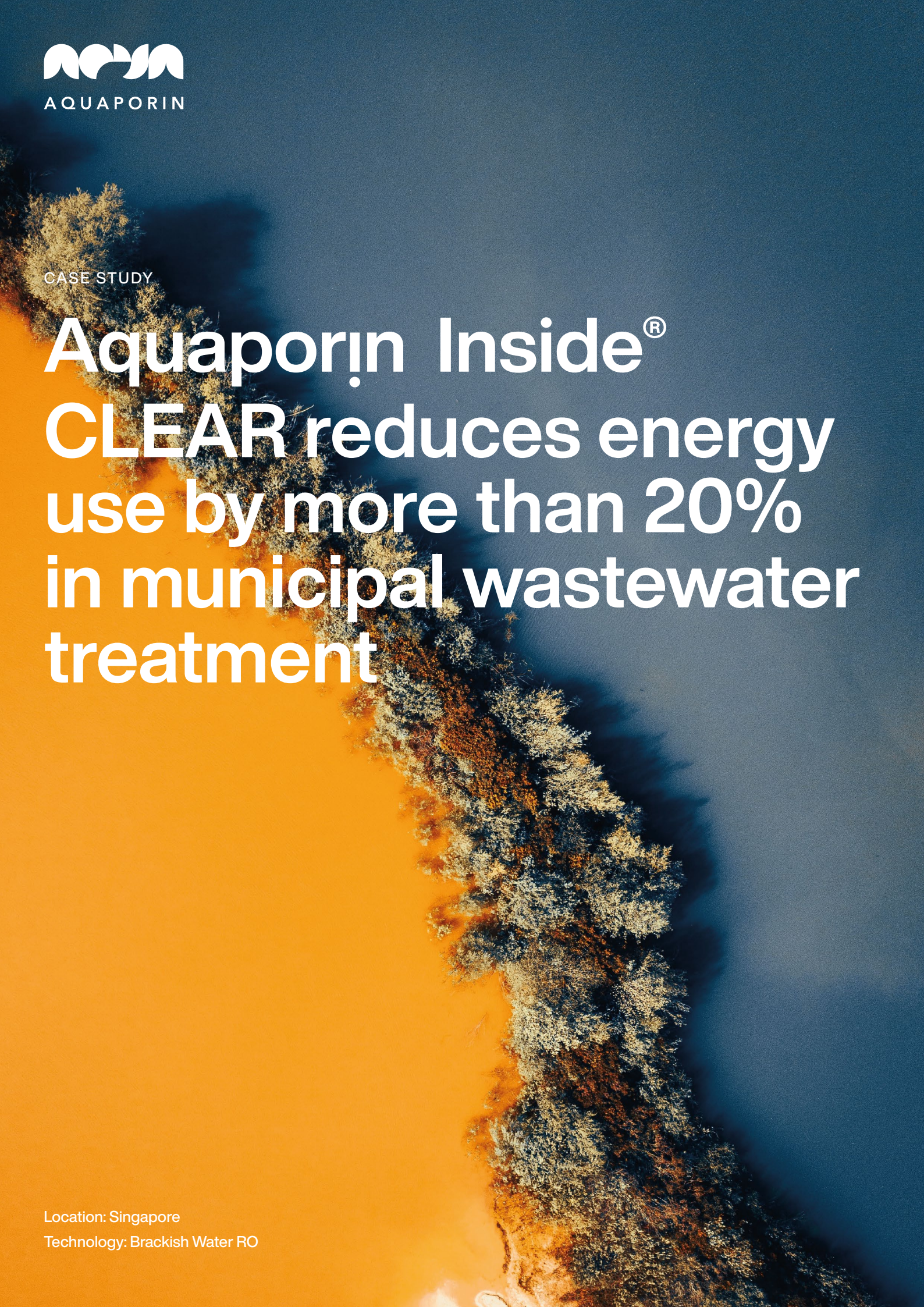
AQUAPORIN

CASE STUDY

Aquaporin Inside® CLEAR reduces energy use by more than 20% in municipal wastewater treatment



Location: Singapore

Technology: Brackish Water RO

A pilot project demonstrates that Aquaporin Inside® CLEAR membranes can reduce pressure requirements in reverse osmosis water treatment, significantly lowering energy consumption and carbon footprint, while meeting high permeate quality standards.

