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In search of affordable SWRO

- US consortium takes off

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ADC

1908 Doolittle Drive, San Leandro, CA 94577, USA
Tel: +1 510 483 7370 Fax: +1 510 483 7371
Email: info@affordabledesalination.com
www.affordabledesal.com

ADC
Affordable Desalination Collaboration

West Coast researchers seek to demonstrate SWRO affordability

John MacHarg and **Randy Truby**, Energy Recovery Inc, USA

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Editor's note

So what is the real cost of drinking water produced by seawater reverse-osmosis (SWRO)? At the recent Aquatech show in Amsterdam, a CEO from a sector manufacturer told D&WR that, stripped of subsidies etc, it costs around $0.62/m^3. OK, you may say, but can a plant be built producing water at that price without the fuss we had over Tampa? These questions have so vexed some private and public desalination entities in the USA that they have banded together to settle the debate once and for all by building and operating an 200-300 m^3/day SWRO Affordable Desalination Demonstration Project. **John MacHarg**, general manager of Energy Recovery Inc, and **Randy Truby**, past IDA president who has just joined ERI, explain what the project is all about.

The Affordable Desalination Demonstration Project 2005 has been set up by a group of leading companies and agencies within the desalination industry that have agreed to combine their efforts and share their expertise in a mission to help make desalination affordable. The project will build and operate a demonstration plant at the US Navy's Seawater Desalination Test Facility in Pt. Hueneme, California.

A combination of proven technologies developed primarily in the US will be used to demonstrate to California, to the US and to the world that seawater reverse osmosis (SWRO) desalination is technically and economically viable for the production of potable and irrigation water. The adjacent panel shows the companies and public bodies currently involved in the Affordable Desalination Collaboration (ADC)

Energy Recovery, Inc, a private San Francisco Bay Area manufacturer of breakthrough energy-saving technology, initiated the project.

Affordable Desalination Collaboration Members and Participants

A partial list of member-participants that the project is seeking to collaborate with includes:

- Energy Recovery, Inc.
- FilmTec Membrane Corporation
- David Brown Union Pumps - Textron
- CodeLine Pressure Vessels
- Carollo Engineers
- WaterEye
- Piedmont Pacific Corporation
- U.S. Naval Facilities Engineering Service Center Seawater Desalination Test Facility
- West Basin Municipal Water District
- Municipal Water District of Orange County
- Rolled Alloys
- California Department of Water Resources
- California Energy Commission
- U.S. Bureau of Reclamation
- Office of Naval Research
- US Desalination Coalition

RO and energy

Energy is the single largest cost component of operating a seawater desalination system. Early distillation

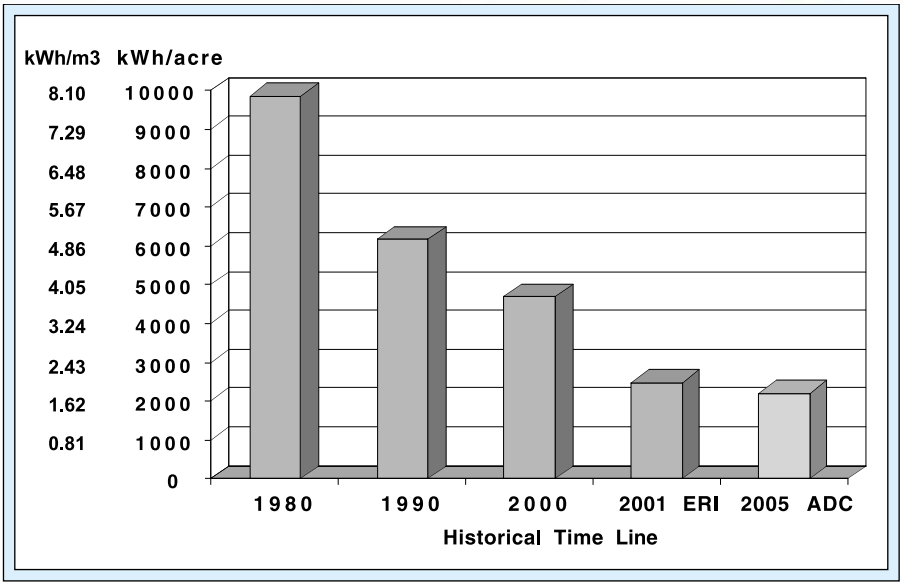


Figure 1: Historical Power Consumption of SWRO

systems consumed as much as 25 kiloWatt hours/m^3 (95 kWh per 1000 gallons, 30,840 kWh per acre foot). In the late 1970s, early SWRO systems consumed as much as 20 kWh/m^3 (75 kWh/kgal, 24,680 kWh/acre-ft). By the mid 1980s, through improvements in the achievable recoveries of RO membranes and efficiencies of the pumping and energy recovery systems, these numbers were reduced to as low as 8 kWh/m^3 (30 kWh/kgal, 9868 kWh/acre-ft).

