Membrane Seawater Desalination Overview and Recent Trends

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Desalination: An Energy Solution

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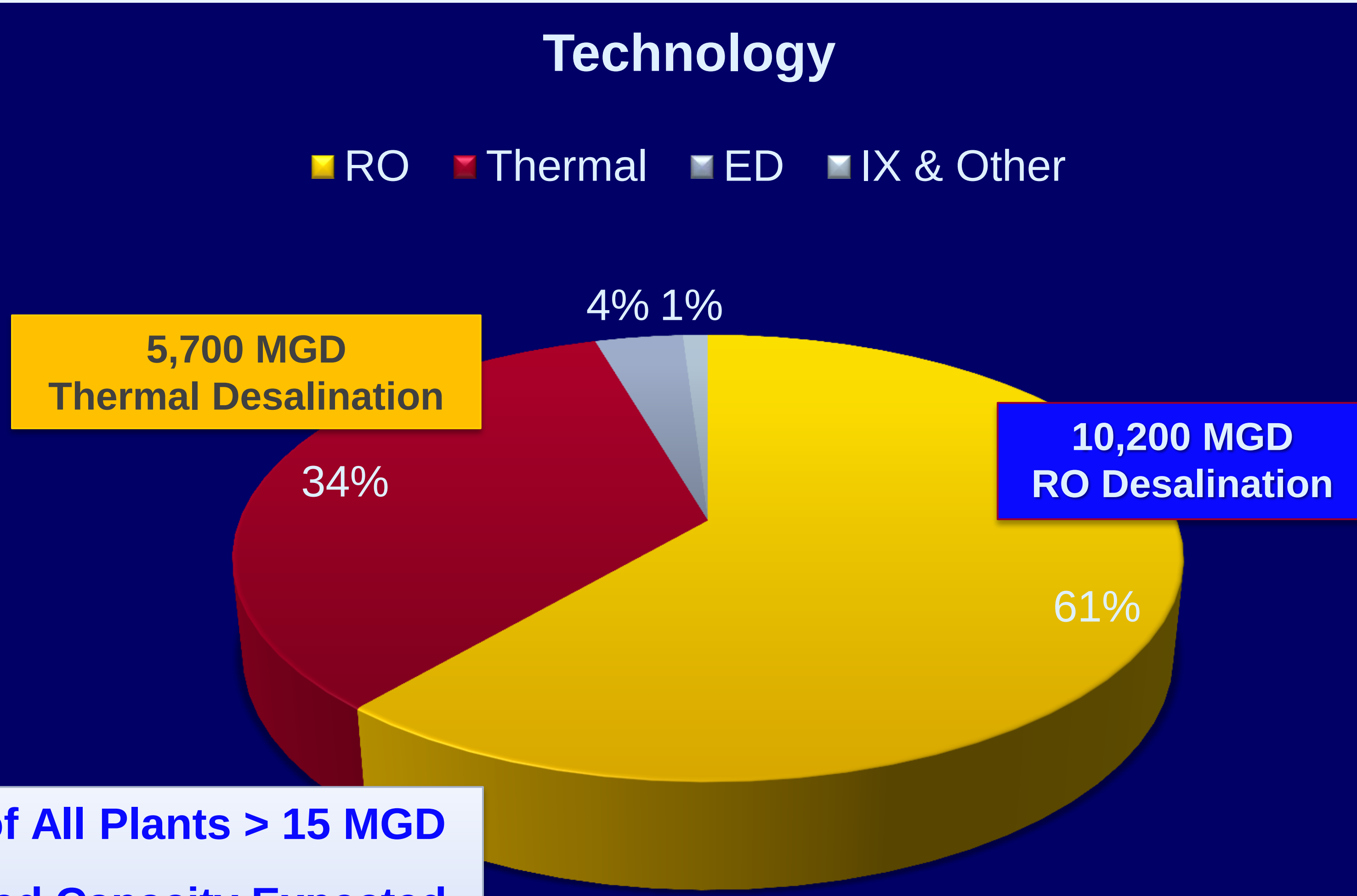
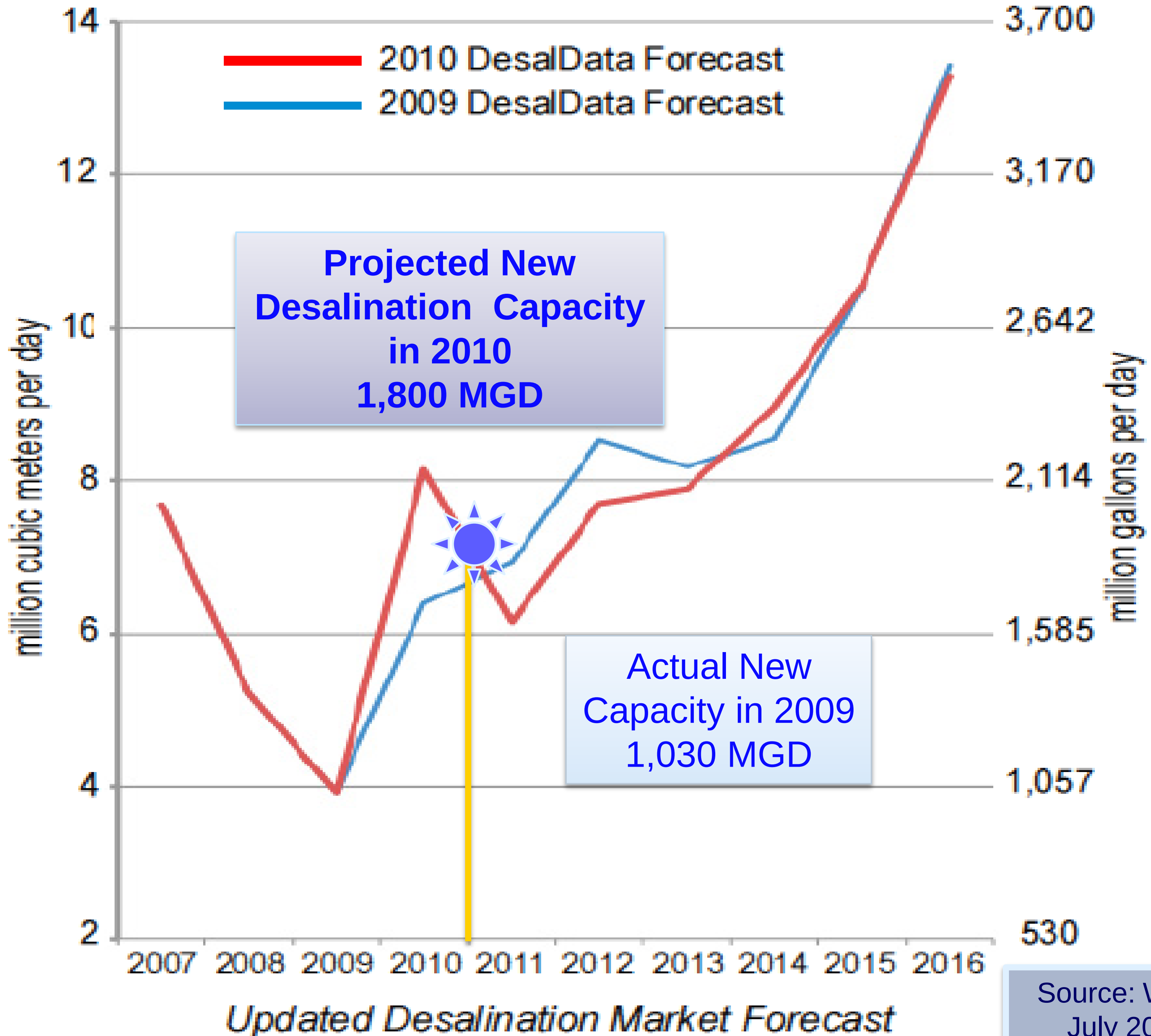
Desalination – Where Are We Today?

14,754 Desalination Plants Worldwide – 16,700 MGD



- 40 % of All Plants > 15 MGD
- Installed Capacity Expected to Double by 2015

Source : IDA Desalination Yearbook 2009-2010



Source: WDR, July 2010

Desalination – Key Trends?

- SWRO Desalination Technologies Dominate;
- Large - (over 15 MGD) and Mega - (over 100 MGD) Desalination Plants Are the Wave of the Future!
- Most Large Urban Coastal Centers Worldwide Have Established a Target to Produce 25 % of their Drinking Water from Desalination.
- R&D Activities are in 10-Year High – Expected to Yield Breakthroughs in Membrane and Desalination Technologies by 2012.
- Large SWRO Projects Are Aiming at Sustainability – Green is In!

Typical Cost and Energy Ranges
(Medium & Large SWRO Plants)

Classification	Cost of Water Production (US$/kgal)	SWRO System Energy Use (US$/kgal)
Low-End Bracket	2.0 - 3.0	9.5 – 10.5
Medium Range	3.5 - 5.5	11.0 - 12.0
High-End Bracket	6.5 - 11.0	12.5 – 14.0
Average	4.0	11.5

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Year 2005-2010
The Five Lowest-Cost SWRO Projects Worldwide

SWRO Plant	Cost of Water (US$/kgal)	Power Use of RO System (kWh/kgal) & TDS (ppt)
Sorek, Israel – 108 MGD (startup – 2014)	2.01	9.8 (40 ppt)
Mactaa, Algeria – 190 MGD (startup – 2013)	2.12	9.7 (39 ppt)
Tuas, Singapore – 36 MGD (startup – 2007)	2.16	11.5 (34 ppt)
Tenes, Algeria – 53 MGD (startup – 2011)	2.23	10.8 (38 ppt)
Hadera, Israel – 87 MGD (startup – 2010)	2.27	10.1 (40 ppt)

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.

