

The Economics of Desalination for Various Uses

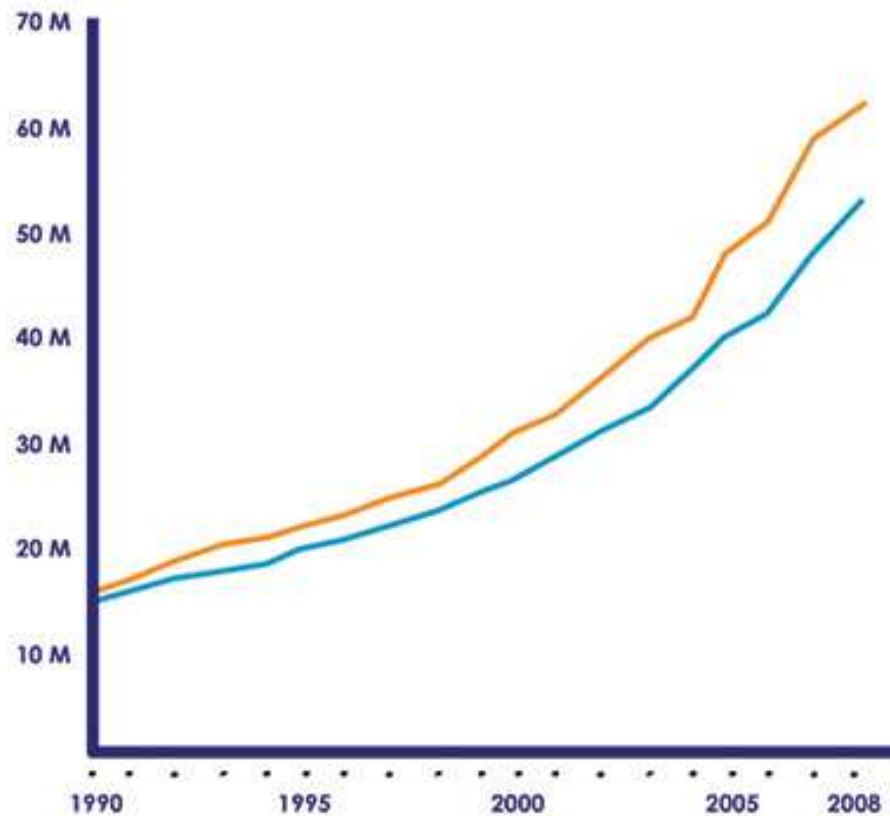
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Introduction



Year Cumulative contracted capacity Cumulative installed capacity
(Cubic meters/day in millions)

1990	15,857,805	14,800,583
1991	16,822,653	15,419,836
1992	18,114,214	16,418,681
1993	20,055,770	17,226,063
1994	20,883,758	18,217,561
1995	21,977,806	19,240,538
1996	23,251,897	20,742,183
1997	24,668,989	22,414,614
1998	26,295,486	23,931,037
1999	28,063,720	25,099,318
2000	30,657,957	26,703,437
2001	33,672,355	28,488,466
2002	35,926,728	31,646,385
2003	39,600,770	33,774,042
2004	42,358,399	37,308,670
2005	47,069,318	39,786,362
2006	51,627,430	42,978,277
2007	58,627,430	47,606,094
2008	62,750,220	52,333,950

Source: Global Water Intelligence/DesalData.com
International Desalination Association

Desalination technologies



Regeneration and reuse

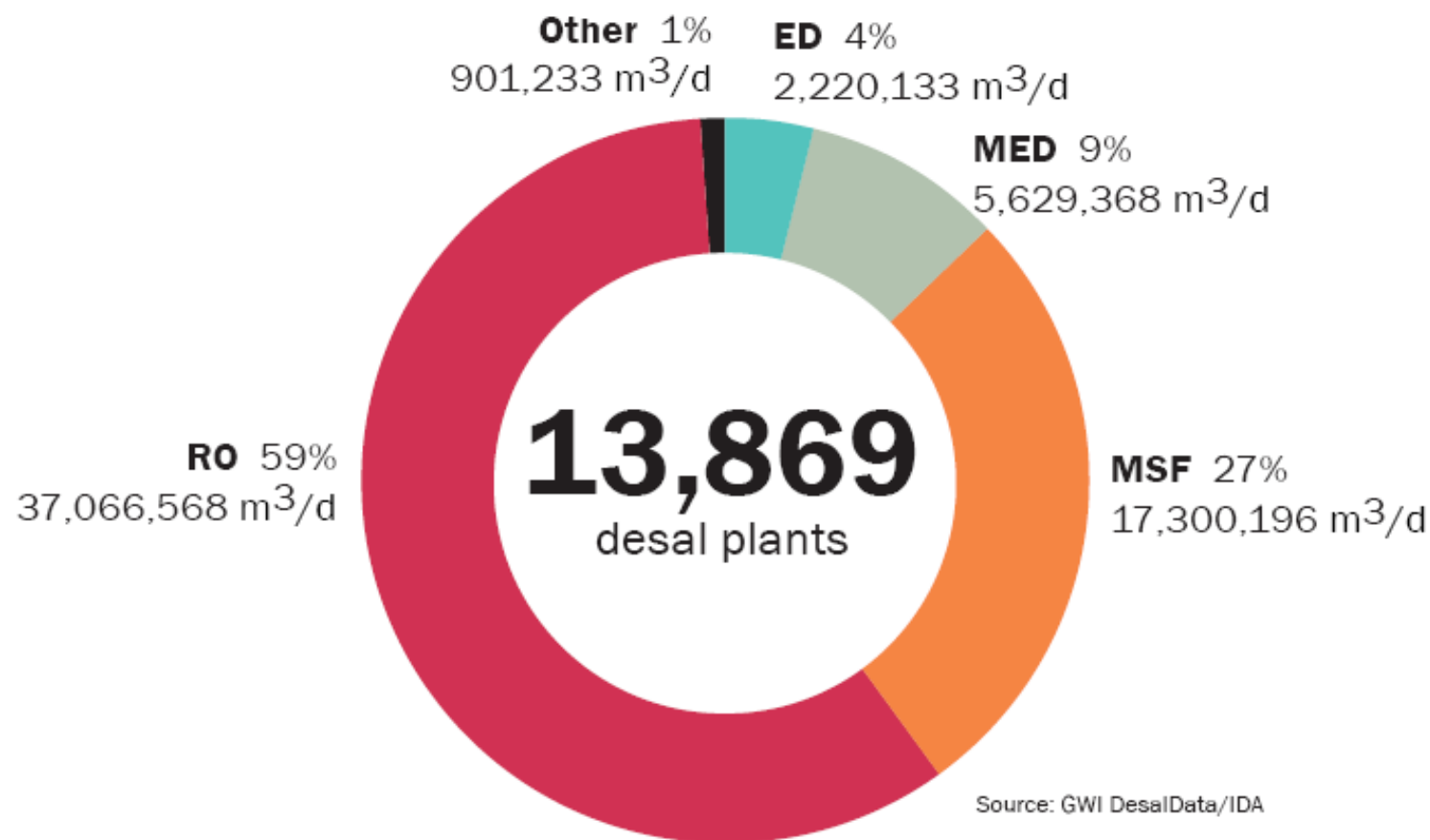


Fulfillment of water requirements in the future

Available desalination technologies (I)

Separation mechanism	Energy	Process	Name
Water separation	Thermal + Electrical	Evaporation	Multi Stage Flash (MSF)
			Multi Effect Distillation (MED)
			Thermal Vapor Compression (TVC)
			Solar Desalination (SD)
		Crystallization	Freezing
			Formation of hydrates
		Evaporation and filtration	Membrane Distillation (MD)
	Electrical	Evaporation	Mechanical Vapor Compression (MVC)
		Ionic filtration	Reverse Osmosis (RO)
Salt removal	Electrical	Ionic migration	Electrodialysis (ED)
	Chemical	Others	Ionic Exchange (IX)
			Extraction

Available desalination technologies (II)