Although these improvements were dramatic, SWRO was still energy intensive and was only practical in special economic zones and/or where energy was cheap. Energy still accounted for as much as 75% of the total operating costs of SWRO systems. For this reason the RO industry re-doubled its effort through the 1990s to create improvements in both the membranes, energy recovery and pumping systems and, towards the end of the decade, had achieved energy consumption levels as low as 3.5 kWh/m^3 (13 kWh/kgal, 4320 kWh/acre-ft).

By the turn of the century, SWRO had become far more widely applied throughout the world. However, the pumping and energy recovery systems that were being used were still achieving overall efficiencies of only 50-75%. These low efficiencies were continuing to push the membrane manufacturers to develop high rejection, high pressure membranes that could achieve higher recovery rates to reduce the RO feed flow rates and consequently the pumping power required by the systems. Around this same time there was a shift to the new isobaric energy recovery technologies that could yield 93-97% net transfer efficiencies. As a result of these new technologies, almost overnight SWRO energy consumption dropped to as low as 2.0 kWh/m^3 (7.6 kWh/kgal, 2467 kWh/acre-ft). Now even further improvements are possible by combining these new devices with other advanced membrane and pumping technologies. The major goal of the project is to demonstrate SWRO at 1.7 kWh/m^3 (6.6 kWh/kgal, 2200 kWh/acre-ft) of permeate produced for the RO process.

The project will also establish the relationships between:

- RO reject rate
- membrane salt rejection
- permeate quality
- boron levels
- feed pressure, and
- energy consumption.

These relationships will help to guide the SWRO industry as to what recoveries, flux rates and salt rejection rates are optimal when using today's best available technologies.

ADC member-participants

To date, the ADC has assembled a group of industry leading manufacturers, government agencies, consultants and professionals to partner together to achieve the goals of the Project. Many of these companies and agencies have pledged their support for the Project and others are expected to participate.

To be an eligible member-participant, organizations should be recognized as leaders in the desalination industry. Second, they must be willing to contribute their equipment, services and/or resources to the project and help it to succeed.

Membership cooperation agreements are executed between the ADC - a non-profit corporation - and each member-participant. The agreement clearly indicates what funds and in-kind contributions the member-participant will be responsible for and who will be authorized to make these commitments on behalf of the member-participant organization.

The agreement also describes the nature of the relationship between the member-participant and the ADC, including the allocation of decision-making authority and liability as well as the tasks to be performed by the different entities and the costs associated with the tasks.

Project duration and content

The initial demonstration at the Pt. Hueneme Seawater Desalination Test Facility is scheduled to run in the first half of 2005. The demonstration may be extended or altered after this initial period if residual funds and/or materials are available.

The project is divided into sections as follows.

Section A: Relevance and Importance

There is a common perception that SWRO is an energy-intensive process and therefore not generally affordable. In the past, this was certain, but recent developments in the field have significantly changed the cost equation for this technology.

These developments have been happening at such a rapid rate that even industry experts are not fully aware of the extent to which energy consumption in SWRO plants has been reduced. Government officials, decision-makers and experts alike will benefit by knowing what is possible today.

The partners in the project will embark on building a 200-300 m^3/day SWRO plant that will demonstrate fresh water production from seawater at 1.7 kWh/m^3 (6.6 kWh/kgal, 2200 kWh/acre-ft). This low energy-consumption level, when combined with the latest technological improvements to help reduce desalination plant capital and maintenance costs, should lower the overall cost of SWRO to within the range of what is affordable by many municipal consumers today.

It can be argued that the energy consumption of SWRO plants is the single most important variable in pushing the technology forward as a reliable, affordable and environmentally responsible source of fresh water. Energy

consumption is the single largest cost in operating an SWRO plant and carries the most significant environmental impact concerns.

Reducing the power consumption of SWRO to the levels of other conventional methods used in areas like Israel and California would be a monumental achievement, and Figure 2 (above) shows that the ADC plans to demonstrate that the technology has arrived.

