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June 17th, 2019

New Technology for Water Production and Zero Liquid Discharge (ZLD)

Dr. Nobuya Fujiwara

Corporate Officer, TOYOBO

Director, International Desalination Association (IDA)

Vice President, Japan Desalination Association (JDA)

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Ideas & Chemistry

SUSTAINABLE DEVELOPMENT GOALS

17 GOALS TO TRANSFORM OUR WORLD

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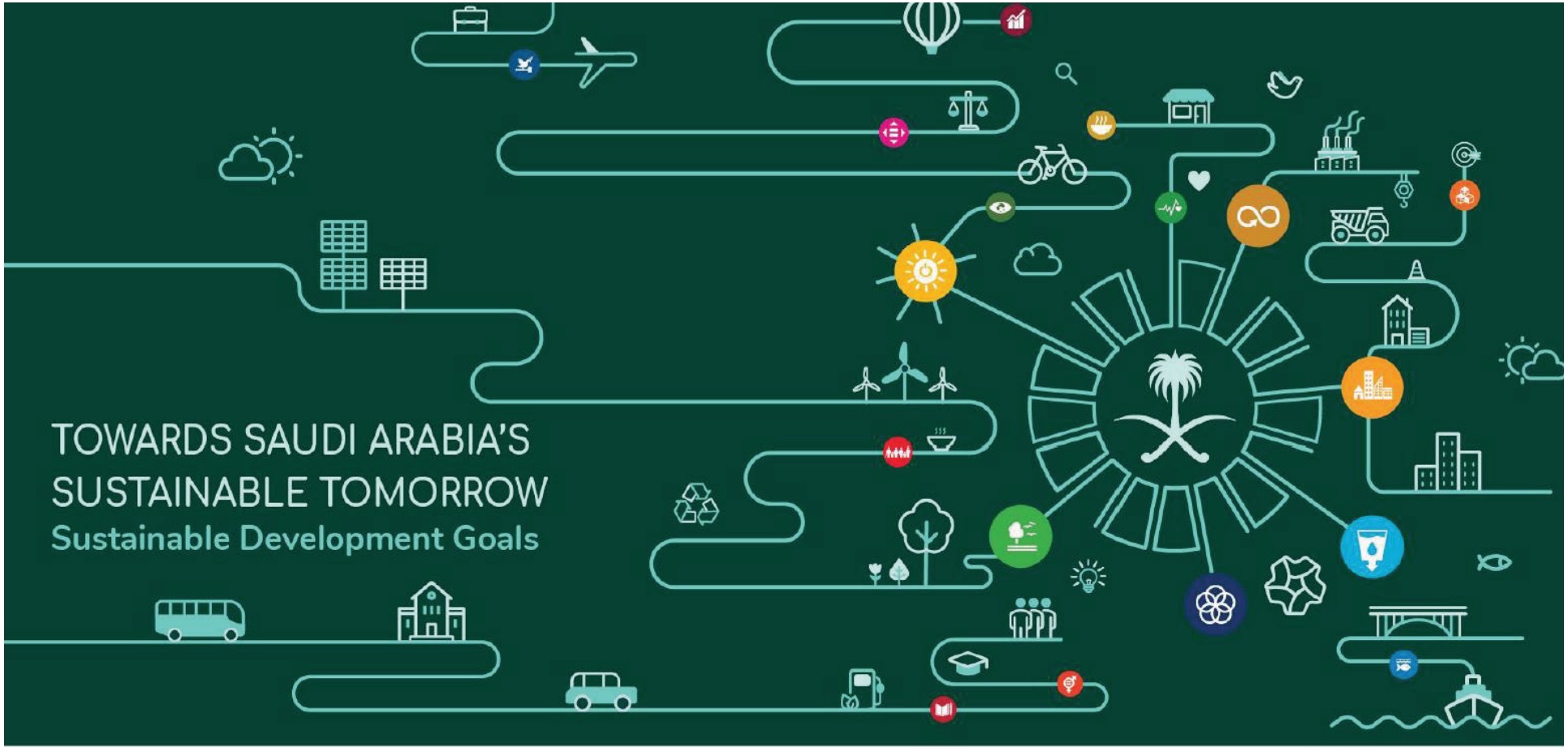
- United Nations General Assembly adopted the 2030 Agenda in 2015, "Sustainable Development Goals(SDGs)" came into effect in 2016.

- The kingdom of Saudi Arabia is a founding member of the United Nations and has played an active role throughout its history. The kingdom helped in shaping the outcome of the SDGs.

Saudi Arabia submitted its first National Report at the High-Level Political Forum took place in July 2018 at the UN Headquarters in New York. More than 1,000 governments, delegations, businesses, and civil society leaders convened to discuss progress done by governments towards the implementation of the SDGs.



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Saudi Arabia's National Review was based on a comprehensive review of the status of the SDGs, alignment with the Saudi Vision 2030, and the actions taken by national entities including the government, the private sector, and non-government organizations to fulfill the 2030 Agenda for Sustainable Development.

Our Commitment to SDGs

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6 CLEAN WATER AND SANITATION

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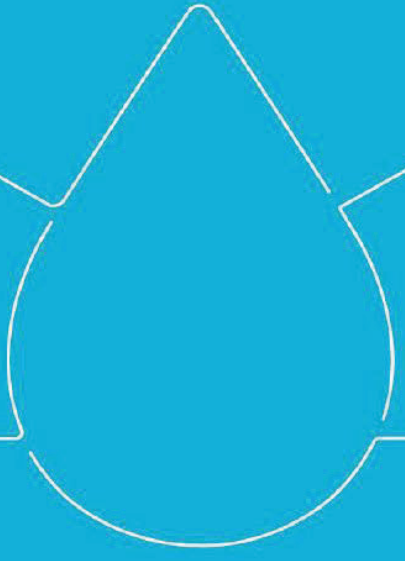
Ensure availability and sustainable management of water and sanitation

06
Clean water and hygiene



The National Water Strategy

Promote surface water resources through the construction of cover 500 dams

99%
Proportion of the population living in households with access to sanitation services in 2016

29
Desalinated plants across the country

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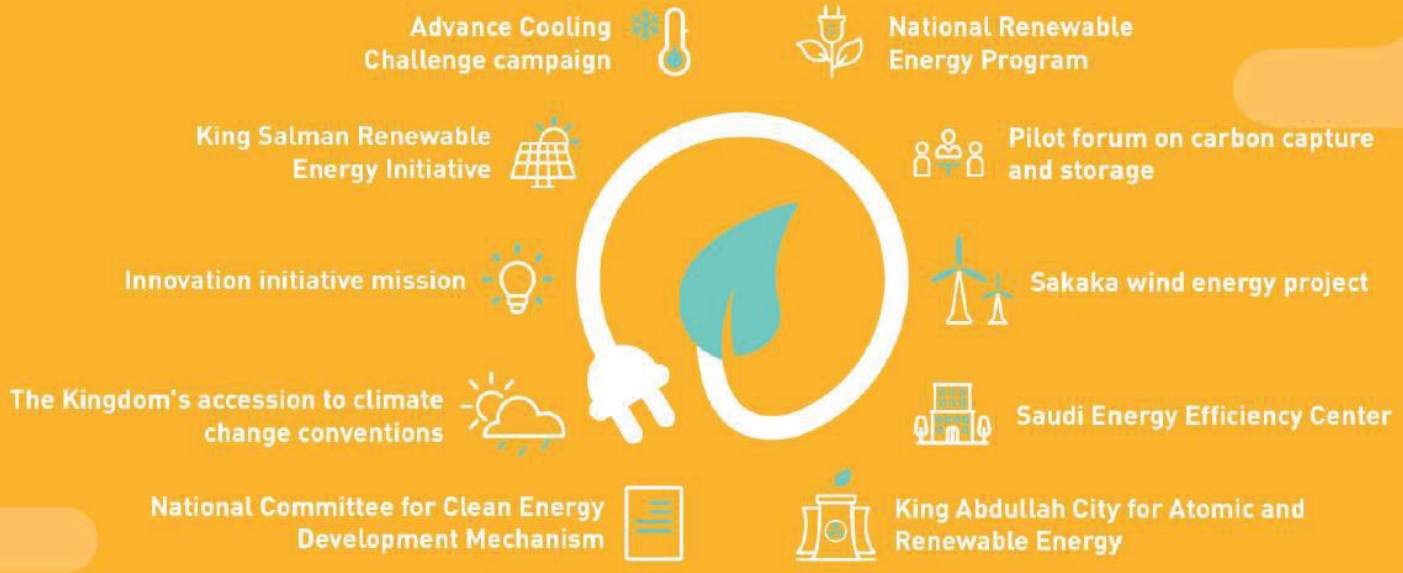
7 AFFORDABLE AND CLEAN ENERGY

Renewable energy and energy efficiency

07

Clean and affordable energy



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Energy Saving
Seawater Desalination

Zero Liquid Discharge
- Seawater Desalination
- Brackish Water Treatment
- Waste Water Treatment

Reverse Osmosis (RO)
Forward Osmosis (FO)

Brine Concentration (BC)
Forward Osmosis (FO)

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World leading-edge technologies

About TOYOBO

- **Foundation : 1882**
- **Original Business : Textiles**

- **Paid-in Capital*:** ¥51.7bn ($480m)
- **Net Sales*:** ¥331bn ($3.1bn)
- **Employees*:** 9,895
- **Businesses**
  - Films & Functional Polymers
  - Industrial Materials
  - Healthcare
  - Textiles

* As of March 31, 2018

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Our local entity to address the specific market needs

Arabian Japanese Membrane Company (AJMC) in Saudi Arabia

- First Hollow Fiber RO membrane manufacturing company in Saudi Arabia

1 Independent Manufacturer

- ✓ Fully localized manufacturer
- ✓ Complete production process

2 Excellent Local Technical Services

- ✓ Full technical services by local staff
- ✓ Ensuring stable operations
  - Anti-bio/organic fouling
  - Stable and reliable operation
  - High plant availability

3 Localization of Technology

- ✓ Technology transfer of RO manufacturing

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RO for Seawater Desalination

Key Takeaways

1. **Unique Cellulose Triacetate (CTA) Hollow Fiber (HF) membranes** with over 40 years' experience in membrane water treatment
2. **One of the Top 3 SWRO membrane suppliers in the GCC** with the largest share of installed capacity (>75%) in Saudi Arabia
3. **Excellent features to minimise biofouling**, the major operational issue faced by the SWRO industry
4. **20% OPEX savings** compared to Polyamide (PA) Spiral Wound (SW) RO membranes, leading to significant **Life Cycle Cost savings**
5. **Trusted and repeatedly selected** by renowned customers

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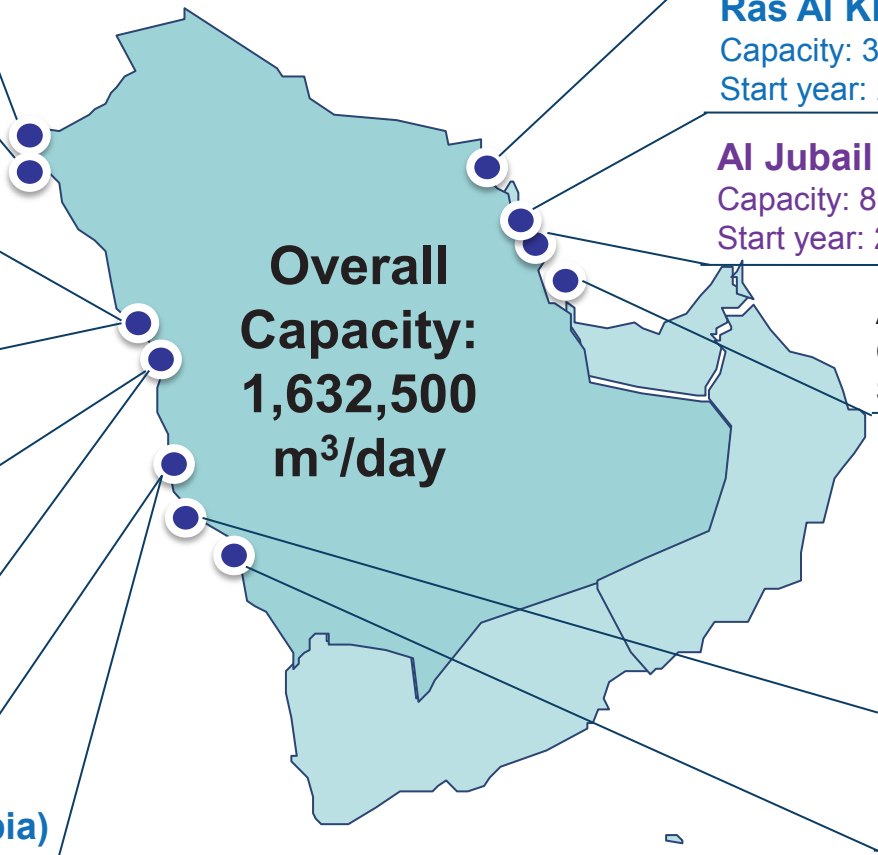
Numerous successful applications in the Middle East

