International Conference on Desalination and Sustainability

1 - 2 March 2012

International Desalination Association

IDA

الجمعية المغربية للأغشية وتحلية المياه

SMMD

Société Marocaine des Membranes et de Dessalement

in cooperation with

ONEP

supported by

EDS

Casablanca 2012

MOROCCO

The Future of Membranes in Seawater Desalination

Antonio Casañas

MOR12-003

History overview

1845-1960
Invention & Membrane focus

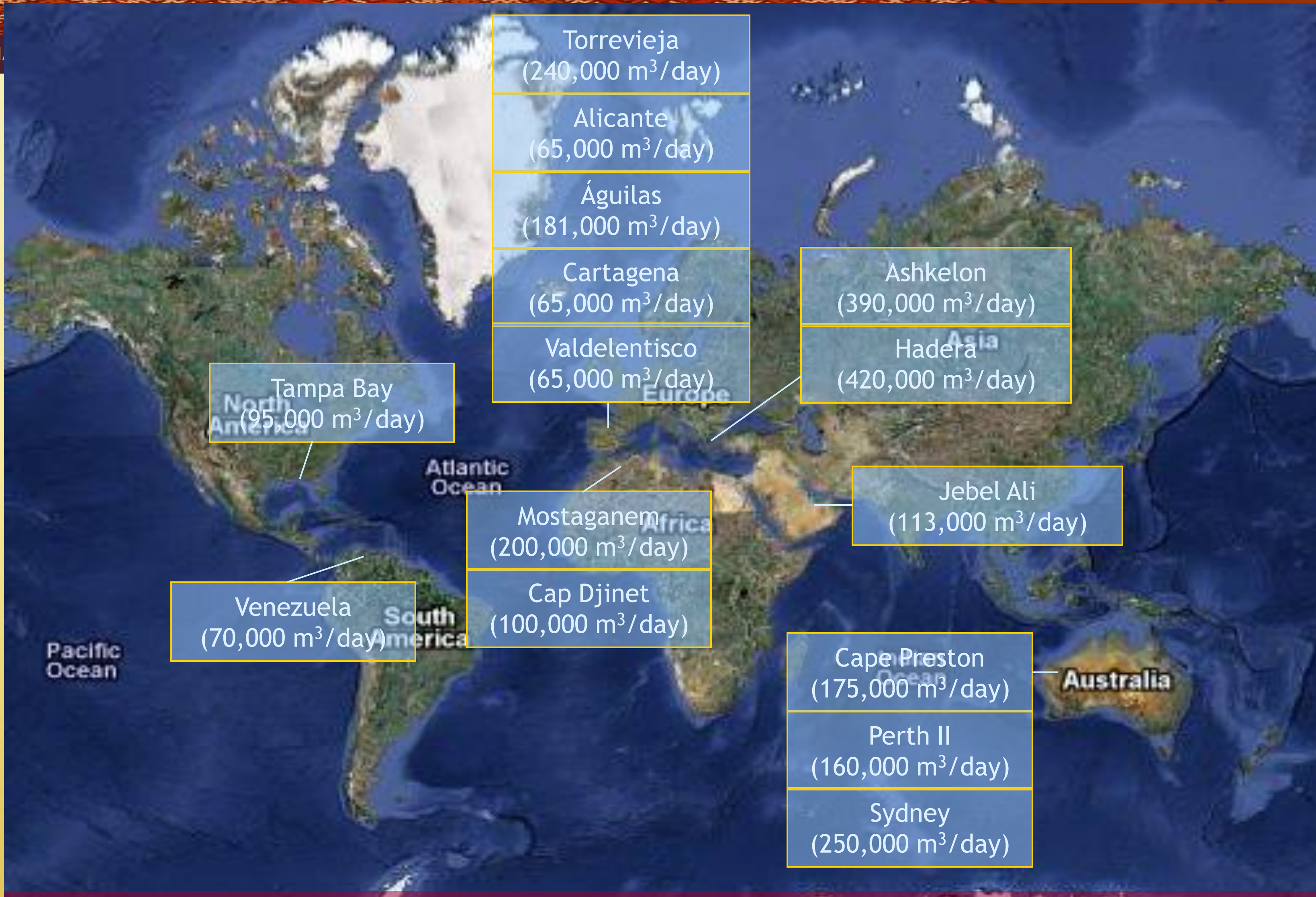
- Schönbein Nitrocellulose, Fick diffusion
- Ried & Breton: RO demo
- Loeb & Sourirajan assymetric cellulose membrane

1960s-1980s
Membrane & module diversity

- Dow, Toyobo: cellulose acetate HFF modules
- Dupont aramid HFF modules
- Fluid Systems, North Star (later Dow): polyamide spiral wound

Since 1990s
Standardization & up-scaling

- Converging to TFC polyamide spiral wound
- Large market growth
- Mega plants (100,000s m^3/d)

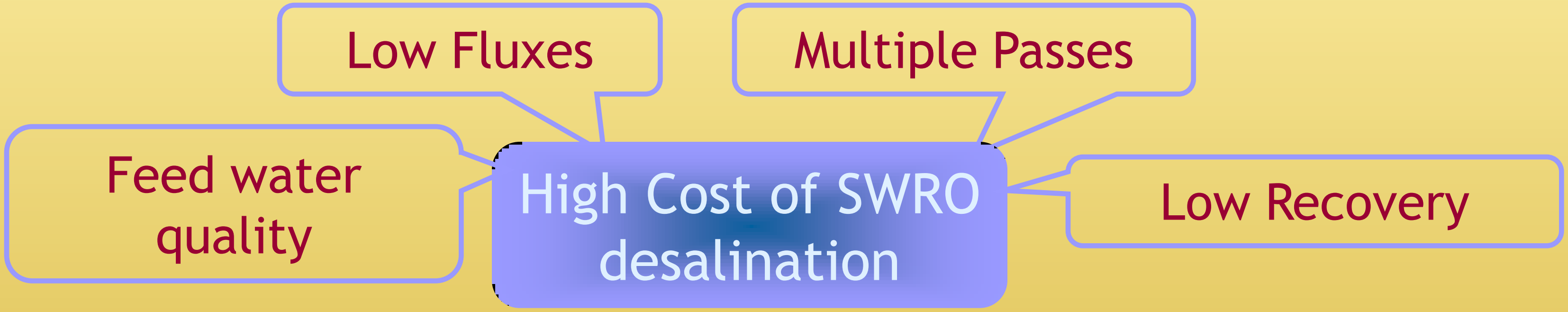


Dow's presence in the largest SWRO desalination plants

20/03/2012

Key Facts in Seawater Desalination

- **Multiple passes** are often still required to reach water quality despite latest improvements in salt rejection – extra capital and energy cost
- **Low recovery** results in extra capital and energy cost. Water needs to be pretreated and pumped back to the sea
- **Low flux rates** require more vessels, pipings, elements – and increase the capital cost of the system
- **Marginal waters** use increases pretreament cost and / or SWRO unit cost