Reducing Power Use for SWRO Separation – Still a Hair Rising Challenge?

Lowest Theoretical Energy Use =
3.0 kWh/kgal (100 % Recovery)

Lowest Theoretical Energy Use
@ 50 % Recovery =
4.12 kWh/kgal

ADC - Lowest Energy Use @
42 % Recovery & 6 gfd =
6.0 kWh/kgal

ADC – "Most Affordable Point"
48 % Recovery & 9 gfd =
7.6 kWh/kgal

Low Bracket of Energy Use for
Large SWRO Projects
(45-50 % Recovery & 8.5 to 9.5 gfd) =
9.5 to 10.5 kWh/kgal

Note: All Energy Use Values for Seawater @
TDS = 35 ppt & 25^{o}C

50 MGD SWRO Plant – Key Energy Uses

RO System – 71 % (9.6 kWh/kgal)

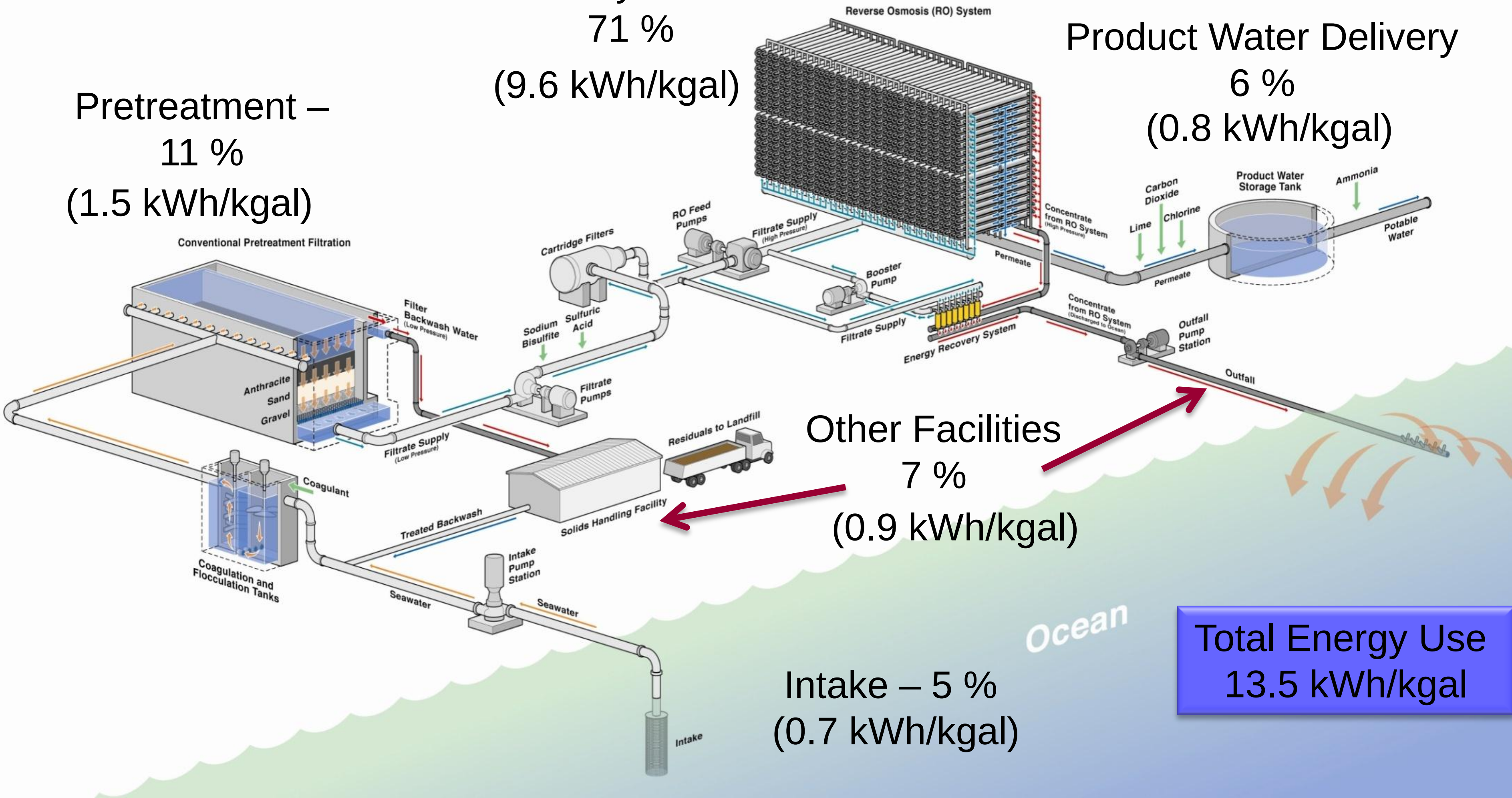
Pretreatment – 11 % (1.5 kWh/kgal)

Product Water Delivery 6 % (0.8 kWh/kgal)

Other Facilities 7 % (0.9 kWh/kgal)

Intake – 5 % (0.7 kWh/kgal)

Total Energy Use 13.5 kWh/kgal



Desalination Energy Use Factors

Factor	Energy Saving Approach	Potential for Energy Savings (%)
Plant Size	Larger Plants Yield Economies of Scale	20 % - 50 %
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 Productivity and Fouling Losses	Use Low-Rejection or Higher Productivity Membranes	5 to 10 %
RO Feed Pump Efficiency	Maximize Pump and Motor Efficiency	3 to 10 %
Recovery of Energy from RO Concentrate	Use Isobaric Chamber Technology	5 to 15 %

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SWRO Plant Size Matters!

Plant Size	SWRO System Energy Use (kWh/kgal)
0.25 MGD	14.0-18.0
10 MGD	11.0-12.0
50 MGD	9.5-10.5

Optimizing RO System Performance

- **Higher Productivity 8-inch RO Elements;**
- **Large –Diameter RO Membranes;**
- **Innovative RO System Configurations;**
- **Pump-Center or Three -Center Designs;**
- **Larger Energy Recovery Devices.**

2008-10 – Evolving SWRO Membrane Performance

- Larger Membrane Element Area: 440 sq ft vs. 400 sq ft;
- Larger RO Element Productivity: 9,000 to 12,500 gpd;
- Improved Salt Rejection: 99.7 to 99.8 %;
- Increased Boron Rejection: 90 to 93 %;
- Wider Membrane Spacers: 28 mil vs. 34 mil

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2.6 MGD PowerSeraja SWRO Plant, Singapore – 16-inch Elements

Large RO Elements – Key Manufacturers/Models

		DOW/FilmTec	Hydranautics (Nitto Denko)	Koch Membrane Systems		Toray	Woongjin Chemical
		SW30HRLE-1725	SWC5 1640HYD	TFC SW–MegaMagnum® 18061-		TM840-160	CSM RE16040-SHN
				SW-3050	HF-3050		
Nominal diameter x length[a]		16 x 40 in.	16 x 40 in.	18 x 61 in.		16 x 40 in.	16 x 40 in.
Membrane material		Composite polyamide	Composite polyamide	Composite polyamide		Composite polyamide	Composite polyamide
Nominal surface area, m^2		160	149	283	283	149	149
Feed spacer thickness, mm		0.71	0.76	0.7	0.7	0.71	0.71
Salt rejection, nominal at standard test conditions, percent		99.75 (91 percent B)	99.8	99.75	99.7	99.75	99.75
Salt rejection, minimum at standard test conditions, percent		99.60	99.6	99.5	99.5	99.5	99.6
Permeate flow at standard test conditions, m^3/d		121	129	200	263	101	92.4
Weight (approximate), dry, kg		57	52	90	90	66	60
Weight (approximate), wet, kg		68	63	113	113	76	66
Standard Test Conditions	NaCl, mg/L	32,000 (and 5 mg/L B)	32,000	32,800		32,000	32,000
	Applied pressure, bar	55	55	55		55	55
	Temperature, °C	25	25	25		25	25
	Permeate recovery, percent	8	10	11		8	8
	pH	8.0	6.5 to 7.0	7.5		7.0	6.5 to 7.0

[a]Nominal membrane element diameter x length: 16-in. x 40-in. (0.41 x 1.0 m) or 18-in. x 61-in. (0.46 x 1.5 m)
Source: Bergman et al, 2009

