Desalination
Technology and Energy

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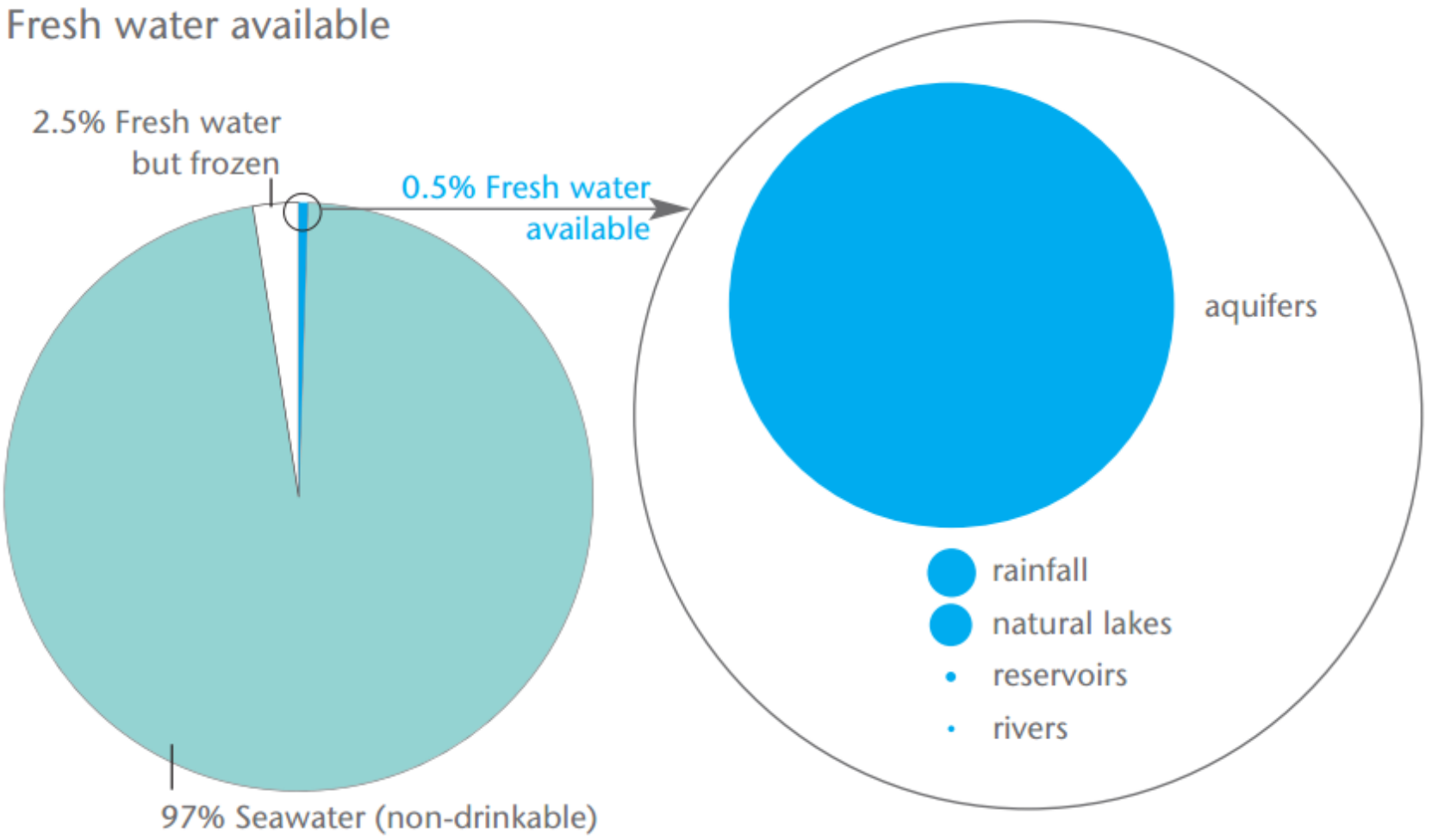
Desalination in history

“Salt water when it turns into vapor becomes sweet and the vapor does not form salt water again when it condenses.“

----Aristotle, Meteorologica

Pliny the Elder, *Natural History*

Water on Earth



Numbers about Desalination

- World annual water consumption: 9,087 Gm^3/y
- World desalination capacity: 31.7 Gm^3/y

