# The Economics of Desalination for Various Uses

Carlos Campos

CETaqua
WATER TECHNOLOGY CENTER

Agbar UPC CSIC

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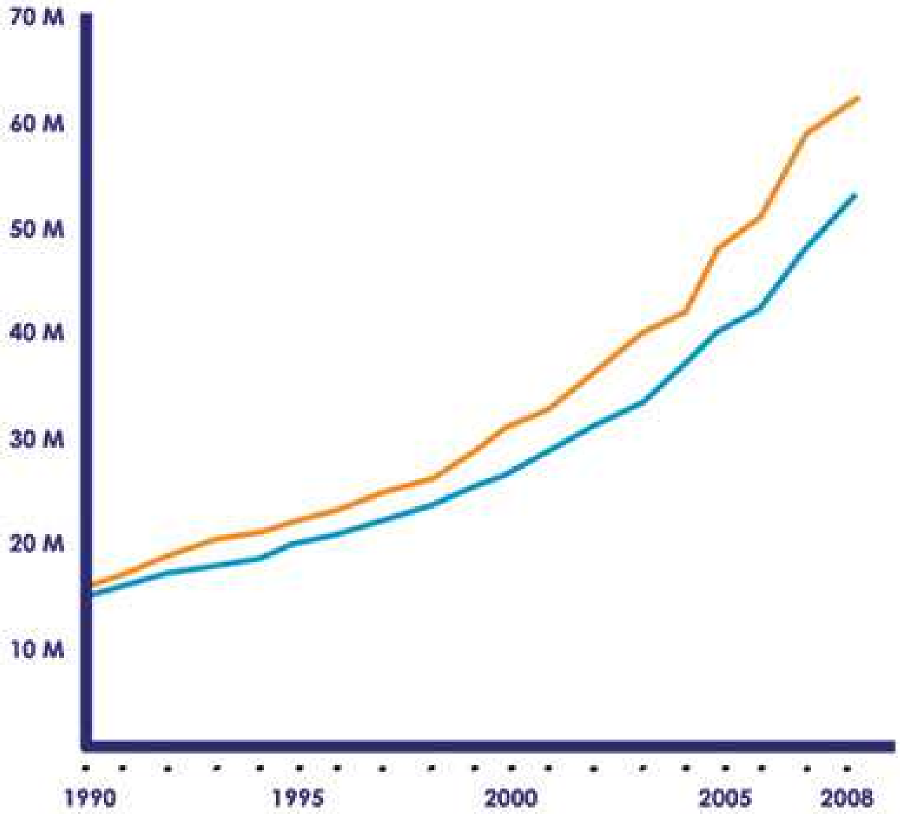
# Introduction






| 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)

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| 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)

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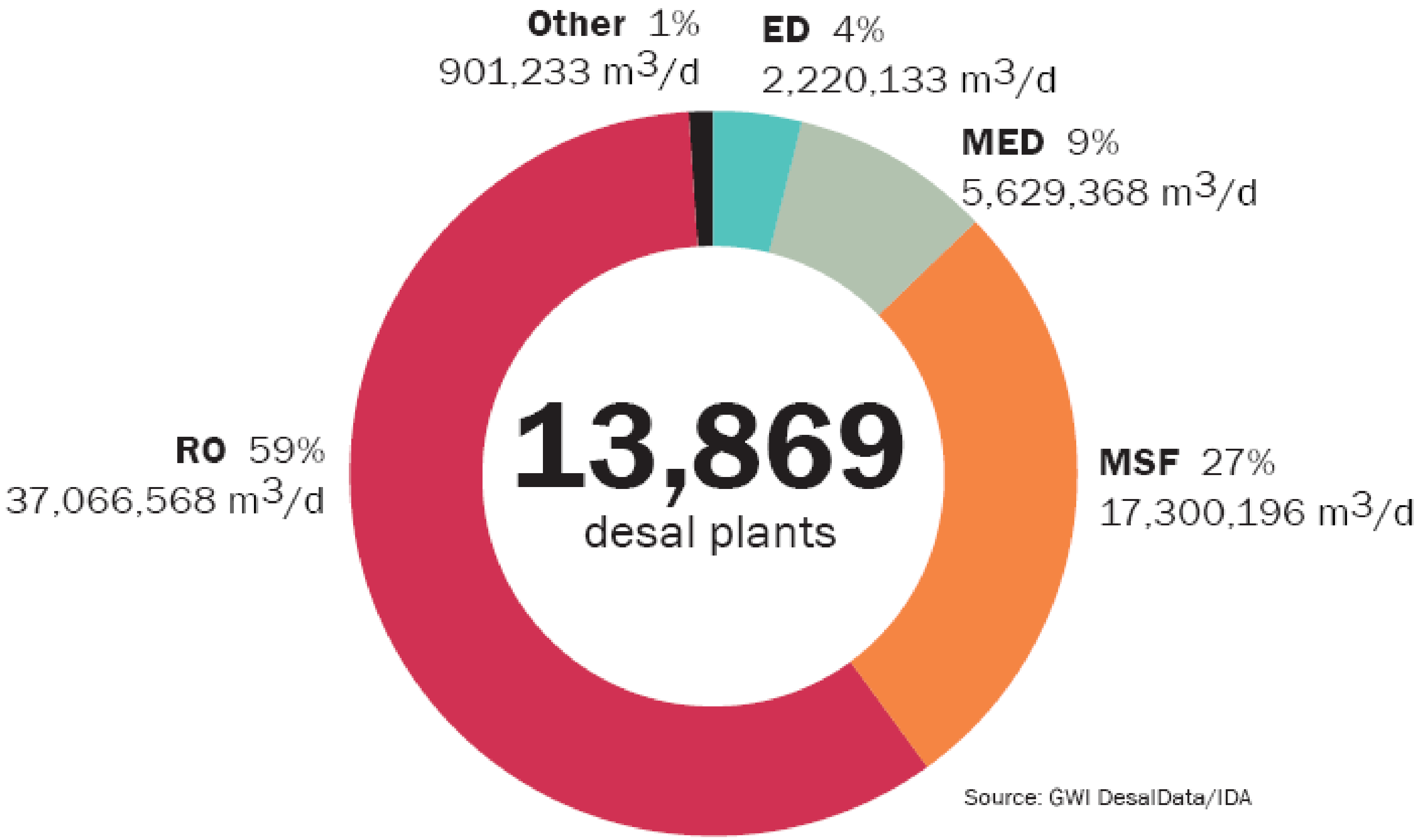