Water demand is growing across the globe, driven by high population growth, industrialization, and rapid urbanization. This increases the need for diversified, sustainable, and reliable water resources. As a result, many municipalities are ramping up efforts to reclaim municipal secondary effluents for industrial reuse - or even potable applications. But this is not easy. There are stringent quality requirements for recycled water to ensure it is safe and consistent. The ongoing drive to make every drop count and to minimize liquid discharge means solutions must be highly reliable.

One common solution is to improve recovery in reverse osmosis units. However, reverse osmosis is a very energy-intensive process. Municipalities are looking for ways to improve the energy efficiency of reverse osmosis solutions. This enables greater water reuse while minimizing carbon footprint and protecting reclamation plants against energy price shock or supply shortage.

Designed for municipal wastewater recycling, our Aquaporin Inside® CLEAR membranes can significantly reduce feed pressure requirements and drive down energy consumption - as this pilot project shows.

The challenge

Increasing efficiency and quality in municipal wastewater recycling

Reducing the energy consumption of a reverse osmosis operation while maintaining the permeate quality is a delicate balancing act. Municipal wastewater treatment plants often use conventional anti-fouling brackish water membranes to improve operational stability. But these membranes have high rejection rates and are not energy efficient.

Aquaporin's solution is the Aquaporin Inside® CLEAR series. Utilizing biomimicry, advanced membrane chemistry, and smart element design, Aquaporin Inside® CLEAR membranes bring energy efficiency, stable operation, and high permeate quality to municipal reverse osmosis wastewater recycling.

The demonstration

A 100 m³ per day pilot wastewater recycling system

To determine if Aquaporin Inside® CLEAR membranes can deliver significant energy reductions while maintaining good permeate quality, a pilot study was conducted at a municipal wastewater reclamation plant in Singapore.

Technical system set-up and operation
The 100 m³/day pilot system employed Aquaporin Inside® CLEAR Plus 4040XL elements in a 2-stage design, achieving > 75% recovery. The feed was taken from a membrane bioreactor (MBR) permeate stream with average TDS between 400 - 700 ppm, with suitable sodium bisulfite (SBS) and anti-scalant dosing, coupled with cartridge pre-filtration of 25 µm followed by 5 µm.

The system operated with an average designed flux of 17 LMH. A regular Clean-in-Place (CIP) operation was performed monthly to simulate actual plant operation. Operation was automated to maintain stable permeate production, with online monitoring and data logging for analysis. This system operation was repeated similarly to benchmark with commercially available membranes that are commonly found in municipal wastewater recycling operations.

Table 1: Operational details of pilot demonstration

Array	**2×7 – 1×7**
Element model	**Aquaporin Inside® CLEAR Plus 4040XL**
Recovery	**> 75%**
Flux	**17 LMH**
Feed flow	**4 m³/hr**
Feed source	**MBR permeate**
Chemical dosage	**SBS & Anti-sealant**
Clean-In-Place	**Monthly**

The full-scale validation

A 9480 m³ per day wastewater recycling system

Following the highly satisfactory results of the pilot system, 504 pieces of Aquaporin Inside® CLEAR Plus 8040-400 membrane elements were installed in a full-scale treatment train at a water reclamation factory site in Singapore (Table 2). The CLEAR Plus membranes are operated and benchmarked against conventional 8-inch BWRO membranes in a parallel train.

Technical system set-up and operation
The 9480 m³/day system employs Aquaporin Inside® CLEAR Plus 8040-400 elements in a 2-stage design, achieving 80% recovery. The feed is taken from a microfiltration (MF) permeate stream with an average TDS between 250 – 350 ppm, with suitable monochloramine and antiscalant dosing.

The system operates with an average designed flux of 17 LMH. CIP operations are performed as needed during plant operation. Operation is automated to maintain stable permeate production, with online monitoring and data logging for analysis.

Table 2: Operational details of full-scale demonstration

Array	**48×7 - 24×7 (504 pcs.)**
Element model	**Aquaporin Inside® CLEAR Plus 8040-400**
Recovery	**80% (315 m³/h permeate production)**
Flux	**17 LMH**
Feed flow	**395 m³/h (9480 m³/day)**
Feed source	**MF permeate**
Chemical dosage	**Monochloramine & Antiscalant**
Clean-In-Place	**As-needed, alkaline (pH = 11.5) + acidic (pH = 2.5)**

The results

Part 1

Pilot-scale benchmarking

Lower pressure operation reduces energy use by more than 20%

System performance data demonstrates that at 100 m^3/day capacity, 75% recovery and 24/7 operation, Aquaporin Inside® CLEAR Plus 4040XL elements deliver exceptional performance, with consistently low feed hydraulic pressure (< 5 bar) compared to conventional membranes (> 7 bar). This translates to a 22-41% reduction in required feed pressure compared to the two conventional membranes operating in the same conditions and for the same duration (Figure 1).

