Low Fouling and Energy Consumption two-stage Forward and Reverse Osmosis desalination Process

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UNIVERSITY OF SURREY

Overview of Presentation

MODERNWATER

- Why Desalination is Important
- Predominant Technology Available
- Energy Consumption of the Existing Predominant Technology
- Is There Scope for Energy/Cost Savings?
- Present the Technology developed at the Centre for Osmosis Research Applications

Global Challenges

- Water

- Energy

- Food

- 70% of All Global Water Use is for Irrigated Agriculture for Food Production.

Water Scarcity

- By 2050 - 47% of will be living in areas of clean water scarcity (UN)

- Relationship between clean water scarcity, spread of disease and child mortality.

How to Supply this Growing Water Demand?

- Implement measures such as utilizing water more efficiently, reduce leakages in public water supply networks – Will NOT give you more than what we get from the Hydrological Cycle.

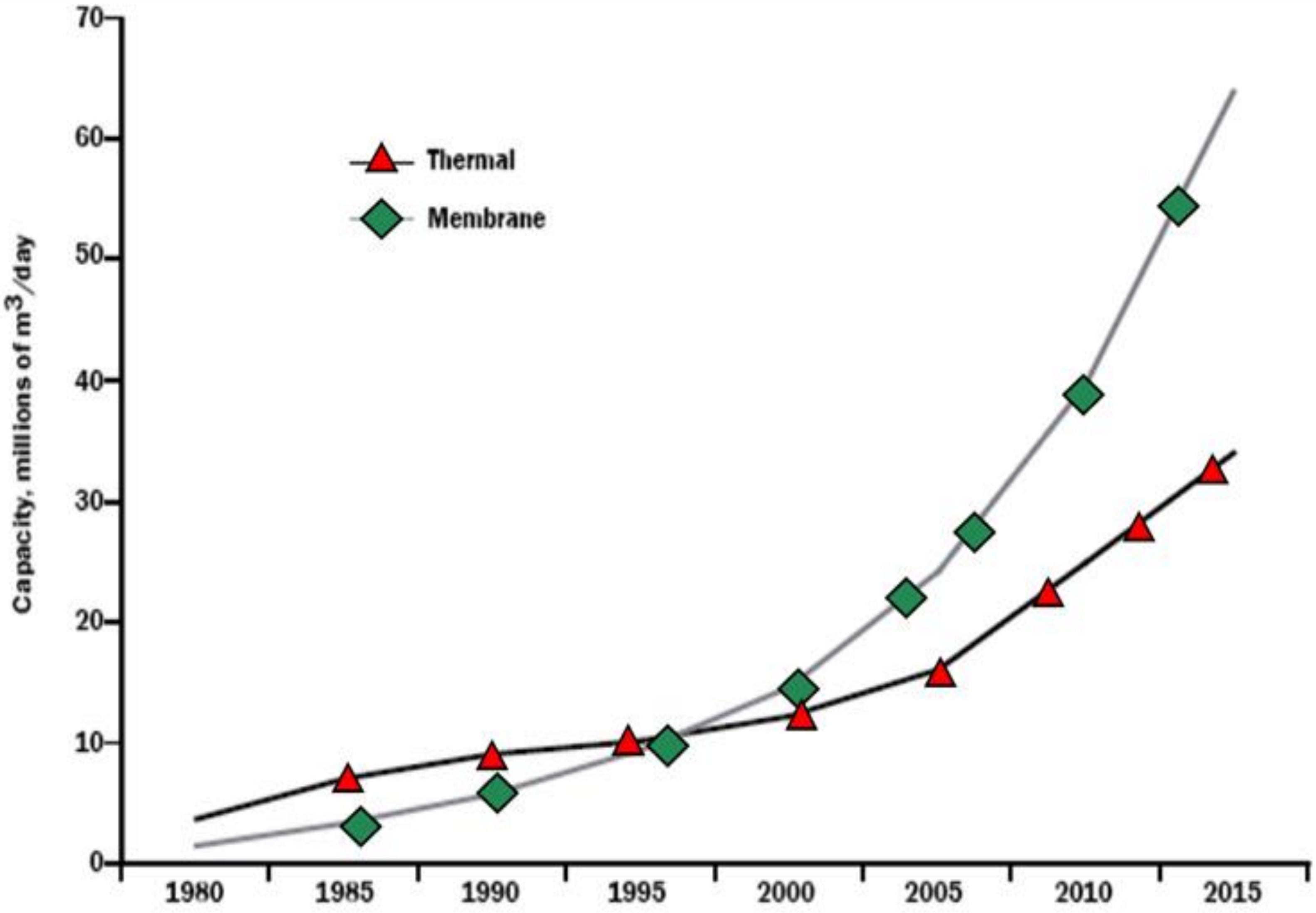
- Desalination

- Reuse of waste water

Desalination Technologies

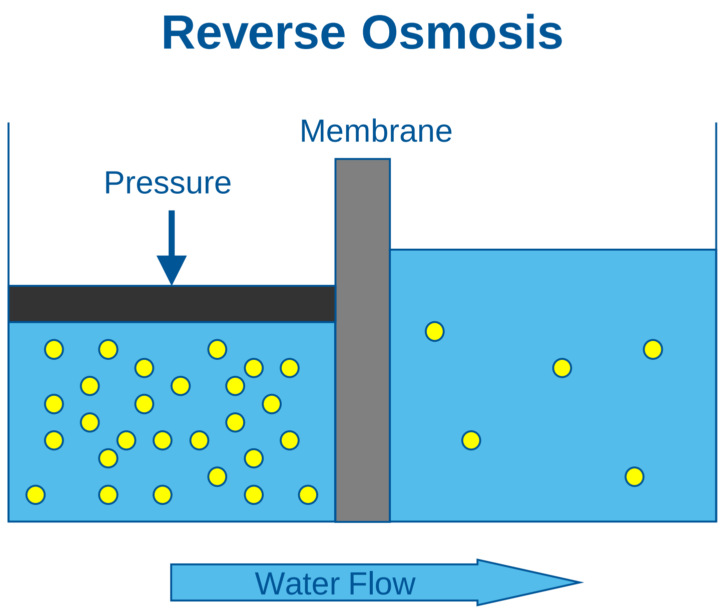






www.globalwaterintel.com

Reverse Osmosis



$$J = A_W(\Delta P - \Delta \Pi)$$

Pressure is applied to concentrated solution to overcome osmotic pressure and force water through the membrane from the high concentration side to the low concentration side

Newly Constructed SWRO Plants

- Spain: 2012 completed a major SWRO plant which produces 1 billion cubic meter per year.

