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Innovation beyond product specifications: the advantage of superior membrane durability in reverse osmosis installations worldwide

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ABSTRACT

Advancements in membrane technology have made seawater desalination an economically feasible option in the search for freshwater sources for municipal purposes and for industrial applications. Over the last three decades, the cost of desalination has dropped by more than half. According to the International Desalination Association, over 300 million people get their water from desalination plants globally. Ongoing innovation will continue to improve the efficiency and sustainability of the process over the long run, and desalination is fast becoming a safer investment for securing water supply. Membrane replacement can account for up to 5% of the total cost of water and 12% of the operating cost. Therefore, it is of utmost importance to develop durable membranes as they can yield significant cost savings during the lifetime of a desalination installation. DuPont's experience in membrane chemistry and element design uniquely positions us to offer durable reverse osmosis (RO) technology that reliably provides high-quality performance while extending membrane life and reducing the lifecycle costs of operations. Benefits of superior durability include up to 50% lower membrane cost, decreased downtimes, employee cost reductions, and reduced membrane disposal waste for improved sustainability. This paper will present several case studies of real installations from all over the globe. It will showcase the economic advantages of durable RO membranes, as they have been in operation continuously for 9–16 y without replacement.

Keywords: Reverse osmosis; Durability; Desalination; Efficiency; Sustainability

1. Introduction

Water scarcity is widely acknowledged as one of the major global challenges facing humanity [1]. Reverse osmosis (RO) membrane technology is a promising solution for this issue, holding roughly 44% market share and growing among all the desalinating technologies [2]. This increase has been driven as materials are improved and costs dropped [3]. This is especially relevant for Middle East countries (ME), where population is in arid and semi-arid regions, with a very limited rainfall, and where due to high ambient temperatures and low relative humidity, evaporation contributes to a higher stress on the naturally available water sources. Moreover, water scarcity is aggravated by the recent population increase in this region, as well as by economic development [4]. All these factors, together with the favorable energy to product quality ratio that seawater reverse osmosis (SWRO) offers, have situated this technology as one key driver to sustain population living standards in Middle East countries [5].

The rise of seawater desalination is, therefore, a consequence of population growth and climate change

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that continues to place demands on limited freshwater resources. By 2050, 30% more water will be needed to keep up with the rising population and 400% more water will be required for manufacturing. Having a reliable water supply is essential, and desalination has proven to be a secure investment for ensuring consistent access to water [6].

1.1. DuPont leading the path in desalination

DuPont's extensive experience in membrane chemistry and element design uniquely positions it to offer durable reverse osmosis technology that reliably provides high-quality performance while extending membrane life and reducing the lifecycle costs of operations.

DuPont has the largest footprint in the desalination market, with more than 1,000,000 elements operating in large installations. It should be noted that large installations are defined as plants with a nominal capacity of 50,000 m^3/d or higher. The global footprint of DuPont membranes in total installed capacity can be observed in Fig. 1. Also, DuPont has the longest experience in the desalination market, as it built the first large desalination plant in the world in Ashkelon, Israel [7].

1.2. Innovating beyond product specifications

The cost of seawater desalination has decreased substantially over the last few decades. During the 1980s, the cost of seawater reverse osmosis was over 2 \$/m^3. However, over the course of the intervening years, significant improvements have been made to key components of the value chain, resulting in better performance. These advances benefited from innovation in new membrane materials, improvement in energy efficiencies, in valves, and in the development of energy recovery devices, among other improvements. As a cumulative result of these innovations, the desalination industry has achieved a cost of water that is less than 0.5 \$/m^3. It should be noted that additional improvements to the components of a reverse osmosis membrane installment do not have the potential to decrease the total cost of water much further as the technology approaches its thermodynamic limit. Therefore, to continue reducing the total cost of water, it remains of utmost importance to innovate beyond product specifications [8]. The evolution of the desalination cost can be observed in Fig. 2.

1.3. Importance of durable membranes

Having durable membranes is a key factor in reducing the operating expenses of seawater desalination plants. Also, longer-lasting membranes contribute to increasing the plant availability and reducing workforce, as membranes need to be replaced less often and the plant can keep operating at a higher capacity for a longer time. This also helps reduce the amount of solid waste a desalination plant generates as fewer worn or expired? membranes need to be disposed. Therefore, durable membranes can yield significant operational savings. In fact, membrane replacement can account for 5% of total water costs and 12% of total operating expenses [9,10]. The operating expenses (OPEX) cost breakdown can be observed in Fig. 3.