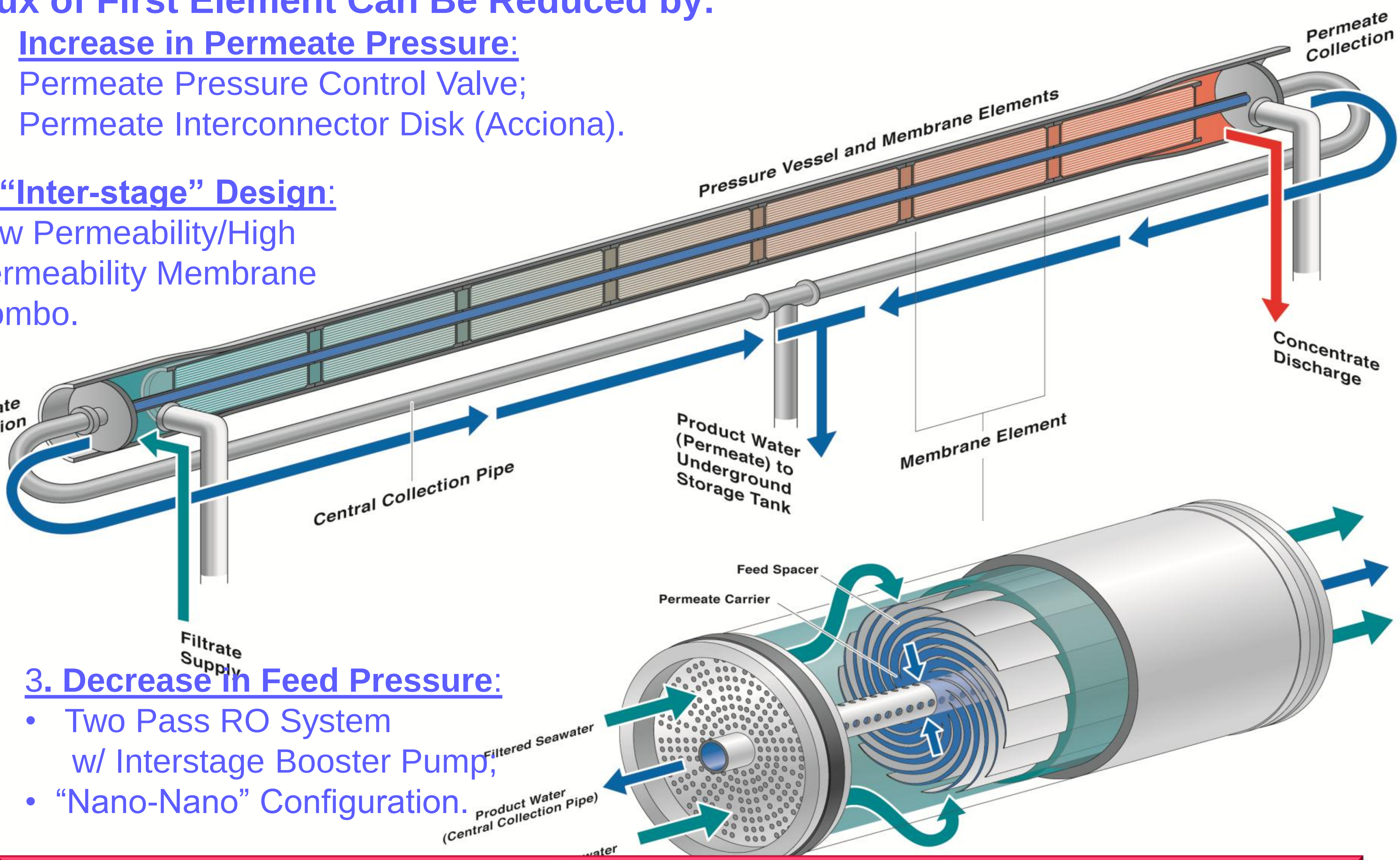
Source: IDA Journal, Vol. 2, 2010

Optimizing Performance by Redistributing Flux/Energy

Flux of First Element Can Be Reduced by:

1. **Increase in Permeate Pressure**:
- Permeate Pressure Control Valve;
- Permeate Interconnector Disk (Acciona).

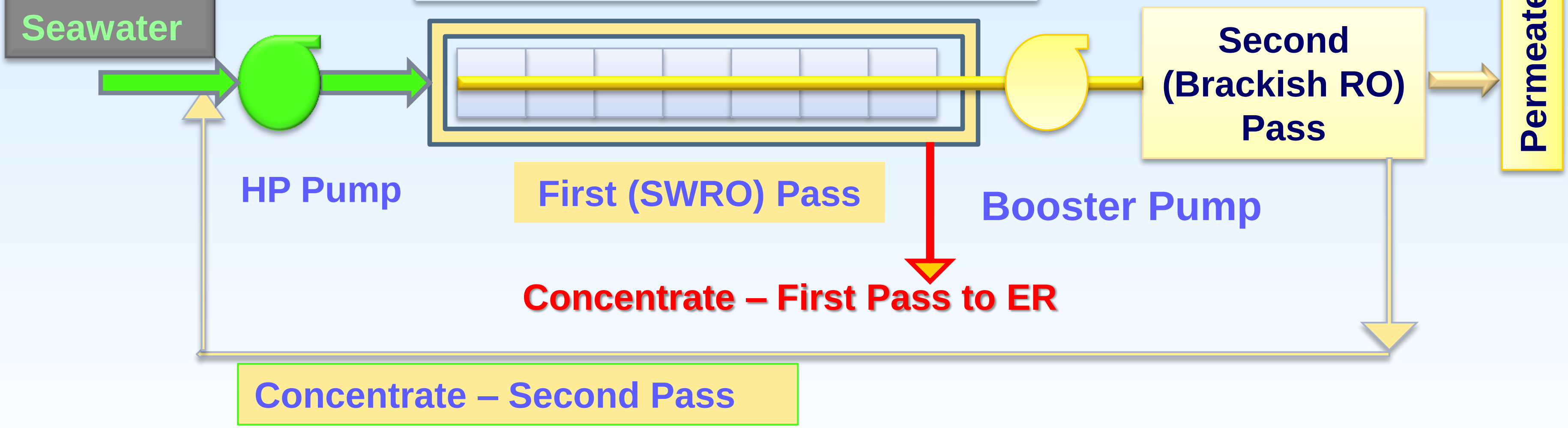
2. **“Inter-stage” Design**:
Low Permeability/High Permeability Membrane Combo.



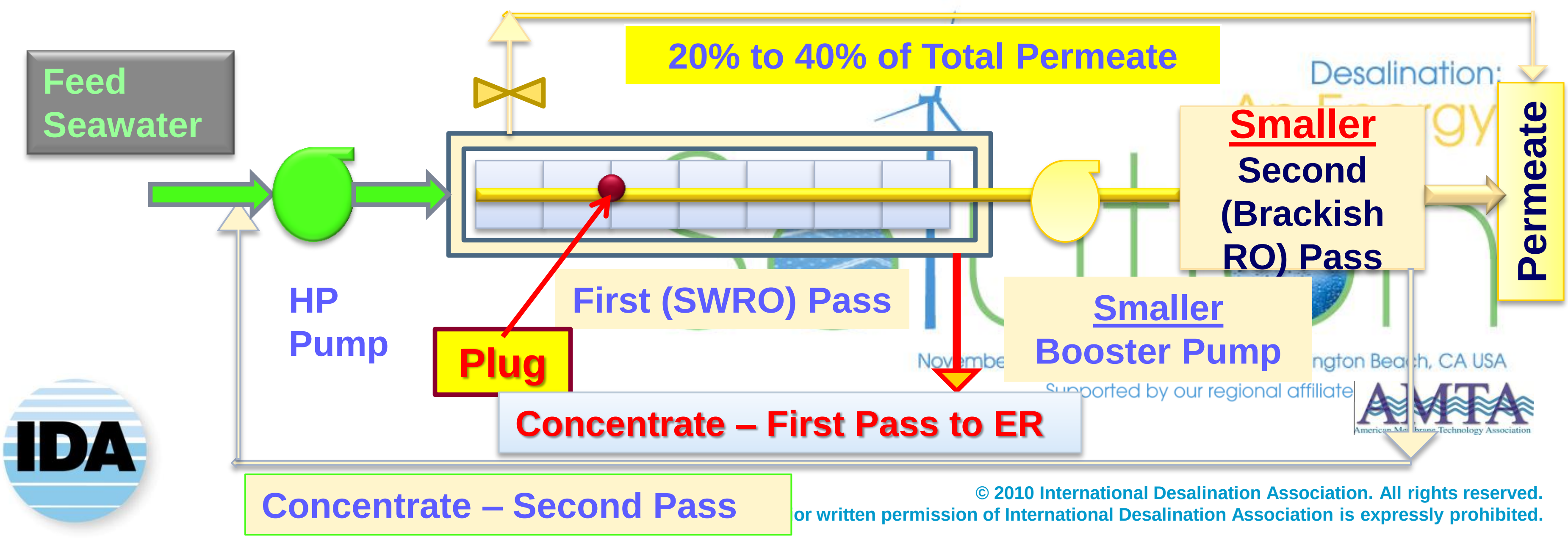
3. **Decrease in Feed Pressure**:
- Two Pass RO System w/ Interstage Booster Pump;
- “Nano-Nano” Configuration.