- Singapore: to reduce its reliance on imported water from Malaysia. In 2013 built a second large SWRO plant producing 318,500 cubic meter per day. Desalinated water can meet up to 25% of Singapore’s current water demand.

Sea Water Reverse Osmosis Process

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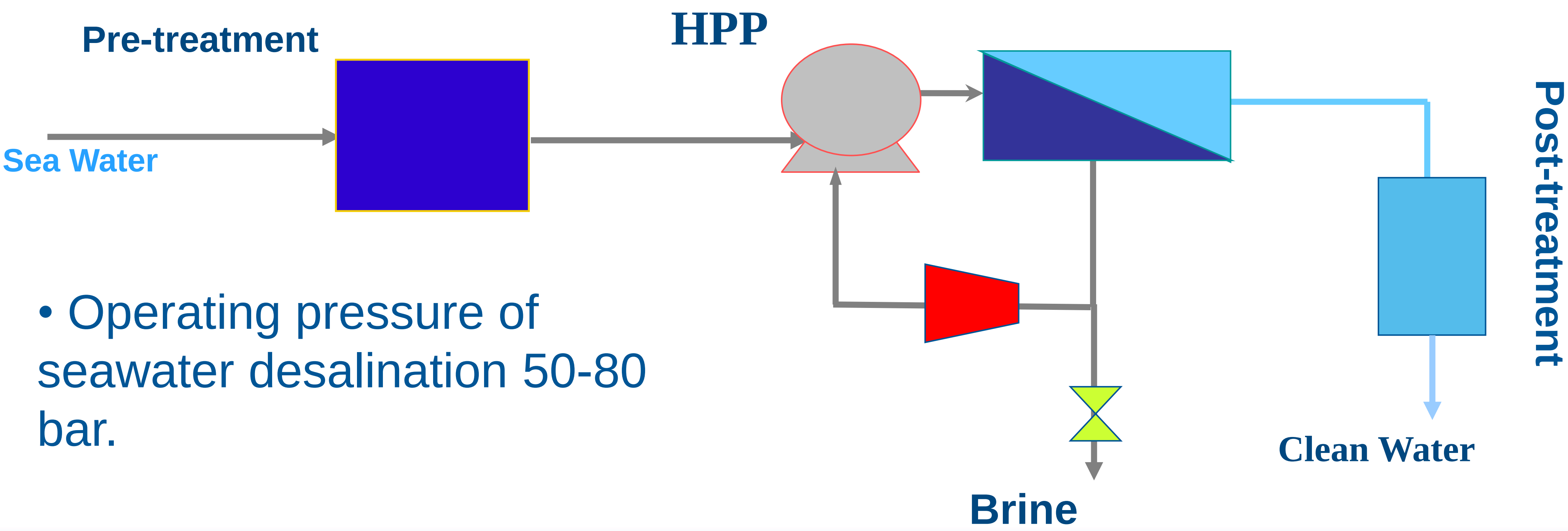
- About 50% of the total cost is for Energy.
- The main component of the energy consumed is the HPP.
- High Energy Consumption is due to the High Operating Pressure used to overcome the osmotic pressure barrier.
- But also the Membrane Resistance.



- Operating pressure of seawater desalination 50-80 bar.

Reductions in Energy Consumption by SWRO stage in the past 20 years

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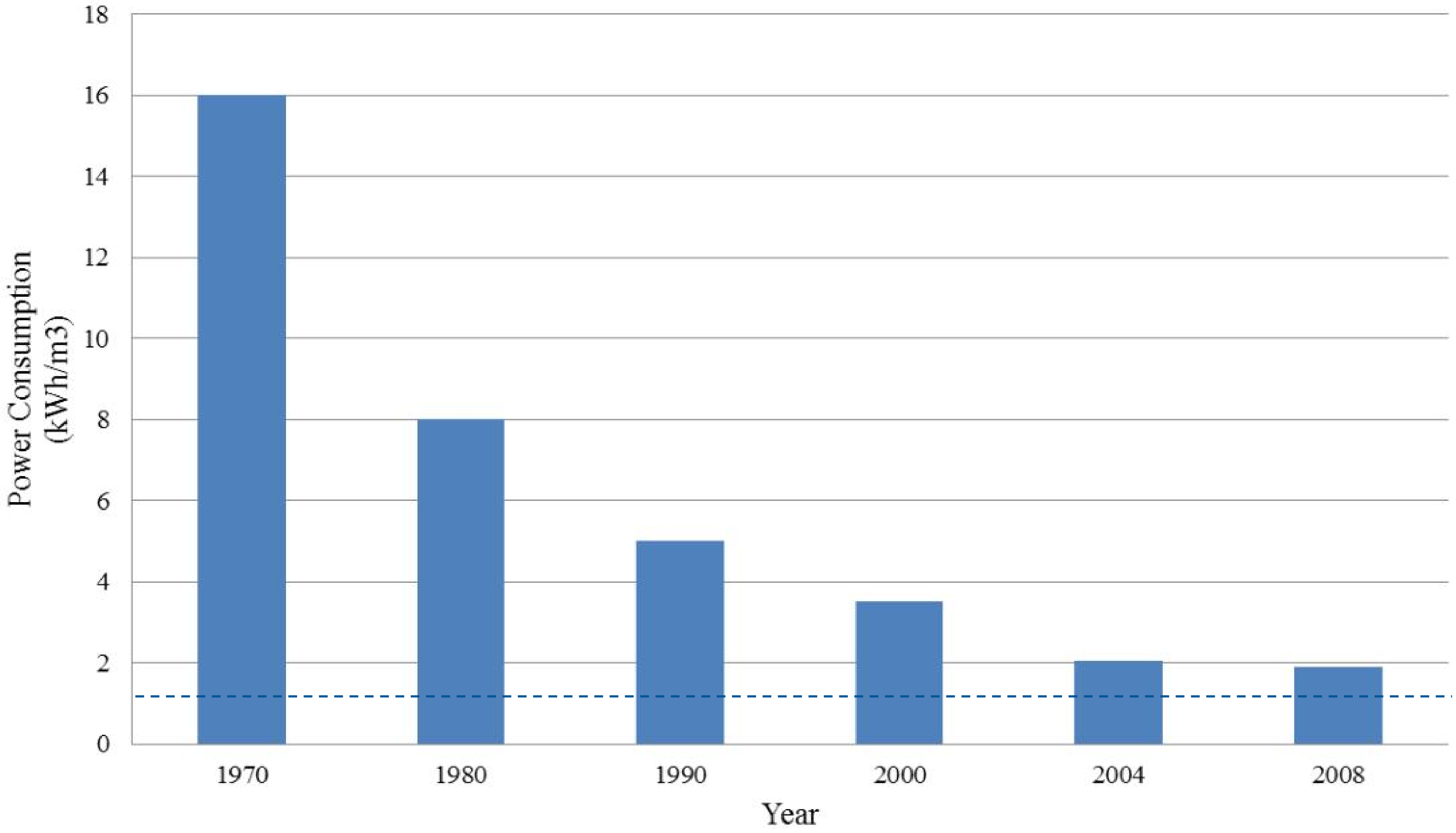

