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New Membranes for Solar Desalination Plant

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Outline

- **Why Solar desalination**
- **Collaboration between KACST & IBM for membrane research & development since 2008.**
- **Time line for the membrane project**
- **Site location for solar powered desalination plant with SWCC**
- **An overview of KACST-IBM membrane development process**
  - Reverse osmosis and challenges
  - Development of new membrane anti-foulants coatings for SWRO
  - Coating candidates for seawater RO
  - Future work (Mini-model fabrication and testing).

Why solar desalination?

- Abundant of solar radiation in the Kingdom.
- Growing needs for fresh water in the Kingdom.
- Reduce dependence on fossil fuels (non-renewable energy) for operating desalination plants.
- Suitable for remote area.
- Reduction of water cost in the long run.
- Environmentally friendly - seawater desalination is highly energy consuming process.
- Gaining knowledge and experience on solar powered desalination plant as future technology

IBM/KACST Joint Project: Energy Efficient Desalination Plant

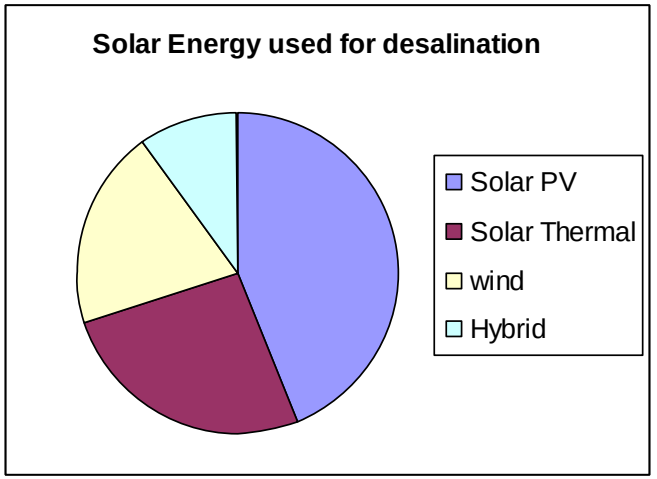
with IBM Yorktown

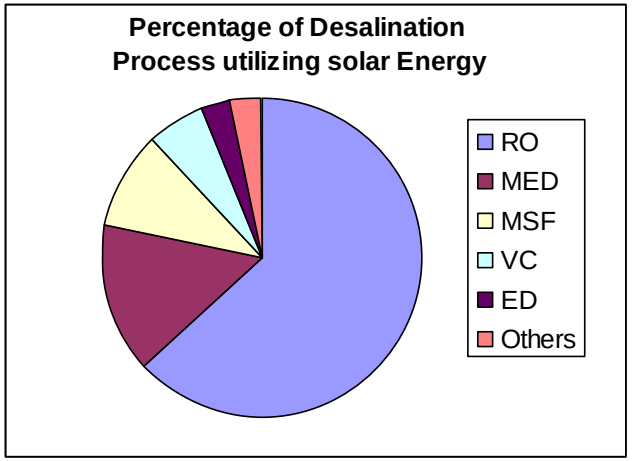
High Efficiency CPV Systems

Combination of the most utilized technology in water desalination

with IBM Almaden

High Performance Membranes





Source; Solar desalination for the 21st century

Seawater Reverse Osmosis Membranes for Solar-Powered Water Desalination

Nanomembrane Project (Research)

Develop New Materials & New Concepts

1. **Anti-fouling Coatings (MF, UF, NF, or RO)**
2. **New membrane for desalination and toxic substance removal (RO or NF)**
3. **Well-defined Nanostructured Membranes for low energy(cost) operation (enhanced water flux) (NF or RO)**

High salt rejection: ≥ 99.5 %, Reasonable water flux: about 35 LMH or More
Outstanding anti-fouling efficiency for RO

DMMD Project (Research to Development and Manufacturing)

Target: High Performance, fouling resistant RO membranes for use initially in KSA and then beyond

IBM-KACST Water Technologies (Nano-Membranes)