Flux is Proportional to the Difference of the Feed and Permeate Pressures

Conventional RO System Configuration

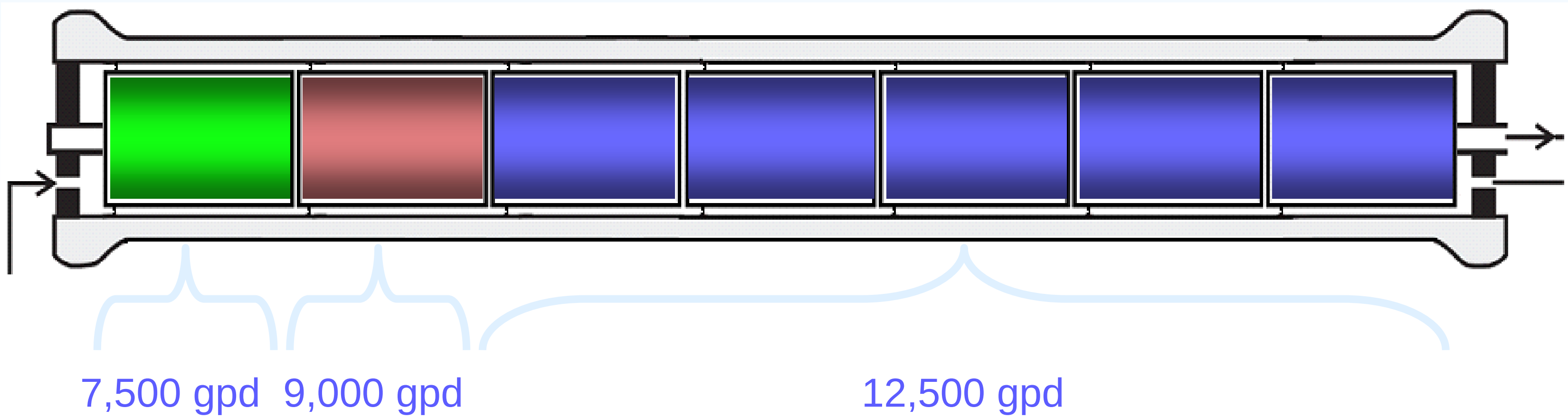


Split "Regulated" First Pass RO System Configuration



Internally Staged Design (1-1-5)

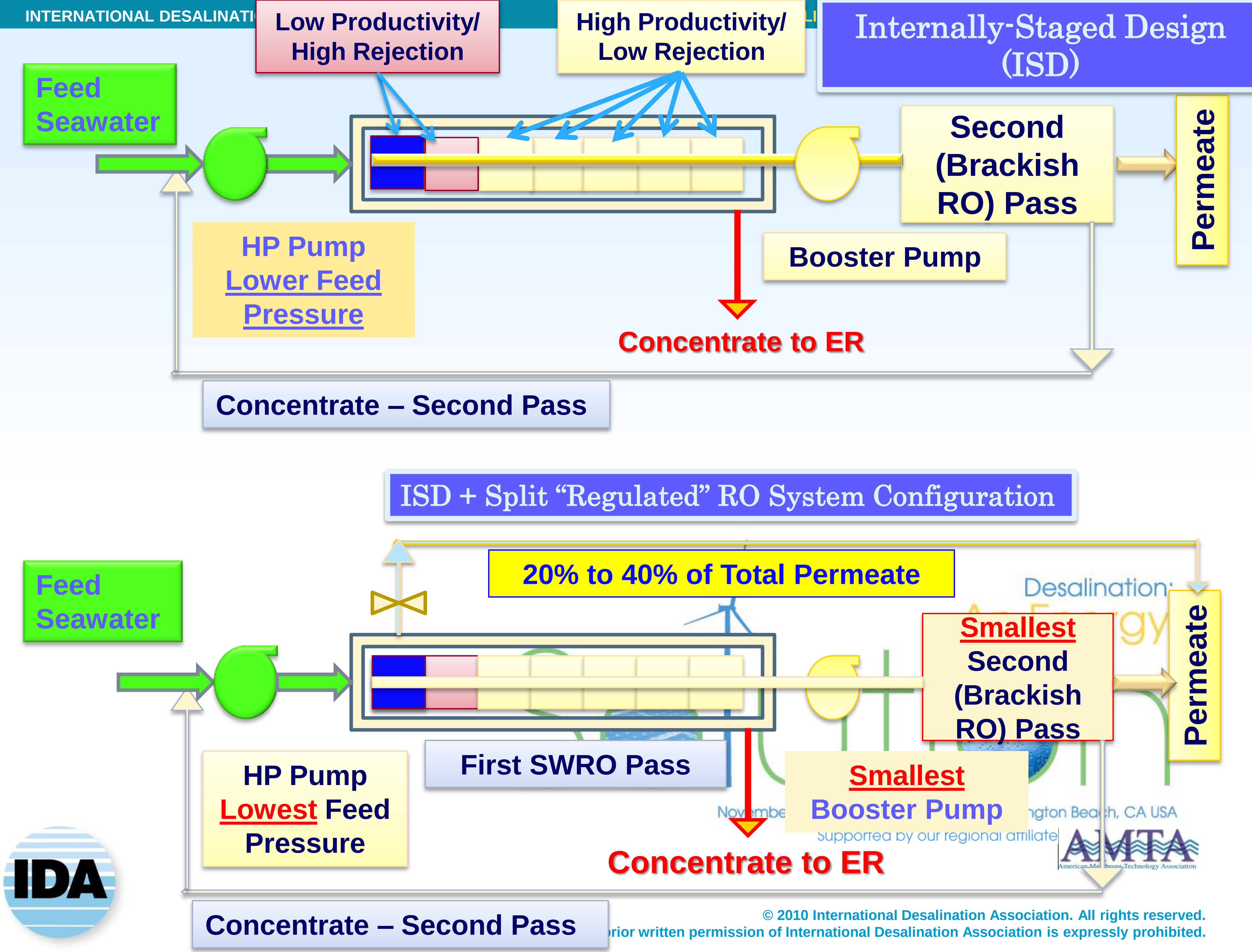
Element Flow at Standard Test Conditions



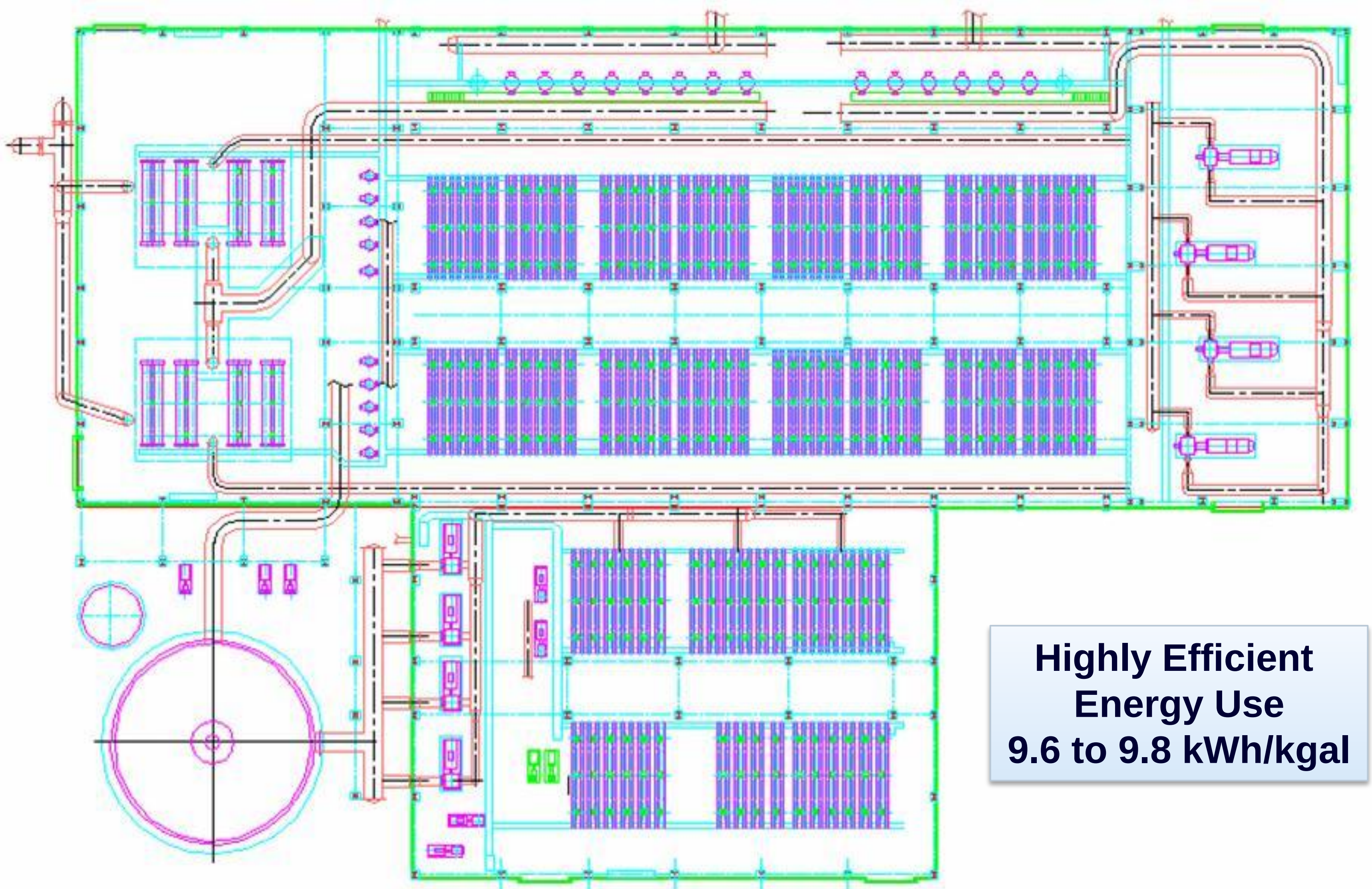
Compared to Standard SWRO Design, ISD SWRO Offers:

- Higher average permeate flux with same lead element flux;
- Good permeate quality;
- Energy Savings - 5% - 10%.

Courtesy: Dow Filmtec


Internally-Staged Design (ISD)
Low Productivity/ High Rejection
High Productivity/ Low Rejection
Feed Seawater
HP Pump Lower Feed Pressure
Concentrate to ER
Booster Pump
Second (Brackish RO) Pass
Permeate
Concentrate – Second Pass
ISD + Split "Regulated" RO System Configuration
20% to 40% of Total Permeate
Feed Seawater
HP Pump Lowest Feed Pressure
First SWRO Pass
Smallest Booster Pump
Smallest Second (Brackish RO) Pass
Permeate
Concentrate to ER
Concentrate – Second Pass

3-Center Design – Pump, Energy Recovery & RO Membrane Centers



Highly Efficient Energy Use 9.6 to 9.8 kWh/kgal

Courtesy: IDE

Bigger Pumps Rule!
Pump Efficiency Increases with Size

Perth , Australia –
3 Pumps for 6 RO Trains

- 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 %;

Three Pumps Per 16 Trains – 88 %.

