CPET, Continued Professional Education and Training

THE MIDDLE EAST DESALINATION RESEARCH CENTER

Cost Estimating of SWRO Desalination Plants

Day 2: Total Capital Costs and O&M Expenditures

June 26, 2013

10:45-12:00

2.2 Variable O&M Costs

Water Globe Consulting

Nikolay Voutchkov, PE, BCEE

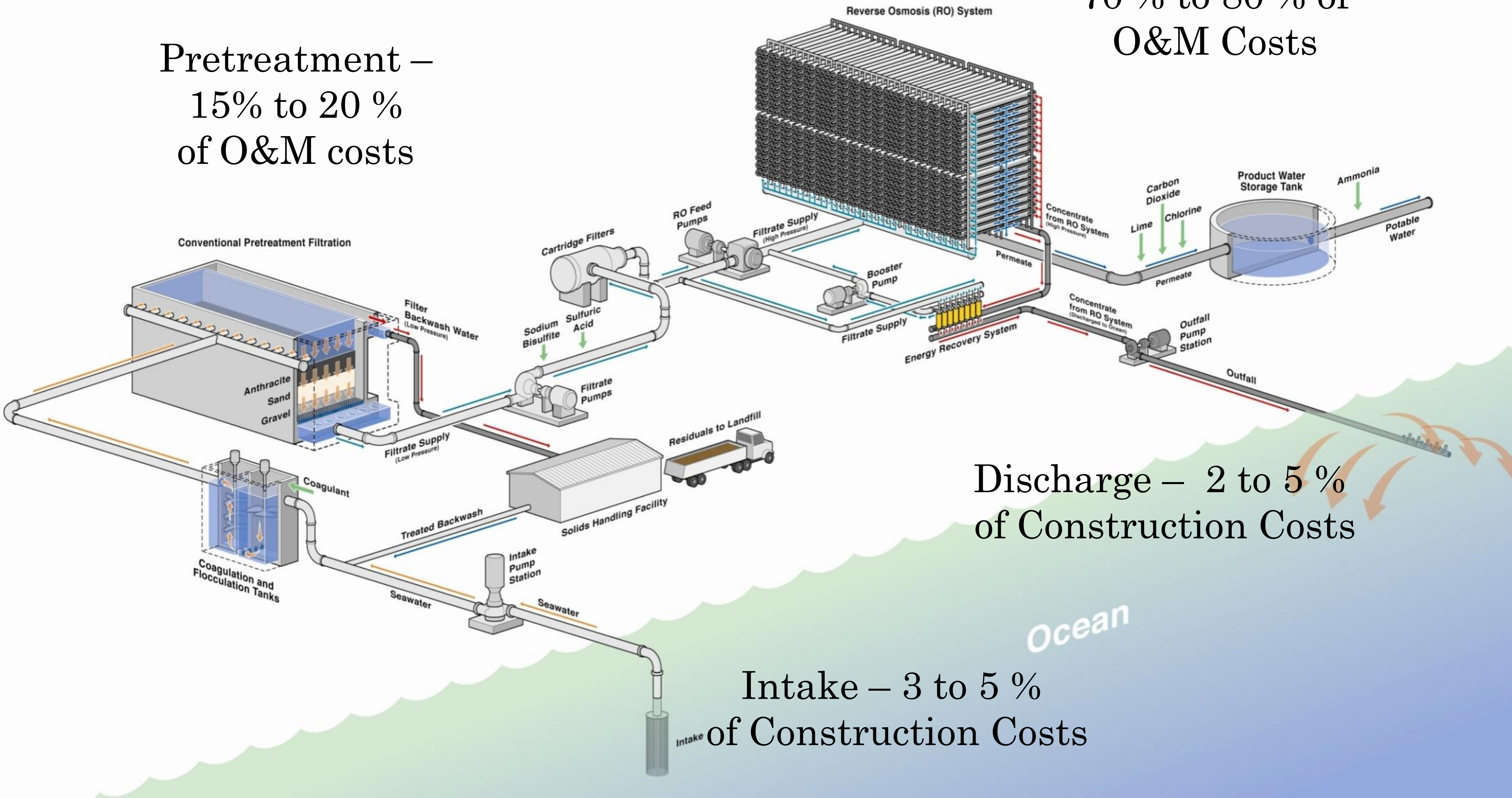
Variable O&M Costs - Outline

- Power
- Chemicals
- Replacement of Membranes and Cartridge Filters
- Waste Stream Disposal

Seawater Desalination Plant – O&M Costs

Pretreatment – 15% to 20 % of O&M costs

RO System – 70 % to 80 % of O&M Costs



Discharge – 2 to 5 % of Construction Costs

Intake – 3 to 5 % of Construction Costs

Desalination Cost Components

- Capital Costs:
  - Construction (Direct or “Hard”) Capital Costs;
  - Indirect (“Soft”) Capital Costs.
- Operation & Maintenance Costs:
  - **Variable;**
  - Fixed.
- Cost of Water:
  - Annualized Capital Costs;
  - O&M Costs.

Total O&M Cost Breakdown

Annual O&M Cost Breakdown

Cost Item	Percentage of Total O&M Cost (%)	
	Low-Complexity Project	High-Complexity Project
Variable O&M Costs		
5. Power	45.0 – 61.0	35.0 – 58.0
6. Chemicals	3.0 – 6.5	5.5 – 9.0
7. Replacement of Membranes and Cartridge Filters	5.0 – 9.0	6.5 – 11.0
8. Waste Stream Disposal	2.5 – 5.5	3.5 – 7.0
Subtotal - Variable O&M Costs	***55.5 – 82.0***	***50.5 – 85.0***
Fixed O&M Costs		
5. Labor	5.0 – 9.5	4.0 – 11.0
6. Maintenance	6.5 – 12.5	3.0 – 13.0
7. Environmental and Performance Monitoring	0.5 – 4.0	1.0 – 5.0
8. Indirect O&M Costs	7.5 – 18.5	7.0 – 20.5
Subtotal - Fixed O&M Costs	***19.5 – 44.5***	***15.0 – 49.5***
Total O&M Costs	**100 %**	**100 %**

Variable O&M Costs - Power

Annual O&M Cost Breakdown

Cost Item	Percentage of Total O&M Cost (%)	
	Low-Complexity Project	High-Complexity Project
Variable O&M Costs		
5. Power	45.0 – 61.0	35.0 – 58.0
6. Chemicals	3.0 – 6.5	5.5 – 9.0
7. Replacement of Membranes and Cartridge Filters	5.0 – 9.0	6.5 – 11.0
8. Waste Stream Disposal	2.5 – 5.5	3.5 – 7.0
Subtotal - Variable O&M Costs	***55.5 – 82.0***	***50.5 – 85.0***
Fixed O&M Costs		
5. Labor	5.0 – 9.5	4.0 – 11.0
6. Maintenance	6.5 – 12.5	3.0 – 13.0
7. Environmental and Performance Monitoring	0.5 – 4.0	1.0 – 5.0
8. Indirect O&M Costs	7.5 – 18.5	7.0 – 20.5
Subtotal - Fixed O&M Costs	***19.5 – 44.5***	***15.0 – 49.5***
Total O&M Costs	**100 %**	**100 %**

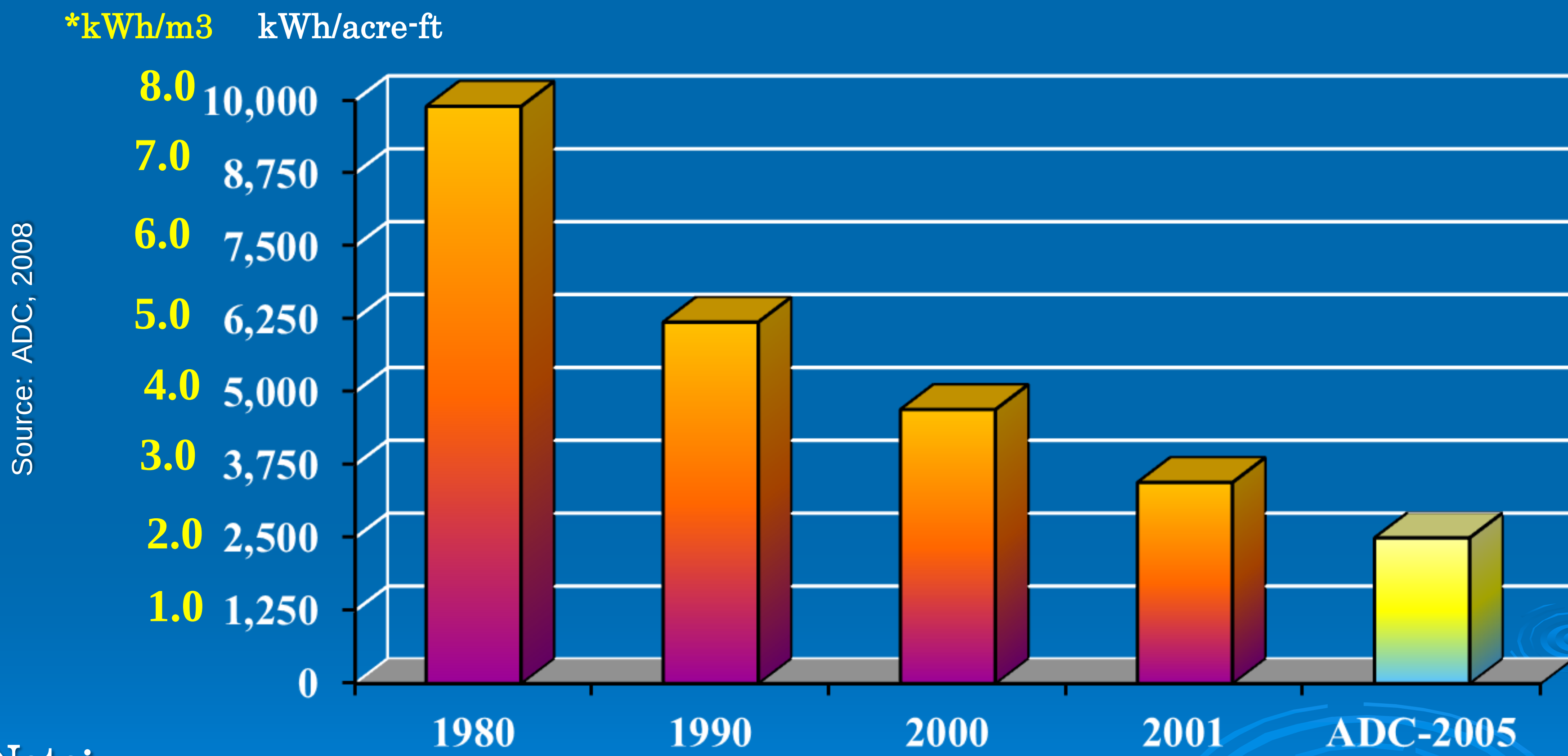
Typical Cost and Energy Ranges Worldwide
(Medium & Large SWRO Plants-2013US$)