Recent projects | Retrofit projects

TOYOBO SWRO references in the Middle East



Haql (Saudi Arabia)
Capacity: 4,400m³/day
Start year: 1989

Duba (Saudi Arabia)
Capacity: 4,400m³/day
Start year:1989

Yanbu (Saudi Arabia)
Capacity:128,000m³/day
Start year:1998

Yanbu (Saudi Arabia)
Capacity: 50,400m³/day
Start year: 2006

Rabigh (Saudi Arabia)
Capacity: 218,000m³/day
Start year: 2008

Rabigh (Saudi Arabia)
Capacity: 109,000m³/day
Start year: 2015

Jeddah (Saudi Arabia)
Capacity: 113,600m³/day
Start year: 1989,1994

Jeddah RO3 (Saudi Arabia)
Capacity: 260,000m³/day
Start year: 2013

Manifa (Saudi Arabia)
Capacity: 27,000m³/day
Start year: 2012

Ras Al Khair (Saudi Arabia)
Capacity: 345,000m³/day
Start year: 2014

Al Jubail (Saudi Arabia)
Capacity: 85,000m³/day (90,900m³/day)
Start year: 2007

Ad Dur (BAHRAIN)
Capacity: 45,500m³/d
Start year: 2005

Al Birk (Saudi Arabia)
Capacity: 2,200m³/day
Start year: 2001

Shuqaiq (Saudi Arabia)
Capacity: 240,000m³/day
Start year: 2010

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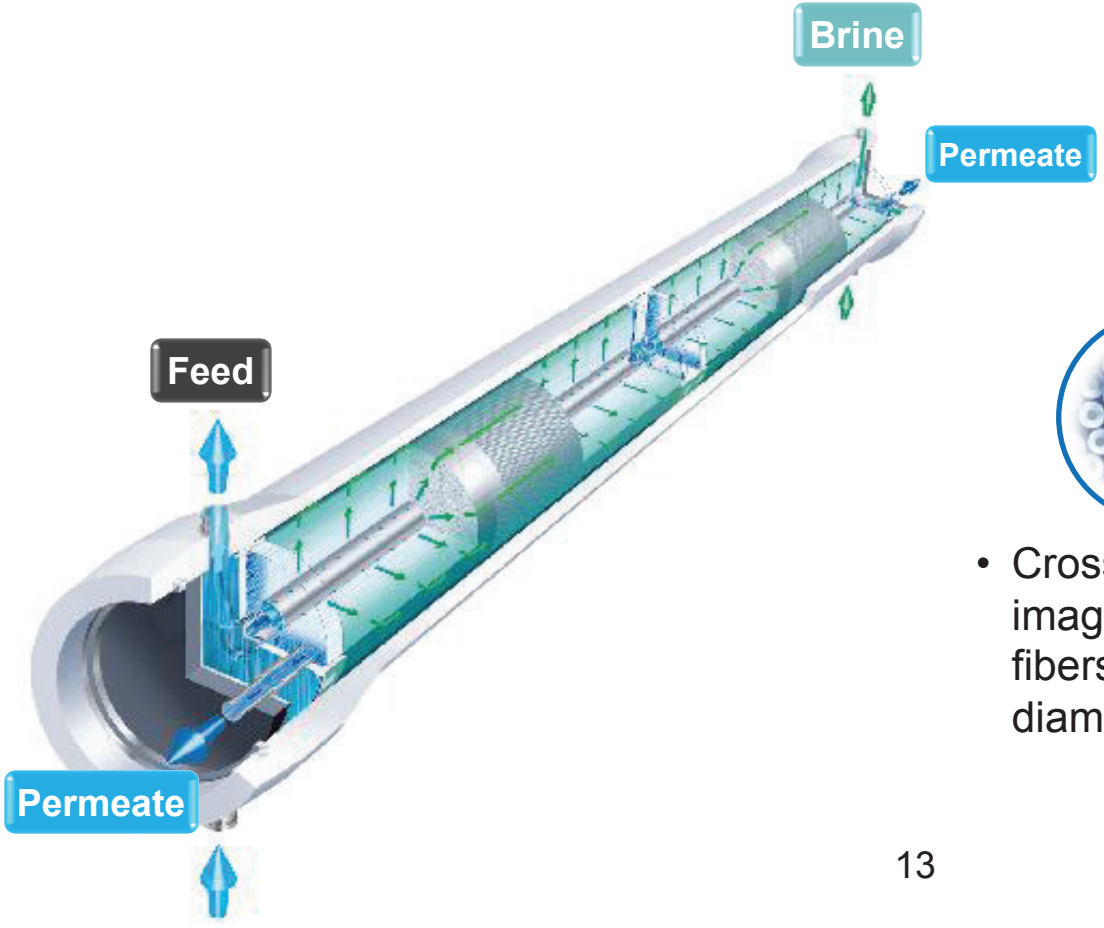
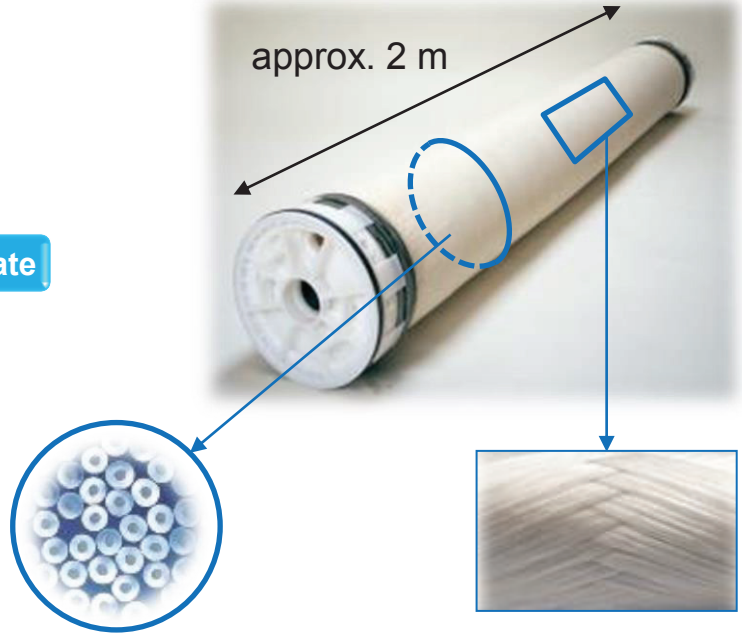
Key features of TOYOBO RO membrane modules

Brand name : HOLLOSEP®

- **Type:** Hollow Fiber RO membrane
- **Membrane Material**: Cellulose Triacetate (CTA)
- **Application**: Seawater Desalination





- Cross section image of hollow fibers (fiber diameter:140μm)
- Millions of hollow fibers are wound into the module construction by a cross winding

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Low cost, reliable and stable seawater desalination

1 Proven and one of the most commonly used technology

- Proven technology with numerous installation **in the Middle East**
- **Largest installed capacity in Saudi Arabia**

2 Excellent operational stability

- **Chlorine-tolerant membrane material** for low-cost chlorine injection
- **Large membrane surface area** to better tolerate potential fouling

3 Low cost operation

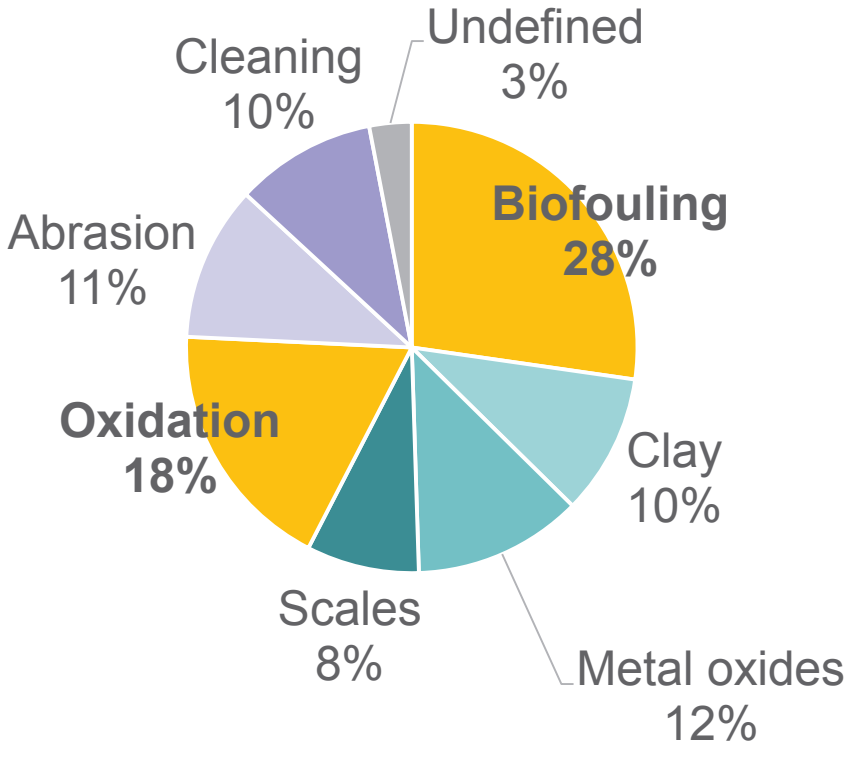
- **Reduced membrane cleaning and replacement**
- **Significant OPEX and Life Cycle Cost savings**

4 High quality service team in Saudi Arabia

- **Local manufacturing and service entity**
- **Full technical services by local team** ensuring stable operations

Biofouling control is a major challenge in SWRO

Causes of membrane failures



Biofouling leads to many issues..

- x Production loss
- x Product quality deterioration
- x Low availability
- x Frequent chemical cleaning
- x High chemical cost
- x Frequent replacement
- x Headache to operators
- x Risk of plant shut-down

Controlling biofouling with chlorine causes Oxidation of PA membranes

Oxidation is another major common cause of membrane failures

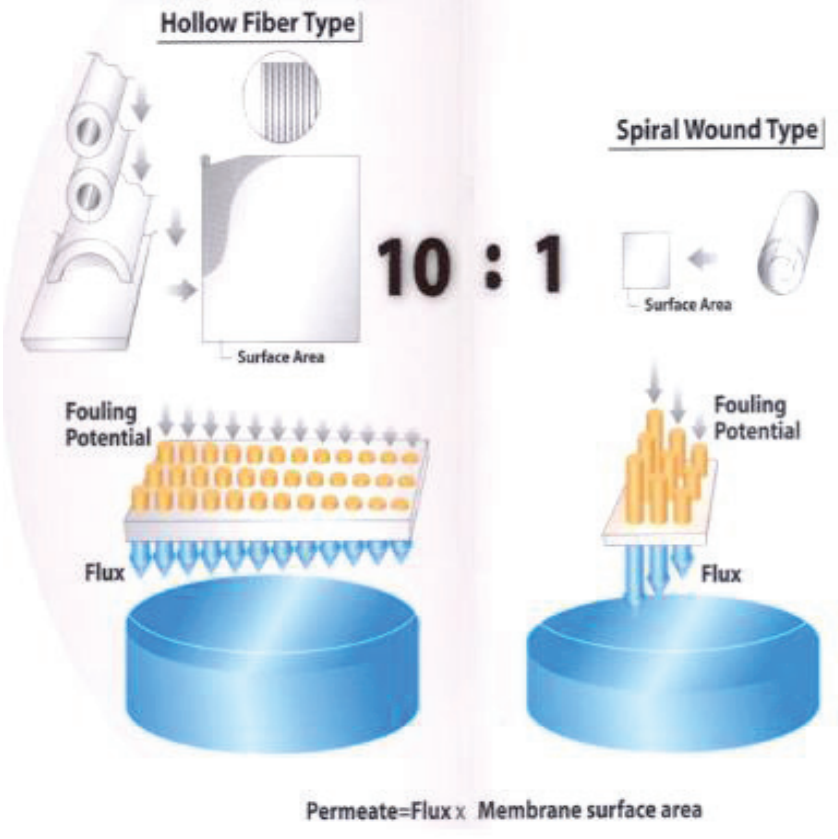
Oxidation is typically associated with the failure of PA membranes due to the weak chlorine tolerance

Source: Chesters, et.al. "Results from 99 Seawater Membrane Autopsies" (2011)

CTA HF membrane: the best solution to fouling

Large surface area

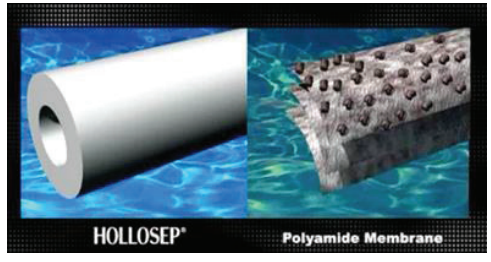
- About 10 times larger surface area than PA SW membranes
- Greater dilution of the fouling load

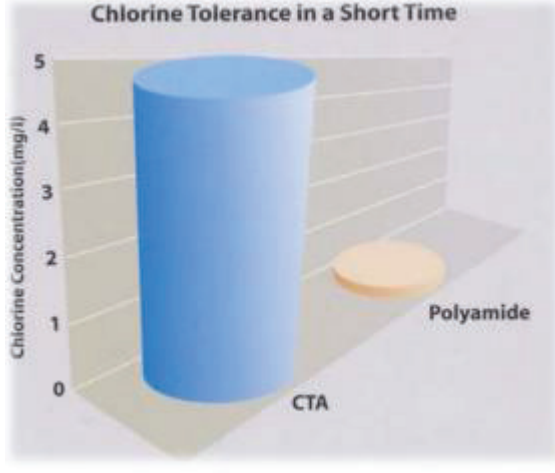


+

Superior chlorine tolerance

- CTA chemistry offers superior chlorine tolerance
- Effective and low cost biofouling control through direct chlorine injection