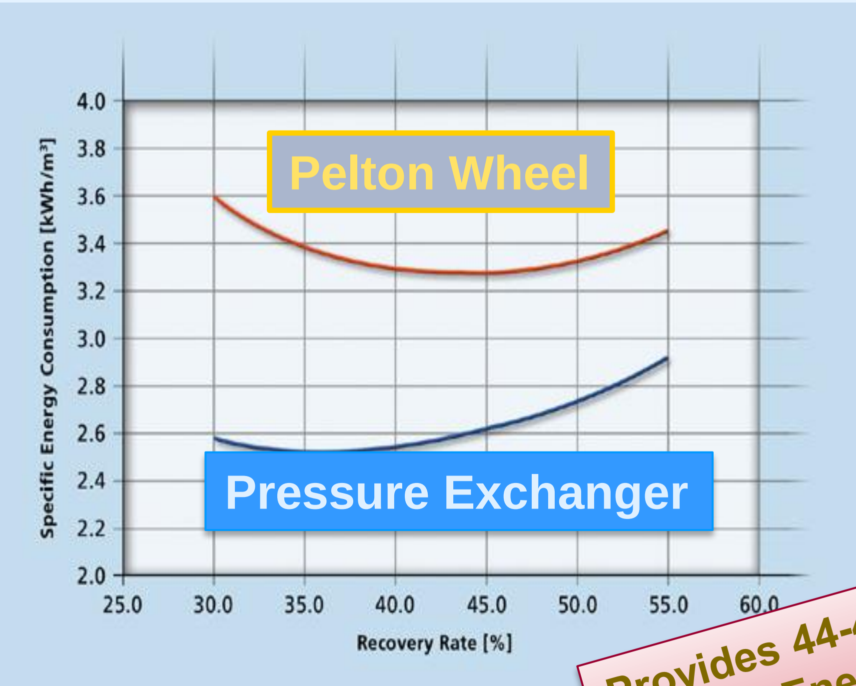
Ashkelon, Israel –
(3+1) 7,100-hp Pumps per 16
RO Trains

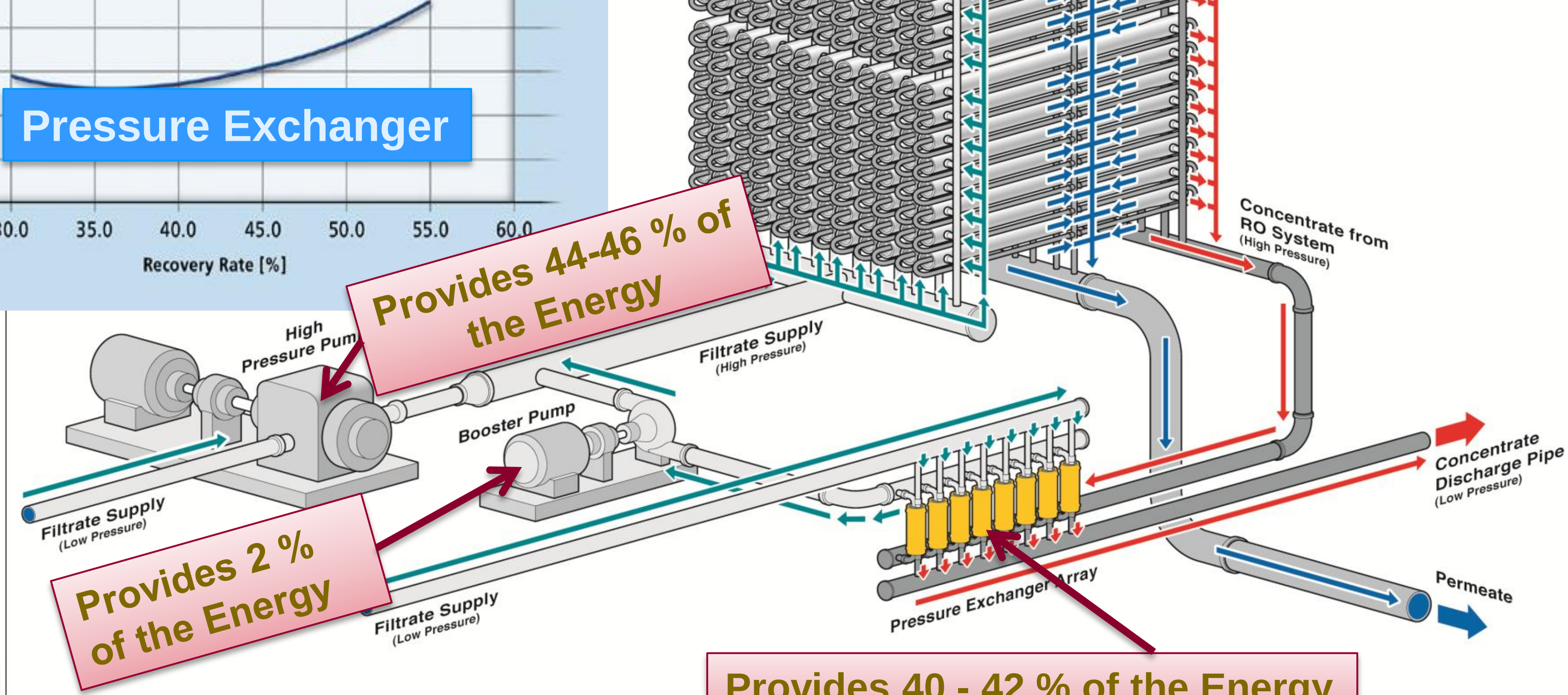
Radially Split Case Pumps

- Occupy Less Space;
- Easier to Maintain;
- Less Vibrations;
- Only One Mechanical Seal on the Drive End (Horizontally Split Case Pumps Have2 seals);
- Internal Fiber-Composite Bearings (Water Lubricated) – vs. External Grease Lubricated;
- Largest Pumps First Installed for Expansion of Dhekelia SWRO Plant (Cyprus) to 14 MGD;
- Unit Capacity – 7 MGD (2,800 hp) – 87 % Efficiency.

Energy Recovery Systems are Getting Bigger & More Efficient!

Pressure Exchangers Allow the Use of Larger Pumps/RO Trains



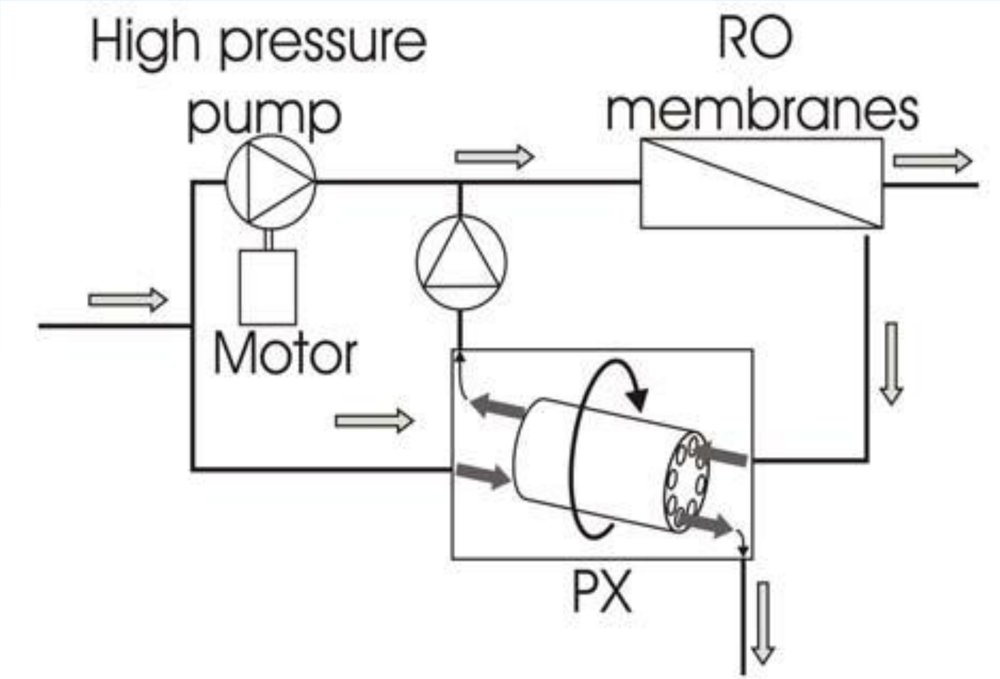


Provides 44-46 % of the Energy

Provides 2 % of the Energy

Provides 40 - 42 % of the Energy

ERI System – Current Status



- Largest In Operation - Hamma (Algeria) – 50 MGD
- Largest in Construction – Hadera (Israel) – 73 MGD;
- Base Unit – PX 220; (0.37 MGD) in ops since 2002;
- 10 to 16 Units per RO Train (2.5 – 4 MGD RO Train).

ERI – New Energy Recovery Equipment

- **PX 260**

- 18 % Larger Capacity than PX220;
- Wider Flow Paths to Higher Throughput @ Minimum Pressure Losses.