# Comparison of large-scale desalination technologies

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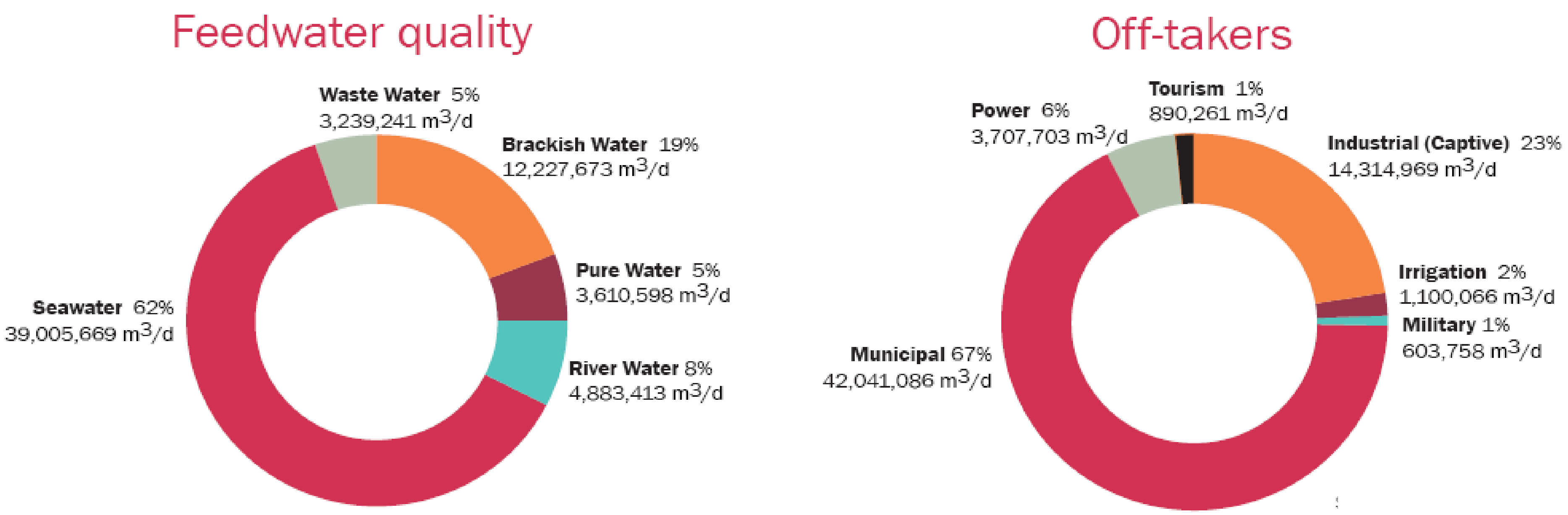
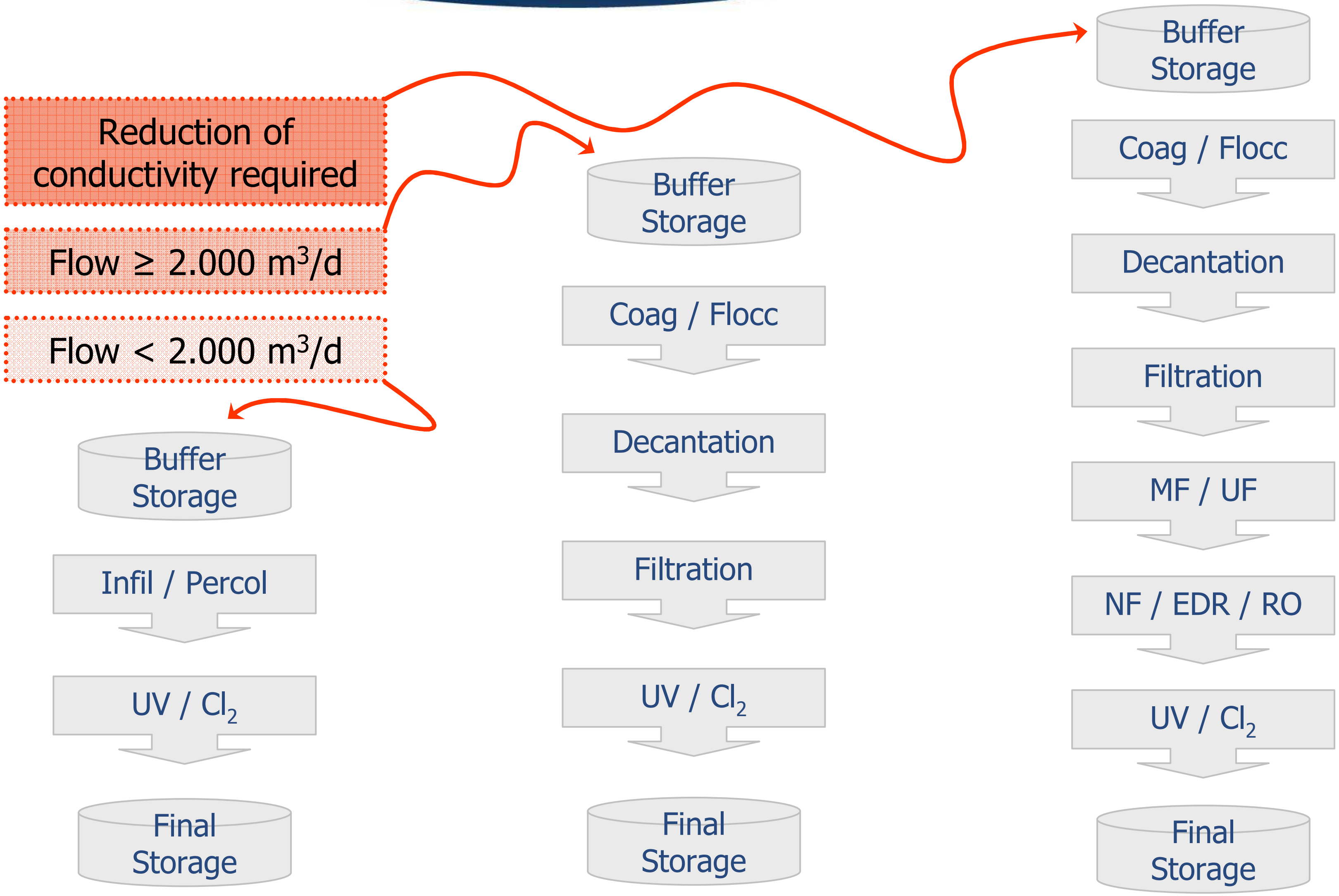
| | MSF | RO |
|---|---|---|
| Physico-chemical principle | Flash evaporation | Solution-diffusion |
| Energy consumption (including auxiliaries) | Electrical: 2.5-5.0 kW·h/m$^3$ Thermal: 40-120 kW·h/m$^3$ | Electrical: 3.5-4.5 kW·h/m$^3$ Thermal: None |
| Plant top temperature level | ~ 120ºC | Seawater temperature. Limit ~ 35ºC |
| 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