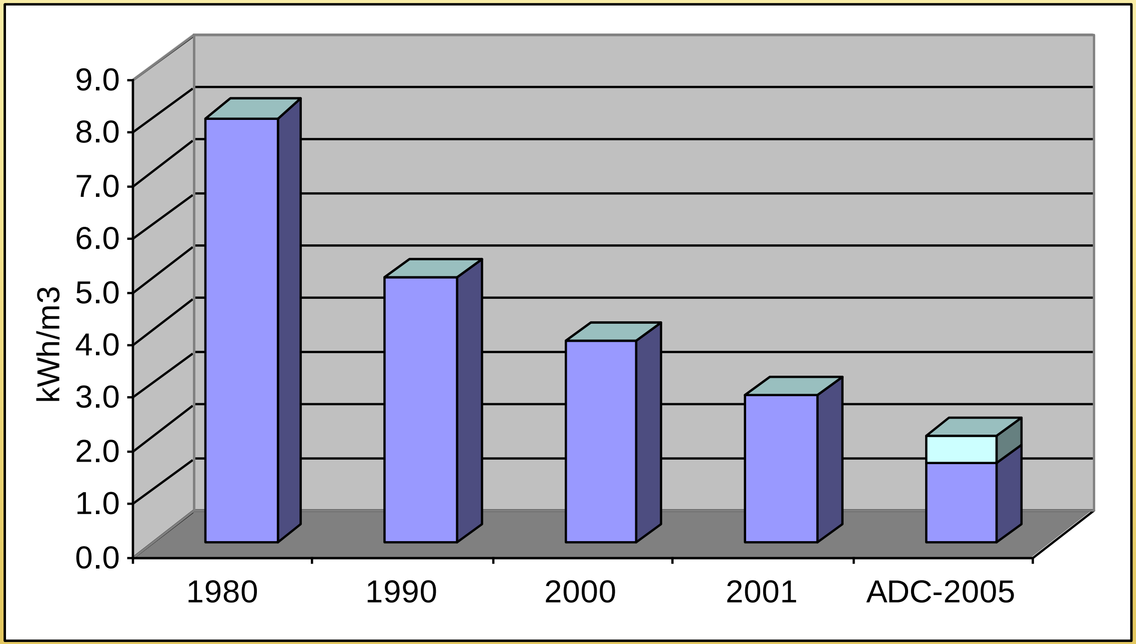


- **Energy consumption** being single largest factor >30% of water cost, still offers tremendous cost reduction potential

The challenge

Can we make seawater desalination more widely affordable ?

Can we produce higher purity water at lower cost ?



Note:

1. **Energy consumption related only to the RO process.**
2. **Average values for standard locations according to ASTM.**

Source: Affordable Desalination Collaboration

PRETREATMENT

Ultrafiltration → Reduced **CAPEX** due to higher flux, reduced **OPEX** due to lower energy

FIRST PASS

Highest Rejection FILMTEC™ SW30 membranes → Reduces or eliminates **CAPEX** and **OPEX** of second pass

Highest Production FILMTEC™ SW30 membranes Guaranteed highest active area → Reduction in piping, vessels and elements (**CAPEX** decrease)

Patent Pending ISD (Internally Staged Design) → Downsizing Intake, pretreatment and brine discharge. Reduction of **CAPEX** and **OPEX**

SECOND PASS

Highest Boron Rejection FILMTEC™ BW30 membranes → Reduction in secon pass size (**CAPEX** & **OPEX** decrease)

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SEAWATER PORTFOLIO OVERVIEW

- Introduce FilmTec™ **SW30XHR** membrane
  - Highest durable TDS and B rejection allowing single pass designs when 2 passes would usually be required

Launched in 2008

- Introduce FilmTec™ **SW30ULE** membrane
  - To be used in patent pending internally staged designs iSD for reliable high flux and high recovery operations

Launched in 2008

- Upgrade membrane rejection
  - SW30XHR TDS 99.82% (99.80%) Boron 93%
  - SW30HRLE TDS 99.80% (99.75%) Boron 92% (91%)
  - SW30XLE TDS 99.75% (99.70%) Boron 90.5% (88%)
  - SW30ULE TDS 99.75% Boron 89% (87%)

2009 - 2010

- Upgrade membrane rejection
  - SW30XLE TDS 99.8% (99.75%) Boron 91.5% (90.5%)

2011

* In brackets: previous values of rejection

Novel element construction

- **440 square foot design** with wide spacer (28 mil)
  - Highest active area with widest spacer
  - Low delta p, low capital footprint
  - On all membrane chemistries
    - SW30XHR-440i
    - SW30HRLE-440i
    - SW30XLE-440i
    - SW30ULE-440i

Launched in 2009

- **34 mil spacer** with highest active area (370 sq ft)
  - Low fouling, easy cleaning

Launched in 2008

FURTHER DECREASE IN THE COST OF WATER

2007

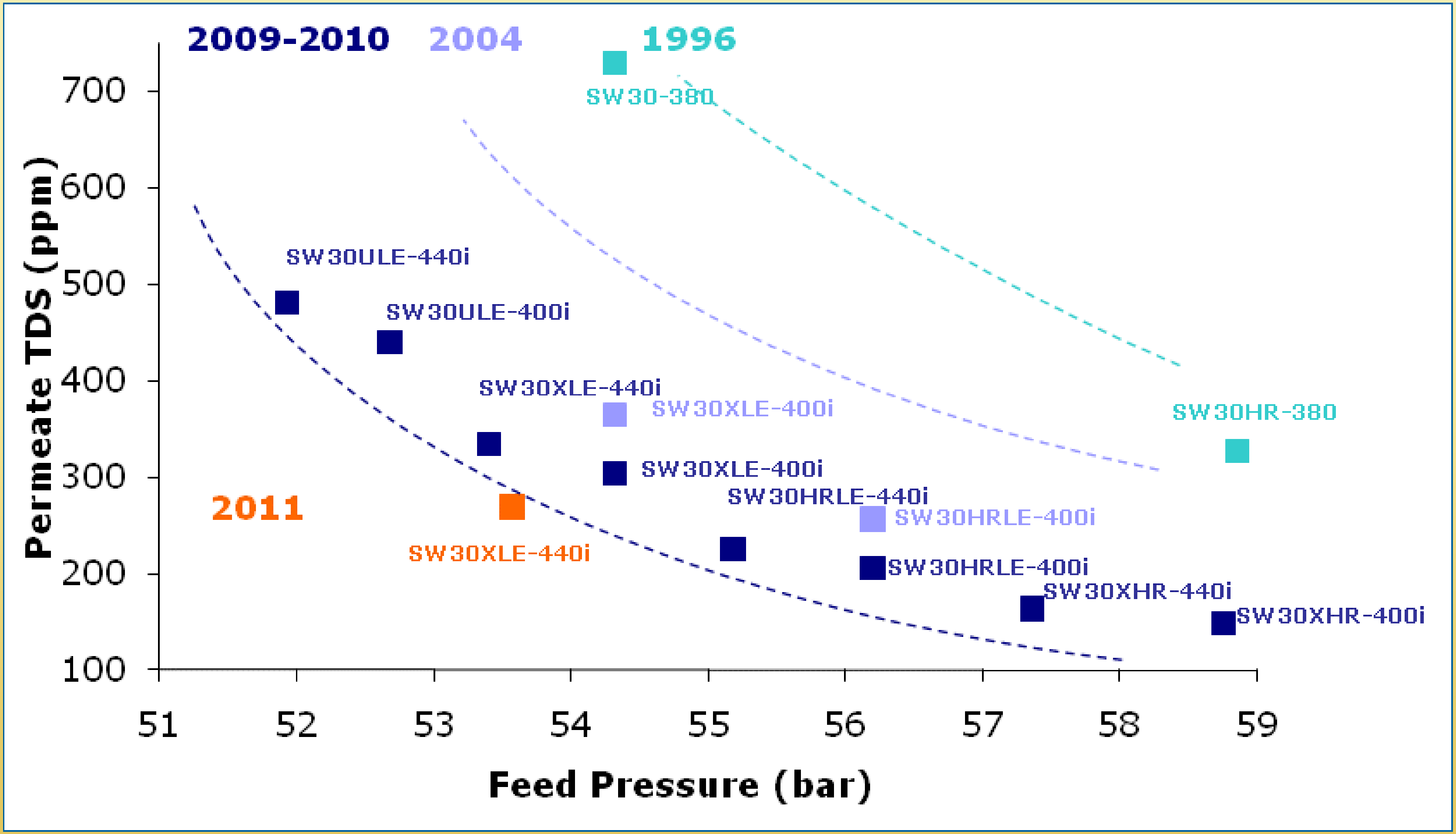
SW30XHR-400i: 6,000 gpd, 99.8%, 93%
SW30HRLE-400i: 7,500 gpd, 99.75%, 91%
SW30ULE-400i: 11,000 gpd, 99.70%, 87%