- **Titan 1200**

- 500% Larger Capacity than PX220;
- Similar Overall Energy Recovery (Slightly Lower Efficiency Compensated by Lower Mixing);
- Side-ported Design Allows to Maximize Flow Production.

- **PX 300 (45 to 68 m3/hr)**

- 36 % Larger Capacity than PX220
- Reduced Cycle Speed - Less Mixing than PX 220 and 260
- Quieter Unit
- Site-ported Housing

DWEER System – Current Status

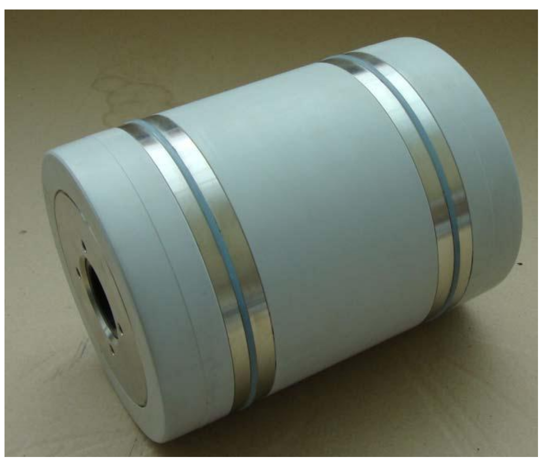
- Used in Ashkelon, Gold Coast, Sorek, and Singapore.
- 1.34 MGD SWRO Train – One DWEER System – Model 1100;
- Ashkelon – 2 x 40 DWEER 2200 Systems;
- RO w/ DWEER – 0.5 to 0.7 kWh/M3 Less Energy than Pelton Wheel @ (45 % Recovery).

Tuas, Singapore
Triple DWEER 1100
4 MGD SWRO Trains

Calder AG (Flowserve) – ROVA 300

- Can Handle 1.8 MGD of Brine Flow (Three Times Bigger than Existing Units);
- Duplex Stainless Steel;
- New Seal Design Reduces Brine Mixing < 1.5 %.
- Currently Tested in Oman and Cayman Islands.

Calder AG (Flowserve) – DWEER GA



- 25 % Higher Capacity Than DWEER 1100;
- FRP Instead of Steel Vessels;
- New LinX Valve With Two Seal Rings for Lowest Leakage;
- Specific Power Consumption Losses Reduced by 26 %.

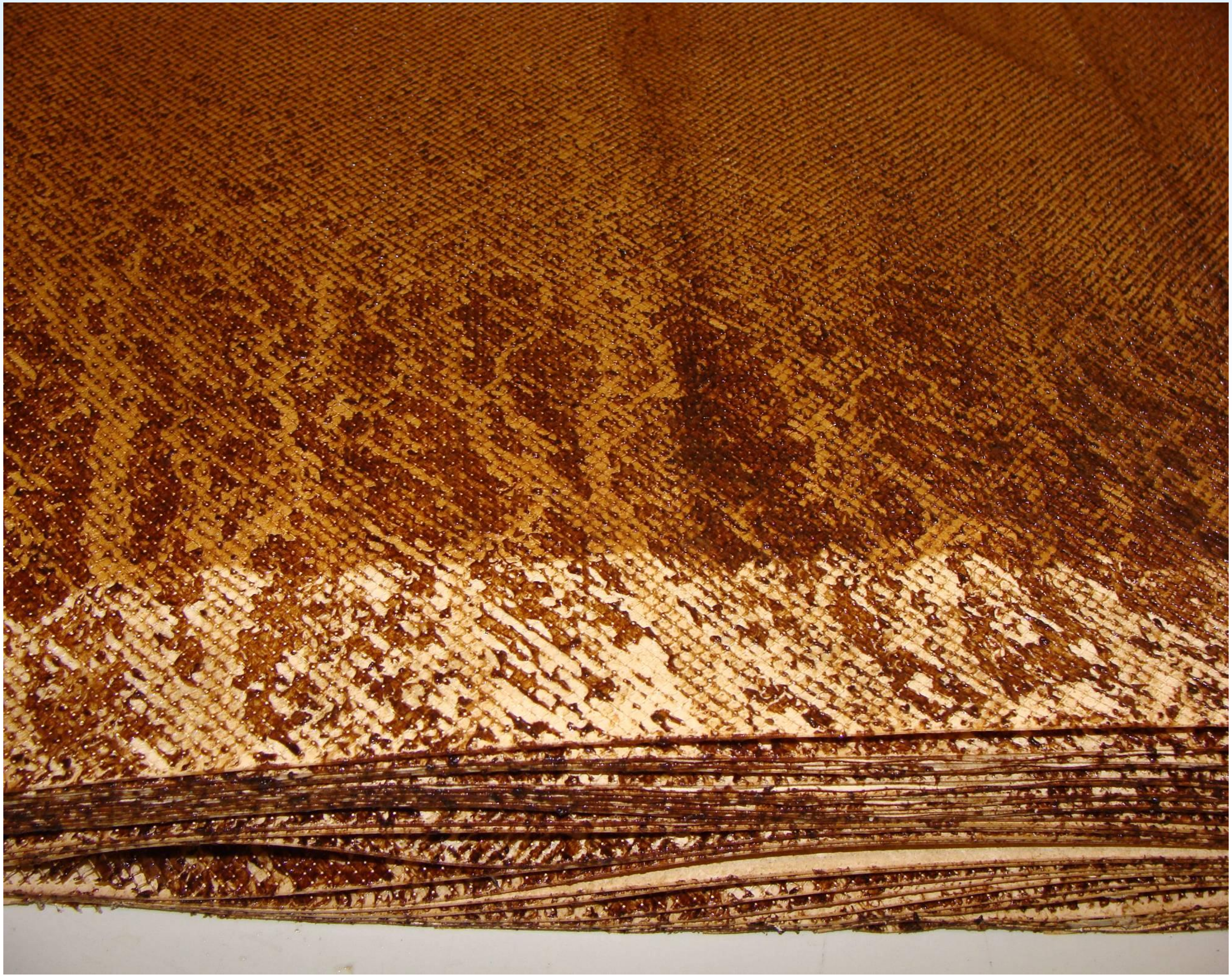
Hydraulic Turbocharger – Large Installations
(8.9 to 10.0 kWh/kgal)

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

- **190 MGD Mactaa, Algeria – 9.7 kWh/kgal**
- **30 MGD Plant in Jebel Ali, UAE**
  - **9 RO Trains;**
  - **16 Single-stage HP RO Pumps;**
  - **Up to 525 psi (40 bars) of Boost;**
  - **HP RO Pumps Operating @ Full Flow @ ½ Pressure –**

    5-7 % Extra Efficiency.
- **38 MGD NEWater Ulu Pandan Plant, Singapore**

Biofouling – Still the Key "Energy Chellenge" of SWRO Desalination



Membrane Pretreatment is Becoming More Popular for Large Plants!

- 40 MGD Adelaide SWRO Plant, Australia
  – Disk Filters + Submersible UF;
  – Largest SWRO Facility with Membrane Pretreatment.
- **Where Membrane Pretreatment Has Worked Well?** – for Source Waters of Low Bio-fouling Potential:
  - Subsurface or Deep Open Ocean Intakes;
  - Plants w/ DAF or Other Pretreatment Ahead of UF/MF Membranes.
- **Where Membrane Pretreatment Has Faced Challenges?**
  - Shallow Open Intakes Exposed to Heavy Algal Blooms;
  - Systems Designed for Overly High Flux Rates Based on Short-term Piloting.

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New "Tools" for Combating Biofouling

- Wider Membrane Element Spacers;
- Lower Fouling Membrane Materials;
- Alternative Means of Controlling Biofouling:
  - Building Deeper Open Intakes (over 40 ft deep);
  - DAF Pretreatment;
  - Granular Media Bio-filtration;
  - Chlorine Dioxide Oxidation;
  - Continuous Membrane Cleaning;
  - Nutrient Balancing;
  - Membrane Bioreactors for SWRO Pretreatment.

Responding to the Clear Trend of Global Warming!

The total Energy Needed to Operate All California Desalination Projects (400 MGD) Will Result in 0.03 – 0.04 % Increase in the Current California Water Sector Energy Demand.

How Does Desalinated Water Compare?

- Desalinated Water Production CF = 8.2 lbs CO_2/1,000 gallons.
- CF of Desalinated Water per Person = **0.11 ton CO_2/person/yr (0.55%).**
- Carbon Footprint of Burgers Consumed by the Average American **- 0.40 ton CO_2/person/yr (2%).**
- CF of the Average American = **20 tons CO_2/person/yr.**

Unit Costs of Carbon Footprint Reduction Alternatives

CF Reduction Alternative	Unit Cost of Carbon Footprint Reduction (US$/tons CO2 reduced)
1. Collocation & Energy Efficient Technology	US$20/ton CO2
2. CO2 Use for Water Production	US$70/ton CO2
3. Purchase of Carbon Credits	US$100/ton CO2
4. Re-forestation	US$200/ton CO2
5. CO2 Sequestration in Coastal Wetlands	US$400/ton CO2
6. Solar Panels	US$1,900/ton CO2
7. Green Building Design	US$3,400/ton CO2

Where Future Cost Savings Will Come From?