2008

2009

2010

2011

2012

2013

Begin Joint Research Into Nanomembrane Materials

Joint Press Release on iPhobe Membranes; Sample Presented to King Abdullah

Incorporation of Membranes in Solar-Powered Desalination Plant in Al Khafji

Initiate DMMD Project to Scale and Commercialize Desalination Membranes

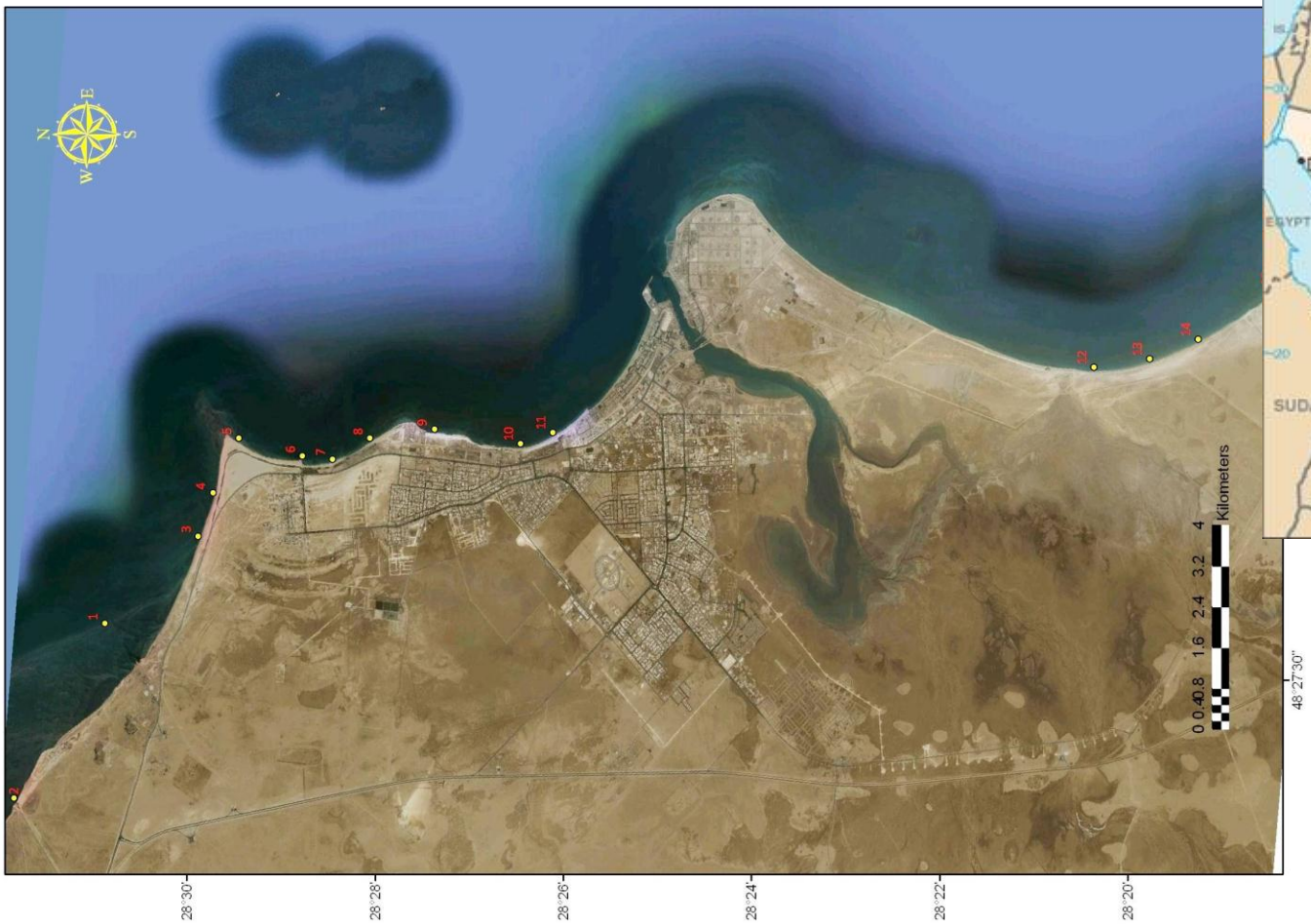
Current Work Plan:

Theme 1: Reduce Energy Requirements (high flux membranes)

Theme 2: Increase Functionality and Capabilities (toxin removal)

Theme 3: Improve Robustness (Anti-fouling coatings, chlorine tolerance)

Site assessment for chemical and biological analysis with seasonal variation – In progress



Production capacity:

30,000 cubic meters per day
For serving 100,000 people

- **Red spots are sample location at Alkhfjee coast**

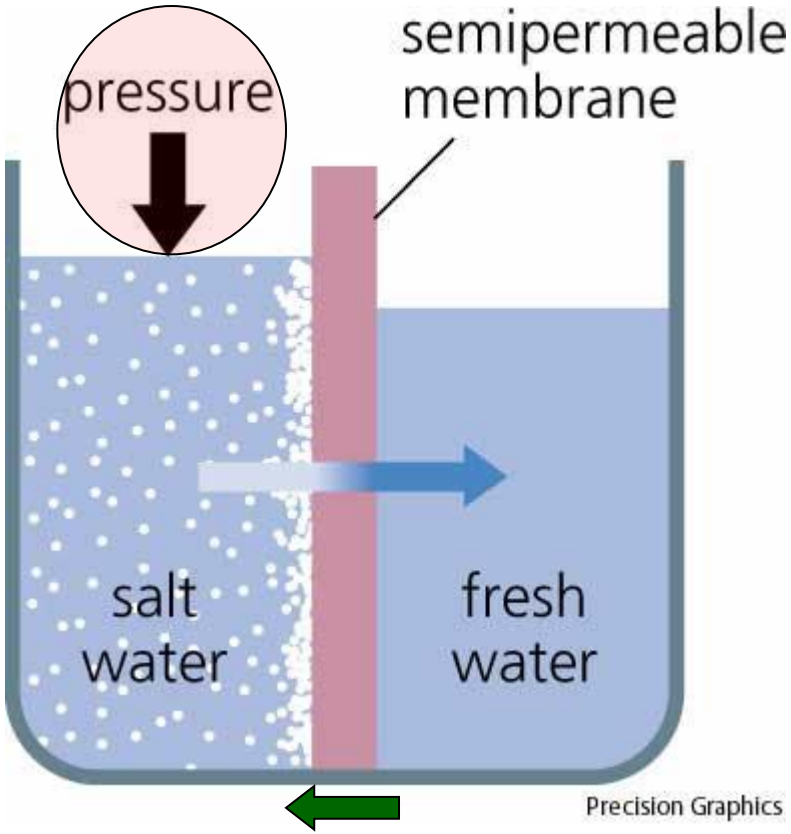
TDS,Temperature,Major Cations, Major Anions, TOC, Turbidity, Trace elements, TSS, BOD5, Chlorophyll, Nutrients,SDI

