ENERGY RECOVERY BEYOND SEAWATER

How the technology that reshaped SWRO can evolve water reuse and low-pressure desalination

March 2025

GLOBAL WATER INTELLIGENCE | energy recovery®

Executive summary

As the world faces the hard reality of climate change and ever-worsening water scarcity, the need to leverage unconventional water resources is now greater than ever. Together, desalination and reuse could provide the water we need, but high energy requirements make them costly options. Energy recovery devices (ERDs) offer an answer.

Energy recovery is now endemic to the seawater desalination industry, providing significant reductions to the single largest source of SWRO OpEx: energy consumption. Today it is a rarity for a large seawater desalination plant to be built without an energy recovery device, with more than 35,000 Pressure Exchanger (PX) ERDs alone deployed worldwide, together saving more than $6 billion in energy costs. However, energy recovery has historically been much less common in low-pressure RO and wastewater reuse applications.

This whitepaper presents the advantages and potential growth opportunities of energy recovery in these comparatively untapped markets.

Glossary

SWRO
Reverse osmosis treatment of seawater, typically with a salinity range of 20,000 to 50,000 ppm TDS, operating at pressures between 700 and 1200 psi (48–83 bar).

Low-pressure RO
Reverse osmosis operating at pressures between 80 and 700 psi (5.5–48 bar).

Energy recovery device
A device used to recover energy that would otherwise be wasted, such as the pressure of a brine stream, and reuse it to help drive the desalination process.

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FOREWORD

David Kim-Hak
VP, Wastewater, Energy Recovery

For more than 30 years, Energy Recovery has been committed to building a sustainable future. The mission for all of our employees is clear: to innovate and solve the challenges of our customers, while positively impacting the world in which we live.

Our PX® Pressure Exchanger® revolutionized seawater reverse osmosis desalination by drastically reducing energy consumption and costs for this energy-intensive process. It has become the industry standard with a simple design that is durable, effective, and highly dependable, delivering consistently high performance in harsh conditions.

But could this groundbreaking technology also serve other applications? Indeed, the water industry is multifaceted, with a wide range of challenges, reaching far beyond seawater reverse osmosis desalination.

Two major applications of salt removal through reverse osmosis are growing in interest. The first is water reuse within industrial and municipal applications to complement fresh water supply. The second involves brine concentration to reduce wastewater volume (ZLD). Both applications have direct impact to the environment whether it is to alleviate water scarcity or reduce pollution.

Fortunately for the planet, more countries are regulating how wastewater is treated. If the burden of high energy costs and operational expenses were alleviated for companies, preserving water sources could be achieved in a sustainable way. The outcome benefits the customer and local populations, not to mention significantly reduces carbon emissions, affecting us all.

With growing challenges like changing conditions and water scarcity, adaptive water management is more critical than ever. Fortunately, we don't have to rely on unproven solutions. Energy Recovery offers a proven, reliable technology that supports sustainable operations for the long term.

The advantages of energy recovery

Recovering waste energy from brine reduces process energy consumption

Today reverse osmosis is substantially cheaper to build and operate than it was two decades ago but it remains a comparatively expensive solution for water supply. High energy requirements are responsible for much of this, accounting for up to a third of total seawater desalination plant costs. Recovering waste energy from a plant's brine stream offers an effective way to reduce net energy requirements and minimise OpEx. This approach allows for energy consumption to be cut by up to 60% and is now the norm in seawater desalination.

High-pressure feed pump

Used to pressurise feedwater to the level needed for RO operation.

Benefit: ERDs mean these pumps can be smaller, reducing energy consumption, OpEx, and CapEx.