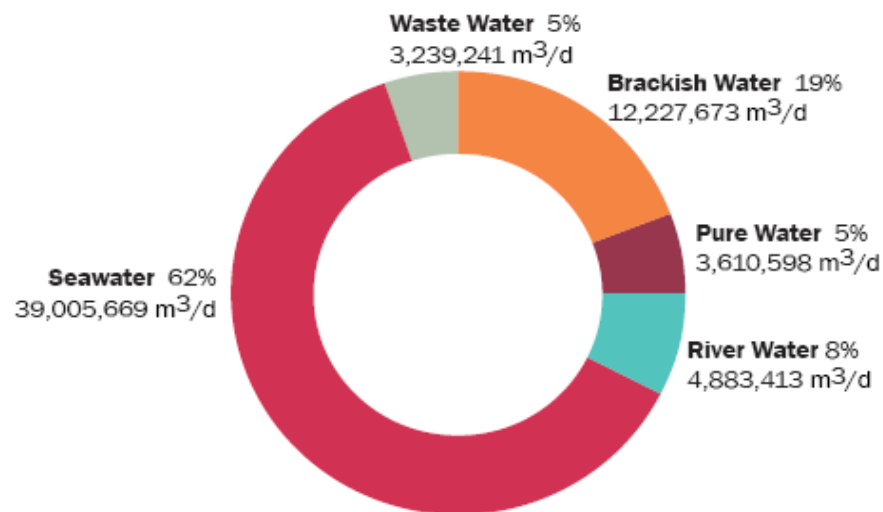


Comparison of large-scale desalination technologies

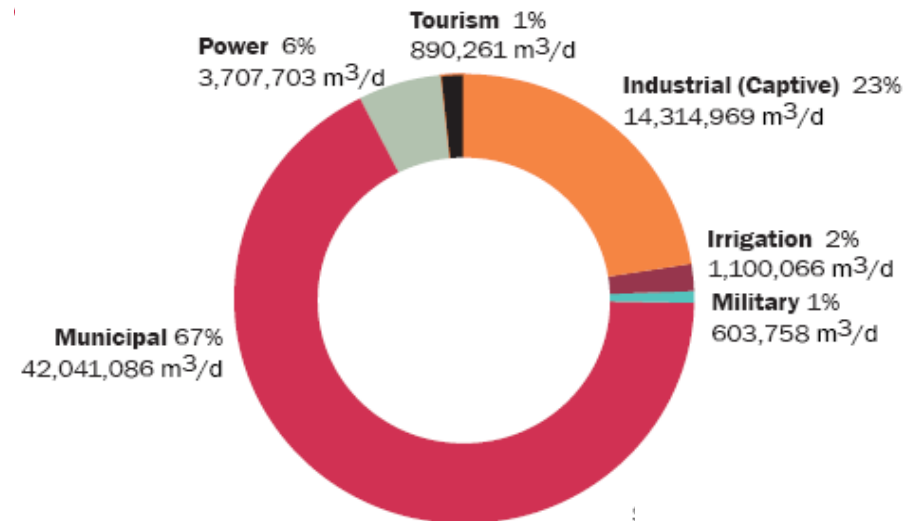
	MSF	RO
Physico-chemical principle	Flash evaporation	Solution-diffusion
Energy consumption (including auxiliaries)	Electrical: 2.5-5.0 kW·h/m ³ Thermal: 40-120 kW·h/m ³	Electrical: 3.5-4.5 kW·h/m ³ Thermal: None
Plant top temperature level	~ 120°C	Seawater temperature. Limit ~ 35°C
Energy requirements	Medium	Low
Product quality (mg/L TDS)	1-50	Single stage: 250-350. Triple stage: 1-10
Single unit size (m ³ /day)	120 000	Multiple of modular systems. 6 000-24 000
Limiting factors	Pumps, valves, vacuum unit	Pumps
Total capital costs	High	Low
Specific water cost	High	Low at 250 mg/L TDS product; High at 10 mg/L TDS product
Fully automatic & unattended operation	Possible	Possible
Tolerance to changes in seawater composition	Medium-High	Very low-Low
Replacement parts requirement	Low-Medium (large special pumps)	High (large pumps, membrane replacement)
Maintenance requirements	Medium	High
Scaling potential	Low-Medium	High
Chemical consumption	High	High
On-site requirements	Medium	Low
Ratio between product to total seawater flow (conversion)	0.1-0.2	0.3-0.5
Experience available	High	Medium
Potential for further requirements	Low (at technological limit)	High
Most needed R&D areas	Cheaper materials, cheaper and more efficient, heat transfer materials	Pre-treatment, stability of membranes