Source: www.nwri-usa.org

Theoretical Minimum Energy of Desalination

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There exists a theoretical minimum energy of separation based on Thermodynamics which is irrespective of the desalination process.

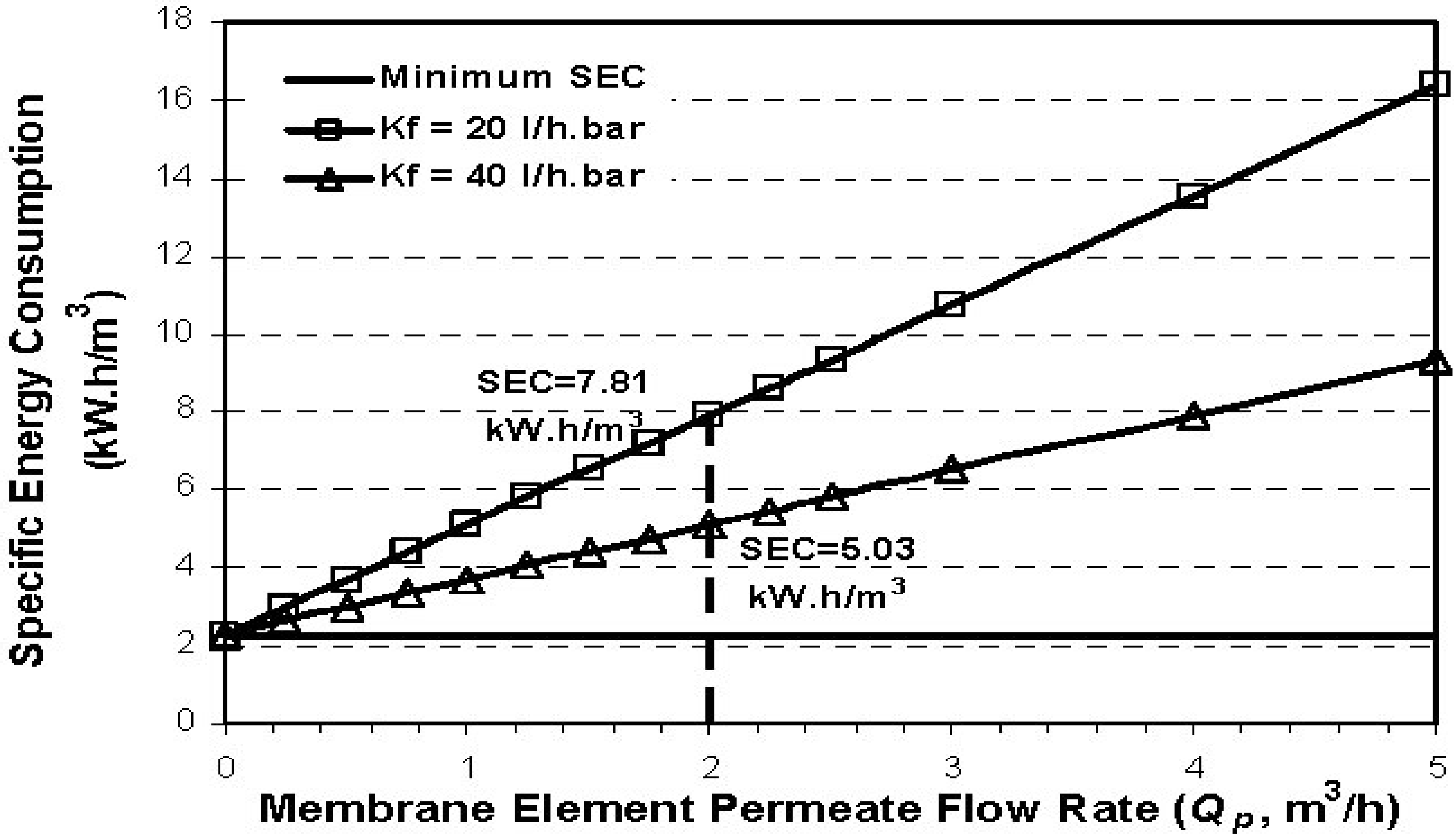
At salt content 35000mg/l, 50% recovery – 1.06 kWh/m3

Best performing SWRO RO stage – 2kWh/m3

Overall Energy consumed for the entire plant – 3-4 kWh/m^3
5-8 kWh/m^3

So Where is the Rest of the Energy Consumed?