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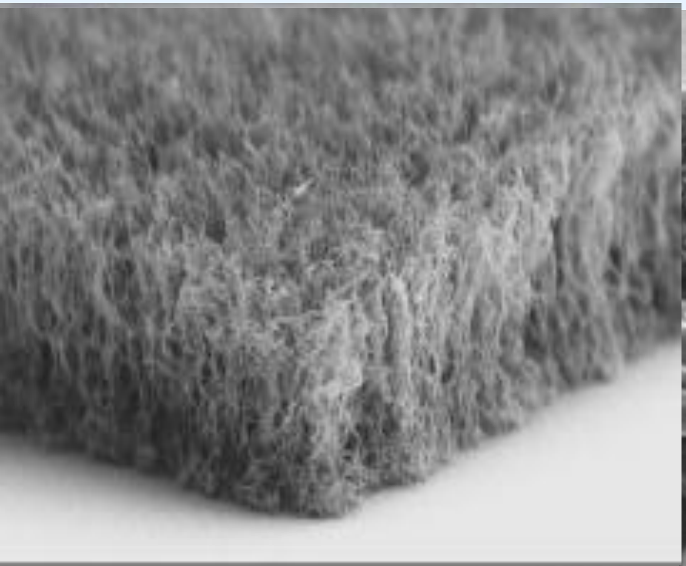
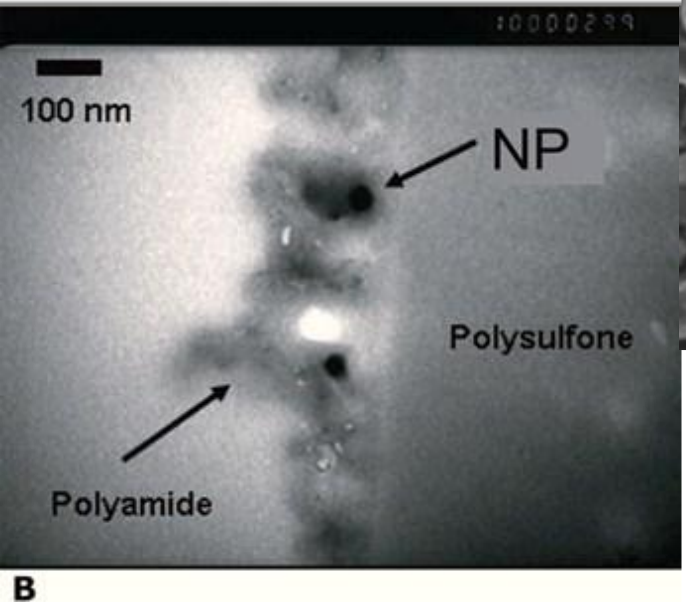
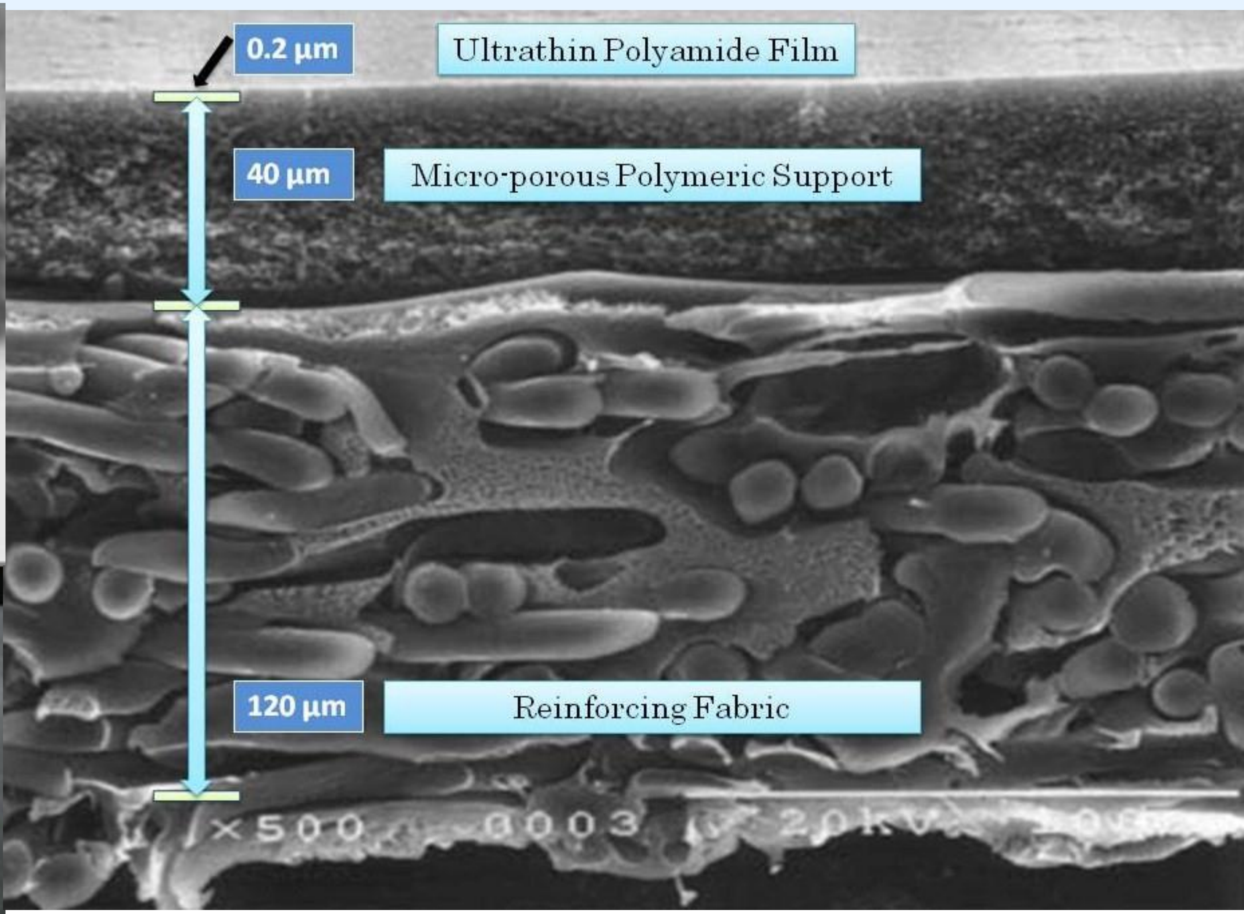
Main Areas Expected to Yield Cost Savings in the Next 5 Years
(20 % Cost Reduction Target)

- **Improvements in Membrane Element Productivity**:
  - **Polymetric Membranes** (Incorporation of Nano-particles Into Membrane Polymer Matrix);
  - **Carbon Nanotube Membranes.**
- **Increased Membrane Useful Life and Reduced Fouling:**
  - Smoother Membrane Surface
  - Increased Membrane Material Longevity;
  - Use of Systems for Continuous RO Membrane Cleaning;
  - UF/MF Membrane Pretreatment.
- **Commercial Forward Osmosis Systems;**
- **Larger RO Elements, Trains and Equipment.**