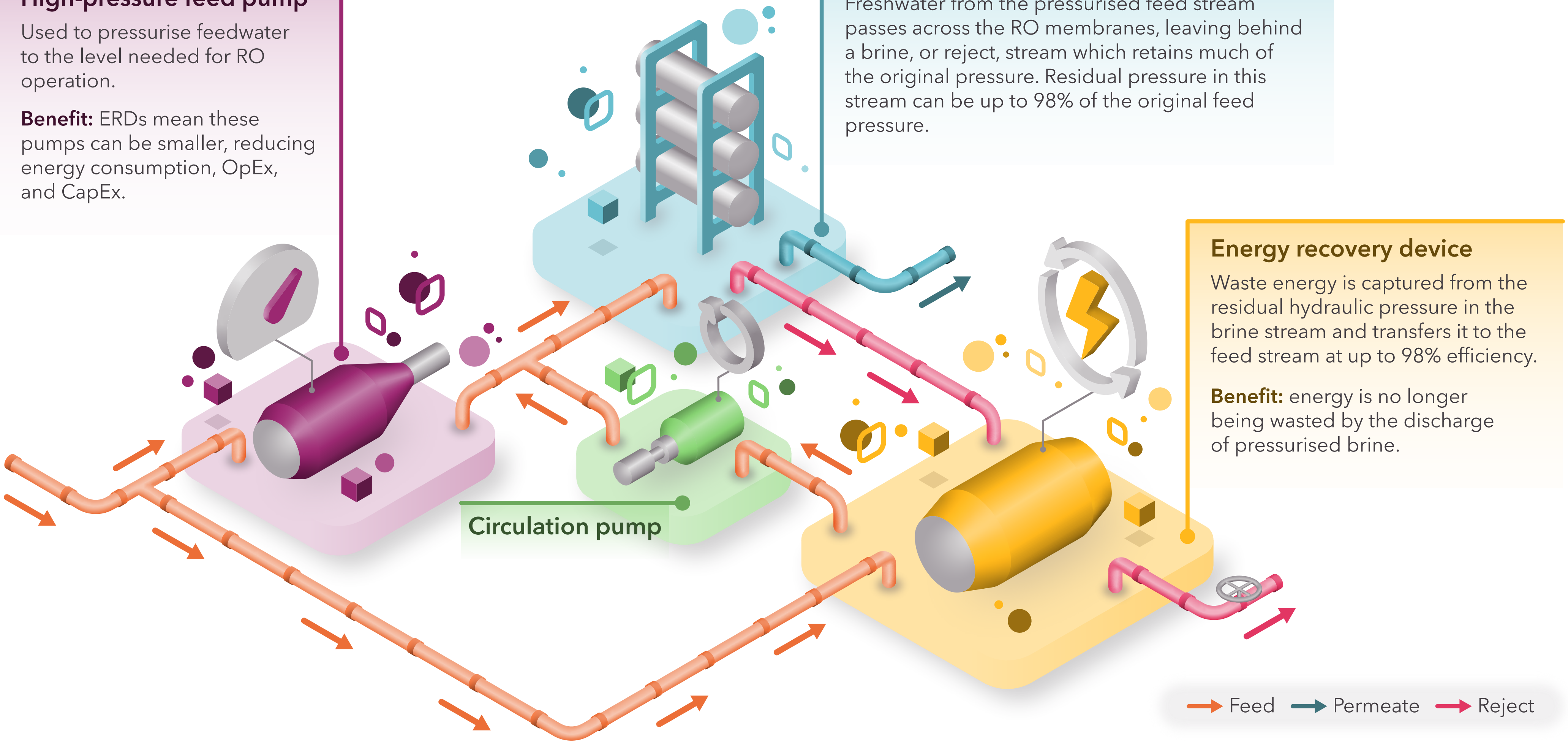
RO array

Freshwater from the pressurised feed stream passes across the RO membranes, leaving behind a brine, or reject, stream which retains much of the original pressure. Residual pressure in this stream can be up to 98% of the original feed pressure.

Energy recovery device

Waste energy is captured from the residual hydraulic pressure in the brine stream and transfers it to the feed stream at up to 98% efficiency.

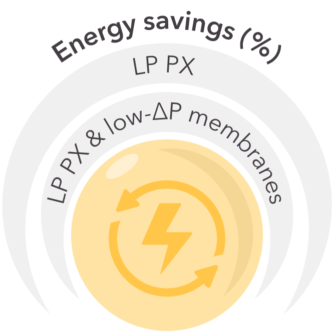
Benefit: energy is no longer being wasted by the discharge of pressurised brine.



Bringing value to low-pressure RO

Energy consumption can be reduced by up to 43% in low-pressure applications

Although the pressures involved in brackish water RO and wastewater reuse are lower than in seawater desalination (80–700 psi (5.5–48 bar) vs. 700–1200 psi (48–83 bar)), these are still high-energy processes which produce reject streams that retain significant energy. Just as in seawater desalination, a low-pressure ERD can be used to recover this energy and transfer it to the feed stream.



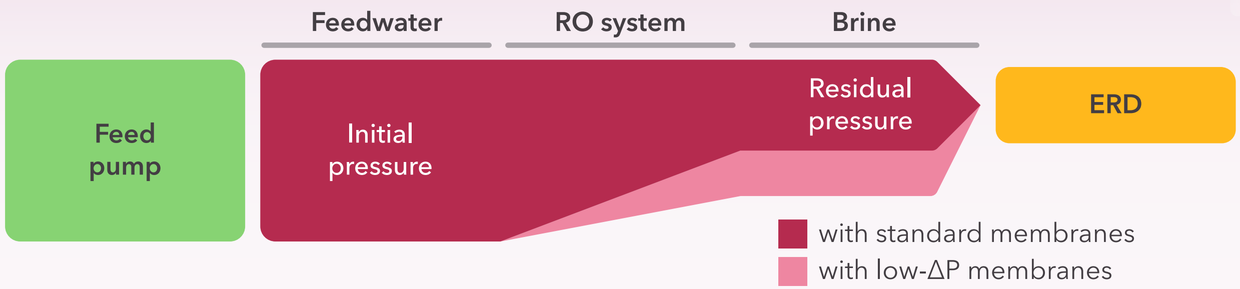
ROI can be as little as eight months in municipal applications.