FILMTEC™ SW elements with 440 ft^2 + Rejection Improvement

2009

SW30XHR-440i: 6,600 gpd, 99.82%, 93%
SW30HRLE-440i: 8,200 gpd, 99.8%, 92%
SW30ULE-440i: 12,000 gpd, 99.7%, 89%

SEAWATER PORTFOLIO OVERVIEW



FILMTEC™ portfolio 2010 – in addition

Second Pass elements

LE-440i

Production: 12,000 gpd

Salt Rejection: 99.3%

Min Salt Rejection: 99%

FilmTec™ LE-440i key reference in Large Desalination plants

High Boron Rejection BW element

BW30HR-440i

Production: 33% lower than LE-440i*

Salt Passage: 50% lower than LE-440i*

* Calculated at LE-440i standard test conditions

Launched 2009

THE PERTH EXAMPLE

PERTH FIRST PASS – DESIGN OPTIONS EVALUATED

FILMTEC™ SW30HRLE-400i (7,500 gpd, 99.8%)

FILMTEC™ SW30XHR-400i (6,000 gpd, 99.82%)

FILMTEC™ SW30ULE-400i (11,000 gpd, 99.7%)

7 x **FILMTEC™** SW30HRLE-400i

5 SW30XHR-400i + 2 SW30HRLE-400i (**iSD**)

2 SW30XHR-400i + 5 SW30ULE-400i (**iSD**)

2 SW30XHR-400i + 5 SW30ULE-400i (**iSD** + **SPLIT)**

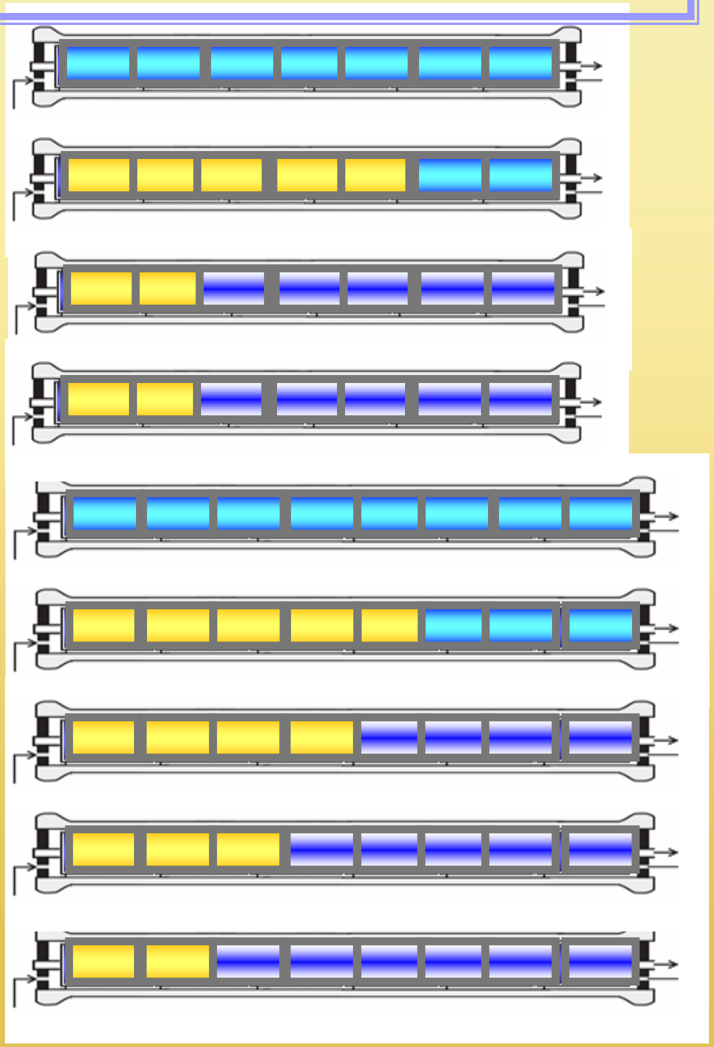
8 x **FILMTEC™** SW30HRLE-400i

5 SW30XHR-400i + 3 SW30HRLE-400i (**iSD** + **SPLIT)**

4 SW30XHR-400i + 4 SW30ULE-400i (**iSD** + **SPLIT)**

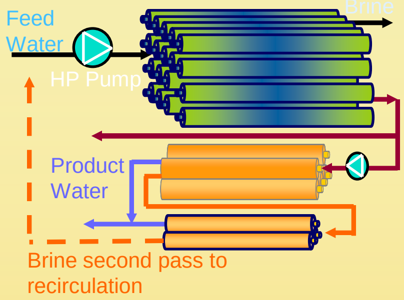
3 SW30XHR-400i + 5 SW30ULE-400i (**iSD** + **SPLIT)**

2 SW30XHR-400i + 6 SW30ULE-400i (**iSD** + **SPLIT)**



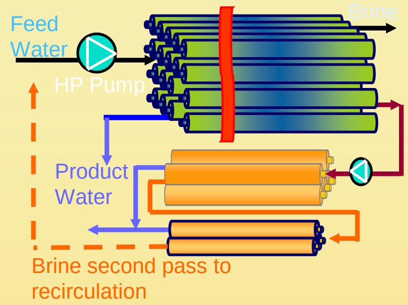
PERTH FIRST PASS – DESIGN OPTIONS EVALUATED

Conventional



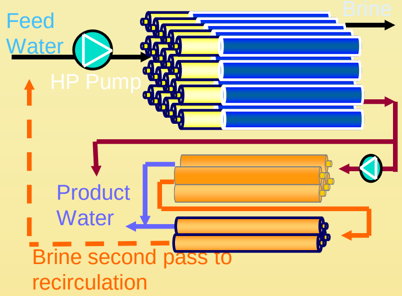
FilmTec™ SW30HRLE-400i

Conventional + Split



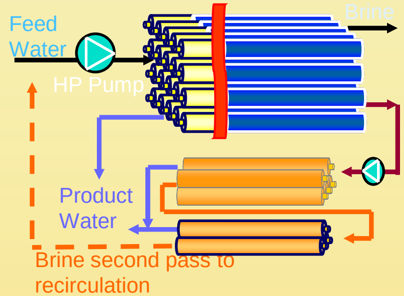
FilmTec™ SW30HRLE-400i

ISD



FilmTec™ SW30XHR-400i
FilmTec™ SW30ULE-400i

ISD + Split

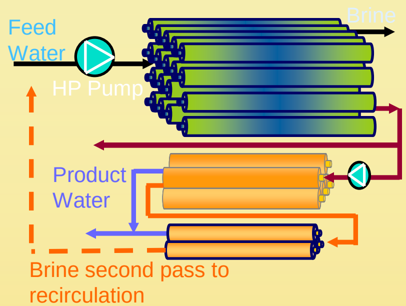


FilmTec™ SW30XHR-400i
FilmTec™ SW30ULE-400i

		Conventional	Conventional + Split	ISD	ISD + Split
FIRST PASS	Feed Pressure (bar)	54.6	54.7	52.0	52.6
	Permeate (m3h)	7016	6902	7065	6928
	Flux (lmh)	13.5	13.2	13.6	13.3
	Vessels (#)	2000	2000	2000	2000
SECOND PASS	Feed Pressure (bar)	10.8	10.7	10.7	10.8
	Permeate (m3h)	5528	4535	5999	4740
	Flux (lmh)	33.9	33.6	33.8	33.1
	Vessels (#)	570	472	620	500