Section B: Innovation and Technological Advancement

There have been some major advances in energy recovery, pumping and membrane technologies of SWRO systems over the past 3 to 5 years. Some examples of these advances include:

- Energy Recovery, Inc. Pressure ExchangerTM which reduces the power required by SWRO systems by as much as 60%
- David Brown Union Pumps which have been running at the Pt. Lisas, 35 mgd desalination plant inTrinidad at over 88% efficiency
- New FILMTEC XLE low energy membranes.

These technologies represent the 'Core RO Technologies' for the Affordable Desalination Demonstration Project. The goal of the project is to combine and optimize these best available technologies to create a system that will produce fresh water from seawater water at an overall energy consumption rate of 1.7 kWh/m^3 (6.6 kWh/kgal, 2200 kWh/acre-ft).

In addition, a primary objective of this project is to use commercially available and scaleable equipment and technologies like those mentioned above as well as standard plant designs that can be directly and economically scaled up to the municipal level. For example, the project will use standard 7-element CodeLine pressure vessels and recoveries between 40-45% at flux rates of 7-10 gallons per square foot per day (gfd).

An energy consumption rate of 1.7 kWh/m3 (6.6 kWh/kgal, 2200 kWh/acre-ft) is approximately 1/12th of the energy required by the original SWRO systems and is less than 1/2 of the energy that was required by the best system designs of just a few years ago. Most importantly, 1.7 kWh/m^3 is far less than what is generally perceived to be possible today.

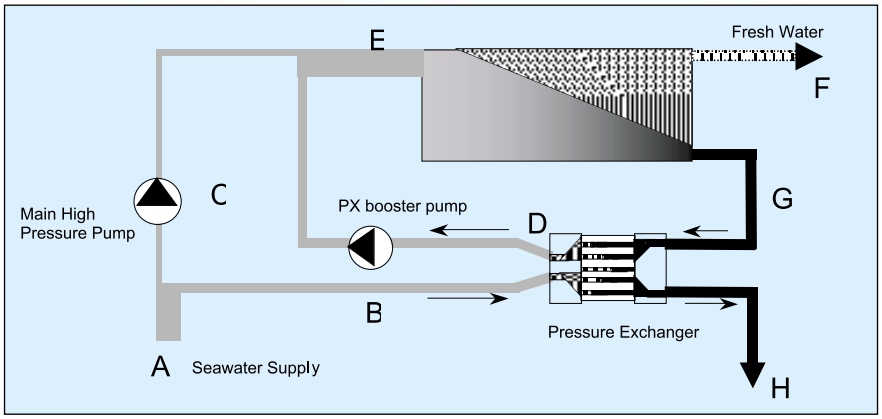


Figure 3. Typical SWRO-PX System Flow Path

STREAM	DESCRIPTION	FLOW RATE	PRESS. PSI/BAR
A	Seawater supply	100	29 / 2.0
B	PX LP Inlet/ Seawater	54	29 / 2.0
C	Main HP Pump outlet	46	700 / 48
D	PX HP Outlet/ Seawater	54	670 / 46
E	SWRO Feed Stream	100	700 / 48
F	SWRO Product Water	45	5 / 0.3
G	PX HP Inlet/ Reject	55	685 / 47
H	PX LP Outlet/ Reject	55	15 / 1.0