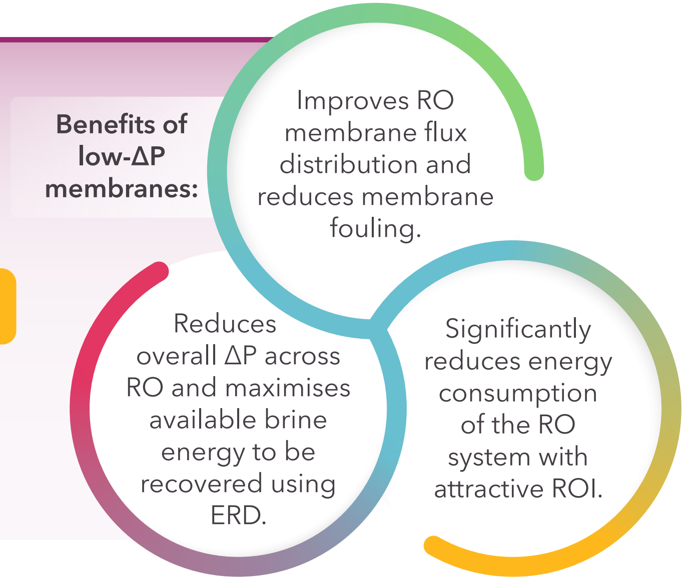
	Municipal (70–85% recovery)		Industry (70–90% recovery)	
	Energy savings*	ROI	Energy savings*	ROI
Low-pressure pressure exchanger (LP PX)	Up to 14–28%	2–3 years	Up to 9–28%	2–4 years
LP PX & low-ΔP membranes	Up to 25–40%	<2 years	Up to 15–40%	<2 years

Estimates based on the assumed RO recovery range

Synergy with new low-ΔP membranes

New low-ΔP membranes allow for maximum energy retention throughout the RO system, meaning more energy can be recovered from the final brine stream.

