THE MIDDLE EAST DESALINATION RESEARCH CENTER

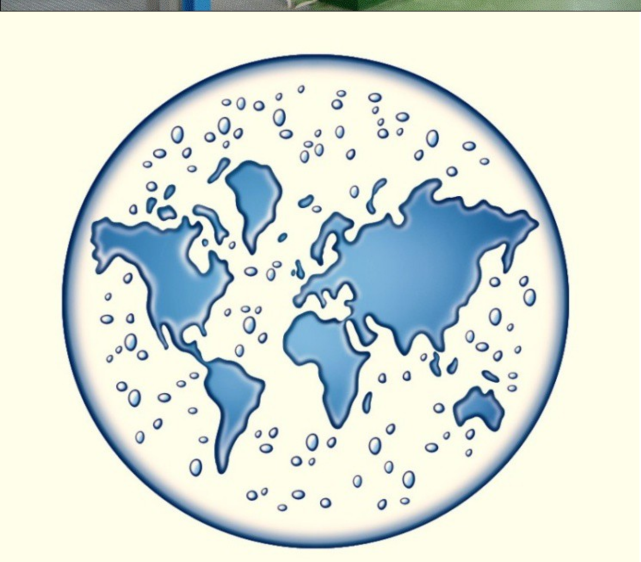
Cost Estimating of SWRO Desalination Plants