Table 1. Example Flow Rates and Pressures

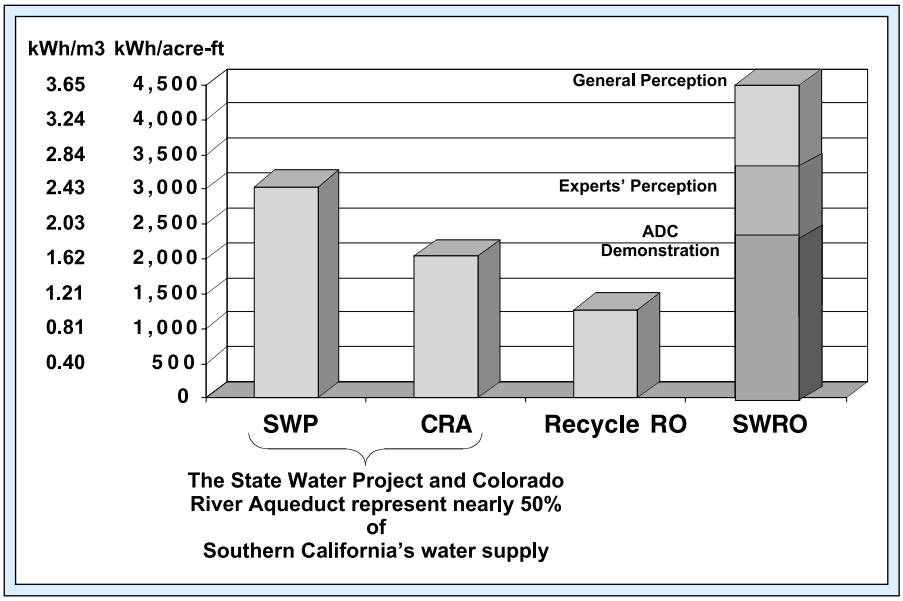


Figure 2: Energy Requirements for Various Water Supplies and the ADC

Section C: Technical/Scientific Merit, Feasibility

The project will use a combination of state-of-the-art technologies and optimized designs to reduce the power consumption of the SWRO system. Figure 3 shows a simple flow diagram for a typical Pressure Exchanger (PXTM) SWRO system.

This will be the basic design employed for the demonstration plant. The reject brine from the SWRO membranes (G) passes through the PX, where its pressure is transferred directly to a portion of the incoming raw seawater at up to 97% efficiency.

This pressurized seawater stream (D), which is nearly equal in volume and pressure to the reject stream, passes through a PX booster pump to add the small amount of pressure lost to friction in the PX, the membranes and the associated piping. The PX booster pump also serves to drive the flow of the high-pressure stream through the PX (G and D).

Fully pressurized seawater then merges with the main seawater flow to the SWRO system after the main high-pressure (HP) pump.

In an SWRO-PX system, the main HP pump is sized to equal the permeate flow plus a small amount of bearing lubrication flow, not the full SWRO feed flow. Therefore, the PX significantly reduces flow through the main HP pump.

This point is significant because a reduction in the size of the main pump results in lower power consumption and operating costs. In a typical SWRO-PX system, the main pump will provide 46% of the energy, the booster will provide 2% and the PX will provide the remaining 52%.

Since the PX uses no external power, the total power saving is 52% compared with a system with no energy recovery.

A 90% efficient David Brown Union positive-displacement main HP pump, a

		A	B	C	D	E	F	G	H
FLOW	GPM	93	51	43	51	93	42	51	51
	m^3/hr	21.2	11.5	9.7	11.5	21.2	9.5	11.7	11.7
	m^3/day	509	277	232	277	509	229	280	280
PRESSURE	PSI	19	19	763	737	763	0	747	9
	bar	1.3	1.3	52.6	50.8	52.6	0.0	51.5	0.6
QUALITY		SEA	SEA	SEA	SEA	SEA	PERM	BRINE	BRINE
PX-70		QTY	**1**						
PX UNIT FLOW		GPM	51		**LEGEND**			**INPUTS REQUIRED**	
PX Internal Bypass		GPM	1		A - Seawater to feed pump				
PX Differential HP side		PSI	10		B - Seawater to PX				
PX Differential LP side		PSI	10		C - HP Seawater from feed pump				
PX efficiency		%	96.3		D - HP Seawater from PX				
Membrane Differential		PSI	16		E - Feed to membranes				
Recovery		%	45%		F - Permeate from membranes				
					G - Concentrate from membranes				
HIGH PRESS. PUMP					H - Concentrate discharge				
Feed Pump eff		%	90%		PX Differential from grapl				
Motor eff		%	95%		Membrane differential assumed				
VFD eff		%	97%						
Power		kW	16.6		Total RO Process (kW)			17.7	
BOOSTER PUMP									
Boost Pump Eff		%	60%		kWh/m3 Permeate			1.85	
Motor Eff		%	92%		kWh/1000 gal Permeate			7.02	
VFD eff		%	97%		kWh/acre-ft Permeate			2286	
Power		kW	1.1						
sea water Feed Pump kW			0 0						

Table 2. ROSA5.4 (Worst-Case) Projections XLE-400, 7.2 gfd, 45% recovery, 60°F, 34,432 TDS feed, 0.85 Fouling

96% efficient ERI Pressure Exchanger energy-recovery device, and FILMTEC XLE low-energy membranes will provide the foundation for the project. Using the latest Filmtec ROSA5.4 SW30XLE-400i membrane projections for the system operating at 7.2 gfd and 45% recovery yields a 763 psi feed pressure.