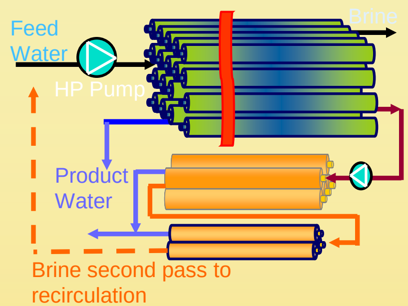
PERTH FIRST PASS – DESIGN OPTIONS EVALUATED

Conventional



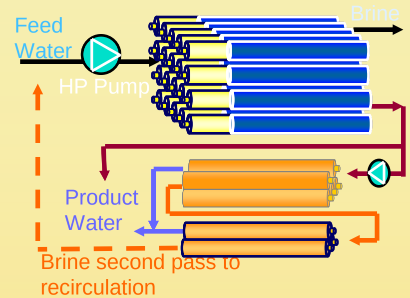
FilmTec™ SW30HRLE-400i

Conventional + Split



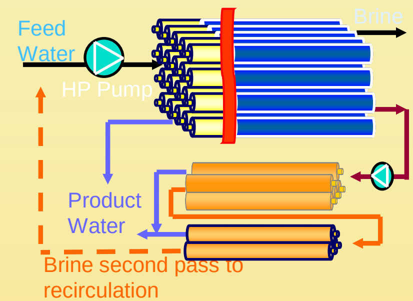
FilmTec™ SW30HRLE-400i

ISD



FilmTec™ SW30XHR-400i
FilmTec™ SW30ULE-400i

ISD + Split



FilmTec™ SW30XHR-400i
FilmTec™ SW30ULE-400i

Cost (Uscts/m³)	Conventional	Conventional + Split	ISD	ISD + Split
O&M: Cost of Electricity	32.2	31.1	31.7	30.6
O&M: Labor and Overhead	1.5	1.5	1.5	1.5
O&M: Chemicals	4.3	4.2	4.4	4.2
O&M:Replacement and repair	3	2.9	3.0	2.9
O&M: Insurance	0.4	0.4	0.4	0.4
Subtotal O&M	41.4	40	41	39.6
Amortization	19	18.9	19.1	18.9
Water cost	60.4	58.9	60.15	58.54

ENERGY CONSUMPTION kWh/m^3 Pre-treatment and Reverse Osmosis

	Pre-treatment	First Pass RO	Second Pass RO	Total
Best Case	0.21 k	2.26	0.23	**2.7**
Normal	0.21	2.36	0.23	**2.8**
Worst Case	0.35	2.4	0.35	**3.1**

- Values given for old membranes
- Normal case for new membranes is 2.7 kWh/m^3

Translating membrane & design evolution into cost of water reduction

Cost of Water

Basic design	Improved membrane chemistry and construction	Advanced Design (Split)	Advanced Design (ISD & SPLIT)
60 UScts/m^3	57.4 UScts/m^3	56.7 UScts/m^3	56.4 UScts/m^3

- Improved rejection: SW30HRLE from 99.75 to 99.80%
- Increase in active area: from 400 to 440 ft^2

- Same as basic design but using split in the firts pass

- Same as basic design but using split and ISD in the firts pass

- Evaluation based on a large SWRO desalination plant (>100,000 m^3/day), 41,000 feed TDS, 16-32 ºC, Boron in permeate below 0.26 ppm
- Number of pressure vessels not modified. Cost evaluation based on energy savings (OPEX).

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NEW DIAMETERS OF THE RO ELEMENTS

¿What is the benefit of enlarging the diameter in RO elements?

- Decrease in Capital Expenses
- Lower final cost of water

Yun, T.I.; Gabelich, C. J.; Coffey, B.M.; Bergman, R.A.; "Performance and Economic Evaluation of a 16-inch-Diameter Reverse Osmosis Membrane for Surface Water Desalting", AWWA Membrane Conference Proceedings, 2001.

Yun, T.I.; Gabelich, C. J.; Cox, M.R.; Mofidi, A.A.; Lesan, R.; "Reducing Costs for Large-Scale Desalting Plants Using Large-Diameter, Reverse-Osmosis Membranes", AMTA Membrane Conference Proceedings, 2002.

Bartels, C.; Bergman, R.; Hallan, M.; Henthorne, L.; Knappe, P.; Lozier, J.; Metcalfe, P.; Peery, M.; Shelby, I.; "Industry Consortium Analysis of Large Reverse Osmosis and Nanofiltration Element Diameters", Desalination and Water Purification Report No. 114, U.S. Bureau of Reclamation, 2004.

16-inch offering

Understanding the economical benefit

	Millions of Dollars ($)		
	8-inch	16-inch	Savings
UF Pretreatment	35.2	35.2	0.0
Seawater RO	70.9	59.6	11.3
Other Process	10.1	10.1	0.0
Infrastructure	32.6	29.4	3.2
Contractor Mark-Up	31.7	28.6	3.1
Contingency	36.1	32.6	3.5
Total	216.6	195.6	21.1

Fewer, Larger RO Trains Provides Reductions in…

- Racks
- Piping
- Manifolds
- Instrumentation
- Footprint
- Building

10% Savings

- U.S. Dept. of Interior, DWPR Report 114, "Industry Consortium Analysis of Large RO/NF Element Diameters", 2005.
- Cost Analysis by CH2MHill

16-inch offering

FILMTEC™ 16-inch Comparison to Standard 8-inch:

- Same materials
- Same rejection
- Same feed pressure
- Same pressure drop

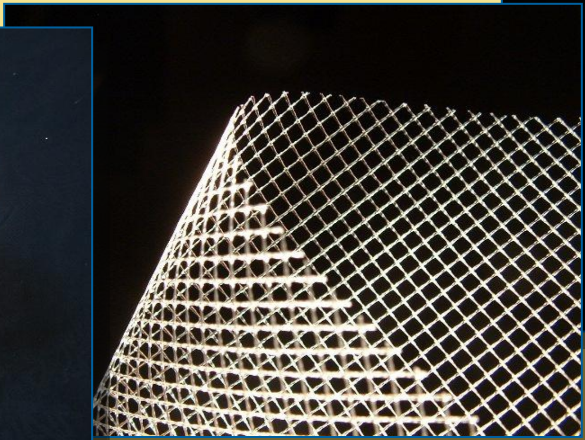
- 4.3-times increase in active area and permeate flow