Nano-Structured SWRO Membranes



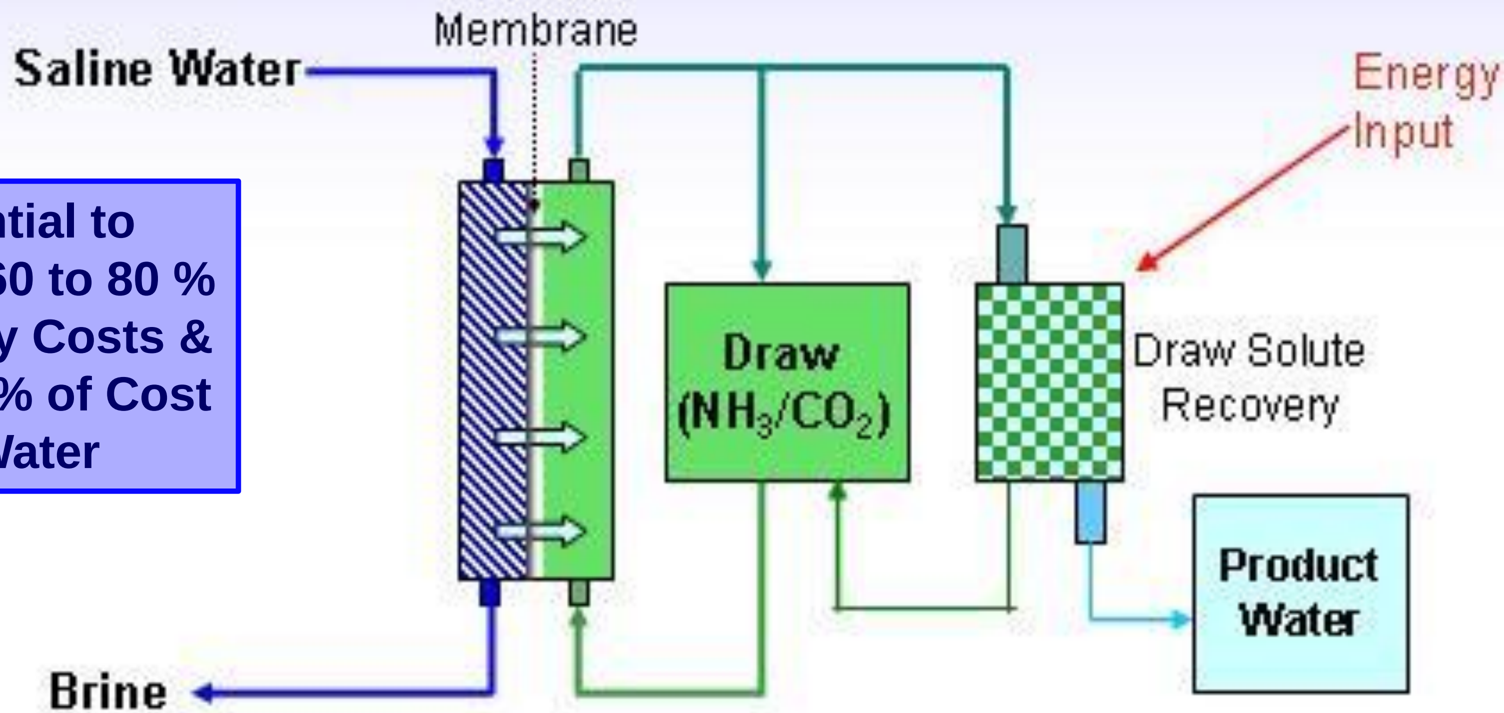




Forward Osmosis

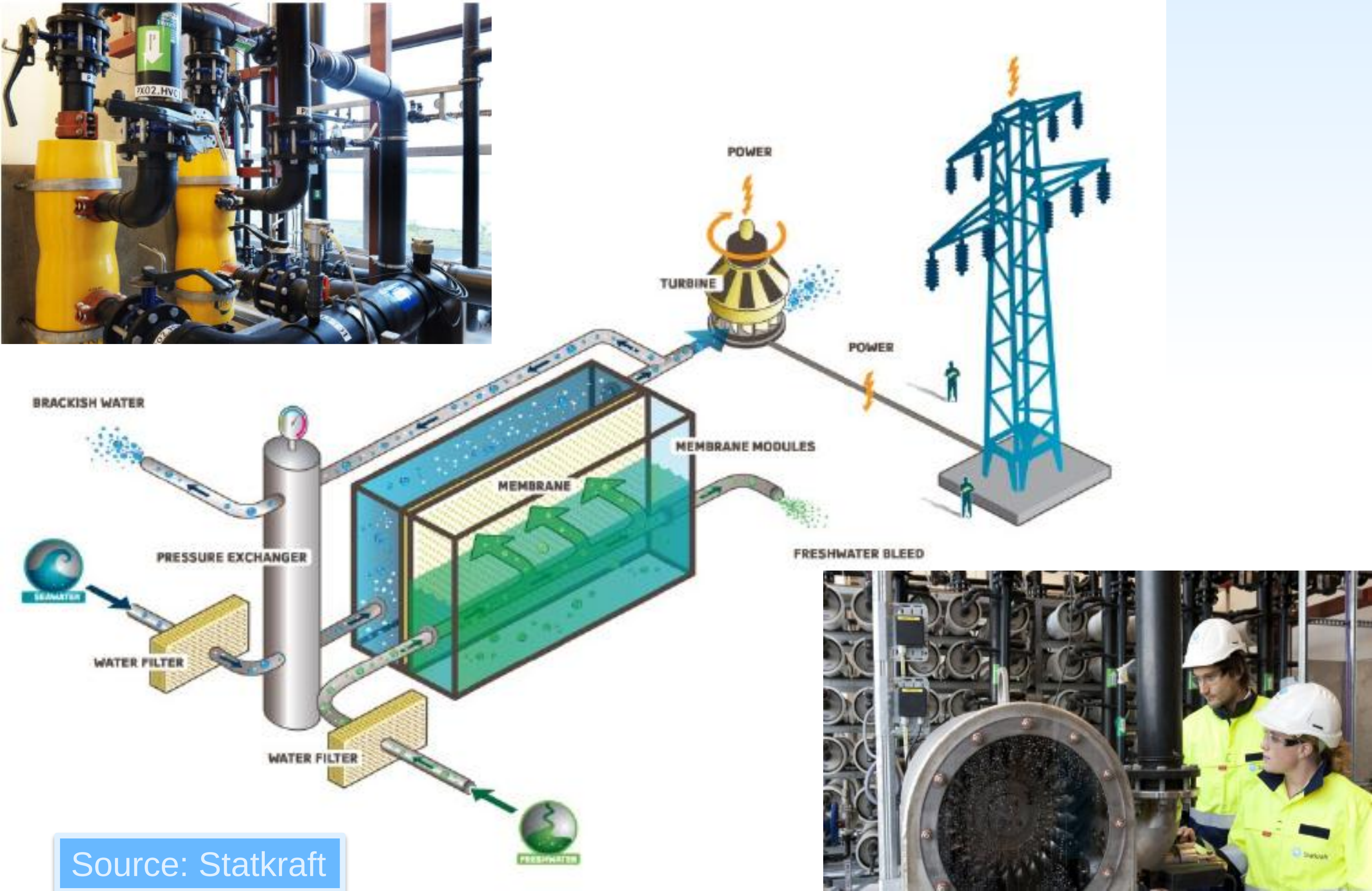
(solute recycle)

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



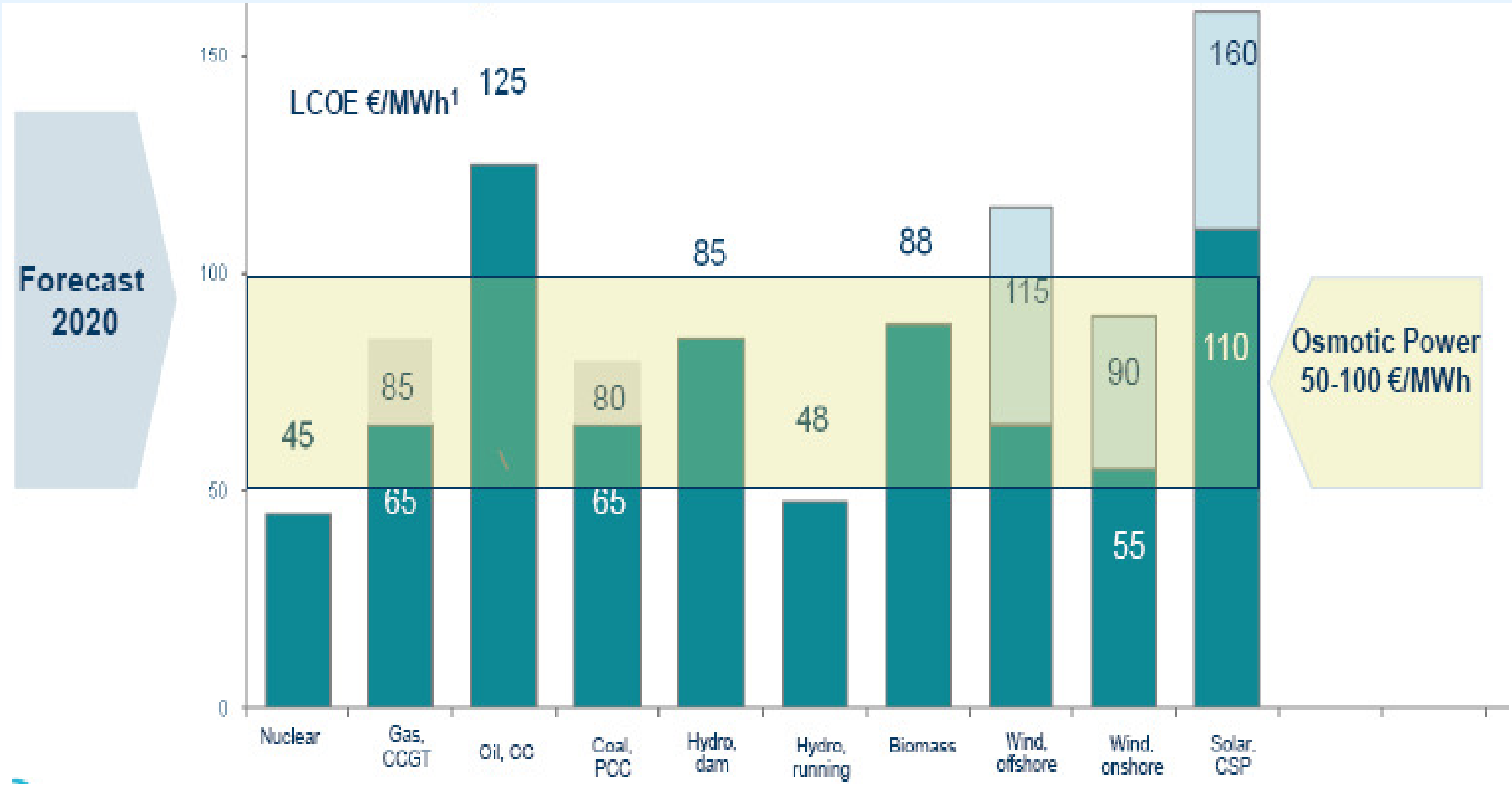
Source: OASYS

Harnessing Osmotic Power



Source: Statkraft

Osmotic Power – A Competitive Energy Source



Source: Statkraft

"The Best" of Seawater Desalination Present Status & Future Forecasts

Parameter	Today	Within 5 Years	Within 20 Years
Cost of Water (2010 US$/kgal)	US$2.0-3.0	US$1.5-2.5	US$1.0-1.5
Construction Cost (Million US$/MGD)	4.5-8.0	4.0-6.5	2.0-3.5
Power Use of SWRO System (kWh/kgal)	9.5-10.5	8.0-10.0	5.0-6.5
Membrane Productivity (gallons/day/membrane)	6,500-12,500	9,000-15,000	25,000-40,000
Membrane Useful Life (years)	5-7	7-10	10-15
Plant Recovery Ratio (%)	45-50	50-55	55-65

Concluding Remarks

- The Ocean Is Becoming One of the Key Sources of Reliable and Draught-Proof Coastal Water Supply in the Next 10 Years;
- 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.

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Questions?