A. Executive Summary

A key challenge facing inland desalination today is to develop a new generation of reverse osmosis (RO) plants that deliver high-quality, fresh water at reduced economic and environmental cost. Two key areas of focus that will help achieve these goals are the energy consumption and the achievable RO recoveries of inland brackish water systems.

The Affordable Desalination Collaboration (ADC) was formed in 2004 to fund and execute the first part (ADC I) of what has become a multiple phase Affordable Desalination Demonstration Project. ADC I built and is still operating a demonstration plant at the United States Navy's Seawater Desalination Test Facility in Pt. Hueneme, California. To date, ADC I has achieved remarkable results by desalinating seawater at energy levels between 6.0-6.9 kWh/kgal (1960-2250 kWh/acre-ft).

This proposal seeks funding to pursue the following demonstration, and development tasks.

1. Test and demonstrate state of the art isobaric energy recovery technology in an optimized brackish water design. The ADC expects to achieve 15-30% energy savings over traditional brackish water systems even where energy recovery turbines are applied.
2. Develop and demonstrate new process designs that are possible as a result of the isobaric energy recovery technologies. As a natural result of the pressure exchanger (PX) technology in particular, there are new kinds of flow schemes that can improve the performance of higher recovery brackish water systems. We will use the ADC pilot system to test and demonstrate these new flow schemes in order to push the recoveries beyond what has been traditionally achievable.

The ADC represents a unique collaboration leading government agencies, municipalities, RO manufacturers, consultants and professionals that are working together to improve the designs and technology applied in state of the art desalination systems. Through our collaborative approach, we have established a peer review process that is unmatched in our industry. Our demonstration plant, processes and personnel have been pre-qualified and proven to meet project goals and produce valid data on the operation of desalination systems. Our outreach and information sharing efforts have been extensive and reached a wide range of audiences. In short, the ADC is an established leader in the field of reverse osmosis technology and we are uniquely qualified to conduct the proposed project and disseminate the results to the appropriate audiences.

B. Statement of Work, Part 1: Relevance and Importance

The ADC's proposal seeks to address two key issues in operating inland brackish water desalination systems:

1. Improved efficiency will be demonstrated by using state of the art isobaric energy recovery technology in combination with optimized process designs and leading membrane manufacturers' latest generation membranes.
2. Improved brine/concentrate management will be achieved through employing novel isobaric energy recovery process designs to increase the achievable recovery of brackish water reverse osmosis systems.

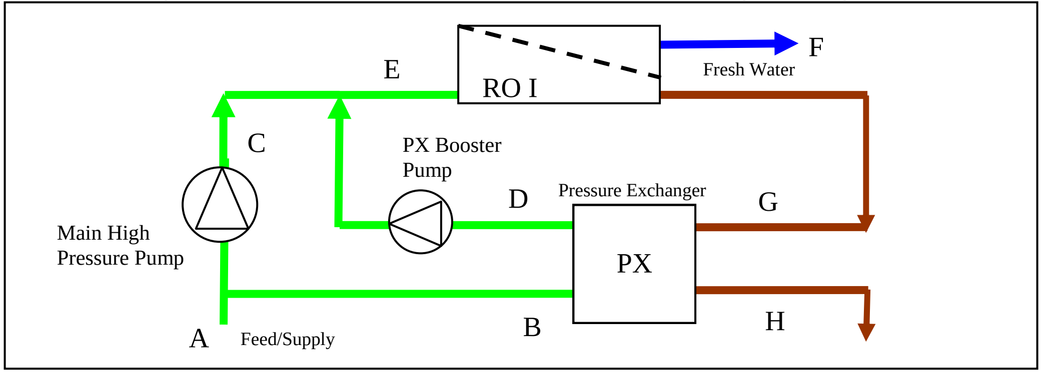
One of the single largest operating cost components of any desalination plant is energy and reducing the energy consumption of desalination systems has been and will remain the ADC's primary focus. In pursuit of that focus we will use our ultra-efficient pilot system to demonstrate and test optimized brackish water designs. In addition, we will test and demonstrate new pressure exchanger process designs to increase the practical recoveries that RO systems can achieve while still maintaining high velocities and thereby inhibiting scale formation. Reducing energy and increasing the recovery that RO systems can practically operate at are the two most powerful levers available for decreasing the treatment costs and environmental impacts associated with inland desalination.