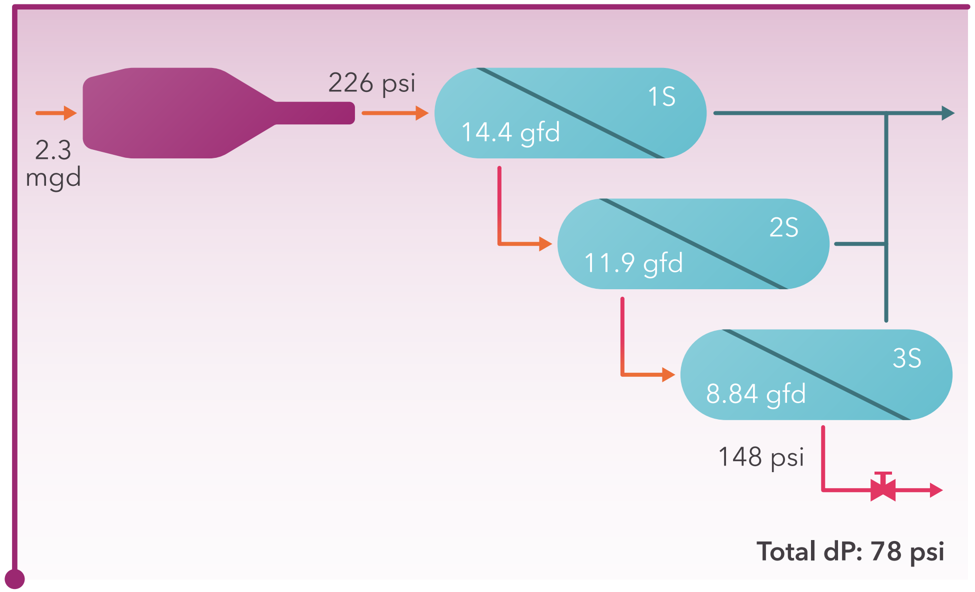




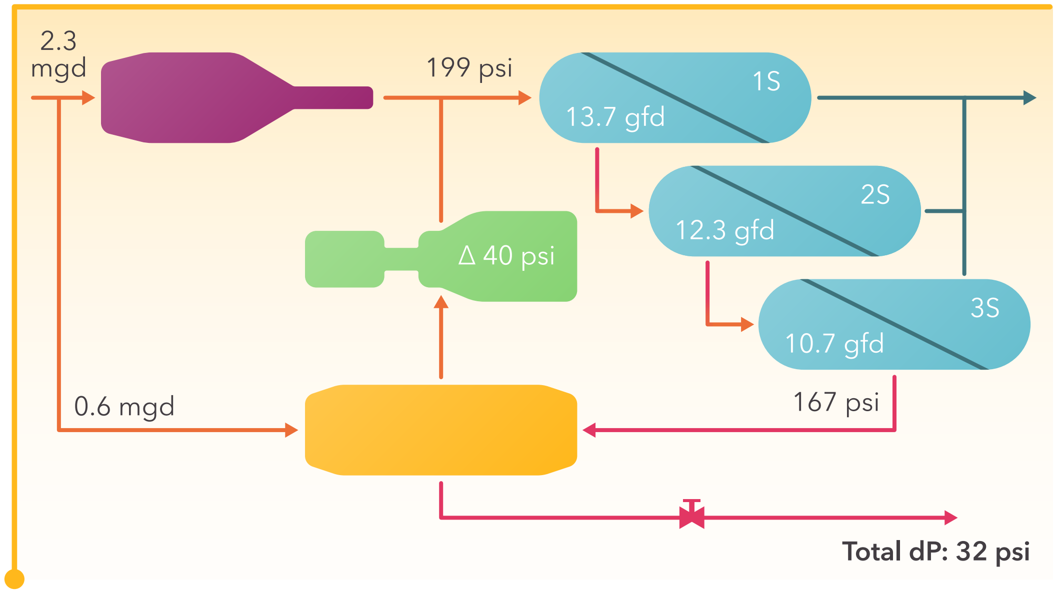
Case study: industrial RO plant

A 1.7 MGD (6,435 m³/d) industrial plant treating a mix of brackish waters sourced from rivers, reservoirs, and wells for use in a boiler-feed application, using a three train, three stage RO system. By applying low-pressure PX devices and low-ΔP membranes, energy consumption could be reduced by almost a third, saving more than $22,000 each year for an RoI of just two years.

Existing design: standard RO and no ERD



Retrofit case: standard LP PX configuration with low-ΔP membranes



High-pressure pump · Circulation pump · RO · LP PX · Feed · Permeate · Reject

	HPP power	Circulation pump power	Total power	SEC	Power reduced	% Energy reduced	Annual CO_2 savings	Annual energy cost savings*	Return on investment**
Standard RO with no ERD	64.3 kW	–	64.3 kW	0.74 kWh/m³	–	–	–	–	–
Retrofit case	43.3 kW	3.7 kW	46.9 kW	0.54 kWh/m³	17.4 kW	27.1%	89.6 Ton	$22,856	2.09 years

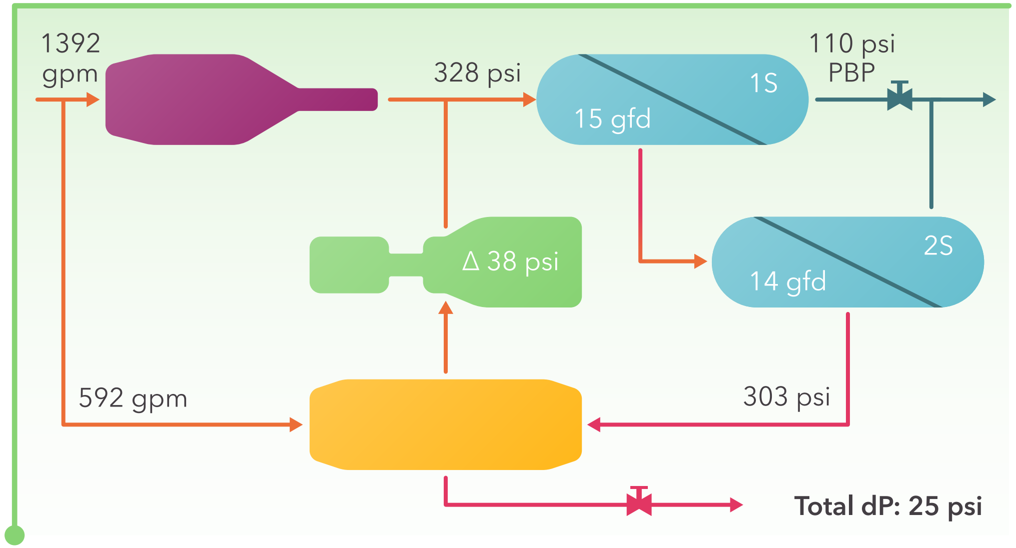
**Includes budgetary retrofit cost estimate including LP PX, circulation pump & variable frequency drives (VFD), instrumentation, piping, install / labour, RO replacement cost per train*