Thanks to SWCC-research institute for Chemical and Biological analysis

An overview of KACST-IBM membrane development process

Reverse Osmosis and Energy Requirement

Reverse Osmosis



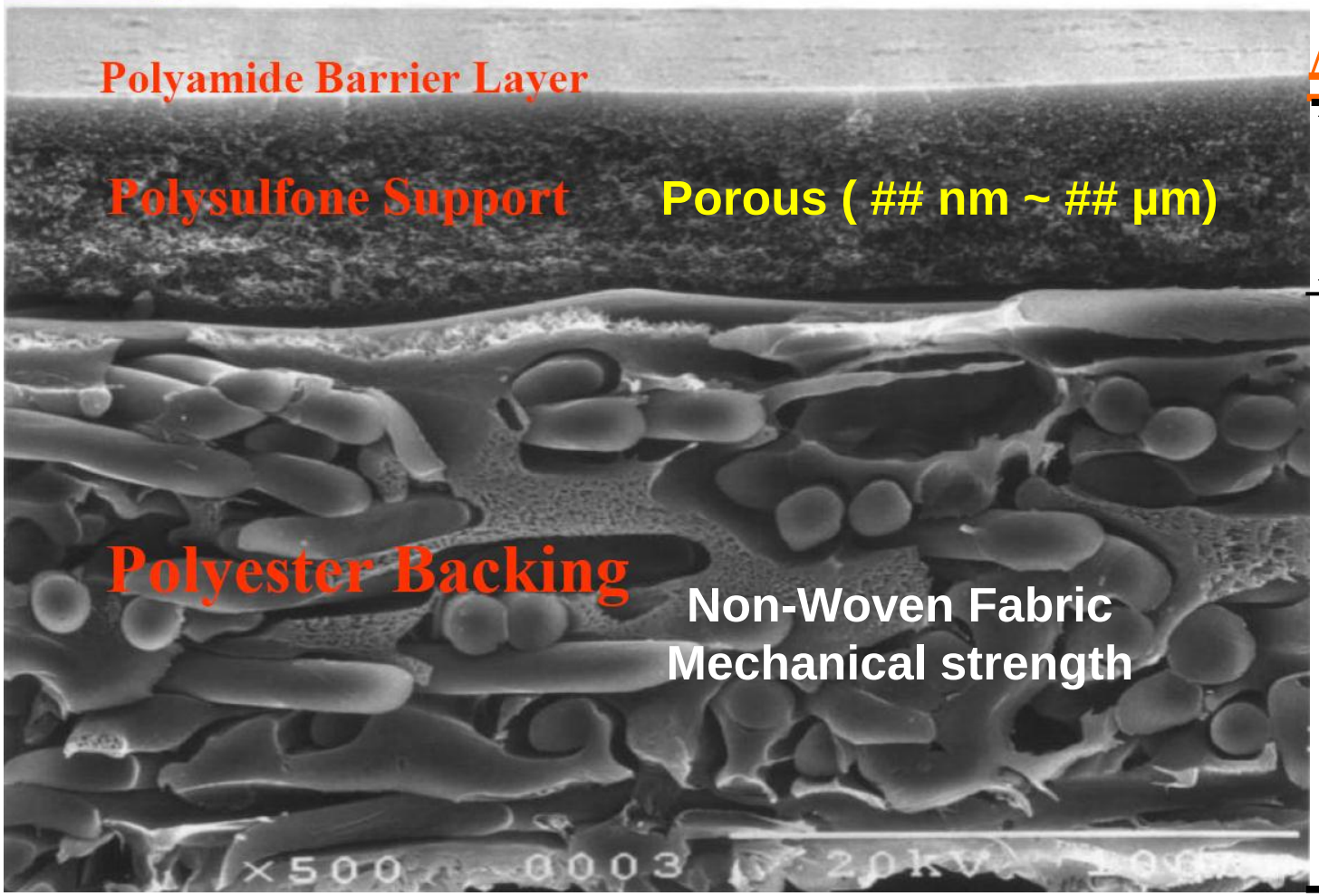
Water flow by osmosis

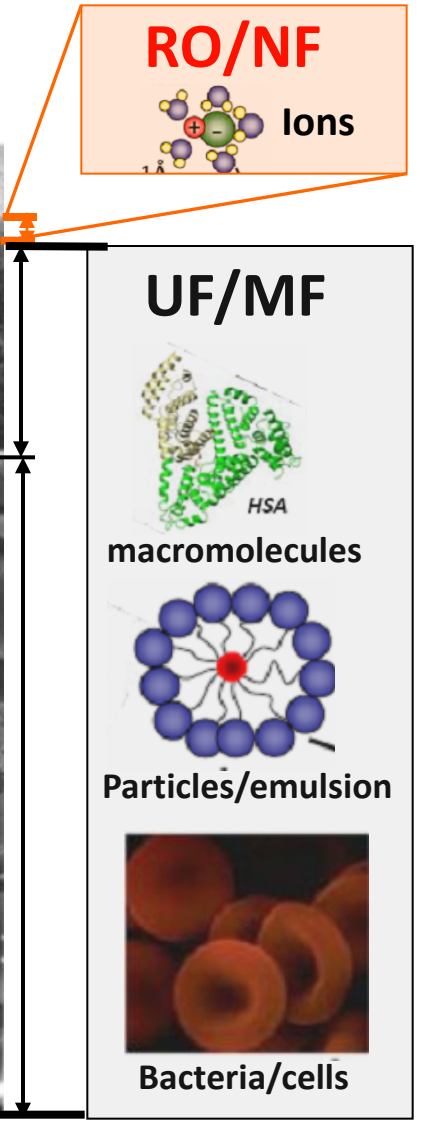
Energy Requirement

Desalting Technology	Total Electric Energy Equivalent (Kwh/m^3)
Reverse Osmosis (Membrane Filtration)	**2 - 4**
Multiple Effect Distillation	**5.7 – 6.5**
Multiple Stage Flash	**17 – 18**
Vapor Recompression	**8.5**

Salt concentration of seawater: 35000 ppm (3.5 %), Osmotic pressure of seawater: 350 psi (26 bar)
Normal pressure for seawater purification: 800 psi (55 bar)