2. Methods

2.1. Installations with outstanding durability

The outstanding durability of DuPont seawater reverse osmosis membranes has been documented in multiple installations. This paper aims to summarize six case studies where the extraordinary durability of DuPont membranes has been demonstrated, and where the customer benefitted from superior membrane life and attained the maximum value of DuPont™ FilmTec™ membranes.

2.1.1. Torrevieja desalination plant

Local water demand has outstripped supply in southeast Spain in the face of population growth and climate

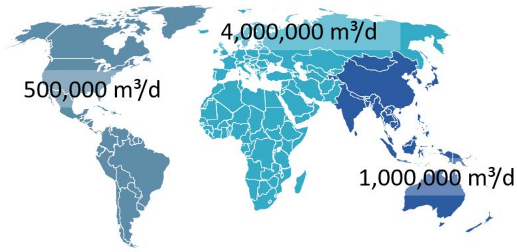

Fig. 1. DuPont global footprint in seawater reverse osmosis installed capacity.

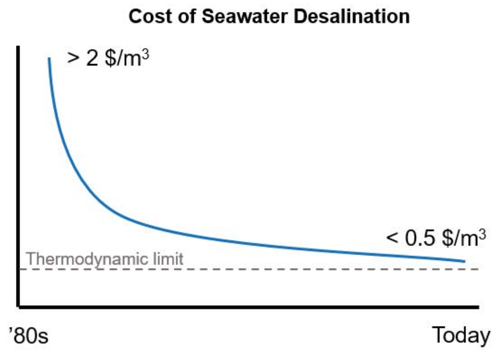

Fig. 2. As the cost of desalination gets closer to its thermodynamic limit, it is of utmost importance to innovate beyond product specifications.

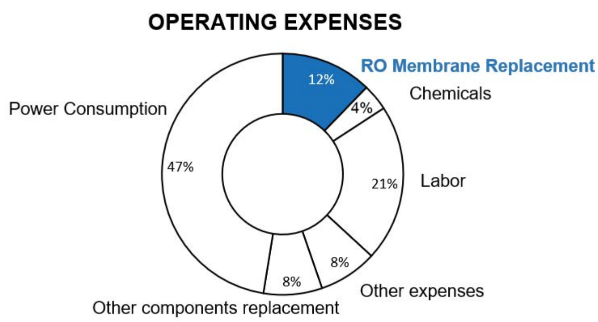

Fig. 3. Membrane replacement is a significant cost for operating expenses.

change. As a result, the Torrevieja Seawater Desalination Plant sought to minimize the effects of drought and water scarcity to benefit local communities [11]. Torrevieja SWRO plant is the largest desalination plant in Europe. Its main features can be found in Table 1.

2.1.2. Alicante desalination plant

Freshwater supplies in southeast Spain are significantly impacted by climatic change and population growth. The Alicante II Seawater Desalination Plant, located in the Spanish Mediterranean Coast, was built with the aim of minimizing the effects of water scarcity and drought conditions suffered by local communities [12]. The Alicante II SWRO plant's features can be found in Table 2.

2.1.3. Águilas desalination plant

Climate change and population growth have taken a significant toll on potable water supplies in Southeast Spain. Located on the Mediterranean coast, the Águilas Seawater Desalination Plant is one of the biggest seawater desalination plants built in Spain. To minimize the impact of drought conditions and water scarcity in the region, the plant sought an effective, long-lasting water treatment solution [13]. The Águilas SWRO plant's features can be found in Table 3.

2.1.4. San Pedro del Pinatar II desalination plant

Located on the Spanish Mediterranean Coast, the San Pedro del Pinatar II Seawater Desalination Plant helps address the region's potable water supply challenges. To overcome the impact of drought and repair the damage done by water scarcity, the plant sought a water treatment solution that would stand the test of time [14]. The San Pedro del Pinatar II SWRO plant's features can be found in Table 4.