Classification	Cost of Water Production (US$/m³)	SWRO System Energy Use (kWh/m³)
Low-End Bracket	0.5 – 0.8	2.5 – 2.8
Medium Range	1.0- 1.5	3.0 – 3.5
High-End Bracket	2.0 – 4.0	4.0 – 4.5
Average	1.1	3.1

Energy Use and Function of Water Source (Medium & Large SWRO Plants)

Seawater Source	SWRO System Energy Use (kWh/m³)
Mediterranean	3.6 – 4.0
Gulf of Oman	3.9 – 4.2
Red Sea	4.0 – 4.3
Arabian Gulf	4.2 - 4.5

Seawater Reverse Osmosis System – Energy Use Trend

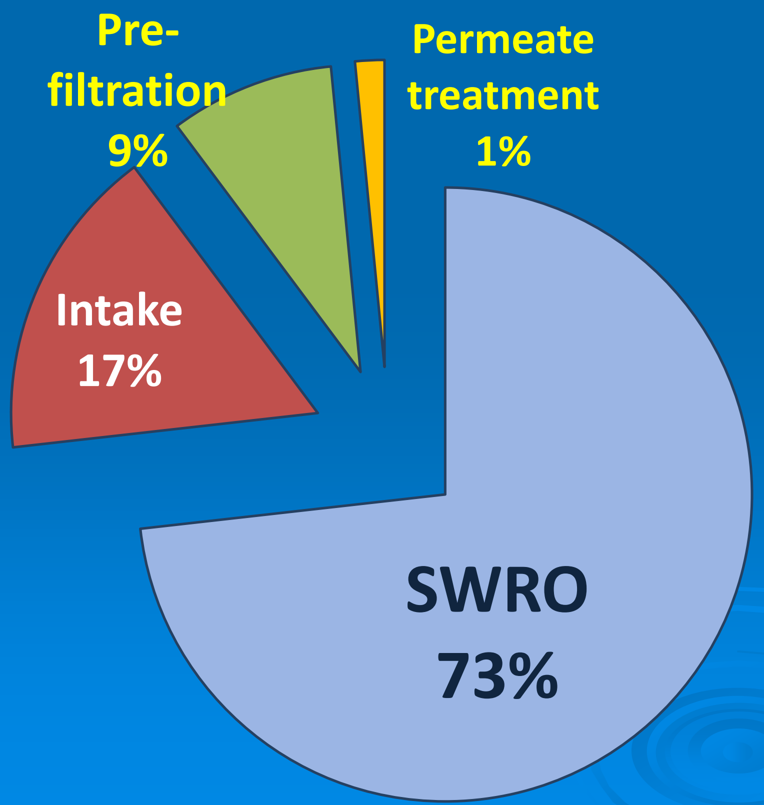


Note:

*Numbers for energy consumption represent the **RO process only**. They do not include any allowance for supply or distribution.

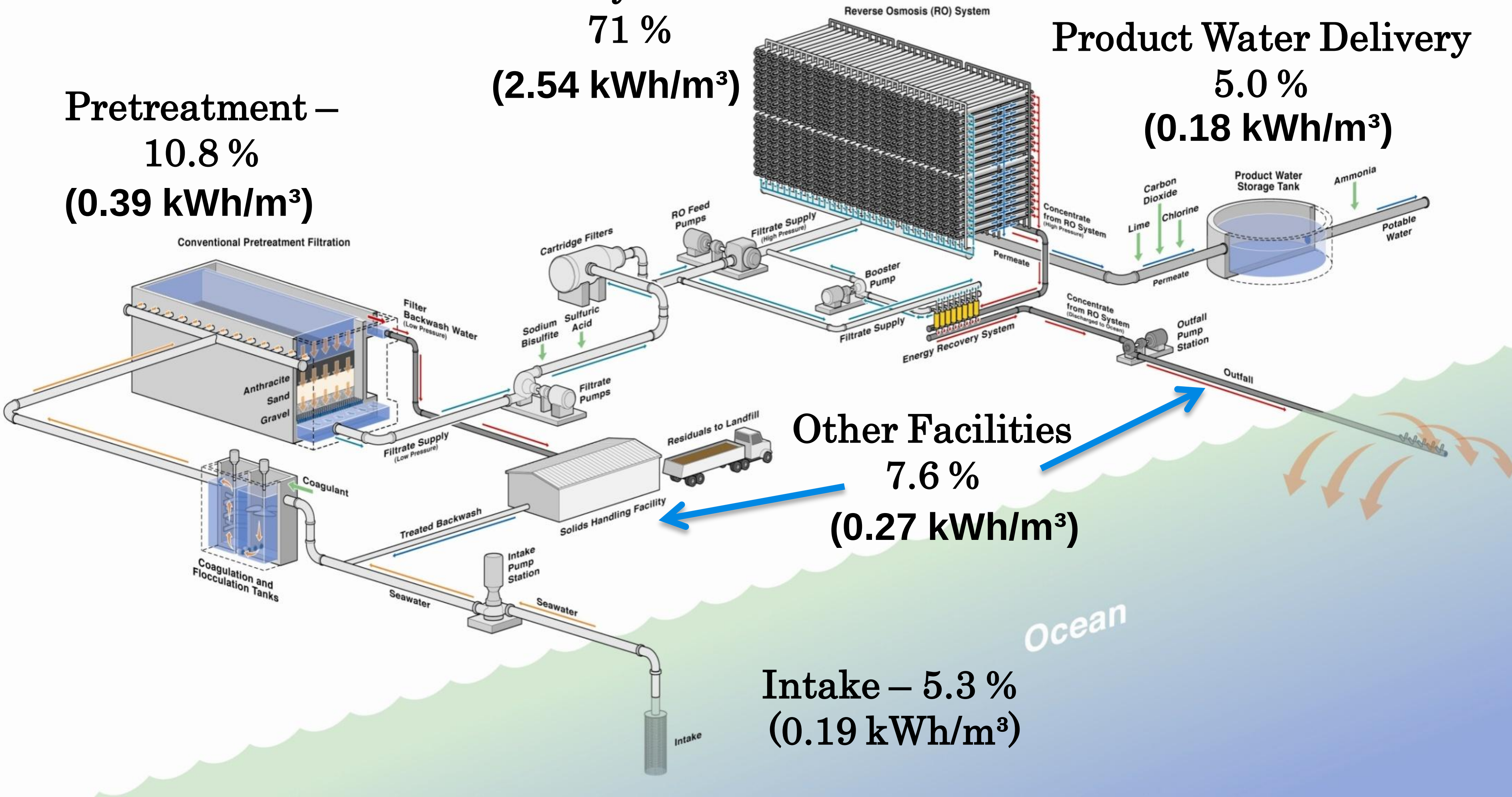
Key Energy Use Components of SWRO Desalination Plants

- **Reverse osmosis** system is the major component of energy consumption



- For SWRO Plants RO System Uses over 70 % of the Total Plant Energy

200,000 m³/d SWRO Plant – Key Energy Uses



Pretreatment – 10.8 %
(0.39 kWh/m³)

RO System – 71 %
(2.54 kWh/m³)

Product Water Delivery 5.0 %
(0.18 kWh/m³)

Other Facilities 7.6 %
(0.27 kWh/m³)

Intake – 5.3 %
(0.19 kWh/m³)

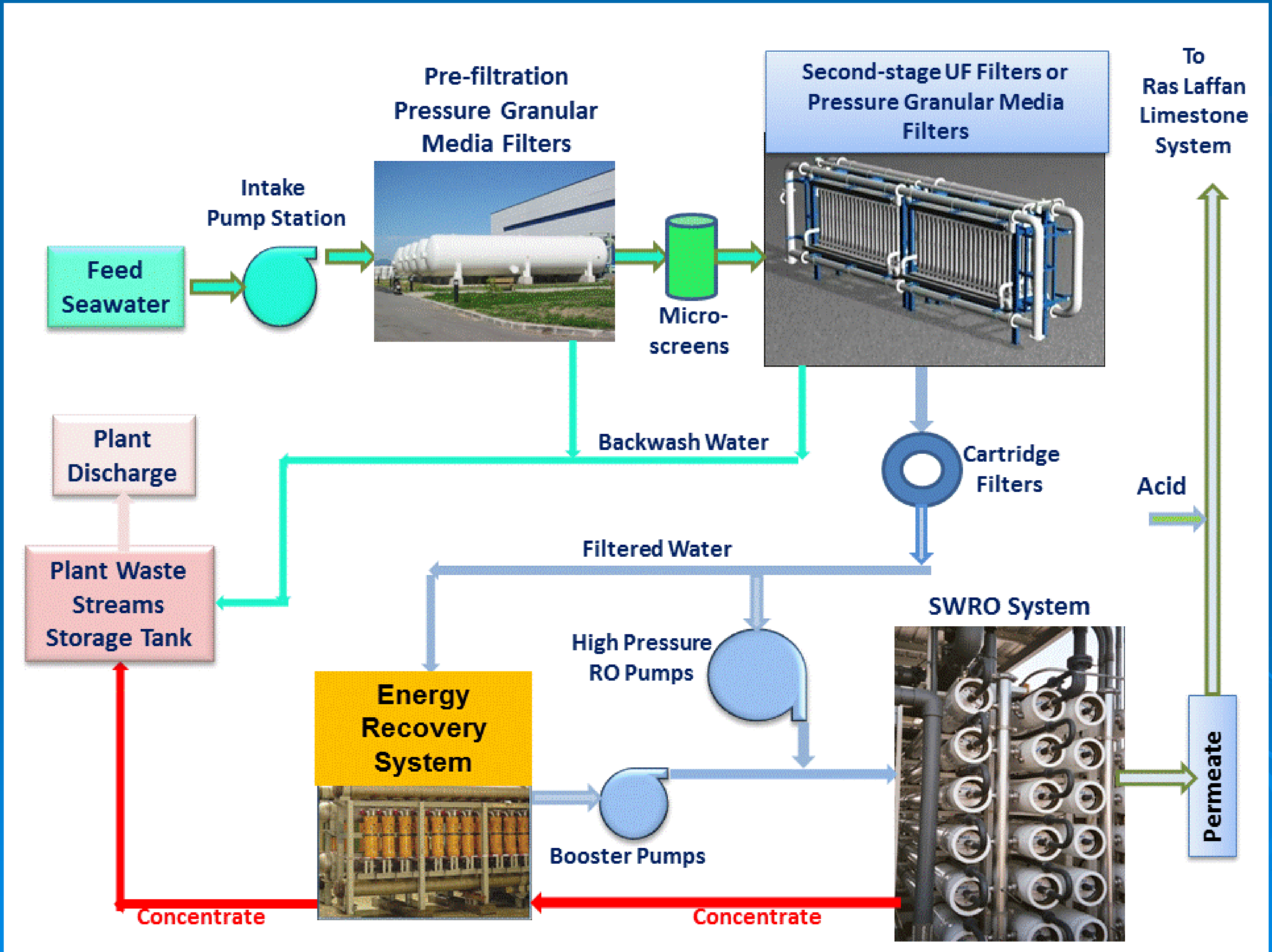
Example

Energy Use of 45,000 m^3/d SWRO Plant (TDS =42 ppt & Temp = 28°C)