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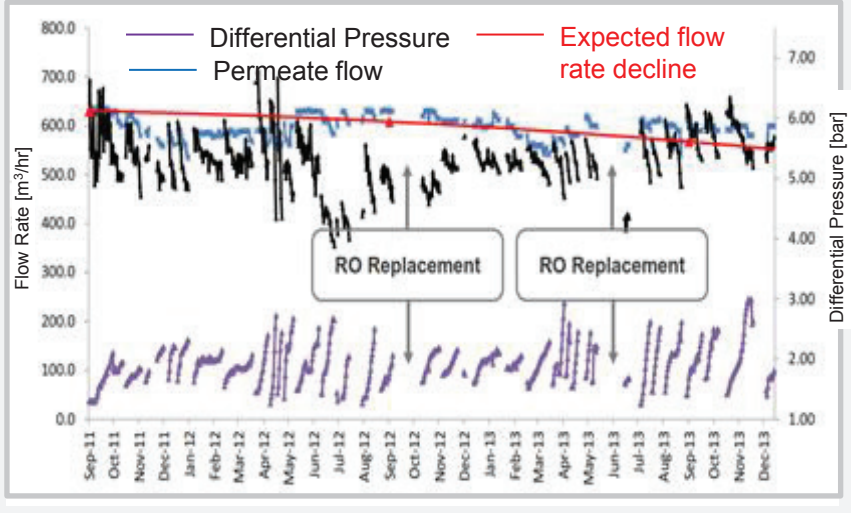
Case study: real operational data showing clear benefits

- TOYOBO's membranes have delivered more stable and reliable operation with greater protection against biofouling

PA Spiral Wound RO

Kuwait Shuwaikh SWRO (Train No.03)

137,000 m^3/d facility using DAF-UF pretreatment

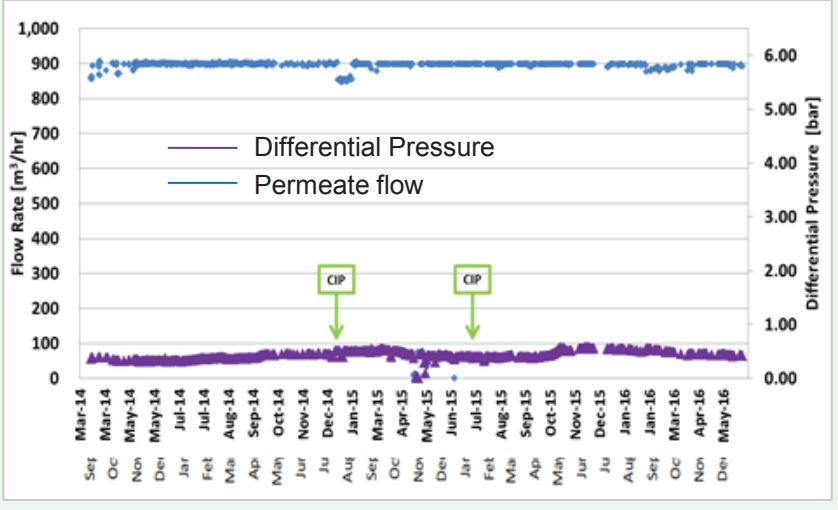


- X **Production:** Decreasing
- X **Differential Pressure:** Increased rapidly
- X **Chemical cleaning:** 24 / year
- X **Membrane replacement (%/year):** > 20

TOYOBO's CTA Hollow Fiber RO

SWCC Ras Al Khair SWRO (Train No. A8)

345,000 m^3/d SWRO facility using DAF-DMF pretreatment



- ✓ **Production:** Stable
- ✓ **Differential Pressure:** Stable
- ✓ **Chemical cleaning:** 2 / year
- ✓ **Membrane replacement (%): 0 (for 4 years)**

Source: SWCC Workshop, Al Khobar, Sep. 2014

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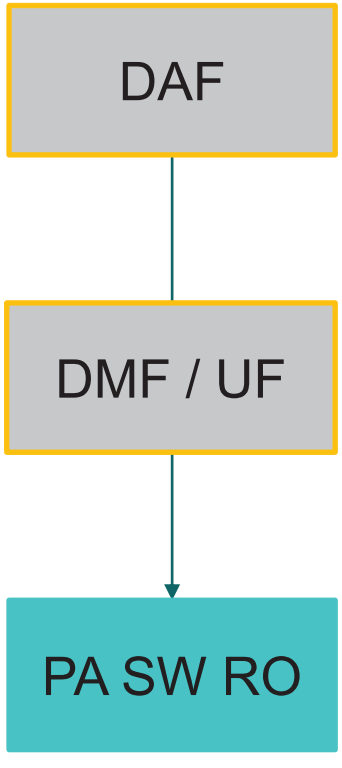
Robust membranes requiring simple pretreatment

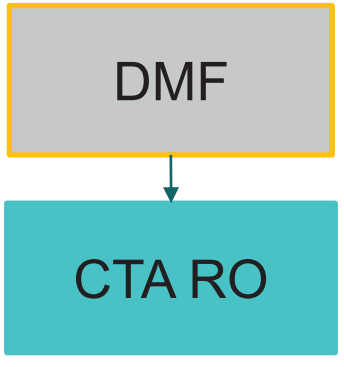
- TOYOBO's RO enables stable operations with simple pretreatment
- There is a growing need for more stable RO systems as:
  - ✓ Market shifts to stand-alone RO configurations
  - ✓ Plants become larger in size

Typical PA Spiral Wound RO process



- Require more careful pretreatment, adding cost and operational complexity

Typical TOYOBO's CTA RO process



- Conventional only with DMF for reliable and simpler operation

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Brine Concentration(BC) Membrane

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Key takeaways

1. **The Brine Concentration (BC) market is growing rapidly**, driven by a number of economical, regulatory, environmental, and social factors
2. **Conventional thermal evaporation** and **crystallization technologies are very complex** and **extremely energy-intensive**
3. Our **unique hollow-fiber CTA membrane** is capable to concentrating brines **up to 20% NaCl with less energy than existing technologies**
4. Our membrane applies solutions of equal salt concentrations to **two distinct sides** (Bore and Shell), requiring a small hydraulic pressure to push water through the membrane
5. **Using Toyobo's membranes can lead to reduced pumping requirement and deliver energy savings of 70% or more** compared to conventional thermal BC processes
6. Our membranes have unique advantages to **minimize the risks of biofouling** and ensure **stable operations**

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The global BC market drivers

There are a number of key factors leading to the increasing adoption of BC technologies globally

Tightening regulations	**Regulations are tightening and better enforced** to prevent industrial users to minimize discharge of polluted wastewater
Limited disposal sites	Some areas have **limited access to suitable brine disposal sites or facilities**, leading to a high cost of water transport
Water scarcity	Water scarcity is intensifying in various parts of the world, **requiring industries to reuse more water**
Increasing industrialization	Increasing industrialization especially in developing countries resulting in **larger volumes of 'difficult to treat' wastewater residuals**
Reputation and public acceptance	Many international companies are trying to "go green" to **ensure public acceptance to their businesses**

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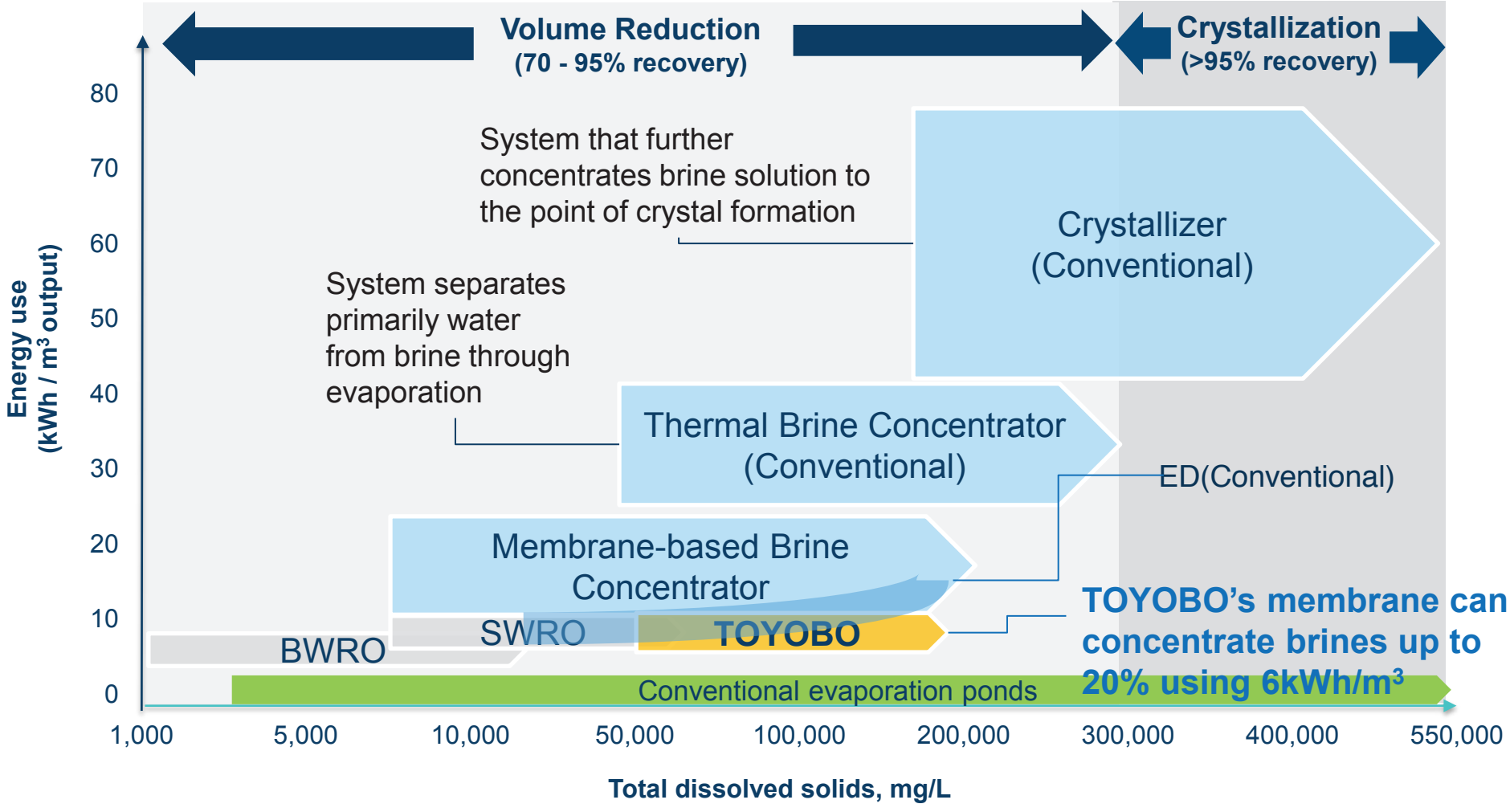
Membranes are energy efficient BC technology

Energy intensities of BC/ ZLD processes



Note: Low-grade waste heat is not included in the energy consumption
Sources: GWI, Amane Advisors

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Applications of TOYOBO's membranes

TOYOBO's BC hollow fiber membrane process can:

1. **Reduce CAPEX and OPEX** in thermal evaporator and crystallizer ZLD systems
2. **Minimize the volumes** of difficult-to-treat wastewaters
3. **Deliver higher recovery** for desalination
4. **Increase wastewater reuse rates** for various industries
5. **Recover valuables** from wastewater

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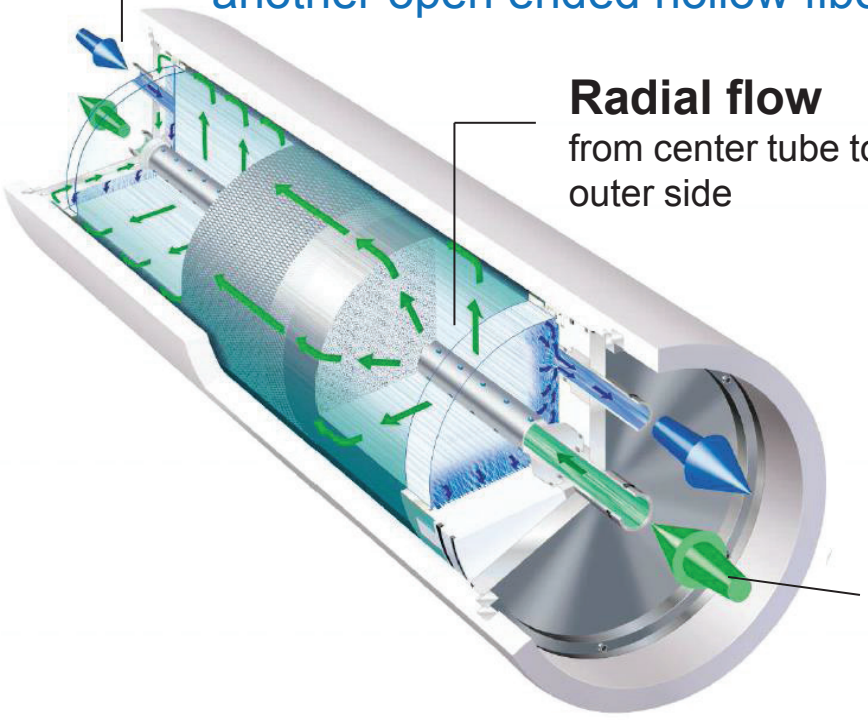
Toyobo's hollow-fiber CTA membrane