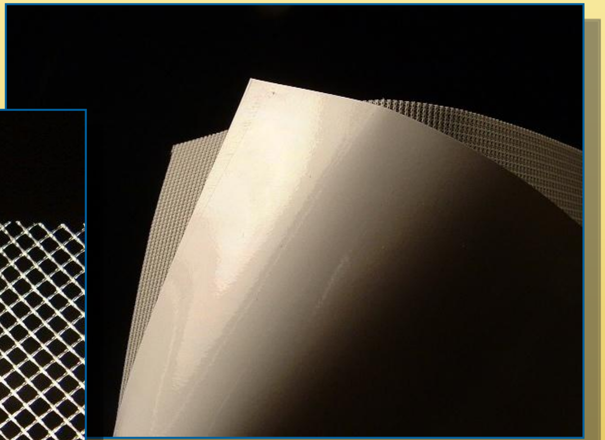
Membrane	Diameter	Active Membrane Area ft² (m²)	Permeate Flow gpd (m³/d)	Feed Spacer Thickness Inch (mm)	Stabilized Rejection (%)
SW30HRLE	8	400(37)	7,500 (28.4)	0.028 (0.71)	99.80
	16	1725 (160)	32,000 (121)		

16-inch offering

Materials are identical to those used for 8-inch modules

- Proven history of reliability in a broad range of applications
- Well established supply chain
- Ease of regulatory approval
- Leveragability of existing fabrication infrastructure

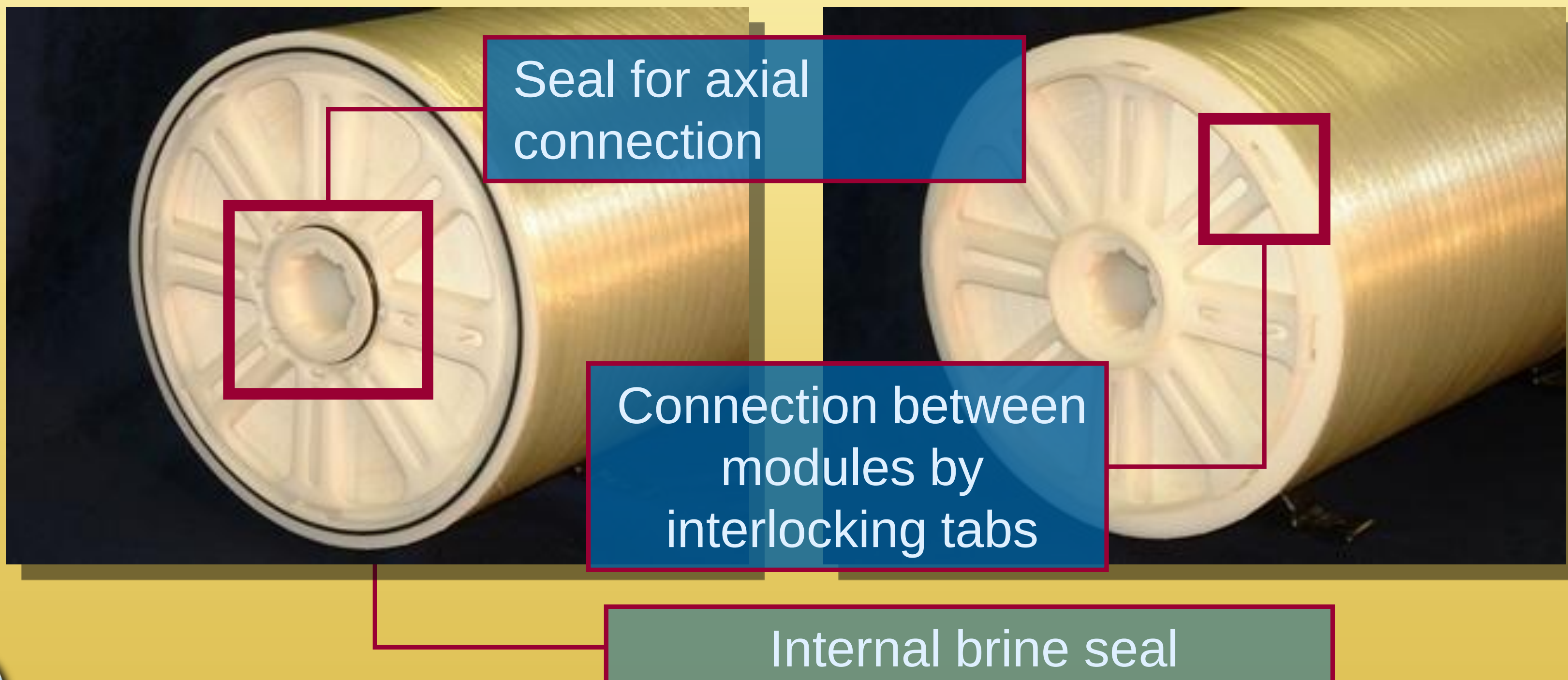




Connection between elements

iLEC™ technology adapted to 16-inch modules

There is no preferential direction for loading and unloading imposed by the brine seal, and the module stack can be pushed or pulled from the most convenient end.

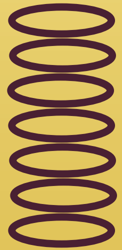


Connection between modules

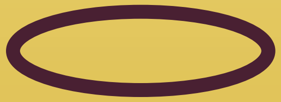
iLEC™ technology adapted to 16-inch modules

Number of o-rings is 7 times higher in installations using 8-inch elements with conventional interconnectors

8-inch elements with conventional interconnectors	16-inch elements with iLEC™ Interlocking Endcaps
25 MGD (95,000 m^3/d) SW	25 MGD (95,000 m^3/d) SW
7,518 elements	1,904 elements
15,036 o-rings	2,176 o-ring



O-ring ratio is 7:1



End Caps

Unique brine seal in the pressure vessel

Pressure vessel adaptor

Manipulation

Weight of dry elements:

- 16 inch: 54 kg
- 8 inch: 14 kg

Manual loading of 16-inch elements not possible

Manual loading 8-inch elements

Manipulation

Support for elements installation

Elements packaging and transportation

Manipulation

Elements loading

Equipment for automatic loading of elements

Includes:

- Support to ensure proper alligment of elements
- Hydraulic motor to install and extract elements from the vessel
- Automatic connection between elements

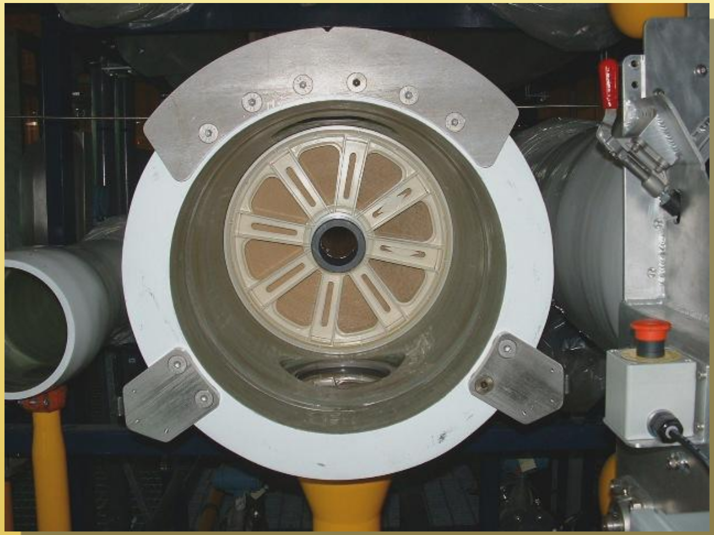
Loading tool attached
to 16-inch pressure vessel