Unit	Number of Duty Units	Number of Standby Units	Unit Motor Size (Hp)	Average Power Use Total (Hp)	Average Power Use (% of Total)	Average Power Use (kWh/m^3)	Maximum Power Use Total (Hp)	Maximum Power Use (% of Total)	Maximum Power Use (kWh/m^3)
Desalination Plant Intake Pump Station									
Seawater Intake Pumps	4	1	525	180	1.73	0.071	2,032	13.02	0.667
Pretreatment Facilities									
Pre-filtration Pressure Filters - Blowers	1	1	100	13	0.12	0.005	25	0.16	0.008
Pre-filtration Filter Backwash Pumps	2	1	250	31	0.30	0.012	63	0.40	0.021
Other Pre-filtration Pretreatment Equipment	4	4	2	8	0.08	0.003	10	0.06	0.003
Micro-screening System - Backwash Pumps	1	1	100	8	0.08	0.003	17	0.11	0.005
UF Filters - Blowers	0	0	0	-	-		-	-	
UF Filters - Backwash Pumps	4	2	150	75	0.72	0.030	150	0.96	0.049
Other UF System Equipment	4	4	5	20	0.19	0.008	40	0.26	0.013
Reverse Osmosis System									
High Pressure RO Feed Pumps	5	1	3100	12,500	57.27	2.353	16,154	49.43	2.534
Energy Recovery System - Power Reduction	5	0	0	(6,531)			(8,440)		
ERI Booster Pumps	5	5	75	360	3.45	0.142	440	2.82	0.145
Booster Pumps for Second RO Pass	4	1	875	2,304	22.11	0.908	3,416	21.89	1.122
Waste Discharge Pump Station									
Discharge Pumps	4	1	250	940	9.02	0.371	1,000	6.41	0.328
Waste Discharge Tank Mixers	4	0	10	40	0.38	0.016	40	0.26	0.013
Membrane Cleaning System/s									
Membrane Cleaning Pumps	2	1	5	10	0.10	0.004	10	0.06	0.003
Flush Pumps	2	1	7.5	15	0.14	0.006	15	0.10	0.005
Mechanical Mixers for Chemical Batch Tank	2	0	0.75	2	0.01	0.001	2	0.01	0.000
Chemical Cleaning System	2	0	10	20	0.19	0.008	20	0.13	0.007
Chemical Feed Equipment									
Coagulant Feed System	2	1	10	20	0.19	0.008	20	0.13	0.007
Polymer Feed System	1	1	0.5	1	0.00	0.000	1	0.00	0.000
Hydrochloric Acid Feed System	1	1	5	5	0.05	0.002	5	0.03	0.002
Sodium Hypochlorite Feed System	1	1	0.5	1	0.00	0.000	1	0.00	0.000
Sodium Bisulfide Feed System	1	1	1.5	2	0.01	0.001	2	0.01	0.000
Sodium Hydroxide Feed System	2	2	2	4	0.04	0.002	4	0.03	0.001
Biocide	1	1	0.5	1	0.00	0.000	1	0.00	0.000
Service Facilities									
HVAC	1	0	70	70	0.67	0.028	100	0.64	0.033
Lightning	1	0	100	100	0.96	0.039	200	1.28	0.066
Controls and Automation	1	0	20	20	0.19	0.008	20	0.13	0.007
Service Air Compressors	5	5	1	5	0.05	0.002	10	0.06	0.003
Other Miscellaneous/Contingency			200	200.00	1.92	0.079	250.00	1.60	0.082
				10,421	**hp - 100%**		**15,604**	**hp - 100%**	
Other Desalination Plant Power Uses				**7.77**	**MW**		**11.64**	**MW**	
TOTAL DESALINATION PLANT POWER USE				**4.11**	**kW/m^3**		**5.13**	**kWh/m^3**	

Example

Energy Use of 45,000 m³/d SWRO Plant (TDS =42 ppt & Temp = 28°C)



SWRO Plant Size Matters!

Plant Size	SWRO System Energy Use kWh/m³
1,000 m³/d	4.5 - 6.0
40,000 m³/d	3.0 - 4.0
200,000 m³/d	2.5 - 3.0

Examples of Energy Use of Largest Desalination Projects Worldwide

SWRO Plant	Seawater Salinity (ppt)	Total Plant/RO Power Use (kWh/m³)
Sorek, Israel – 510 ML/d **(Largest in the World) – BOOT**	40	3.6 / 2.9
Point Lisas, Trinidad – 130 ML/d (Largest in The Americas) - BOOT	38	4.8 / 3.8
Tuas, Singapore – 136 ML/d (Largest in Asia) - BOOT	33	4.3 / 3.3
Al Dur, Bahrain – 220 ML/d (Largest in the Middle East) - BOO	46	4.6 / 3.8
Victorian Plant, Melbourne – 444 ML/d (Largest in Australia) – DBO	36	3.9 / 3.0
Barcelona, Spain – 200 ML/d (Largest in Europe) – DBO	35	3.7 / 2.6

Methods to Minimize Desalination Plant Energy Use

Desalination Energy Use Factors

Factor	Energy Saving Approach	Potential for Energy Savings (%)
Source Water Salinity	Use Low-Salinity Source or Blend	1.5 to 5 times
Source Water Temperature	Use Warmer Source Water (Co-Location)	5 to 15 %
Membrane Element Losses and Productivity	Use Low-Rejection or Higher Productivity Membranes	5 to 10 %
RO Feed Pump Efficiency	Maximize Pump and Motor Efficiency	3 to 5 %
Recovery of Energy from RO Concentrate	Use Isobaric Chamber Technology	5 to 15 %

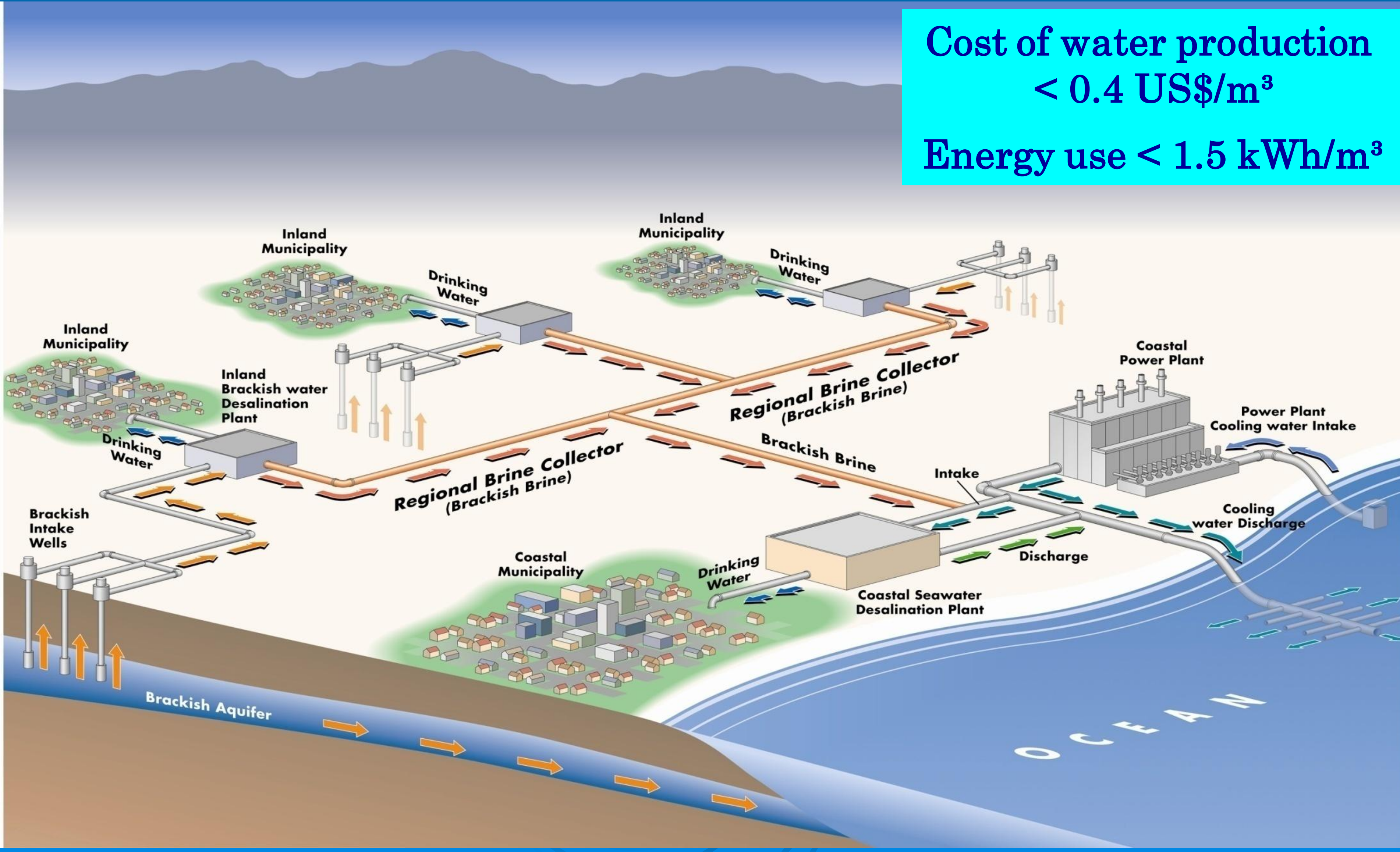
Power Reduction Using Lower Salinity Source Water

- Use of brackish water when available – 1.5 to 5 times lower power costs
- Co-desalination of brackish water and/or brine from brackish desalters with seawater
- Use of lower salinity bay water vs. open ocean seawater

