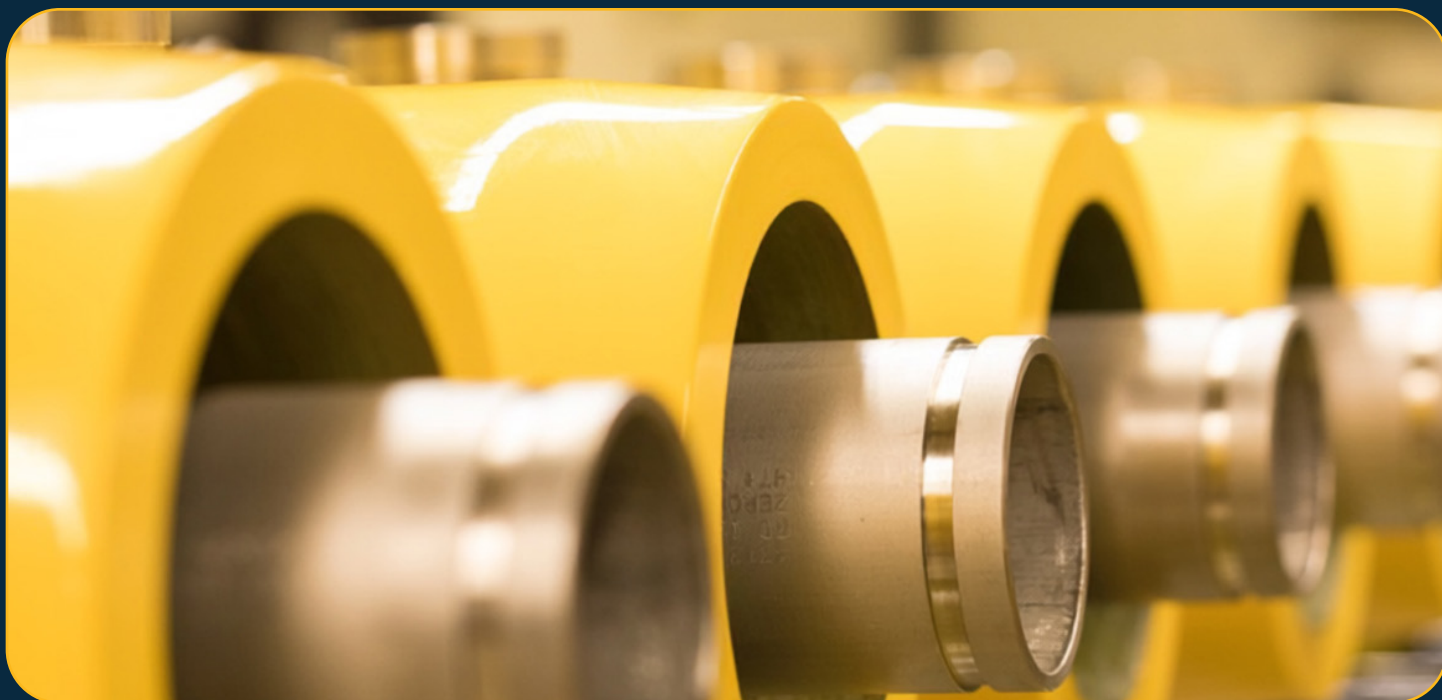


The Hidden Energy Cost of Low-Pressure Reverse Osmosis



Presenters:

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KEY TAKEAWAYS

- Wasted energy is the largest hidden cost of low-pressure reverse osmosis systems.
- Several market factors have changed the ROI of energy recovery devices.
- Systems with unbalanced flux across a multi-stage array can suffer from multiple issues.
- A pressure exchanger combined with interstage booster pump provides the greatest energy savings.

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The Hidden Energy Cost of Low-Pressure Reverse Osmosis

OVERVIEW

Energy recovery devices (ERDs) are commonly associated with high-pressure seawater desalination systems. As a result, many municipal and industrial operators assume the economics do not work for lower-pressure brackish water reverse osmosis (BWRO) and water reuse applications. However, that assumption is frequently incorrect.

There is an often-overlooked issue in low-pressure reverse osmosis (RO): significant amounts of hydraulic energy remain in the reject stream, yet are typically discarded. Utilizing modern low-pressure pressure exchanger (PX®) technology with careful RO system design considerations can recover this otherwise wasted energy while also improving the hydraulic balance across multi-stage RO systems, reducing energy consumption, operating costs, and even capital costs.