C. Statement of Work, Part 2: Technical/Scientific Merit, Innovation and Technological Advancement

Optimized Isobaric Energy Recovery Demonstration

The PX unit utilizes the principle of positive displacement to pressurize filtered feed water by direct contact with the high-pressure concentrate (waste) stream or reject from an RO system. Pressure transfer occurs in the longitudinal ducts of a ceramic rotor that spins inside a ceramic sleeve. The rotor-sleeve assembly is held between two ceramic end covers. At any given instant, half of the ducts are exposed to the high pressure fluid side and half the ducts are exposed to the low pressure fluid side. Figure 1 shows the flow path of a typical seawater reverse osmosis (SWRO) PX system. The concentrate from the RO membranes (G) passes through the PX, where its pressure is transferred directly to a portion of the incoming feed water at up to 97% efficiency. This pressurized feed water stream (D), which is approximately equal in volume and pressure to the reject stream, passes through a PX auxiliary pump (not the main high-pressure pump) to add the small amount of pressure lost due to the differential pressure across the membranes and to friction in the associated piping and the PX. The PX booster pump drives the flow through the high-pressure side (G and D) of the PX. Fully pressurized feed water then merges with the main feed water line of the RO system after the main high-pressure pump. In an RO-PX system, the main pump is sized to equal the RO permeate flow plus a small amount of rotor lubrication flow, not the full RO feed flow. Therefore, the PX significantly reduces flow through the main pump. This point is significant because a reduction in the size of the main pump results in lower power consumption and operating costs.

Figure 1. Typical Seawater Pressure Exchanger Diagram.



The RO-PX system requires a booster pump to make up the small amount of pressure losses through the membranes, PX, and the associated piping circuit. In the standard single stage seawater system this pump is applied at the outlet of the PX. However, in a 2 stage brackish water system the PX booster pump can serve 2 purposes by being installed in between stages 1 and 2 as shown in Figure 2. In this configuration the PX booster pump also acts as an interstage booster pump helping to reduce the required pressure from the main high pressure feed pump, by balancing the flux between the 1st and 2nd stages

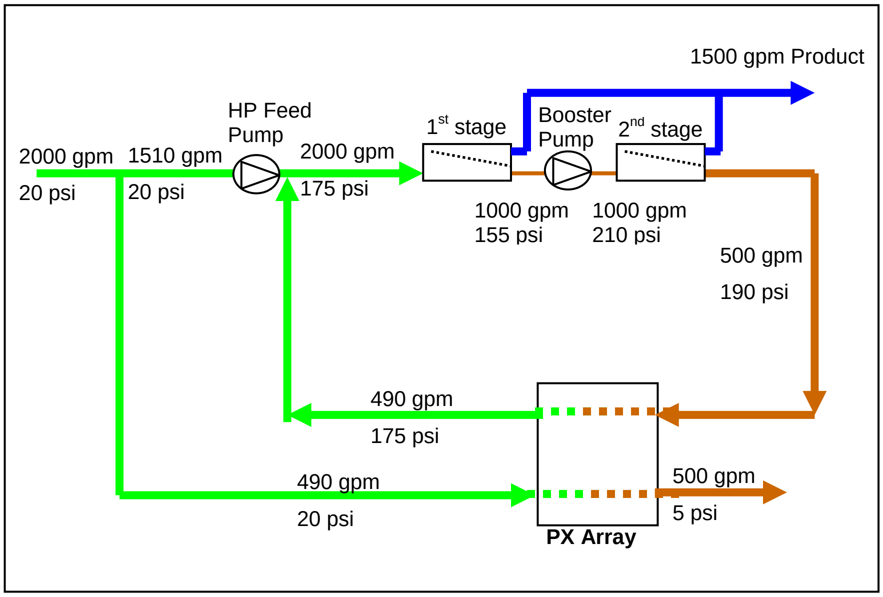


Figure 2. Example Interstage Booster PX Design

The example in figure 2 shows that while the PX booster is supplying the energy to drive the water around the PX circuit it is also conveniently providing 55 psi of interstage boost pressure. In addition to improving the flux balance, it also results in significant savings by both the PX reducing the main HP pump size and the lower 1st stage feed pressure inherent to an interstage booster design. Table 1 shows the PX power savings verses a standard interstage booster design.