Integrating Collocation & Brackish Water Desalination

Cost of water production
< 0.4 US$/$m^3$

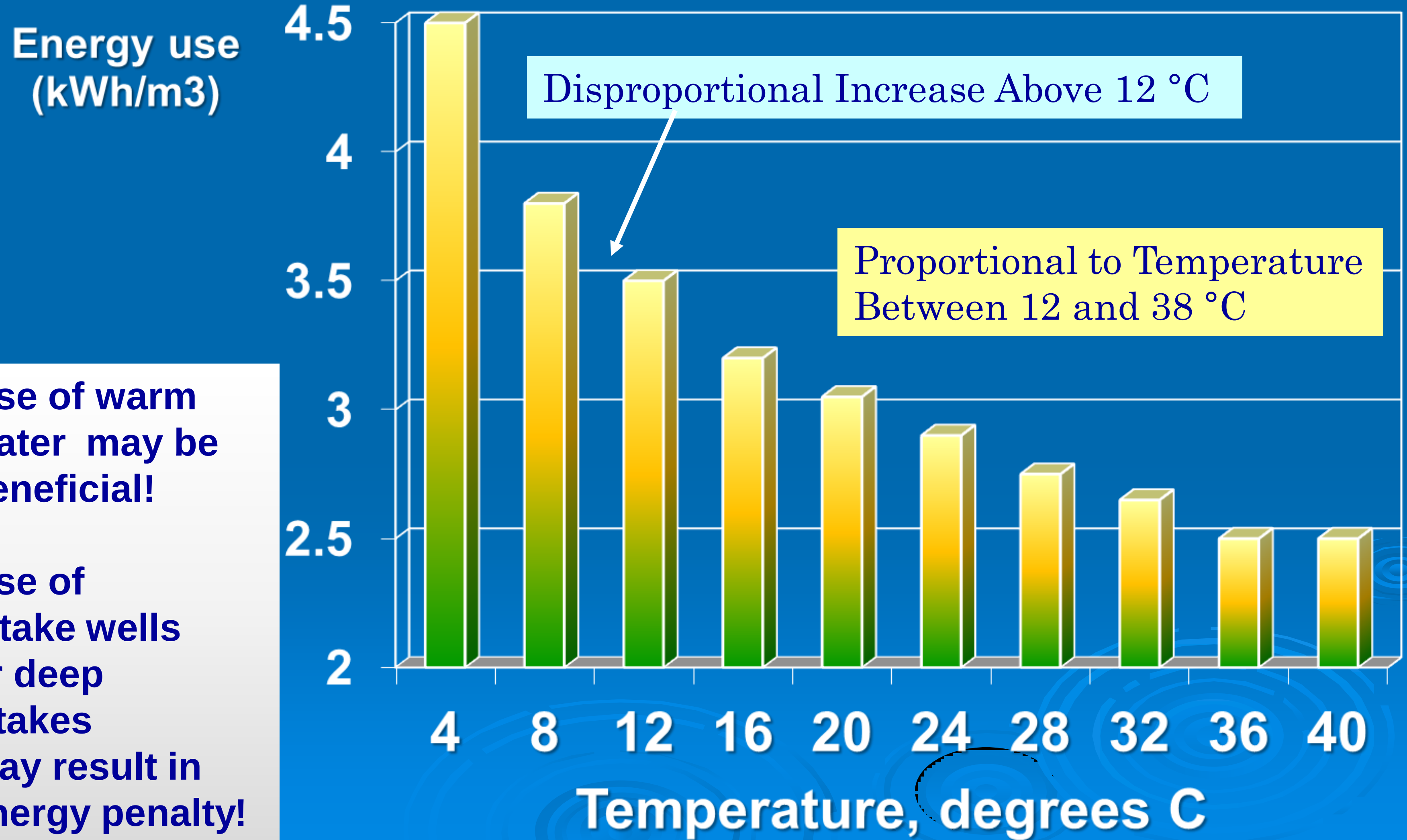
Energy use < 1.5 kWh/m^3



Integrating Brackish & Seawater Desalination – Where Would the Benefits Come From?

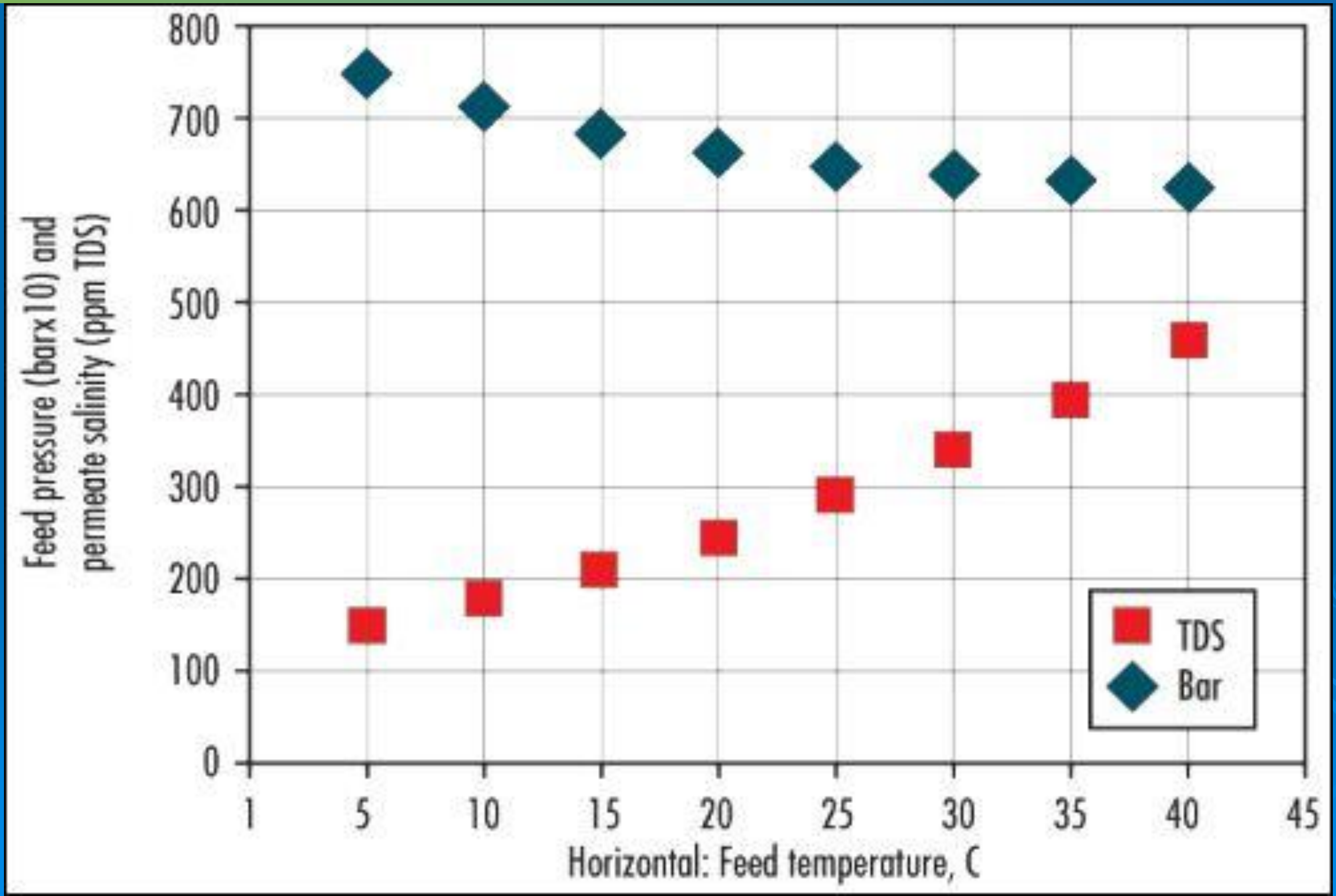
- Higher SWRO plant recovery – 65 % vs. 45 %
  - Lower salinity
  - Beneficial use of anti-scalant in brackish brine
- Lower energy use – energy reduction proportional to brine flow & concentration
- Avoided costs associated with brackish brine disposal
- Lower environmental impacts
  - Lower salinity of desalination plant discharge
  - Solution to ion-imbalance triggered toxicity of brackish brine

Influence of Temperature on Energy Use

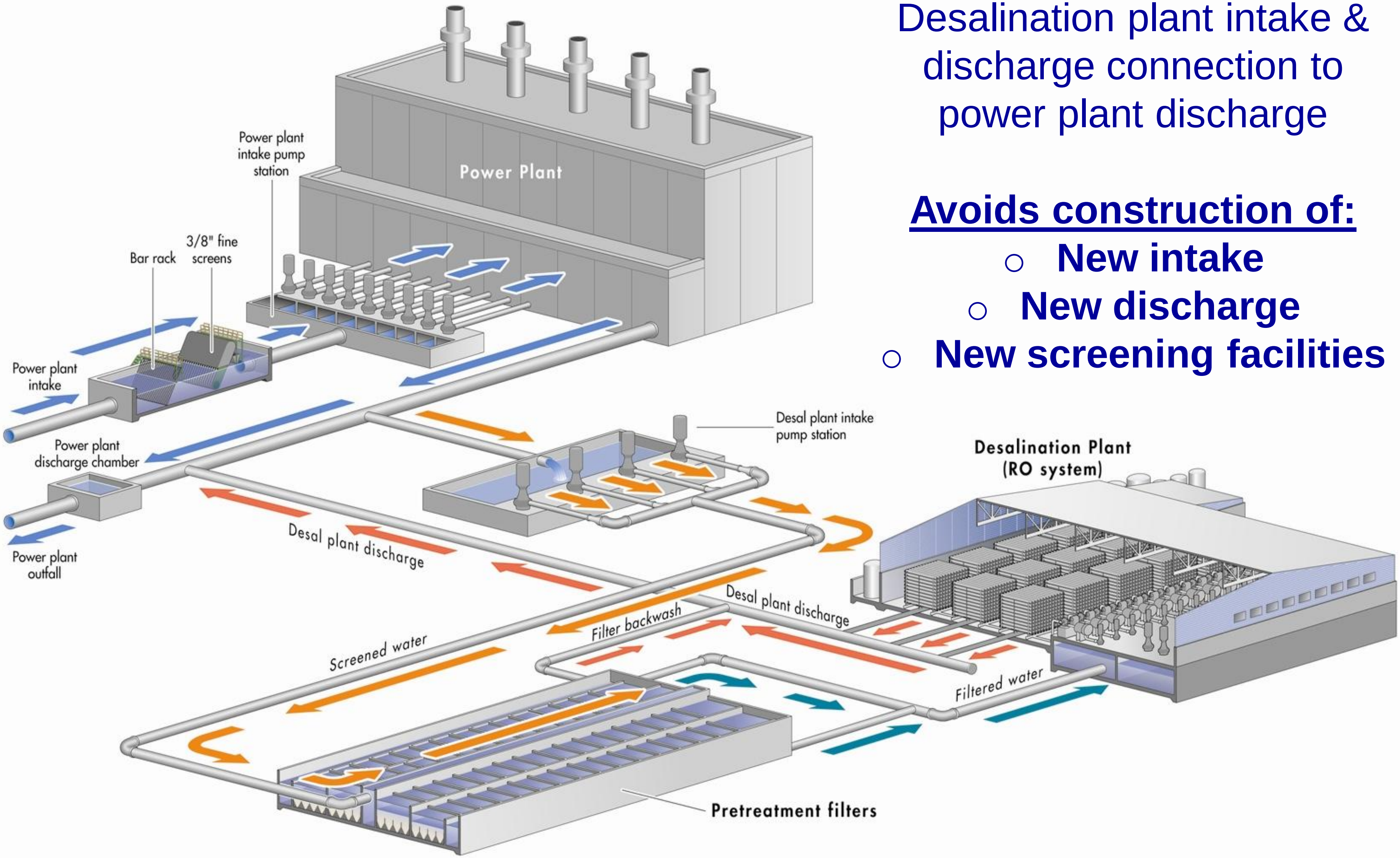


- Use of warm water may be beneficial!
- Use of intake wells or deep intakes may result in energy penalty!