Desalted water sources and uses

Feedwater quality

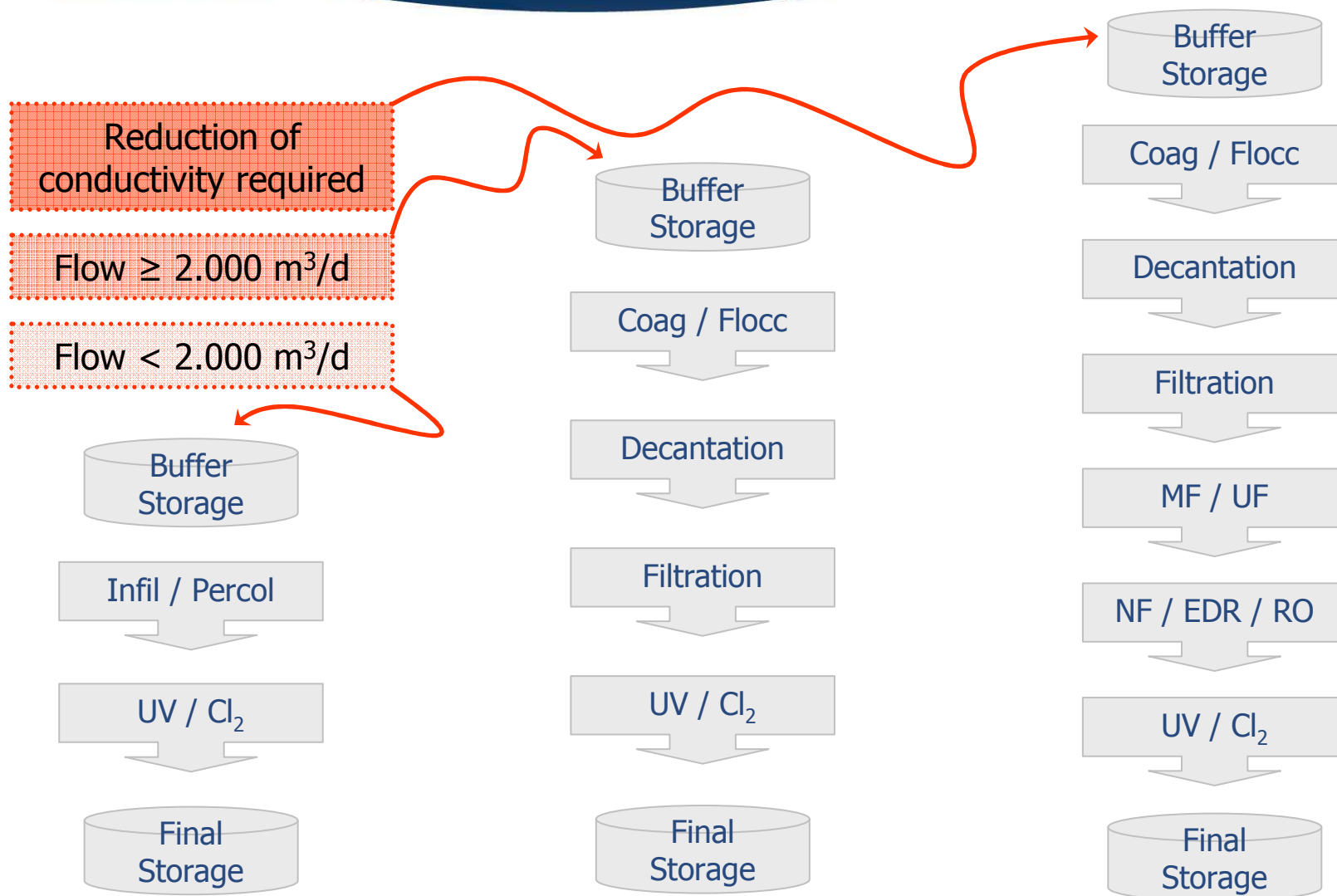


Off-takers

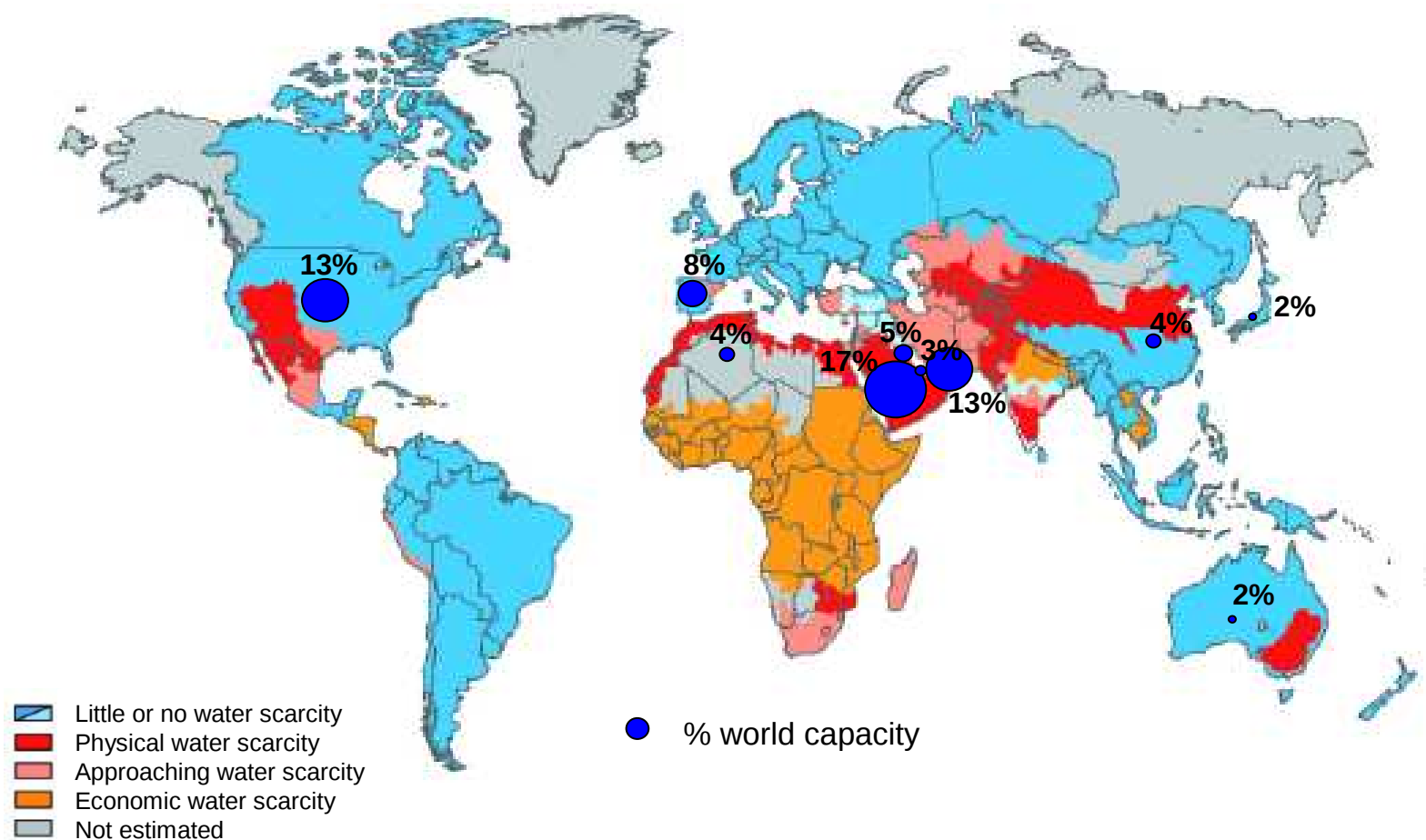


Source: GWI DesalData/IDA

Water regeneration technologies



Major desalted water producing countries



Source: International Water Management Institute (2006) & GWI DesalData/IDA (2009)

Desalination membrane manufacturers in the world

Dupont 

Dow-Filmtec (USA) 

General Electric-Osmonics (USA)  GE Water & Process Technologies

Koch (USA) 

Toyobo (Japan) 

Nitto Denko (Hydranautics) (Japan)  NITTO DENKO

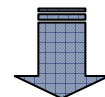
Toray  'TORAY'

Woongjin Chemical (Korea) 

Vontron (China) 

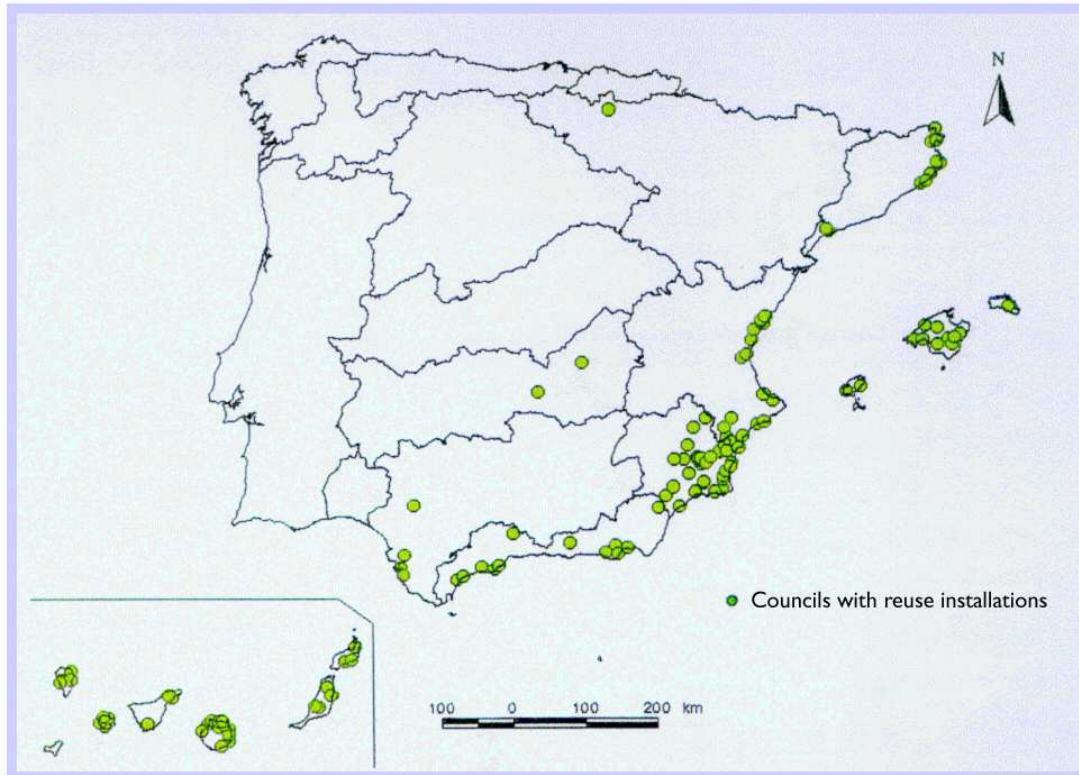
Urgent actions to be undertaken in the Spanish Mediterranean coast in the framework of the **A.G.U.A. Program**:

	Nº of actions	Contribution (Hm ³ /yr)	Investment
Southern Mediterranean Basin	17	312	554 M€
Segura Basin	24	336	1.336 M€
Júcar Basin	40	270	798 M€
Ebro Basin & Catalonia Internal Basins	24	145	1.110 M€
TOTAL	105	1.063	3.798 M€

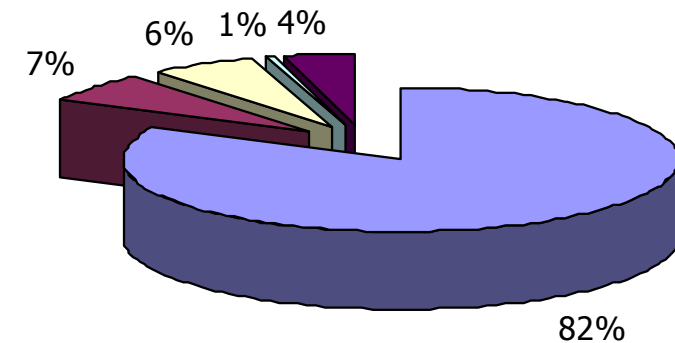


21 desalination facilities are planned for
6 provinces on the Spanish Mediterranean coast