Day 3: Desalination Project Costs – Trends, Examples and Interactive Session

June 27, 2013

09:00-10:15

3.1 Desalination Cost Trends



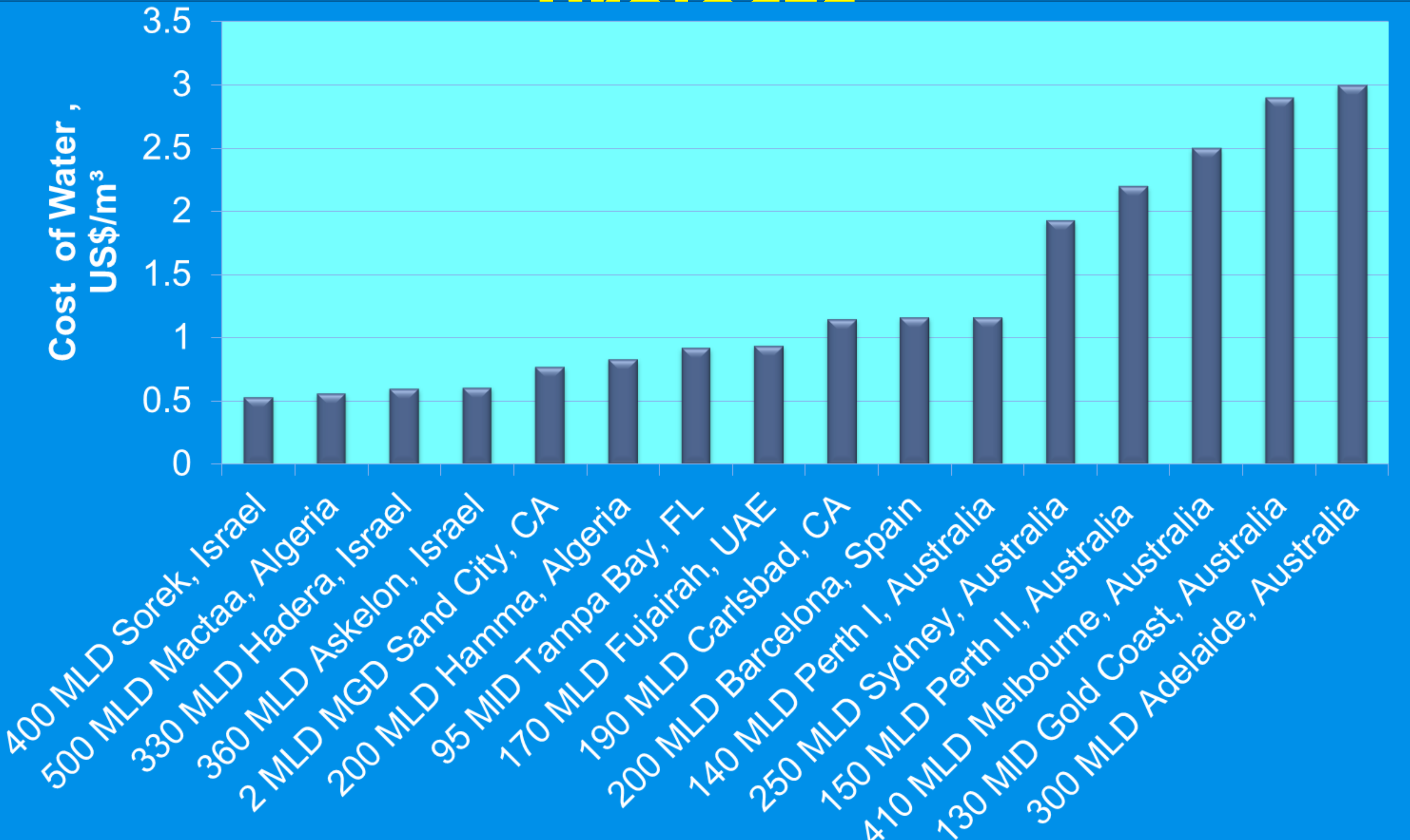
Water Globe

Nikolay Voutchkov, PE, BCEE

Desalination Cost Trends - Outline

- Overview of Recent Projects and Their Cost Breakdown
- High-end Cost Projects – Key Factors Contributing to Their High Costs
- Low-end Cost Projects – Key Factors Resulting in Their Low Costs
- Impact of Project Delivery on Costs
  - Design-Bid-Build (DBB) Projects
  - Design-Build-Operate (DBO) Projects
  - Build-Own-Operate-Transfer (BOOT) Projects

Water Production Costs of Recent SWRO Desalination Projects



Key Factors Affecting Costs

- Source Water Quality - TDS, Temperature, Solids, Silt and Organics Content.
  - Product Water Quality – TDS, Boron, Bromides, Disinfection Compatibility.
  - Concentrate Disposal Method;
  - Power Supply & Unit Power Costs;
  - Project Risk Profile;
  - Project Delivery Method & Financing;
  - Other Factors:
    - Intake and Discharge System Type;
    - Pretreatment & RO System Design;
    - Plant Capacity Availability Target.

Common Features of Low-Cost Desalination Projects

- Low Cost HDPE Open Intakes or Beach Wells;
- Near-Shore/On-Shore Discharges w/o Diffuser Systems or Co-discharge w/ Power Plant of WWTP Outfalls;
- Point of Product Water Delivery within 5 Miles of Desalination Plant Site;
- RO System Design w/ Feed of Multiple Trains by Common High Pressure Pumps and Energy Recovery Systems;
- Turnkey (BOOT, BOO) Method of Project Delivery.

Key Reasons for Cost Disparity Between High-End & Low-end Cost Projects

- **Desalination Site Location** (NIMBI vs. Science Driven)
  - **Costly Plants Have Overly Long Product Water Delivery Pipelines**
    - **120 MGD Melbourne Plant – Cost of Plant/Delivery + Power Supply Systems = US$1.7 BB/1.1 BB (50 miles)**
    - **66 MGD Sydney SWRO Plant – Cost of Plant/Delivery System = US$560 MM/US$490 MM (10 miles of underground tunnel under Botany Bay).**
- **Environmental Considerations**
  - **Complex Intakes & Diffuser Systems**
- **Phasing Strategy**
  - **Intake and Discharge System Capacity;**
  - **Pretreatment & RO System Design;**
- **Labor Market Pressures**
- **Method of Project Delivery & Risk Allocation**

Project Delivery Alternatives

- **Design-Bid-Build (DBB):**
  - Key Benefit - Utility Owns All Assets;
  - Key Disadvantages – Utility Takes All Risks and Reduces Borrowing Capacity.

- **Design-Build-Operate (DBO)/"Alliance":**
  - Key Benefit – Utility Owns All Assets;
  - Key Disadvantages – Utility Shares Some Construction & Operations Risks and Reduces Borrowing Capacity.

- **Build-Own-Operate-Transfer (BOOT):**
  - Key Benefit – Utility Transfers Most Risks to Private Sector and Only Pays for Water it Receives;
  - Key Disadvantages – Utility Does Not Own the Assets.

Risk Allocation Profiles for BOOT & Alliance (DBO) Project Delivery

Type of Project Risk	BOOT	Alliance/DBO
Permitting	Private	Public
Source Water	Private	Shared
Technology	Private	Shared
Operations	Private	Shared
Water Demand	Public (Take or Pay – Private Equity at Risk)	Public
Power Supply	Private	Public
Construction	Private	Shared
Financial	Private	Public

Worldwide the Lowest Cost of Desalinated Seawater Has Been Delivered Under BOO/BOOT Contracts!