Table 1. PX Savings in Interstage Booster system

	Std	ERI
Feed pump efficiency	83%	83%
Feed pump motor efficiency	94%	94%
Feed pump power, kW	172.9	130.3
Booster pump efficiency	80%	80%
Booster pump motor efficiency	94%	94%
Booster pump power, kW	23.2	31.8
RO Feed Pressure, PSI	175	175
RO Recovery, %	75%	75%
KWh/kgal	**2.19**	**1.82**
17% savings yields $17,500/year @ $0.06/kWh		

In conclusion, an optimally designed brackish water PX system can provide many benefits including energy savings and flux balance. These concepts could save operators of brackish water systems as much 10-30% of the operating energy compared to traditional systems while simultaneously improving the performance of the RO membranes. Attached is an article that describes how the PX was first introduced to brackish water desalination in Florida. In addition, the article discusses the potential for the interstage booster design as described above. To the best of our knowledge this optimized interstage booster design has not been demonstrated before.

High Recovery Process Design Testing

This proposal will also seek to develop and test a new process design that is possible with isobaric energy recovery technology. As a natural result of PX technology in particular there are new kinds of flow schemes that may improve the performance of higher recovery seawater and brackish water systems. One example is shown in Figure 3 below where the PX is intentionally unbalanced yielding an overall system recovery (F divided by A) of 85% and 2000 tds feed water, but the membrane recovery (F divided by E) is at 65% and 4,886 tds feed water.

Figure 3. The Unbalanced Pressure Exchanger Diagram.

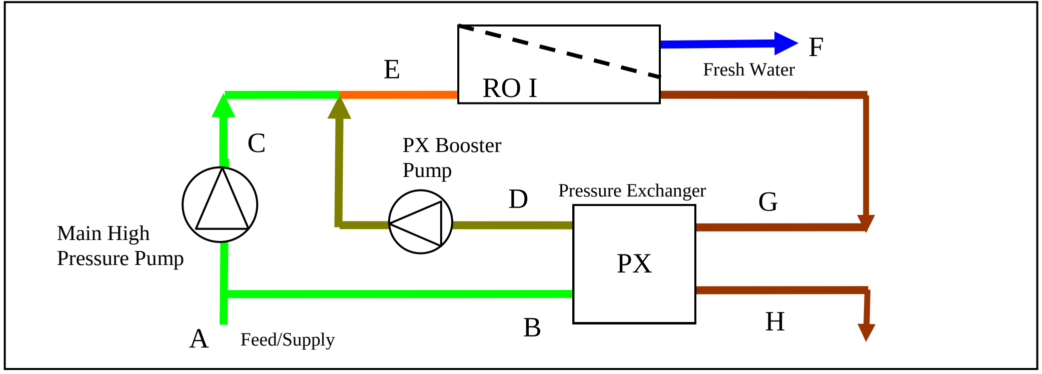


Table 2. Unbalanced PX 65/85% Recovery Projection (Preliminary/Draft).

		A	B	C	D	E	F	G	H
Flow	gpm	1774	250	1524	775	2299	1500	799	274
	gpd	2,554,560	360,000	2,194,560	1,116,000	3,310,560	2,160,000	1,150,560	394,560
Pressure	PSI	25	25	241	221	241	5	231	10
Quality	mg/l TDS	2,000	2,000	2,000	10,563	4,886	92.0	14,000	14,000
					PX Brine cross flow =		549	gpm	
PX-70		QTY	**4**		Temperature = 25ºC				
PX UNIT FLOW		GPM	200		Flux ~ 13 gfd				
PX Internal Bypass		GPM	24						
Membrane Differential		PSI	10						
RO Recovery		%	65%						
System Recovery		%	85%						
HIGH PRESS. PUMP									
Feed Pump eff		%	90%						
Motor eff		%	93%						
VFD eff		%	97%		Total RO Process (kW)			189.1	
Power		kW	176.2						
BOOSTER PUMP					kWh/m3 Permeate			0.55	
Boost Pump Eff		%	60%		kWh/1000 gal Permeate			2.10	
Motor Eff		%	90%		kWh/acre-ft Permeate			684	
VFD eff		%	97%						
Power		kW	12.9						
Supply/Feed Pump kW			0.0						

Mechanisms associated with this novel mode of operation that might lead to improved performance at higher recoveries include:

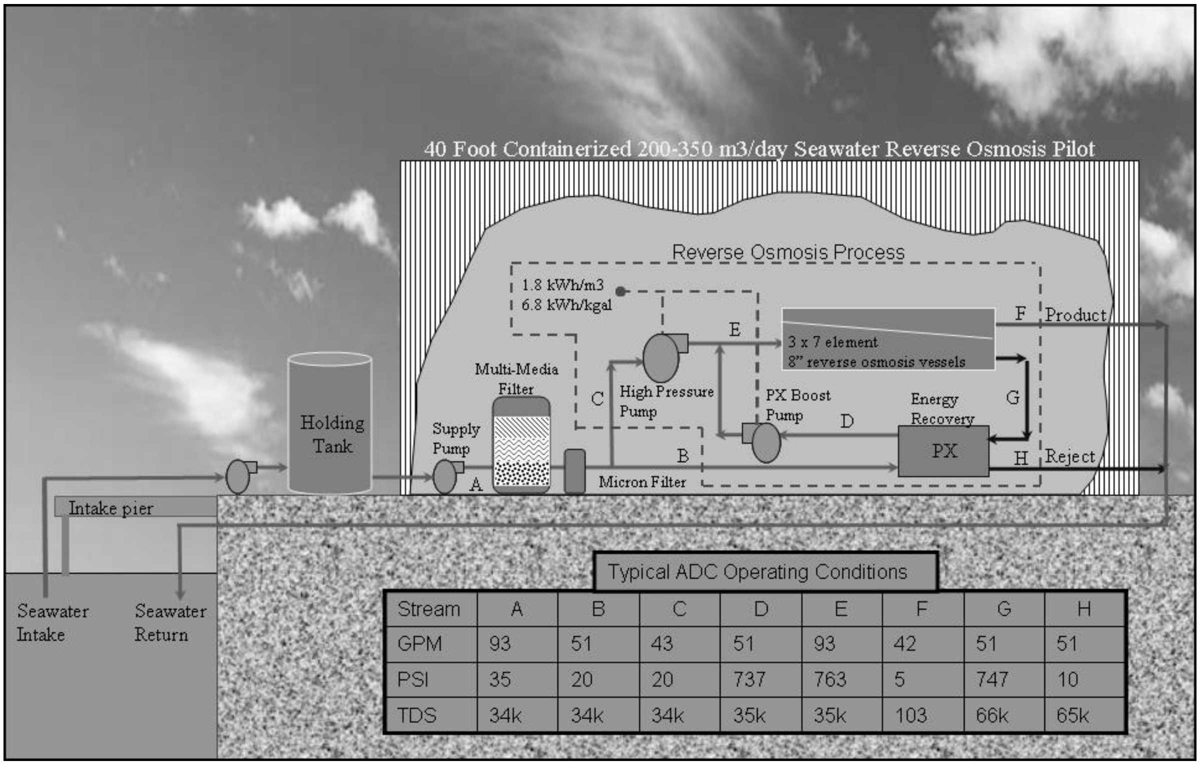
- Improved boundary layer conditions by maintaining “high” velocities/flow
- Balanced membrane flux through increased lead element velocities
- Balanced membrane flux through increased lead element salinity
- Minimum brine flow requirements within manufacturers specifications
- Maximum allowable recoveries within manufacturers specifications

Testing the unbalanced PX effect is straight forward and can be achieved with the ADC Demonstration system in its current configuration. In fact, the ADC is testing this approach on seawater through our California Proposition 50 Grant Program. Attached is an article that presents some of these concepts as well as other possible new configurations for the isobaric energy recovery technologies. To the best of our knowledge the unbalanced PX approach has never been demonstrated in a brackish ground water application.

D. Project Readiness

System Readiness

The ADC has built and operates an ultra-efficient, state-of-the-art demonstration plant that will be utilized in this brackish ground water demonstration project. The plant design includes a 3-vessel x 7-element 8-inch membrane array with an adjustable permeate flow rate of 35-55 gpm (50,000-77,000 gpd). The overall recovery of our pilot system can also be adjusted from 30-85% over the entire range of permeate flows. See figure 4 for a basic diagram of the system.



Typical ADC Operating Conditions

Stream	A	B	C	D	E	F	G	H
GPM	93	51	43	51	93	42	51	51
PSI	35	20	20	737	763	5	747	10
TDS	34k	34k	34k	35k	35k	103	66k	65k

Figure 4. Overview of the High-Efficiency Pilot Demonstration Plant

The ADC system is ready to execute task 1 of this proposal. Minor modification will be required to convert the system into an interstage booster design for task 2.

Site Readiness

The ADC plans to partner with a Texas water agency and/or municipality in order to access a representative source of ground water, logistical and operational support. To these ends we have identified and/or been in contact with several organization including the following:

Brownsville Public Utility Board
North Alamo Water Supply Corporation
El Paso Water Utilities
San Antonio Water Systems

Should we receive an award we feel confident that we can secure a site for testing.