***Assumed electricity cost of $0.15/kWh*

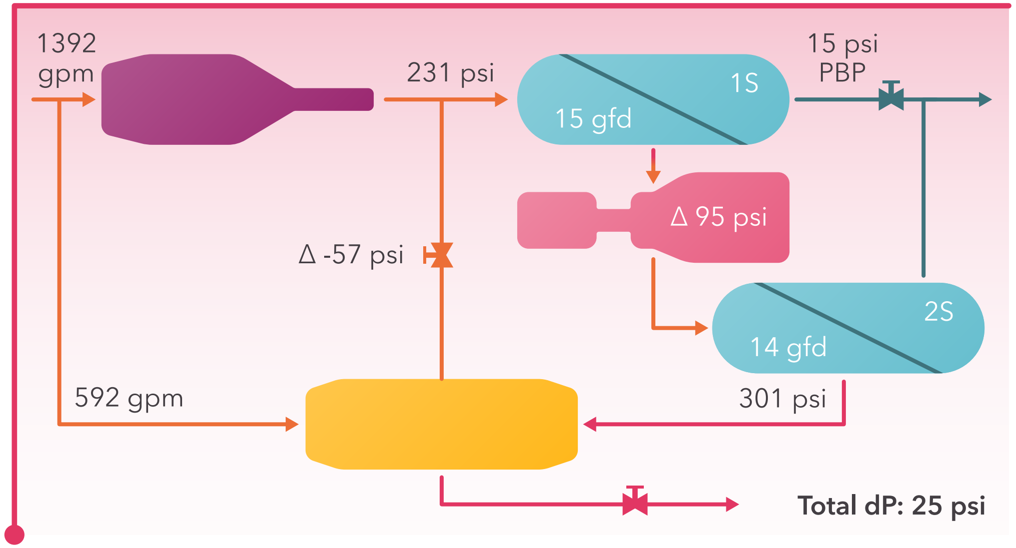
Case study: municipal groundwater treatment plant

A 2.0 MGD (7,571 m³/d) municipal plant treating the high TDS groundwater resultant from seawater intrusion using a one train, two stage RO array. Using a standard low-pressure PX and low-ΔP membrane configuration, energy consumption could be reduced by 34%, saving more than $180,000 for the client each year. Balancing the system by installing a booster pump between the first and second RO stages and removing the circulation pump allowed the benefits to be maximised, pushing energy savings to almost 45% and annual cost savings above $230,000, for an RoI of less than eight months

Scenario 1: standard LP PX configuration with low-ΔP membranes



Scenario 2: balanced LP PX configuration with low-ΔP membranes



High-pressure pump | Circulation pump | Booster pump | RO | LP PX | Feed | Permeate | Reject

	HPP power	Circulation / booster pump power	Total power	SEC	Power reduced	% Energy reduced	Annual CO_2 savings	Annual energy cost savings*	Return on investment**
Standard RO with no ERD	404.3 kW	-	404.3 kW	1.28 kWh/m³	-	-	-	-	-
Scenario 1	252.0 kW	13.9 kW	265.9 kW	0.84 kWh/m³	138.3 kW	34.2%	712.2 Ton	$181,760	0.69 years
Scenario 2	170.4 kW	57.9 kW	228.3 kW	0.72 kWh/m³	176.0 kW	43.5%	906.4 Ton	$231,247	0.64 years

**Includes budgetary retrofit cost estimate including LP PX, circulation pump & VFD, instrumentation, piping, install / labour, RO replacement cost per train*

***Assumed electricity cost of $0.15/kWh*

The reuse opportunity

High-value reuse is growing rapidly; ERDs can make the costs more attractive.

> There is no single larger opportunity to save energy in a water reuse flow sheet than to include an ERD.
>
> **Erik Desormeaux, Energy Recovery**

High-value reuse applications

Utilities and industries are looking to address shortages of high-quality water by treating available effluent to a much higher level than is required for discharge or agricultural irrigation. For potable and high-value industrial use cases RO is the only technology that can practically meet most treatment requirements. This means significant volumes of pressurised brine; a prime opportunity for the benefits of ERDs to be applied.

Potable reuse growth

2015–2024 capacity (m^3/d)

130,328

2025–2034 capacity (m^3/d)

1,063,632

Potable activity reuse is expected to increase by **716%** in the next 10 years.

Source: GWI

Cost is a particular issue in potable reuse applications where water quality requirements of up to 20-log contaminant reduction can make the cost of projects prohibitively high.

Bringing down the cost barrier

RO-based wastewater treatment is more expensive than conventional resources. The use of efficiency-driving technology such as ERDs could close this gap and alleviate the higher water tariffs associated with the treatment of effluent.

Indirect potable reuse plant example

Original | With ERD

Cost ($/$m^3$)

Original	1.31
With ERD	1.23

A reduction in the cost of producing water of approximately **6%** can lead to a ROI in as little as **6 months** (assuming 30% energy saving).

Annual energy usage (MWh) / carbon emissions (tons)

Original	17,260 / 8,195
With ERD	12,044 / 5,736

Energy savings of over **5 GWh/year** will reduce carbon emissions by **several thousand tons**.