  0.3% of total consumption

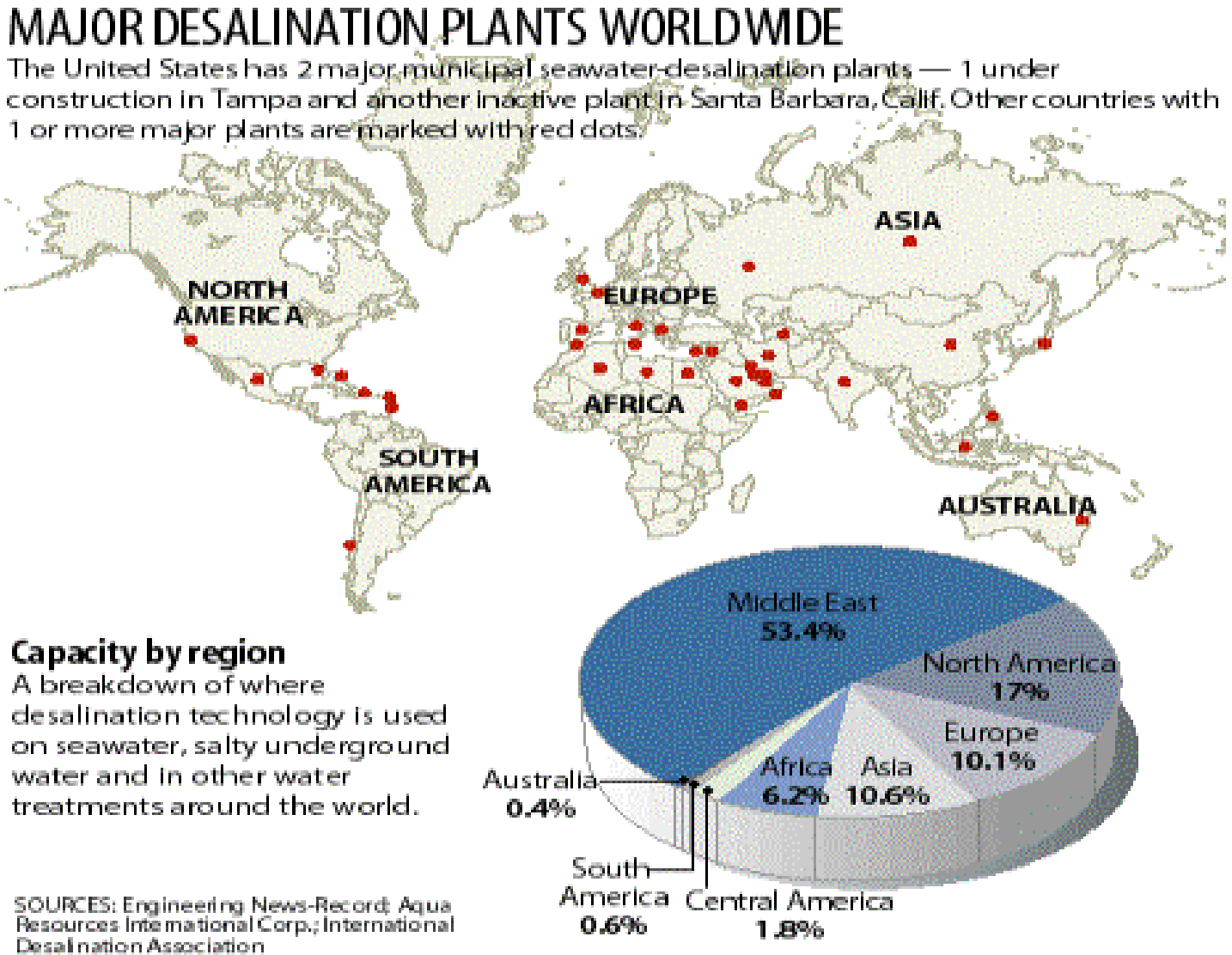
- World energy consumption: 1.1×10^{14} kWh/y
- World desalination energy consumption: ~1.8×10^9kWh/y