Temperature and Water Quality



Collocation with Power Plant



Desalination plant intake & discharge connection to power plant discharge

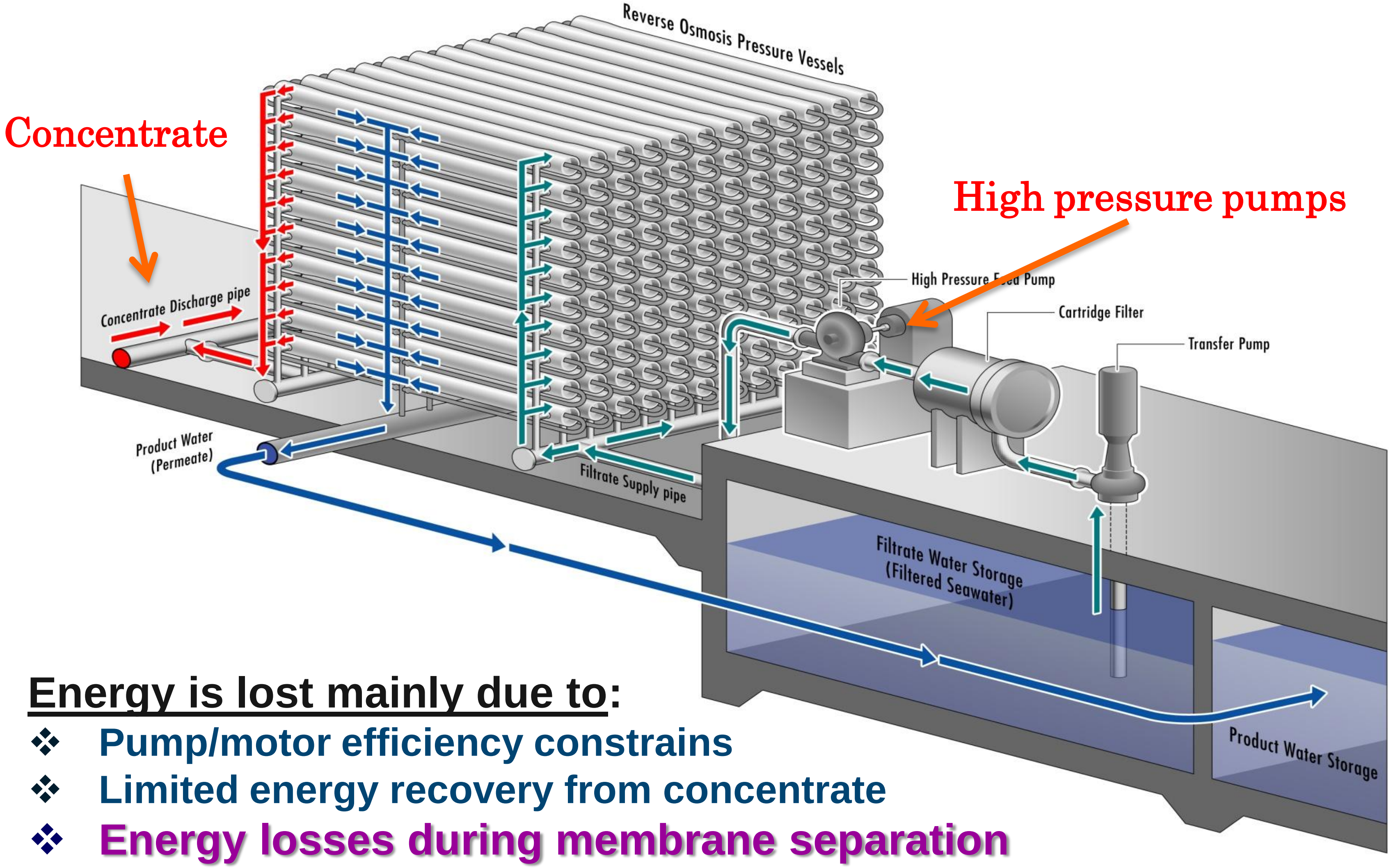
<u>Avoids construction of:</u>

- **New intake**
- **New discharge**
- **New screening facilities**

Potential Energy Benefits of Collocation

- Reduced intake and discharge pumping costs
  - 1-3 % power savings
- Power cost savings due to warmer source water
  - 5-15 % power use reduction
- Use of power plant "spinning reserve" energy where available
- Use of power plant emergency energy generator – savings from avoidance of separate emergency power supply
- Potential avoidance of power grid connection charges/power tariff fees

Energy Losses in SWRO Systems



Energy is lost mainly due to:

- ❖ Pump/motor efficiency constrains
- ❖ Limited energy recovery from concentrate
- ❖ Energy losses during membrane separation

Pump & Motor Efficiency Constraints

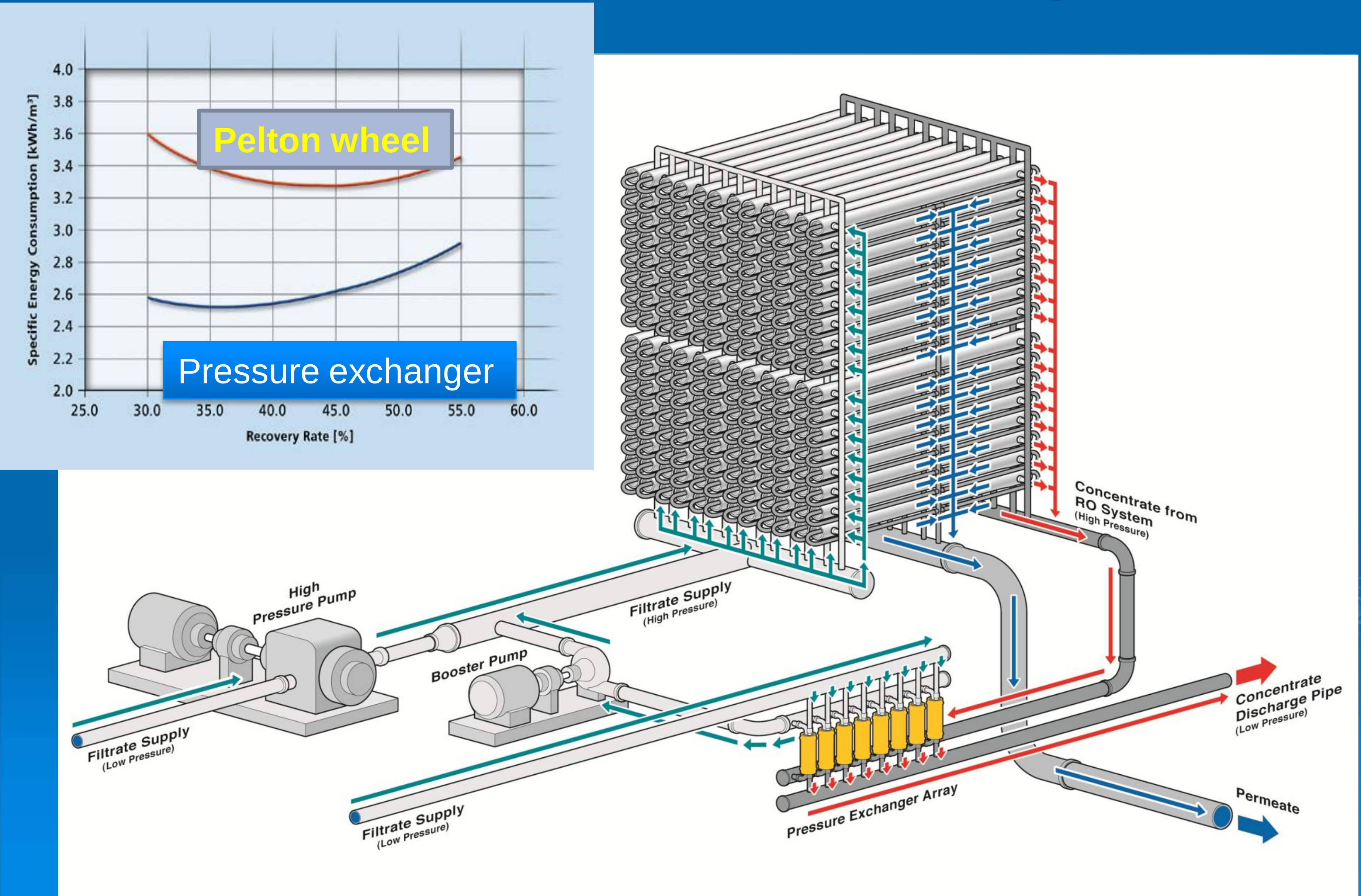
- Typically all pumps higher than 200 hp are equipped with Premium Efficiency Motors (96 to 98% efficient)
- Piston-driven pumps can be up to 98% efficient
- Typical centrifugal pumps are 82 to 85% efficient
- Centrifugal pumps have theoretical efficiency limitation of 92%
- Pump efficiency increases with increase of pump size and with the decrease of the delivered pressure:
  - Bigger is better!
  - Two pumps in series are more efficient than one!

Piston Driven Pumps Have Highest Energy Efficiency (Up to 98 %)

Practical Applications

- Piston high pressure feed pumps are widely used in small plants
- Piston pumps are used as energy recovery devices (Pressure exchangers)
- Newest trend – development of combination of piston high pressure feed pump & piston energy recovery device

Pressure Exchangers Pump Seawater @ 94 to 96 % Efficiency



Pump Efficiency Increases with Pump Size

- Pump efficiency ~ $n \times (Q/H)^{0.5} \times (1/H)^{0.25}$

Where:

n = pump speed (min^{-1});

Q = nominal pump capacity (m^3/s);

H = pump head (m).