Table 2 (above) provides a power model for this system showing a power consumption of 1.85 kWh/m^3 (7.02 kWh/kgal, 2,286 kWh/acre-ft).

Membrane projection models are typically conservative, causing them to predict inferior water qualities at significantly higher feed pressures than what may be achieved on site. Furthermore, the ROSA projection summarized above assumes a worst-case scenario with a 15% fouling factor and 60°F feed water. The above table is therefore a worst-case projection.

Normalizing the projection to 77°F and 0% fouling factor, ROSA projects a 731 psi feed pressure, which yields a 1.77 kWh/m^3 (6.70 kWh/kgal, 2183 kWh/acre-ft) power consumption.

To achieve the goal of 1.7 kWh/m^3 (6.6 kWh/kgal, 2200 kWh/acre-ft), it is necessary to operate at 700 psi RO feed pressure. A power model under these conditions is provided in Table 3 (over the page).

To reach these low operating pressures it may be necessary to operate at lower recoveries and flux rates, but the project's Core RO Technology suppliers and advisors believe that the energy-consumption goal of 1.7 kWh/m^3 will be achieved when the plant is put into operation.

The project will gather data at various flux rates, recovery rates and membrane rejection rates. Flux rates will be varied using a VFD on the positive-displacement main HP pump. Recovery rates will be adjusted by varying the flow through the PX booster pump controlled using a VFD.

The PX allows SWRO systems to run with independent permeate and reject flows as described above. The project will vary membrane performance by using separate sets of membranes.

These will include, for example:

- FILMTEC SW30HALE-400i membranes rated at 7,500 gpd,
- FILMTEC SW30XLE-400i low-energy membranes rated at 9,000 gpd, and,
- The classic FILMTEC SW30HR-380 rated at 6000gpd.

Pressures, flow rates, feed and product water quality, product boron levels, feed water SDI and power consumption data will be collected around the plant during operation.

It is an objective of this project to establish trends between membrane formulation and salt rejection rates, permeate quality, boron levels, feed pressure, and energy consumption.

The graphs shown on page 16 provide examples of the trends anticipated by the Project. These graphs were developed using the FILMTEC ROSA5.4 projection tool and ERI power models. The Project will develop similar graphs to these using real data to provide guidelines and establish goals for the SWRO industry as to what recoveries, flux rates and salt rejection rates the industry should strive to achieve. The data will also be used to perform net present value analyses of operating and capital costs associated with the membranes and intake structures.

		A	B	C	D	E	F	G	H
FLOW	GPM	105	62	43	62	105	42	63	63
	m^3/hr	23.8	14.2	9.7	14.2	23.8	9.5	14.3	14.3
	m^3/day	572	340	232	340	572	229	343	343
PRESSURE	PSI	19	19	700	670	700	0	680	9
	bar	1.3	1.3	48.3	46.2	48.3	0.0	46.9	0.6
QUALITY		SEA	SEA	SEA	SEA	SEA	PERM	BRINE	BRINE

PX-70	QTY	1	
PX UNIT FLOW	GPM	63	
PX Internal Bypass	GPM	1	
PX Differential HP side	PSI	10	
PX Differential LP side	PSI	10	
PX efficiency	%	96.3%	
Membrane Differential	PSI	20	
Recovery	%	40%	
HIGH PRESS. PUMP			
Feed Pump eff	%	90%	
Motor eff	%	95%	
VFD eff	%	97%	
Power	kW	15.2	
BOOSTER PUMP			
Boost Pump Eff	%	60%	
Motor Eff	%	92%	
VFD eff	%	97%	
Power	kW	1.5	
Seawater Feed Pump kW		0.0	

LEGEND

A - Seawater to feed pump
B - Seawater to PX
C - HP Seawater from feed pump
D - HP Seawater from PX
E - Feed to membranes
F - Permeate from membranes
G - Concentrate from membranes
H - Concentrate discharge
PX Differential from grapl
Membrane differential assumed

INPUTS REQUIRED

Total RO Process (kW)	16.7
kWh/m3 Permeate	1.75
kWh/1000 gal Permeate	6.64
kWh/acre-ft Permeate	2163

Table 3. 1.7 kWh/m³ Goal Projections

Section D: Monitoring/Assessment and Assurances

Carollo Engineers will prepare the test procedures and protocol to ensure accuracy and validity of the data. The Naval Facilities Engineering Service Center's Seawater Desalination Test Facility in Pt. Hueneme, California will operate the plant and collect the data.

