CornellEngineering
Civil and Environmental Engineering

CEE 4540

Sustainable municipal drinking water treatment

Topic: Desalination

Instructor: YuJung Chang

YuJung.Chang@aecom.com

Class #16 10/24/2018 2:55 – 4:10pm

Desalination - Seawater

Homework: Provide Basic Design for a Seawater RO (SWRO) Membrane Plant (Due 10/31)

- Capacity: 20 MGD
- Assumptions:
  - Membrane Production Flux: 8 gfd
  - TDS: 32,000 mg/L
  - 7 RO elements in each RO vessel
  - No more than 9 Height (9 membrane vessels in vertical direction in each skid)
  - No more than 50 membrane Vessels per skid
  - 10% Redundancy

Your Design:

- Select a SWRO Membrane from Dow's product line (an example shown below)
  - Provide reasons/benefits for the RO element selection
  - Determine how many membrane elements needed
  - Determine how many RO Trains needed
- How many membrane elements needed?
- How many RO skids required?
- Determine Osmotic Pressure for the raw seawater
- https://www.dow.com/en-us/markets-and-solutions/products/dowfilmtecseawaterreverseosmosis8elements/DOWFILMTECSW30HRLE440i

AECOM Imagine it. Delivered.

Seawater Desalination
It’s Past, Present, and Future

Seawater Desalination: Historical Perspective

- Desalination has been practiced since ancient times
- Used by explorers since the since the early 1600’s
- Commercial scale thermal desalination used since World War II
- Rapid increase in membrane desalination in recent years

Seawater Desalination: Historical Perspective

– It has always been the most expensive way to produce drinking water at the commercial scale (and still is):

- High Planning & Permitting costs
- High Capital Costs
- High Operation & Maintenance Costs

Seawater Desalination: Historical Perspective

– Historically, seawater desalination has therefore been practiced almost exclusively in areas that are:

- Close to the ocean (duh !)
- With very low annual rainfall
- With abundant and/or low cost energy
- Example: The Middle East

Seawater Desalination: A Solution to the World’s Water Crisis ?

- New Global Influences are changing this situation:
  - Global warming…..severe drought conditions becoming more common (e.g. Australia, Spain)
  - Approximately 50% of the world’s population live within 200 km of the coast
  - Many of the world’s largest and fastest growing cities are near the coast
  - More people move to coastlines (both younger & older generation)

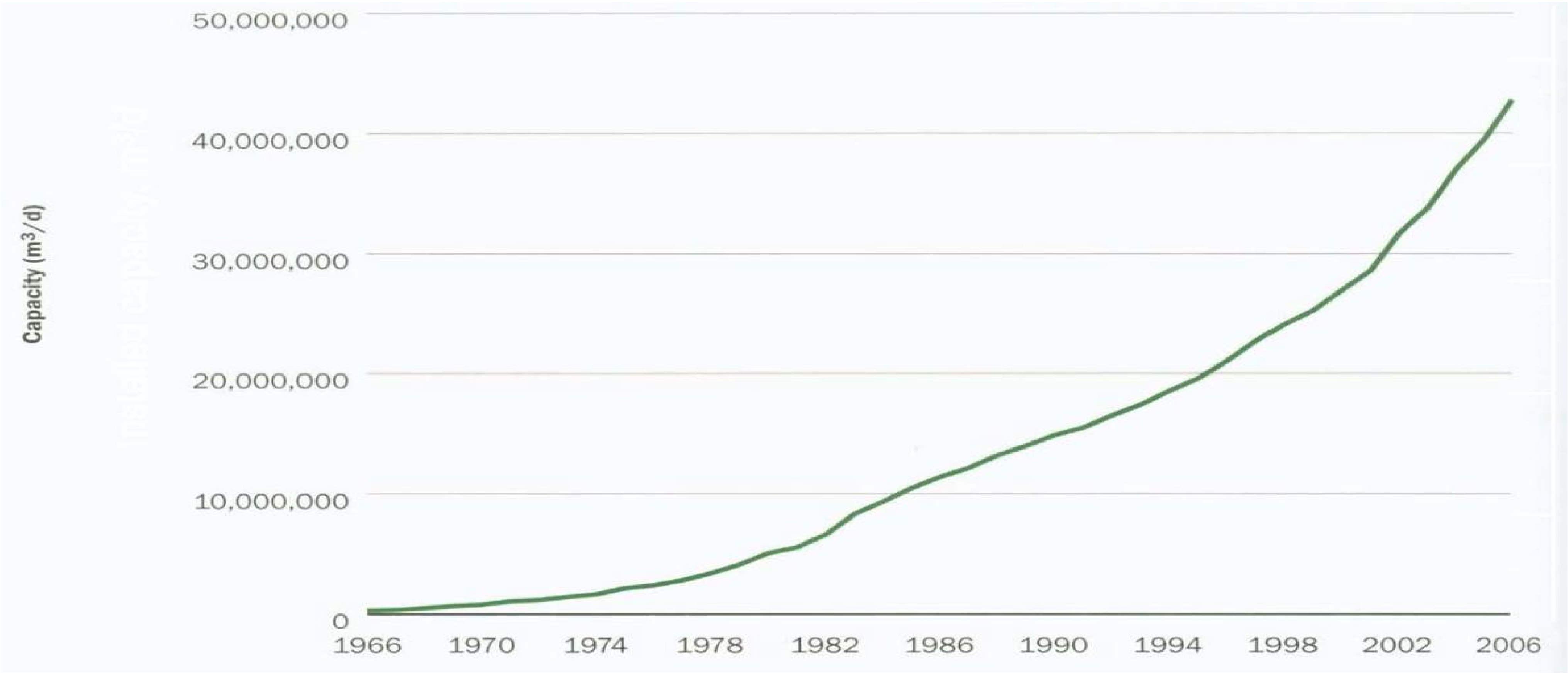
Seawater Desalination
A Solution to the World's Water Crisis ?

- Available, lower cost water sources are nearing or at exhaustion in many areas
- Desalination has been gradually getting cheaper
- Seawater desalination is growing astronomically on a global scale

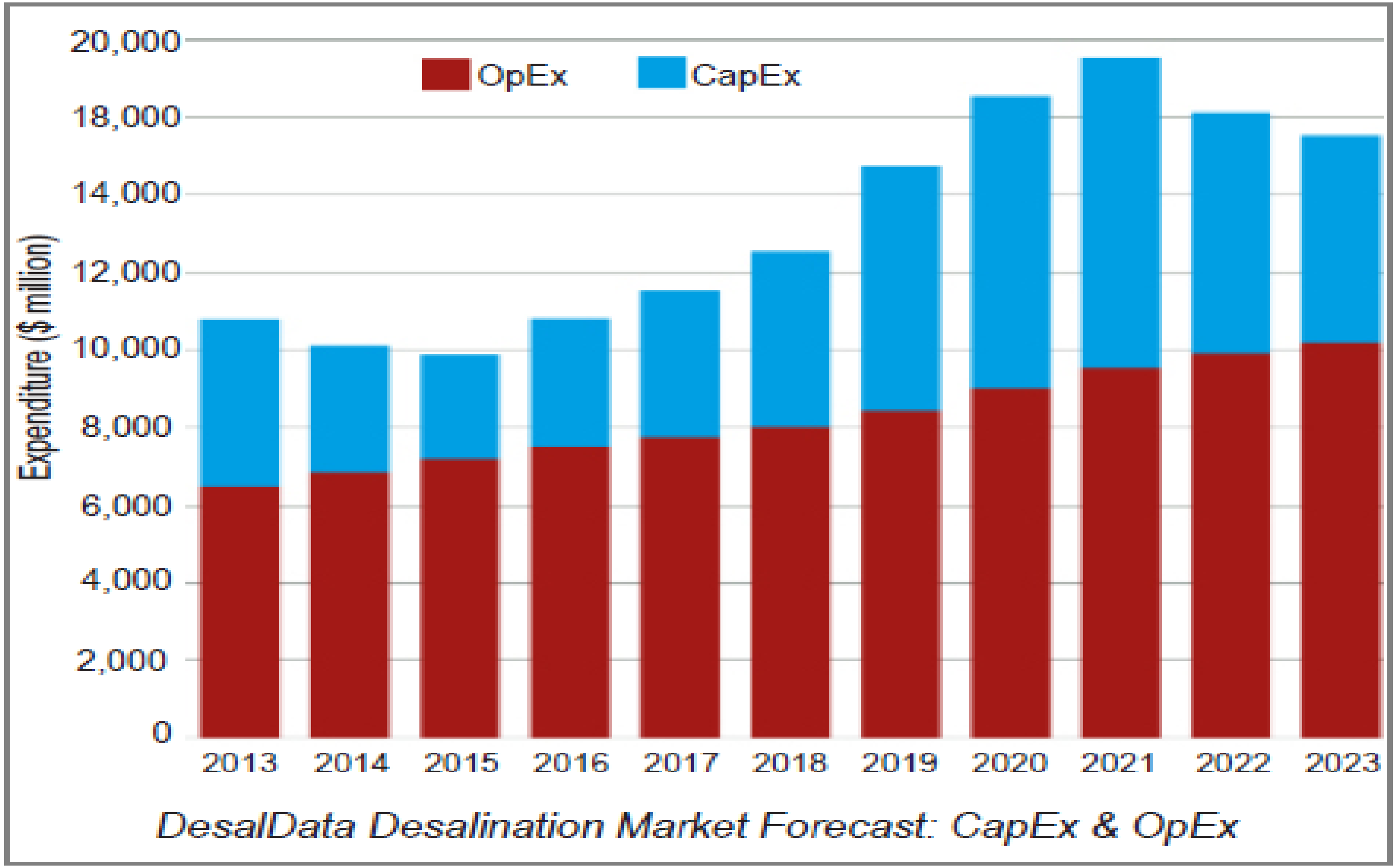

Applications for SWRO

- Desalination for municipal costumers (e.g., Tampa Bay, FL; Carlsbad, CA)
- Industrial applications (mining industry, power generation, etc.)
- Water Reuse (treating wastewater treatment plant effluent)

World Installed Desalination Capacity (1966 through 2006)



Global Desalination Market



Seawater Desalination – The Basics

- Seawater desalination is achieved on the commercial scale in two main ways:
  - Thermal Processes, where water is evaporated, then condensed, leaving impurities behind
  - Membrane Processes, where contaminants are removed from water to purify it
- The specific process used in a Project is highly dependent on site specific variables:
  - Seawater salinity
  - Seawater quality (TOC, Algae, biological activities, etc.)
  - The cost of electrical power
  - Co-location with wastewater treatment plant, heavy industry and/or power plants

Seawater Desalination Technologies

Thermal Technologies

- Multiple Effect Distillation (MED)
- Multi-Stage Flash Distillation (MSF)
- Mechanical Vapour Compression (MVC)
- Thermal Vapour Compression (TVC)
- Absorption Vapour Compression (AVC)
- Solar Distillation (SD)