Membrane Resistance and SEC of RO



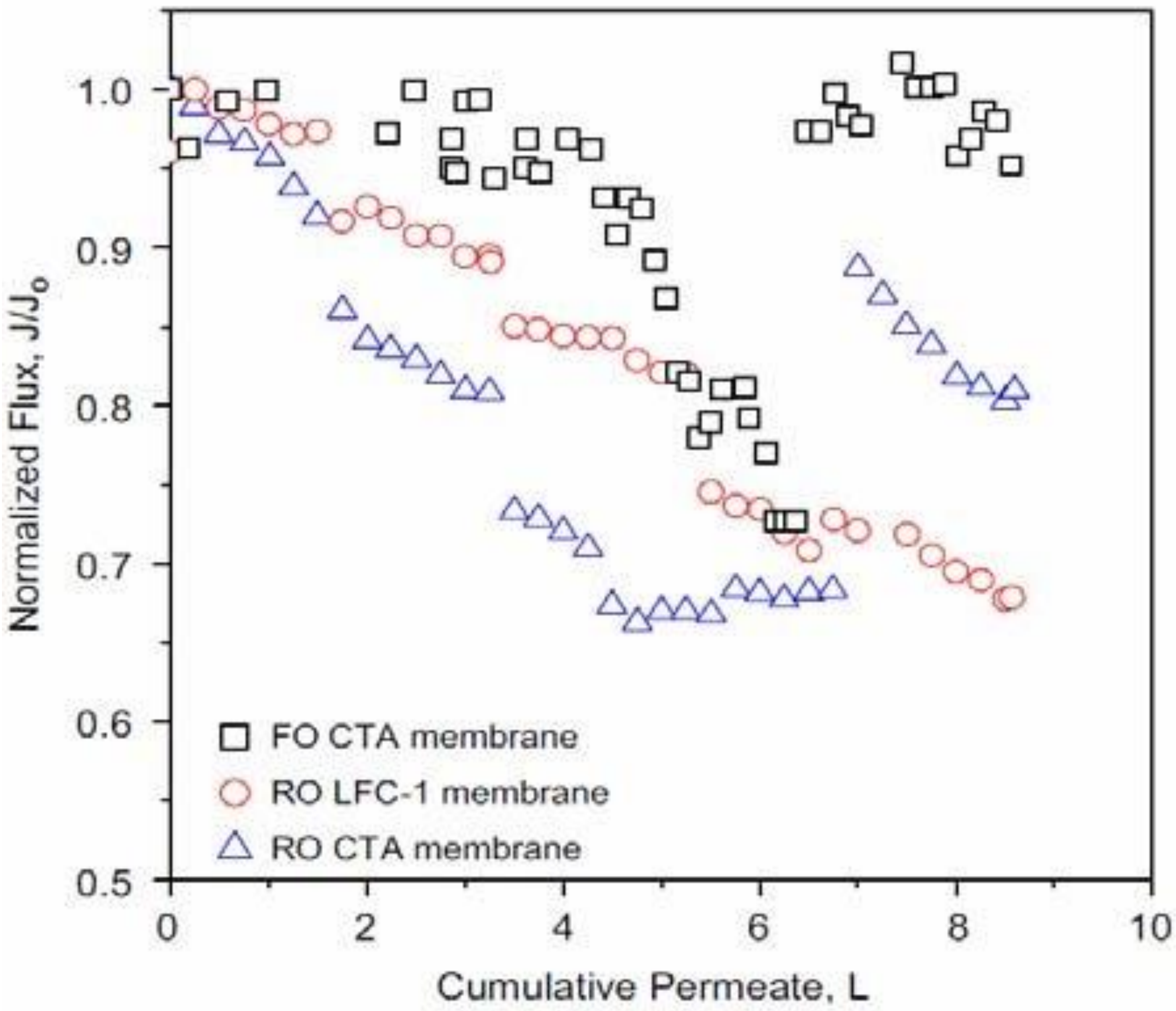
*Sharif et al, Desalination and Water Treatment, **1,** (2009)1001-1013*

Energy Consumption in SWRO

- Fouling
- The significant proportion of the degree of Energy Saving depends on Fouling.
- Fouling involves the deposition and adsorption of feed constituents the membrane surface.
- Significantly increases the resistance of the membrane to keep permeate flux constant pressure is is increased to compensate the reduction in permeate flux.

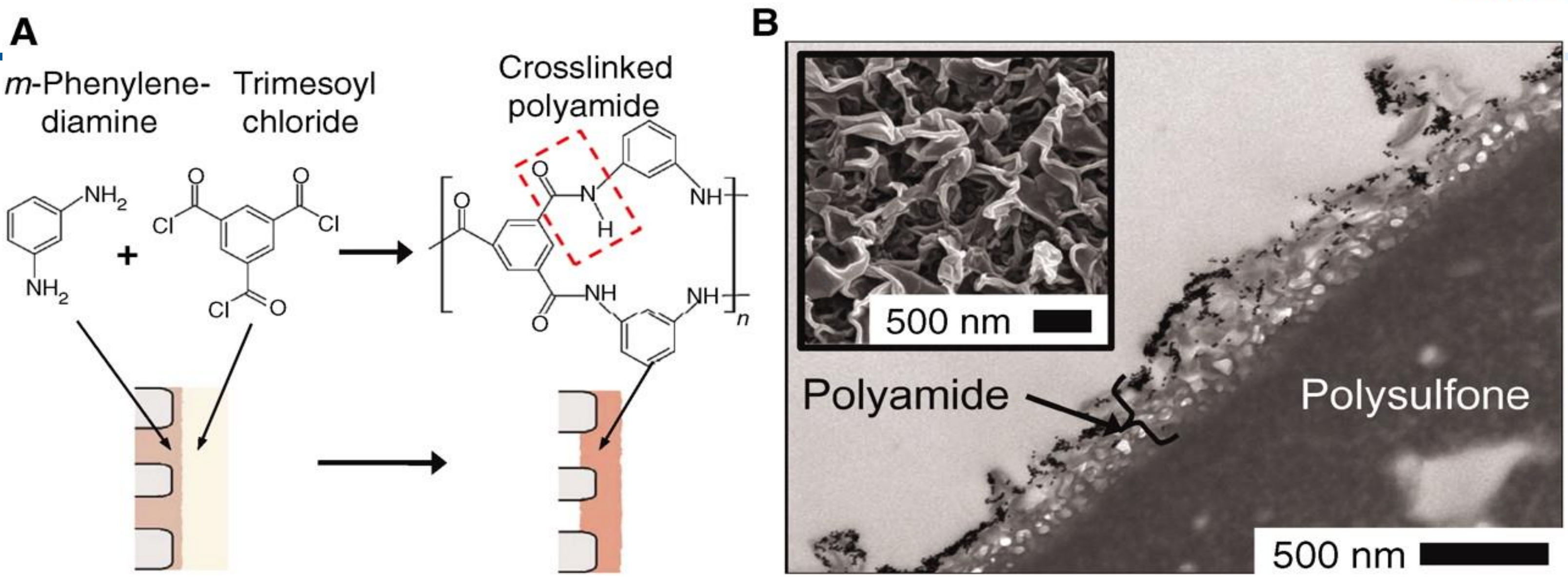
Irreversible Fouling in RO

Relative water flux as a function of water produced for three experiments, including one chemical clean each



Holloway et al,, Water Research, 4,(17),2007

Thin-film Composite (TFC) membranes.