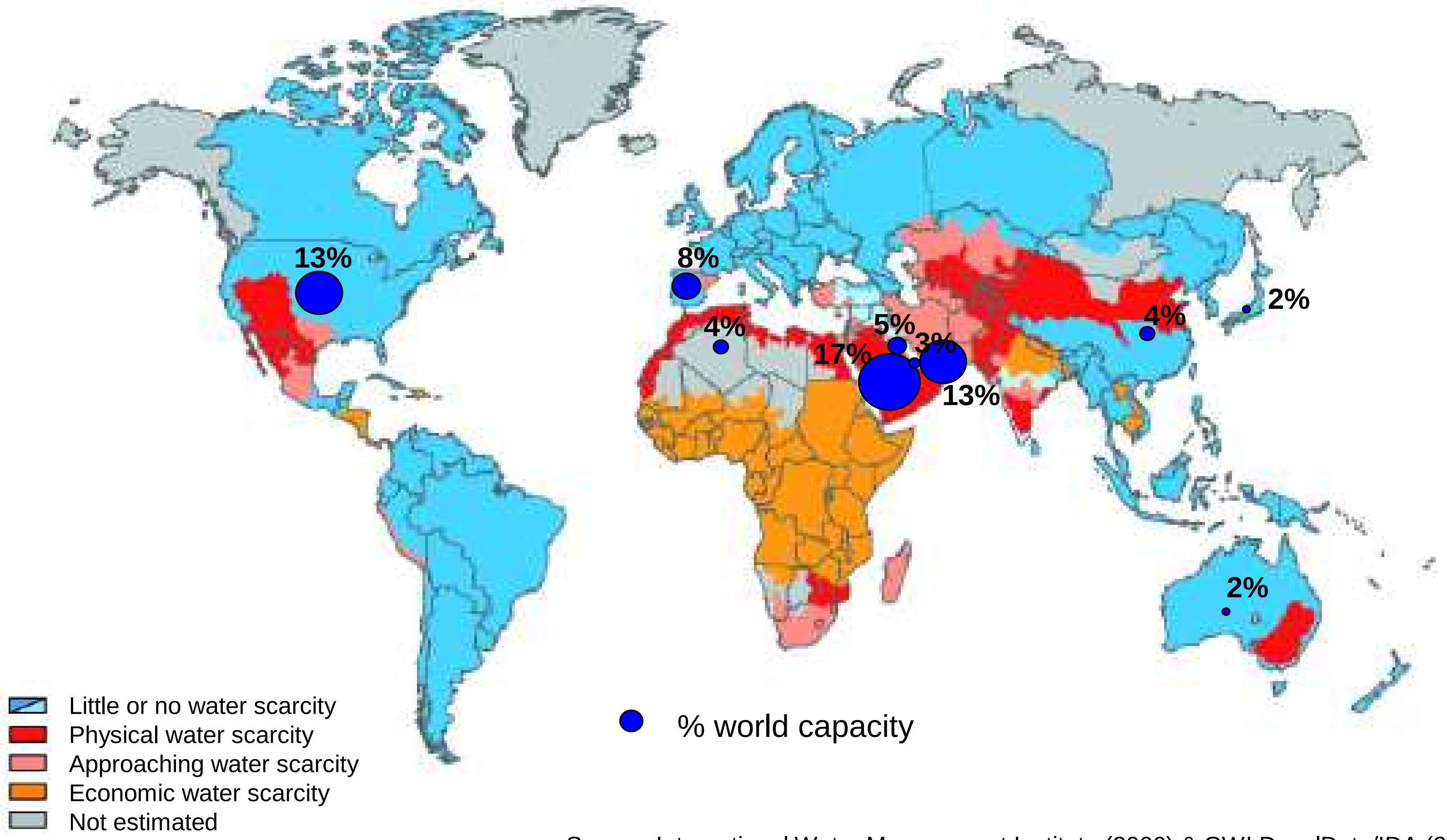



Source: GWI DesalData/IDA

# 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)

Toray

Woongjin Chemical (Korea)

Vontron (China)

# Situation of desalination in Spain

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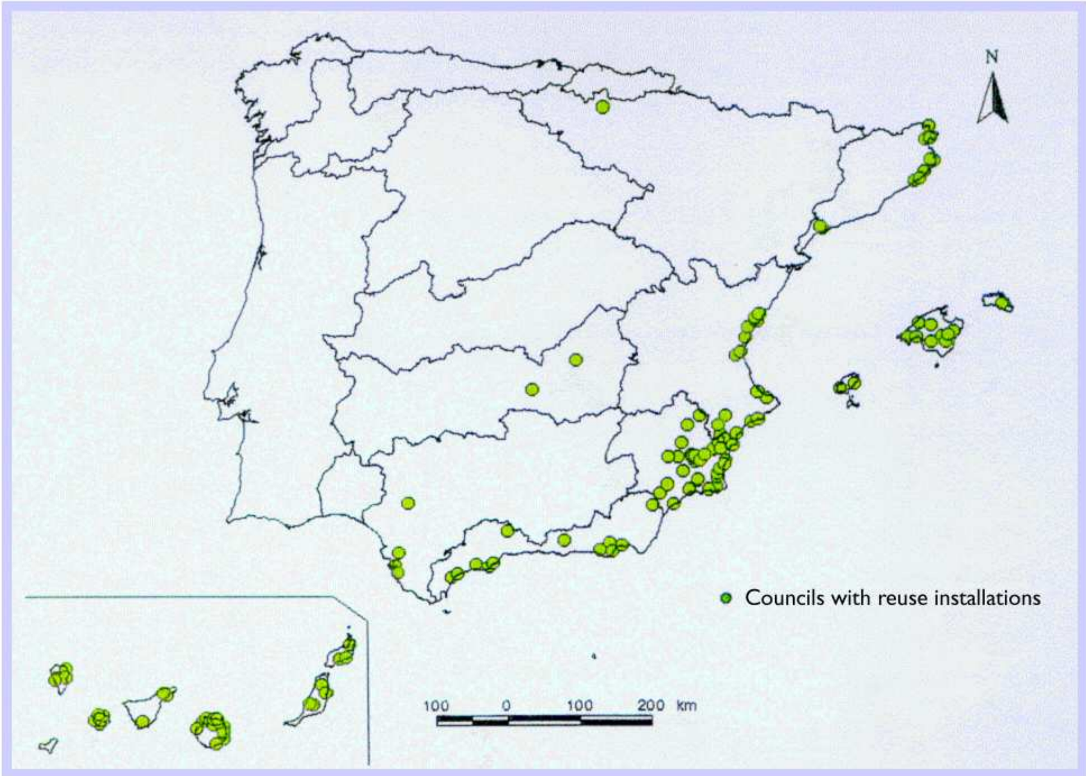
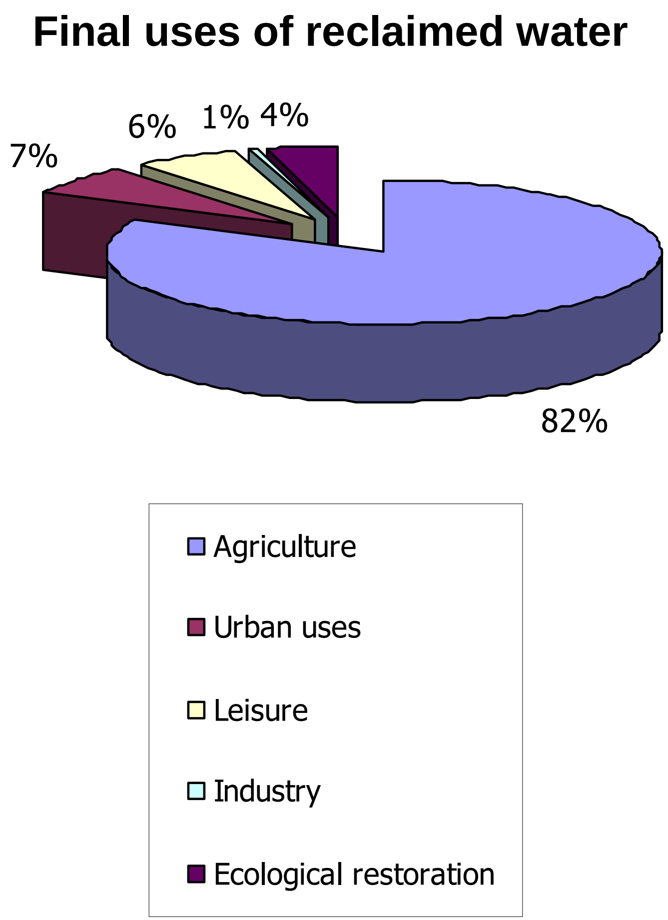
Urgent actions to be undertaken in the Spanish Mediterranean coast in the framework of the **A.G.U.A. Program**:

| | 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

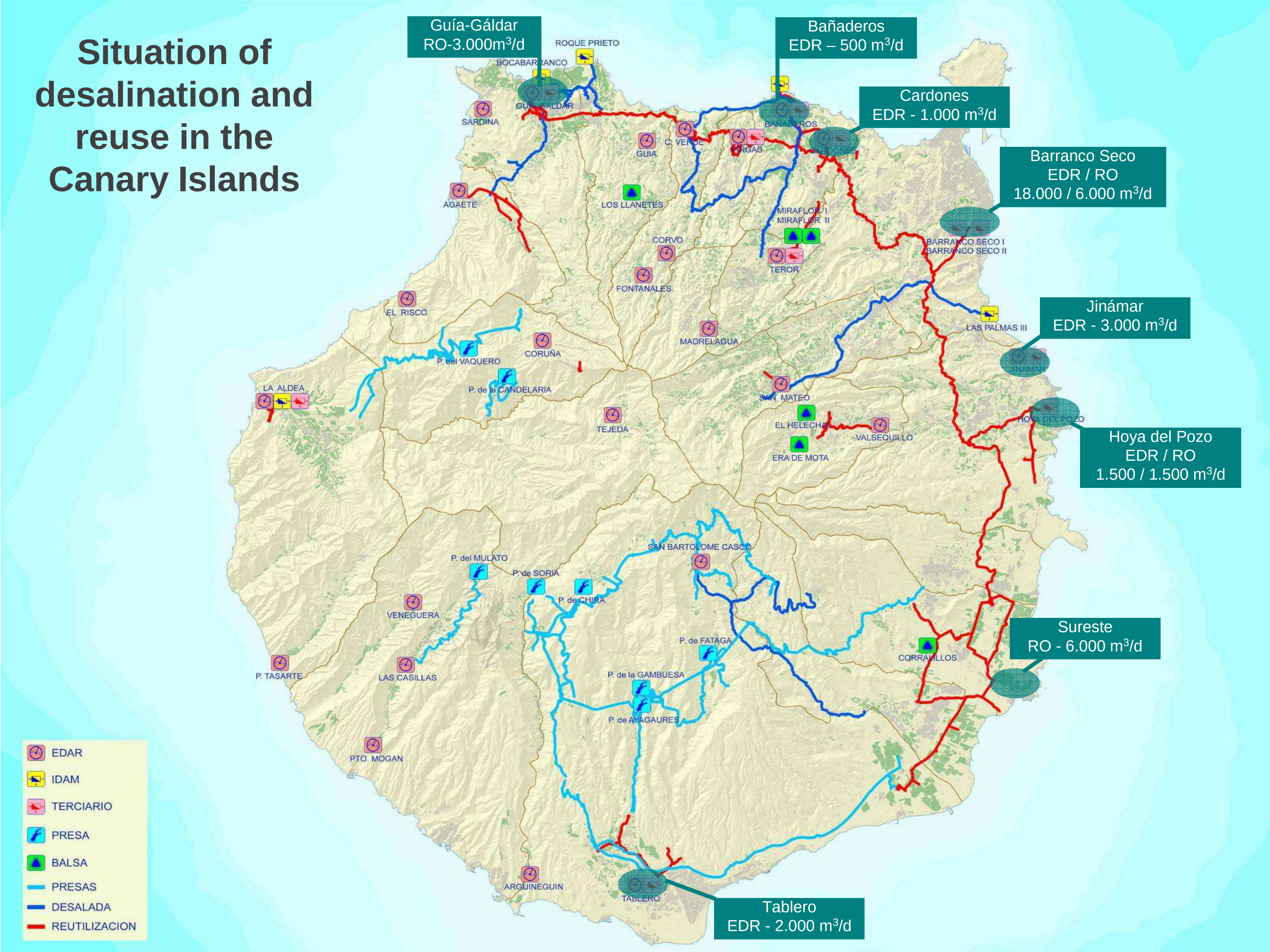
# Situation of reuse in Spain




- 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)

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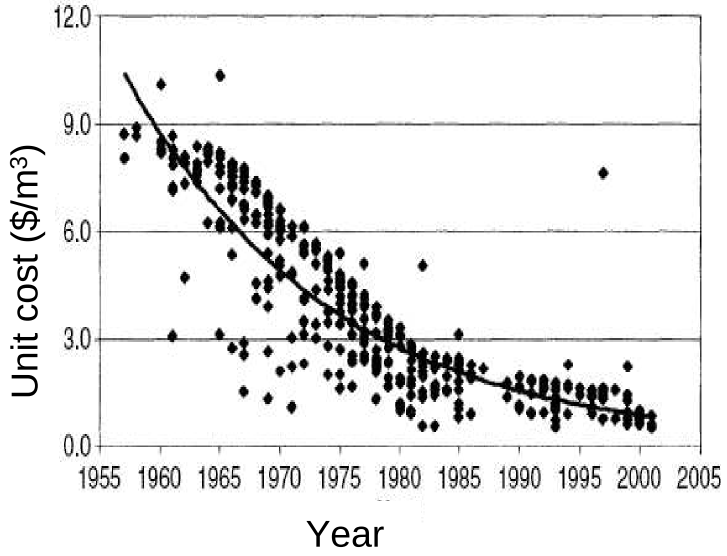
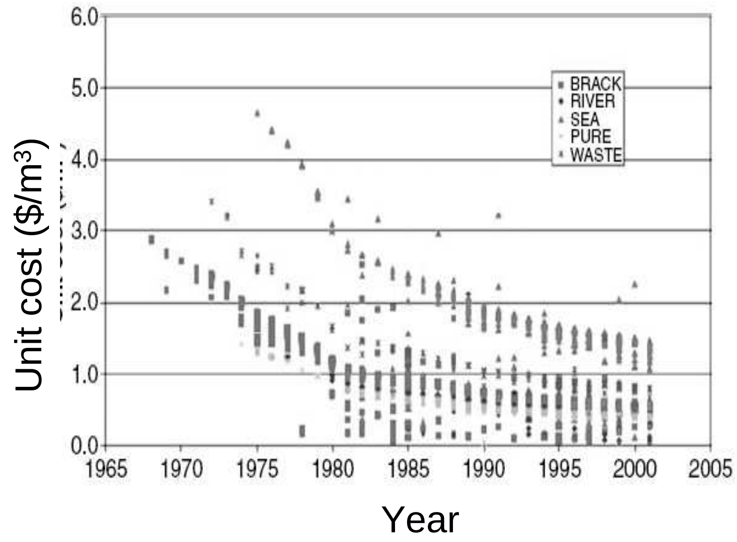
**MSF**




**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.

# Desalination cost evolution (II)

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## 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