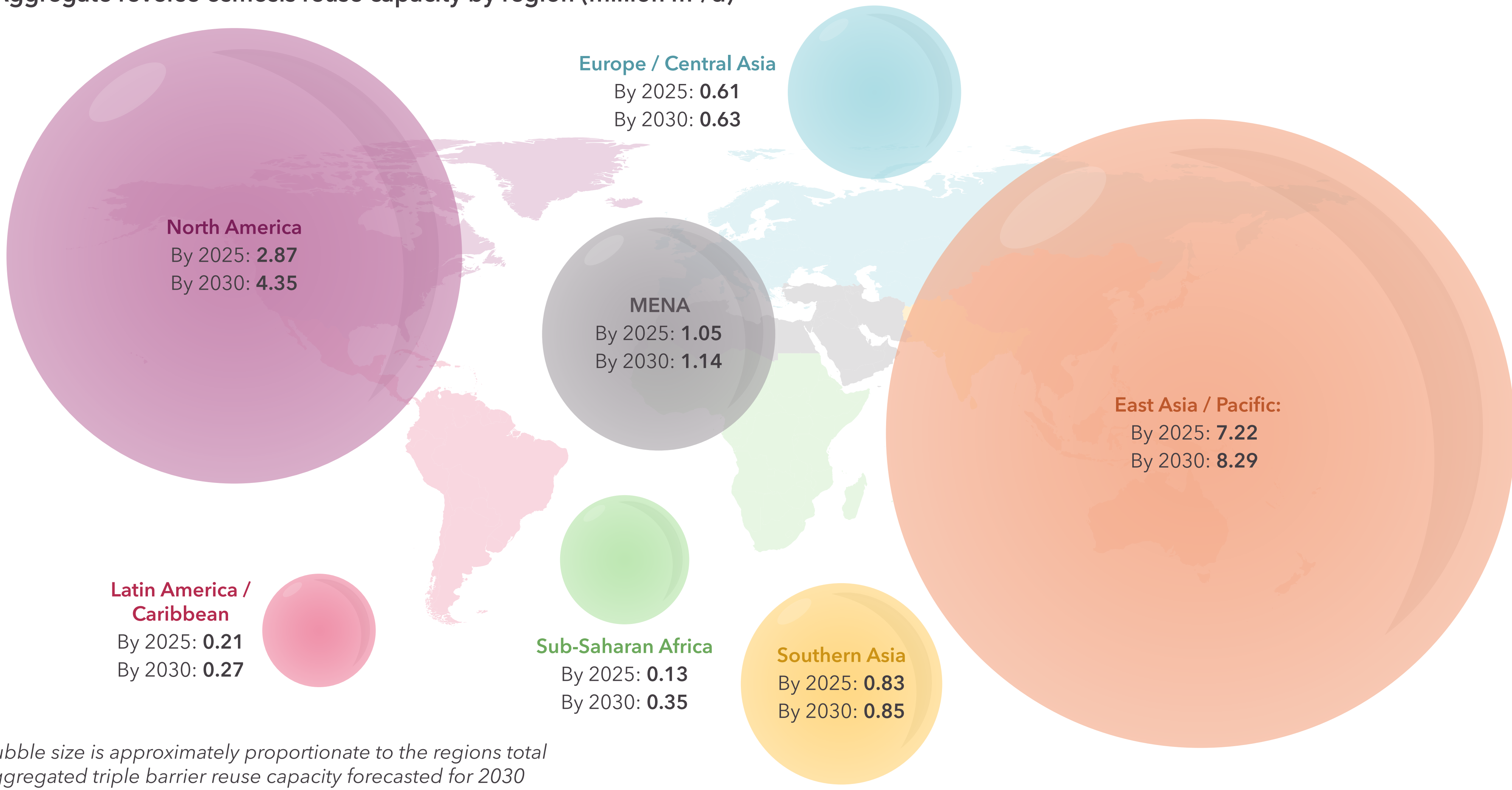
Source: Water Reuse Journal / GWI

Regional breakdown

Where is the opportunity strongest?

RO-driven wastewater reuse is on the rise around the globe with the largest markets located in North America, East Asia / Pacific, and the Middle East and North Africa (MENA). Demand for high-value wastewater reuse is expected to drive these markets to new heights in coming years. For the moment, North America is set to see the strongest growth as potable reuse begins to take off as a serious solution to water supply. Going forward, there are expected to be rich opportunities for the application of ERDs in wastewater reuse.

Aggregate reverse osmosis reuse capacity by region (million m^3/d)



Bubble size is approximately proportionate to the regions total aggregated triple barrier reuse capacity forecasted for 2030

Regional breakdown

Where is the opportunity strongest?