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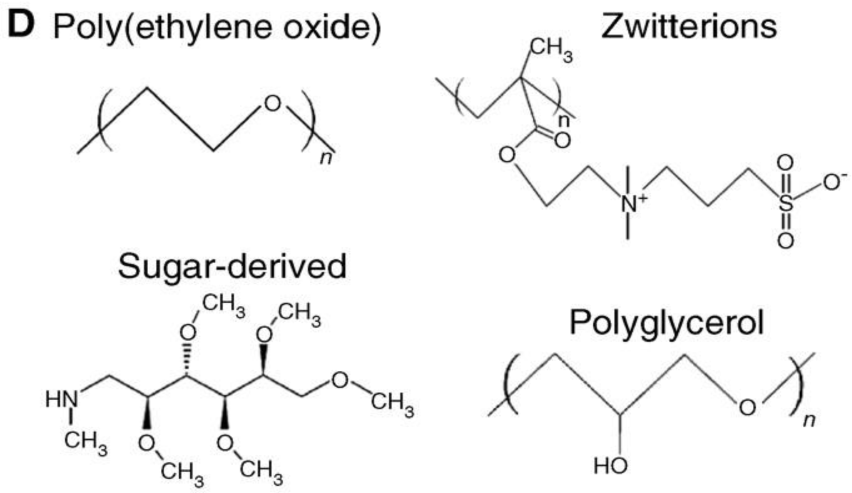
Surface property	TFC membrane
Contact angle	50 – 60°
Surface charge	Negative
$-COO^{-}/nm^2$	20 – 30
RMS roughness	100 – 200 nm



M Elimelech, and W A Phillip Science 2011;333:712-717

SWRO Membranes are Prone to Fouling

Thin-Film Composite Polyamide Membranes

Advantages: Have Highly Permeability and High Rejection

Disadvantages: Highly prone to Fouling

Hydrophobic, Charged Surface, rough surfaces
And sensitive to oxidants.

Its Not just the Chemistry of the Membrane But also the Process

Fouling is much more severe in Pressure-driven membrane processes

SEC and Quality of Water Product

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- Post-Treatment (Additional Energy) – Boron removal important for agriculture. Where rejection rates can be as low as 43% with 1 RO stage.

- Passage of not only traditional contaminants but also emerging Micropollutants is a problem in RO plants.

- Micropollutants are substances that include:
- Pharmaceutically active compounds
- Endocrine disrupting compounds

- Fouling can change the surface characteristics of the membrane either to improve or reduce rejection capability.

Reliability of SWRO?

HABS – Red Tides

Source: http://www.nualgi.org/

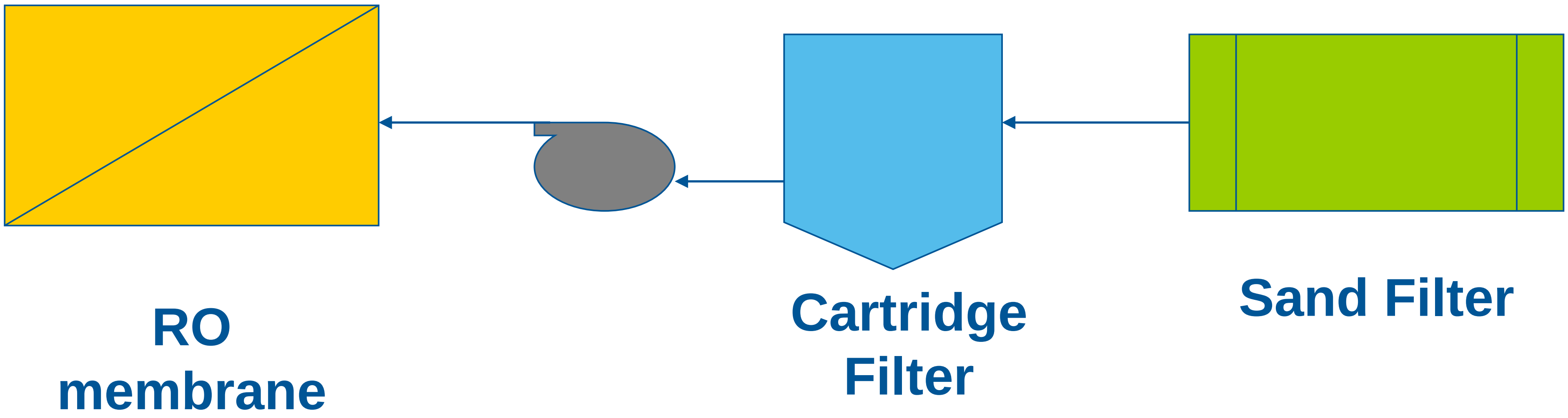
HABS – Red Tides

- Explosion of Microscopic Algae growth
- Appeared in several areas around the world including UAE and Qatar coasts
- Increase in Biomass and Organic load
- Concentration: up to 250000 cell/L
- Seasonal: during Spring and Autumn
- *Release toxins into the water*
- *Pose Significant Challenges to ensure removal*

- *We do not know how much of the toxins pass through the RO process. Since many toxins are near the size rejected by RO membranes*

SWRO Plants Shut Down

- ***Blocking the cartridge filters***
- ***Particles escape the cartridge filter will damage the RO membrane***
- ***Conventional Pretreatment is not Enough***



Desalination by RO–Practical Limitations

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Advantages

- Suitable for desalinating both seawater and saline groundwater
- Requires less energy than Thermal Desalination

Practical limitations

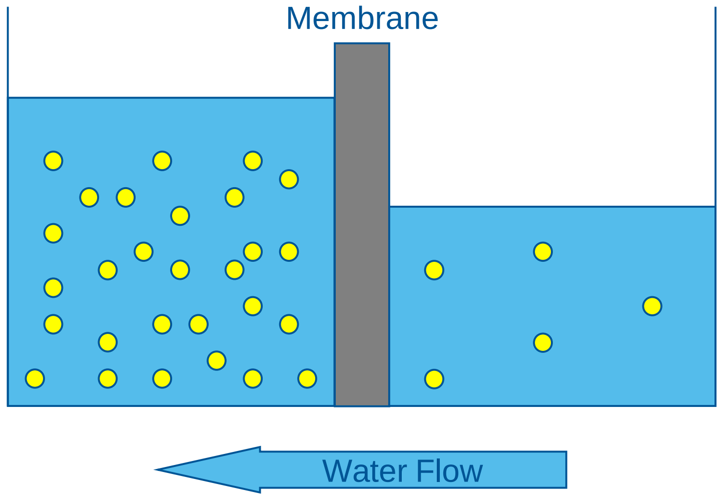
- Product Water Quality ranges between 250-500 ppm salinity
- Prone to Fouling (Irreversible)
- Short membrane life time
- High operating pressure
- Continuous membrane cleaning
- Low recovery rate, up to 50% for sea water and 75% for BW
- Essential Pre-treatment and post-treatment (Chemical additives)

Desalination Technology

- A Step Change to Existing Technology is Needed
- This brings me to the Final part of my talk
- Research at the University of Surrey lead by Professor Adel Sharif resulted in the development of a Hybrid desalination process combining FO and RO.
- This technology incorporates the natural process Osmosis.