Pump efficiency

One pump per train – 83 %

One pump per 2 trains – 85 %

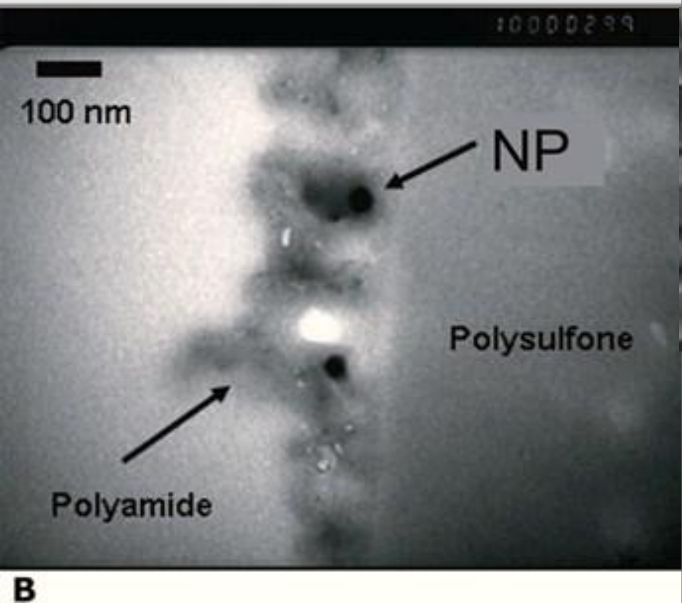
Two pumps per 16 trains – 88 %

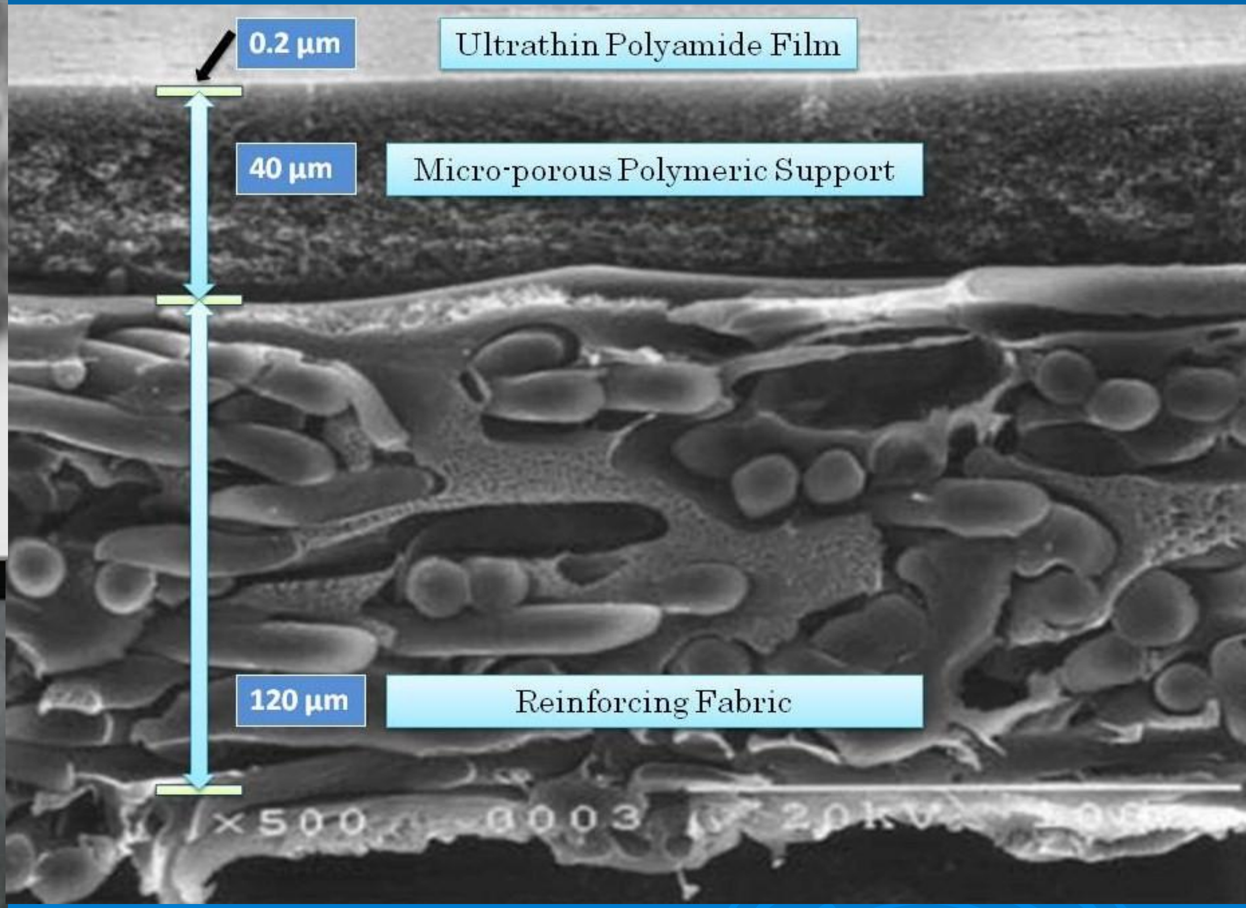
Carboneras, Spain & Perth – One pump per 2 RO trains

Ashkelon, Israel – Two pumps per 16 RO trains

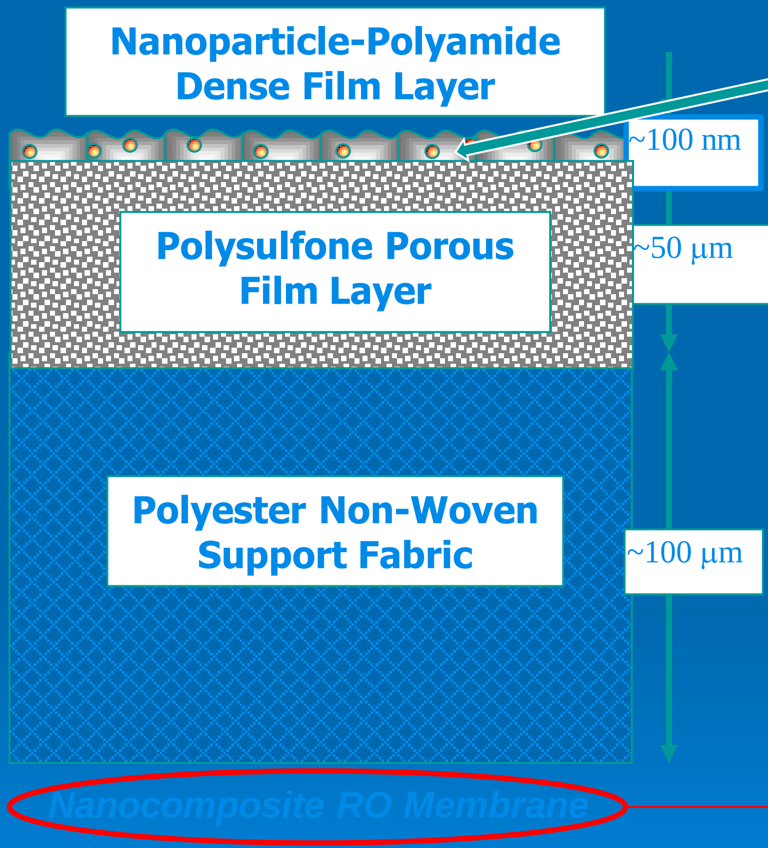
Reducing Energy Losses Through the SWRO Membranes