Energy Recovery designs and manufactures high-efficiency energy recovery devices for industrial fluid-flow markets. The company's flagship product, the PX® Pressure Exchanger®, captures and transfers pressure energy directly from high-pressure liquid to low-pressure liquid with up to 99% energy transfer efficiency. Energy Recovery also supplies high-pressure pumps and circulation/booster pumps designed to work in RO systems. The PX offers strong energy and cost savings opportunities for high-demand applications, including municipal reuse, industrial water reuse, and BWRO applications.

CONTEXT

The presenters discussed the hidden energy cost of low-pressure RO systems and explained how the Energy Recovery PX ERD significantly improves energy efficiency.

KEY TAKEAWAYS

Wasted energy is the largest hidden cost of low-pressure reverse osmosis systems.

Reverse osmosis systems typically recover between 30% and 85% purified water (permeate), depending on the application, feedwater quality, desired permeate quality, and other design considerations. Water that does not become permeate leaves the final membrane stage in form of a pressurized reject stream, which eventually hits a throttle valve, reducing the pressure and effectively wasting the hydraulic energy within.

Unrecovered hydraulic energy released in the reject stream is the hidden energy cost of low-pressure RO. In a typical low-pressure RO system, energy represents the highest percentage of operational costs (Other OPEX contributors include membrane replacement, labor, chemicals, and maintenance costs.) An unoptimized design can incur potential wasted energy of 15% up to 70%, representing money.

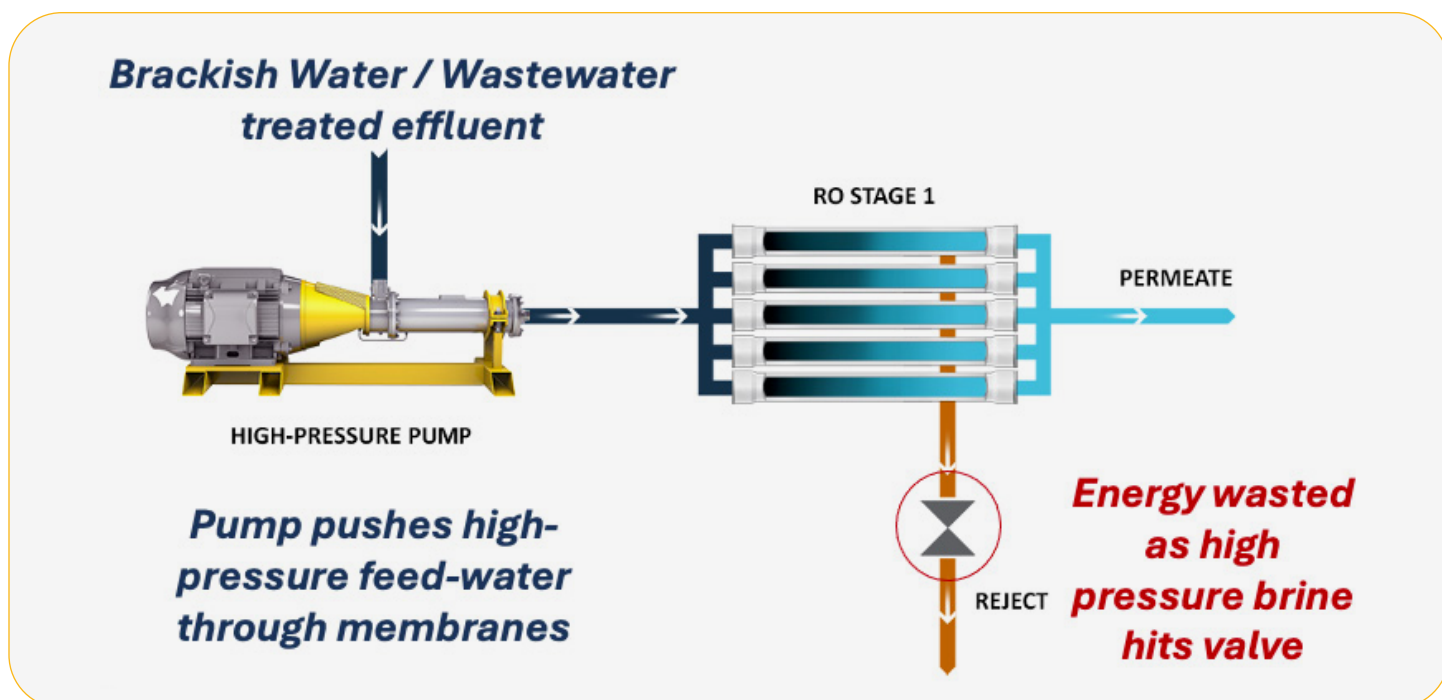
“The real problem is designers are not optimizing low-pressure RO systems for OPEX, especially on the energy side. Without an energy recovery device, you’re wasting anywhere from 15% to 35% of your energy, depending on your system design and overall recovery.”