Carollo Engineers will write the final test report. Energy Recovery Inc, David Brown Union Pumps and FILMTEC Membranes, the providers of the Core RO Technology, will provide additional expertise in data analysis and identify significant trends to help improve the designs and guide future projects and development. The consortium will also want to include an oversight committee that will provide reviews of the project's progress and the data.

Section E: Outreach, Information Sharing, and Promotion

This project is designed to demonstrate both how economical SWRO has become in recent years and how economical SWRO systems can be by combining best available technologies.

The general perception is that SWRO is still an energy-intensive process, thus making it expensive and environmentally unsound. But at 1.7 kWh/m³ (6.6 kWh/kgal, 2200 kWh/acre-ft), SWRO is now no more energy-intensive than many conventional sources of water.

For example, it requires between 2000-3800 kWh/acre-ft to pump water to various areas in Southern California by way of the State Water Project and Colorado River aqueducts and pipelines, and the final quality of this water is quite marginal compared with desalination permeate.

SWRO avoids many of the pitfalls associated with traditional water management. For example, SWRO is a reliable, "drought proof" source of fresh water. It produces high quality water. It avoids the environmental and political impacts of taking water from areas that have water.

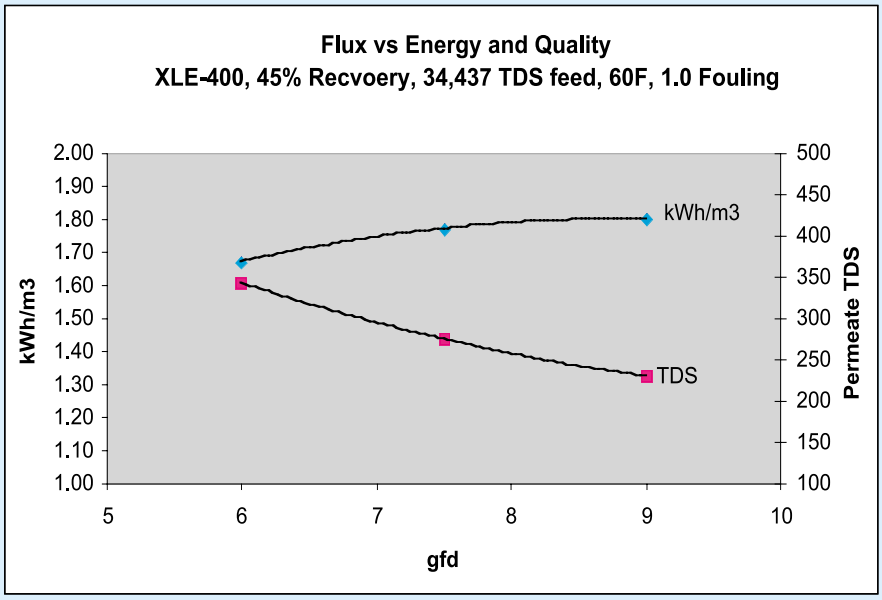
An SWRO plant is easier to secure and maintain than hundreds of miles of pipelines, aqueducts and pumping stations. The main drawback to SWRO has almost always been its high energy use, but this is no longer the situation. SWRO is now a safe, reliable and environmentally sound source of fresh water.