2.1.5. Khor Fakkan desalination plant

Severe water scarcity has been faced by the population of Khor Fakkan, Al Iulia, Al Zibara and Hissah. To provide fresh drinking water to the region, the Khor Fakkan Seawater Desalination Plant was built. It is located on the Oman Peninsula on the east coast of the UAE, facing the Gulf of Oman and the Arabian Sea [15]. The Khor Fakkan SWRO plant's features can be found in Table 5.

2.1.6. Perth desalination plant

Climate change and population growth have taken a significant toll on potable water supplies in Perth, Western Australia. Located south of Perth, the Perth Seawater Desalination Plant was the first largest seawater desalination plant when constructed at that time in the southern

Table 1
Torrevieja desalination plant fast fact

Country	Spain
End-user	Acuamed
Technology	DuPont™ FilmTec™ SWRO and BWRO
Membranes	25,536
Plant capacity	240,000 m^3/d
Start-up date	2013
Feed water quality	38,000 ppm TDS, 5 ppm B
Product water quality	<300 ppm TDS, <0.5 ppm B
Temperature range	14°C–30°C
Pretreatment	Dual media filters

Table 2
Alicante desalination plant fast facts

Country	Spain
End-user	Mancomunidad de los Canales del Taibilla (MCT)
Technology	DuPont™ FilmTec™ SWRO
Membranes	6,272
Plant capacity	65,000 m^3/d
Start-up date	2008
Feed water quality	41,000 ppm TDS, 5 ppm B
Product water quality	<250 μS/cm, TDS, <1 ppm B
Temperature range	14°C–30°C
Pretreatment	Dual media filters

Table 3
Águilas desalination plant fast facts

Country	Spain
End-user	Acuamed
Technology	DuPont™ FilmTec™ SWRO and BWRO
Membranes	20,020
Plant capacity	180,000 m^3/d
Start-up date	2013
Feed water quality	41,000 ppm, 5 ppm B
Product water quality	<400 ppm TDS, <1 ppm B
Temperature range	13°C–28°C
Pretreatment	Dual media filters

Table 4
San Pedro del Pinatar II desalination plant fast facts

Country	Spain
End-user	Mancomunidad de los Canales del Taibilla
Technology	DuPont™ FilmTec™ SWRO
Membranes	6,426
Plant capacity	65,000 m^3/d
Start-up date	2006
Feed water quality	41,000 ppm TDS, 5 ppm B
Product water quality	<400 ppm TDS, <1 ppm B
Temperature range	13°C–29°C
Pretreatment	Dual media filters

hemisphere [16]. The Perth SWRO plant's features can be found in Table 6.

2.2. Experiment showing superior durability

This durability assessment was performed in an 8-inch pressure vessel industrial scale unit. Piping and pressure vessels are made of super duplex stainless steel. A high-pressure pump is responsible for delivering seawater at a required pressure into the plant. The plant is fully automated, and all data is recorded into the Programmable Logic Controller (PLC). A plant schematic can be found in Fig. 4, and a picture of the installation is shown in Fig. 5.

This study was done using seawater from the Red Sea. Its composition is set forth in Table 7. The membranes were operated in recirculation at a feed flow of 8–11 m^3/h for both the FilmTec™ SW30HRLE-440 reverse osmosis element and the alternative membrane. Water recovery was set to 12%. Water temperature was 26°C. After 1 d of operation, a cleaning-in-place (CIP) was performed, consisting of a caustic cleaning at pH 12 at 35°C for 135 min and an acid cleaning at pH 2 and 25°C for 135 min. This operating cycle was repeated until 8 cleanings were performed. After this time, membranes were left in operation until they were fully stabilized.

2.3. Cost savings from superior durability

The cost savings that can be obtained using a membrane with superior durability are calculated using the DuPont WaterApp software platform from DuPont. In particular, the tool "Invest to Save" calculator was used for performing this assessment.