Membrane Technologies

- Reverse Osmosis (RO)
- 2-Stage Nanofiltration (NF)

Seawater Desalination Technologies

Thermal Technologies

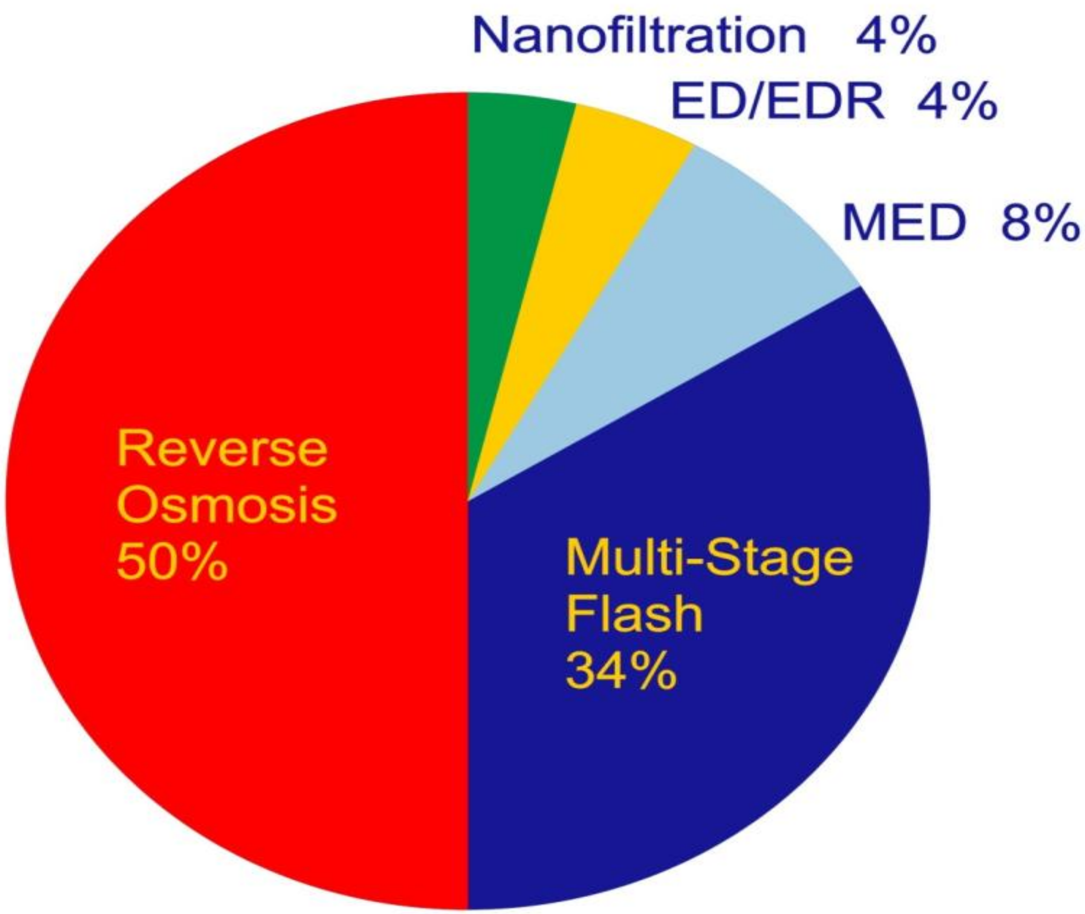
- Multiple Effect Distillation (MED)
- Multi-Stage Flash Distillation (MSF)
- Mechanical Vapour Compression (MVC)
- Thermal Vapour Compression (TVC)
- Absorption Vapour Compression (AVC)
- Solar Distillation (SD)

Membrane Technologies

- Reverse Osmosis (RO)
- 2-Stage Nanofiltration (NF)

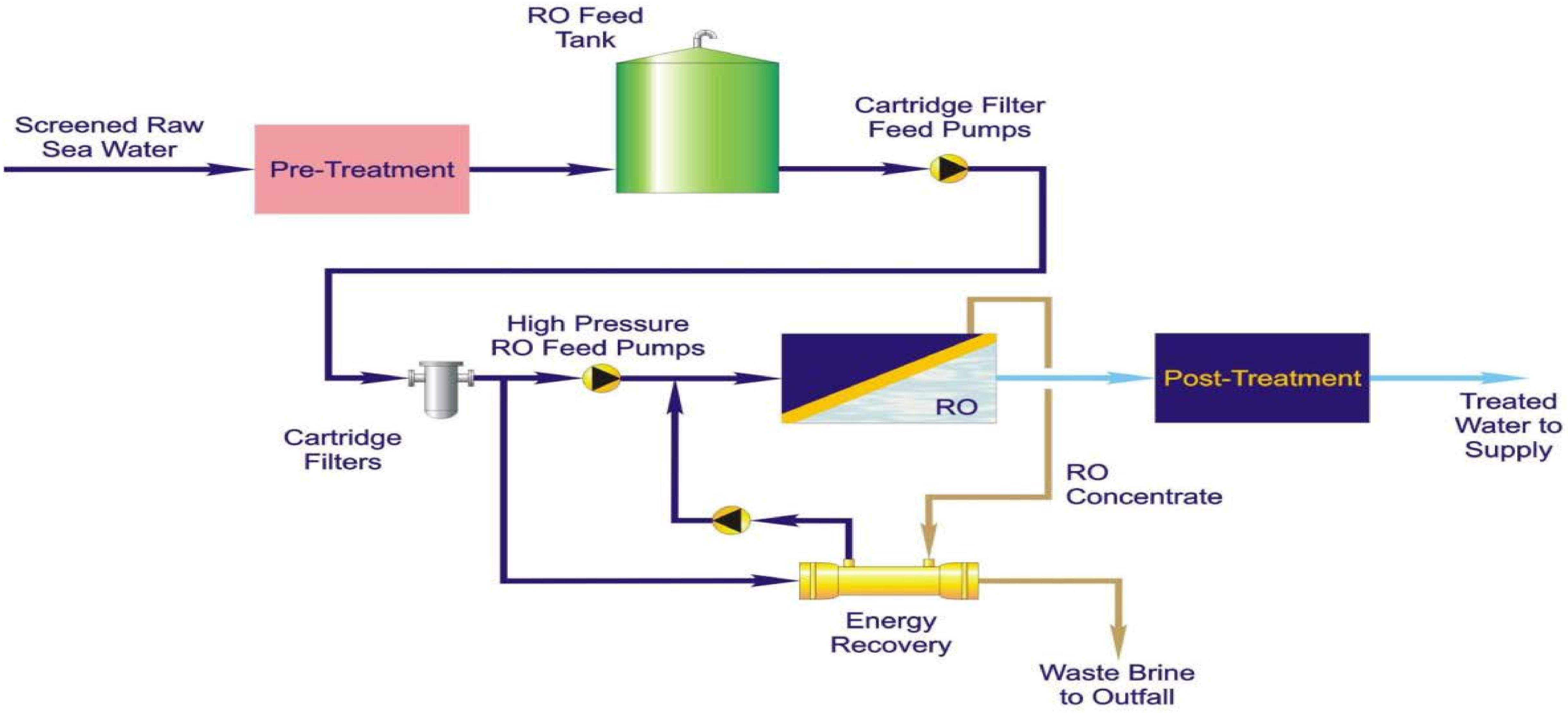
Installed Capacity, by Process

- RO and MSF dominate the industry
- Highest total capacity for non-RO seawater desalination is MSF



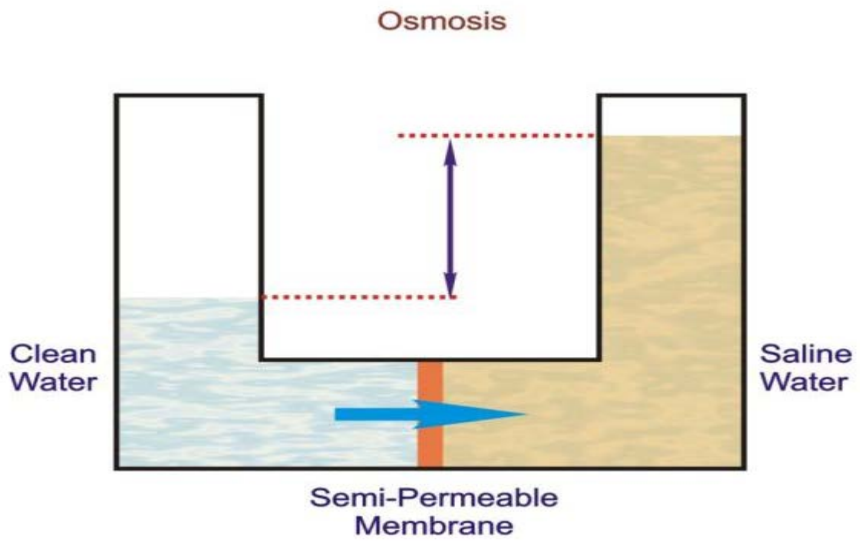
Seawater Desalination Fundamental Principles

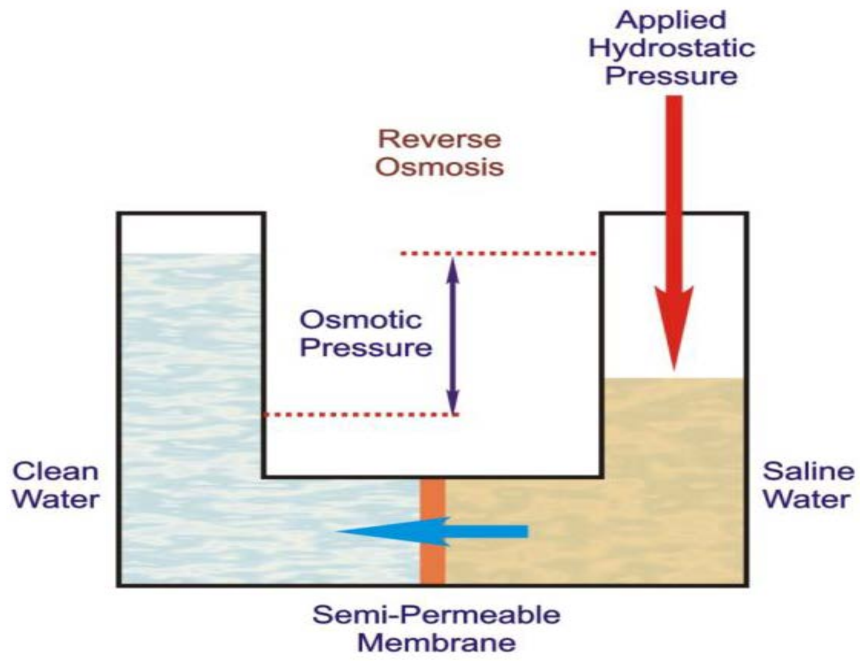
Typical PFD for Seawater Reverse Osmosis (SWRO)