Situation of reuse in Spain

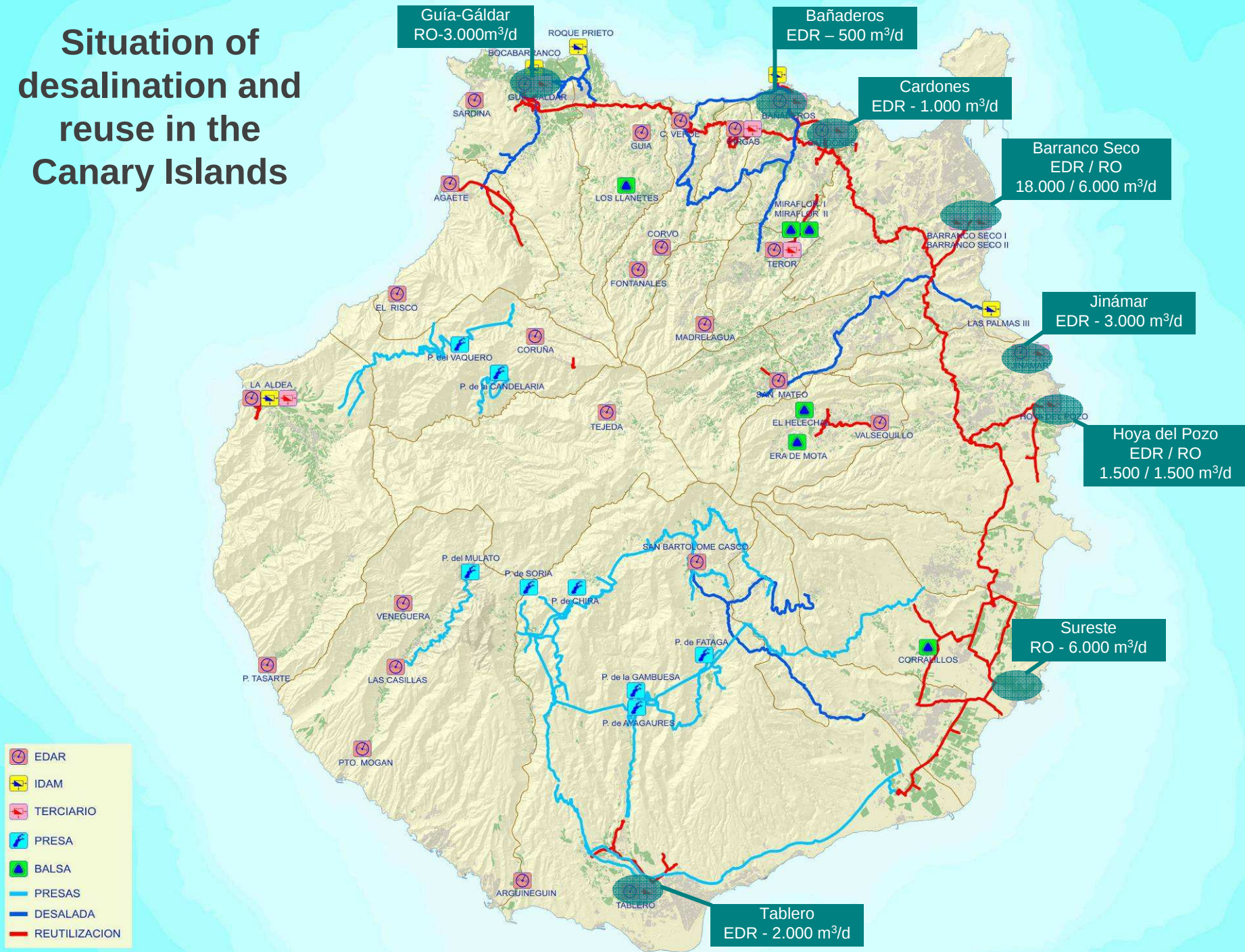


Final uses of reclaimed water



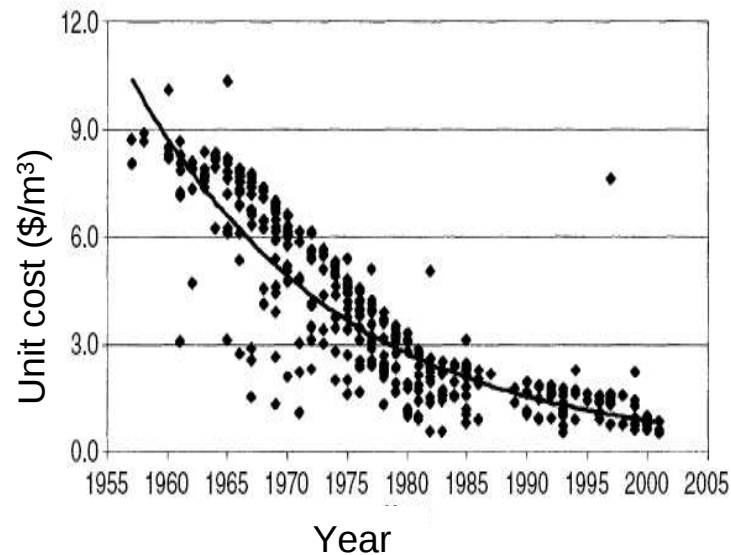
- ➔ In Spain, 22% of the reclaimed wastewater produced is reused
- ➔ 85% of the produced reclaimed water is consumed in the Mediterranean Coast and the Canary Islands

Situation of desalination and reuse in the Canary Islands

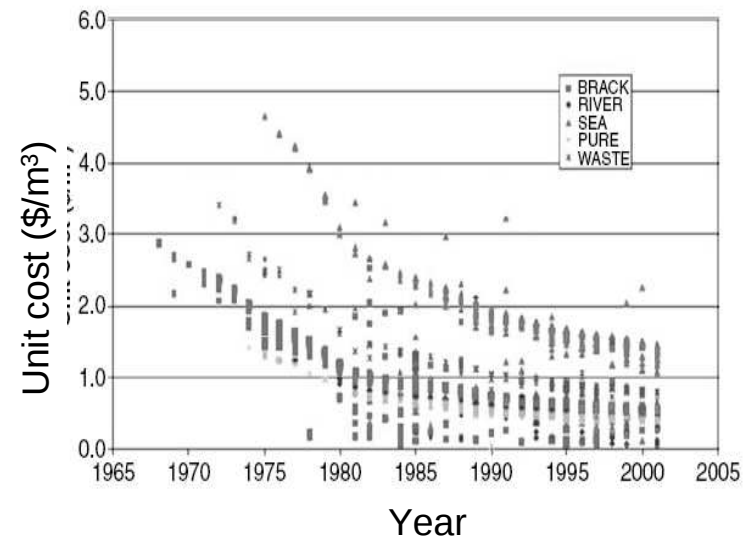


Desalination cost evolution (I)

MSF



RO



Source: Reddy and Ghaffour (2007) Desalination 205: 340-353

Desalination is **still a costly water supply option** compared to natural water resources (e.g. ground or surface water), but it **may be soon a competitive alternative** even in non-water stressed regions.