Membrane module structure

Bore side (dilute solution)
Flow into module from one open ended hollow fibers and out from another open ended hollow fibers

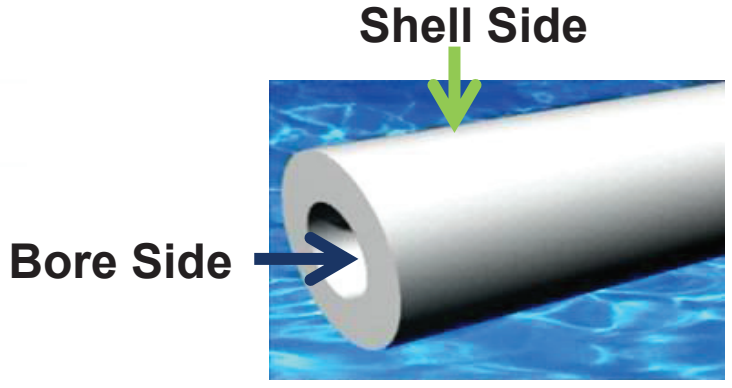


Radial flow
from center tube to outer side

Shell side (concentrated solution)
Flow into center tube and flow uniformly and radially between hollow fibers, thanks to our cross wound configuration

Product specification

- **Material:** Cellulose Triacetate (CTA)
- **Diameter:** 280 mm
- **Length:** 1.4m / 2.0m
- **Surface area:** 600m^2/ 900m^2



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Advantages of TOYOBO's BC membranes

TOYOBO's membranes enable more stable, effective and energy efficient Brine Concentration

- ✓ **Only supplier of Hollow Fiber CTA membranes**
- ✓ **Proven commercial applications** in key industries
- ✓ **Capable of achieving higher concentration levels** (20% NaCl) using less energy (7MPa) than conventional RO (10 – 12% NaCl using 10MPa)
- ✓ **>70% energy savings** compared to a typical thermal BC process, and **>40%** compared to FO-based BC process
- ✓ **Chlorine-tolerant membrane material** allowing direct chlorine injection to minimise biological fouling
- ✓ **No need for draw solution** like Forward Osmosis
- ✓ **High membrane surface area** for efficient operations and reduced fouling
- ✓ **Greater pressure resistance**, enabling applications for various usages

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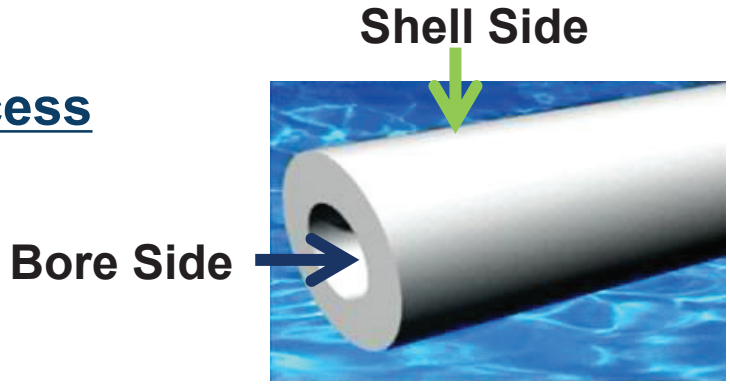
Toyobo's BC process mechanism

The same concentrated solutions are applied to both shell side and bore side and a certain pressure is applied to one side, **the same osmotic pressure difference as applied hydraulic pressure** can be obtained

Higher Concentration rate than RO membrane is available

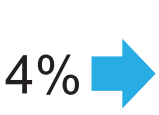
Concept of Toyobo's BC process

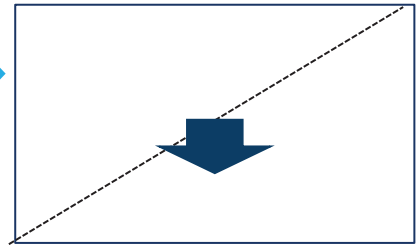
(% in NaCl)

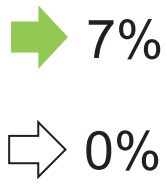


RO

Pressure:7MPa

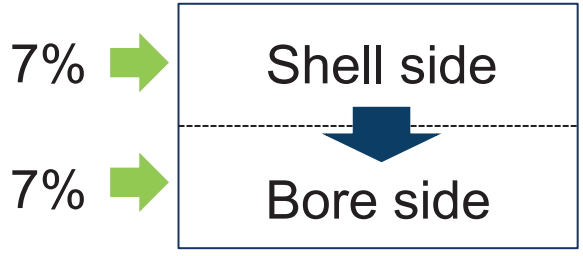






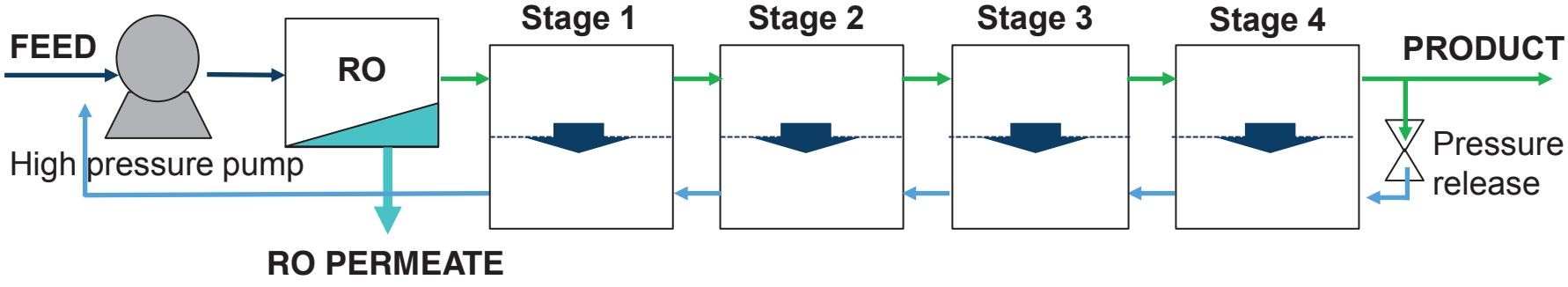
Permeate

Pressure:7MPa

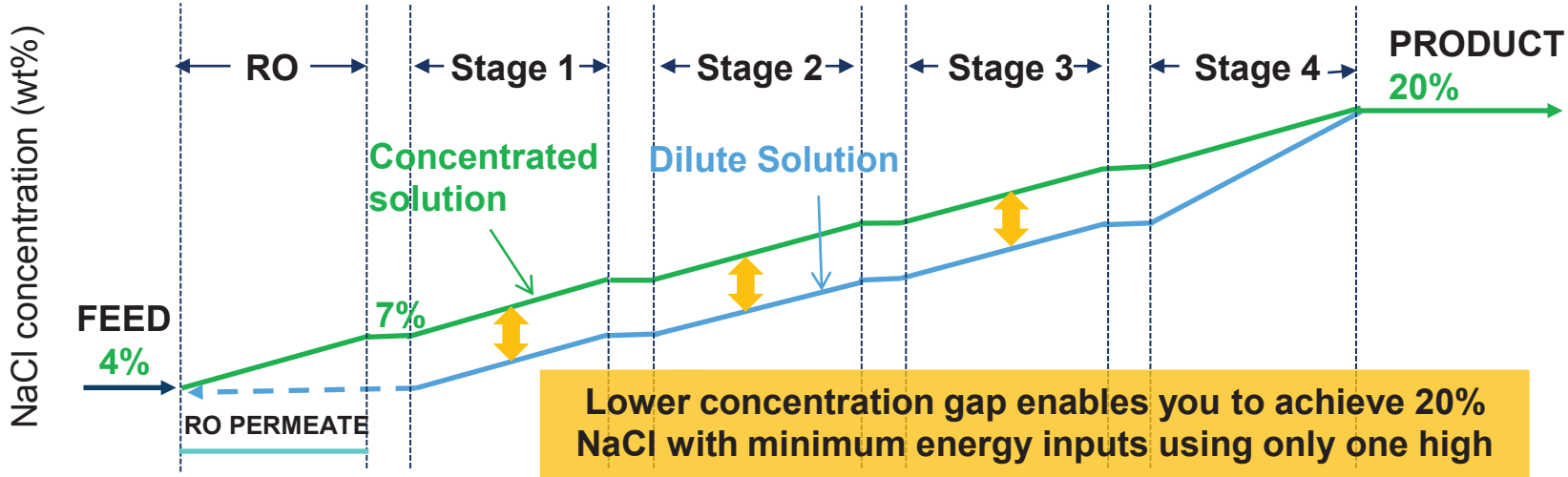


Energy-efficient process using only one high pressure pump

Toyobo BC Process



Concentration change in series arrangement



Lower concentration gap enables you to achieve 20% NaCl with minimum energy inputs using only one high pressure pump

NOTE:
Higher concentration and continuous operation are available;
The number of stage varies depending on required concentration.

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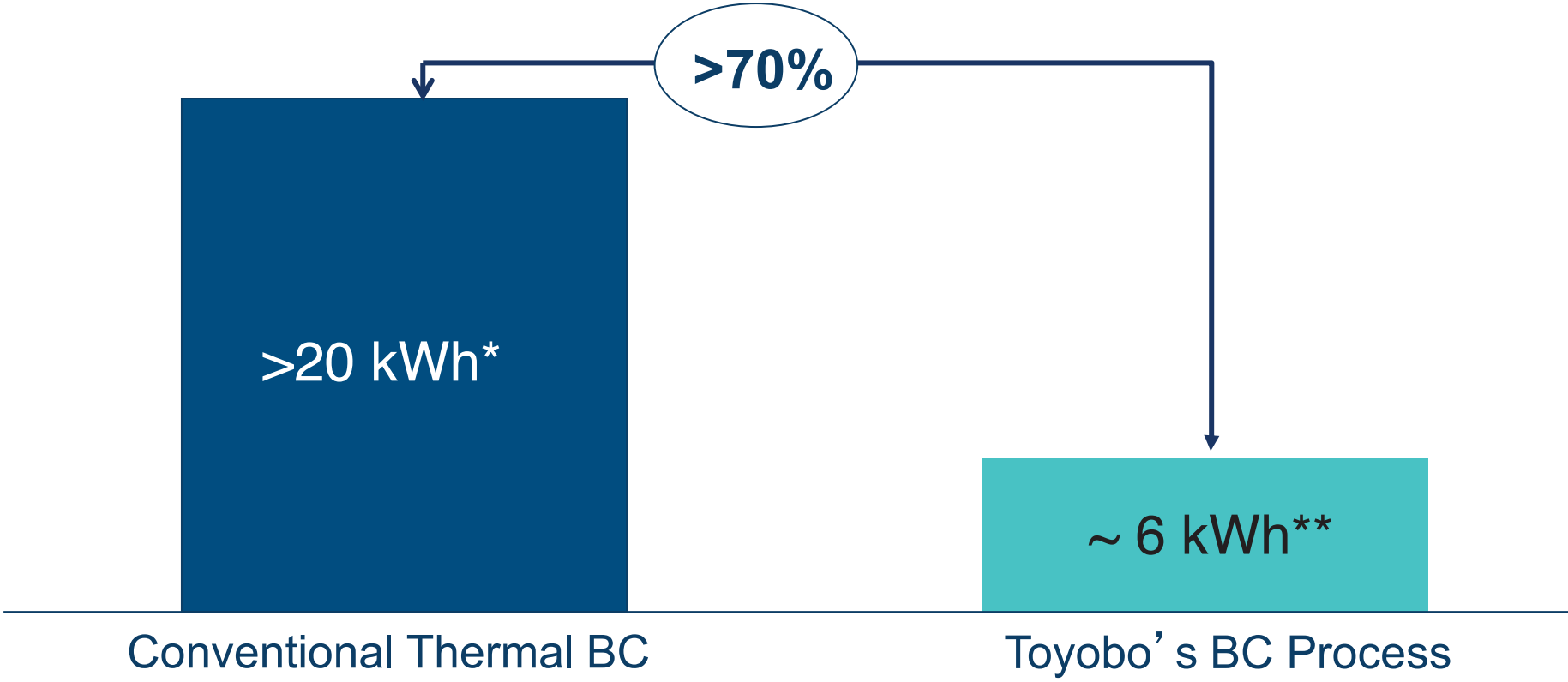
Superior Energy Savings

Reported typical energy requirement for m^3 of product water to achieve 20% NaCl



NOTE:

**Literature review and expert inputs on a typical energy requirement to achieve NaCl 20%*

***TOYOBO's process is based on NaCl 4% feed solution at a capacity of 100m^3/day, operated at the pressure of 7MPa to achieve NaCl 20%*