# Desalination cost evolution (III)

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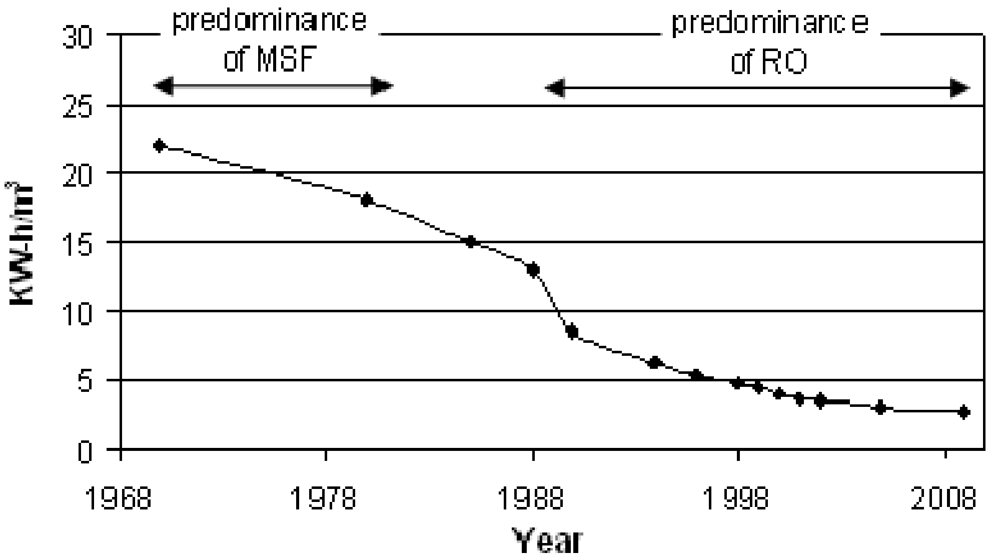
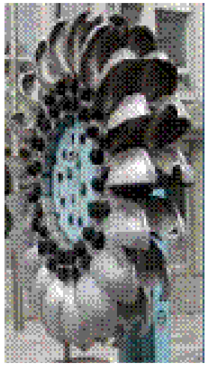
## Evolution of the energy consumption of desalted seawater in Spain



Source: AEDyR (2009), Ponencias del curso Desalación

- Energy required per m$^3$ 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)

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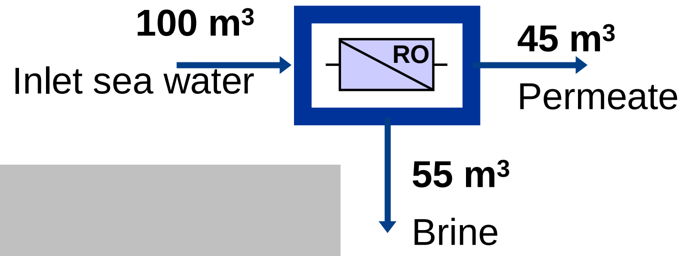
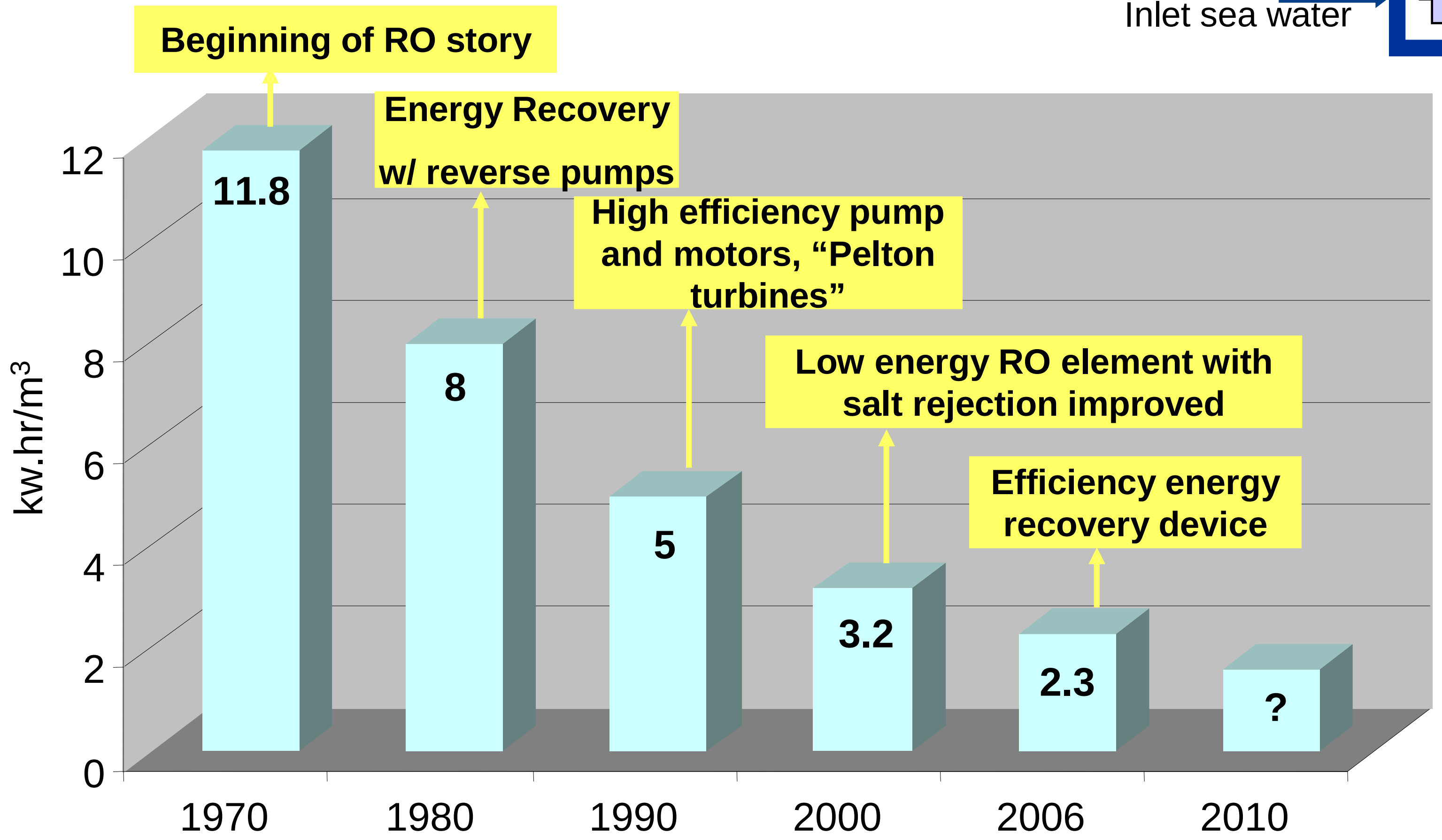
## Evolution of the electrical consumption for seawater 1st pass RO



# Main factors affecting desalination cost (I)

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## 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)