Reduction of unit water cost mainly due to:

➤ Technological developments

- Optimisation of the process design (equipments and configurations)
- Improvement in the thermodynamic efficiency
- use of newer materials
- new construction and transportation techniques

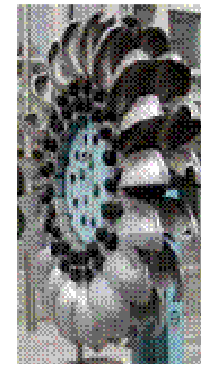
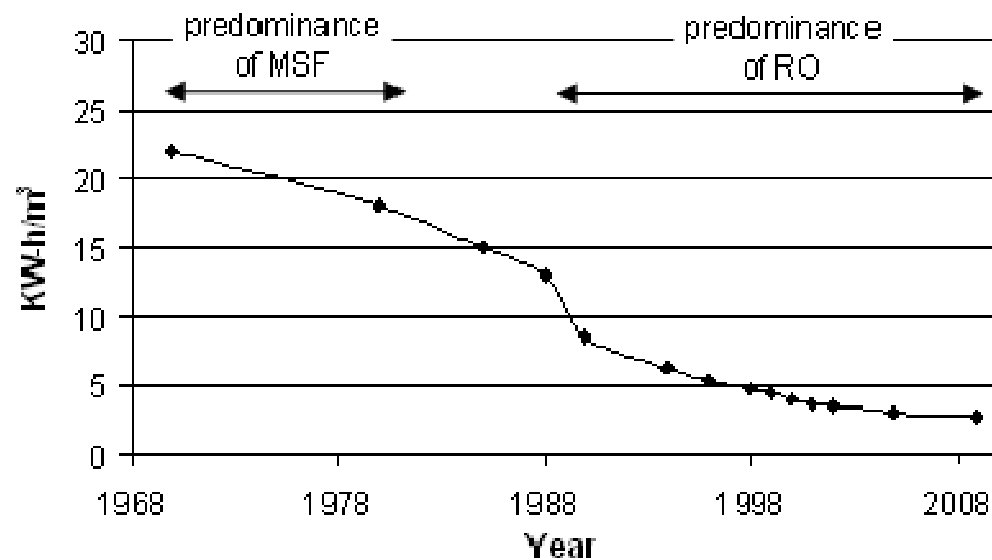
MSF

- higher surface area per unit volume
- higher salt rejection factors
- extended life-span of membranes
- optimisation of pre-treatment options
- use of energy recover devices

RO

- Increasing size of plants
- Lower interest rate and energy costs
- Changes in managing enterprise performance
- Intense competition between equipment suppliers worldwide

Evolution of the energy consumption of desalted seawater in Spain

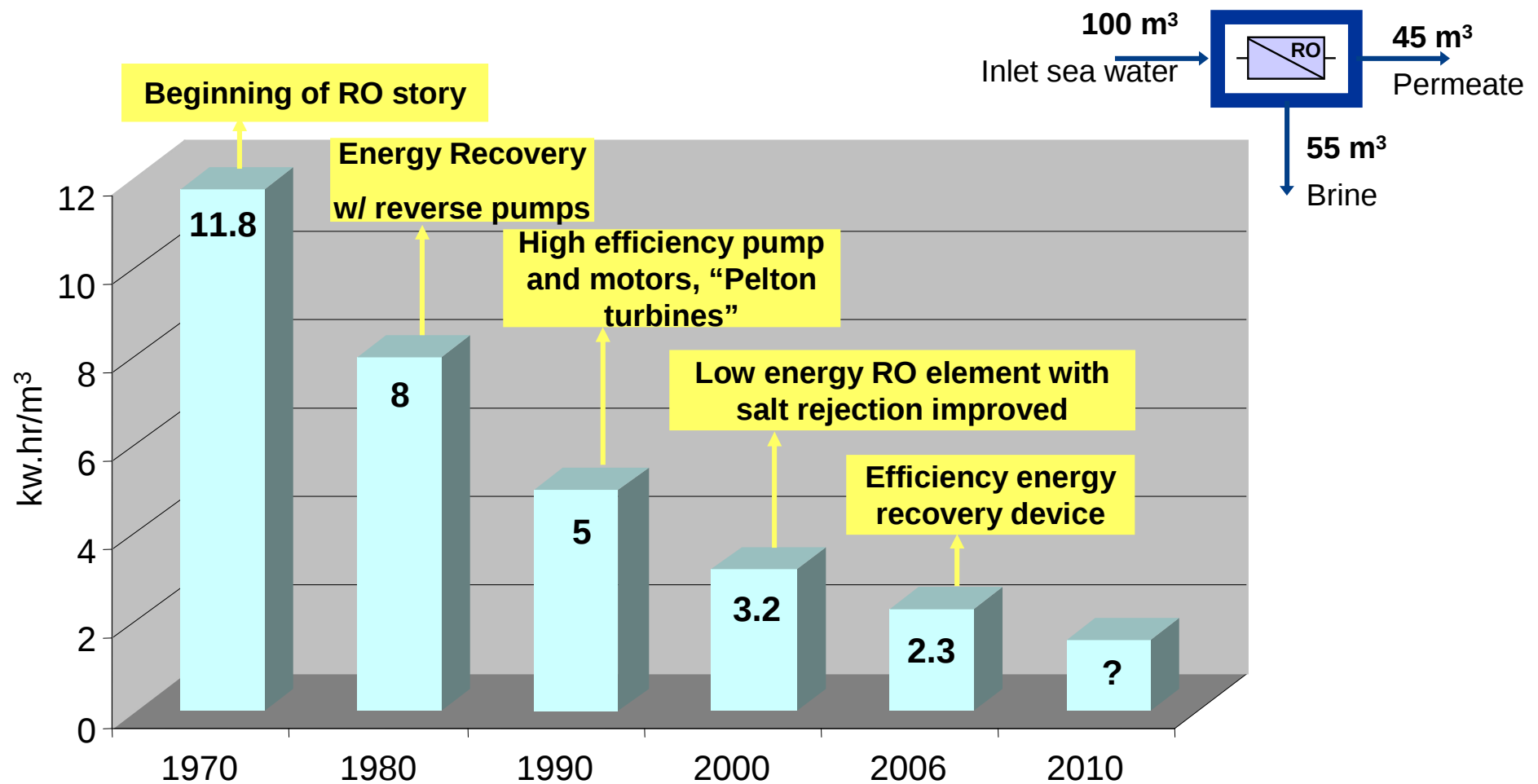


Source: AEDyR (2009), Ponencias del curso Desalación

- ➡ Energy required per m³ of desalted water has been reduced by almost 90%
- ➡ The irruption of RO in the market notably helped in reducing energy needs

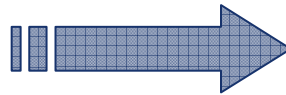
Desalination cost evolution (IV)

Evolution of the electrical consumption for seawater 1st pass RO

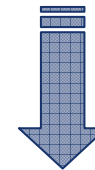


Site-specific cost-determining factors:

- Feed water characteristics
- Product water quality
- Plant capacity
- Plant reliability
- Concentrate disposal
- Space requirements
- Operation and maintenance
- Geographic location
- **Energy availability**



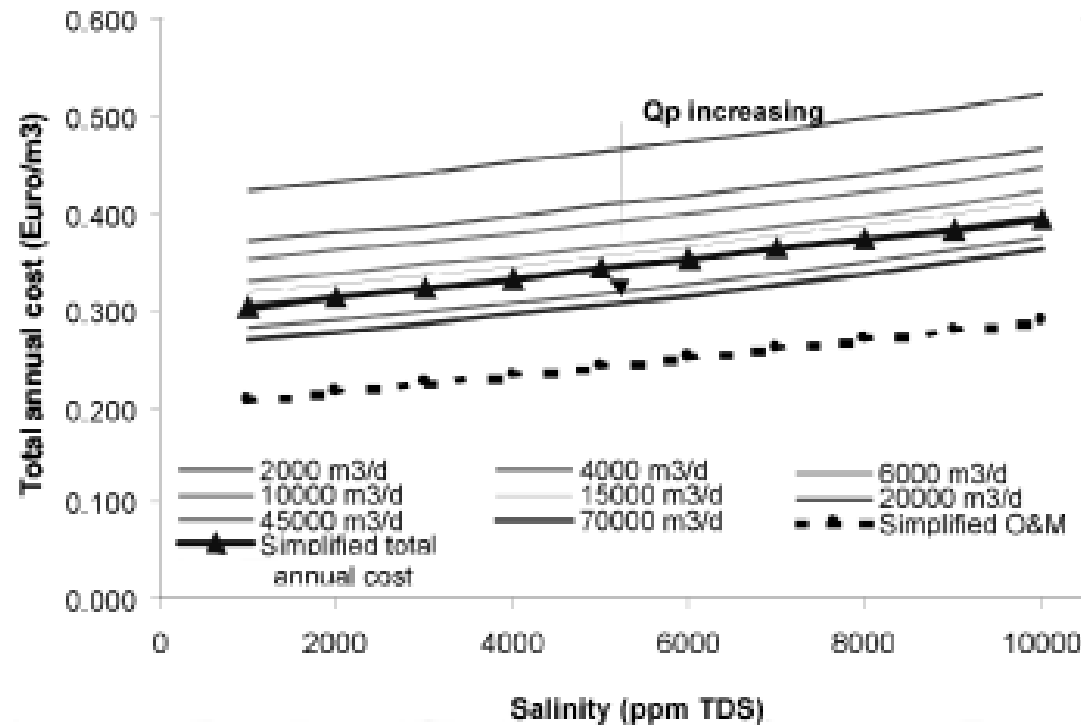
Most critical factor! It dictates not only the final cost but often also the desalination method



Most MSF plants operate in oil-producing countries (Persian Gulf)
RO more common worldwide (Mediterranean Basin, Asia-Pacific region, USA...)