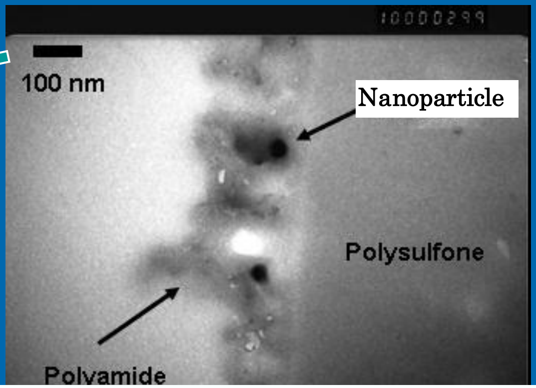
Nano-Structured SWRO Membranes

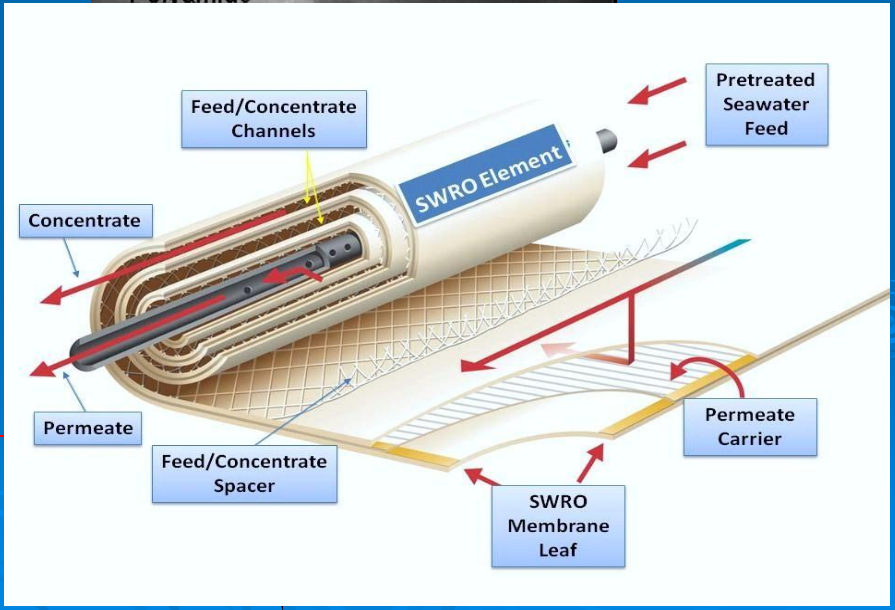




Nano-composite Membranes – NanoH2O



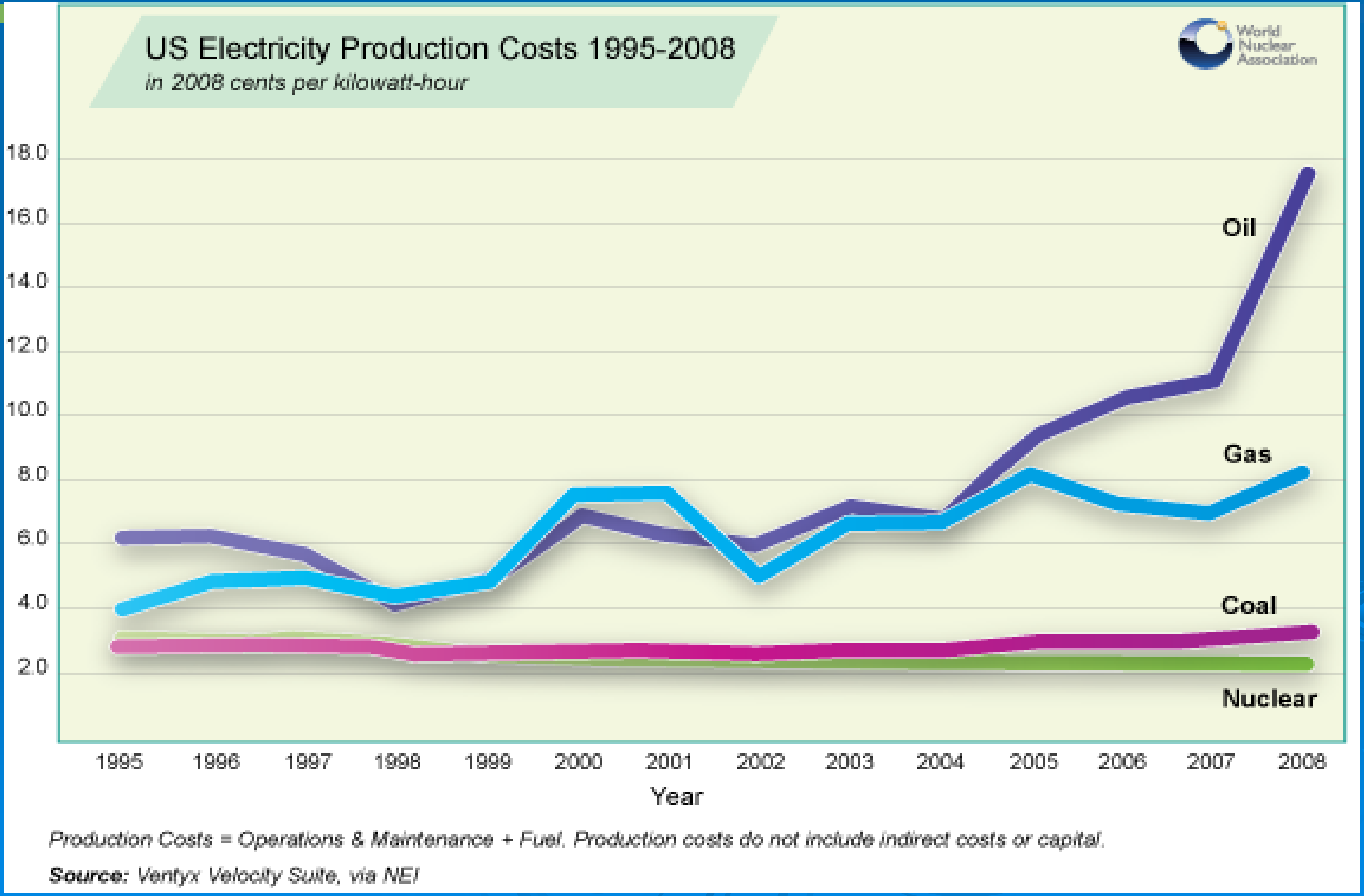




Other Energy Saving Approaches

- RO Design Around Time-of-Use/Peak Load Reduction Rates.
- Peak Summer Day Saving Programs – Power Bill Discount for Reduced Energy Use During Specified Summer Days.
- RO Design Around Interruptible Power Supply Tariff.
- Power Self-Generation (Use of Natural, Methane or Landfill Gas to Run Gas Generators or Gas Driven Engines).
- Use of Waste Heat from Power Plants or Other Sources.

Power Self-Generation from Natural Gas – Why it May Make Sense?



Ashkelon SWRP Plant – Power Self-generation System

Energy Saving Approaches/Alternatives (Continued)

- Stimulate Private Power Generation Companies to Get Involved in Seawater Desalination – Savings from Economies of Scale and Synergies Between Energy and Water Production.
- Encourage Industries to Build Desalination Plants for Their Water Supply and Reduce Reliance On Municipal Water Supply.
- Introduce High-Efficiency Equipment Rebates for Desalination Plants.
- Fund R&D Efforts to Develop the Next Generation of Energy Efficient Desalination Technologies.

Renewable Energy Desalination

- Solar Desalination
  - Total Installed Capacity Worldwide – 0.88 MGD
  - Over 80 % in the Middle East;
  - Largest Facilities in Libya (0.40 MGD) and UAE (0.15 MGD).
  - Largest Plant Outside the Middle East - Spain
- Wind Powered Desalination
  - Total Installed Capacity Worldwide – 0.66 MGD
  - Over 95 % in the Middle East;
  - Largest Facilities in Libya (0.53 MGD) and Egypt (0.11 MGD);
  - Largest Plant Outside the Middle East – Spain
- Solar & Wind Desal Plants
  - 0.02% of Total Plant Capacity Worldwide;
  - 67 % Brackish & 33 % Seawater Plants.

Solar Desalination – Photovoltaic (PV) Panels

- Cost of Produced Power = US$0.12 - $0.40/kWh
- Cost of Produced Water = $2,000 – $3,000/AFY
- 1,000 gpd PV-RO Plant Costs ~ US$50,000 & Needs 150 sq ft of Solar Panels
- Small Size (Yacht) Units – 160 gpd - US$10,000
- Commercially Available Container Systems – up to 50,000 gpd

Solar Desalination – Costs & Viability

- Cost of Generated Energy – US$0.12 – 0.40/ KWh
  Suitable for Small Plants (< 1 m^3/day);
- Production of 100 gpd Requires 150 Watts (approx. 15 to 20 sq ft of PV panels);
- Cost of 1 sq ft of Solar Panels = $30 to $50/sq ft
- 1 MGD Plant Needs 3.4 to 4.5 acres of PV Panels ($4.5 MM to $10 MM).
- The Footprint of the Desalination Plant is 0.5 acres/(Construction Cost - $4.5 to 5.0 MM).

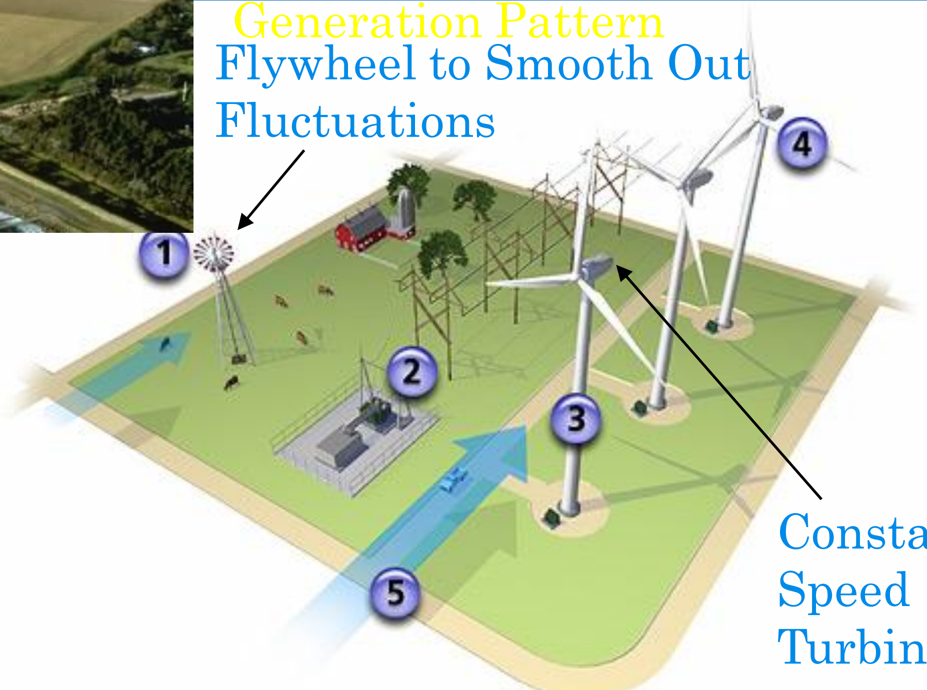
Wind-Powered Desalination

Wind Turbines

Surplus Energy Sale to Grid or Storage in Batteries

Many RO Units of Small Capacity to Match Power Generation Pattern

Flywheel to Smooth Out Fluctuations



Constant Speed Turbines

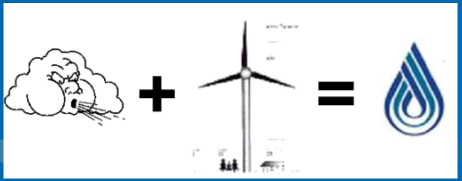
Most Suitable Locations – Along the Coast & Passes or Canyons Inland

When Available Power Is Low System Typically Operates at Low Recovery – 10 % for Seawater

Wind-Powered Desalination

- More Promising for Coastal Areas With Strong Winds;
- Cost of Generated Power - US$0.15 to $0.20/kWh;
- Suitable for Areas with Wind Speed > 18 fps
- More Cost Effective if it Can Supply Excess Energy to the Electric Grid.

Perth Seawater Desalination Project



Stanwell/Griffin Joint Venture – Emu Downs wind generation facility –at Badgingarra 200 km north of Perth

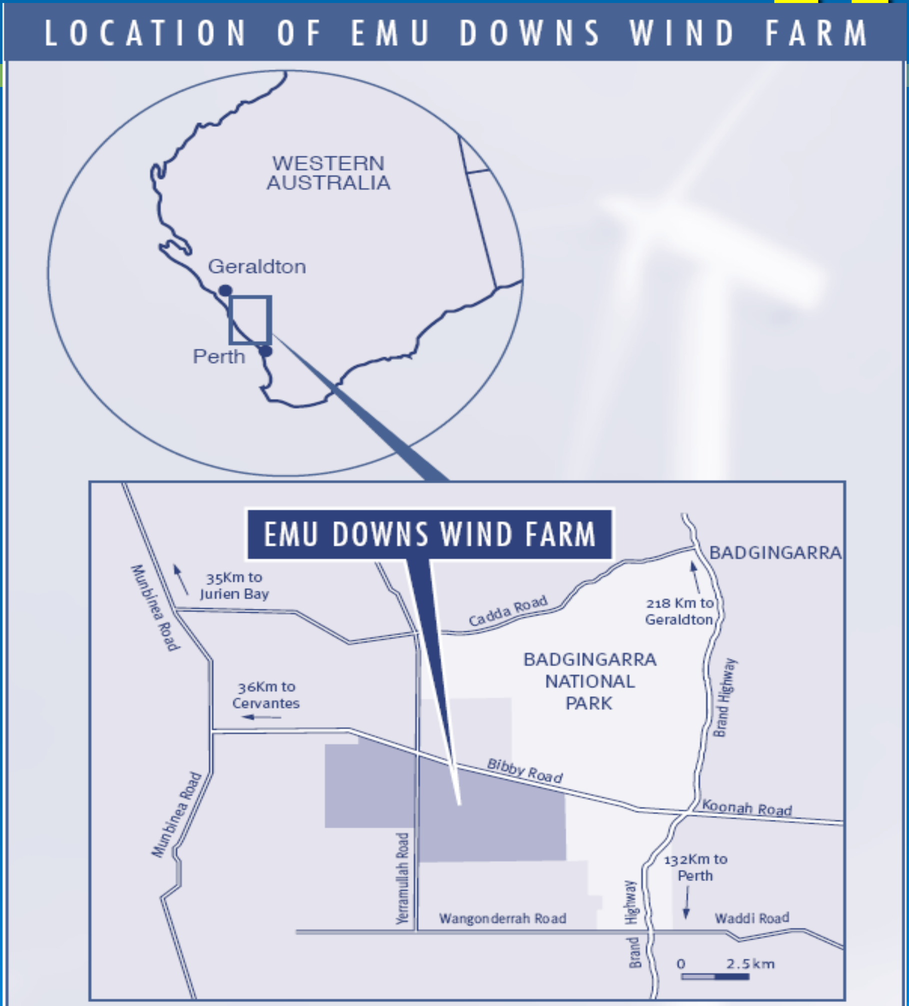
Water Corporation is purchasing 68 percent of the energy output

24 MW (185 GW hrs/annum)

Opened on 12 November 2006

Courtesy of the Water Corporation

Perth Seawater Desalination Project



Emu Downs Wind Farm is located 30 kilometres east of Cervantes on Bibby Road, Badgingarra. The site is approximately 200 kilometres north of Perth and can be reached via the Brand Highway.