  0.002% of total energy consumption

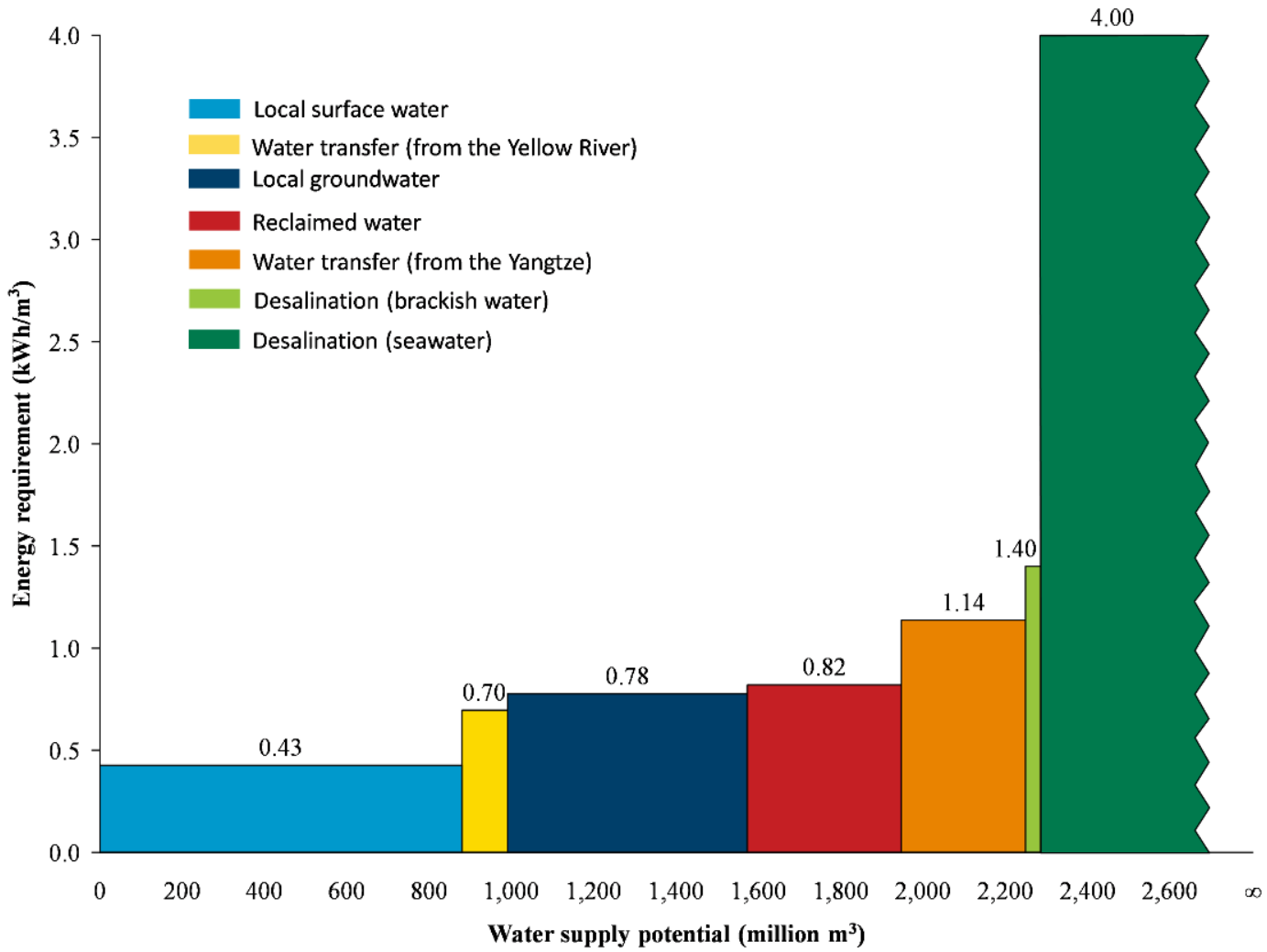
  Compare to Haber process 1-2%

IDA 2015
Arjen Y. Hoekstra, *PNAS* 2011

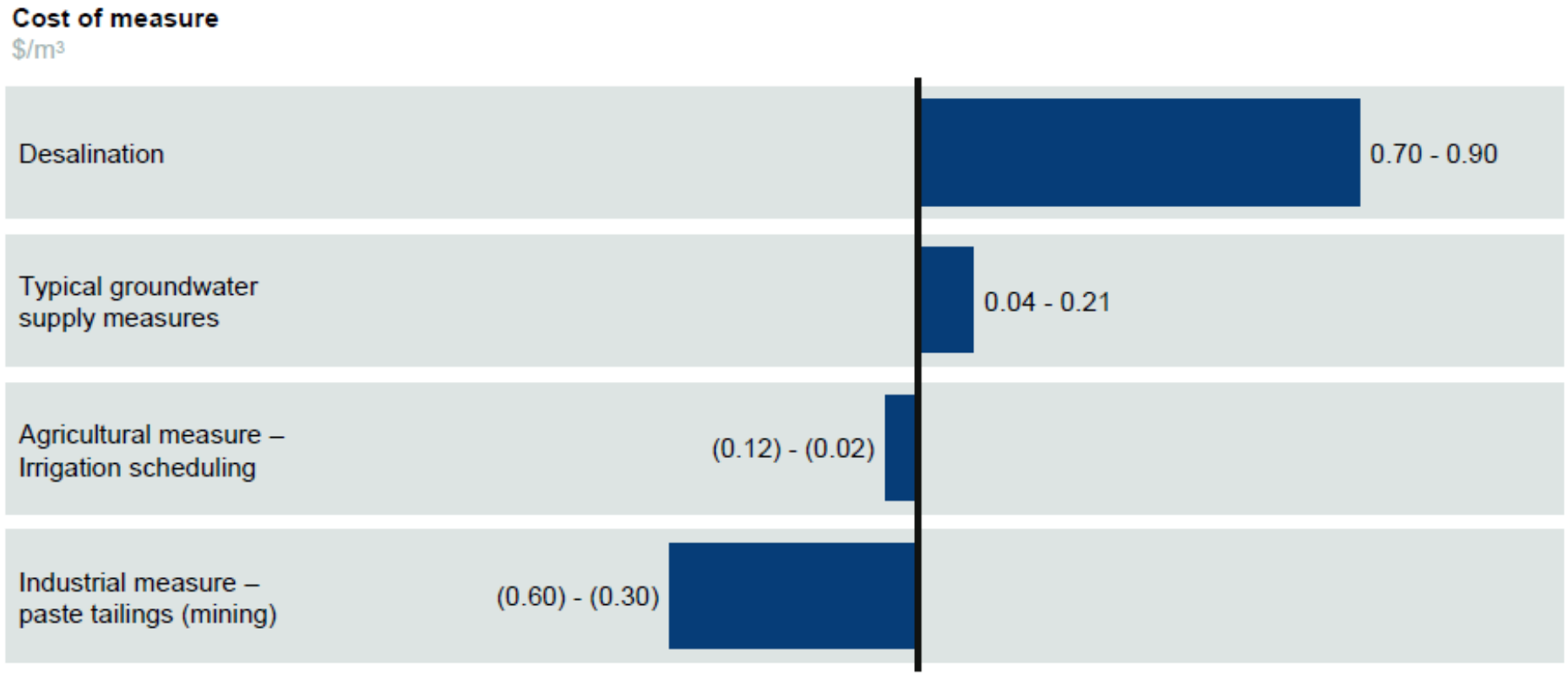
Desalination plans in the world



Energy cost of water supply (Qingdao, China)



Water Price



2030 Water Resource Group

Analysis of energy cost of desalination

- Estimate osmotic pressure of seawater
- Thermal dynamic (limit)
- Practical cost

Calculate Seawater Osmotic Pressure

Osmotic Pressure

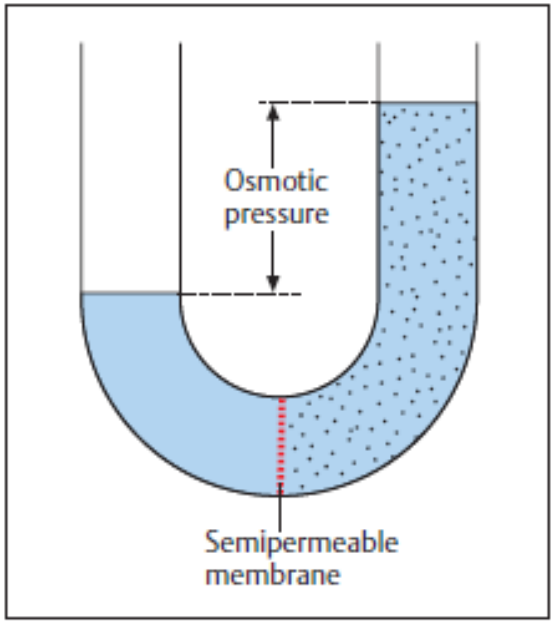
Molarity (mole/L)

Temperature (K)

$$\pi = iMRT = 2{,}675\text{kPa} = 26.4\ \text{atm}$$

van't Hoff's factor (1.8)

Ideal gas Constant



Pressure of ~260m high water pillar !!!