Main factors affecting desalination cost (II)

Water desalination costs with regards to the **type of feed water and plant capacity**:



Source: Georgopoulou et al., (2001) Desalination 136: 307-315

➡ The more salts to be removed, the more expensive the desalting process

Main factors affecting desalination cost (III)

Water desalination costs with regards to the **type of feed water and plant capacity**:

Type of feed water	Plant capacity (m ³ /day)	Cost (€/m ³)
Brackish	< 1,000	0.63-1.06
	5,000 – 60,000	0.21-0.43
Seawater	< 1,000	1.78-9.00
	1,000 – 5,000	0.56-3.15
	12,000 – 60,000	0.35-1.30
	> 60,000	0.40-0.80

Source: Karagiannis and Soldatos, (2008) Desalination 223: 448-456

➡ The more salts to be removed, the more expensive the desalting process

Main factors affecting desalination cost (IV)

Water desalination cost with regards to the **type of energy**:

Type of feed water	Type of energy used	Cost (€/m ³)
Brackish	Conventional	0.21-1.06
	Photovoltaic	4.50-10.32
	Geothermal	2.00
Seawater	Conventional	0.35-2.70
	Wind	1.00-5.00
	Photovoltaic	3.14-9.00
	Solar collectors	3.50-8.00

Source: Karagiannis and Soldatos, (2008) Desalination 223: 448-456

- ➡ Existing MSF and RO plants are powered mainly by conventional sources of energy
- ➡ Coupling of renewable energy sources (RES) and desalination systems is holding great promise
- ➡ Current higher cost of RES is counterbalanced by their environmental benefits

Main factors affecting desalination cost (V)

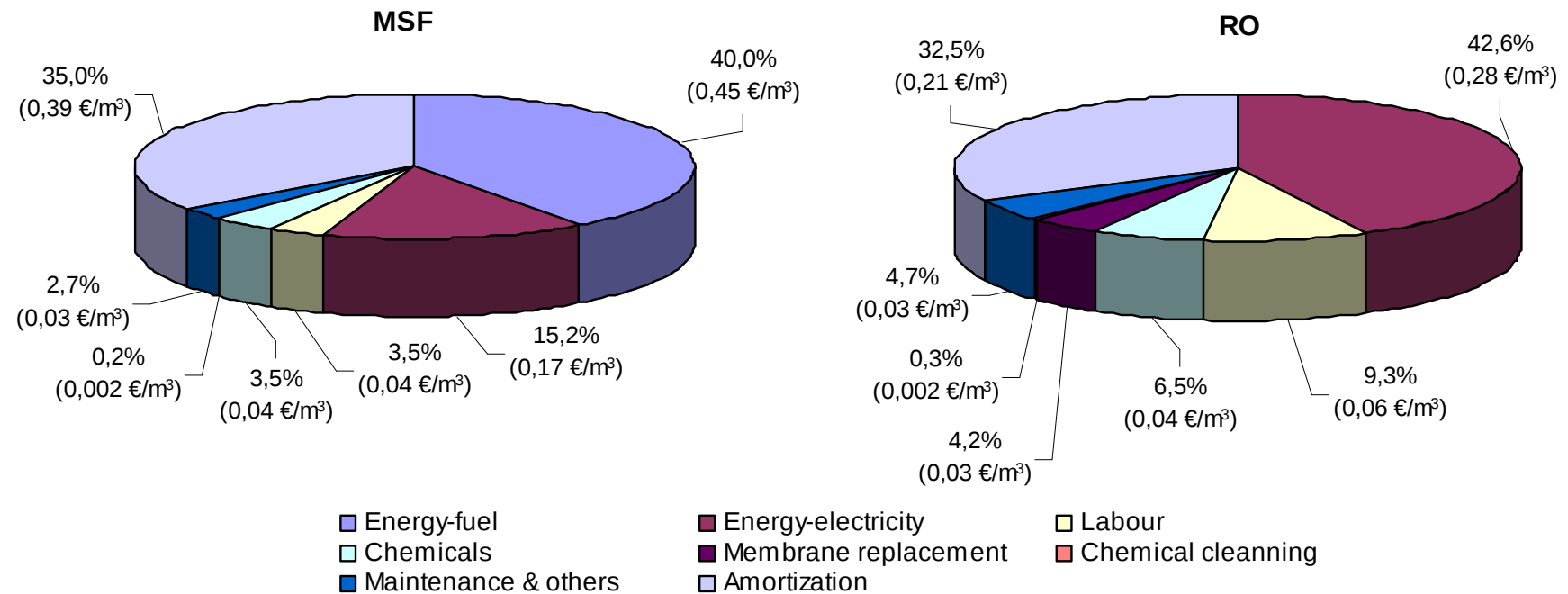
Water desalination cost with regards to the **type of desalination method**:

Des. method	Type of feed water	Plant capacity (m ³ /day)	Cost (€/m ³)
MSF	Seawater	23,000 - 528,000	0.42-1.40
		<20	4.50-10.32
RO	Brackish	20 - 1,200	0.62-1.06
		40,000 - 46,000	0.21-0.43
	Seawater	<100	1.20-15.00
		250-1,000	1.00-3.14
		1,000 – 4,800	0.56-1.38
		15,000 – 60,000	0.38-1.30
		100,000 – 320,000	0.36-0.53

Source: Karagiannis and Soldatos, (2008) Desalination 223: 448-456

- ➡ MSF is more cost intensive but have usually larger production capacities. It is rarely used for brackish water
- ➡ RO is cheaper and more flexible technology. It is applied for both brackish and seawater