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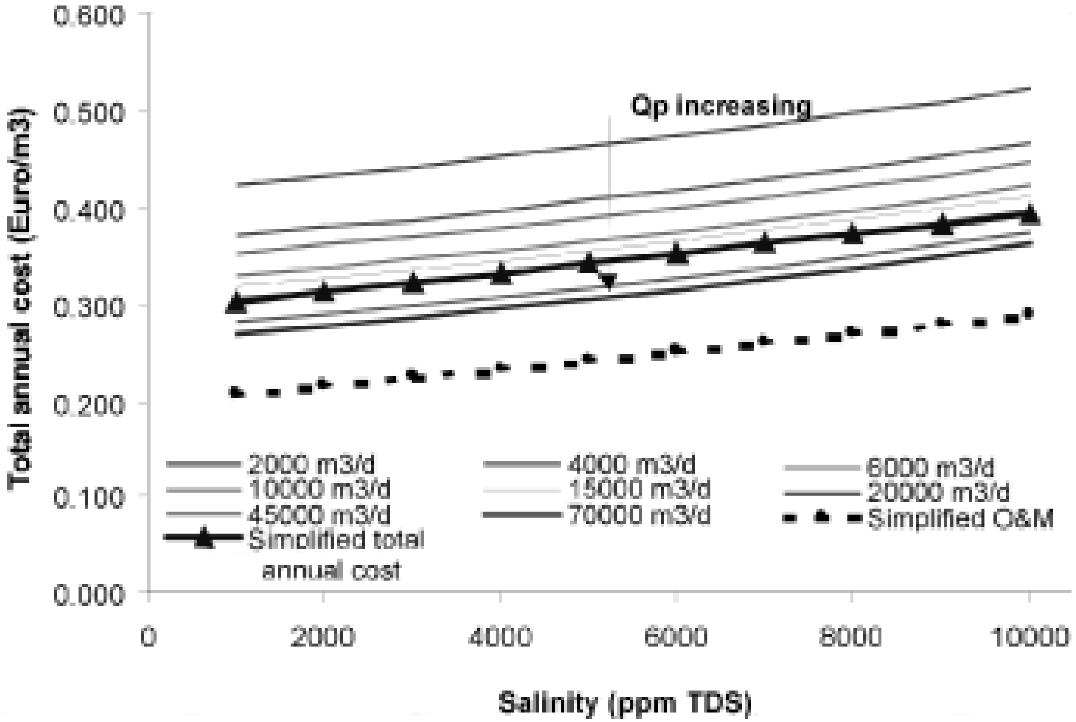
Water desalination costs with regards to the **type of feed water and plant capacity**:




Source: Georgopoulou et al., (2001) Desalination136: 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)

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

| Type of feed water | Type of energy used | Cost (€/m³) |
|---|---|---|
| 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)

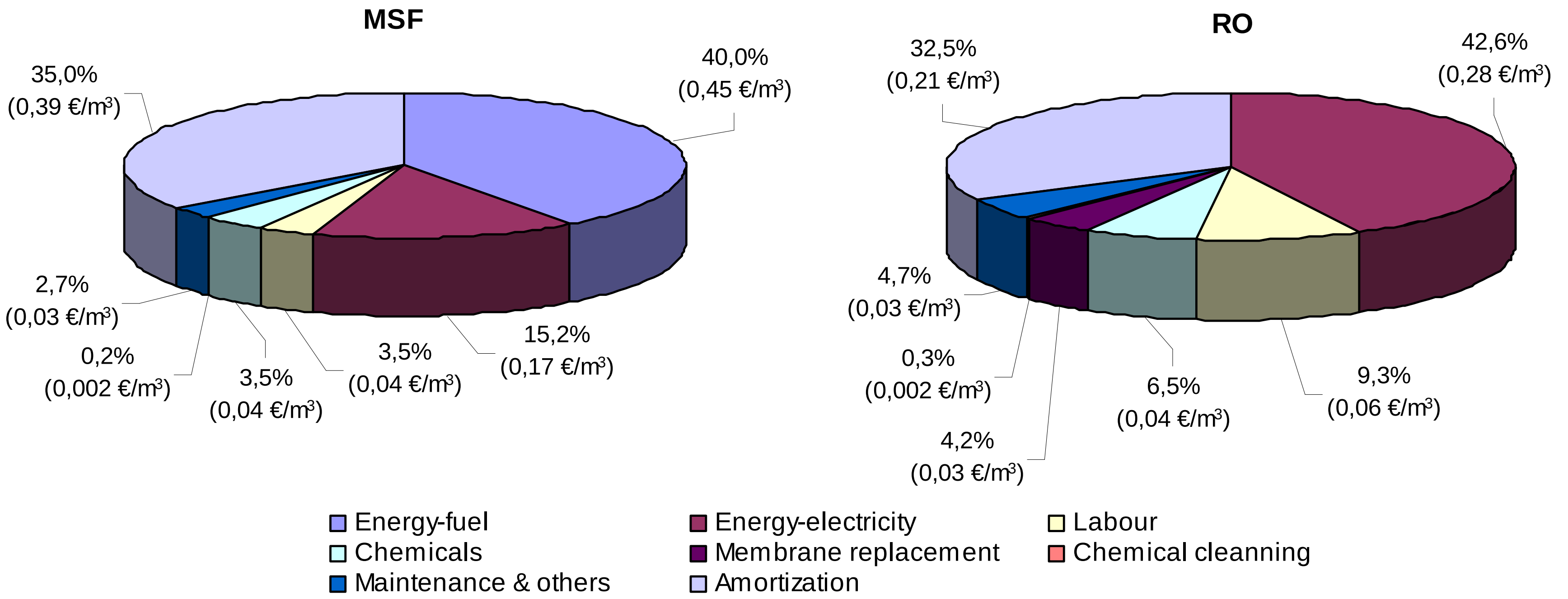
Water desalination cost with regards to the **type of desalination method:**

| Des. method | Type of feed water | Plant capacity ($m^3$/day) | Cost (€/$m^3$) |
|---|---|---|---|
| MSF | Seawater | 23,000 - 528,000 | 0.42-1.40 |
| RO | Brackish | <20 | 4.50-10.32 |
| | | 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