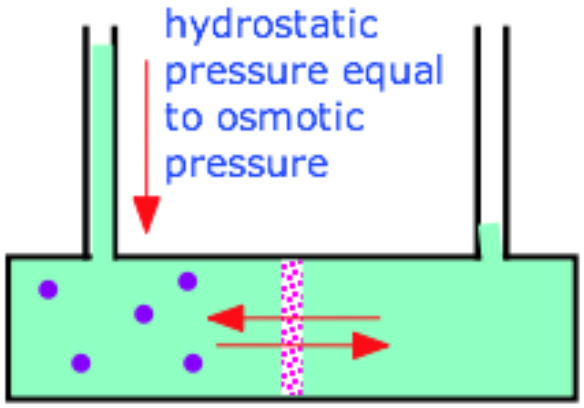
Calculate Ideal Energy Cost of Desalination

How much energy is needed to convert 1m^3 seawater into pure water?

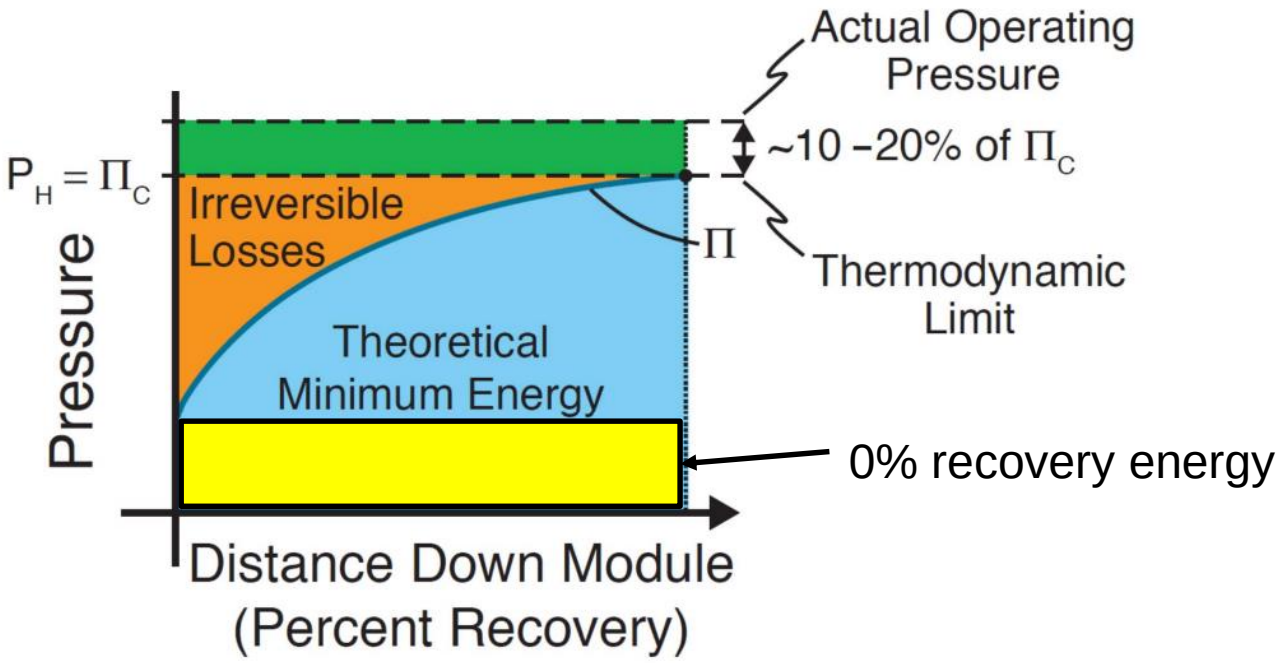
$$W = \pi V = 2675\text{kJ} = 0.743\ \text{kWh}$$

Assumptions:

- Slow conversion
- No osmatic pressure change (0% recovery)
- Ideal ionic membrane