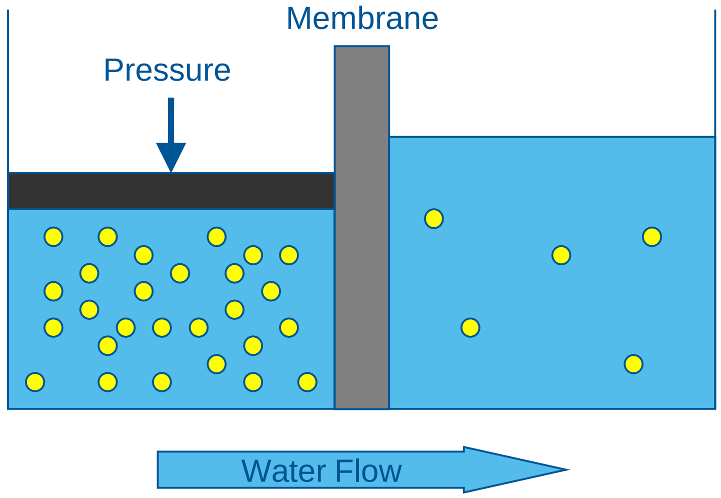
Forward Osmosis

Forward Osmosis



Water diffuses naturally through membrane from low concentration side to high concentration side

Reverse Osmosis



Pressure is applied to concentrated solution to overcome osmotic pressure and force water through the membrane from the high concentration side to the low concentration side

Two-Stage FO Process

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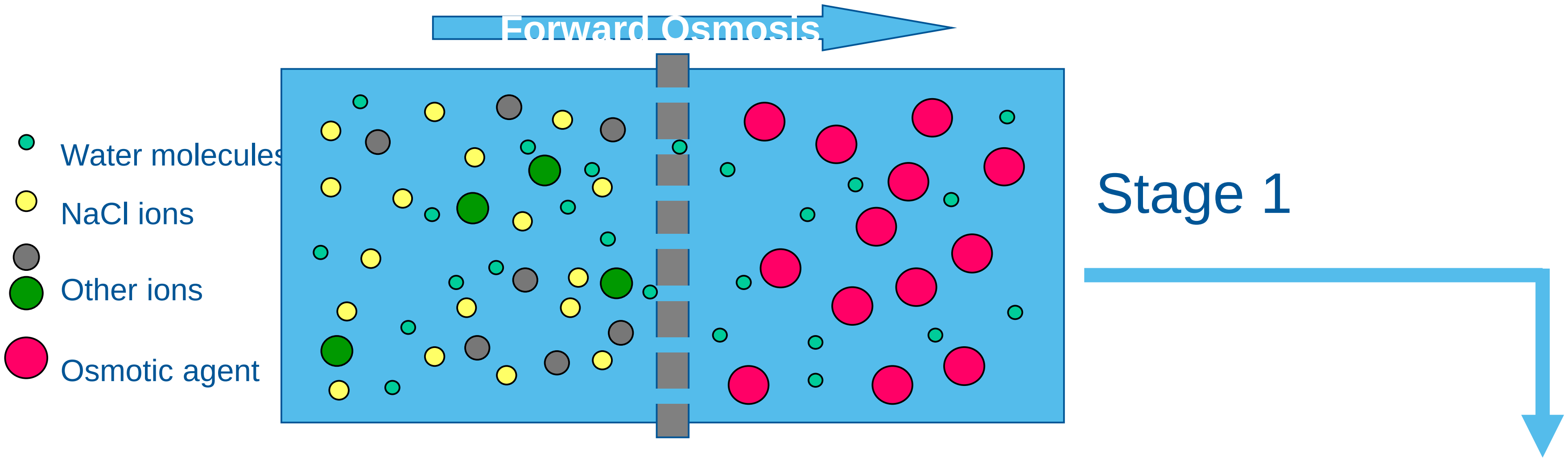
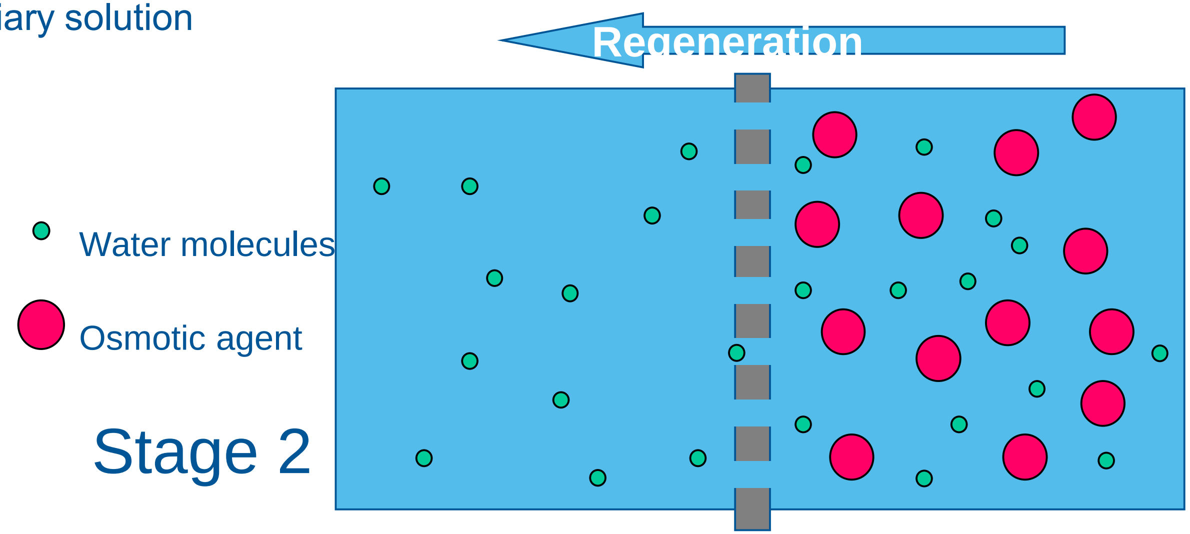
Two stage process