Manipulation

Elements loading

Equipment for automatic loading of elements

Installation in Bedok NEWater Plant, Singapore



ULTRAFILTRATION AS THE NEW PRETREATMENT

FAST ADOPTION OF UF IN SW DESAL

MEMBRANE FILTRATION

- Filtrate quality always achieved
- Lower CAPEX & OPEX RO
- Single stage system
- Less footprint required
- A module can be isolated
- Relatively easy to increase capacity

CONVENTIONAL PRETREATMENT

- Proven and widely used technology
- Production conditioned by quality of Feed
- Two stages potentially needed
- Coagulation/Flocculation migth be required

1- UF productivity to justify economical investment

Operational Flux high dependance on:

- Fiber pore size
- Porosity
- Maximum allowed pressure
- Fiber length and diameter

2- Full potential of low chemical consumption

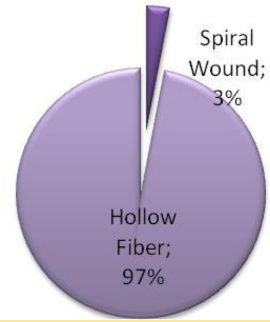
- Eliminate use of chlorination
- Avoid coagulation & pH adjustement
- Cleaning chemicals

3- Optimum operational schemes

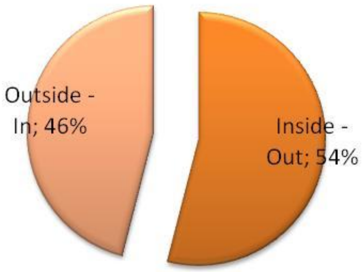
UF TECHNOLOGY OVERVIEW

Pressurized vs Submerged

Hollow Fibers vs Spiral Wound

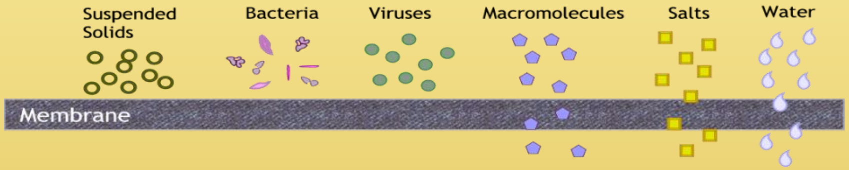


Flow direction



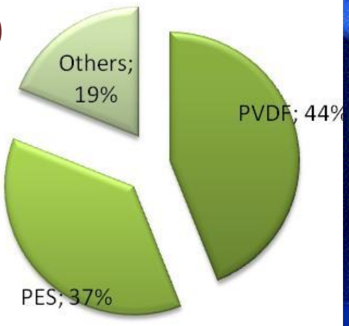
Pore Size

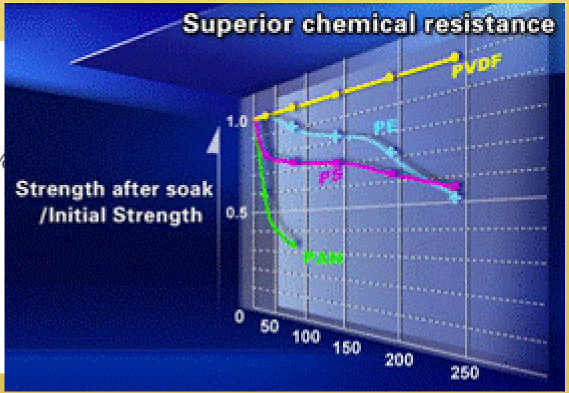
- Typically 20-30 nm
- Some suppliers with 100 nm



Fibers Material

Polyvinylidene fluoride (PVDF)
Polyethersulfone (PES)
Polysulfone (PS)
Polyacrylnitrile (PAN)
Polypropylene (PP)
Regenerated cellulose (RC)
Derivatized cellulose (DC)





The "IntegraPac" Concept

Features:
- Minimized Fittings/Materials
- Highly Compact Design
- Modular and Scalable
- "Plug and Play"
- Lower Cost Solution
- Proven Dow UF Modules
- 2860/2880 Adaptable