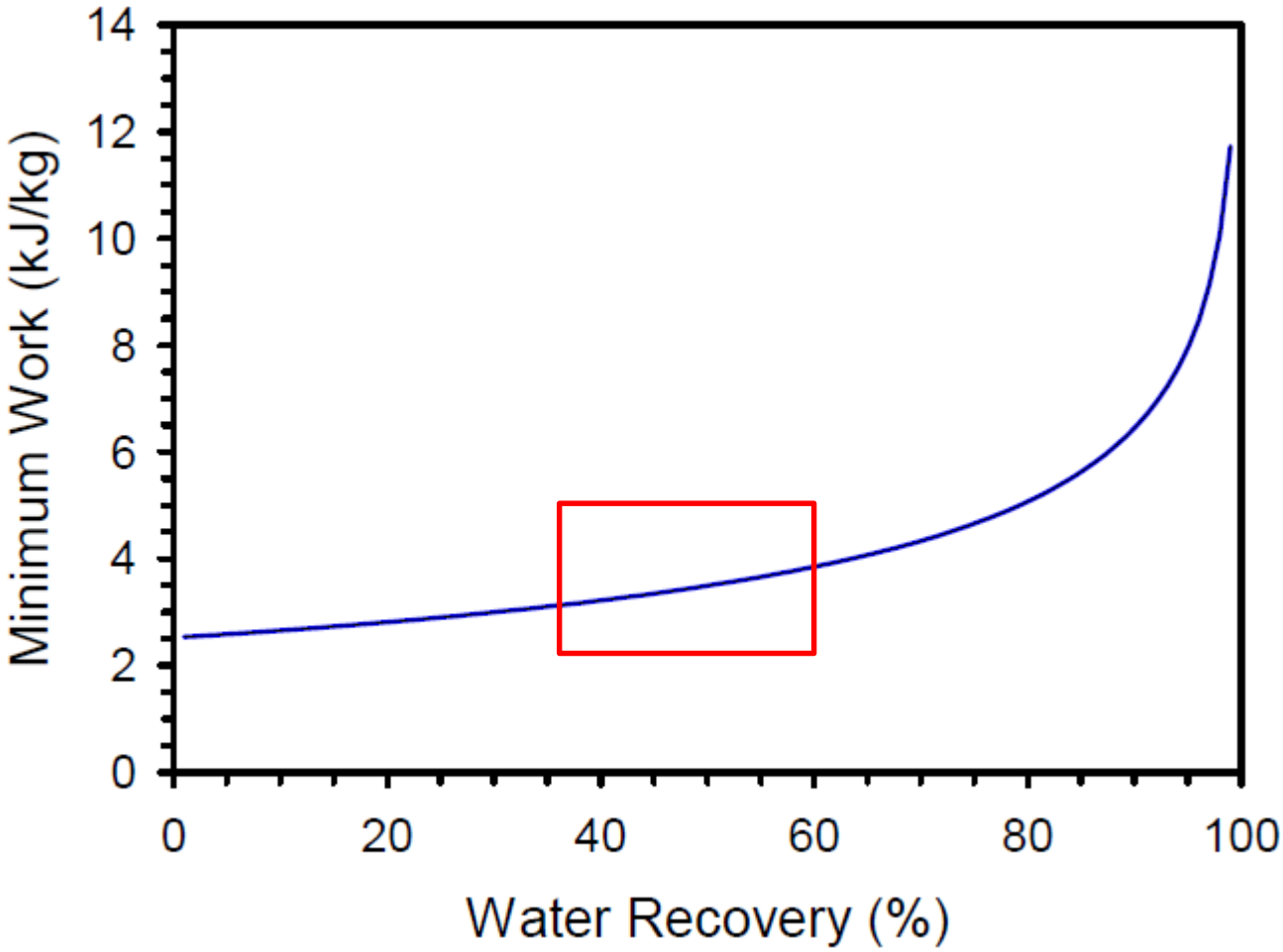


Real Energy Cost of Desalination



- 0% recovery: 0.76 kWh/m^3
- 50% recovery: 1.06 kWh/m^3
- Practical RO: 1.56kWh/m^3
- Real case RO : 2kWh/m^3
- Real case Overall : 3-4kWh/m^3