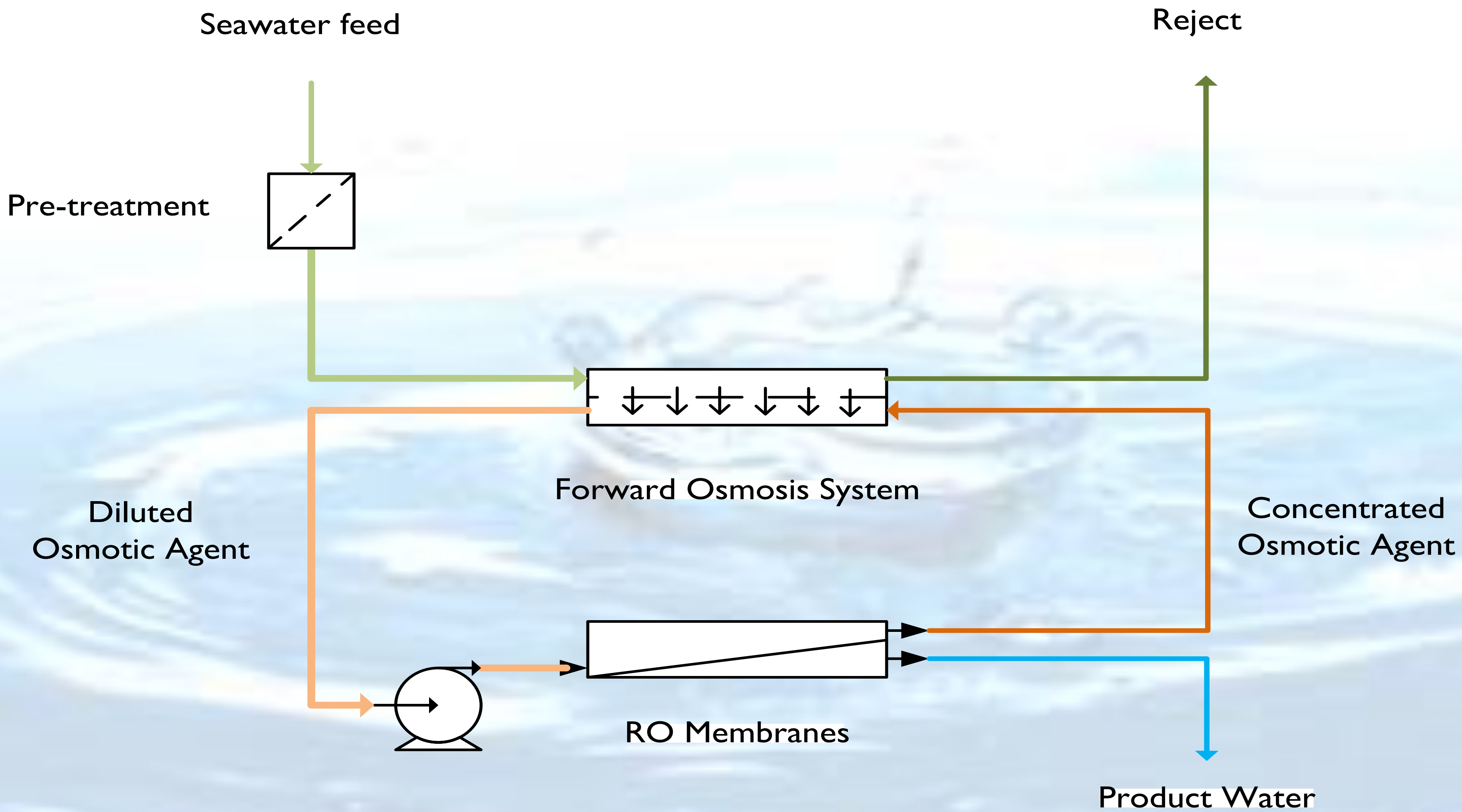


Stage 1: create a 'clean' intermediary solution



Stage 2: extract water and recover agent for reuse

FO-RO Desalination Process



Forward Osmosis

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Advantages

- **Significantly less Fouling**
- **Fouling is up to 100% reversible – requiring osmotic back washing to restore flux lost/ no need for chemicals for membrane cleaning.**
- **Higher Selectivity – Purer Product**
- **Longer Membrane Life**
- **Significantly less Chemicals required for cleaning**

From Labs to Market

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Commercialized by Modern Water

Gibraltar

- 2008 the first FO desalination of its kind in the world
- Operational with fresh water production to the public
- Plant demonstrates up to 30% energy saving, reduces chemical consumption and other operating costs compared with traditional methods

Oman

- Middle East is key market – Accounts for almost 50% of the worlds desalination capacity
- Commercial desalination plant operational and robust with positive results (2009)

Modern Water FO Desal Commercial Plant World's 1st (Oman, Al-Khuluf, Nov-2009)

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Al Khaluf (100 m3/day) - Summary

- **Commissioned in November 2009 – water into public supply**
- **Common pre-treatment with conventional RO plant**
  - Very challenging, high salinity feed water
- **FO System**
  - 35% recovery
  - Membranes never chemically cleaned in over 36 months
- **Product water meets requirements of Omani Standard No. 8/2006 with post-treatment, untreated product:**
  - Total dissolved solids < 200 mg/l
  - Boron 0.6 – 0.8 mg/l
- **Visited by WDR in November 2010 and subsequently given a WDR Technology Rating of 8.9 – currently joint highest**