– Simon Bae, Energy Recovery

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In the example of a two-stage low-pressure RO system designed to operate at 75% recovery, energy consumption represents 31% of overall costs. By optimizing the RO design by utilizing a pressure exchanger paired with an interstage booster pump to achieve interstage flux balance, energy costs drop by 24%, materials and labor costs by 20%, and maintenance costs by roughly 17%. In total, an optimized design yields an overall OPEX reduction of 21%.

Figure 1: Hydraulic energy released in the reject stream is a significant hidden energy cost



Several market factors have changed the ROI of energy recovery devices.

Low-pressure RO systems are often designed for high recovery and operate at low pressure. Historically, energy recovery devices (ERDs) have not been utilized in these systems because the amount of recoverable energy appeared to be small, with a long return of investment (ROI) to justify investment in additional technologies.

However, the market has shifted. Energy costs are rising and there is growing concern over power limitations and water scarcity. The industry has also increased awareness of ESG issues, with new sustainability requirements driving improvements to energy efficiency.

In addition, recent developments in pressure exchanger technology, specifically developed for low-pressure applications, improve system reliability and availability, making the economics of ERD investment much more attractive.

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Systems with unbalanced flux across a multi-stage array can suffer from multiple issues.

Low-pressure RO systems typically operate at high recovery rates and therefore require multi-stage array configurations. Without hydraulic balancing across the multiple stages, first-stage membranes can be forced to produce substantially more water (at equivalent unitary membrane surface area) than the second or later-stage membranes, which can foul membranes more quickly.

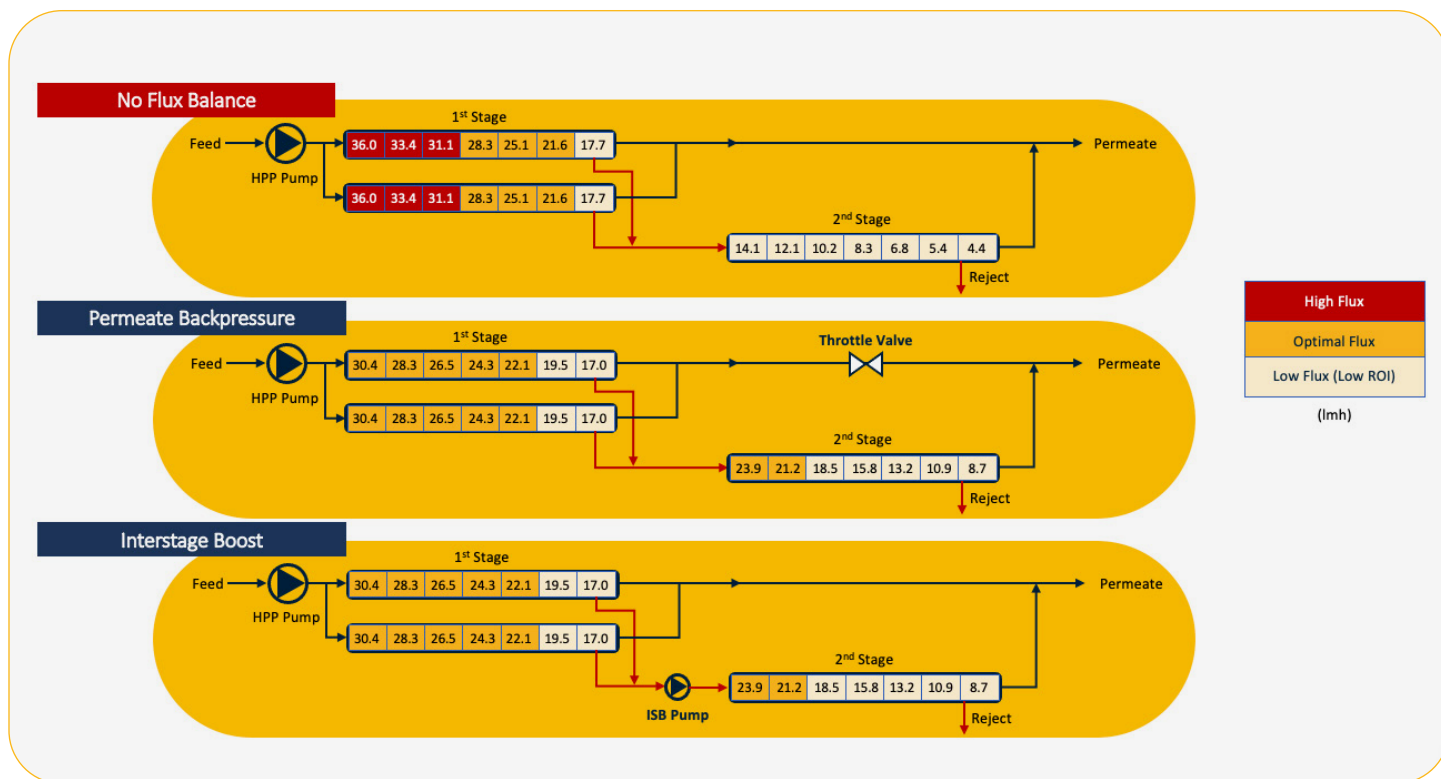
Maintaining a correctly balanced flux across the stages enables better fouling control, reduces clean-in-place (CIP) frequency and downtime, increases system availability, improves second-stage permeate quality, and lowers pressure drop in the first stage.