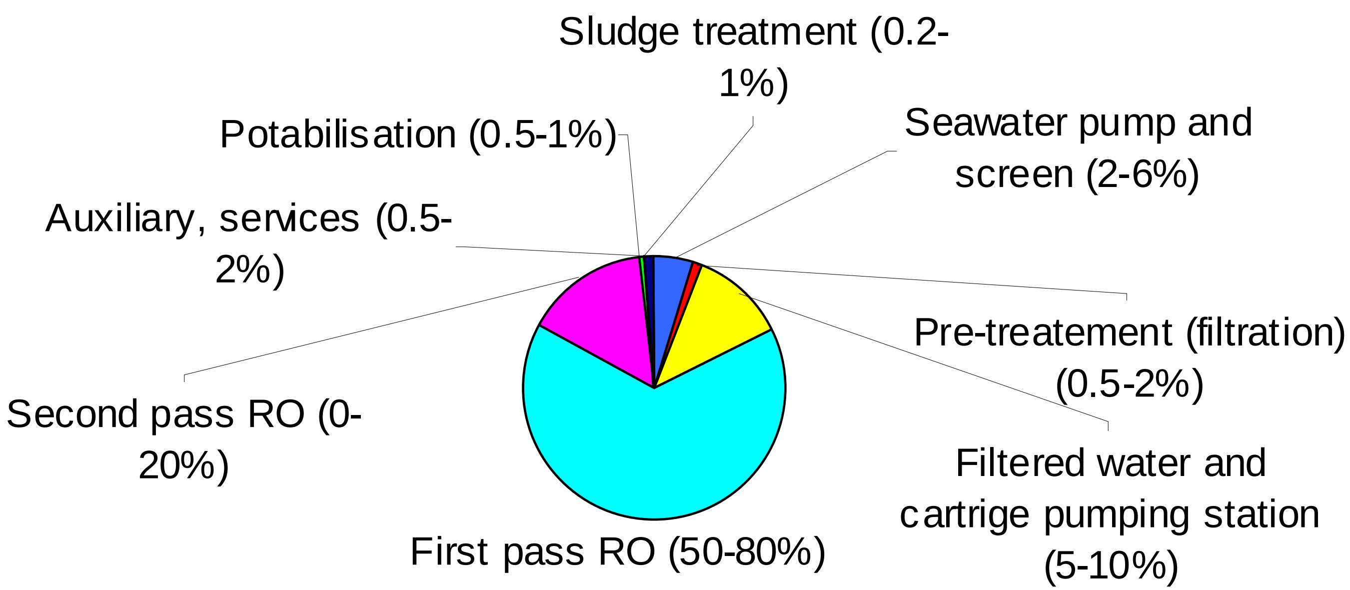
# Breakdown of desalination cost

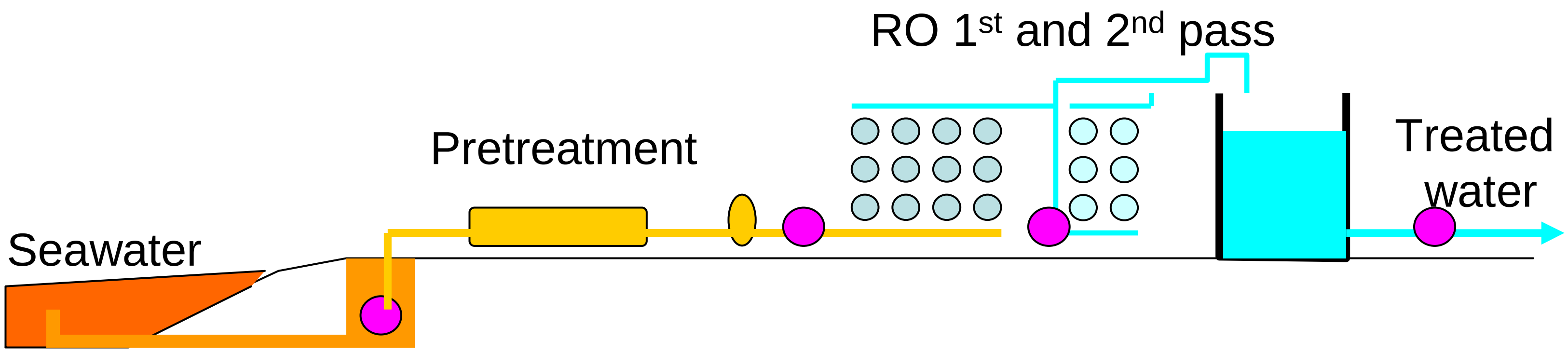



Source: AEDyR (2009), Ponencias del curso Desalación

- 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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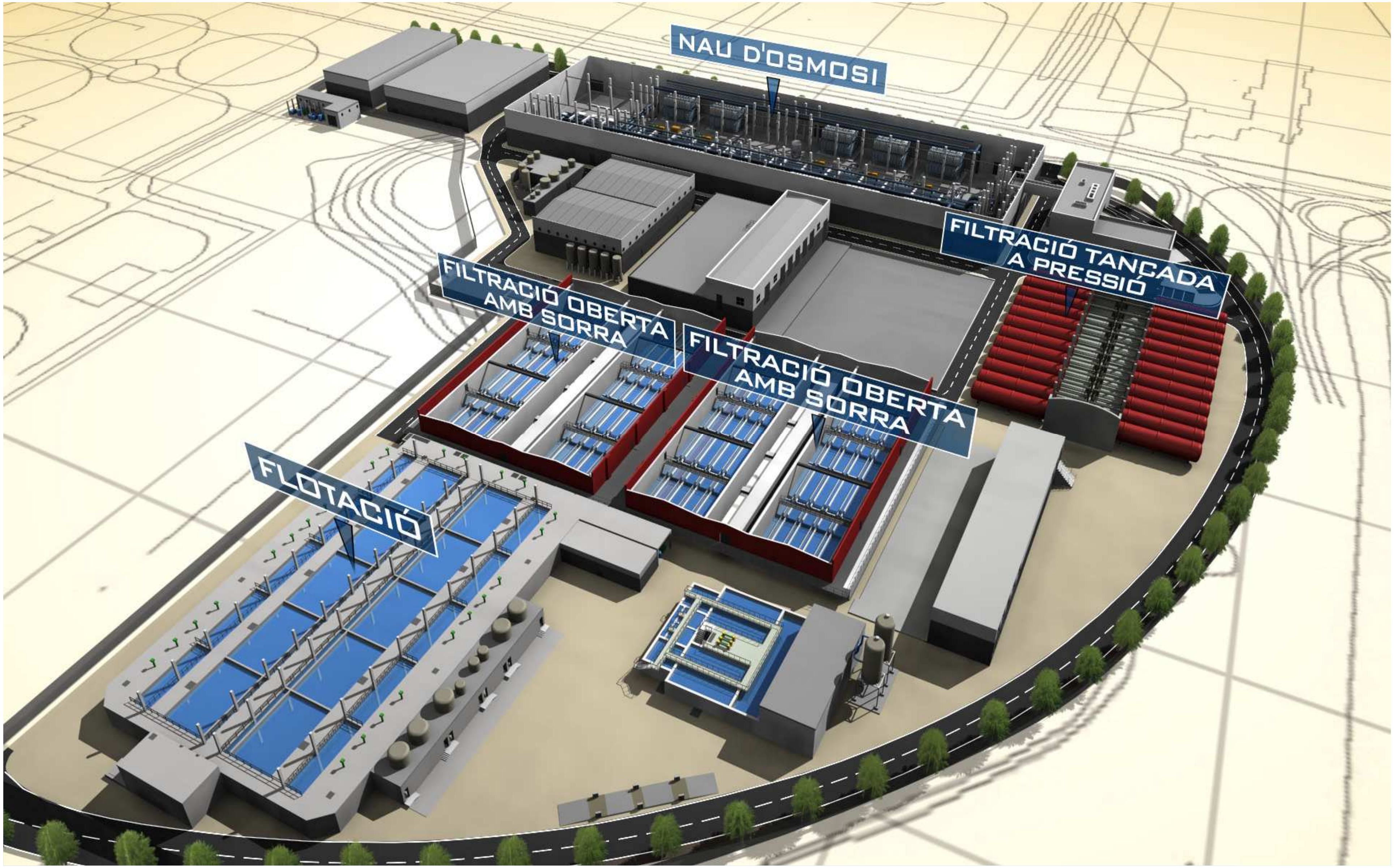
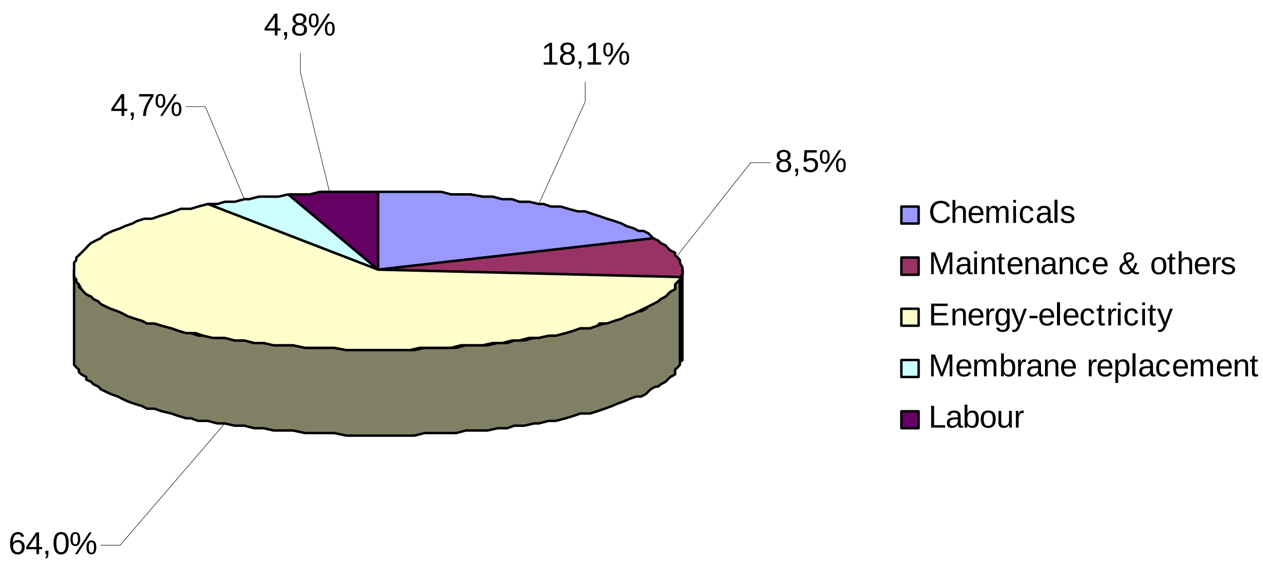