Low-grade waste heat is not included

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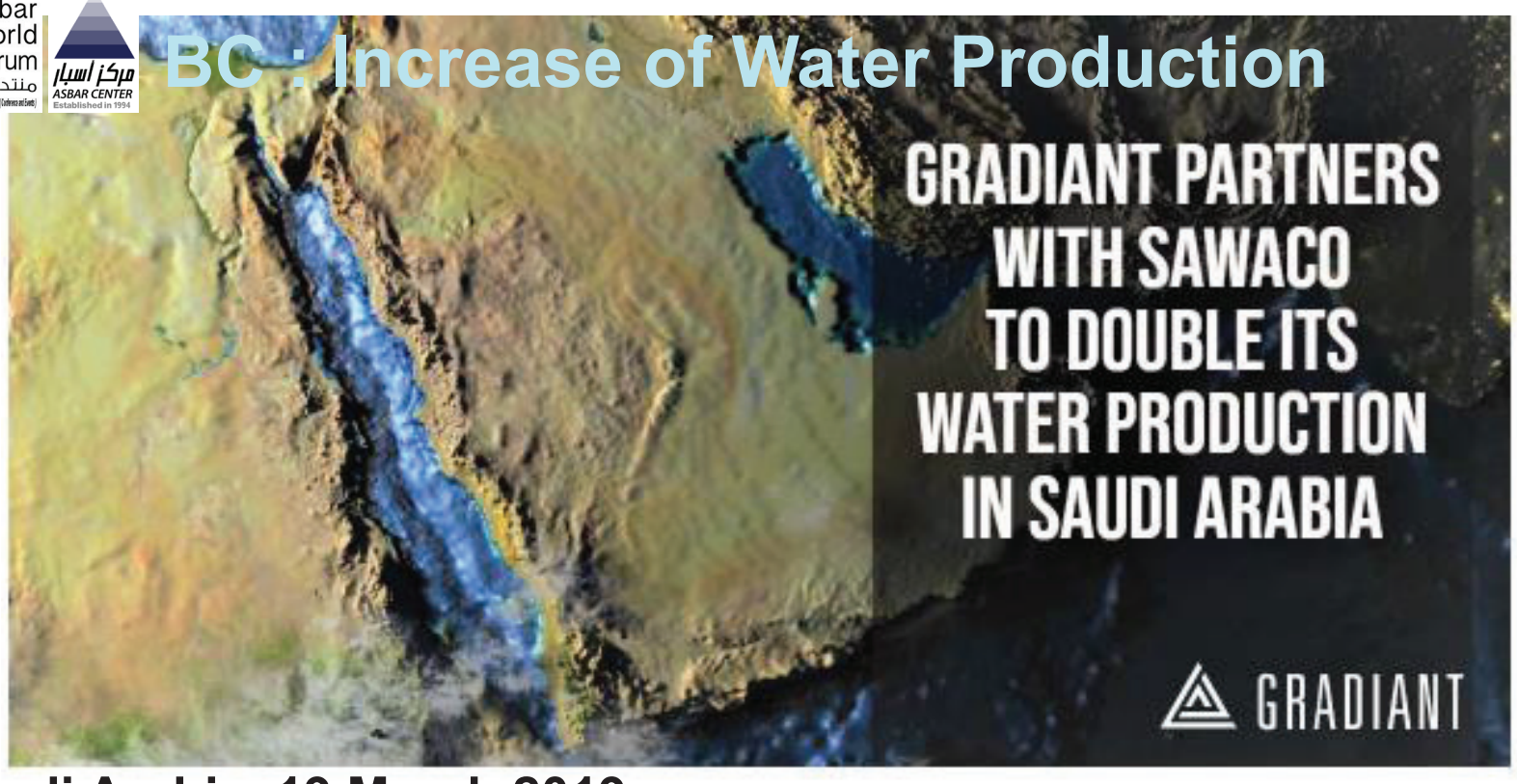
BC : Increase of Water Production



Saudi Arabia, 19 March 2019

Gradiant Partners with Saudi Arabia's SAWACO to Double Production of Fresh Water with Counter-Flow Reverse Osmosis Process

- *SAWACO, Saudi Arabia's largest supplier of un-bottled potable water, owns and operates desalination plants that produce over 30,000 cubic meters per day (m^3/d) in the kingdom's western region.*
- *Increased scarcity of fresh water resources has made it essential to maximize the water production efficiency from the kingdom's desalination and water reclamation plants.*
- *Gradiant's Counter-Flow Reverse Osmosis (CFRO™) technology can double the fresh water produced by SAWACO's existing desalination operations by effectively extracting fresh water i reverse osmosis (RO) reject brine, concentrating seawater to over 20% salinity.*

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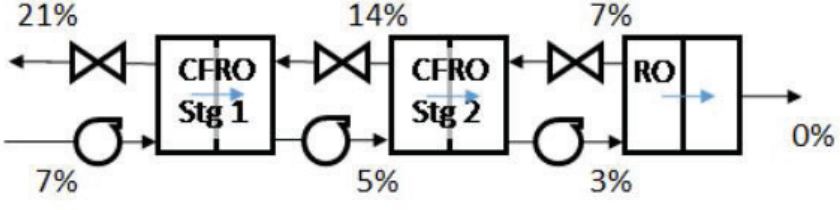
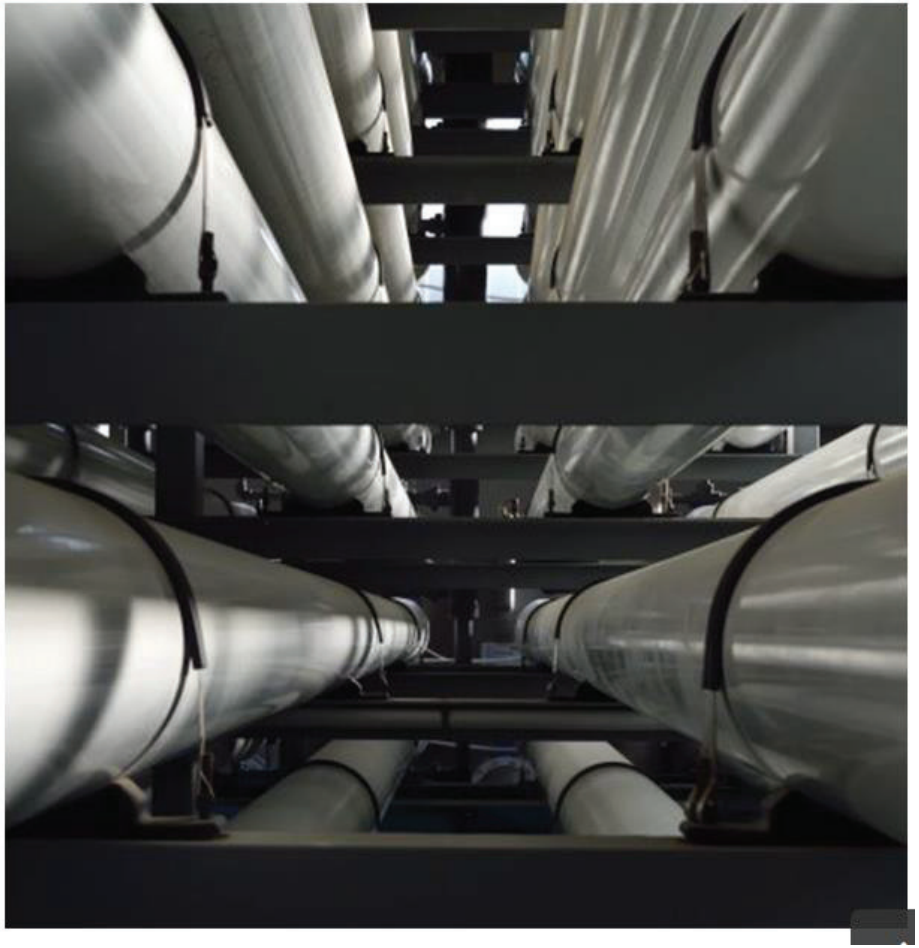
The Technology

In the CFRO process, a dilute saline solution is introduced to the product side of the membrane to reduce the osmotic pressure barrier and thereby reduce the required feed pressure. Brine is cascaded through multiple CFRO stages, concentrating it to saturation for disposal or crystallization while producing a purified product water stream for beneficial reuse. A cascade of CFRO units arranged to enable step-wise concentration of brine is illustrated in the following video and figure: CFRO overview



The CFRO process uses less than half the energy of the most efficient evaporator and costs about half as much.



Saline Water Conversion Corporation (SWCC) Has Signed Mou with Hyrec Technologies Ltd.

Saudi Arabia's Saline Water Conversion Corporation (SWCC) and Hyrec Technologies Ltd. signed a Memorandum of Understanding to deploy Hyrec's Osmotically Assisted Reverse Osmosis (OARO) technology for Zero Liquid Discharge desalination in the Kingdom of Saudi Arabia.

The Memorandum of Understanding was signed at the 2019 Saudi Water Forum in Riyadh by Eng. Ali bin Abdulrahman al Hazmi, the Governor of SWCC, and Hyrec's CEO Dr. Basel Abu Shark.

Summary

1. Our membrane's unique configuration allows brine concentration up to 20% NaCl using far less energy than conventional thermal and membrane-based technologies

2. Our hollow-fiber CTA membranes have unique features of high surface areas and superior chlorine tolerance to enable more rigorous membrane cleaning and stable operation with minimum biofouling

3. Toyobo's BC membranes are commercially proven and can be applied for a wide range of industries

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Forward Osmosis (FO)

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Key Takeaways

1. Toyobo provides **a unique Cellulose Triacetate Forward Osmosis (FO) membrane in a hollow fiber configuration**

2. Applicable to **Seawater Desalination** and **energy generation from Pressure Retarded Osmosis (PRO)**

3. **Unique features to ensure high salt separation efficiency** with minimum pressure loss and biofouling

4. **A number of on-going pilot projects for Seawater Desalination** in various countries in corporation with renowned global companies

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Application of Forward Osmosis

Toyobo's FO membranes can be used in two applications

A **Efficient seawater desalination**

Extensive pre-treatment, high pressure pump and piping are not necessary

B **Pressure retarded osmosis (PRO)**

Stable power generation by using the concentration difference between two solutions while reducing brine discharge

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Advantages of FO desalination and PRO

1 FO Seawater Desalination

- FO is one of the **emerging membrane technologies in desalination,** which relies on natural osmosis
- Key advantages are:
  - ✓ Less fouling potential
  - ✓ No or little pretreatment and chemicals
  - ✓ No high pressure pumps
- FO is gaining increasing interest as **an efficient alternative for RO**

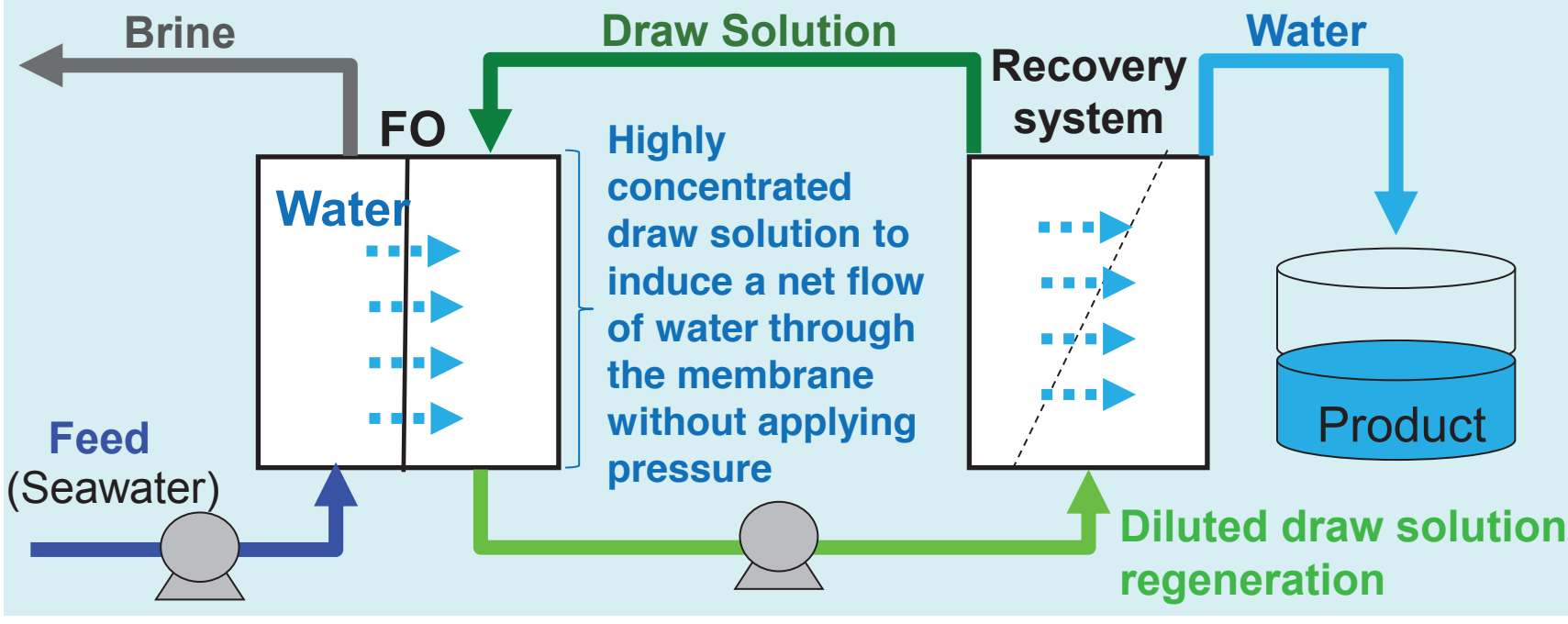
2 PRO Power Generation

- There is **an enormous potential of harvesting renewable energy** from salinity gradients using PRO
- Key advantages are:
  - ✓ No heat emission
  - ✓ No chemical reaction
  - ✓ Stable under any weather condition
- Power generation by PRO has already been considered applicable to **commercial-scale plant**