There are several options for achieving flux balance across stages, including:

- **Utilizing a throttle valve in the first stage permeate.** Applying permeate back pressure reduces the overall net driving pressure, producing less permeate. More flow is then directed to the second stage, increasing second-stage flux.
- **Placing an interstage booster pump between the two stages.** The pump increases the pressure entering the second stage, balancing the flux rates between the two stages.

However, balancing flux does not address the hidden cost of unrecovered hydraulic energy. This is where a pressure exchanger provides the added value.

Figure 2: Multi-stage flux balance designs



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A pressure exchanger combined with interstage booster pump provides the greatest energy savings.

Without a pressure exchanger to reduce energy loss in the final reject stream, a two-stage RO system treating 4000 mg/L salinity feedwater at 75% recovery, utilizing first-stage permeate backpressure but no ERD, has an estimated specific energy consumption (SEC) of approximately 0.8 kWh per cubic meter of permeate.

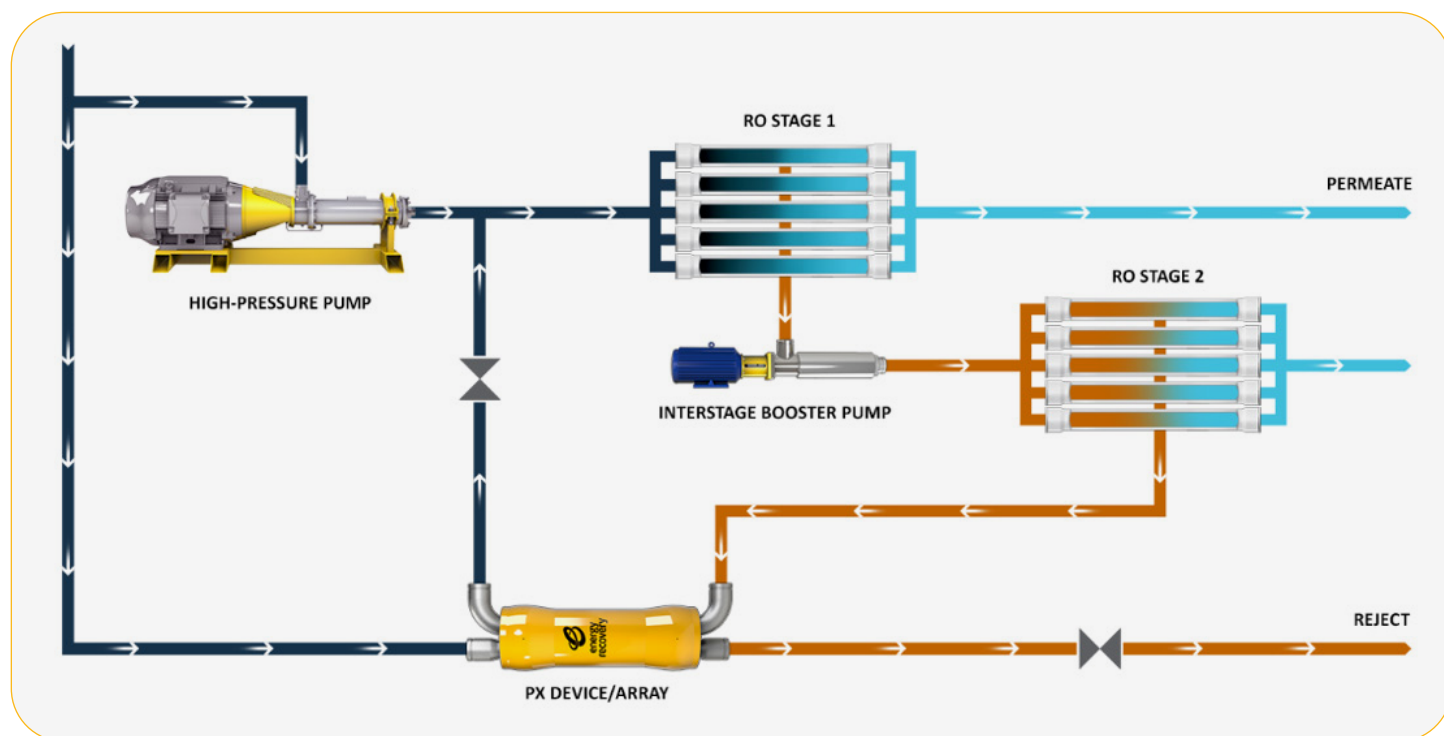
When a pressure exchanger is added to the baseline configuration, SEC falls to approximately 0.59 kWh/m³. The PX provides steady efficiency over a wide operating range, but there is no interstage booster pump in this

configuration, requiring a circulation pump to match the discharge pressure. While the circulation pump consumes some additional energy, the energy reduction achieved is already significant.

Utilizing both a pressure exchanger and an interstage booster pump provides both flux balancing and maximized energy savings, further reducing SEC to approximately 0.56 kWh/m³, making this the lowest OPEX solution.

And PX technology is not only for new installations—existing low-pressure RO systems can be retrofitted with a PX to achieve valuable benefits.