Magtaa Project Bid Structure

MAGTAA PROJECT BID	
Capacity	500,000 m^3/day
EPC Value	approximately US$500 mil
Offtakers	L'Algerienne Des Eaux ("ADE")
Concession Period	25 years
Project Company	51% MenaSpring 49% Algeria Energy Company
Other Bidders (International Open Bidding)	Acciona Agua, Biwater/Tarco/Arcofina, GE Water/Orascom, Inima/aqualia, Befasa

Recent Lowest Cost SWRO Project Bids Worldwide

SWRO Plant	Cost of Water (US$/m³)	Power Use (kWh/m³) & TDS
Sorek, Israel – 411 ML/d BOO (startup – 2014)	0.53	3.7 (40 ppt)
Mactaa, Algeria – 500 ML/d BOOT (startup – 2013)	0.56	3.7 (40 ppt)
Hadera, Israel – 330 ML/d BOO/co-located (startup – 2009)	0.60	3.7 (40 ppt)
Cap Djinet, Algeria – 100 ML/d BOO (startup – 2010)	0.72	4.0 (38 ppt)
Carlsbad, USA – 189 ML/d BOO co-located (startup – 2012)	0.74	2.9 (33.5 ppt)

What All Recent BOOT Projects Have in Common?

- All Yielded the Lowest Costs and Power Use of Desalinated Water in Their Respective Markets;
  - Plant Performance & Permitting Risks Reside with the Private Sector;
  - Debt Repayment is Private Sector Obligation;
  - Private Sector Only Gets Paid for Delivering Product Desalinated Water;
  - Public Utility Can Buy Out (Transfer) Project Ownership Once Plant Has Proven Its Long-term Performance.

Ashkelon – Lowest Cost of Water Worldwide – How Did They Do It?

Ashkelon – Cost of Water Breakdown

Cost Item	NIS/m³	USD/m³*	% of TWP	Linkage
Base Fixed Price	**1.315**	**0.311**	**59.2**	CPI
Base Variable Price				
Energy	0.565	0.134	25.4	electricity price**
Membranes	0.120	0.028	5.4	CPI & USD/NIS exchange rate
Filters	0.020	0.005	0.9	"
Chemicals	0.090	0.021	4.1	"
Post-treatment	0.040	0.009	1.8	"
Others	0.070	0.017	3.2	"
Subtotal	**0.905**	**0.214**	**40.8**	
Base Total Water Price (TWP)	**2.220**	**0.525**	**100.0**	

* At the relevant base exchange rate of 4.23 NIS/USD

** The "Required Revenue per KWH" as published by the Israel Public Utility Authority – Electricity

Source: Dreizin, 2004

Ashkelon – How Did They Do It?

- Low Cost Conventional Pretreatment – Single Stage Dual Media Filters;
- Large Size (20-micron) Cartridge Filters;
- Three-Center RO Design w/ Pressure Exchangers:
- Low Cost Post-Treatment – Calcite Filters & Blending;
- Self-Power Generation – 80 MW Gas Generators and Purchase of Rights to Gas Field Use;
- Discharge Collocation with Power Plant in Well Mixed Tidally Influenced Zone – No Need for Outfall.

Perth & Sydney SWRO Plants

	Perth	Sydney
Capacity (ML/d)	125	250
Distance from intake (km)	< 1	4.5
Distance to delivery (miles)	26.2	14.3
Total Capital Cost ($M)	$325	$1,539
Total Capital Cost – Desal Plant ($M)	*$281*	*$982*
Total Capital Cost - Delivery ($M)	*$44*	*$557*
Annualized Capital Cost ($M/yr)	$25	$120
Total Annual O&M Costs ($M/yr)	*$17*	*$46*
Annual O&M Cost – Desal Plant ($M/yr)	*$16*	*$42*
Annual O&M Cost – Delivery ($M/yr)	$1	$4
Cost of Water – Capital Component ($/m3)	$0.70	$1.65
Cost of Water – O&M Component ($/m3)	$0.44	$0.58
Cost of Water – Delivery Component ($/m3)	$0.02	$0.06
Total Water Cost, $/m3	$1.16	$2.29