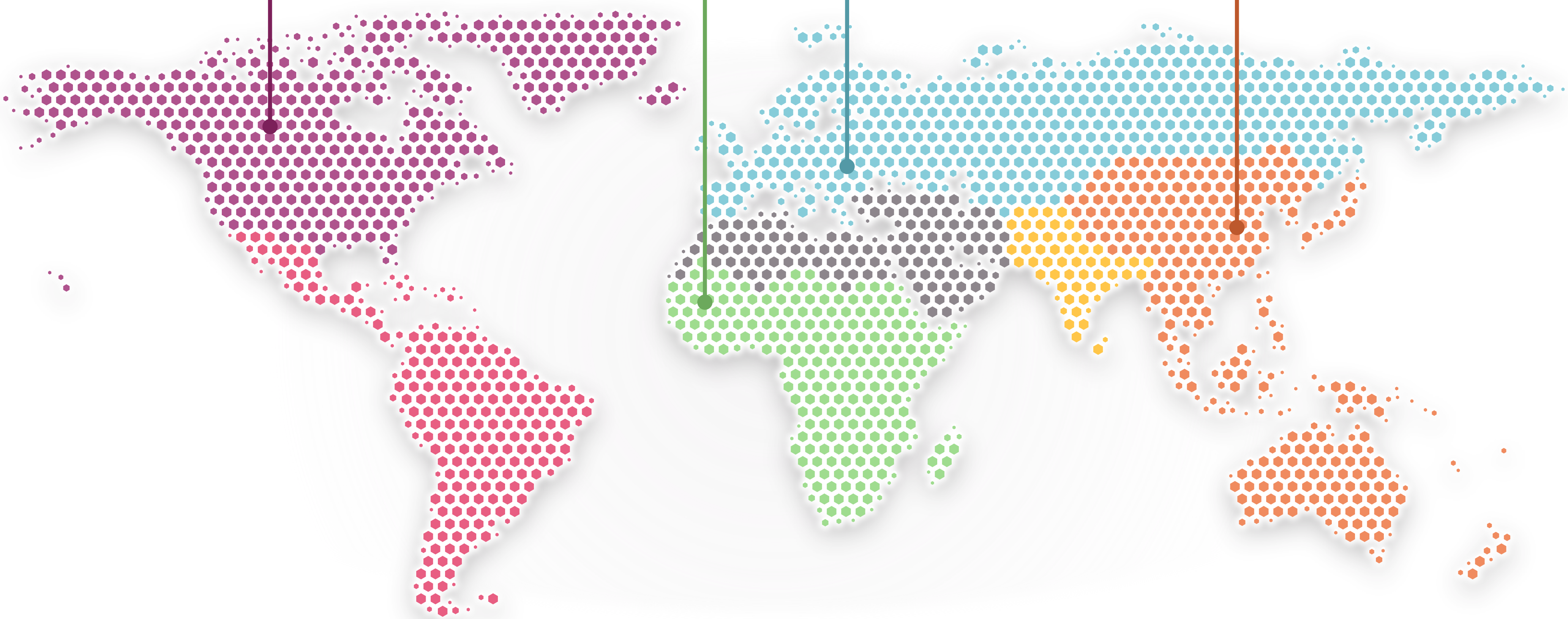
High-value, membrane-driven reuse is becoming a key focus for utilities around the world.

The majority of interest is currently in **North America**, where the ongoing development of potable reuse regulations is set to lay a steady base for a strong pipeline of new RO-based reuse projects.

Potable reuse is seeing growth in **Sub-Saharan Africa** with South Africa following the example of neighbouring Namibia, which has successfully utilised DPR for more than 50 years, albeit using non-membrane-based technology.

In **Europe**, a recent project in Vendee, France marked the region's first potable reuse scheme, providing a case study for the future development of treated effluent as a source of potable supply.

In **East Asia**, potable reuse remains minimal but a landmark DPR scheme in the Philippines has laid the groundwork for further DPR activity. However, high-value industrial reuse is common, with many projects requiring a standard of treatment only achievable with RO.



Global benefits

At the global level, the electricity and carbon savings are substantial.

Due to the energy-intensive nature of RO-based water treatment (even in lower pressure applications) and the large market size, the implementation of ERDs could have tangible sustainability benefits at the global level.

Some regions such as California offer incentives for reductions in energy use as well as carbon credits for larger projects.

	Energy		CO_2 emissions	
	Annual total (GWh)	**Potential savings (GWh)**	Annual total (tons)	**Potential savings (tons)**
Currently	5,674	**1,702**	2,702,338	**810,701**
By 2030	6,966	**2,090**	3,317,700	**995,310**

By **2030**, if installed at every RO reuse plant, every year ERDs could save the equivalent **electricity** of:

More than **450,000 electric vehicles** driving 15,000 km a year

The total annual electricity demand of **the Bahamas**

9% of Microsoft's annual electricity demand

And the **CO_2** equivalent of:

600,000 modern **gas-powered cars** driving 15,000 km a year

A 125 MW **coal-fired power plant**

Obstacles to implementation

ERDs are a flexible solution adaptable to different technologies and feedwaters

Efficiency often comes at the cost of flexibility, however, this is not the case with ERDs. The design of modern ERDs ensures that efficiency can be improved, and costs reduced, without compromise to the range of available plant designs or operating parameters.