Reverse Osmosis: The Basic Principle

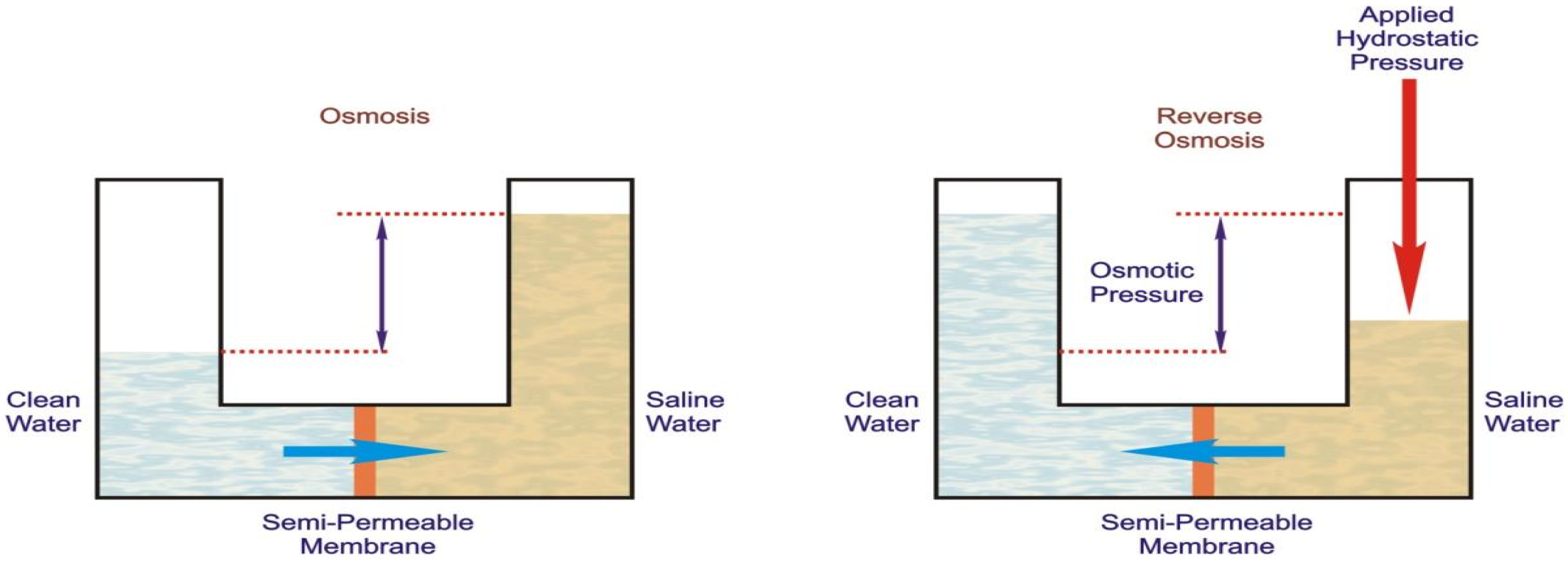
– Osmotic pressure describes the tendency for solute to diffuse from higher concentration region to lower concentration region until the entire solution reaches a homogenous concentration. If salt transport is stopped by membranes, a barrier that posses water “conductivity”, instead of having salt passing through the membranes, water from the lower salinity region will diffuse through the barrier until TDS level in both chambers are equal.





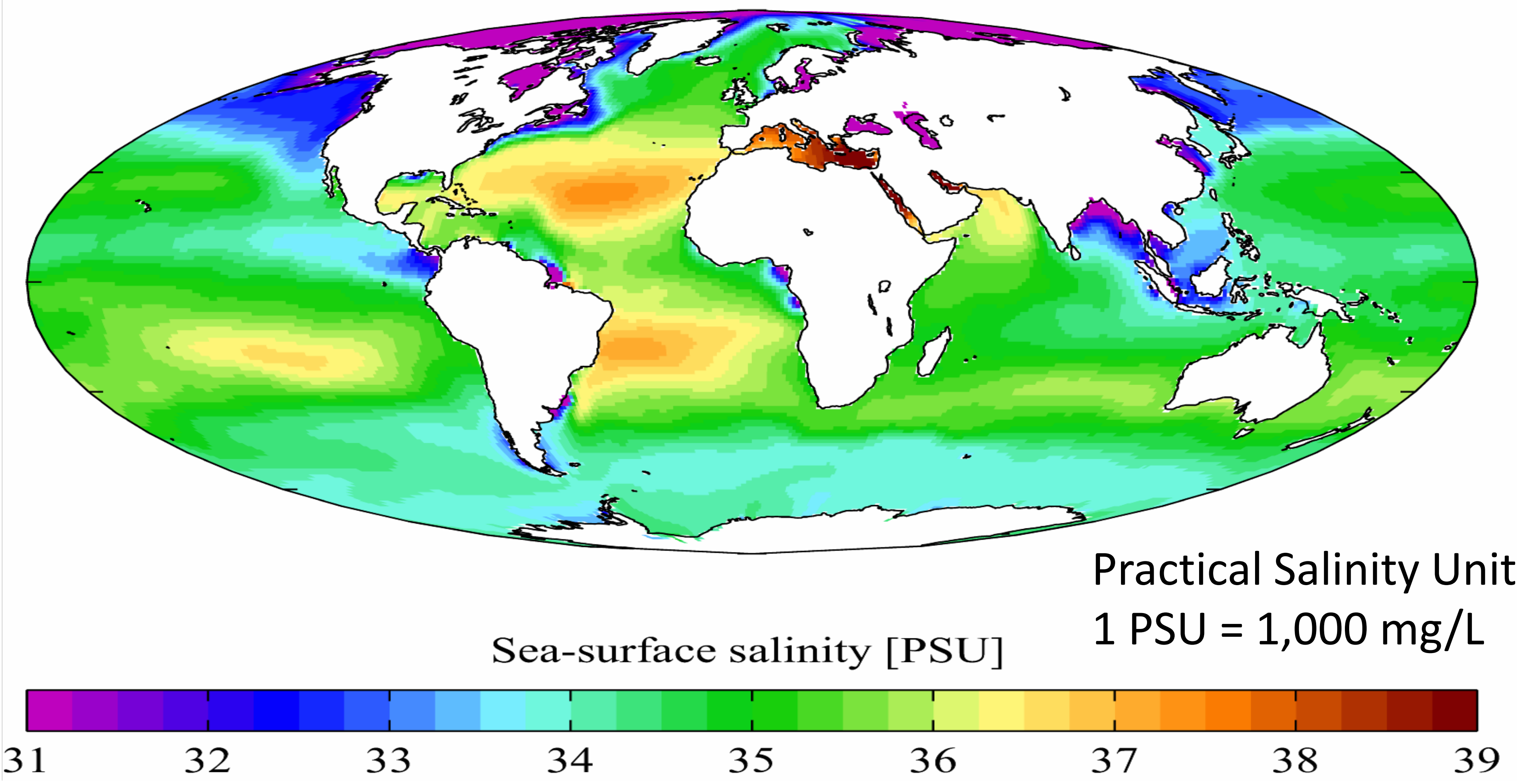
Reverse Osmosis: The Basic Principle

– To force water flow from high TDS solution across the membrane where TDS is much lower on the other side, hydraulic pressure will be needed.



Global Seawater Salinity

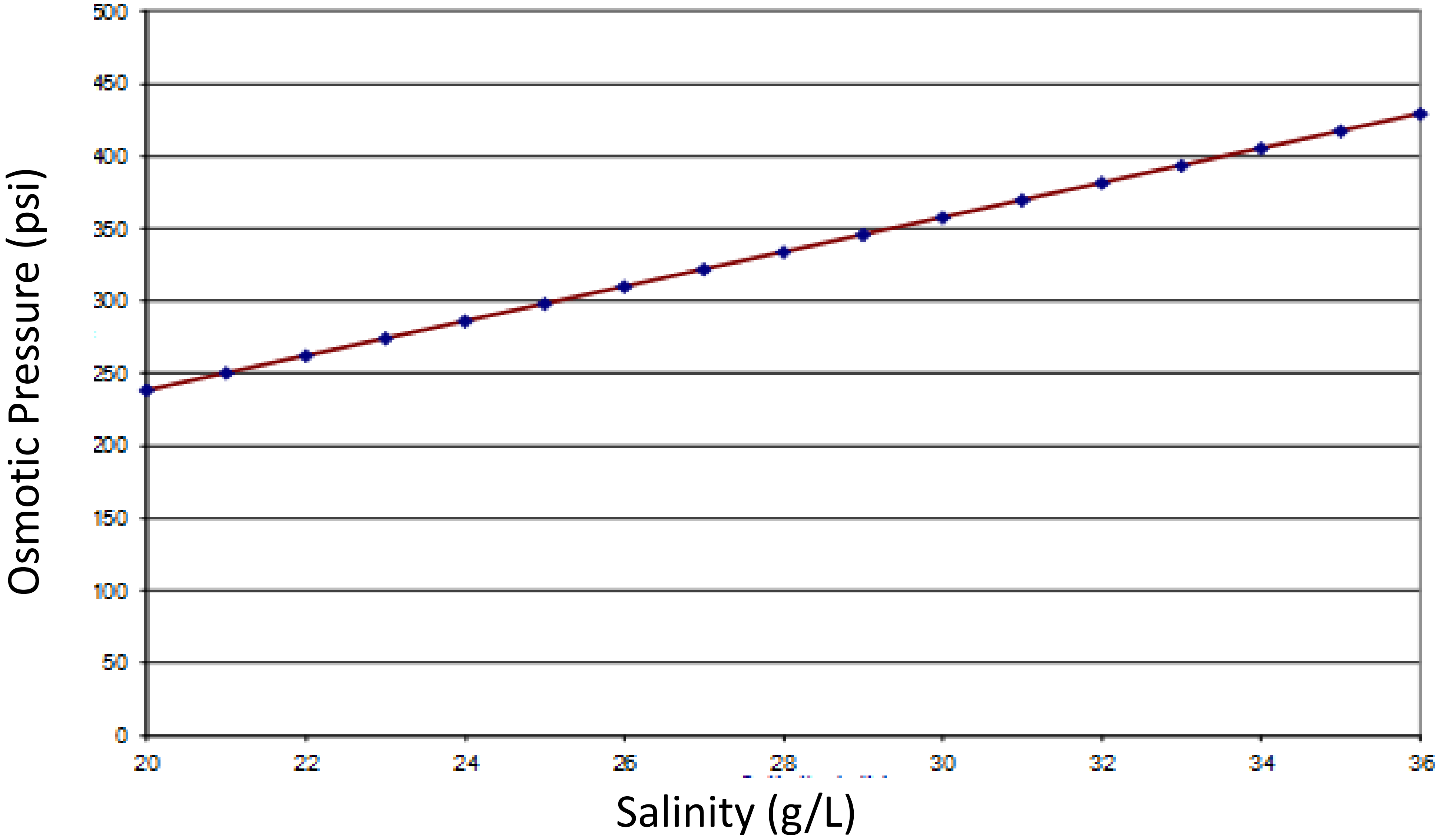
- Ranges from 31,000 – 39,000 mg/L; with 35,000 mg/L as typical for desalination