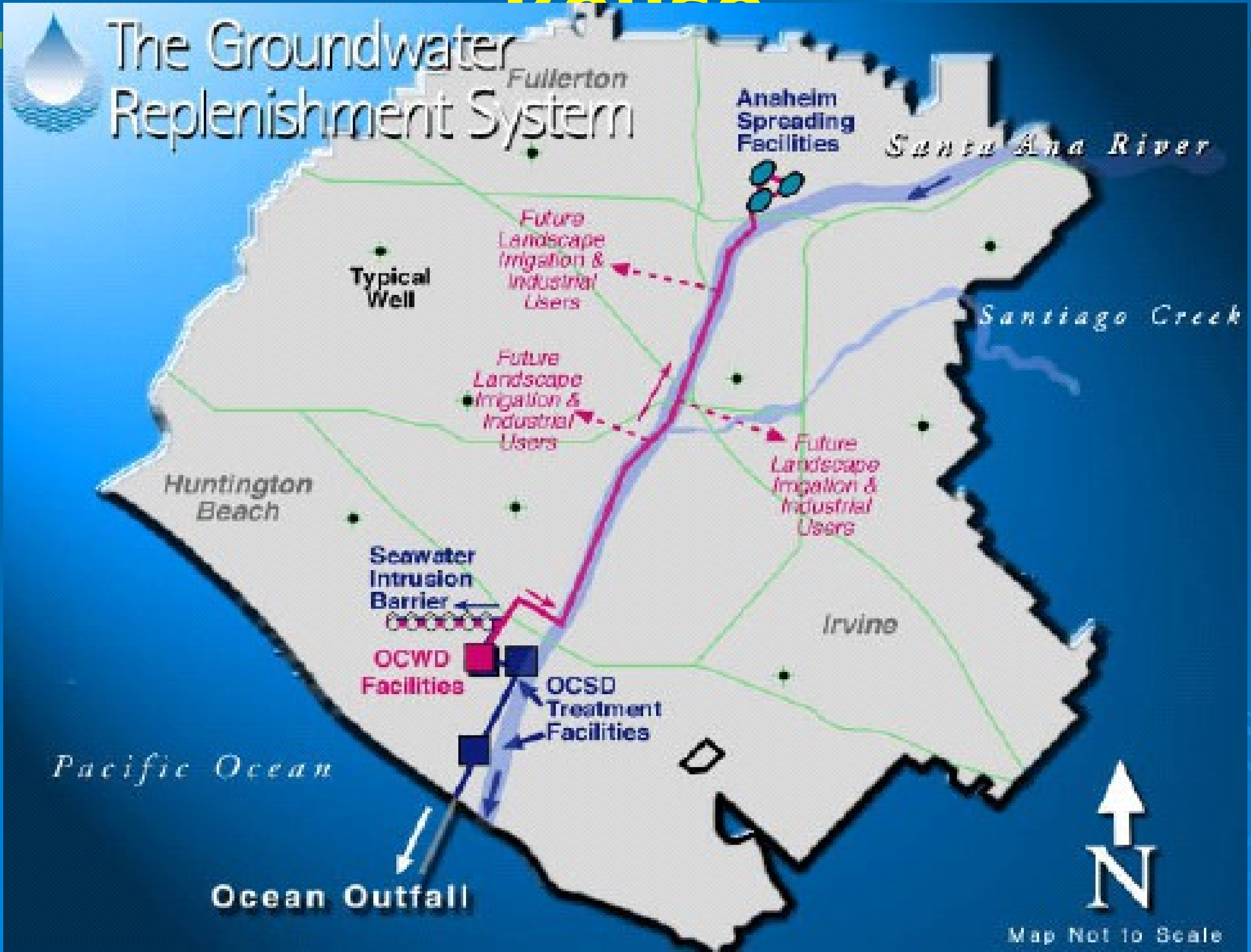
adapted from Waterlines:NWC Australia

Be Careful When Comparing Costs!

- Projects Differ By:
  - Source Water Salinity and Temperature;
  - Product Water Quality;
  - Unit Cost of Construction, Labor and Permitting;
  - Cost of Capital;
  - Unit Cost of Power;
  - Source of Equipment Supply;
  - Project Completion Schedule.

- Projects Have to Be Normalized for These and Other Factors for Accurate Comparison.

Water Production Costs of Desalination vs. Indirect Potable Reuse



Comparison of Huntington Beach Desalination & OC Ground Water Replenishment Projects

Key Project Parameters	Orange County GWR Indirect Potable Reuse Project	Huntington Beach Seawater Desalination Project
Water Production Capacity	206 ML/d	189 ML/d
Source Water	WWTP Effluent Discharge	Seawater - Power Plant Cooling Water
Location	Orange County, California	Orange County, California
Source Water Treatment	MF+BWRO+UV+ Peroxidation+ Lime Conditioning	Granular Medial Filtration+SWRO+ Calcite Conditioning
Product Water Delivery	Groundwater Recharge Wells	Regional Water Distribution System

Comparison of Costs for Drinking Water Production by Indirect Potable Reuse & Seawater Desalination

Key Cost Parameters	Orange County GWR Indirect Potable Reuse Project	Huntington Beach Seawater Desalination Project
Capital Costs (US$)	$486.9 MM @206 ML/d	$335 MM @189 ML/d
Power @ US$0.126/kWh	U$12.4 MM/yr **(1.31 kWh/m³)**	US24.3 MM/yr **(2.8 kWh/m³)**
Chemicals	US$4.6 MM/yr	US$2.3 MM/yr
Maintenance	US$1.4 MM/yr	US$2.5 MM/yr
Membrane Replacement	US$2.4 MM/yr	US$0.9 MM/yr
UV Lamp Replacement	US$0.3 MM/yr	Not Applicable
Labor	US$3.6 MM/yr	US$2.4 MM/yr
Other O&M Costs	US$4.7 MM/yr	US$2.3 MM/yr
Total Annual O&M Costs	**US$29.4 MM/yr**	**US$34.7 MM/yr**
Amortized Capital Costs	**US$27.8 MM/yr**	**US$19.1 MM/yr**
Cost of Water Production	US$57.2 MM/yr **US$0.76/m³**	US$53.8 MM/yr **US$0.78/m³**
Cost of Extraction/Delivery	US$0.12/m³	US$0.07/m³
Total Cost of Water	**US$0.88/m³**	**US$0.85/m³**

Where Future Cost Savings Will Come From?