What if the feedwater conditions are not consistent?

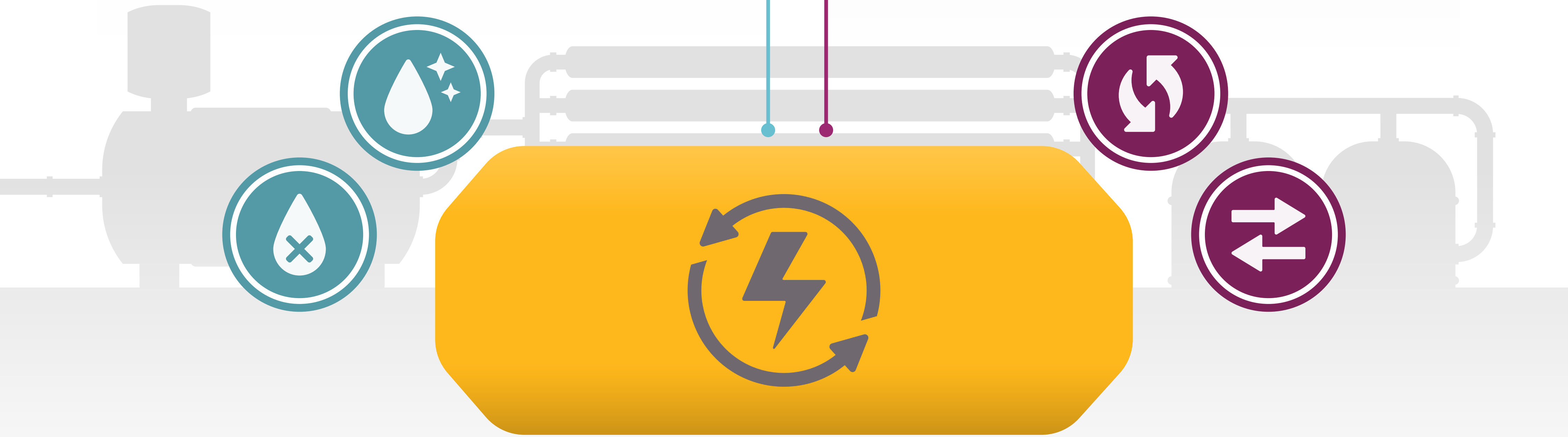
Despite being finely-tuned pieces of equipment, isobaric ERDs can flexibly handle changes in feedwater quality, flow, and pressure, ensuring cost savings can be made even with difficult feed conditions. While pump and turbine efficiencies reduce sharply with flow and pressure changes, isobaric ERDs automatically adjust to variations in system operating conditions. With only one moving part, uptimes of up to 99.8% can be expected, with no scheduled maintenance.

This is particularly useful when dealing with wastewater from industries such as food & beverage, chemicals, pulp & paper, or textiles, where industrial processes operating in batches or at variable production rates can cause the resultant wastewater to fluctuate between periods.

Can a PX be used with unconventional RO system configurations?

Isobaric ERDs, like the PX, are fully compatible with new innovations in RO like semi-batch RO (e.g., closed-circuit RO (CCRO) or flow-reversal RO (FRRO)).

The benefits of ERDs in these systems can actually be stronger than in traditional systems. Where higher recovery is achieved with higher pressure, the payback can be even more attractive, especially if the reuse facility uses CCRO, FRRO, etc., as an "unattached 3rd stage", leaving the 1st two stages as conventional low-pressure RO systems.



Conclusion

LESSON ONE

Low-pressure RO treatment of water and wastewater can be made more financially viable through the use of energy recovery devices and complementary technologies such as low-ΔP membranes.

LESSON TWO

The fledgling potable reuse market can particularly benefit from the cost savings offered by low-pressure ERDs which can reduce low-pressure RO system energy by 10–40% and total cost of water production by ~5%.

KEY LESSONS

ERDs are not just for seawater.

Ignoring brine energy means leaving money on the table and carbon in the air.

Potable reuse is a prime opportunity for ERDs.

LESSON THREE

Implementing energy recovery in low-pressure RO could reduce global wastewater reuse energy consumption by more than 2 TWh and carbon emissions by one million tons of CO_2e.

LESSON FOUR

ERDs are flexible solutions that can provide cost and efficiency benefits for multiple RO configurations, even in cases with variable feedwater conditions.

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Energy Recovery Inc. hones focus on water reuse and ZLD

A thirsty world: how energy efficient low-pressure RO can boost sustainability

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Low pressure PXs

Highly efficient ERD case study

Municipal installation case study

Reliability and design life of ERDs

Solutions for energy efficiency in low-pressure RO and nanofiltration webinar

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