Recovery rate selection

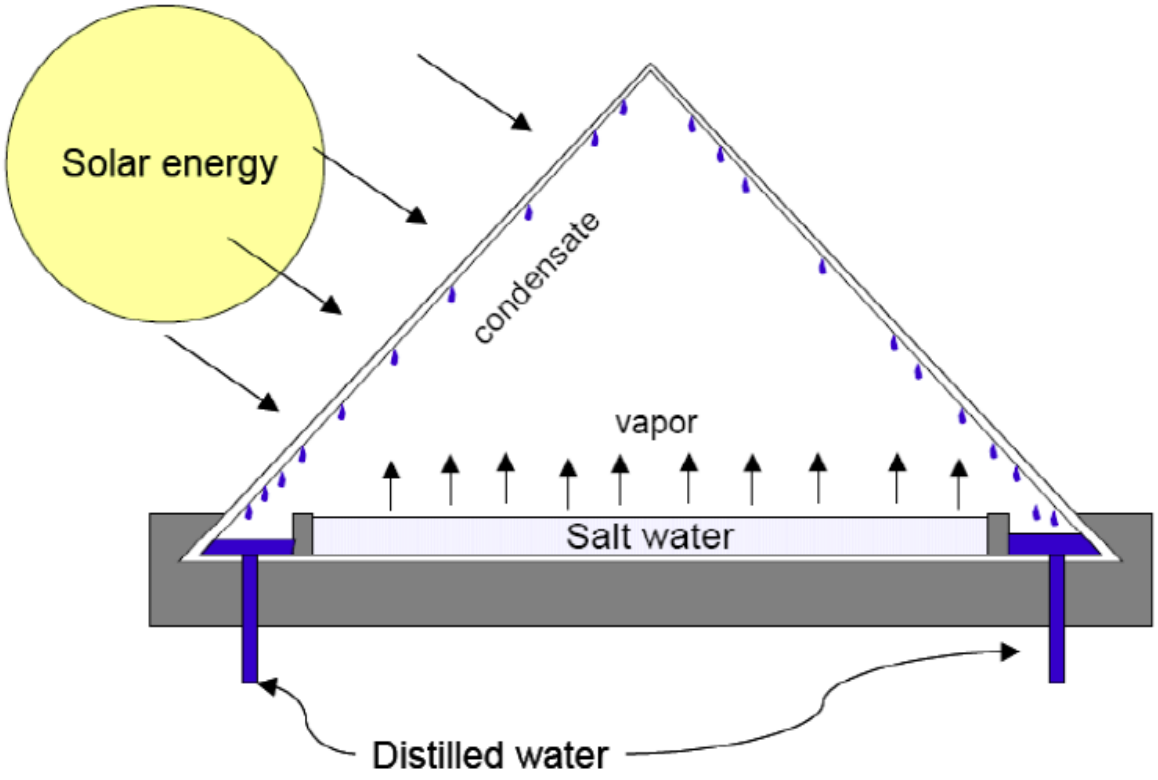


Sand Report 2003

Desalination Technologies

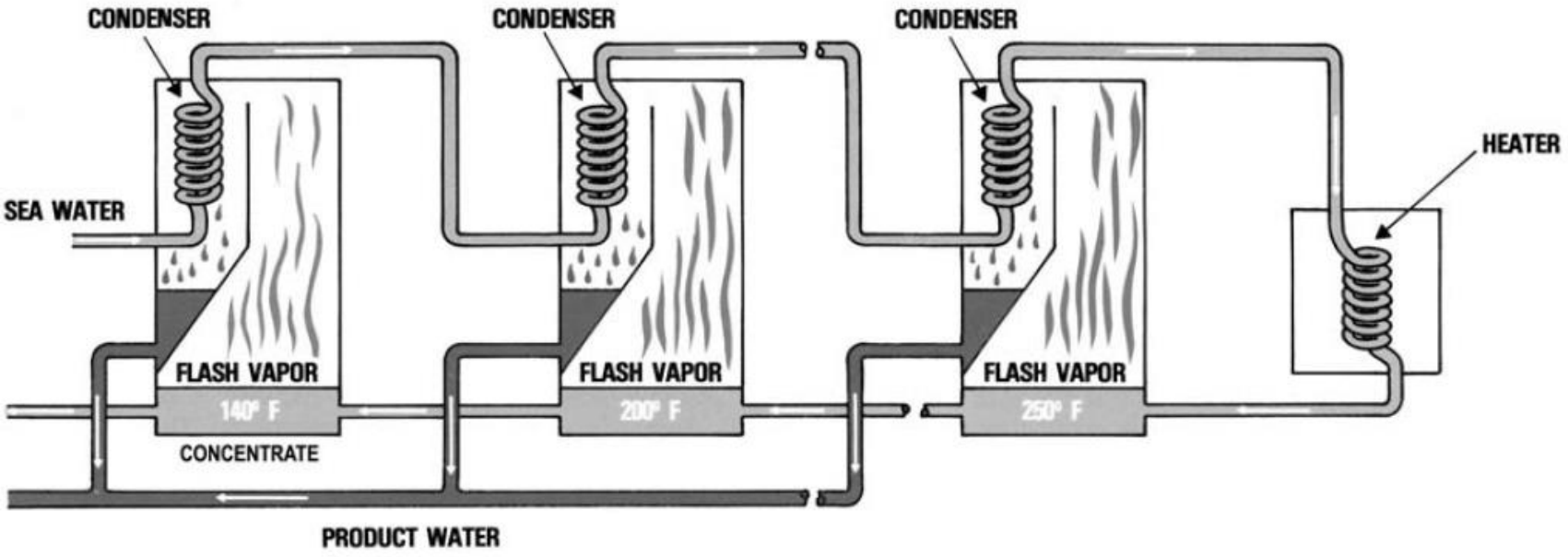
- Phase change technologies
  - Solar still
  - Multi effect distillation (MED)
  - Multi stage flash (MSF)
  - …
- Membrane based technologies
  - Reverse Osmosis (RO)
  - Electrodialysis
  - ….

Solar Still Desalination



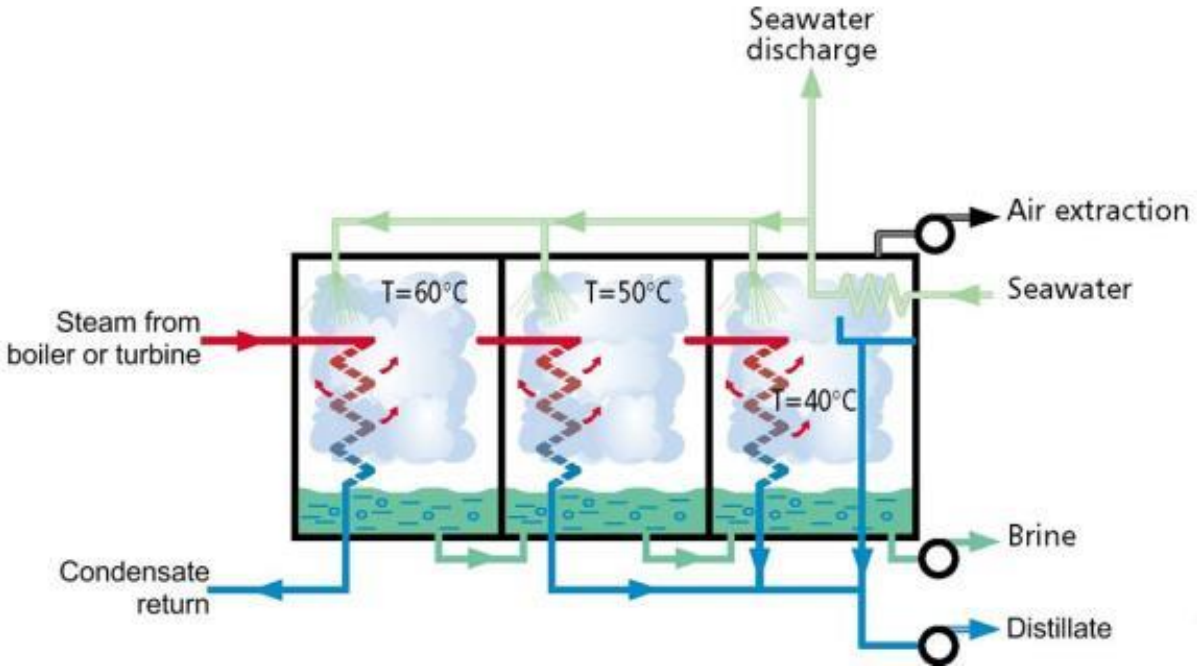
- Simple
- Low cost
- 3-4 L/day
- About 1000kWh/m^3