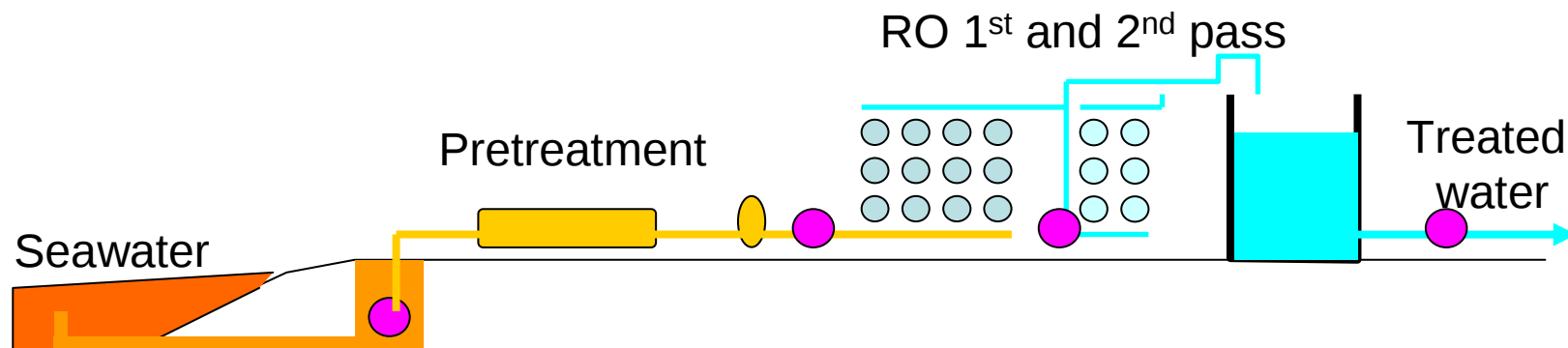
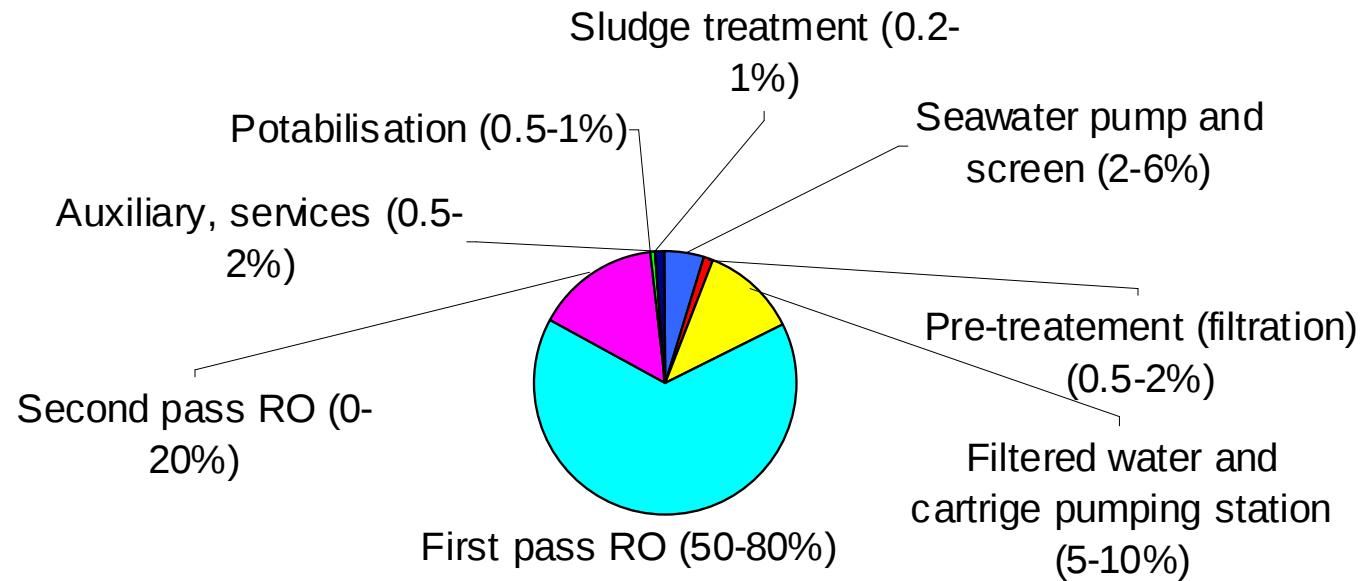
Breakdown of desalination cost



Source: AEDyR (2009), Ponencias del curso Desalación

- ➡ Amortization and energy consumption represent the most significant portion of the total cost
- ➡ Energy consumption amounts up to 55.2% for MSF and to 42.6% for RO

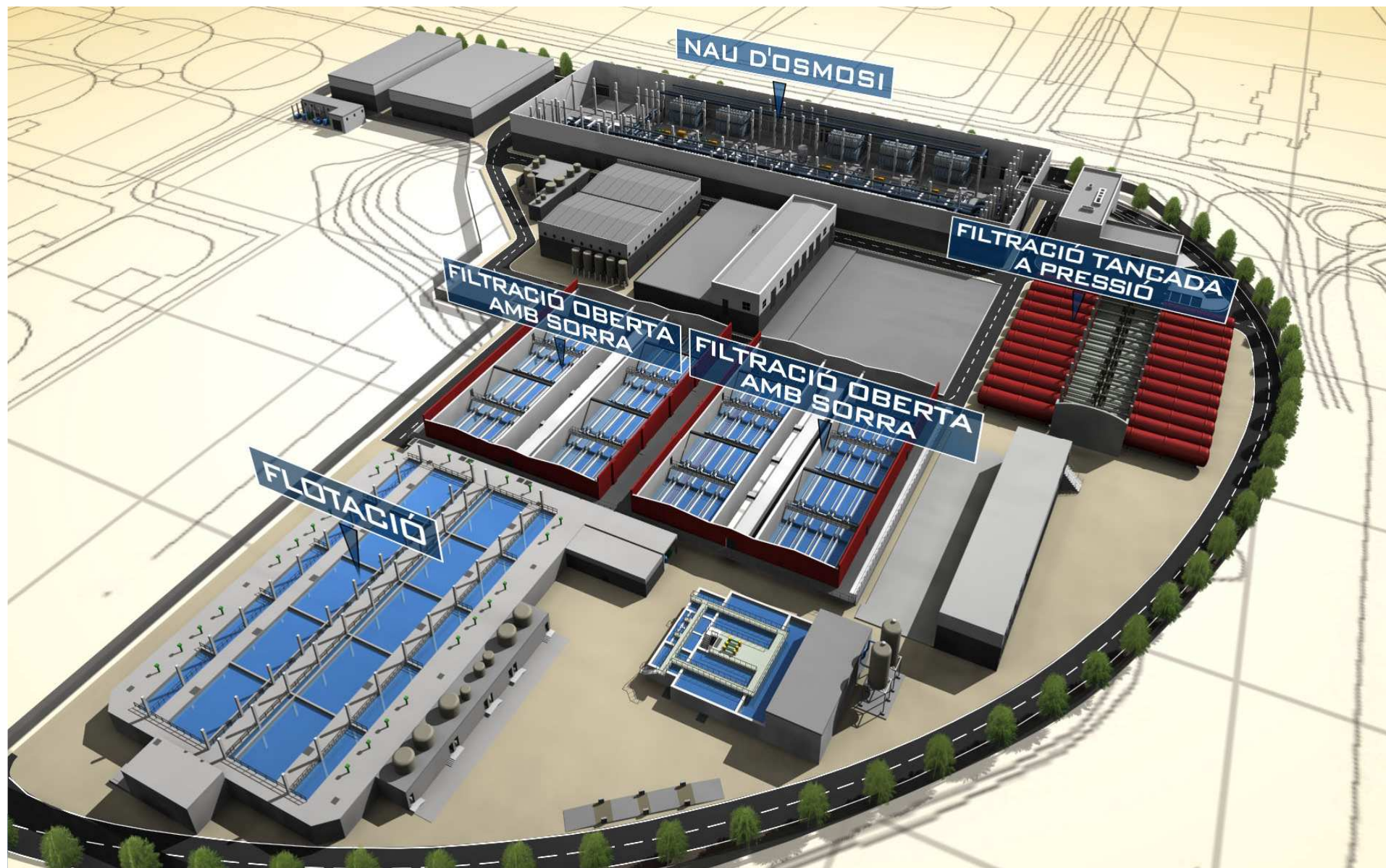
Breakdown of energy consumption



Breakdown of desalination cost

BCN seawater desalination plant

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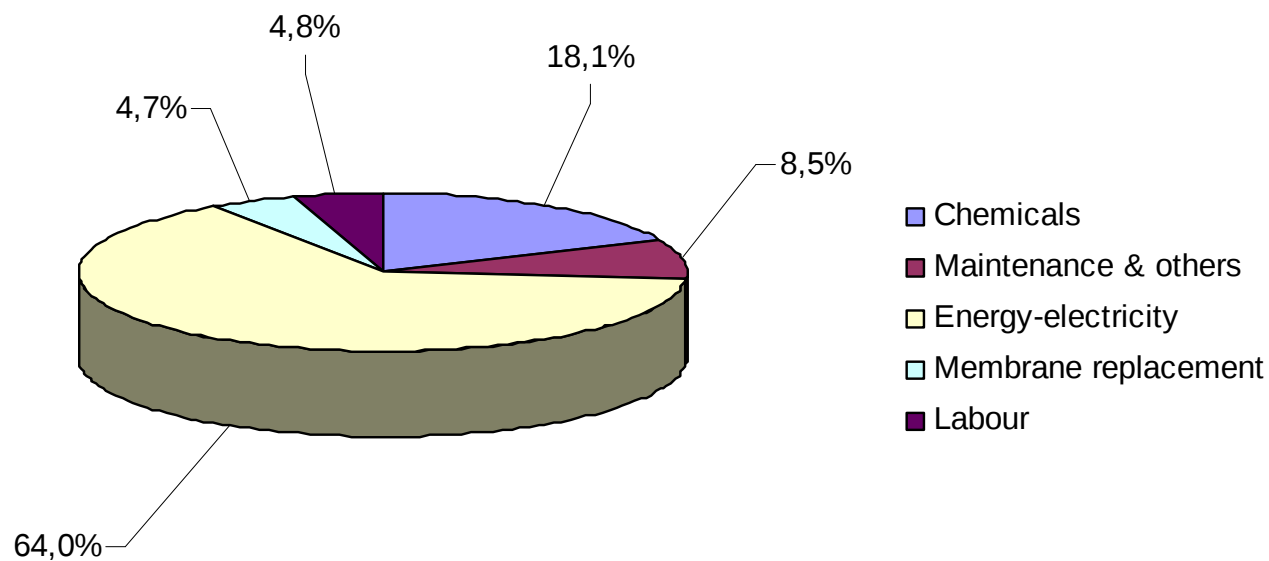