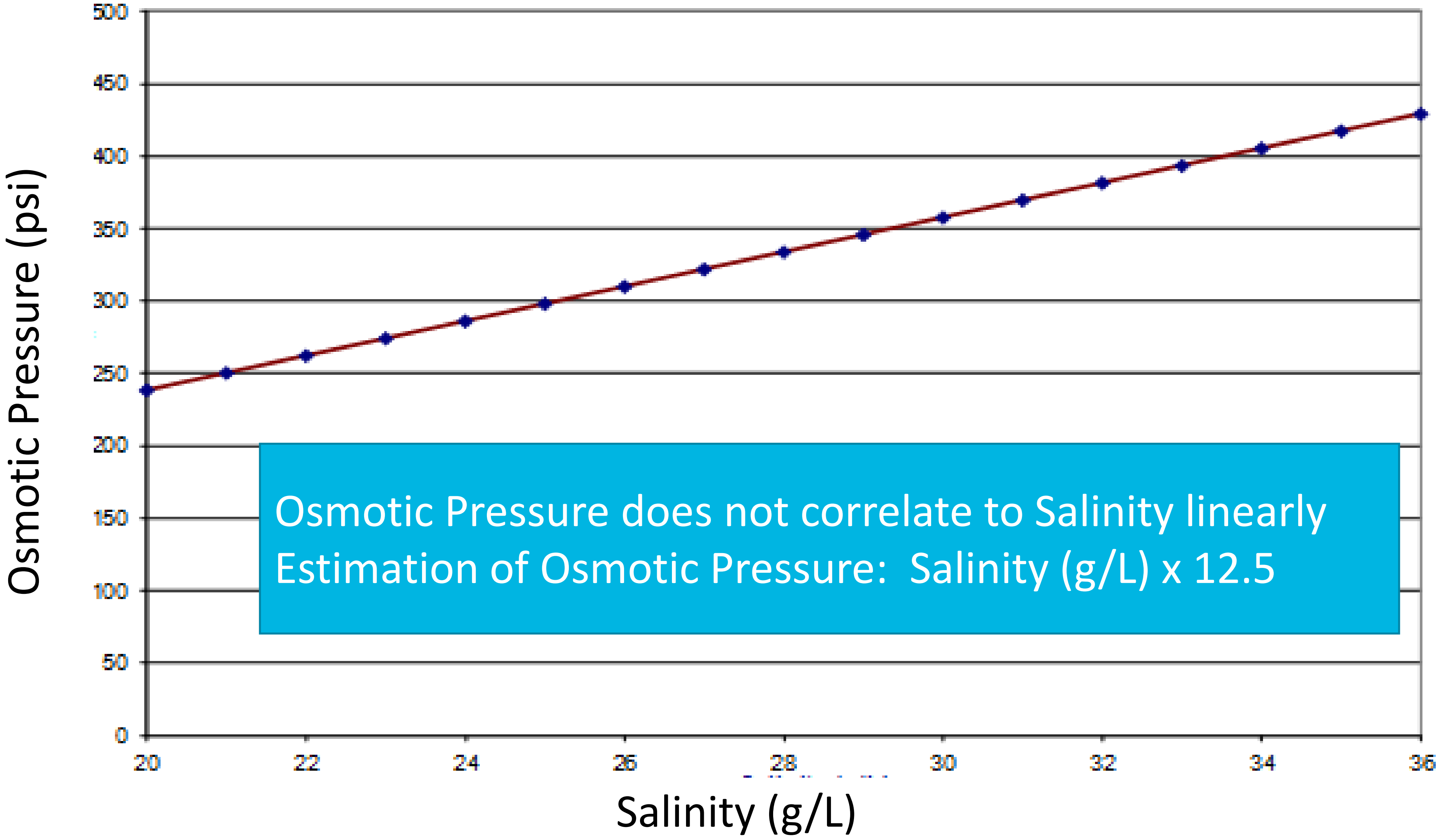
Practical Salinity Unit

1 PSU = 1,000 mg/L

Osmotic Pressure at 20 ºC



Equation for Salinity vs. Osmotic Pressure

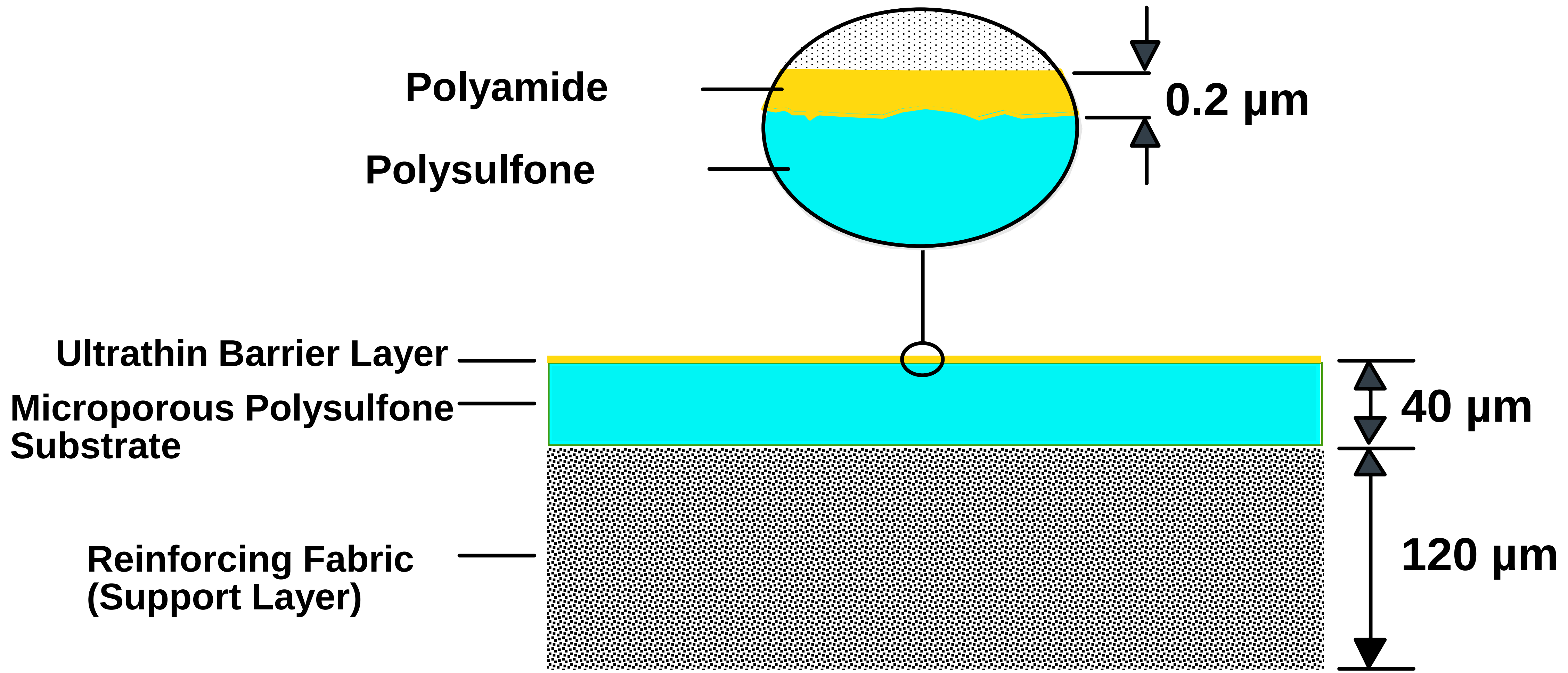


Osmotic Pressure does not correlate to Salinity linearly
Estimation of Osmotic Pressure: Salinity (g/L) x 12.5

Pressure Required for Seawater Desalination

- Theoretical Minimum Energy: 1.02 kWh/m^3
  - Consider osmotic pressure only
- Practical Minimum Energy: 1.52 kWh/m^3
  - Assuming all pumps, valves, piping head-loss, Energy Recovery Devices all work perfectly
- Best Operated SWRO Plant: 2 – 2.5 kWh/m^3

Schematic Cross-Section of Thin-film Composite RO Membranes

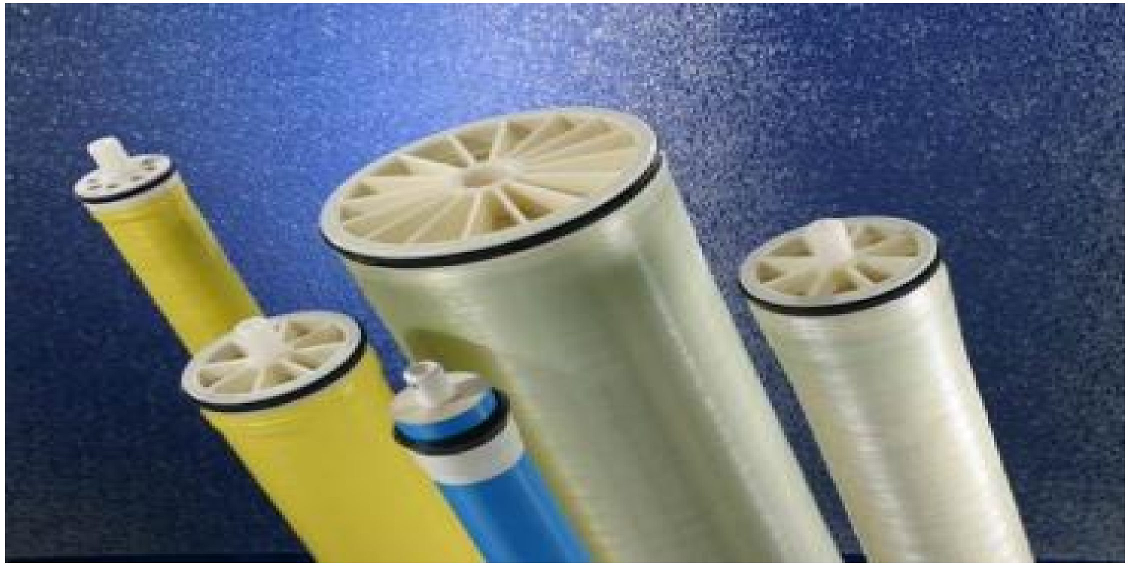


Types of Desalination Membranes

- Nanofiltration (NF)   50 -   225 psi
  - Good for lower TDS, groundwater (with double-valence ions) desalination, or NOM removal applications
  - Rejection % for single valent ions not as good as RO, but still > 95%
- Reverse Osmosis