Table 5
Khor Fakkan desalination plant fast facts

Country	United Arab Emirates
End-user	Sharjah Electricity and Water Authority
Technology	DuPont™ FilmTec™ SWRO
Membranes	1,792
Plant capacity	22,700 m^3/d
Start-up date	2008
Feed water quality	39,000 ppm TDS
Product water quality	<400 ppm TDS
Temperature range	20°C–35°C
Pretreatment	Dual media filters

Table 6
Perth desalination plant fast facts

Country	Australia
End-user	Water Corporation
Technology	DuPont™ FilmTec™ SWRO and BWRO
Membranes	17,976
Plant capacity	145,000 m^3/d
Start-up date	2006
Feed water quality	37,000 ppm
Product water quality	<200 ppm
Temperature range	14°C–26°C
Pretreatment	Dual media filters

3. Results

3.1. Installations with outstanding durability

3.1.1. Torrevieja desalination plant

Since installing 25,536 DuPont™ FilmTec™ reverse osmosis (RO) elements in 2013, the plant has delivered high-quality drinking water to the Spanish population, which is critical to ensure safety and reliability. Since installation in 2013, the plant has operated at a recovery rate of 45% for the first pass seawater RO, and 90% for the second pass brackish water RO when it is required. The well-maintained membranes have been operating for more than 10 y without replacements, demonstrating excellent operating performance, as well as consistent reliability and durability.

3.1.2. Alicante desalination plant

Since installing 6,272 DuPont™ FilmTec™ reverse osmosis (RO) elements in 2008, the plant has delivered high-quality drinking water throughout the region without issue. The plant operates at a recovery of 45% for the single pass seawater RO. The well-maintained membranes have demonstrated excellent operating performance and durability for 14 y with no replacements.

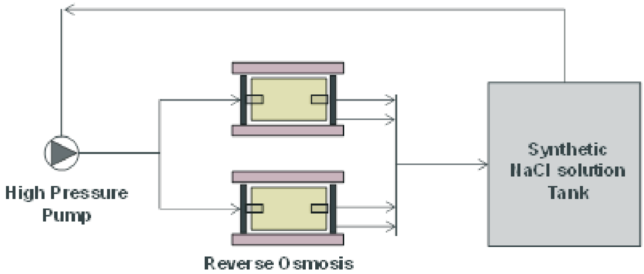

Fig. 4. Durability study pilot plant scheme.

Fig. 5. Durability study pilot plant photo.

Table 7
Red Sea water composition

Compound	Concentration (mg/L)
Ammonium (NH_4^+)	0.1
Barium (Ba)	0.01
Bicarbonates (HCO_3)	124
Boron (B)	3.4
Calcium (Ca)	425
Carbon dioxide (CO_2)	0.29
Carbonates (CO_3^-)	43
Chloride (Cl^-)	22,515
Fluoride (F^-)	1.41
Magnesium (Mg)	1,329
pH	8.1
Potassium (K)	511
Silica (SiO_2)	1
Sodium (Na)	12,833
Strontium (Sr)	6.2
Sulfate (SO_4^{2-})	3,038
Total dissolved solids (TDS)	40,845

3.1.3. Águilas desalination plant

Since 2013, the plant has consistently delivered safe, reliable and high-quality drinking water to the Spanish population. A total of 20,020 DuPont™ FilmTec™ reverse osmosis (RO) elements were installed and now play a vital role in securing long-term water supply for local residents. Since commissioning the installation, the plant operates at a recovery rate of 45% for the first pass seawater RO, and 90% for the second pass brackish water RO. The well-maintained membranes have been operating for more than 10 y without replacement and consistently demonstrate excellent operating performance, reliability, and durability.

3.1.4. San Pedro del Pinatar II desalination plant

After installing 6,426 DuPont™ FilmTec™ reverse osmosis elements (RO) in 2006 – a critical step in providing safe drinking water to the local population – the plant has delivered reliable, high-quality drinking water. Since the elements were installed in 2006, the plant has operated at a recovery rate of 45% for the single pass seawater RO. This translates to more than 16 y of membrane installed without replacement, consistently demonstrating excellent operating performance, reliability, and durability.

3.1.5. Khor Fakkan desalination plant

Since 2008, the plant has been constantly delivering reliable and high-quality potable water, which is a critical installation to provide safe drinking water to Emirates population. A total of 1,792 DuPont™ FilmTec™ reverse osmosis elements were installed and play a vital role in securing long-term water supply for the local residents. Since commissioning the installation, the plant operates at a recovery rate of 40%. The well-maintained membranes have been operating for more than 14 y without replacement and consistently demonstrate excellent operating performance, reliability, and durability.