Main Areas Expected to Yield Cost Savings in the Next 5 Years (20 % Cost Reduction Target)

- **Improvements in Membrane Element Productivity**:

  - **Polymetric Membranes** (Incorporation of Nano-particles Into Membrane Polymer Matrix) – CSIRO & UCLA;

  - Larger Membrane RO Elements (16” Diameter or Higher).

  - **Increased Membrane Useful Life and Reduced Fouling:**

  - Smoother Membrane Surface – **Carbon Nanotube Membranes** – CSRO & University of Texas (Austin).

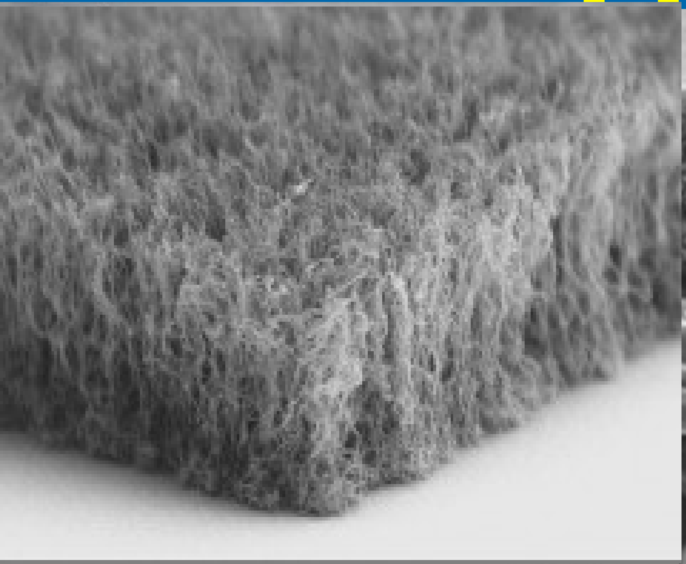
  - Increased Membrane Material Longevity;

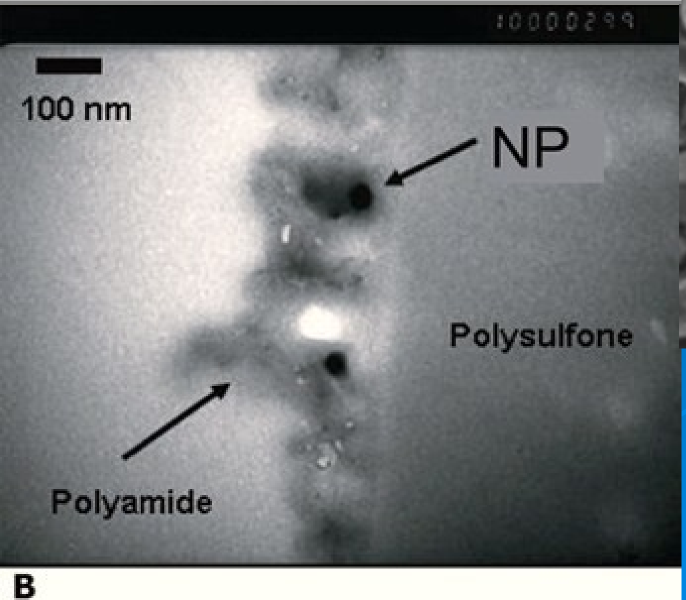
  - Use of Systems for Continuous RO Membrane Cleaning;