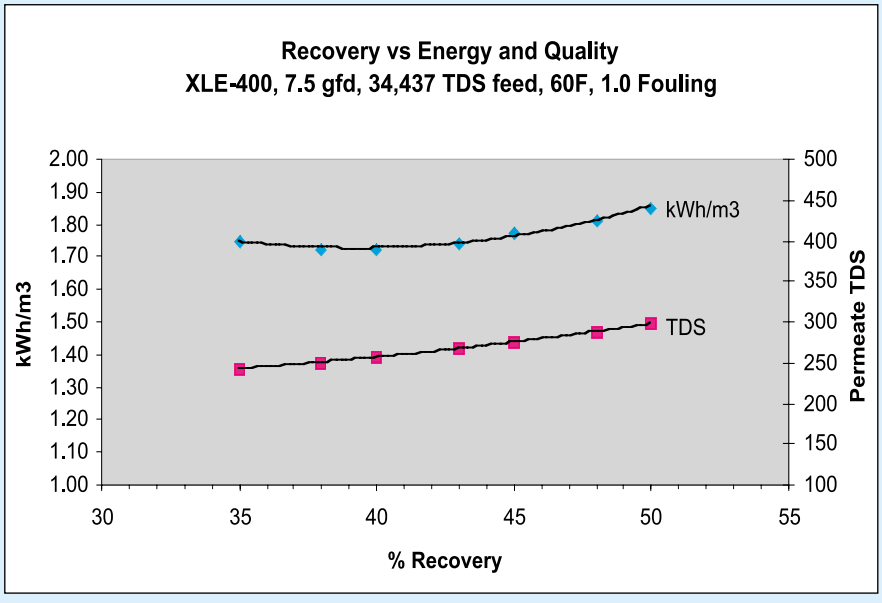
The ADC proposes to work together with industry leading companies and key U.S. and California water agencies to promote what SWRO can do today. We feel that by collaborating with leading companies and agencies we will leverage both the technologies capabilities and our collective ability to publicize the results.

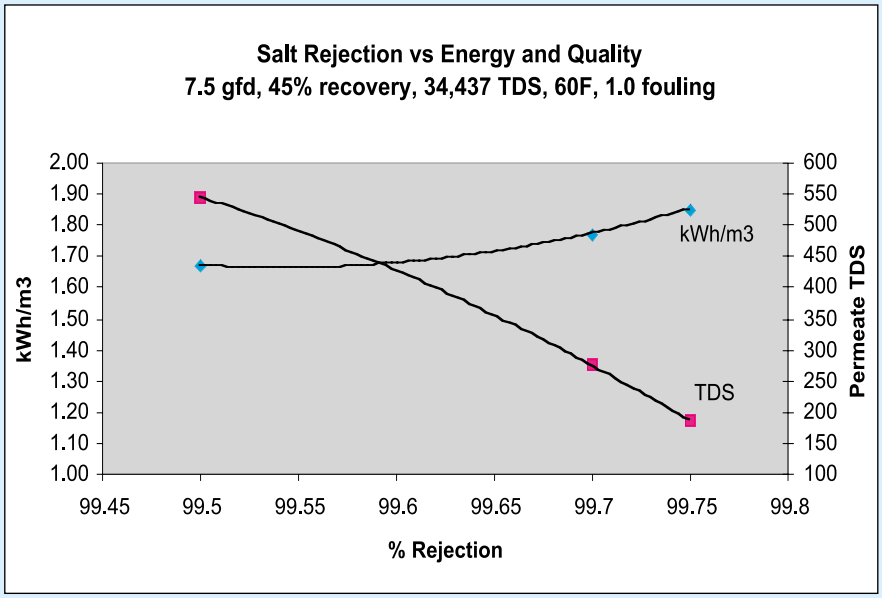
The consortium plans to disseminate the information gathered by the demonstration plant through various technical journals and by way of technical papers at conferences including the International Desalination Association Conferences, American Membrane Technology Conferences, American Water Works Conferences, etc. The Core RO Technology companies have already had good success combining their efforts and putting on regional seminars on low-energy SWRO in countries such as China.

The ADC hopes that the Affordable Desalination Demonstration Project will provide similar opportunities in the US and throughout the world. In addition, the consortium plans to use the collective public relations departments of the partner agencies to publicize the success of the project to the general media.

A public web page is also planned to







operate using Watereye's technology (www.watereye.com) showing live operating data from the plant next to inferior energy and water quality numbers from conventional water sources around the state. We feel that a project that can demonstrate SWRO for 1/12th of the power used in early systems and at consumption rates equal to and less than conventional sources will have a good chance at capturing the public's imagination.

Where it is possible, particular attention will be given to the technical merits and/or quality of member-participants' equipment. In addition, an effort will be made to display the member-participants' names and/or logos in the Projects' media such as banners, signs, web sites, etc.

Many of the companies and agencies listed on page 10 have pledged their support for the project and others are expected to participate. These represent the best companies and agencies involved in desalination from within the United States and around the world including fortune 500 companies and major government agencies.

The probability for the technical success of this project is very high, and, with these companies and agencies working together, the ADC will be able to promote the message effectively that SWRO is now an affordable, reliable and environmentally sound source of fresh water.

Test site and environmental impact

Since 1983, the Port Hueneme Test Facility has provided facilities, equipment and support for desalination technology research and development test programs for a wide variety of customers. Past and present customers include all the military services within the US Department of Defense (DoD) and many commercial equipment developers.