Figure 3: Low-pressure system using a pressure exchanger and interstage booster pump



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Energy Recovery PX ERD: How it works

The Energy Recovery PX is an isobaric energy recovery device integrated into the reverse osmosis process. PX technology with an optimized system configuration for Low Pressure RO system addresses two problems simultaneously: recovering hydraulic energy that would otherwise be wasted, and improving hydraulic balance across multi-stage membranes.

Using a PX splits source water between the high-pressure pump and the PX. The PX transfers energy directly from the high-pressure concentrate to an equivalent flow rate of low-pressure feedwater. Inside the PX, the feedwater is pressurized by high-energy concentrate stream. A small circulation pump compensates for pressure losses in the system, and the high-pressure feedwater is returned to the RO process. Using a PX enables up to 99% of residual energy in the reject stream to be recycled, and a reduction in high-pressure pump size by 15-70% further reduces energy consumption.

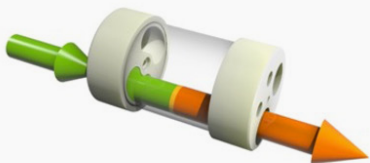
With the PX, the high-pressure pump controls permeate production while the circulation pump can control concentrate flow without affecting permeate, enabling permeate production and concentrate flow to be controlled independently. For example, increasing concentrate flow can increase membrane crossflow and reduce recovery while maintaining or even increasing permeate production. Independent control gives operators much greater flexibility under changing conditions.

“With an isobaric device, flux and recovery rate are decoupled; they are independent from each other. That’s not just a curious characteristic of the pressure exchanger—it means flexibility [under] variable operating conditions.”