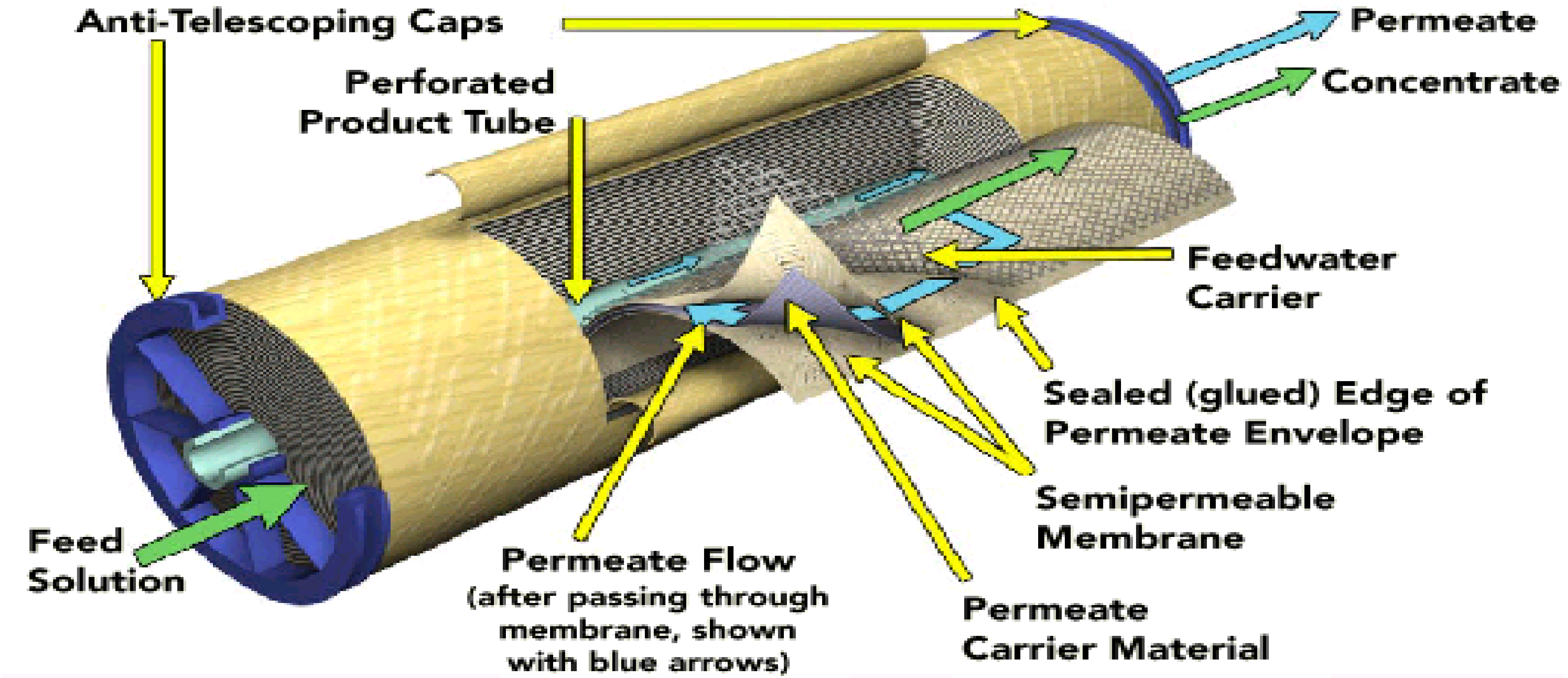
  Brackish water   150 -   600 psi

  Seawater   800 - 1000 psi

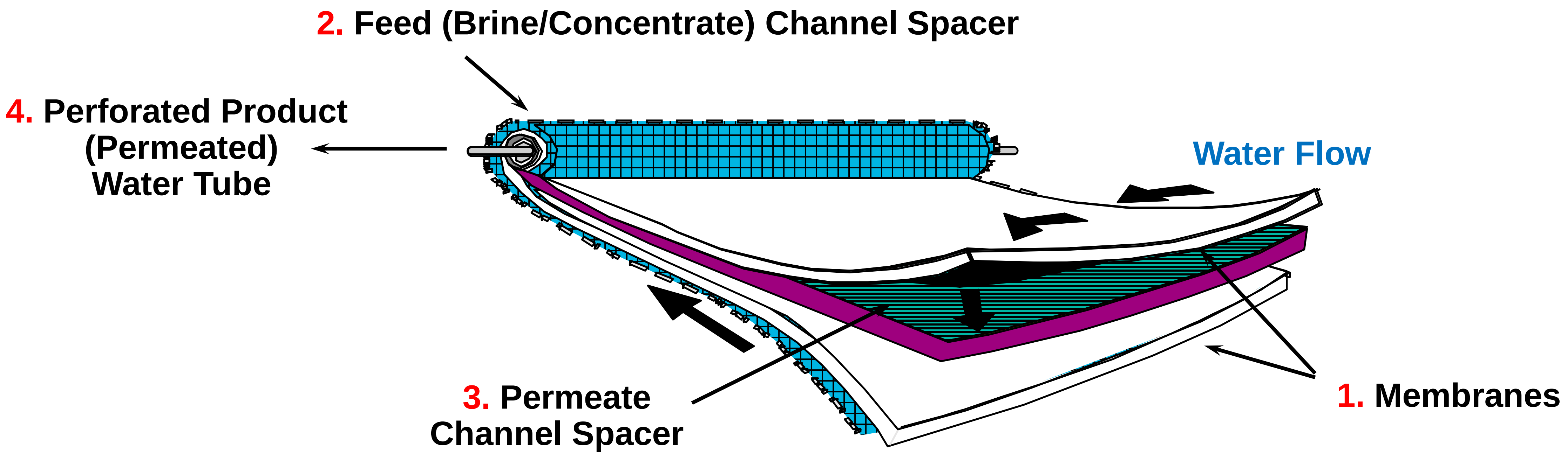


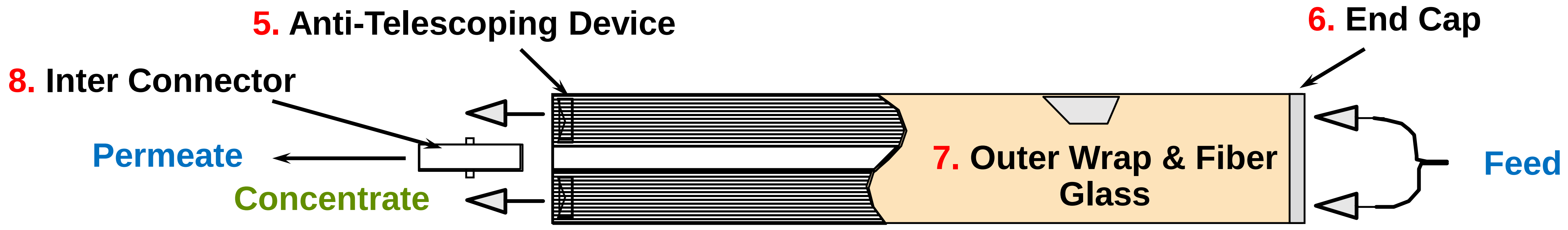
Construction of RO Element, Skid & System

