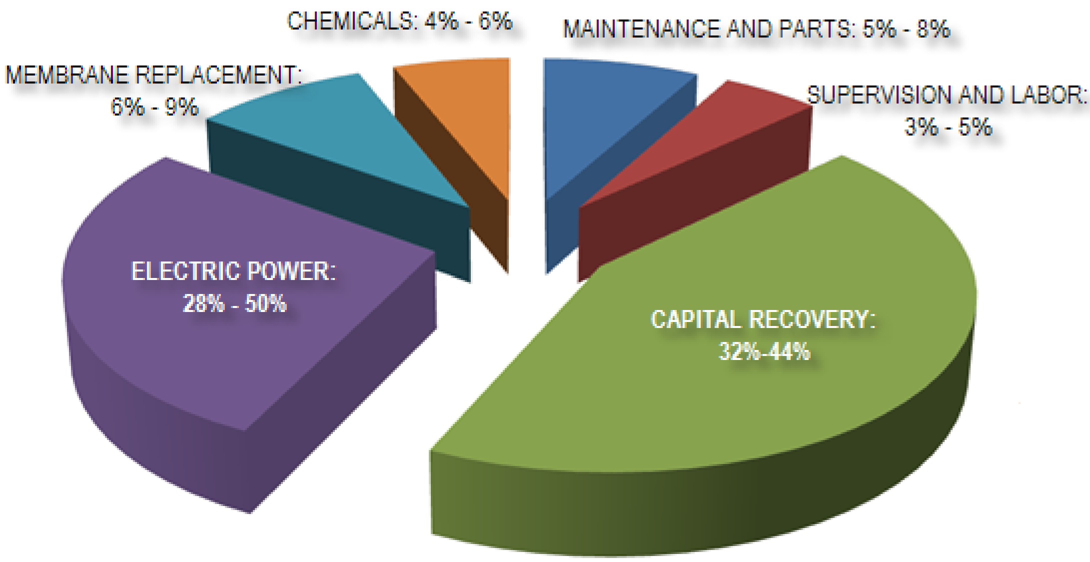


Figure 8
Typical Range of SWRO Facility Cost Components as a Percentage of Total[16]

VI Power Cost Comparison with Other Water Supply Alternatives

Seawater desalination is but one consideration in the portfolio of water supply alternatives that a utility may have to choose from. Fresh groundwater supply may be plentiful in certain areas of Florida, but its availability is becoming very limited in coastal and inland areas. An example of this occurred in the Tampa Bay region in the late 1990's, where permitted groundwater withdrawals had to be reduced from 192 mgd to 90 mgd to reduce environmental impacts related to the withdrawals. After decades of repetitive drought cycles, the drought-proof alternative chosen by the local master utility (Tampa Bay Water) was the seawater desalination plant.

For comparison purposes, the energy use of various water supply alternatives is contained in Table 2. For example, a SWRO plant along the Gulf of Mexico consumes the same amount of power as California imported water, even before the California water is treated. This is but one simple, illustrative example of the energy competiveness of SWRO desalination, although it must be considered in the right context. That said, SWRO along the Pacific coast is competitive, although accurate energy consumption can only be compared once specifics of the site are defined.

16 Graphic provided by Dietrich Consulting Group, LLC.

Table 2
Energy Use of Various Water Supply Alternatives
(1 kWh/kgal = 325.8 kWh/AF)

Supply Alternative[17]	Power Consumption, Range	
	kWh/kgal	kWh/AF
State Water Project (California)		
Raw water delivery to treatment points	9.0 – 10.6	2930 – 3450
Conventional treatment	0.8 – 1.5	260 – 490
State Water Project (California) – Total	9.8 – 12.1	3190 – 3940
Imported Colorado River (California)		
Raw water delivery to treatment points	6.0 – 8.0	1950 – 2600
Conventional treatment	0.8 – 1.5	260 – 490
Imported Colorado River (California) – Total	6.8 – 9.5	2210 – 3090
Reclaimed water for Indirect Potable Reuse		
Wastewater treatment	2.0 – 4.0	650 – 1300
Tertiary treatment for Indirect Potable Reuse	5.0 – 7.5	1630 – 2440
Reclaimed water for indirect potable reuse – Total	7.0 – 11.5	2280 – 3740
Brackish Water Desalination	3.0 – 5.0	980 – 1630
Desalination of Pacific Ocean Water	10.0 – 14.0	3260 – 4560
Desalination of Gulf of Mexico Water	9.1 – 13.2	2970 – 4300

VII Challenges and Perceptions: Is the Relative Power Consumption REALLY Excessive?