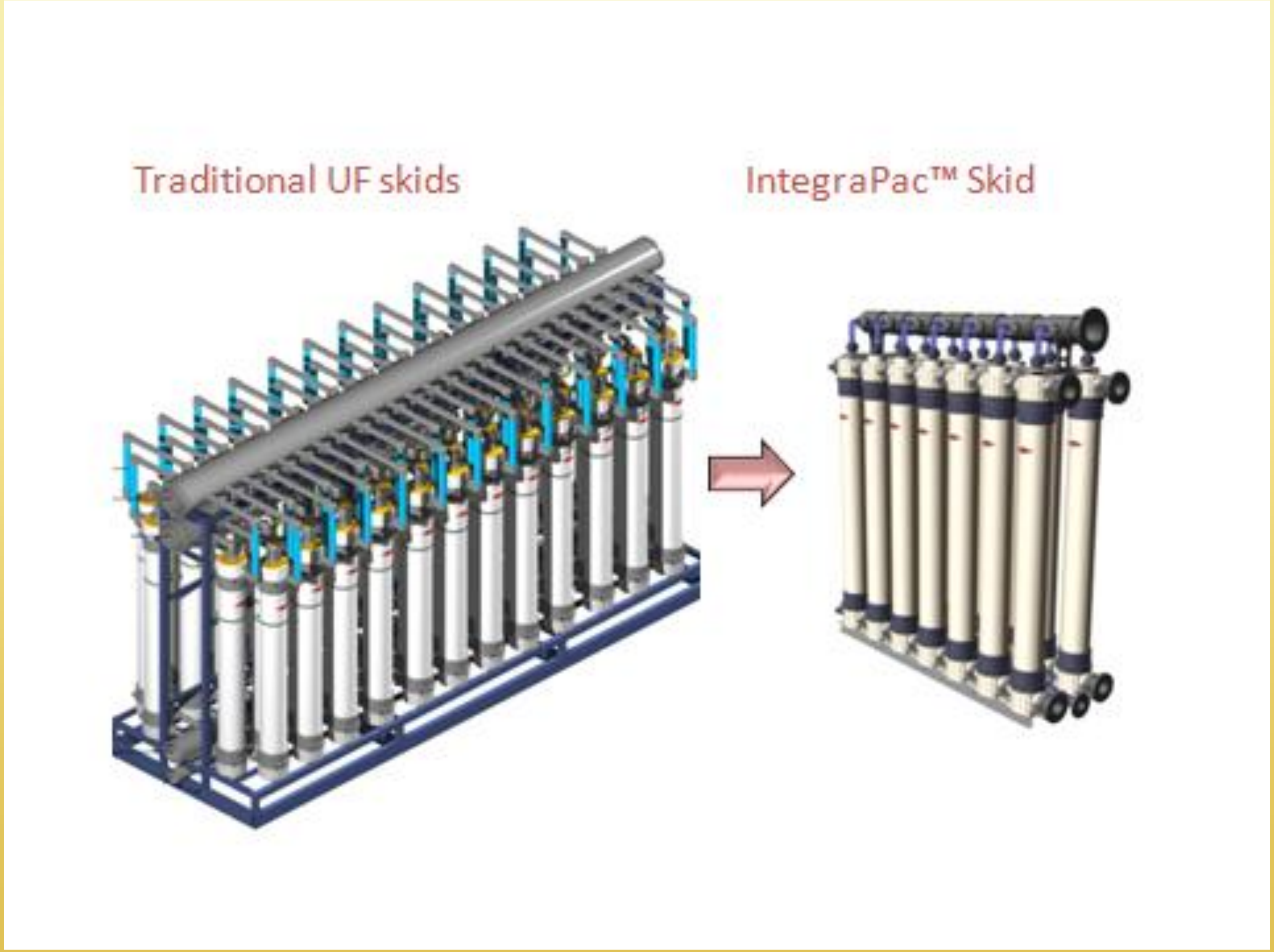
The "IntegraPac" Concept

IntegraPac

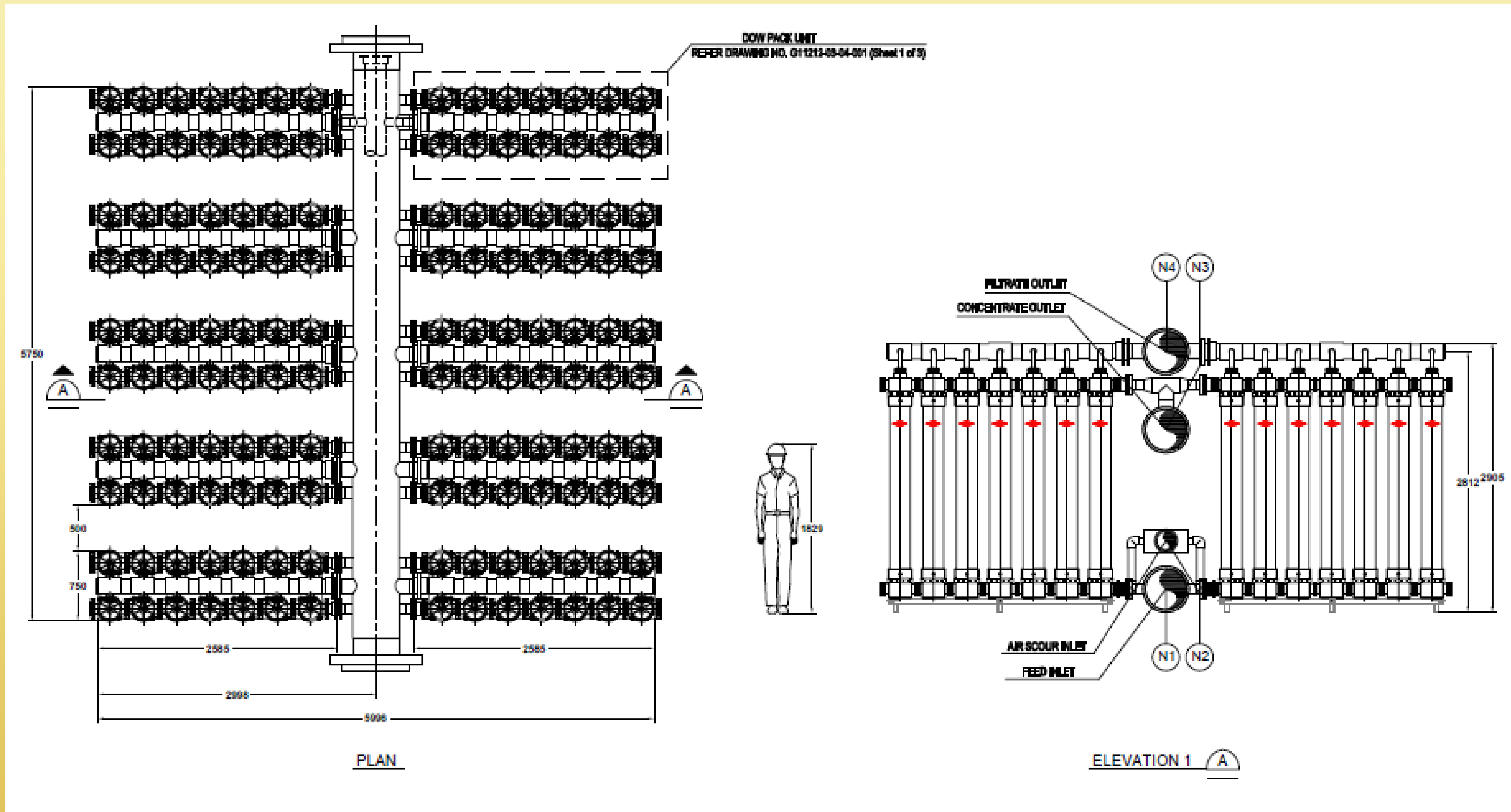
The “IntegraPac” Skid

Features:

- Top port site glasses integrity control
- Module accessibility maintained
- 20 SFX 2880 Modules
- 1540 m^2 filtration surface
- 2.6 m^2 footprint
- 2800 m^3/day Gross Permeate Flow
- Supports shipment by container


Traditional UF skids
IntegraPac™ Skid

“IntegraPac” large projects



REAL CASES USING UF+RO

Seawater Pretreatment

- **Source:** Seawater
- **Capacity:** 25,500 m3/d UF Feed
- **Location:** Magong, Taiwan
- **Running Time:** From 2008
- **Process:** Open Intake, Disc-Filter & DOWTM UF & RO

OEM: OEE, China

Purpose: Potable Water

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Seawater Pretreatment

- **Source:** Seawater
- **Capacity:** 50,000 m3/d UF Feed
- **Location:** Moni, Cyprus
- **Running Time:** From December 2008
- **Process:** Open Intake
  Prefilter 500 & 100 µm
  & DOW^{TM} UF & RO
- **OEM:** Nirosoft, Israel