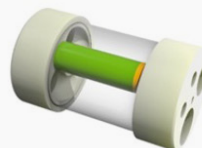
– Rolando Bosleman, *Energy Recovery*

Figure 5: How a PX works

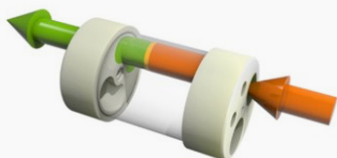
1. Low-pressure feed water fills rotor chamber, displacing brine



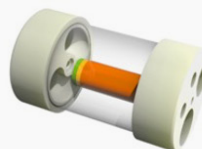
2. Rotor chamber seals, containing low-pressure feed water



3. High-pressure brine pressurizes and displaces feedwater



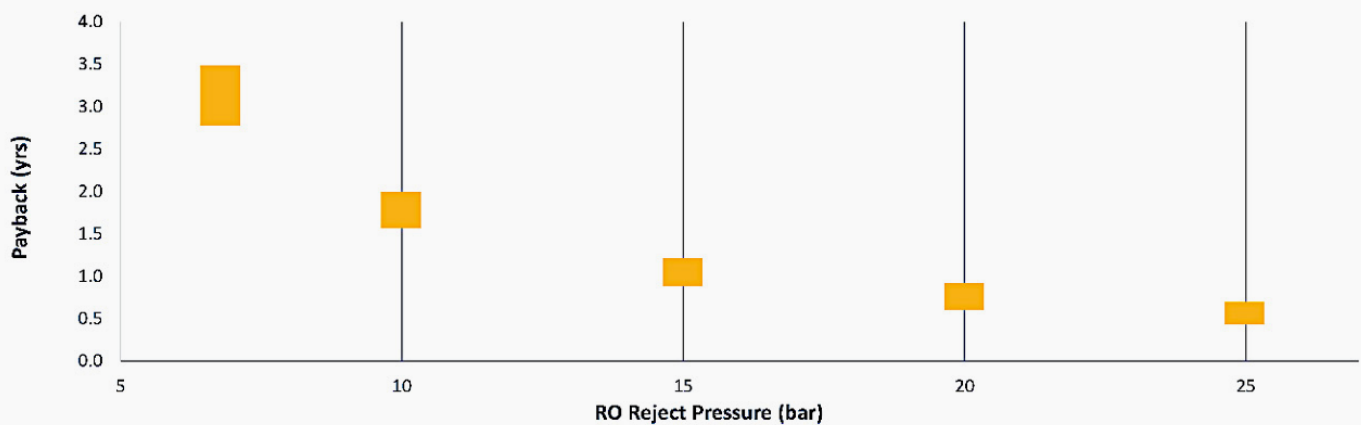
4. Rotor chamber seals, containing high pressure brine



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Energy Recovery low-pressure PX devices are specifically designed for low-pressure RO systems. The standard low-pressure PX is rated up to 450 psi, while an ultra-low-pressure version is rated for 200 psi. Payback depends on operating pressure and electricity costs—higher operating pressure increases the amount of recoverable energy, shortening payback; however, the exact timeline varies based on electricity prices.

Figure 6: Estimate payback time for the Energy Recovery low-pressure PX



ADDITIONAL INFORMATION

Power Model Pro is Energy Recovery's web-based design and product configuration tool for optimizing hydraulic pumping and energy consumption in RO projects. Based on user-provided operating conditions and component information, the software helps select the applicable PX model as well as pumps, offering a full ERD solution, and provide predicted equipment performance metrics, estimate total energy consumption, and project cost savings.

To learn more, visit [Energy Recovery](#)

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BIOGRAPHIES



Simon Bae

Senior Product Manager
Energy Recovery

Simon Bae is Senior Product Manager at Energy Recovery, responsible for the company's product portfolio and roadmap. He also led the development of Power Model Pro, the company's cloud-based system design / product selection software. He has worked in the water industry since 2013, in various roles including applications engineering, process engineering, and project management focused in reverse osmosis and water treatment systems for municipal and industrial applications across brackish water, wastewater reuse, and seawater desalination.



Rolando Bosleman

Technical Support Director
Energy Recovery

Rolando Bosleman holds a degree in Mechanical and Electrical Engineering from the University of Piura (Peru) and an MBA from the Pontifical Catholic University of Peru. Author of numerous articles and technical publications presented at international desalination conferences, he currently serves as the Technical Support Director at Energy Recovery, Inc. He has over 25 years of experience in the industry, having held various roles including commissioning engineer, process and maintenance engineer, plant sub-manager, and technical manager. With a focus on technical consulting, he has participated in the execution of desalination projects in diverse regions worldwide, including the United States, Europe, Asia, Africa, and Latin America.