Moreover, the element design of Aquaporin Inside® CLEAR Plus 4040XL results in up to a 15% lower pressure drop across the 2-stage system compared to the conventional membranes (Figure 2), lowering energy use even further.

With conventional membranes, pressure increases significantly over time, driving up specific energy consumption (Figure 3). In comparison, the Aquaporin Inside® CLEAR Plus 4040XL elements following the same CIP regime show stable performance over the same duration of operation, ensuring that energy use remains stable. Finally, the Aquaporin Inside® CLEAR Plus membranes demonstrate a > 20% lower specific energy consumption compared to the benchmarked membranes (Figure 3).

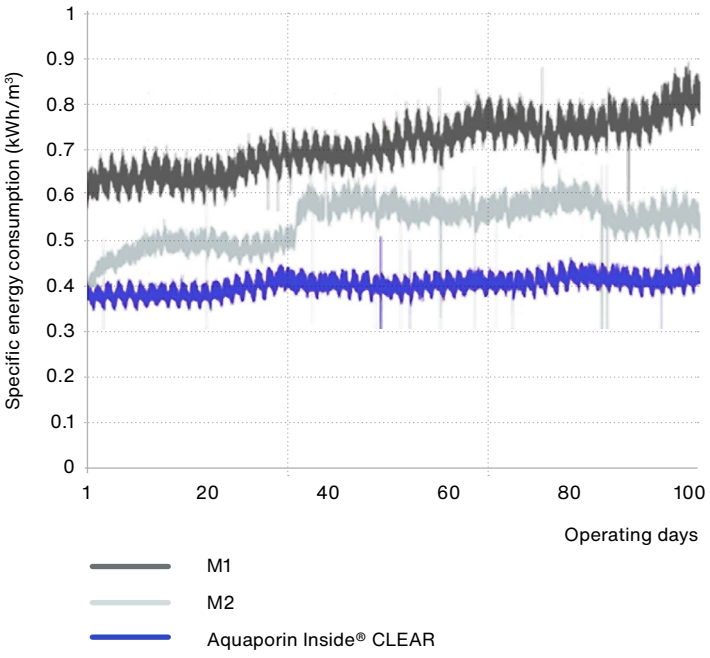


Figure 3: Specific energy consumption.

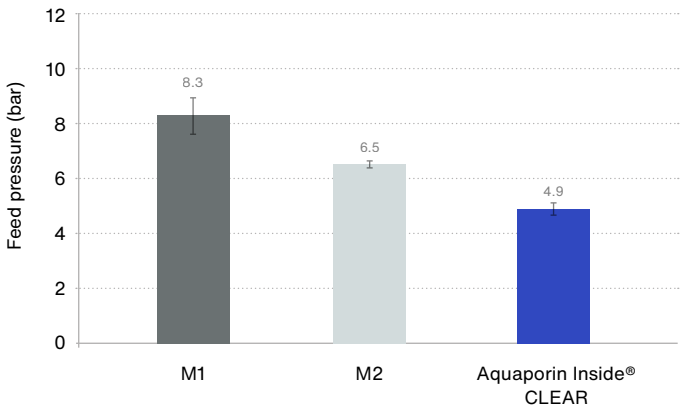


Figure 1: Feed pressure.

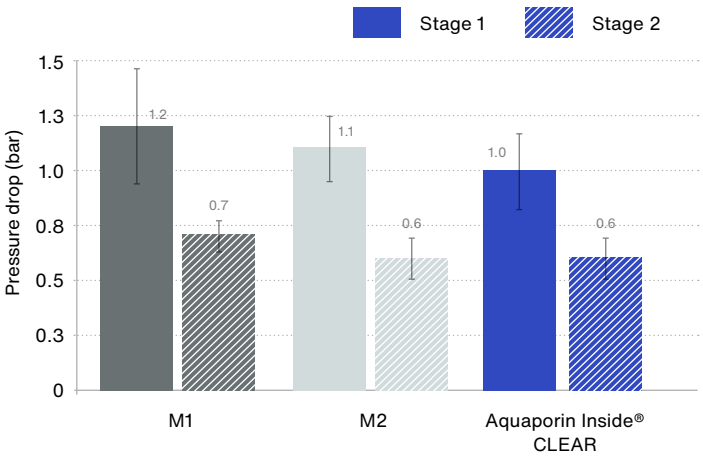


Figure 2: Pressure drop across the membrane array.