Membrane element Arrangement



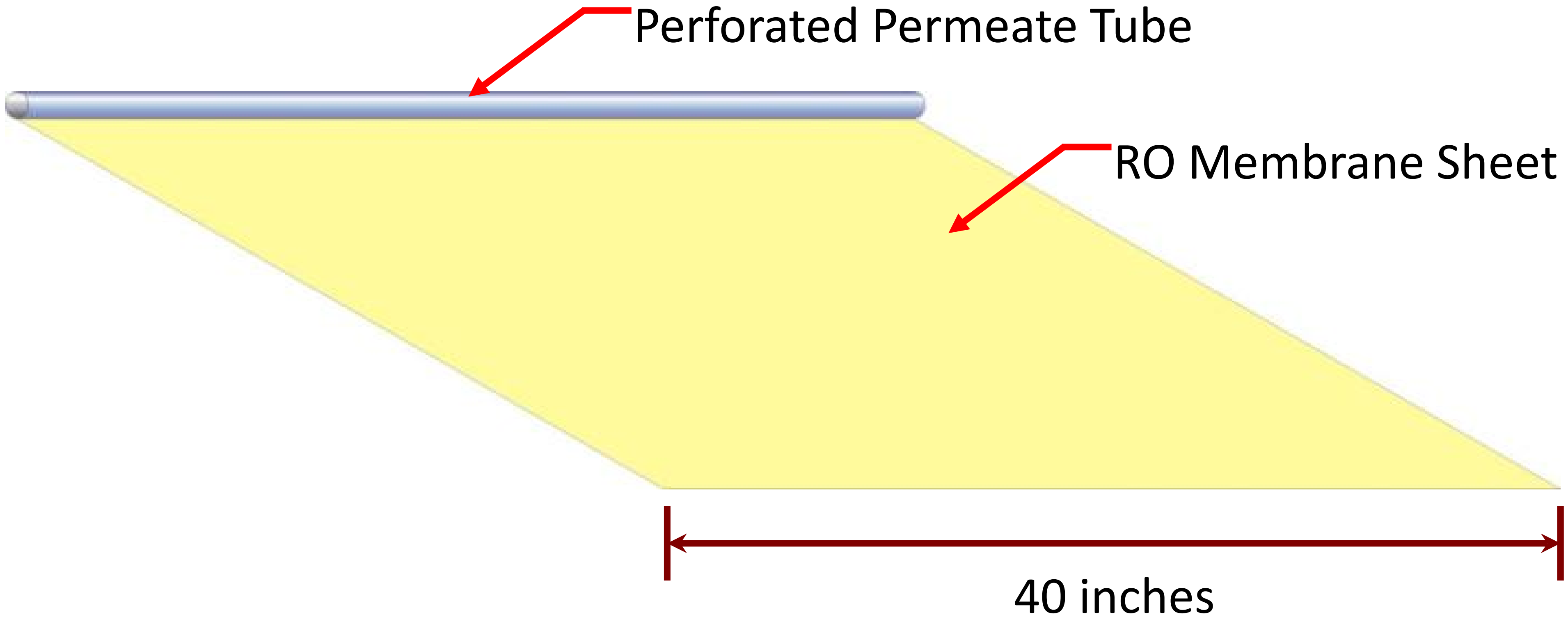
Spiral Wound Element





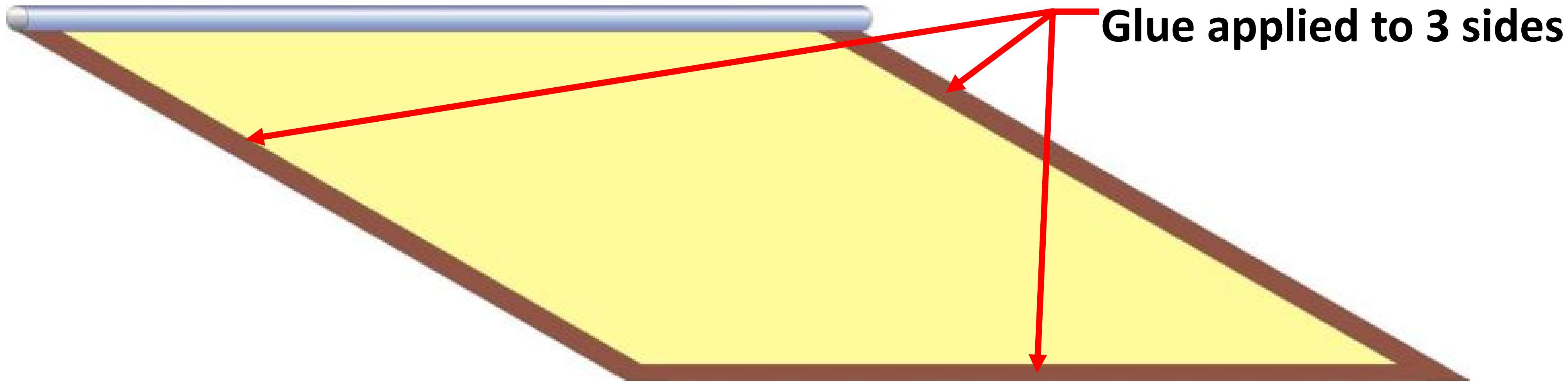
Manufacture of a Spiral Wound Element

- Step 1



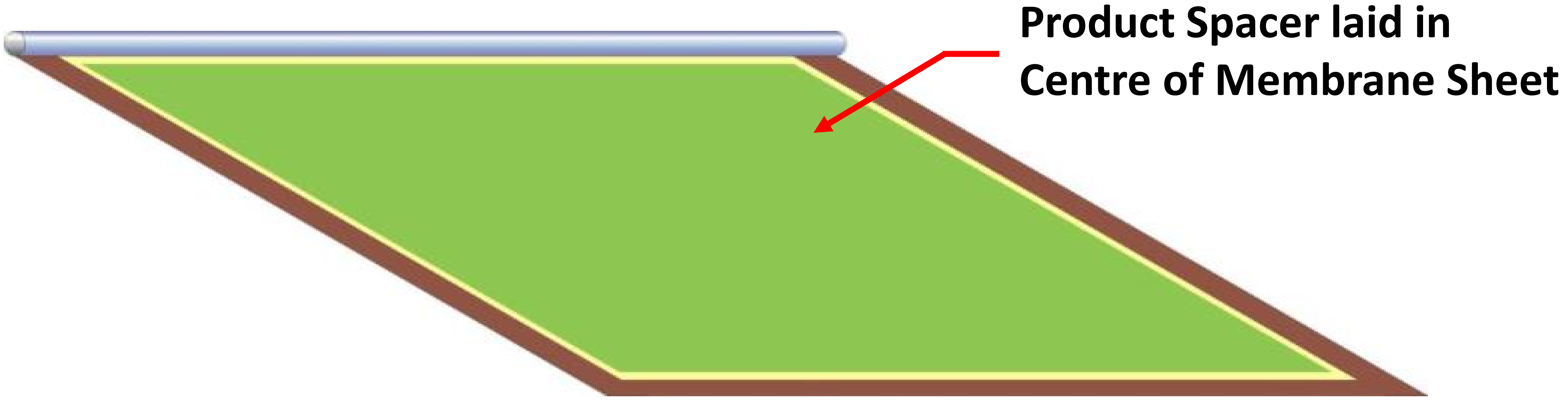
Manufacture of a Spiral Wound Element

- Step 2



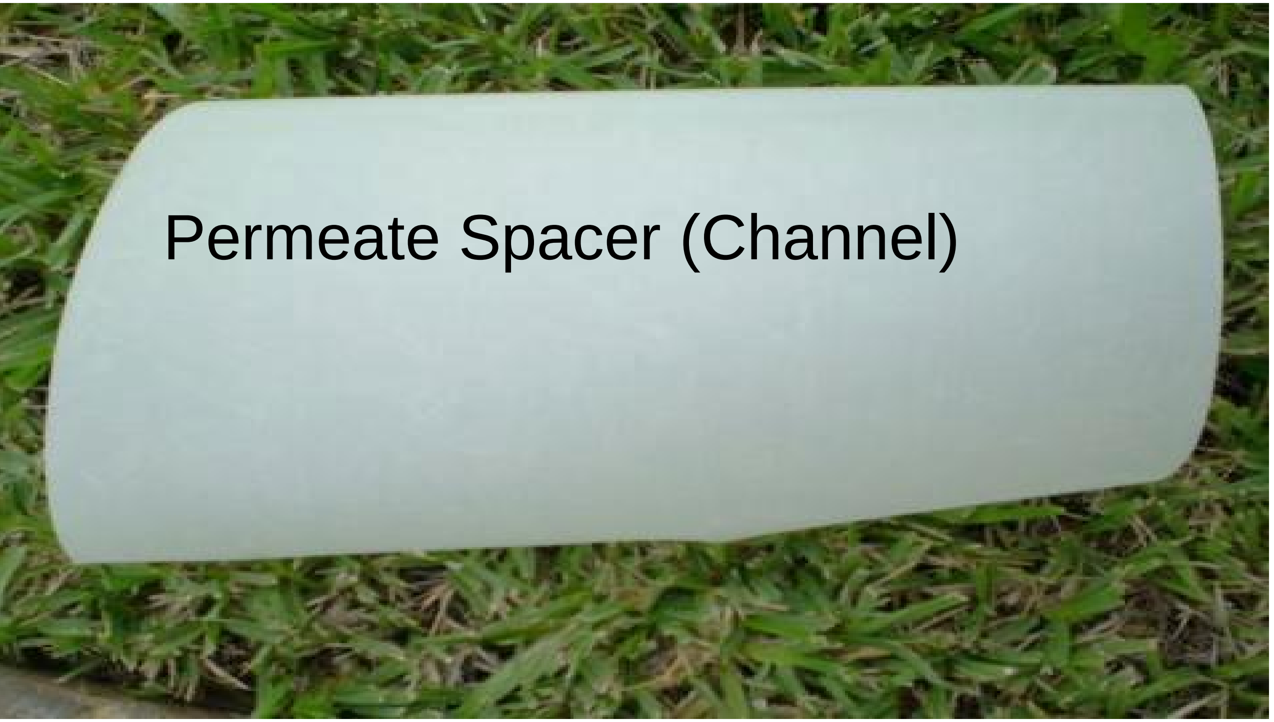
Manufacture of a Spiral Wound Element

- Step 3



Feed Channel and Permeate Channel

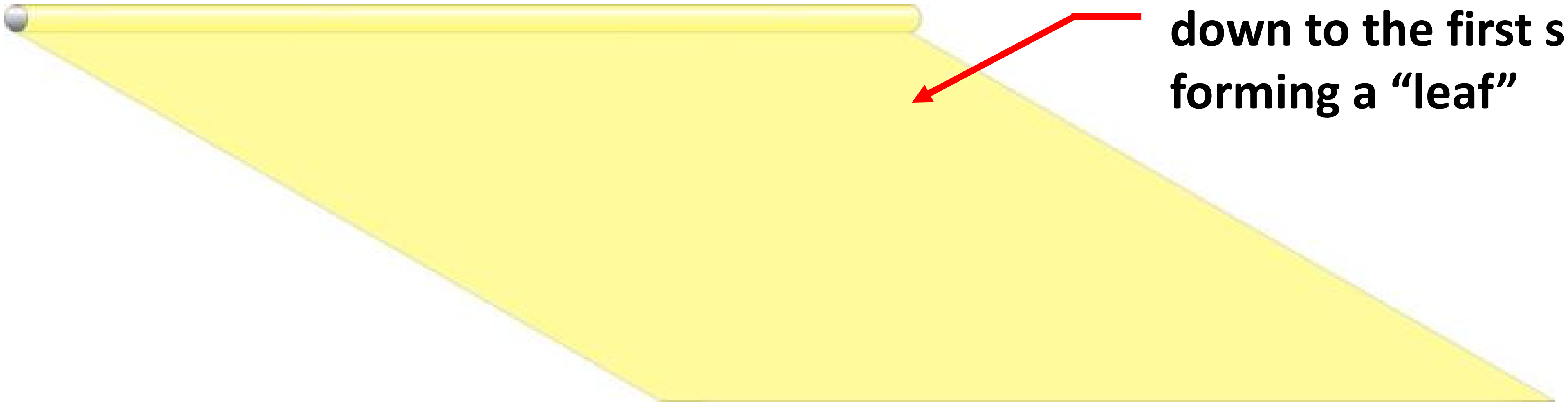
Feed Spacer (Channel)



Spacer: To provide space for water to flow across membrane surface

Manufacture of a Spiral Wound Element

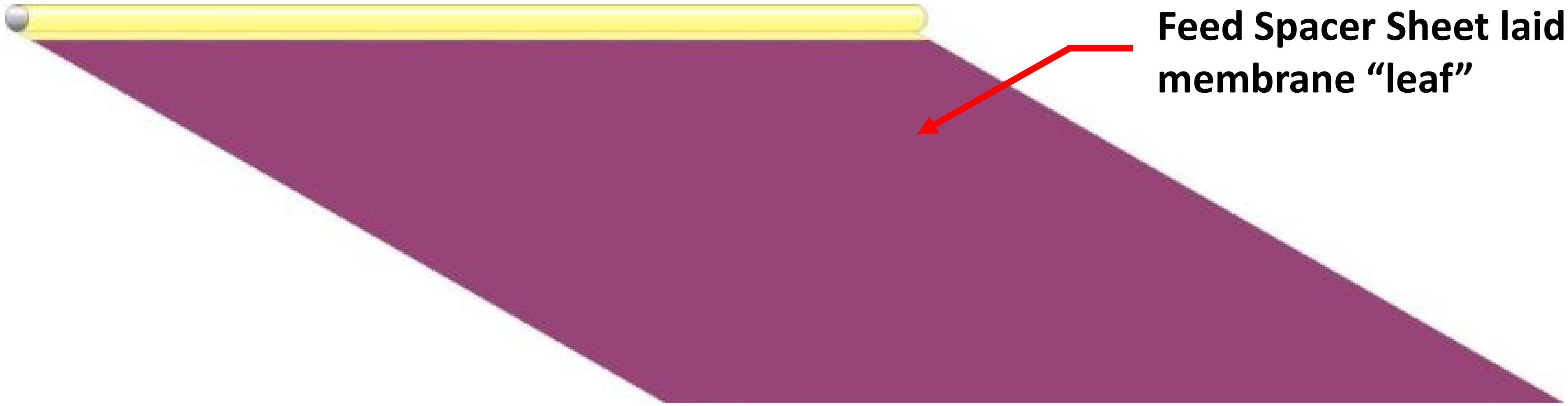
– Step 4



Second Membrane Sheet glued down to the first sheet, forming a “leaf”