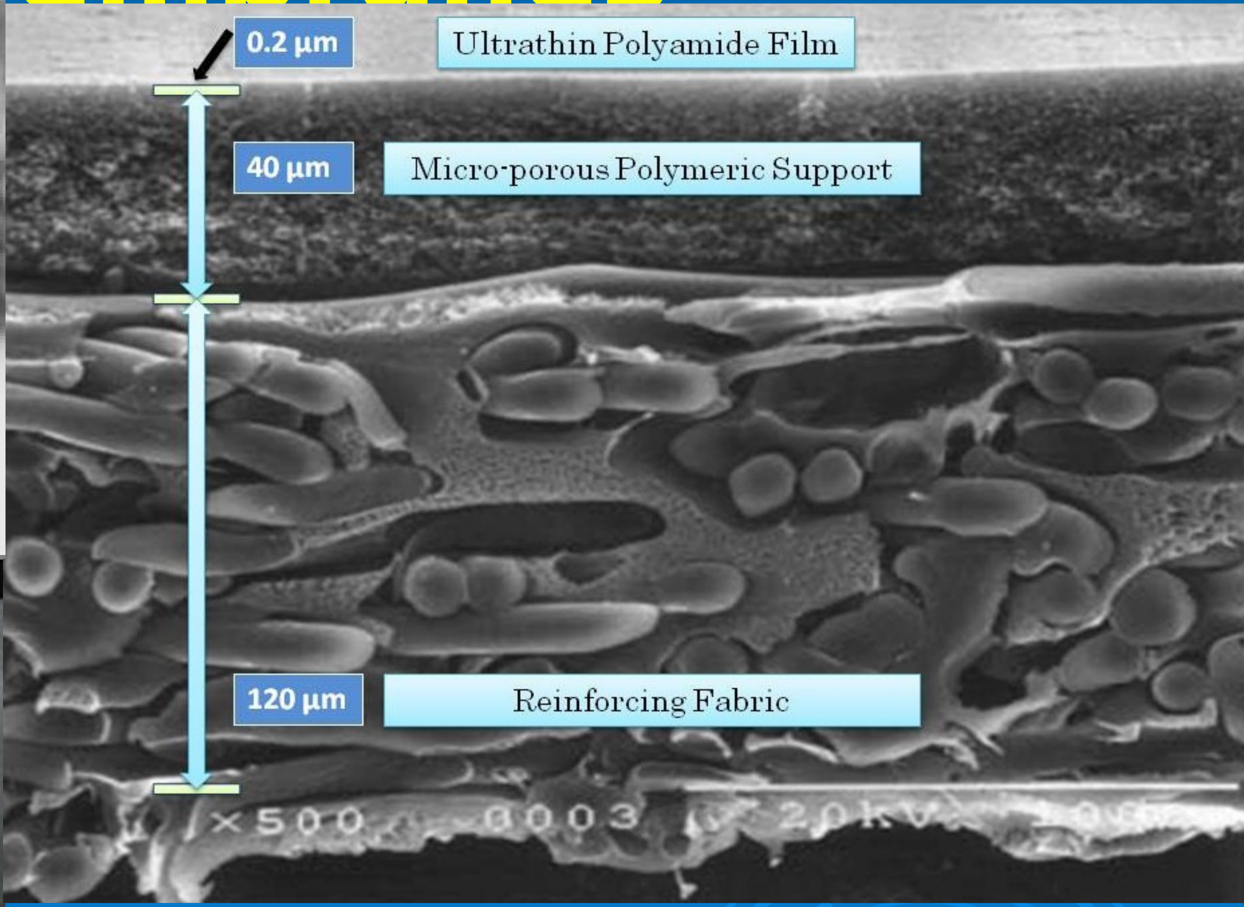
  - UF/MF Membrane Pretreatment.

- **Commercial Forward Osmosis Systems;**
- **Co-Location With Power Plants;**
- **Regional Desalination and Concentrate Disposal;**
- **Larger RO Trains and Equipment;**
- **Full Automation of All Treatment Processes.**