# Breakdown of desalination cost

## 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)<br>3 kWh/$m^3$ (RO) |

**Breakdown of costs (BCN desalination plant)**




BCN brackish water desalination plant
RO
Treated water
UF

# 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)<br>$kWh/m^3$ (RO) |

Breakdown of desalination costs

# Environmental impacts of desalination (I)

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❖ **Greenhouse gas (GHG) emissions** by fossil fuelled plants

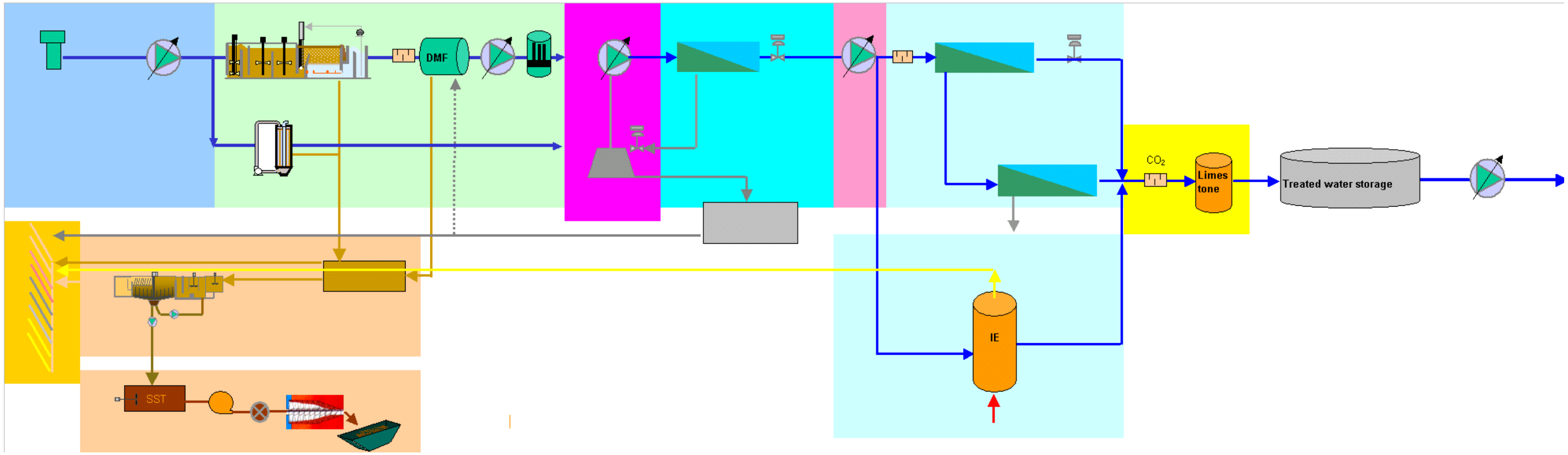
| | MSF (Mt/year) | | | | RO (Mt/year) | | | |
|---|---|---|---|---|---|---|---|---|
| Power plant | $CO_2$ | $SO_X$ | $NO_X$ | Particles | $CO_2$ | $SO_X$ | $NO_X$ | Particles |
| Coal fired | 264.5 | 0.33 | 0.54 | 0.04 | 32.2 | 0.04 | 0.07 | 0.005 |
| Oil fired | 216.2 | 1.31 | 0.3 | 0.03 | 25.7 | 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

# Environmental impacts of desalination (II)

## ❖ 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 transmisivity 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)

# Environmental impacts of desalination (III)

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❖ **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:

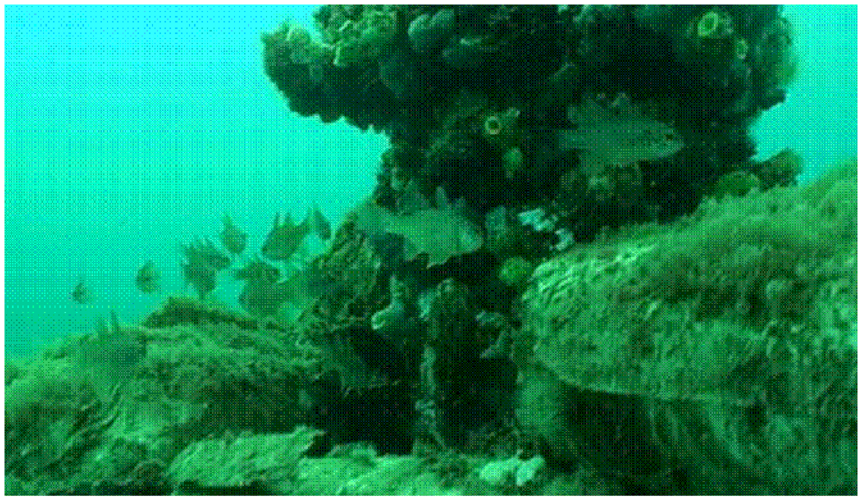
- ❑ Transport direction and the impact range of a discharge plume is controlled by site-specific oceanographic conditions, such as:
  - currents
  - tides
  - water depth
  - bottom and shoreline topography
- ❑ The environmental and operational conditions can be investigated by hydrodynamic computer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

# Environmental impacts of desalination (IV)

❖ **Brine discharge evaluation**

**PERTH brine quality monitoring before discharge:**

- Oxygen
- pH
- Turbidity
- Redox



# Conclusions

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- **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.

# Conclusions



- **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!!