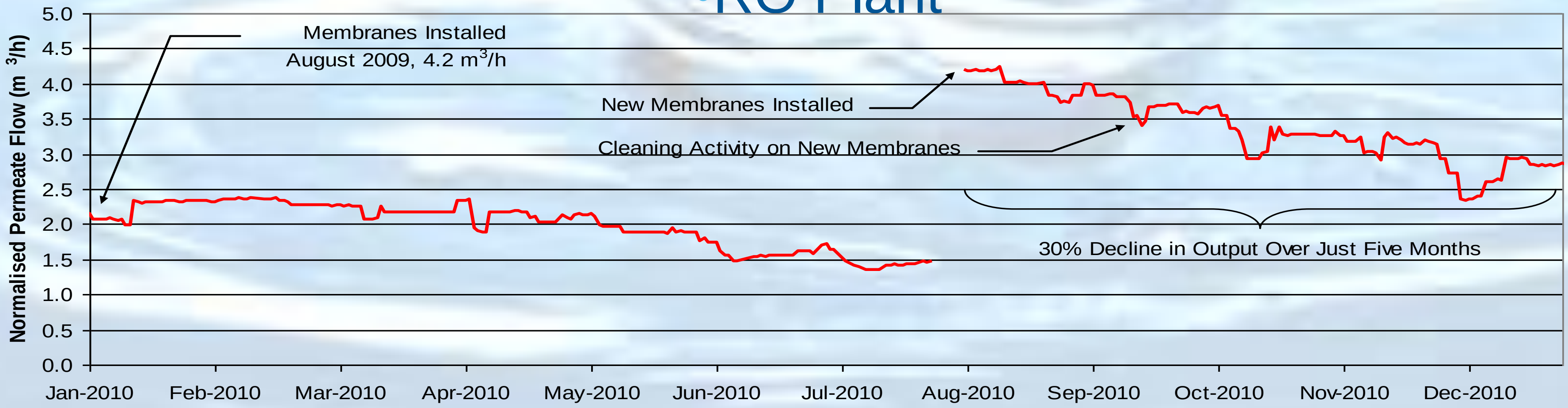
Operating Comparison Data

Technology		SWRO	MOD
Permeate Extraction from Feed water			
Feed water Recovery	%	25	35
Product Water Flow	m3/h	3.0	4.2
Feed water Supply	m3/h	11.9	11.9
Feed water Pump	Bar	65	4
	eff%	85	85
	kw	25.3	1.6
Osmotic Agent Regeneration			
Osmotic Agent Recovery	%		47
Dilute Osmotic Agent Feed	m3/h		8.9
OA Regeneration Pump	Bar		65
	eff%		85
	kw		18.8
Overall Plant			
Specific Energy Consumption (per unit product)	kWh/m3	8.5	4.9

Normalised Flow

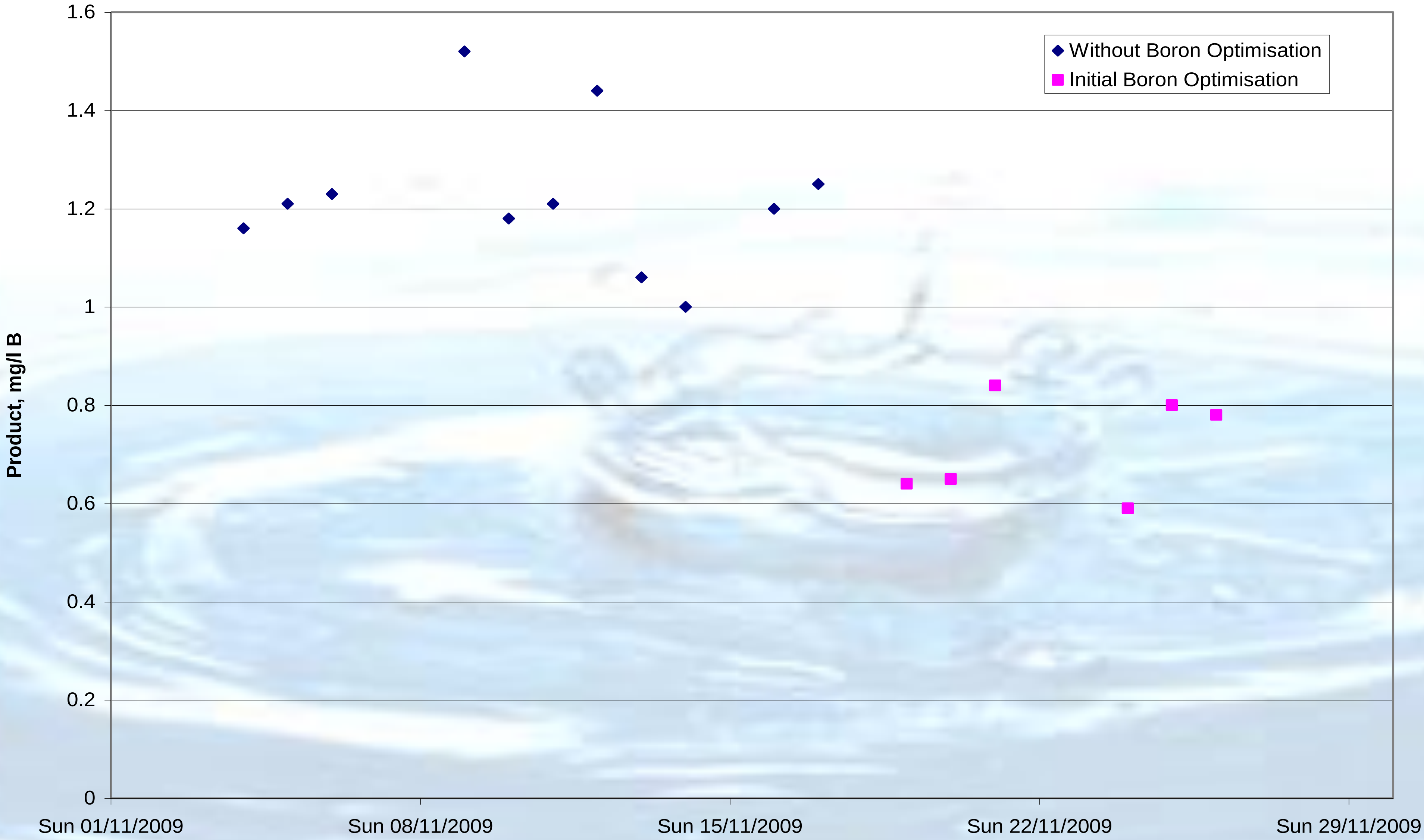
- FO Plant

- RO Plant



Source: Thompson N & Nicoll P 'Forward Osmosis Desalination: A Commercial Reality', Proceedings IDA World Congress, Perth, Western Australia, September 2011

Boron Optimisation



Benefits of technology

- Significant energy savings
- Minimizes discharges back to the environment
- Lower levels of boron without additional treatment
- Reduced chemical consumption
- Reduced carbon footprint
- Reduced OPEX and CAPEX
- More sustainable and cost effective alternative to traditional systems

Conclusions

- Forward osmosis now a proven technology at industrial scale

- Robust process with proven resistance to membrane fouling and Improved Product Water Quality.

- Highly significant OPEX and CAPEX reductions

- The Challenges are:
    - Further reductions in energy and a more practical re-generation method
    - Suitable FO Membrane

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Acknowledgments

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Qatar Foundation
Unlocking human potential.

THE ROYAL SOCIETY

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PUBLIC AUTHORITY FOR ELECTRICTY & WATER
" With electricity we progress & water gives us life "

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