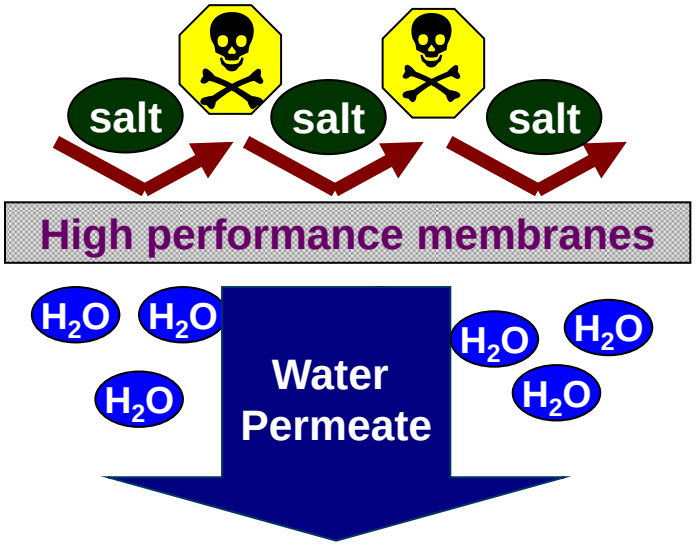
Membranes for Water Purification



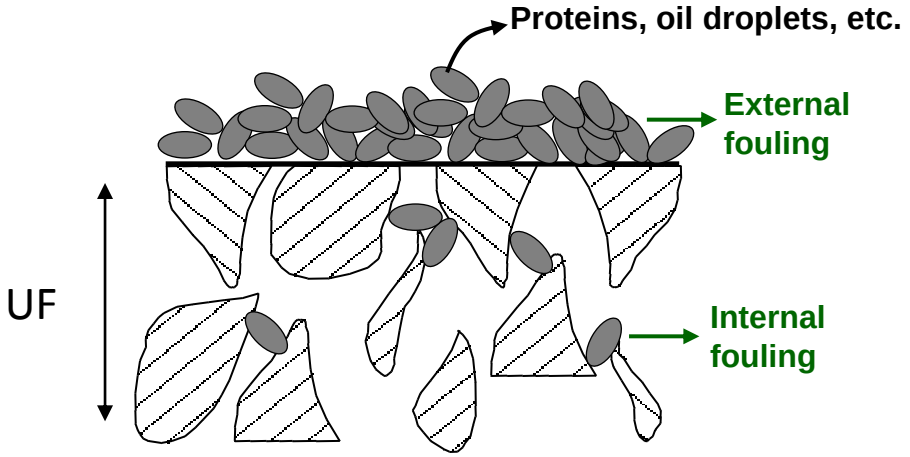


Challenges with Membrane Technologies

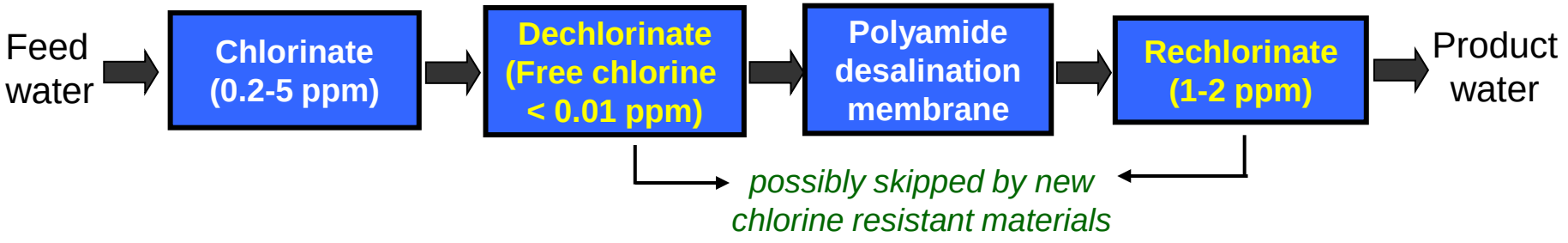
- **Performance**: New materials with high throughput & high salt rejection



- **Fouling**: More robust membrane materials required that will resist fouling



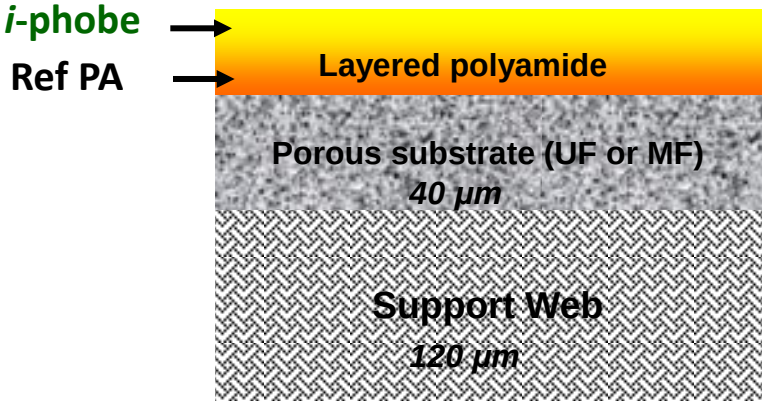
- **Chlorine Damage**: Current RO membranes oxidized by chlorine



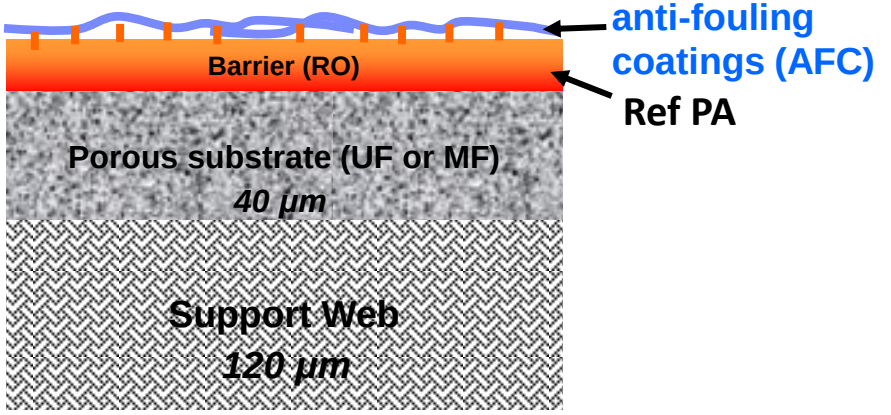
KACST-IBM Desalination Membrane Research