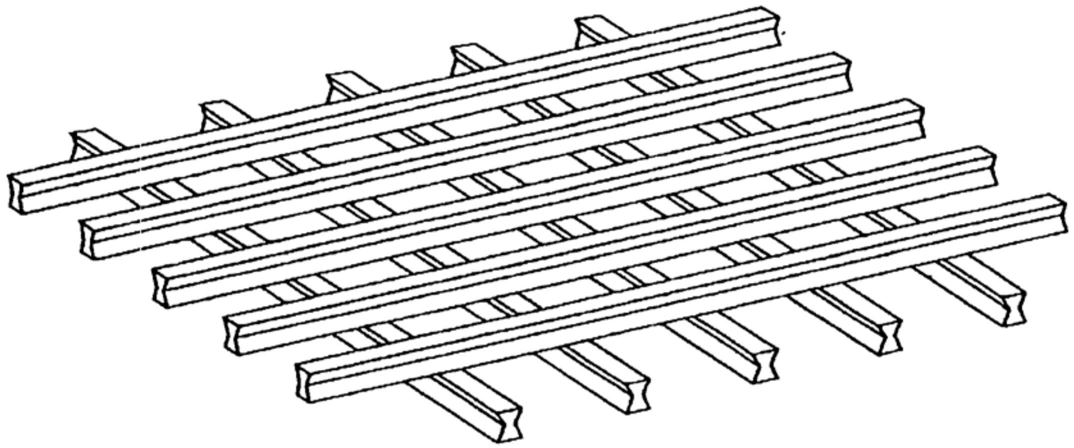
Manufacture of a Spiral Wound Element

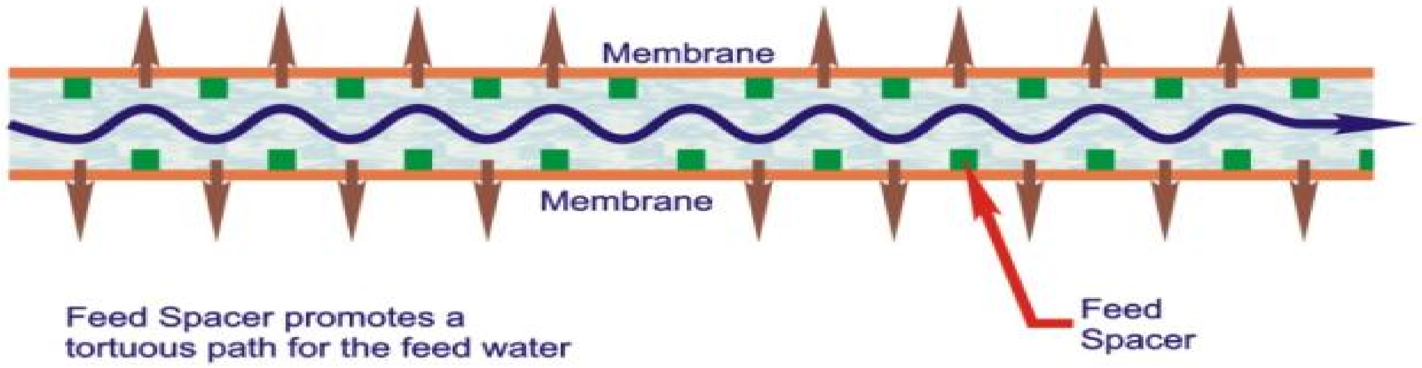
– Step 5



Feed Spacer Sheet laid on top of membrane “leaf”

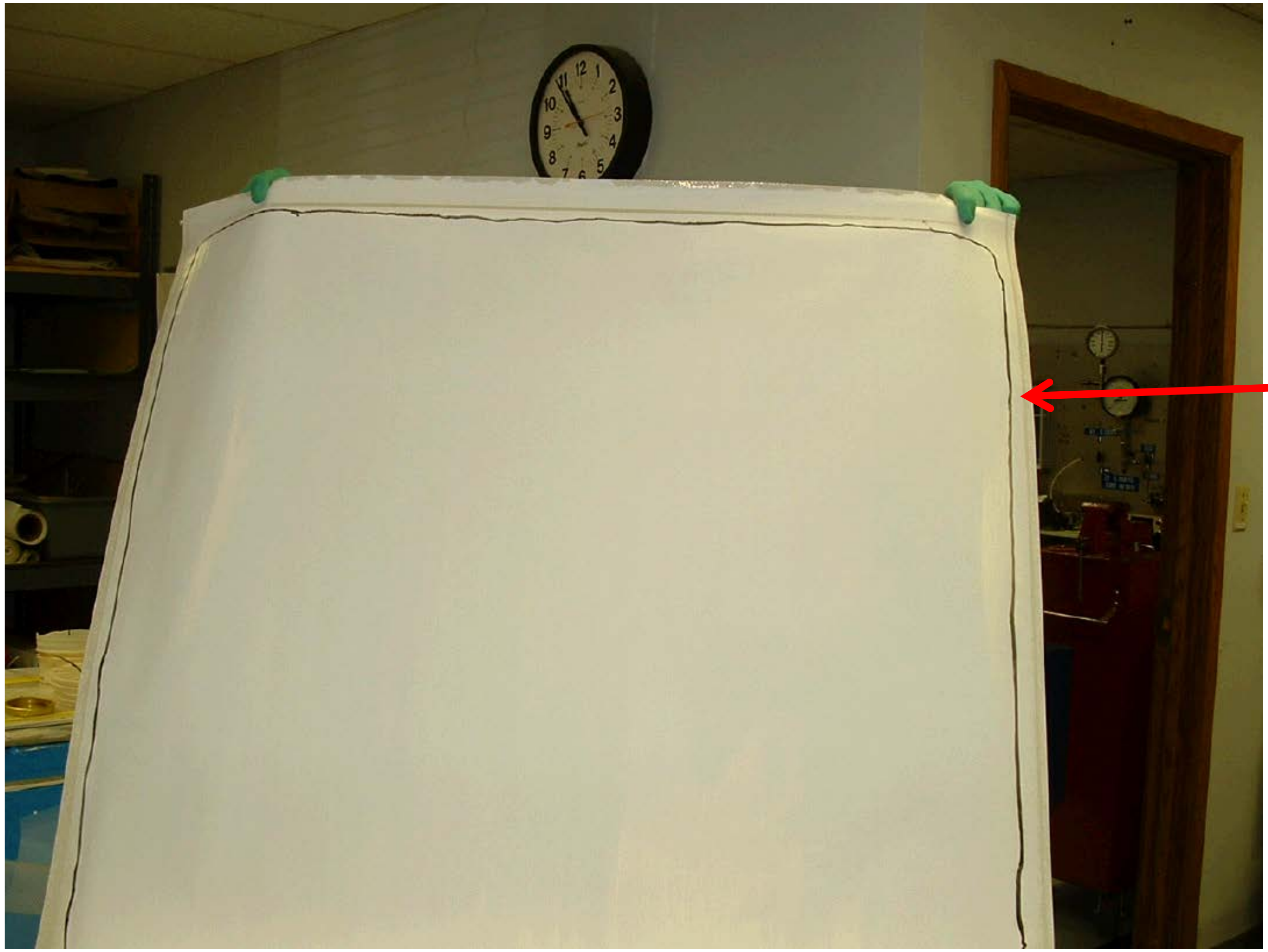
Typical Feed Spacer Detail





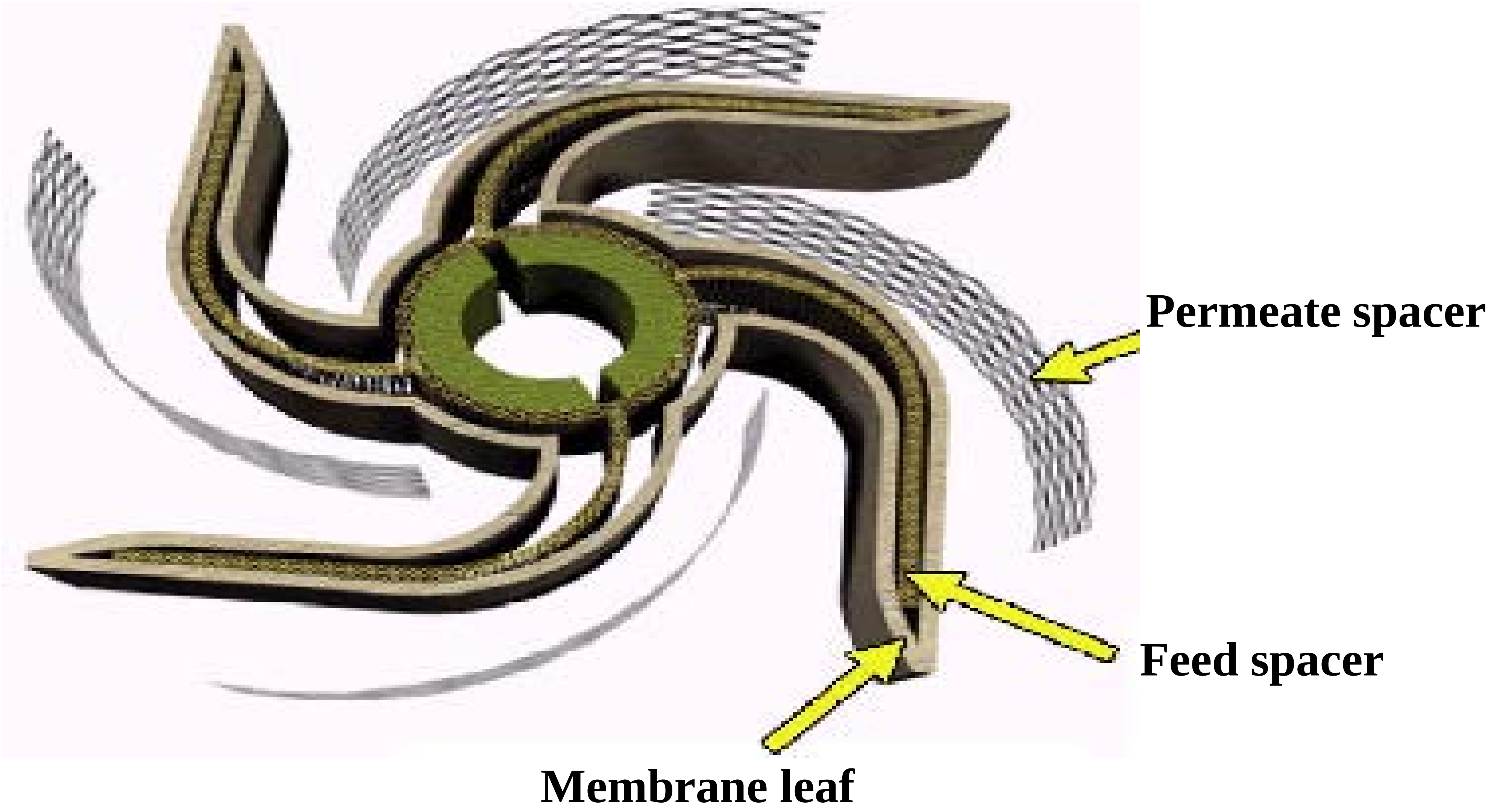
- Typical feed spacer 0.65 - 0.85 mm thick
- Promotes tortuous flow path for feed
- Solids can easily plug the feed spacer channels
- Thicker spacer (0.8 – 0.85 mm) used for higher fouling sources