Mechanism Desalination Process using FO

1 FO Desalination Process Flow

- FO uses **osmotic pressure gradient** to separate water from dissolved solutes efficiently with:
  - ✓ No or little pre-treatment
  - ✓ No high pressure pumps
  - ✓ No extensive piping



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Unique value propositions

1 Higher surface area for efficient operations

- X10 area compared to Flat Sheet membranes

2 Superior biofouling control

- Chlorine-tolerant membrane material

3 Reliable and stable operation

- Less frequent chemical cleaning
- Less frequent membrane replacement
- Higher plant availability

4 Uniform flow of feed and draw solution

- Less channeling and pressure loss

5 Small wall thickness

- Larger effective osmotic pressure difference

6 High salt rejection

- Low back diffusion

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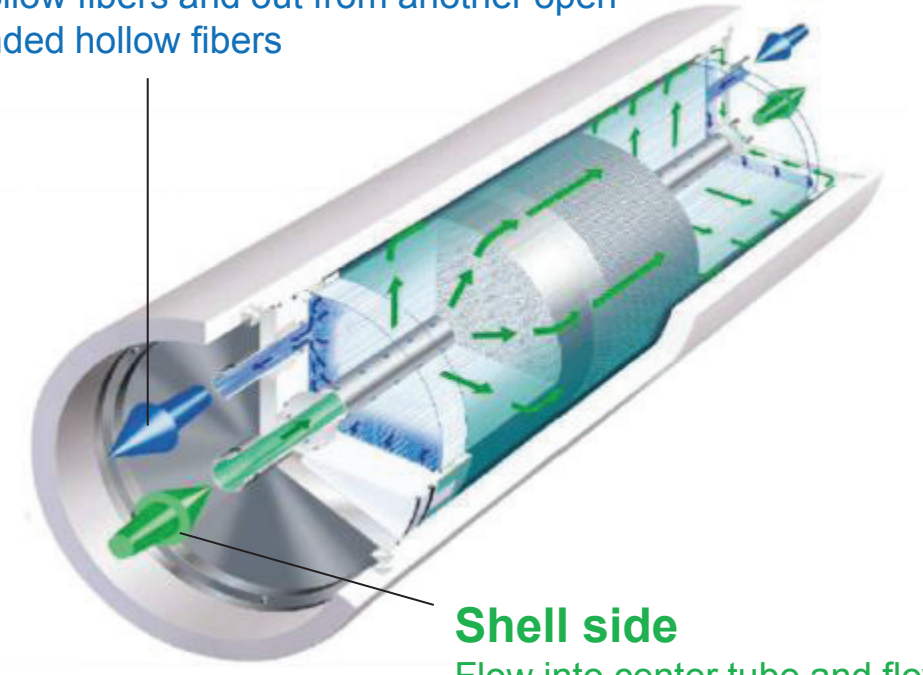
TOYOBO's FO Membrane Element and Module

Structure of Toyobo's FO membrane

Bore side

Flow into module from one open ended hollow fibers and out from another open ended hollow fibers



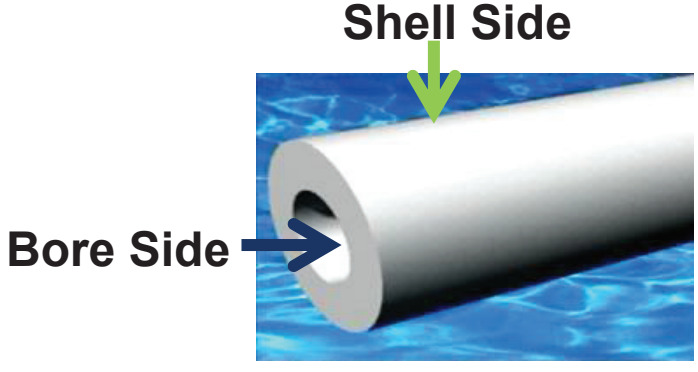
Shell side

Flow into center tube and flow uniformly and radially between hollow fibers

Model: 10 inch (HP10) FO element

Diameter: 280mm

Length: 1.4m Length



- Draw solution and feed solutions are applied to either side of the membrane module, depending on the viscosities

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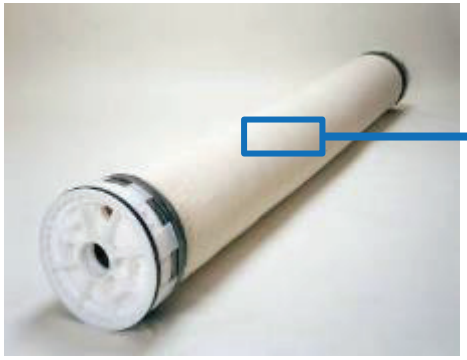
Unique Cross-Wound Configuration

Unique Cross-Wound Configuration



Hundreds of thousands of hollow-fibers are wound into the module construction by Toyobo's cross winding technique

Key benefits

- ✓ Uniform water flow with minimum pressure loss
- ✓ High surface area with increased fouling resistance
- ✓ Excellent volumetric efficiency

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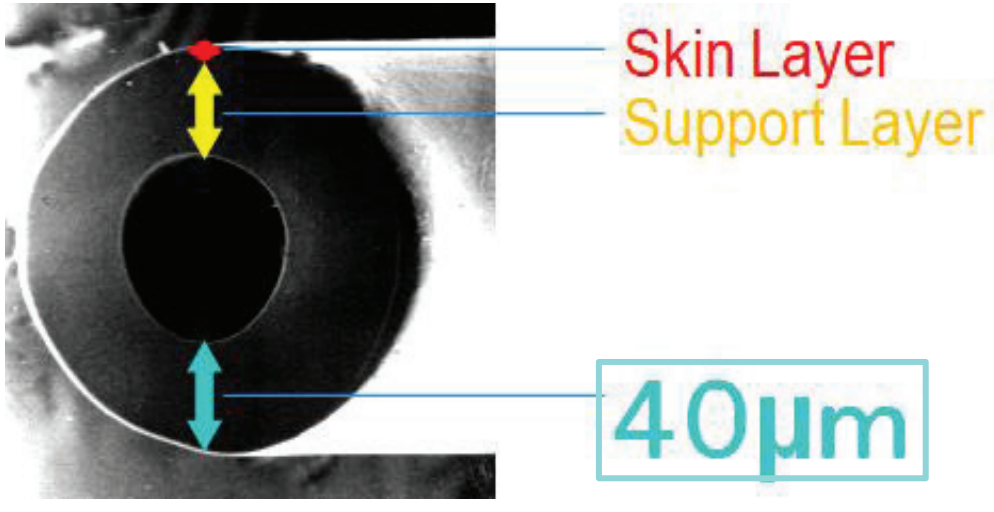
Thinner membrane diving a greater pressure resistance

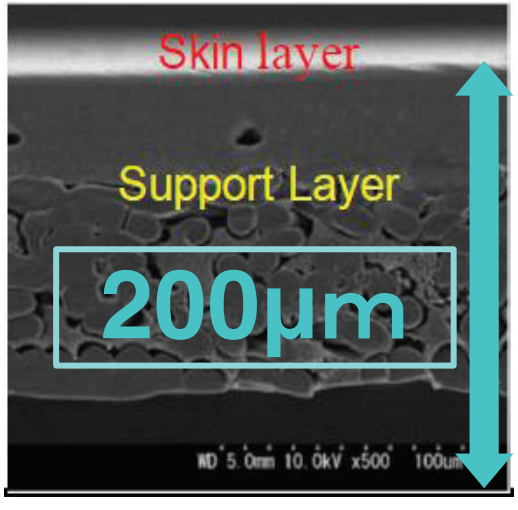
Small wall thickness to deliver **a larger effective osmotic pressure difference** for efficient operation

Cross Section of Hollow Fiber and Flat Sheet Membranes

Toyobo's hollow fiber membrane



Flat Sheet Membrane



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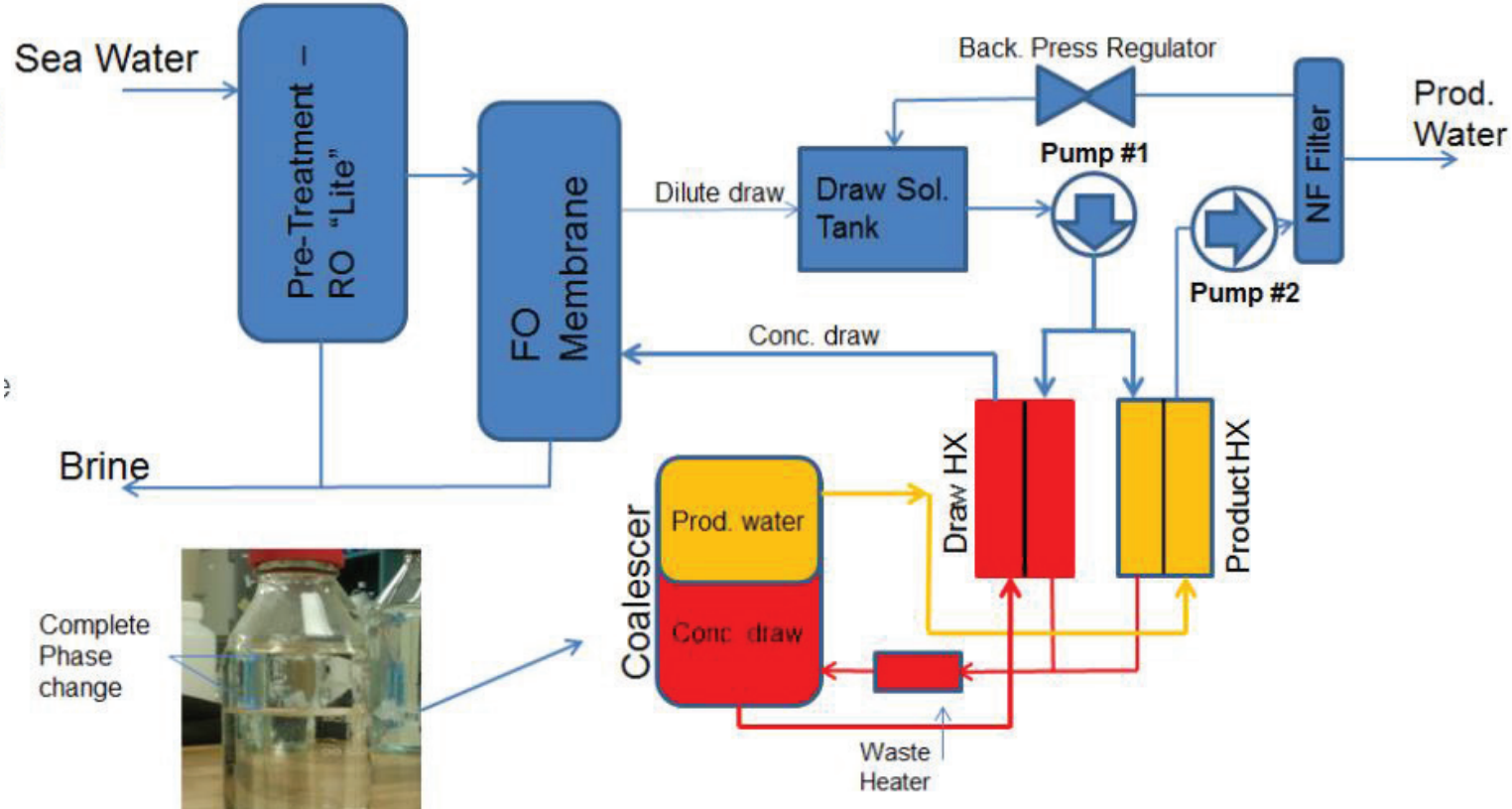

1. The seawater is pretreated by an ultrafiltration process, and pumped to the feed side of the FO membrane.

2. The Brine exits the FO membrane and is discharged through a pipe to a drain at atmospheric pressure.

3. The osmotic pressure gradient is used to induce a net flow of water through the membrane into the draw, thus effectively concentrating the feed.

4. Draw solution, diluted by the passage of water across the FO membrane, is heated by the heat exchangers prior to separation

5. The water is separated from the draw solution by a coalescer.

6. The water is pumped to the polishing nanofilter and then to a holding tank for remineralization.

Benefits

Affordable Water

Trevi FO system operates under very low pressure <60 psi, thereby reducing membrane fouling and the need for expensive piping.

Green Chemistry

Draw solution lifetime is to be determined but is expected to be greater than 2 years. The draw solution is biodegradable and non-toxic in aquatic environments.

Sustainable Design

The process has the ability to desalinate ocean water at 1/8th the electrical energy of current RO systems (0.5 kWh/m3

Trevi Systems of Sonoma County part of $2M Hawaii solar desalination research

Trevi Systems, a forward-osmosis water-desalinization system provider, will be part of a project in Hawaii to lower the cost of turning seawater into fresh water under a $2 million award from the U.S.Department of Energy, Solar Energy Technologies Office.

The funding was awarded to Natural Energy Laboratory of Hawaii Authority (NELHA). The system will tap the sun to power the process of desalinization.

The Hawaii Desal Project is focused on advancing the viability of solar-powered forward osmosis by reducing the water's unit cost 40 percent less than current state-of-the art technology.