In addition to demonstrating stable and robust performance in operation, the Aquaporin Inside® CLEAR Plus membranes maintain the high quality of the permeate water, complying with stringent local standards (Table 3).

Table 3: Filtration efficacy on selected permeate quality parameters.

	Unit	Permeate	Effective rejection[+]	Compliance with PUB's target
Ammonia as NH_3-N	ppm	0.1 – 0.3	> 97.0	✓
Barium as Ba*	ppm	-	-	✓
Calcium as Ca	ppm	0.1 – 0.2	> 99.7	✓
Chloride as Cl	ppm	2 – 3	> 99.1	✓
Conductivity	µS/cm	20 – 40	> 98.3	✓
Fluoride as F*	ppm	-	-	✓
Iron as Fe*	ppm	-	-	✓
Magnesium as Mg	ppm	< 0.01	> 99.9	✓
Nitrate as NO_3-N	ppm	0.3 – 0.5	> 95.5	✓
Nitrite as NO_2-N	ppm	0.1 – 0.2	> 96.0	✓
Phosphate as PO_4-P	ppm	< 0.01	> 99.6	✓
Potassium as K	ppm	0.5 – 0.7	> 98.4	✓
Silica as SiO_2	ppm	0.2 – 0.3	> 98.5	✓
Sodium as Na	ppm	3 – 4	> 97.5	✓
Sulphate as SO_4*	ppm	-	-	✓
Total dissolved solids, TDS	ppm	15 – 20	> 98.2	✓
Total hardness as $CaCO_3$	ppm	0.3 – 0.5	> 99.5	✓
Total organic carbon, TOC	ppb	20 – 40	> 99.6	✓
Total phosphorus as TP	ppm	0.1 – 0.2	> 98.3	✓

* Permeate concentration below detectable limit.
[+] Effective rejection = 100 x (1 – permeate concentration / average of feed and reject concentration).

Part 2

Full-scale validation

20% energy-saving achieved, stable operation over 12 months

To further validate the benefit of Aquaporin Inside® CLEAR product in full-scale operation, a total of 504 pieces of Aquaporin Inside® CLEAR Plus 8040-400 elements were implemented at one of PUB's NEWater production facilities since April 2024. The system installed with biomimetic membrane has a treatment capacity of 395m³/h and is benchmarked against conventional 8" BWRO membrane in a parallel train.

As of April 2025, the full-scale train has been operated continuously over a period of 12 months. Over the long operation time of 12 months, the Aquaporin Inside® CLEAR Plus 8040-400 elements demonstrated stable feed pressure with minimal fluctuation of 1 bar or less (Figure 4). The performance of the membranes was also robust after repeated CIPs (conducted approximately once per month), with stable TDS rejection (Figure 5). High permeate quality was maintained, safely meeting key permeate quality parameters (Table 5).