Breakdown of desalination cost

BCN seawater desalination plant

Production:	60 Hm ³ /yr / 180.000 m ³ /d
Technology:	RO
Conversion rate:	45%
Energy consumption:	4 kWh/m ³ (total) 3 kWh/m ³ (RO)

Breakdown of costs (BCN desalination plant)



BCN brackish water desalination plant

RO

UF

Treated water



Breakdown of desalination cost

BCN brackish water desalination plant

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Production:	Hm ³ /yr / m ³ /d
Technology:	RO
Conversion rate:	95%
Energy consumption:	kWh/m ³ (total) kWh/m ³ (RO)

**Breakdown of
desalination costs**

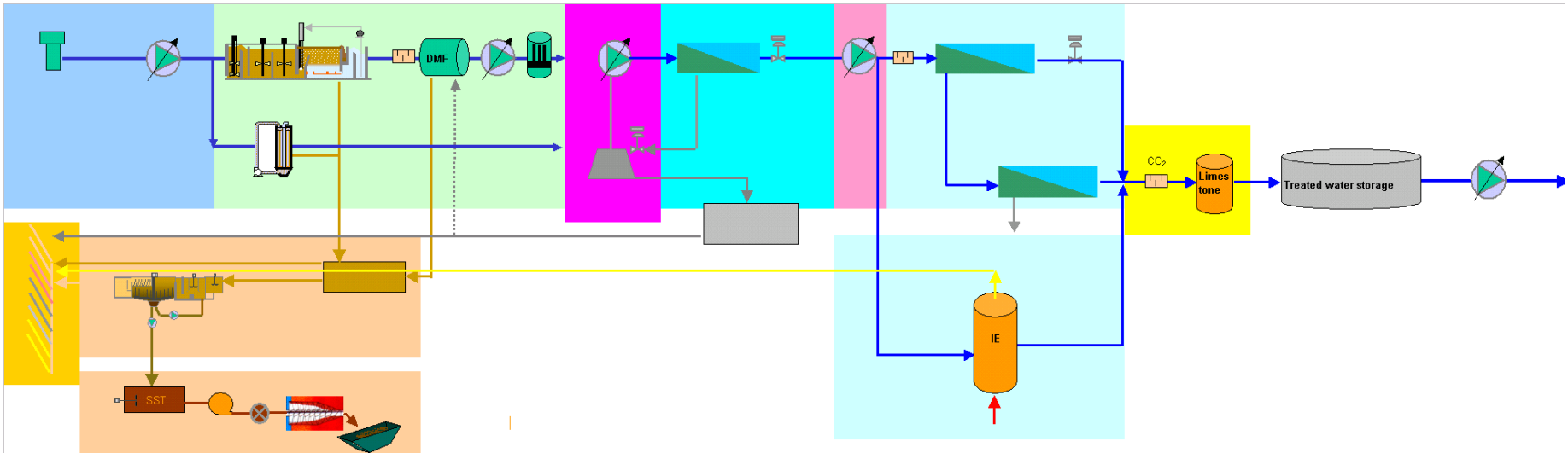
❖ Greenhouse gas (GHG) emissions by fossil fuelled plants

	MSF (Mt/year)				RO (Mt/year)			
Power plant	CO ₂	SO _x	NO _x	Particles	CO ₂	SO _x	NO _x	Particles
Coal fired	264.5	0.33	0.54	0.04	32.2	0.04	0.07	0.005
Oil fired	216.2	1.31	0.3	0.03	25.7	0.16	0.04	0.003
Gas turbine (CC)	141.6	0.01	0.23	0.01	12.9	0.001	0.02	0.001

Source: Nisan and Benzarti (2008), Desalination 229: 125-146



Integration of non-pollution renewable energy sources within desalination plants needed

❖ **Brine and chemicals discharge**

The **brine discharge** can impact the environment due to:

- the high salt content and high density: potential impact on the benthic sea life
- possible oxygen depletion when SBS is used as chlorine control

Pre-treatment residual **turbidity/TSS** can have an impact on photosynthesis activity by lowering the transmissivity of the water body at the reject point

Temperature can also be a potential effect of desalination, but mainly related to distillation (RO brine expected temperature increase is 1 to 2°C)

❖ Brine discharge evaluation

Regulation and dilution objectives:

- ☐ USEPA: 10% TDS limit
- ☐ Florida Department of Environmental Protection has considered an increase of up to 10% of chlorides as acceptable
- ☐ Australian projects request less than 1 to 2% TDS increase at the discharge zone limit.

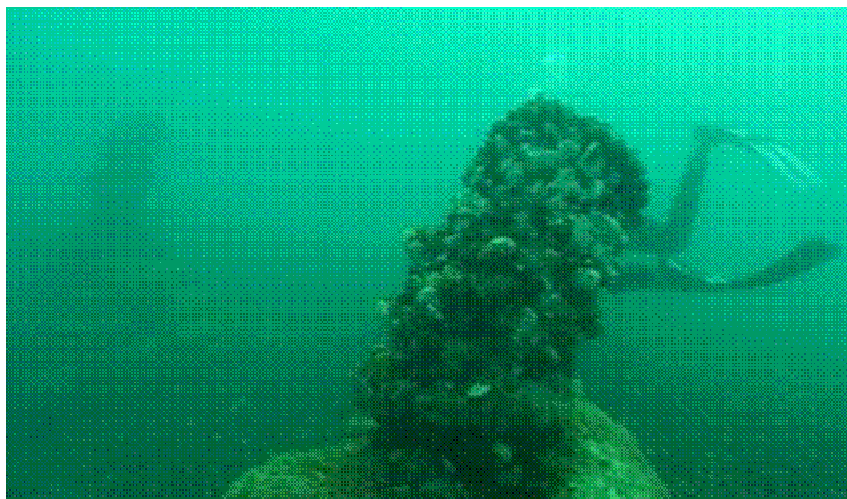
Design of the brine discharge system:

- ☐ Transport direction and the impact range of a discharge plume is controlled by site-specific oceanographic conditions, such as:
 - currents
 - tides
 - water depth
 - bottom and shoreline topography
- ☐ The environmental and operational conditions can be investigated by hydrodynamic computer models

❖ Brine discharge evaluation

PERTH brine quality monitoring before discharge:

- Oxygen
- pH
- Turbidity
- Redox



- **Desalination** represents a **potential alternative technology** for the efficient production of water from many sources.
- **RO and MSF** are the **most installed technologies**, their installation largely depending on energy availability.
- **Costs associated** with desalination **depend on many site specific factors** (feed water characteristics, product water quality, plant capacity) with energy availability being the most critical.
- **Desalination costs have** over the last decades **steadily decreased** thanks to continuous technological developments.
- However, **desalination is still an expensive option compared to natural water resources** and further research is needed to consolidate it as a competitive alternative.

- **Amortization and energy consumption** represent the most significant portion of the total desalination cost.
- **Environmental impacts** of desalination comprise:
 - The **emission of greenhouse gases** by fossil fuelled plants
 - The **production** of huge amounts **of concentrated brine**, which cause adverse ecological effects on the surrounding ecosystems.
- **Research** on the use of renewable energy sources and on the treatment of brines **is needed**.

THANK YOU FOR
YOUR ATTENTION!!