The Seawater Desalination Test Facility is unique because it is fully instrumented for evaluating water treatment processes and because of its seawater access to the Pacific Ocean. The site has been a key testing facility, especially for the evaluation of RO systems and related components.

However, with the facility's automated data collection and permanent seawater access for 24-hour operation, it provides a test-bed for evaluating all technologies related to seawater desalination. Being able to evaluate equipment with natural seawater allows data to be collected under "real world" conditions and allows

	Budget Category	Contributor	Cost	In Kind Contribution	Total Funds Required
	(I)		*(II)*	*(III)*	*(IV)*
					(II + III)
(a)	Administration	ERI			
	Salaries, wages	ERI	65,000.00	(65,000.00)	0.00
	Fringe benefits	ERI	16,250.00	(16,250.00)	0.00
	Supplies	ERI	1,500.00	(1,500.00)	0.00
	Equipment	ERI	500.00	(500.00)	0.00
	Legal services	ERI	2,500.00	(2,500.00)	0.00
	Travel	ERI	3,500.00	(3,500.00)	0.00
(b)	Planning/Design/Engineering	ERI	65,000.00	(65,000.00)	0.00
(c)	Equipment Purchases 350 m3/day SWRO Trailer				
	PX energy recovery and booster pump	ERI	32,400.00	(32,400.00)	0.00
	Membranes 3 sets of 21 ea	FilmTec	44,100.00	(44,100.00)	0.00
	Pressure vessels 3ea 8" x 7 elem.	CodeLine	8,070.00	(8,070.00)	0.00
	Main HP pump package	DB Pumps	26,550.00	(26,550.00)	0.00
	VFDs and Controls	agencies	15,500.00	0.00	15,500.00
	Valves and piping	agencies	15,000.00	0.00	15,000.00
	Gauges, flow meters, Instruments	agencies	7,500.00	0.00	7,500.00
	Trailer and assembly	agencies	65,000.00	0.00	65,000.00
	Freight agencies		3,500.00	0.00	3,500.00
(d)	Web based monitoring system	Watereye	3,000.00	(3,000.00)	0.00
(e)	Materials/Installation/Implementation	agencies	2,500.00	0.00	2,500.00
(f)	Test Protocol, Implementation Verification	Carollo	9,500.00	(9,500.00)	0.00
(g)	Project Legal/License Fees	agencies	23,500.00	0.00	23,500.00
(h)	Equipment and testing contingency	agencies	10,000.00	0.00	10,000.00
(i)	Monitoring and Assessment	NFESC	73,000.00	(18,000.00)	55,000.00
(j)	Final Report Preparation	Carollo	5,500.00	(5,500.00)	0.00
(k)	Outreach and Information sharing	vendors	55,500.00	(25,000.00)	30,500.00
(l)	Contingency	agencies	25,000.00	0.00	25,000.00
(m)	**Total project budget**		579,370.00	(326,370.00)	253,000.00
*Preliminary budget is rough order of magnitude only and subject to change.					

Table 3: Project Costs (Budget)

water treatment prototypes that utilize new technology to be directly compared with more traditional hardware.

Data is collected by the facility's staff, which has worked with virtually all types of water treatment processes, and has helped develop many desalination-related components in their careers.

Because the US Navy Test Facility is unique on the West Coast of the US, testing for commercial companies is permitted. As such, the Seawater Desalination Test Facility has a current waiver letter from the California Regional Water Quality Control Board – Los Angeles Region allowing its water stream discharges into the ocean.

Project leader qualifications

The following is a list of the companies and their representatives that will be providing the Core RO Technology and expertise that will lead to the Projects success.

1. Energy Recovery, Inc., John P. MacHarg, General Manager
2. FILMTEC Membrane Corporation, Lance Johnson, Global Market Manager
3. David Brown Union Pump-Textron, Rick Hammond
4. U.S. Naval Facilities Engineering Service Center Seawater Desalination Test Facility, Ted Kuepper, Director
5. Carollo Engineers, Tom Seacord

The above list represents the core technology and management team that will be working together to execute this project. However, every partner has been selected for its experience and leadership position within the desalination field. All of the companies and agencies associated with this project have played key roles in implementing and promoting desalination as a viable and affordable technology and will make significant contributions to the success of this project.

Costs and benefits

The budget table above lists project costs and respective contributors.