Two Candidates for Module Development

I. *i-phobe* 2: Polyamide Bilayer

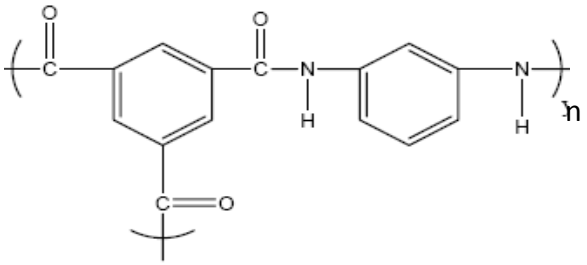


II. Fouling Resistant RO



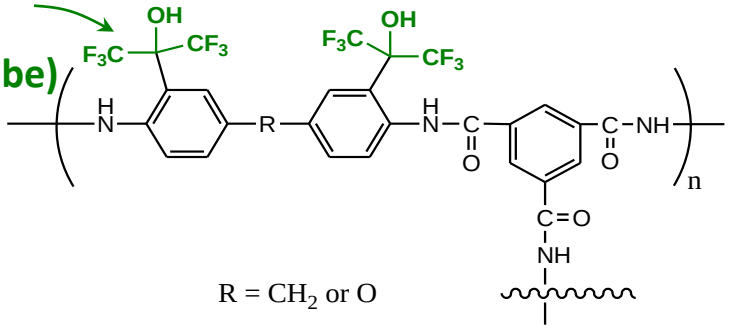
- Building Infrastructures
- Process optimization: manufacturing conditions
- In-depth evaluation w/ seawater (salt rejection, water flux, anti-fouling efficiency, etc)

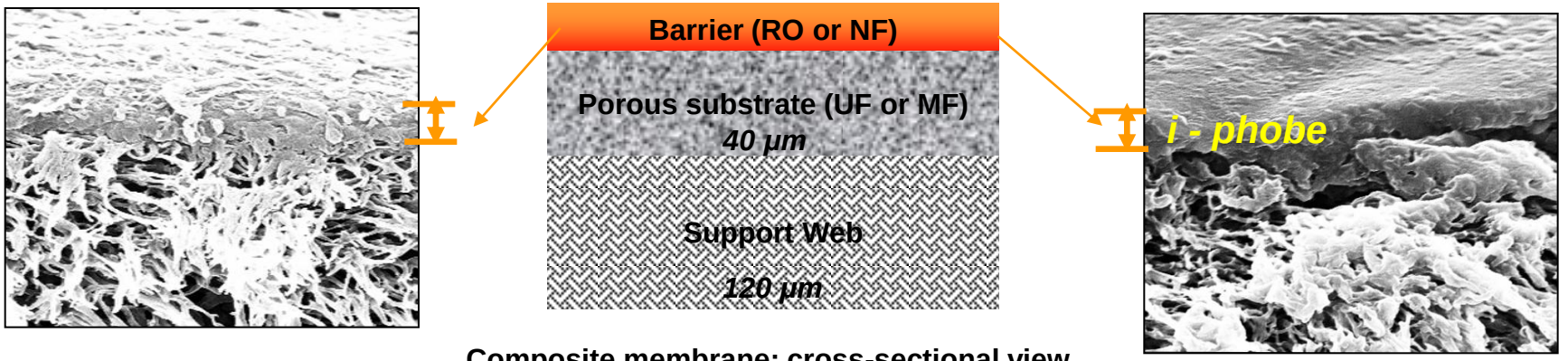
Conventional RO vs. KACST-IBM's Novel RO (*i-phobe* 1)



Hexafluoroalcohol (HFA)
(ionizable hydrophobe: i-phobe)

RO barrier layer





Composite membrane: cross-sectional view

- High salt rejection (99.0 ~ 99.5 %)
- Water Flux: 20-50 L/M²H (LMH)

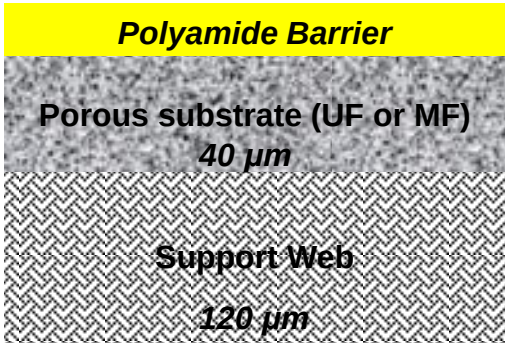
- Bulky electro-withdrawing group (HFA)
- Improved chlorine resistance

Membrane evaluation by cross flow filtration and dead-end filtration

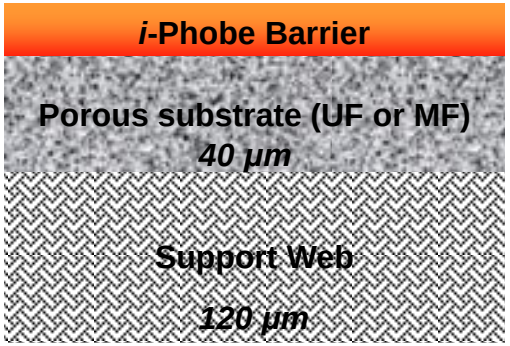
i-phobe: Performance Improvement For Seawater Desalination

(Seawater concentration: 35,000 ~ 47,000 ppm, WHO regulation for drinking water: <1000 ppm)

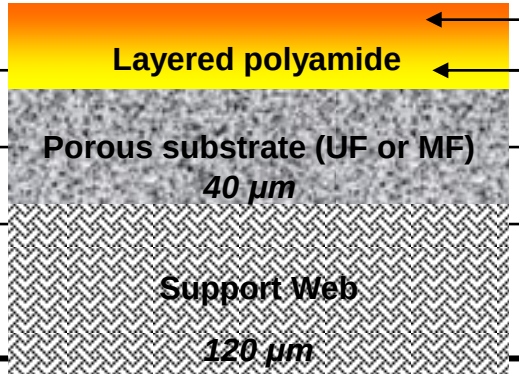
Conventional RO



i-phobe (Gen-1)