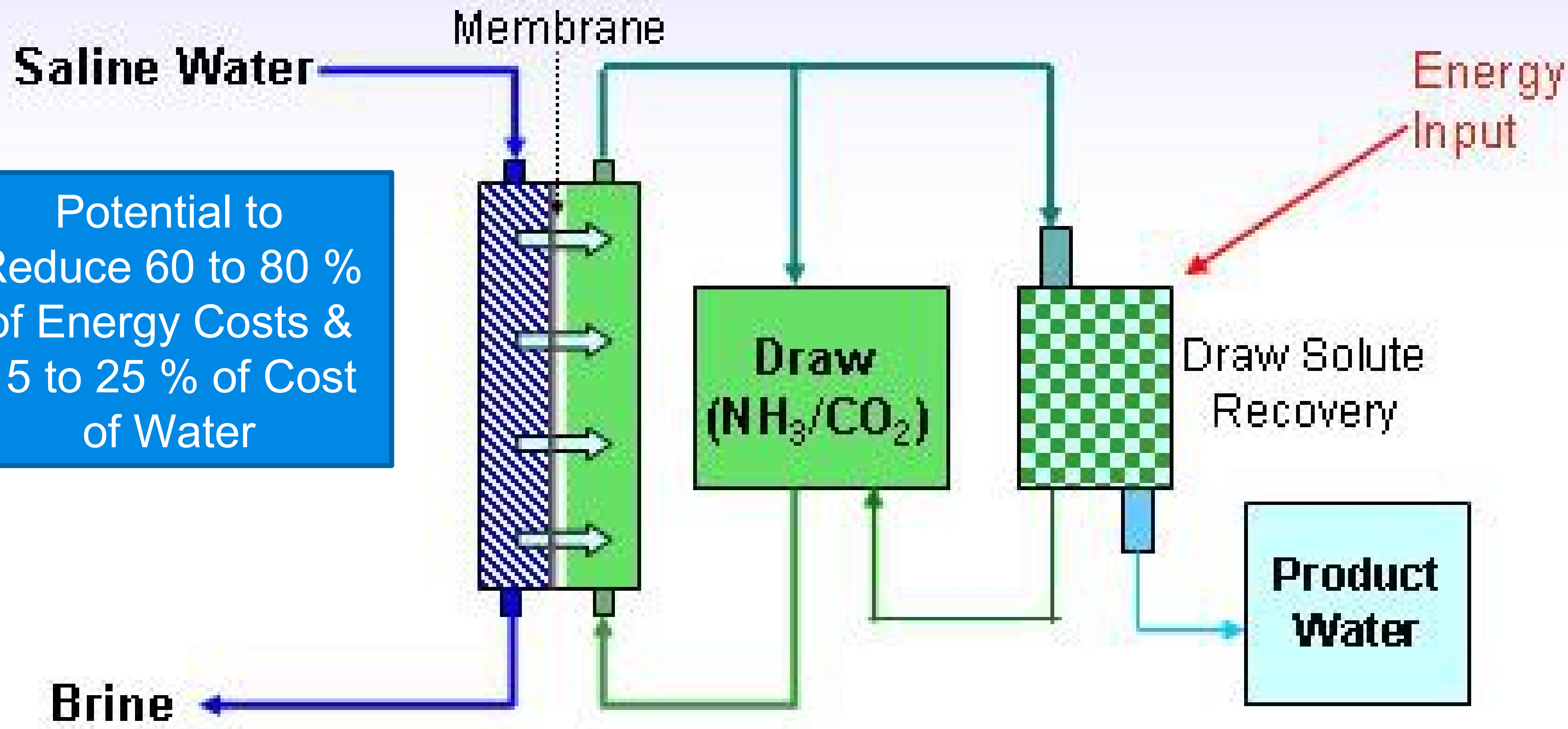
Nano-Structured SWRO Membranes







Forward Osmosis
(solute recycle)