Capacity = 80 MW
Number of Turbines = 48
Hub Height= 68 m
Blade Length= 41 m
Wind Farm Area= 31 km2

Courtesy of the Water Corporation

Variable O&M Costs - Chemicals

Annual O&M Cost Breakdown

Cost Item	Percentage of Total O&M Cost (%)	
	Low-Complexity Project	High-Complexity Project
Variable O&M Costs		
5. Power	45.0 – 61.0	35.0 – 58.0
6. Chemicals	3.0 – 6.5	5.5 – 9.0
7. Replacement of Membranes and Cartridge Filters	5.0 – 9.0	6.5 – 11.0
8. Waste Stream Disposal	2.5 – 5.5	3.5 – 7.0
Subtotal - Variable O&M Costs	***55.5 – 82.0***	***50.5 – 85.0***
Fixed O&M Costs		
5. Labor	5.0 – 9.5	4.0 – 11.0
6. Maintenance	6.5 – 12.5	3.0 – 13.0
7. Environmental and Performance Monitoring	0.5 – 4.0	1.0 – 5.0
8. Indirect O&M Costs	7.5 – 18.5	7.0 – 20.5
Subtotal - Fixed O&M Costs	***19.5 – 44.5***	***15.0 – 49.5***
Total O&M Costs	**100 %**	**100 %**

Typical Chemicals Used in Desalination Plants

Properties of Commonly Used Conditioning Chemicals

Chemical	Typical Application	Typical Product Concentration %	Bulk Density kg/Liter	Application Concentration %
Liquid Ferric Chloride	Coagulation	40	1.42	5
Liquid Ferric Sulfate	Coagulation	40	1.55	5
Sulfuric Acid	pH Adjustment	98	1.83	20
Sodium Hypochlorite	Biogrowth Control	13	1.23	5
Sodium Bisulfite	Dechlorination	99	1.48	20
Antiscalant	Scale Control	99	1.0	20
Sodium Hydroxide	pH Adjustment	50	1.525	20

Unit Costs of Typical Chemicals

Unit Chemical Costs

Chemical	**Unit cost (US$/kg)**
Chlorine Gas	0.5 – 1.0
Sodium Hypochlorite	2.0 – 3.0
Ferric Sulfate and Ferric Chloride	0.3 – 1.0
Sulfuric Acid (93 % H_2SO_4)	0.05 – 0.08
Citric Acid	1.5 – 2.5
Biocide	2.5 – 5.0
Sodium Hydroxide (50 % NaOH)	0.6 – 0.75
Sodium Bisulfite	0.3 – 0.5
Antiscalant (Scale-Inhibitor)	1.5 – 4.0

Unit Cost of Typical Chemicals (Continued)

Sodium Bisulfite	0.3 – 0.5
Antiscalant (Scale-Inhibitor)	1.5 – 4.0
Ammonium Hydroxide	0.5 – 1.0
Hydrated Lime	0.26 – 0.28
Calcite	0.03 – 0.04
Carbon Dioxide	0.07 – 0.09
Sodium Tripolyphosphate (Corrosion Inhibitor)	1.5 – 3.0
Other Cleaning Chemicals (US$/$m^3$ of permeate)	0.004 – 0.006

Calculation of Daily Chemical Use & Annual Costs (Example – Coagulant)

- Desalination Plant Capacity Q = 10,000 m3/day (50 % recovery)
- Intake Capacity Q i= (Q /Recovery) x 1.10
- Q i = (10,000/0.5) x 1.1 = 22,000 m3/day
- Coagulant (Fe) Dosage = 10 mg/L (0.01 kg/m3)
- Coagulant Use (100 %) = Qi x Fe dosage = 22,000 x 0.01 = 220 dry kg/day of coagulant
- Annual Cost of Coagulant = Unit Cost (US$1/dry kg) x 220 dry kg/day x 365 days = US$80,300/year

Example of Chemical Costs of 40 MIGD (182 MLD) Plant

Chemical	Dosage (mg/L)	Cost per kg ($/kg)	Kgs per m^3	Cost per m^3	Costs per Day ($/day)	Annual Cost(k$/yr) for Continuous Feed	Projected Feed (%/yr)	Actual Cost per Year (k$/yr)
Sodium Hypochlorite (Pre- and Post-treat.)	8	2.000	0.0080	0.0160	7429	2711	25%	678
Ferric Sulfate/Chloride (Pretreatment)	10	0.400	0.0100	0.0040	1857	678	100%	678
Polymer (Pretreatment)	0.5	1.000	0.0005	0.0005	232	85	100%	85
Hydrochloric acid (Pretreatment)	40.0	0.085	0.0400	0.0034	1579	576	100%	576
Sodium Bisulfite (Pretreatment)	24.0	0.400	0.0240	0.0096	4457	1627	25%	407
Antiscalant (Pretreatment)	2.5	2.500	0.0025	0.0063	2902	1059	100%	1059
Biocide (Pretreatment)	2.2	2.500	0.0022	0.0055	2554	932	25%	233
Sodium Hydroxide (Boron Removal)	40	0.600	0.0400	0.0240	11143	4067	25%	1017
Hydrochloric Acid (Post-treatment)	70	0.085	0.0700	0.0060	1081	395	100%	395
Limestone (Post-treatment)	70	0.060	0.0700	0.0042	763	279	100%	279
RO Membrane Cleaning Chemicals- 6 cleanings/yr						180	100%	180
UF Membrane CIP Cleaning Chemicals - 12 cleanings/yr						120	100%	120
					Total Annual Chemical Costs (1,000 US$/year)			$ 5,705

Variable O&M Costs – Replacement of Cartridge Filters and RO Elements

Annual O&M Cost Breakdown

Cost Item	Percentage of Total O&M Cost (%)	
	Low-Complexity Project	High-Complexity Project
Variable O&M Costs		
5. Power	45.0 – 61.0	35.0 – 58.0
6. Chemicals	3.0 – 6.5	5.5 – 9.0
7. Replacement of Membranes and Cartridge Filters	5.0 – 9.0	6.5 – 11.0
8. Waste Stream Disposal	2.5 – 5.5	3.5 – 7.0
Subtotal - Variable O&M Costs	***55.5 – 82.0***	***50.5 – 85.0***
Fixed O&M Costs		
5. Labor	5.0 – 9.5	4.0 – 11.0
6. Maintenance	6.5 – 12.5	3.0 – 13.0
7. Environmental and Performance Monitoring	0.5 – 4.0	1.0 – 5.0
8. Indirect O&M Costs	7.5 – 18.5	7.0 – 20.5
Subtotal - Fixed O&M Costs	***19.5 – 44.5***	***15.0 – 49.5***
Total O&M Costs	**100 %**	**100 %**

Replacement of Cartridge Filters (CFs)

- Cartridge Filter Replacement Rate = Once Every 4 to 6 weeks (avg. once per 2 months)
- Cartridge Filter Costs – US$8 – 15/CF
- Cartridge Filter Number – Rule of Thumb – 25 CFs/1,000 m^3.day
- Example:

Desalination Plant Capacity Q = 10,000 m3/day;

- Total Number of CFs = (10,000 x 25)/1000 = 250 CFs
- Annual Replacement Cost @ US$10/CF = 250 CFs x 6 times per year x US$10/CF = US$15,000/year.

Replacement of RO Elements

- Avg. SWRO & BWRO Element Replacement Rates = 15 %/yr & 10 %/yr, respectively
- RO Element Costs – US$400 – 550/Element
- SWRO Element Number – Rule of Thumb – 90/1,000 m^3.day
- BWRO Element Number – Rule of Thumb – 30/1,000 m^3.day
- Example:

Desalination Plant Capacity Q = 10,000 m3/day;

- Total Number of SWRO membranes = 10,000 x 90/1000 = 900
- Total Number of BWRO membranes = 10,000 x 30/1000 = 300
- Annual Replacement Cost @ US$450/RO Element = (900 x 0.15 + 300 x 0.1) /year x US$450/RO Element = US$74,250/year.

Variable O&M Costs – Waste Stream Disposal

Annual O&M Cost Breakdown

Cost Item	Percentage of Total O&M Cost (%)	
	Low-Complexity Project	High-Complexity Project
Variable O&M Costs		
5. Power	45.0 – 61.0	35.0 – 58.0
6. Chemicals	3.0 – 6.5	5.5 – 9.0
7. Replacement of Membranes and Cartridge Filters	5.0 – 9.0	6.5 – 11.0
8. Waste Stream Disposal	2.5 – 5.5	3.5 – 7.0
Subtotal - Variable O&M Costs	***55.5 – 82.0***	***50.5 – 85.0***
Fixed O&M Costs		
5. Labor	5.0 – 9.5	4.0 – 11.0
6. Maintenance	6.5 – 12.5	3.0 – 13.0
7. Environmental and Performance Monitoring	0.5 – 4.0	1.0 – 5.0
8. Indirect O&M Costs	7.5 – 18.5	7.0 – 20.5
Subtotal - Fixed O&M Costs	***19.5 – 44.5***	***15.0 – 49.5***
Total O&M Costs	**100 %**	**100 %**

Variable O&M Costs
Waste Stream Disposal

- Waste Stream Disposal - US$0.01 to 0.03/$m^3$
- Includes:
  - Concentrate Discharge
  - Spent Backwash Water from Pretreatment Filters
  - Discharge of Cleaning Solutions from RO System
  - Other Waste Streams


Questions?

Lunch Break