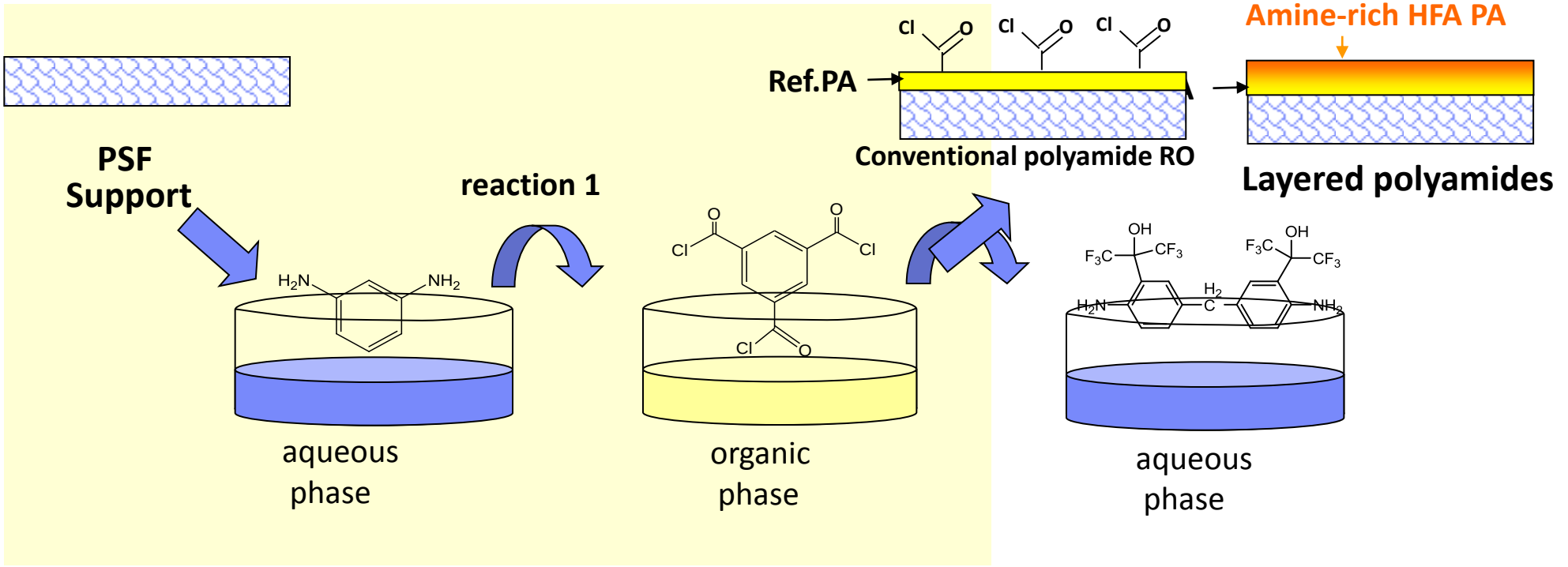
Gen-2



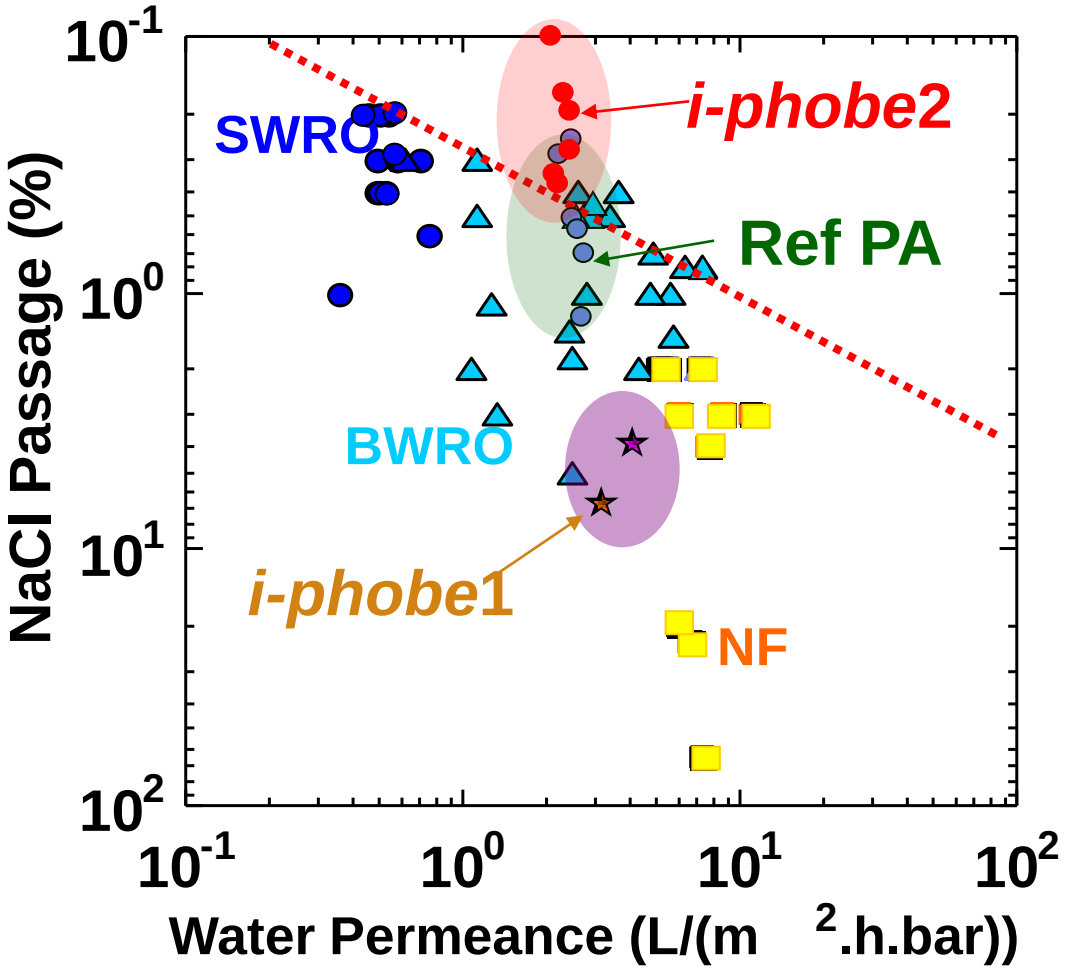
	Conventional RO	i-phobe 1
Chlorine Resistance		Good ☺
Salt Rejection (%)		96 at pH 10 (poor)☹
Water flux (L/m^2.h)		45 (pH 6) ~ 80 (pH10)
Boron Rejection (seawater)		38 % at pH 7 ☹ 98 % at pH 11 ☺