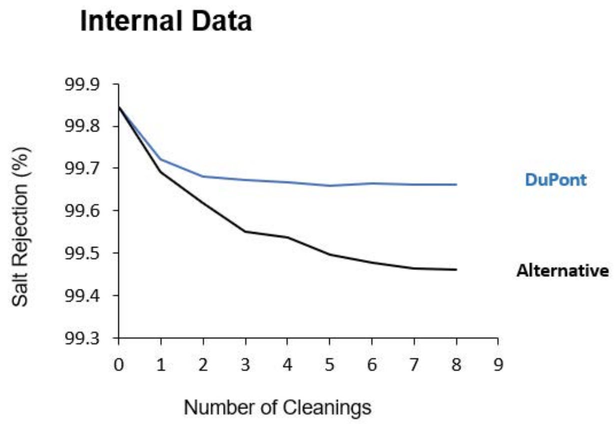

Fig. 6. Durability advantage of DuPont membrane after multiple chemical cleanings.

3.1.6. Perth desalination plant

Since 2006, the plant has consistently delivered safe, reliable and high-quality drinking water, which accounts for about 17% of Perth's water supply. A total of 17,976 DuPont™ FilmTec™ reverse osmosis (RO) elements were installed and now play a vital role in securing long-term water supply for local residents. Since commissioning the installation, the plant operates at a recovery rate of 45% for the first pass seawater RO, and 90% for the second pass brackish water RO. The well-maintained membranes have been operating for more than 16 y without replacement and consistently demonstrate excellent operating performance, reliability, and durability.

3.2. Experiment showing superior durability

The durability advantage of DuPont membrane has been assessed and the results are depicted in Fig. 6. These data demonstrate that the salt rejection of the alternative membrane continues to decrease significantly over time, while the DuPont membrane offers a much more stable performance after as few as two chemical cleanings (CIP). These results are consistent with other results previously published [10].

3.3. Cost savings from superior durability

The financial impact of superior durability has been assessed using the Invest to Save calculator, that can be found in the DuPont WaterApp. This tool serves a specific purpose in financial and economic assessments. It is intended to provide users with guidance on the advantages of investing in longer-lasting membranes, based on their input data. In this particular case, two different membranes were assessed. One of the membranes is more durable and costs more (500$/element), and an alternative membrane is less durable and costs less (400$/element). The prices of

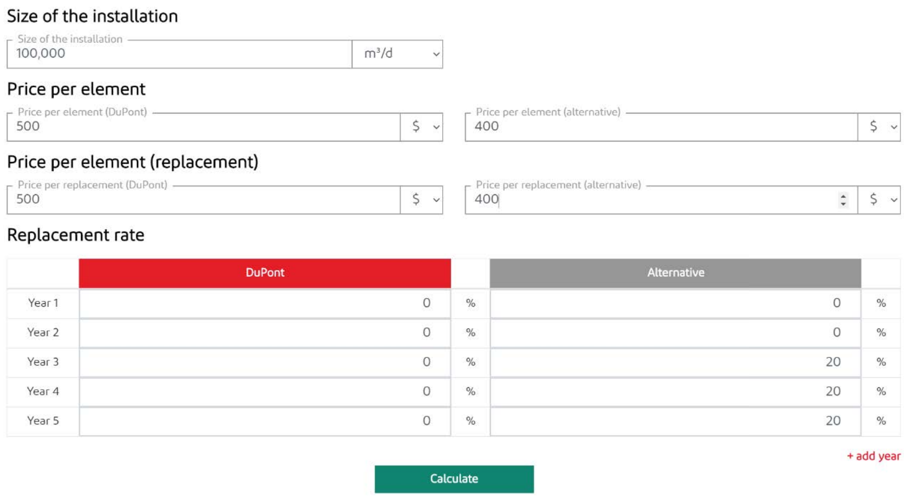

Fig. 7. Input assumptions to estimate savings from a superior durable membrane.