February 23, 2019

Hawaii considers special bonds for solar desalination

Hawaii Island is looking to introduce new special purpose bonds to build and operate solar-powered desalination plants.

The Department of Budget and Finance could issue up to $100 million in bonds to support construction of two or more desalination plants which use 100 per cent renewable solar energy. The special-purpose bonds can be made available for public-interest projects and are for purchase by private investors.

The funding could be used to support construction of a 6,000 m3/d plant by Trevi systems and Kona Coast Water.

Summary

1. Our FO membranes can be applied for efficient Seawater Desalination and energy generation from Pressure Retarded Osmosis
2. Our membranes have distinctive advantages to minimize the risks of biofouling and ensure stable operations
3. Our membrane has been used in a prototype PRO through a national to demonstrate the potential to deliver 10% energy savings in a large-scale SWRO facility

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Thermal (Evaporation) or Membrane

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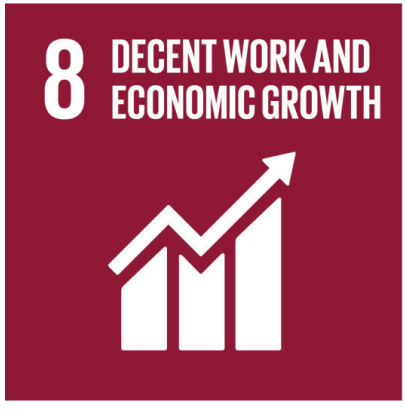
Toyobo and AJMC will make every effort to achieve Saudi Vision 2030 and SDGs.

We commit to contribute not only to water technology but also to the development of Saudi society by transferring the most advanced technology.



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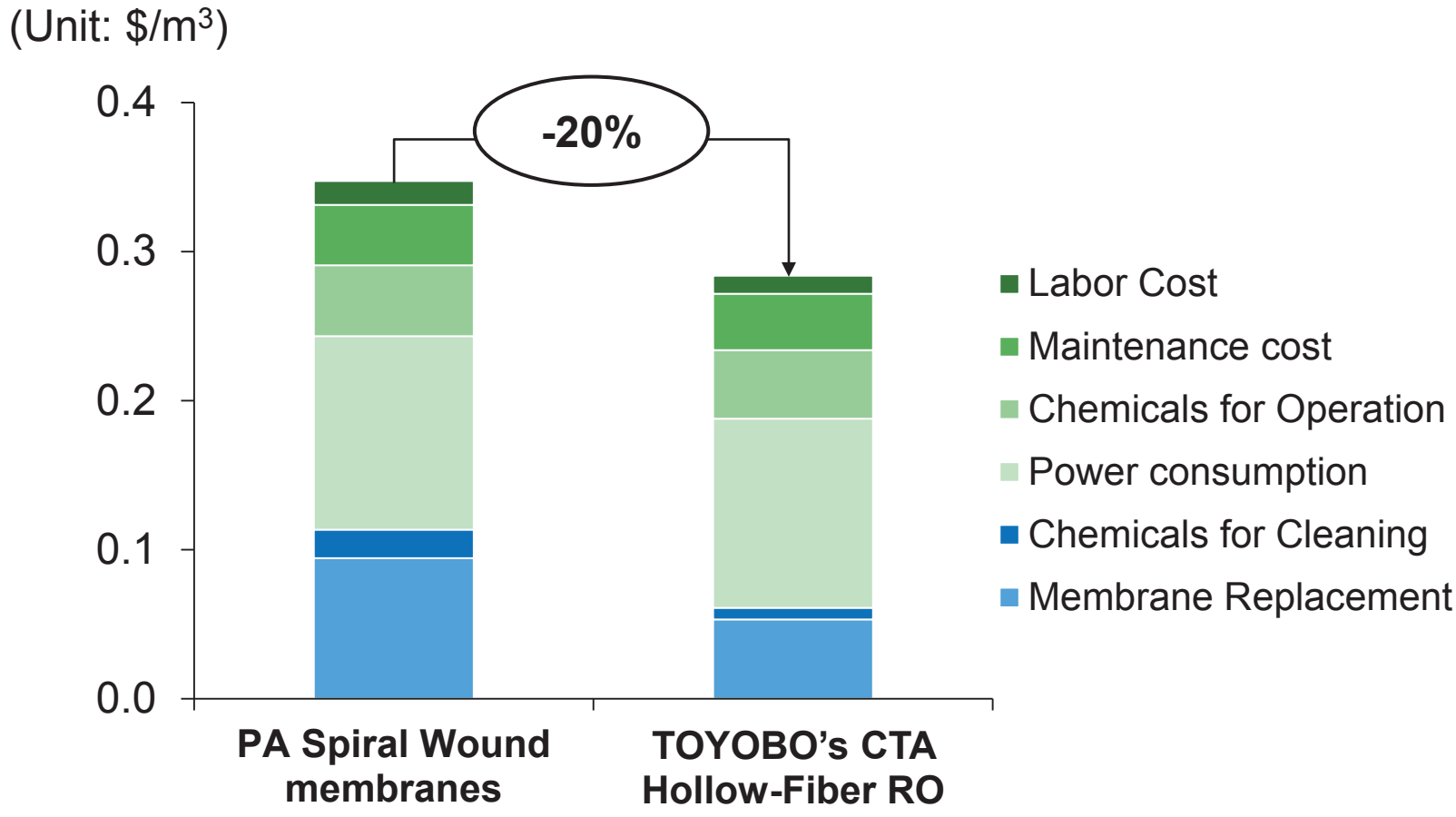
Appendix 1 :Robust technology leading to 20% OPEX reduction

OPEX comparison: TOYOBO vs PA Spiral Wound RO



NOTE: Based on the operational data for an Arabian Gulf Seawater RO plant with the capacity >50,000 m^3/d

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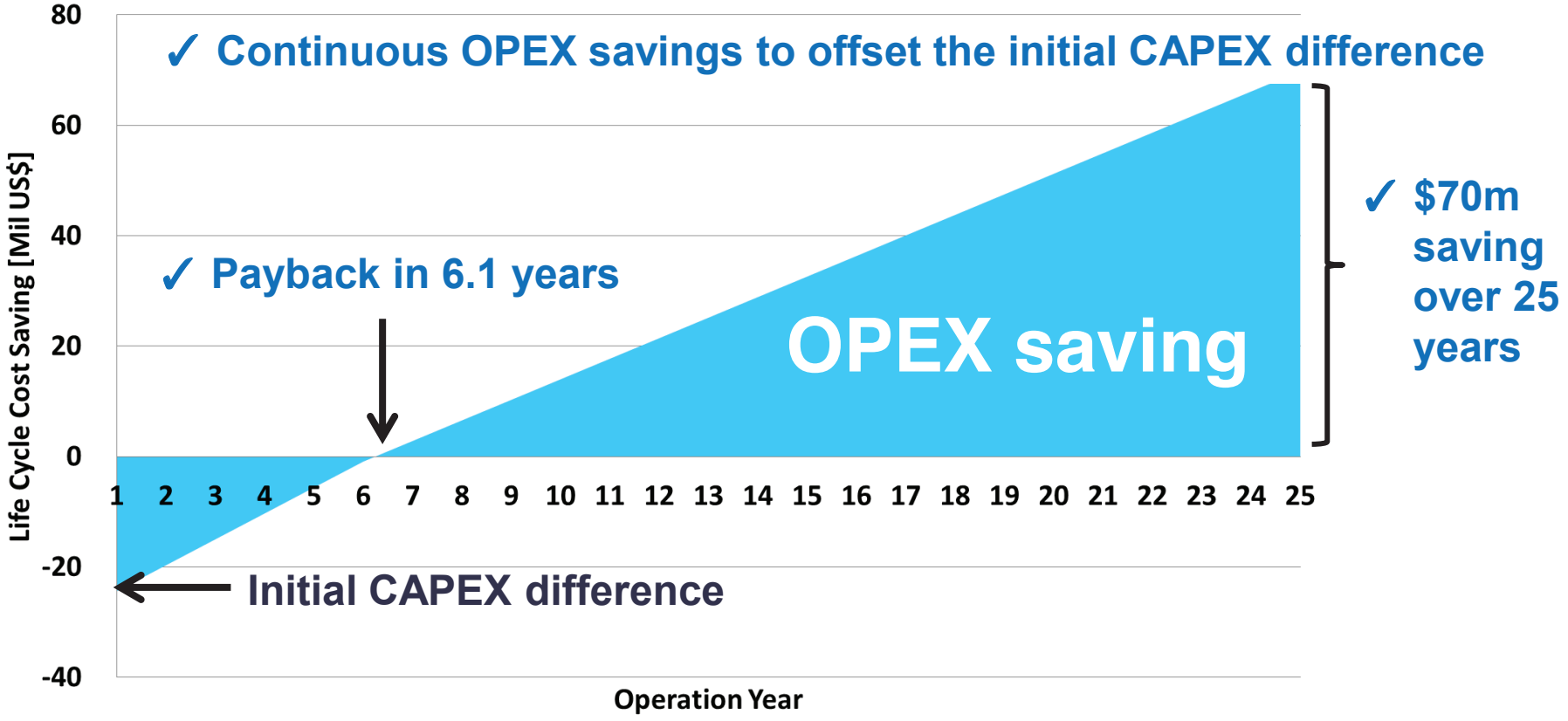
Appendix 2 :Significant Life Cycle Cost savings

Life Cycle Cost savings



NOTE on assumptions used:
CAPEX in a large new SWRO plant with 440,000m³/day capacity, inclusive of pretreatment cost
OPEX saving: 3.9 million USD/year based on TOYOBO's experience, inclusive of chemicals, energy, labour, and replacement membranes

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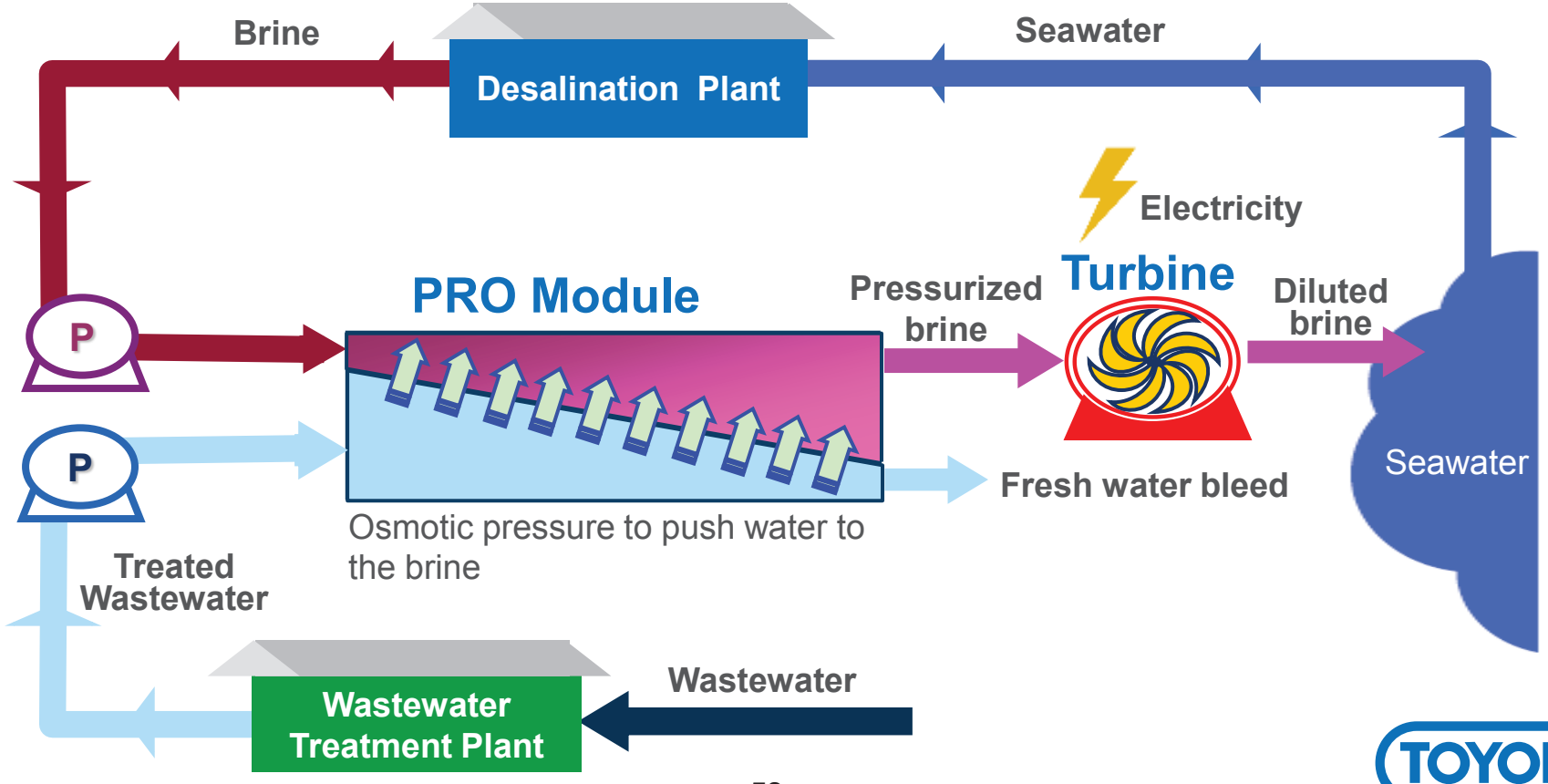
Appendix 3 : Mechanism PRO using FO