Layered polyamides

Layered polyamide membranes prepared by Sequential Interfacial Polymerization



HFA-Layered Polyamides vs. Commercial Membranes



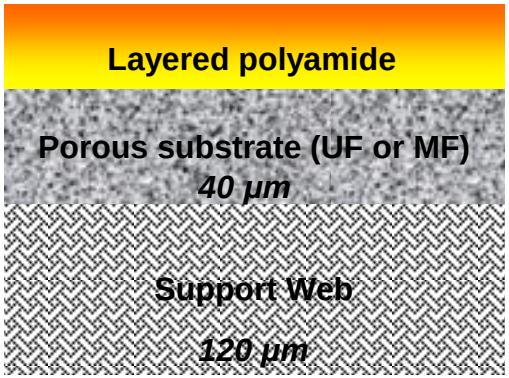
- Commercial sea water RO membranes
- Commercial brackish water RO membranes
- NF brackish water membranes

★ **Layered Polyamide RO membranes**

Excellent combination between salt passage and water permeance

Salt passage vs. water permeance curve: provided by Prof Benny Freeman (UT-Austin)

Seawater Desalination by *i-phobe* (Gen-2) Membrane



Bilayered PA membrane

- Evaluation done by a RO manufacturer

- Feed water: seawater (sand filtration before RO)
- Pressure: 5.5 MPa (ca. 800 psi)
- pH: 6.5
- Temperature: 25 ^{o}C
- Membrane surface flow velocity: 0.18 m/s

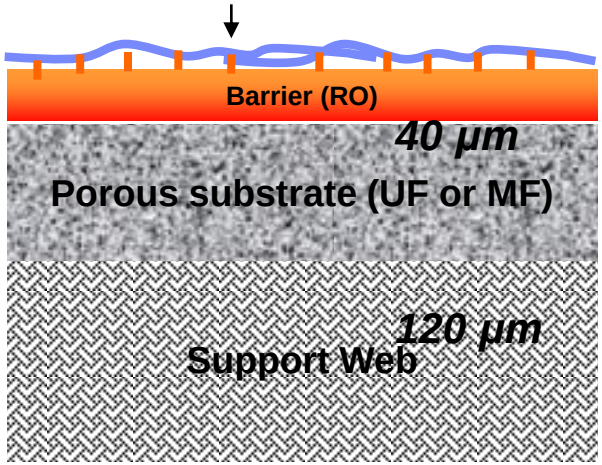
	TDS* rejection (%)	Flux (L/M^2h)	Boron Rejection (%)
Sample 1_A	99.66	31.25	86.0 (pH 6.5)
Sample 2_A	99.75	24.17	90.5 (pH 6.5)

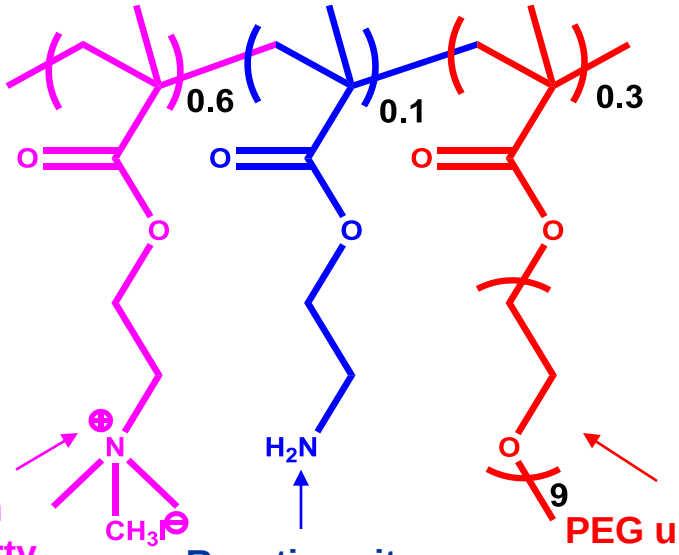
*TDS: total dissolved solid, Sample 1 and Sample 2 were prepared on different support membranes

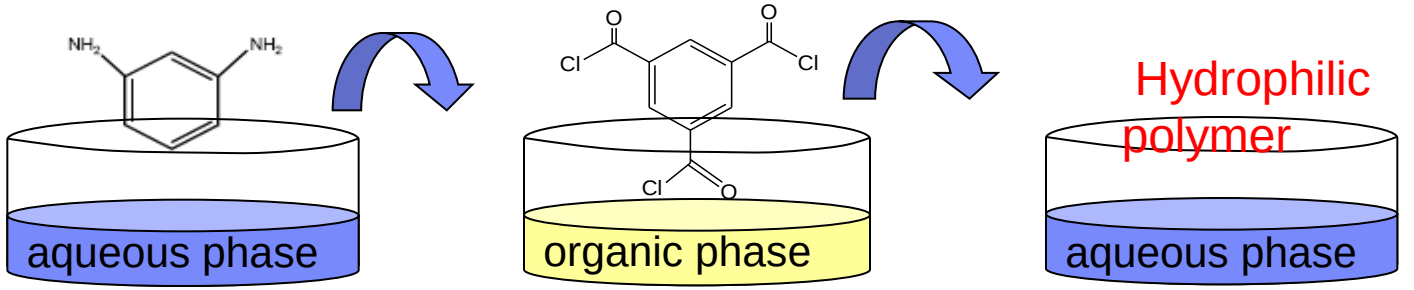
The performance of KACST-IBM's hand-casted i-phobe II membrane was comparable to commercial high performance sea water desalination membranes made by optimized coating process => Very Promising!