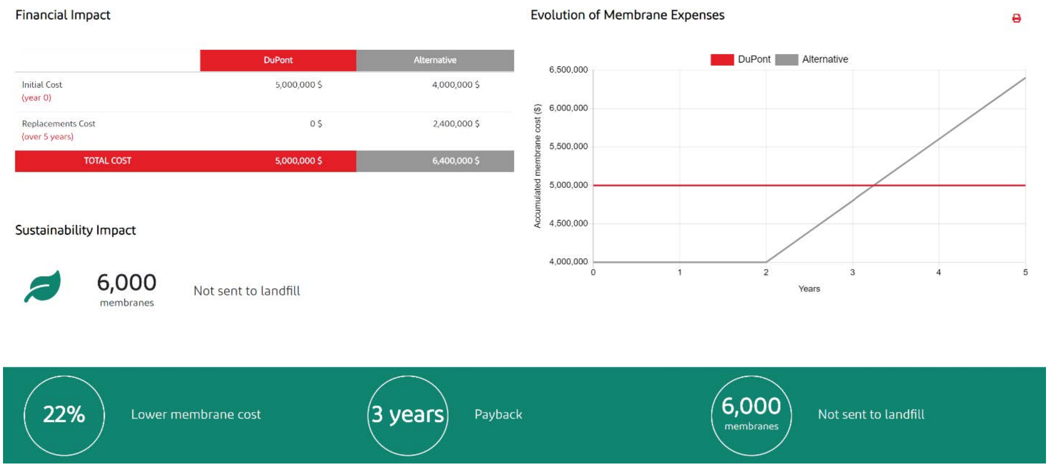

Fig. 8. Output assumptions to estimate savings from a superior durable membrane.

replacement membranes were kept the same in both cases. The more durable membrane was set at a 0% replacement rate for 5 y, while the less durable membrane was set up to 0% replacement rate for the first 2 y and 20% replacement for years 3–5. This corresponds to an average annualized replacement rate (CARR) of 12%. The plant simulated has a capacity of 100,000 m^3/d. This scenario is depicted in Fig. 7.

The results of this economic simulation are depicted in Fig. 8. Initially, the more durable membrane (DuPont option) has a higher cost of $5 million, while the less durable membrane (alternative option) has a total cost of $4 million. After 3 y, however, when the less durable membranes are replaced, the cost increases up to the point that the less durable membranes become more expensive. After the 5-y period that has been evaluated, the total cost of the more durable membrane is still $5 million. In comparison, the total cost of the less durable membrane has increased to $6.4 million. This investment to save means that eventually, a more durable membrane can yield, in this particular case, a cost reduction of $1.4 million over the whole period evaluated. Thus, this initial investment in more durable membranes translates into a direct decrease of 22% in the total membrane cost, and a payback of the investment after 3 y. Also, more durable membranes directly impact sustainability, as fewer membranes replaced also means, in this specific example, avoiding the disposal of 6,000 used membranes. This reduces the installation total solid waste.

3.4. Benefit of superior membrane durability

The benefits of superior membrane durability are clear. As it has been shown in this example, a reduction of more than 22% on membrane cost can be achieved thanks to the superior durability. Depending on the replacement rates and membranes cost assumed, a customer can save up to 50% in membrane cost). Other advantages include reduced downtime, lower staffing costs, and decreased membrane disposal expenses.

From an operational point of view, the advantages are also clear. Durability offers non-interrupted production, eliminates disruption, reduces the hazards and operational risks, offers enhanced system predictability, and provides a smoother and continuous downstream operation.

Improved durability has the added benefit of promoting sustainability. It reduces the need for frequent replacements, which in turn reduces solid waste and improves the sustainability footprint.

Finally, FilmTec™ seawater reverse osmosis elements that offer enhanced durability help reduce the total cost of water by up to 5% and membrane cost by up to 50%. As a result of the enhanced durability customers will replace their membranes less frequently and realize the cost reduction. This favorable economic posture enables original equipment manufacturers (OEM) and constructors to provide a more competitive offering to end users and operators. For end users and operators, superior durability provides lower operational costs, a smoother and safer operation, and an improved sustainability footprint.

4. Conclusions

This paper showcases six successful real-life seawater reverse osmosis installations that have used DuPont membranes for a considerable amount of time without requiring any replacements. In some cases, the membranes have functioned reliably for over 16 y. This durability improvement is also proven experimentally, and it is consistent with previous trials performed. This superior performance is of high importance because membrane replacement can account for up to 5% of the total cost of water and 12% of the operating cost. Benefits of superior durability include up to 50% lower membrane cost, decreased downtimes, employee cost reductions, and reduced membrane disposal waste for more sustainability. To estimate the potential economic savings of a specific installation, the Invest to Save calculator is available through the DuPont WaterApp.

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