PRO process flow

- **Osmotic power** is generated using the movement of water molecules through a semi-permeable membrane into the concentrated brine solution, which generates pressurized brine allowing energy to be recovered using a turbine



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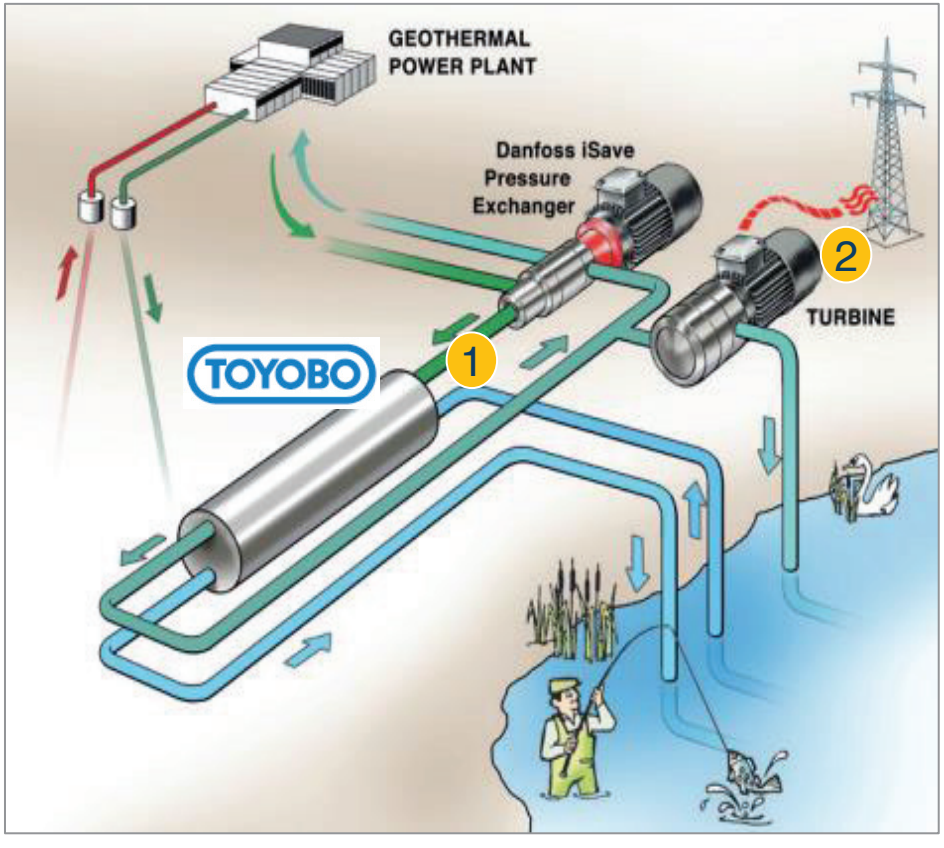
Appendix 4 : PRO pilot using Geothermal Brine

Geothermal osmotic power generation pilot (Sønderborg, Denmark)

- Collaboration with Saltpower (Denmark) in geothermal osmotic power generation pilot
- Utilizes the osmotic pressure from hyper-saline water from geothermal wells to generate power

1. Geothermal water containing high salinity (>10% NaCl) used as feed source
2. Water flow across the membrane builds up pressure, and by passing the pressurised water through a turbine to generate electricity



Potential Levelized cost of renewable energy for 1MW system

	Wind	Solar	Salt
Total investment (€m)	1.5	1	1
Energy production (MWh / year)	2,000	1,000	8,000
Cost of Renewable Energy (€/kWh)	0.1	0.1	0.012

Source: SaltPower (2016) http://ipaper.ipapercms.dk/esbenthomsen/saltpower/

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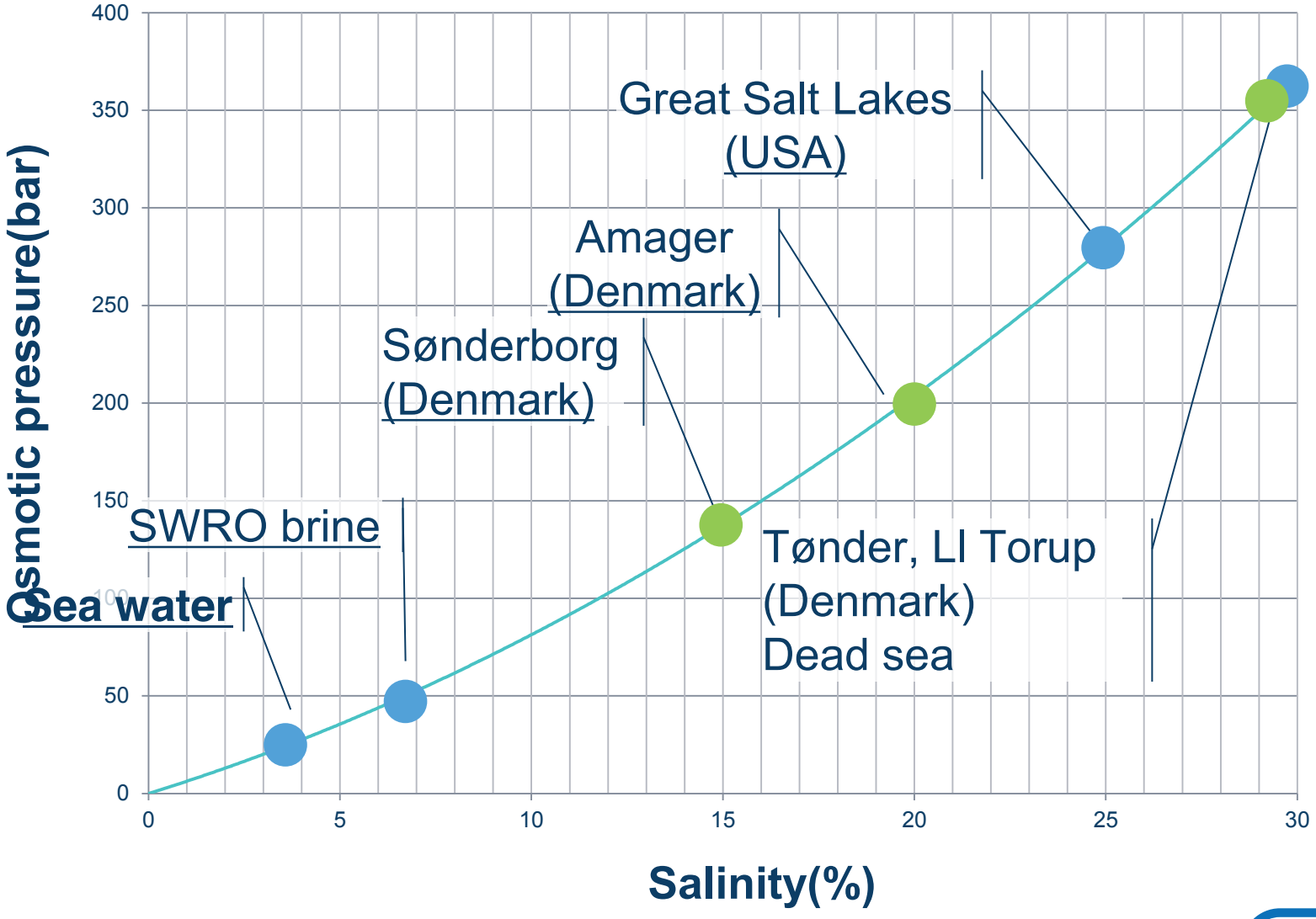
Appendix 5: PRO pilot using Geothermal Brine

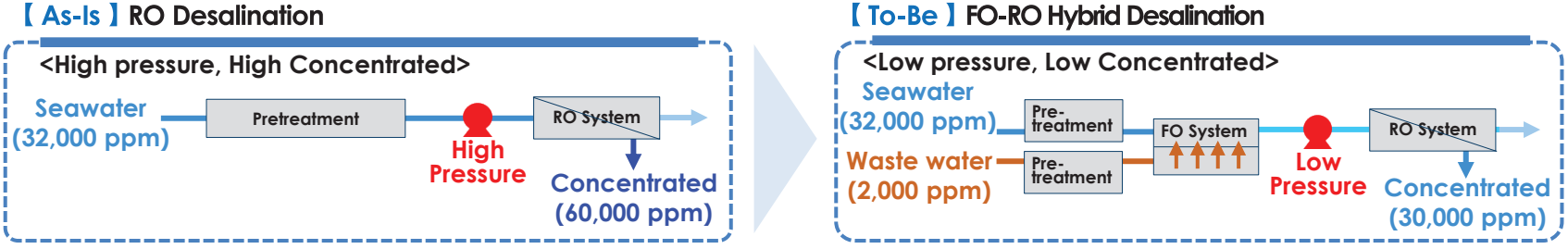


High salinity enables high pressure operation.

Appendix 6: Low Energy & Low Impact Desalination technology

☐ FO-RO Hybrid Desalination technology

- Reduction of power cost by low-pressure desalination
- Reduction of waste water discharge in industrial complex
- Low Impact to coast by RO concentrate



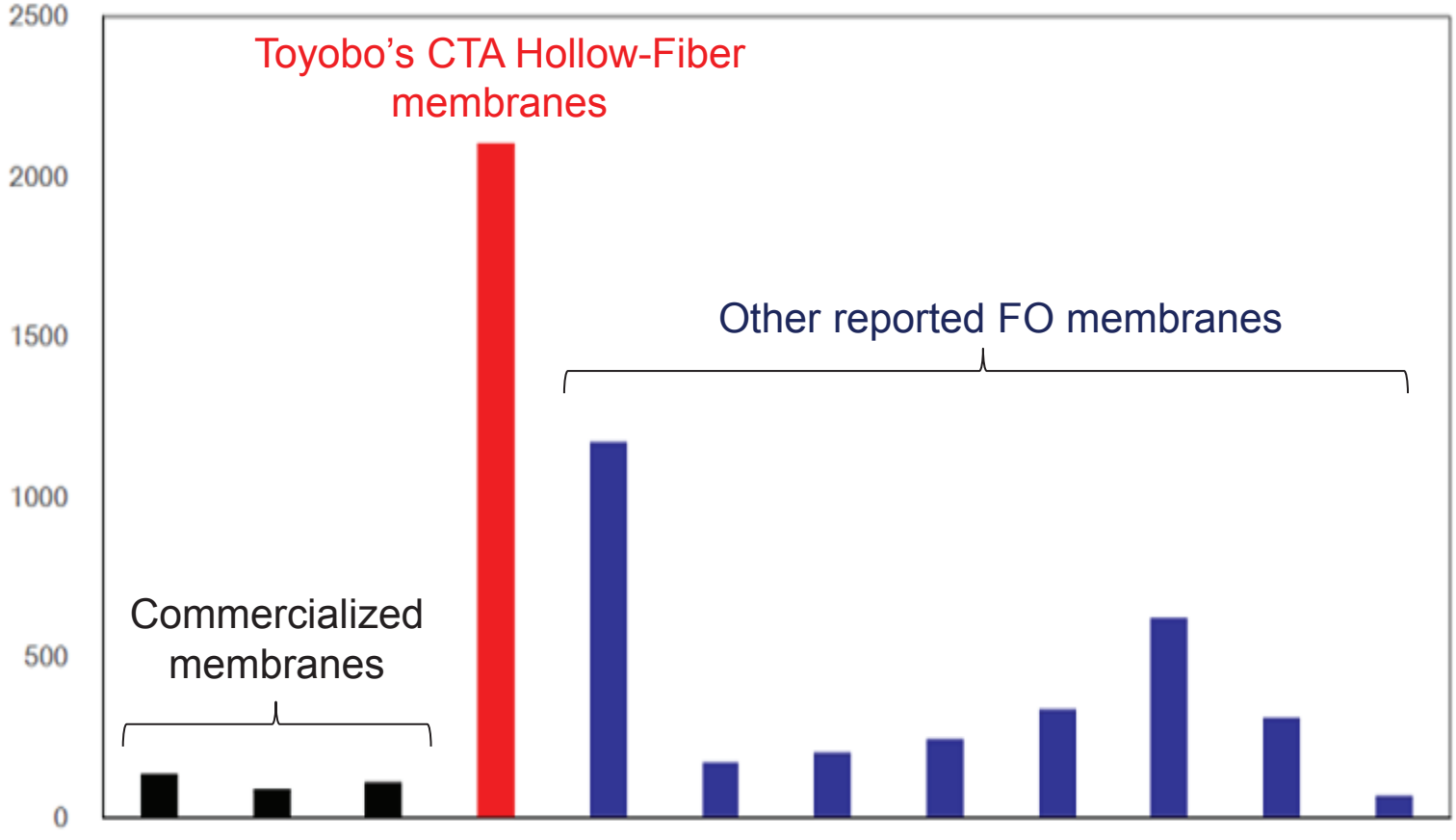
☐ Development for design of FO-RO desalination system and operating technology

- Gwangyang-si, South Korea)

FO Hollow fiber module
(100㎥/day)

Appendix 7 : Higher salt separation efficiency with low salt leakage

Specific water/salt flux (Jw/Js) Comparison



Source: M. Yasukawa, et.al,, ICOM (2014)

Note: Feed solution: deionized water; Draw solution: 0.6M NaCl solution; Temperature: 298K