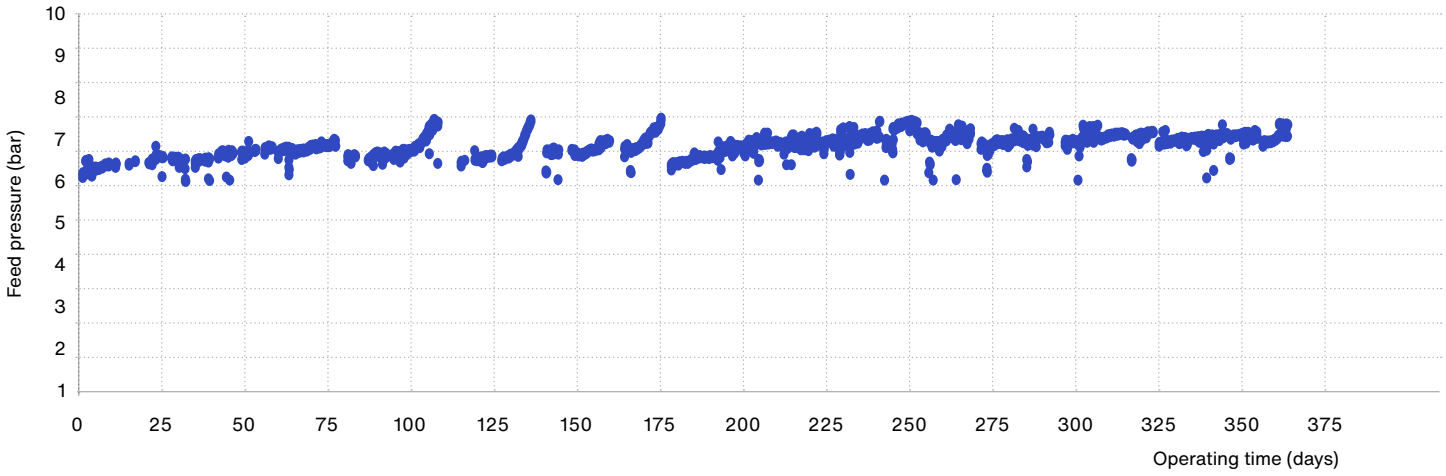


Figure 4: Feed pressure of the Aquaporin Inside® CLEAR Plus 8040-400 over 12 months.

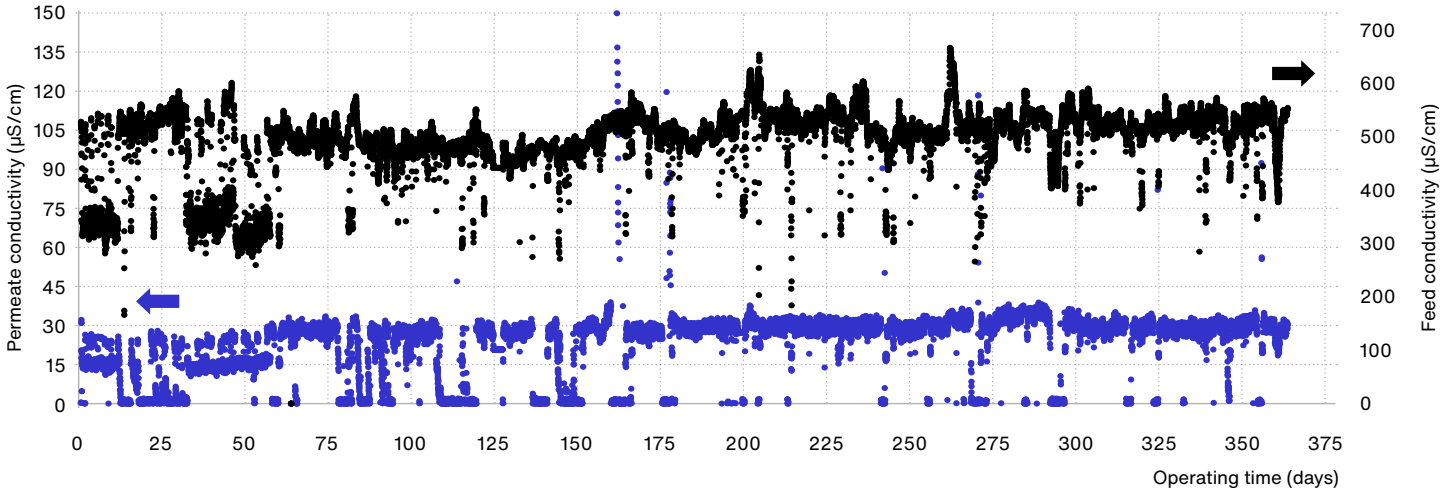


Figure 5: Permeate and feed conductivity of the Aquaporin Inside® CLEAR Plus 8040-400 over 12 months.

Part 3
Economic analysis and sustainability impact

Table 5: Key permeate quality parameters and rejections based on grab sampling

Parameter	System Effective Rejection +	Compliance with Target
Cl^-	> 98.5%	✓
Reactive NH_4-N *	> 98.0%	✓
NO_3-N	> 95.1%	✓
Si	> 98.1%	✓
TDS	> 97.8%	✓
Total Organic Carbon (TOC)	> 99.2%	✓

+ Effective rejection = 100 x (1 – permeate concentration/average of feed and reject concentration).
* calculated according to 30˚C, feed pH = 6.5, reject pH = 6.8, permeate pH= 5.7

The full 1-year operation was stable with significantly reduced feed pressure by 20% as compared to the parallel train operating under the same operational parameters with a conventional membrane. In addition, pressure drop across the element array was benchmarked to be comparable with conventional membrane as well (Figure 6).

With the reduced feed pressure, the targeted specific energy consumption savings have been achieved, while the minimum rejection of key permeate quality parameters was also met.