I-2. Ultra-Thin Anti-Fouling Materials for RO

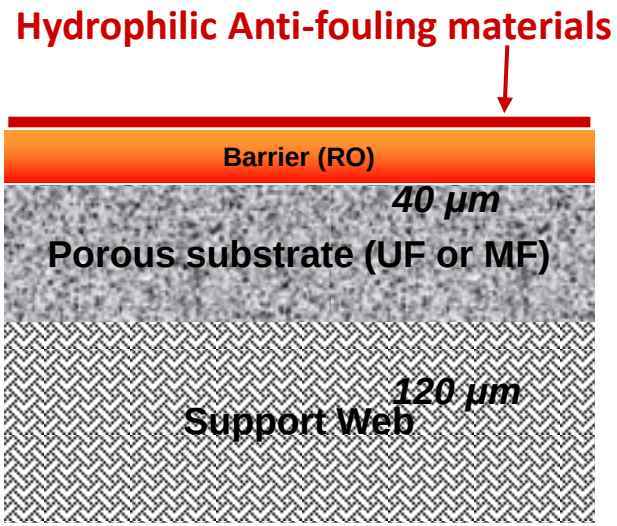
Ultra-thin hydrophilic layer (grafting, interfacial crosslinking..)

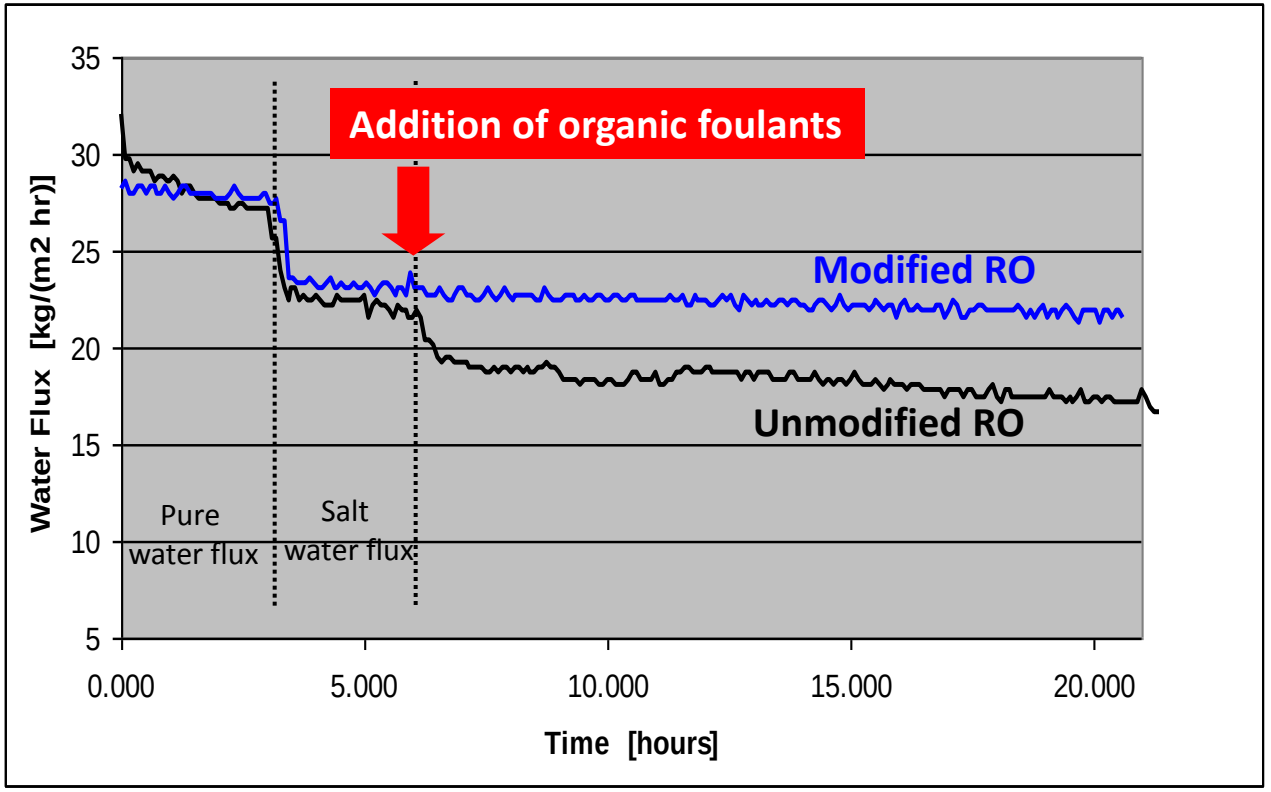






I-2. Improved Anti-Fouling Efficiency: RO process

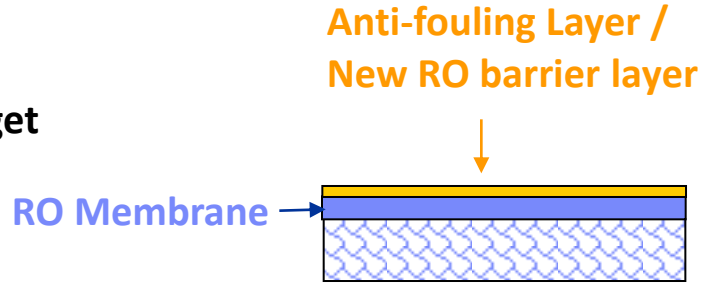




From Research Materials to Product Development

Phase 1 (Research at ARC)

- Optimize materials (both RO layer and antifouling coating) (Target performance: NaCl rejection ≥ 99. 5 %, Water Permeance > 0.6 ~ 1 L m^{-2} h^{-1} bar^{-1})
- Integrate film stack (Fouling Resistant, RO Membranes)



Thin-film composite membrane

2” diameter,
10” length

Phase 2 (Cooperative work between ARC and Vendor 1)

- Prototype module phase (rapid cycles of learning)
- Evaluation of prototype modules at IBM and at KACST
- Optimized membrane module (chemistry and process)

Phase 3 (manufacturing)

- Technology transfer to Vendor 2
- Full scale modules for use in CPV-driven desalination plant

8”, 16” or 20” diameter,
40” length

Conclusions

- KACST and IBM has a highly successful collaboration in membrane research and development
- We have introduced two new platforms for RO desalination membranes
- i-phobe2 membrane has superior flux and salt rejection
- Currently we are working on developing partnership with Vendor 1 for small scale module fabrication
- Antifouling coating modified RO membranes showed higher flux than the reference polyamide membranes
- New Applications = New Innovation

Thank you for your attention!