Water entering the envelope is trapped; it can only go to the product water tube



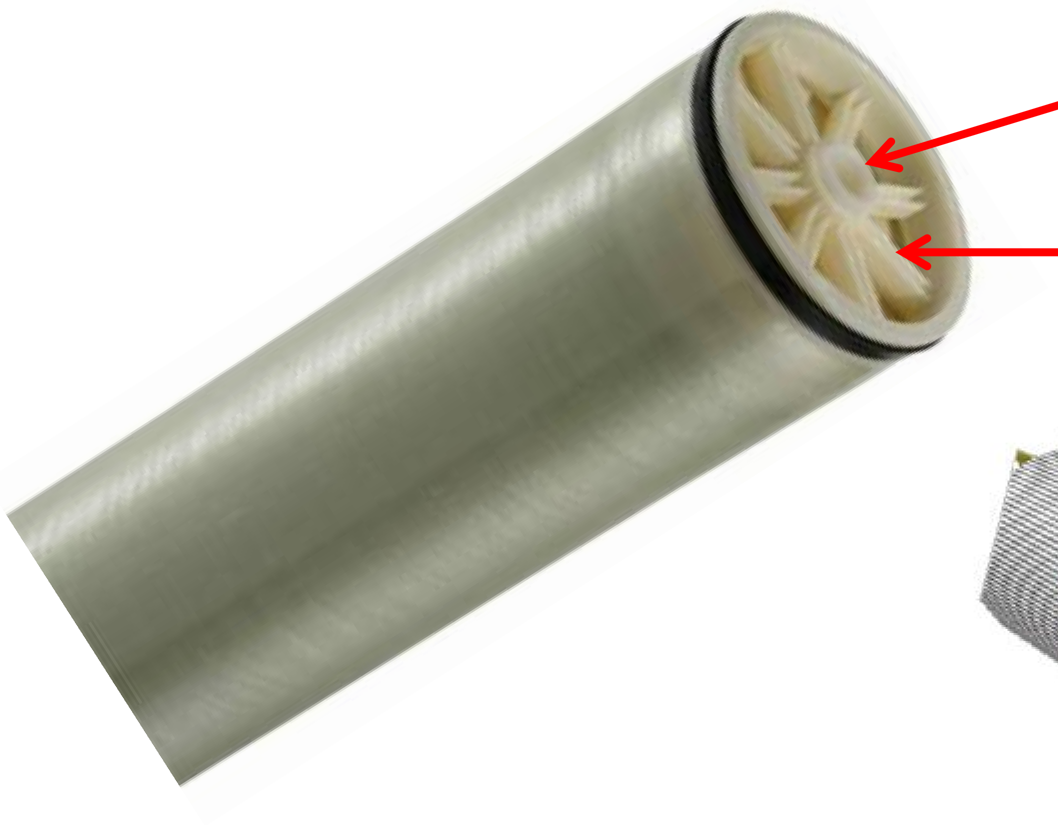
Glue Line

Illustration of RO Membrane Construction



Product Water Tube

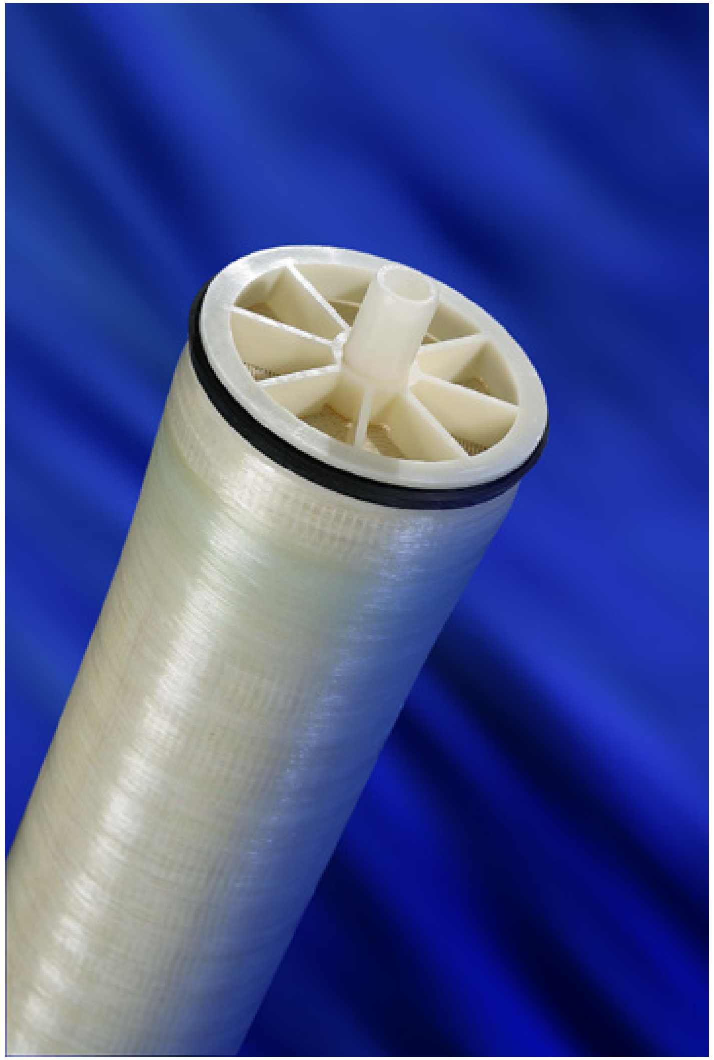
- Serves as center support and collects permeate from permeate carrier



Damaged RO Element

- Excessive Fouling
- Telescoping

Tape it and Fiberglass it



Boxed

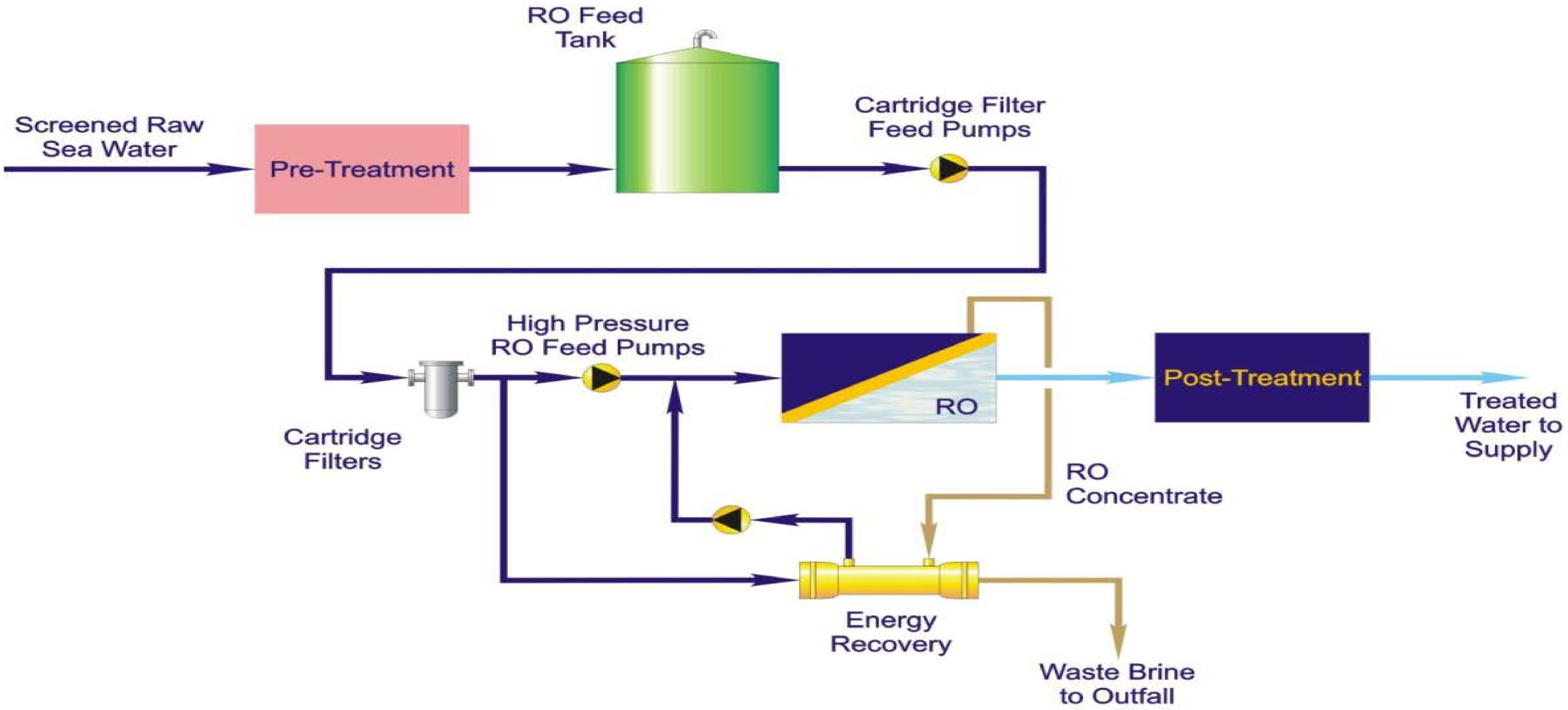
Bagged

Unwrapped Upon Arrival at the Plant…

Loaded …

RO Skids & Plants

Typical PFD for Seawater Reverse Osmosis (SWRO)



Seawater Reverse Osmosis (SWRO)