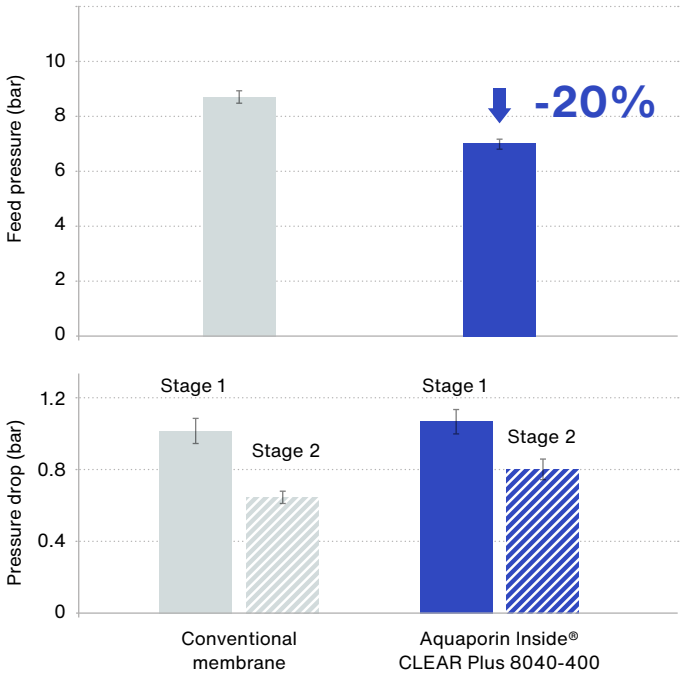


Figure 6: Feed pressure and pressure drop across the element array of the CLEAR Plus 8040-400 and the benchmarked conventional membrane.

Based on the 20% energy savings achieved in the full-scale validation, the potential OPEX saving projection and CO_2 emission avoided in the system installed with Aquaporin Inside® CLEAR Plus 8040-400 were evaluated against a conventional system.

The following assumptions were made for the two parallel systems:

- Treatment capacity of 395m^3/h and 80% recovery
- Target permeate quality is achieved in both systems
- Identical CIP frequency and system maintenance protocols
- Minimum membrane lifetime of 5 years
- Identical membrane price
- Energy price of USD 0.22 / kWh

The economic analysis shows that over 440,000 USD in operation costs can be saved over the first 10 years of operation, attributed to the energy savings achieved (Figure 7). It means that, for each Aquaporin Inside® 8" membrane installed, the user can save 70-90 USD from the operation every year!

In addition, when we convert the energy savings (in kilowatt-hours avoided) into the amount of equivalent greenhouse gas, about 230 metric tons of CO_2 emission* could be avoided every year, just by replacing with Aquaporin Inside® membrane.

Overall, the analysis shows that the Aquaporin Inside® membrane reduces both the OPEX and CO2 emissions of the RO system significantly, helping the end-users to achieve both financial and sustainability goals.

*CO2 Emission is calculated based on energy consumption in the RO system, and converted with US EPA Greenhouse Gas Equivalencies Calculator (https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator)

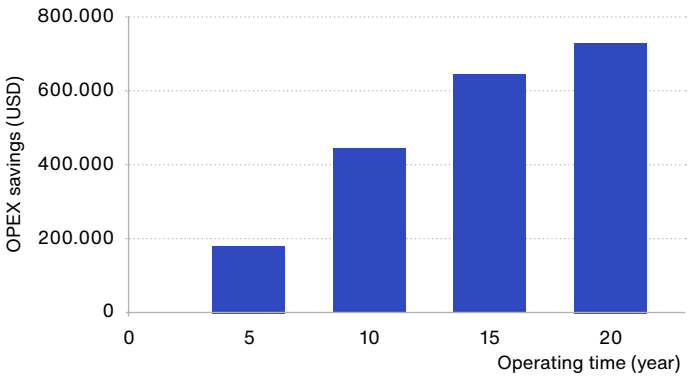


Figure 7: Calculation of accumulative OPEX saved by using Aquaporin Inside® CLEAR membrane over a maximum of 20 years, in USD.

The benefits

Reduced energy use, costs, and carbon footprint

A > 20% reduction in energy consumption results in important benefits for companies and local authorities running municipal wastewater recycling operations. At a 100,000 m^3/day wastewater treatment plant, Aquaporin Inside® CLEAR Plus membranes can deliver savings of more than 4,000,000 kWh per year compared to conventional membranes, while still ensuring high permeate quality. This enables plant operators to reduce operating costs and lower carbon footprint, while helping municipalities increase resilience to energy shortages and price fluctuations - which are all important considerations when tackling the water challenges of the 21st century.

Disclaimer
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Aquaporin Inside® CLEAR membranes

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