No, the relative power consumption is not excessive. Documented yearly gains in SWRO efficiency certainly help. In fact, the total power cost to produce desalinated seawater for a family of four[18] is equivalent to the power consumption of about one household refrigerator. Considering carbon footprint issues, the impact of seawater desalination is comparatively modest; for example, the average person, through the natural process of breathing, produces approximately 2.3 pounds (1 kg) of carbon dioxide per day[19]. Similarly, the amount of carbon dioxide generated from 3-4 minutes of moderate exercise (e.g., taking the stairs instead of the elevator) is equivalent to the CO2 emissions from a SWRO facility producing one gallon of water for an individual to drink throughout the day[20].

Additionally, the energy requirements of conventional water treatment processes are increasing. The reason is that for most surface water sources, the typical treatment process is chemical addition, coagulation and settling, followed by filtration and disinfection. In the case of groundwater (well) systems,

17 http://www.affordabledesal.com/home/news/WConPurJan07.pdf
18 Family of four consuming 400 gpd at 0.0144 kWh/gal with a total annual energy use for water production = 2,102 kW/yr; versus a 16 cu ft. refrigerator with consumption of 725 (http://www.energysavers.gov/your_home/appliances/index.cfm/mytopic=10040) x a conservative 33% operating time = 2,117 kW/yr.
19 United States Environmental Protection Agency. Considered part of the “Natural emissions”cycle and does not count towards greenhouse gas generation.
20 Calculation based on 600 lbs. CO2 generated per MWh, which is a recognized, conservative equivalent value representative of a power provider in Southern California; 50 MGD SWRO facility; 35 MWh power required for SWRO facility; 120 gpd consumed per 3.2-person household; and respiration rate doubled during exercise time.

the treatment may consist of only disinfection with chlorine. Wells that are under the influence of surface water must meet surface water treatment criterion. All methods of treatment must comply with certain treatment techniques, water quality goals, and contaminant removal criterion. As a result, future implementation of new drinking water regulations will increase the use of higher energy consuming processes, such as ozone and membrane filtration.[21]

In 2002, the California Legislature approved Assembly Bill 2717 (Hertzberg, Chapter 957), which asked the Department of Water Resources (DWR) to convene the California Water Desalination Task Force to look into potential opportunities and impediments for using seawater and brackish water desalination, and to examine what role, if any, the State should play in furthering the use of desalination technology[22]. A primary finding of the Task Force is that economically and environmentally acceptable seawater desalination should be considered as part of a balanced water portfolio to help meet California's existing and future water supply and environmental needs. One significant energy-related conclusion of the Report is that the energy generation capacity of the State would not be a constraint to implementation of currently proposed desalination projects. In fact, applying 2002 SWRO membrane technology, over half a dozen proposed SWRO facilities (totaling more than 350 mgd[23]) would add about 0.4% to the State's peak power load. Since the time of that Report, and considering current SWRO membrane technology advances and increases in energy recovery device efficiencies, the addition would be reduced to 0.35% or less.

SWRO energy consumption can be relatively high compared to many other water treatment methods. However, when considering the total water/energy equation, including intake source, location, distance, and quality, the power numbers can become quite competitive and perhaps even attractive. The added benefit of utilizing a state-of-the-art water treatment method, producing the highest quality drinking water available, certainly helps. In addition, other (alternative) water supplies 1) may be declining; 2) are becoming more impaired and require more treatment; and 3) regulations are becoming more stringent which, in turn, is requiring more treatment of unimpaired surface waters.

As the amount of necessary energy decreases with increased membrane efficiencies and new products, the power requirements of SWRO will continue to approach the energy cost of existing sources of conventional supply, in particular the existing sources requiring further treatment to meet drinking water standards and regulations.

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21 Burton, Franklin L., 1996, *Water and Wastewater Industries: Characteristics and Energy Management Opportunities,* Electric Power Research Institute Report CR-106941.
22 California Desalination Task Force: "Water Desalination: Findings and Recommendations," October, 2003.
23 http://www.water.ca.gov/desalination/pud_pdf/Desal_Handbook.pdf