Purpose: Potable Water

Seawater Pretreatment

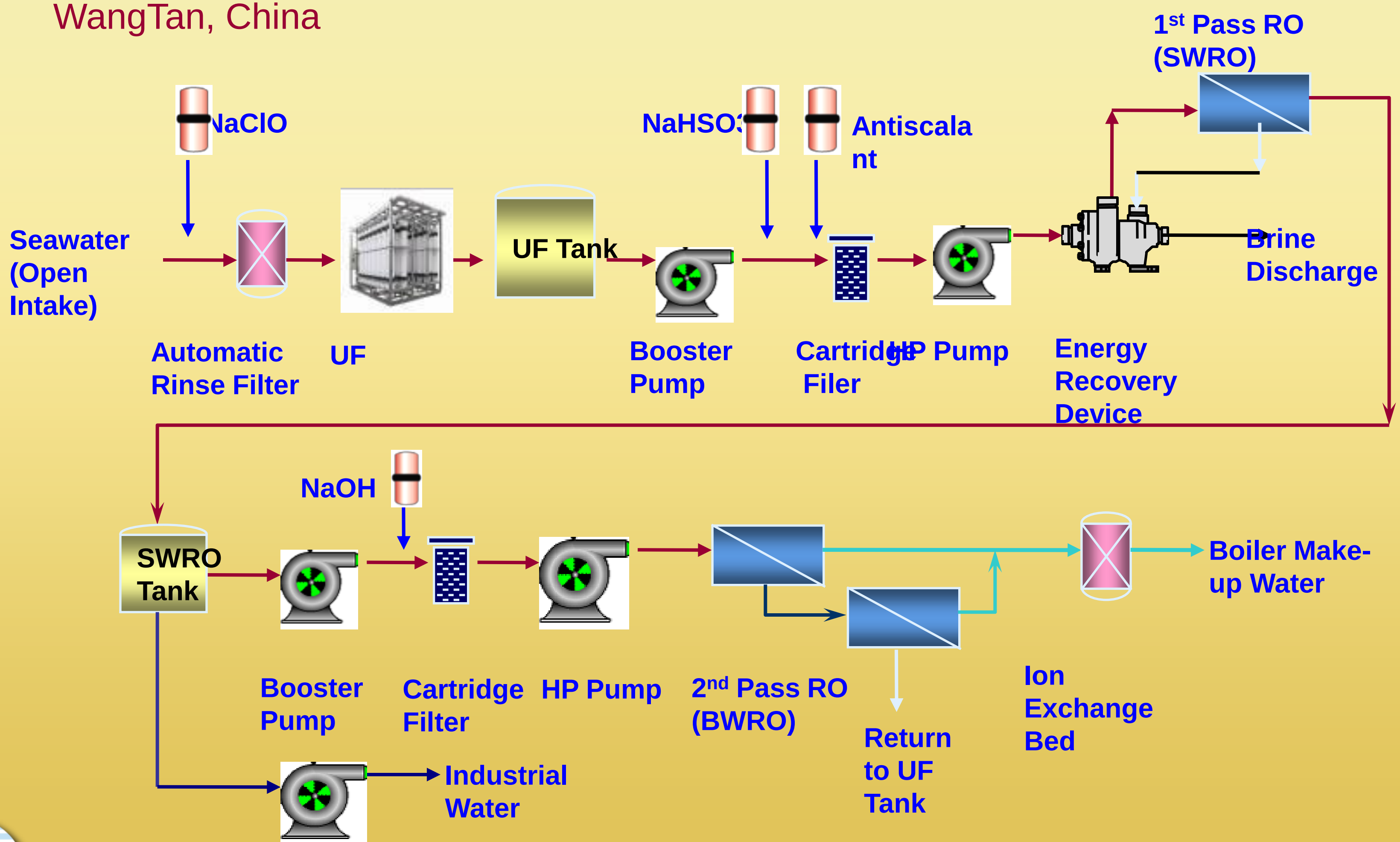
- **Source:** Seawater
- **Capacity:** 28,800 m3/d (UF)
- **Location:** WangTang, China
- **Running Time:** Since 2005
- **Process:** Open Intake, Disc-Filter & DOW™ UF & RO

OEM: OEE, China

Purpose: Boiler Feed

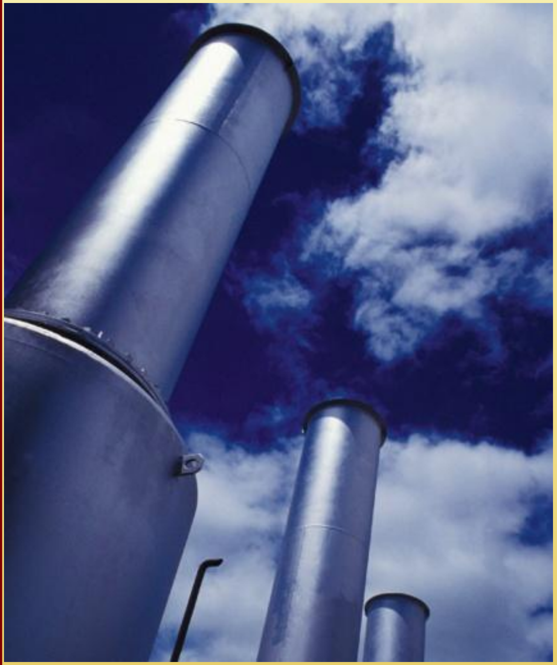
Process Flow

WangTan, China



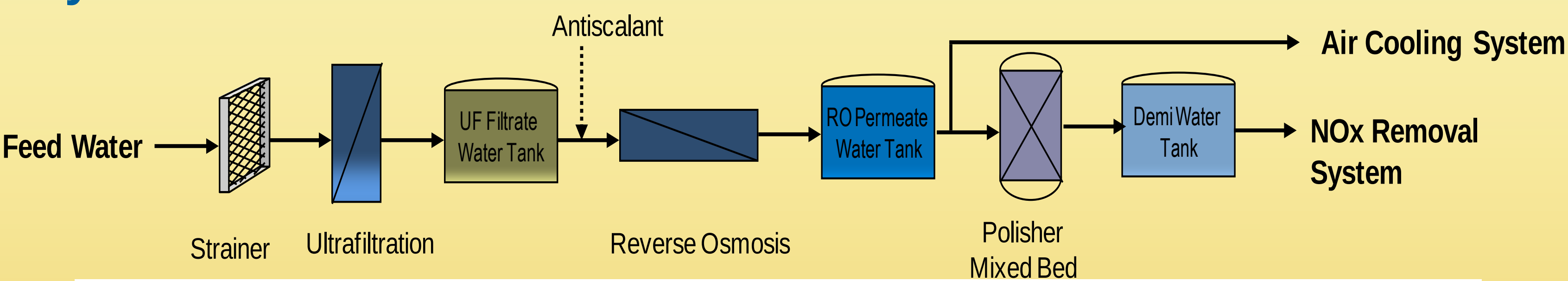
Integration of Dow Components Uses Nile Water to Produce High-Purity Water for Power Industry in Egypt (Damietta)

- **Location:** Damietta, Egypt
- **Source:** River Water (Nile)
- **End-user:** Cogeneration Power Plant
- **Capacity:** 3,710 m^3/day of RO permeate flow
- 3,120 m^3/day Mixed Bed product flow
- **Start-up:** July 2011
- **Purpose:**
  - Feed for NOx Removal system and feed for Evaporate Air Cooler system
- **Constructed by:** PROTECNO Srl (Italy) and EMIT SpA (Italy)
- **Main particularities:**
  - Full chain of DW&PS's technologies:
  - DOW™ Ultrafiltraion + DOW FILMTEC™ Reverse Osmosis + DOWEX™ Ion Exchange Resins.



Integration of Dow Components Uses Nile Water to Produce High-Purity Water for Power Industry in Egypt (Damietta)

System Information



Unit	Design Flux (lmh)	Design Recovery (%)	Number of Trains	Product Installed	Total Number of Modules
UF	40[a]	85[b]	2+1 standby	DOW™ UF SFP-2880	138
RO	23.5	75	2+1 standby	DOW FILMTEC™ BW30HR-440*i*	252

[a]UF operating flux of all three UF trains on duty: Instantaneous filtrate flow (L/h) / total active area (m^2)
[b]UF recovery (related to UF feed) % of all three UF trains on duty: UF filtrate net flow / UF feed flow • 100

Unit	Trains	Product Installed	Regenerant	Total volume (L)
Mixed Bed Polisher	2 + 1 standby	DOWEX MARATHON™ C	H_2SO_4	3,750 (H^+ form)
		DOWEX MARATHON™ A	NaOH	7,200 (OH^- form)

Integration of Dow Components Uses Nile Water to Produce High-Purity Water for Power Industry in Egypt (Damietta)

3D Layout of the UF + RO + MB System in Damietta

Integration of Dow Components Enables High-Purity Water Production for the Power Industry in Egypt (El Shabab)

3D Layout of the UF + RO + MB System in El Shabab

Summary

- Constant pipeline of innovation
- In 2008 major new membrane chemistries were launched, which extended the envelope
- In 2009 element construction improvement to 440 ft^2 was introduced
- In 2009 - 2011 rejection upgrade of the SW family
- Lower energy consumption
- New designs: ISD & Split partial
- New diameters
- UF as a pretreatment
- New developments in the UF technology

DOW Water & Process Solutions