Potential to Reduce 60 to 80 % of Energy Costs & 15 to 25 % of Cost of Water

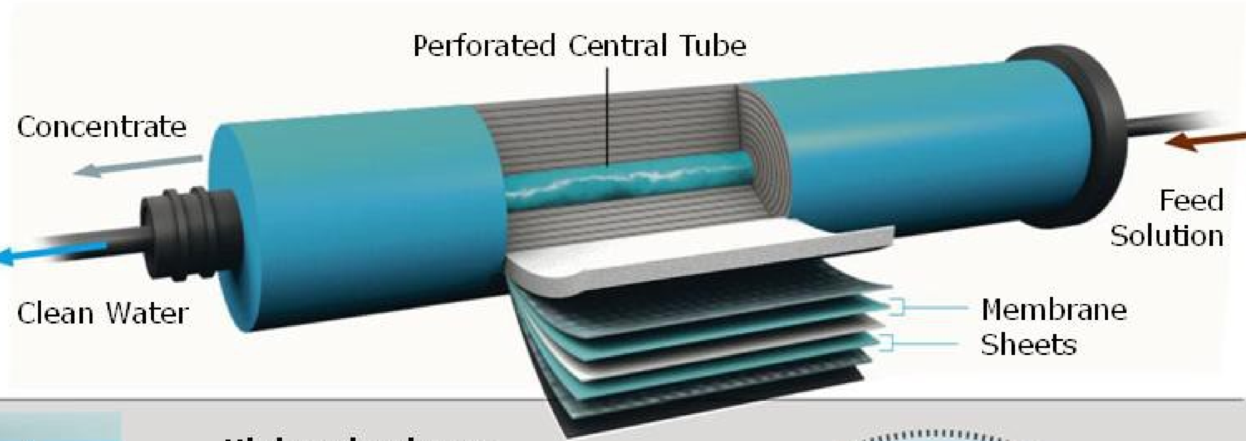
OASYS

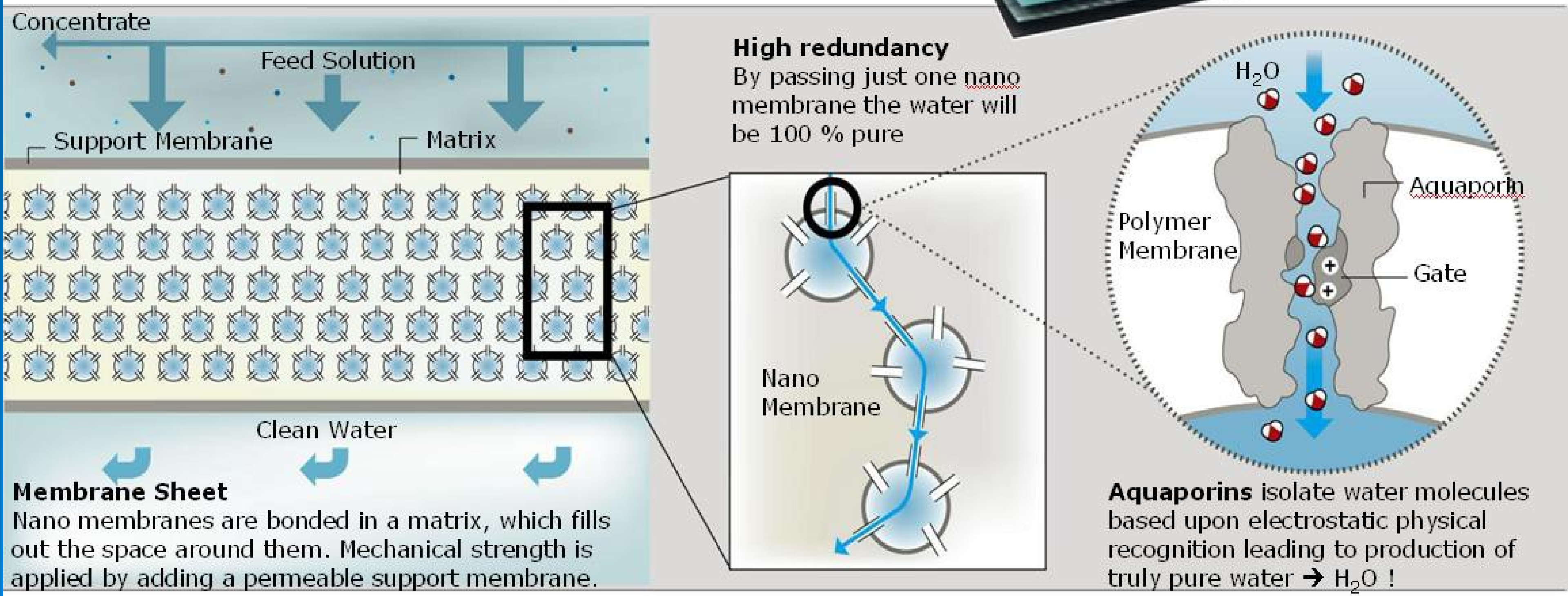
Research Directions to Meet the Long-Term 80 % Cost Reduction Goal

- Improve Membrane Useful Life and Productivity;
    - Develop Corrosion Resistant Non-Metallic Materials to Replace High-Quality/High Cost Stainless Steel RO Piping;
- Reduce Pretreatment Costs;
- Develop New-Generation Energy Recovery Systems;
- Introduce Low-Cost Technologies for Beneficial Concentrate Use and Disposal;
- Explore New Technologies for Seawater Desalination Different from RO and Thermal Evaporation.

Aquaporine-Based Desalination

- Saves 70 % on specific power consumption!
- Increases production efficiency >5 times!
- Robust and scalable





The Best" of Seawater Desalination
Present Status & Future Forecasts

Parameter	Today	Within 5 Years	Within 20 Years
Cost of Water (US$/m³)	**US$0.6-0.8**	**US$0.5-0.6**	**US$0.1-0.2**
Construction Cost (Million US$/ML)	**1.2-2.4**	**1.0-2.0**	**0.5-1.0**
Power Use (kWh/m³)	**2.8-4.0**	**2.5-3.5**	**2.0-2.5**
Membrane Productivity (gallons/day/membrane)	**5,000-12,000**	**8,000-15,000**	**20,000-40,000**
Membrane Useful Life (years)	**5-7**	**7-10**	**10-15**
Plant Recovery Ratio (%)	**45-50**	**50-55**	**55-65**

Concluding Remarks

- The Ocean Will Become One of the Key Sources of Reliable and Draught-Proof Coastal Water Supply in the Next 10 to 20 Years;
- Large-scale Seawater Desalination is Economical Today and Will Become Even More Cost-Competitive in the Future;
- The Future of Seawater Desalination Is Bright – 20% Cost of Water Reduction in the Next 5 Years;
- Long-term Investment In Research and Development Has the Potential to Reduce the Cost of Desalinated Water by 80 % In the Next 20 Years.

Desalination Cost Trends

Questions?

Coffee Break