Multi stage flash (MSF) distillation



- High temperature & high pressure
- Energy recovered by heating up seawater

Multi effect distillation (MED)



- Low temperature & reduced pressure
- Energy recovered by vaporizing sea water

Comparison between MSF & MED

MSF

- High P high T
- Easy scale up
- Severe corrosion
- Require high T steam
- 10-16 kWh/m^3

MED

- Reduced P, Low T
- Difficult to scale up
- Less corrosion
- Recover low T steam
- 5.5-9kWh/m^3

Hug March *Advanced Review* 2015

Desalination Technologies

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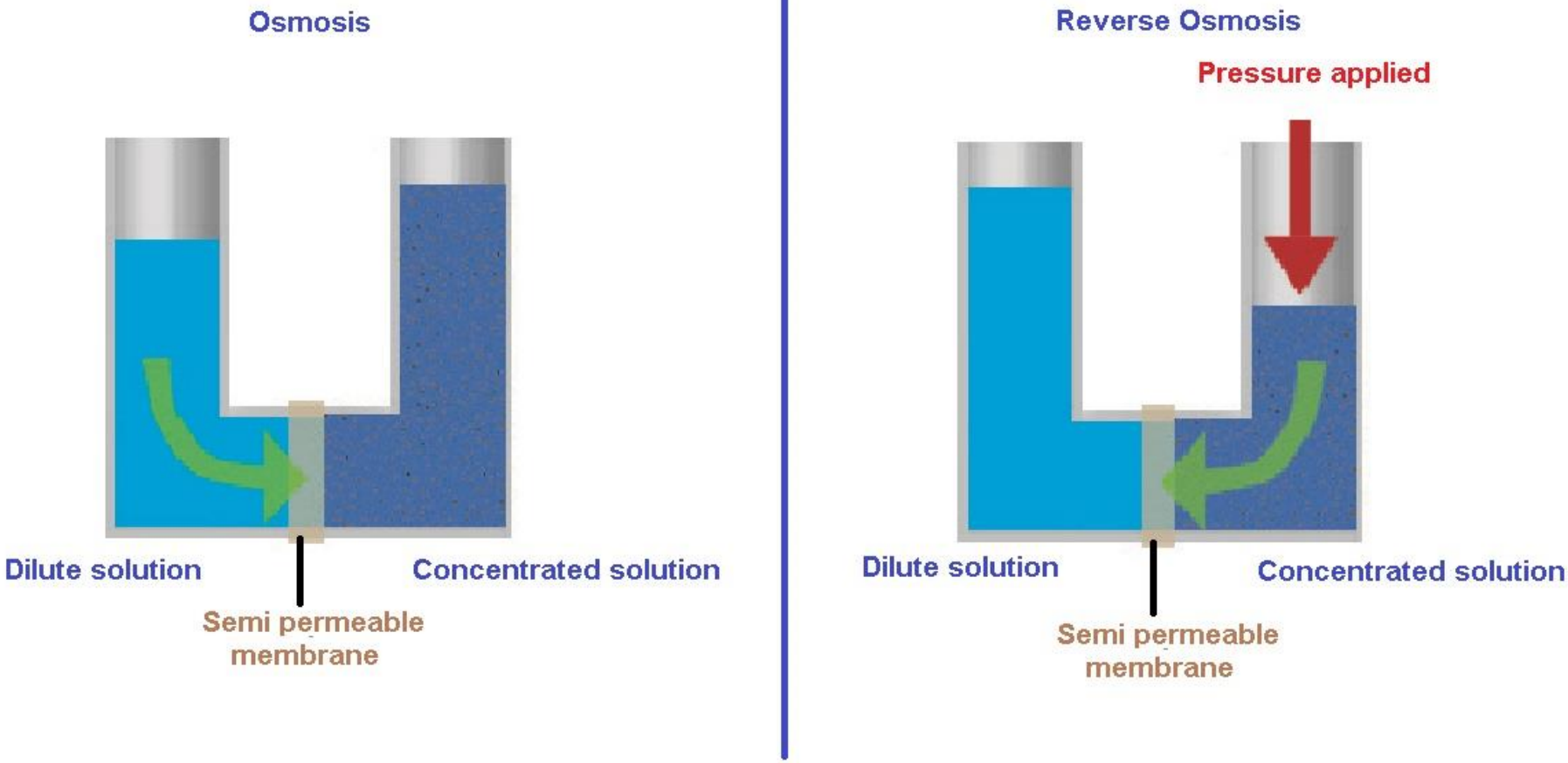
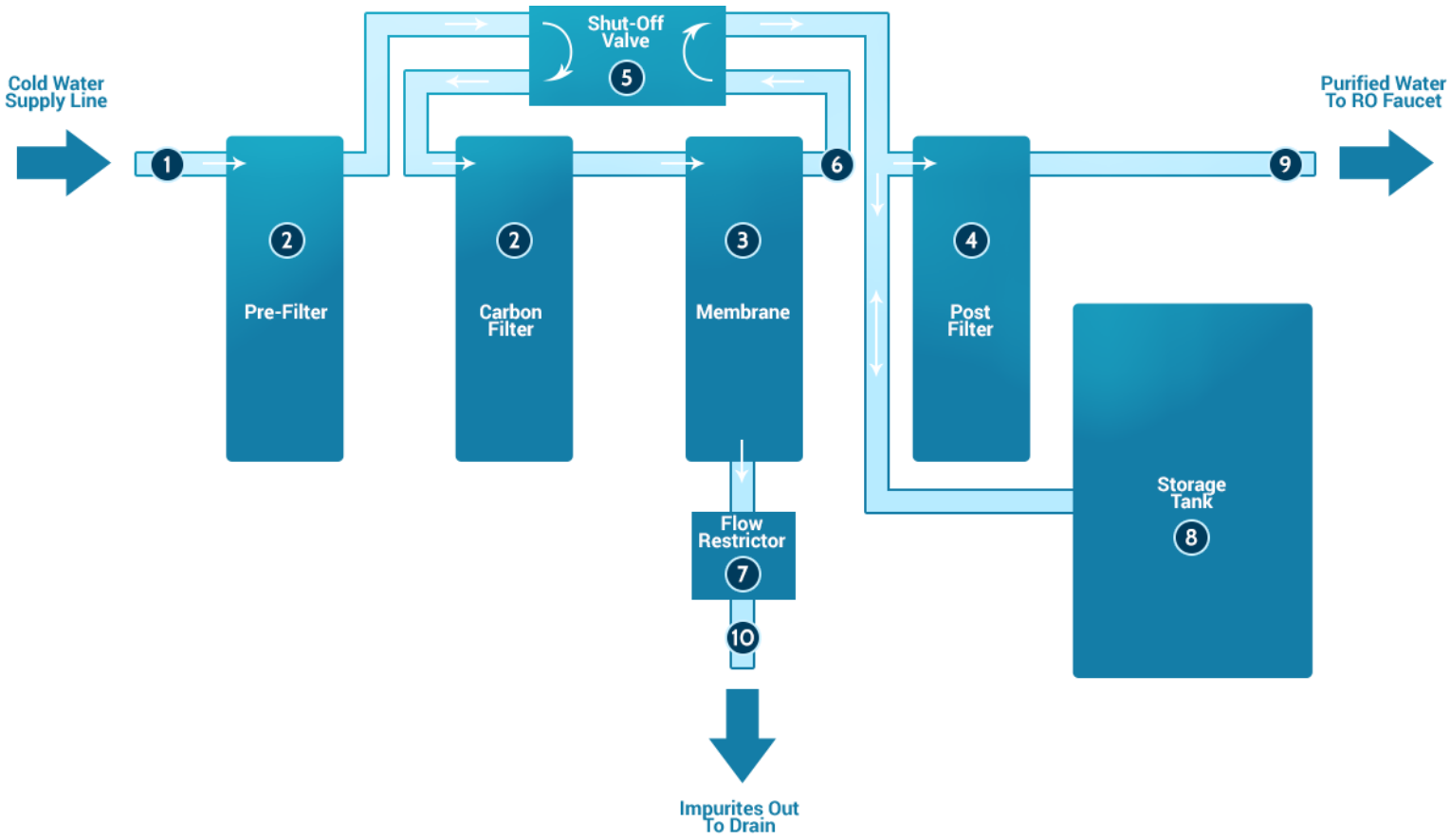
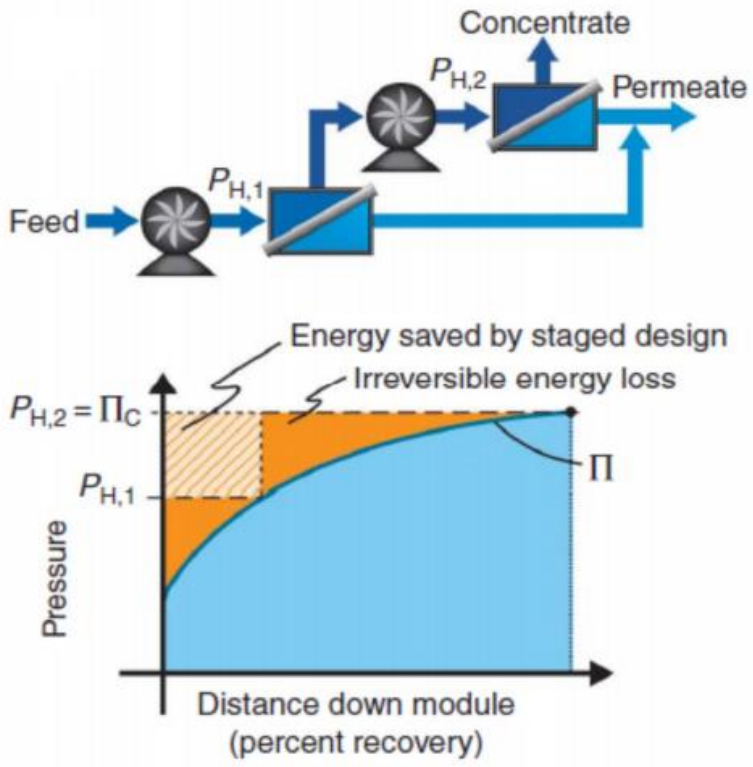
Reverse Osmosis (RO)



Single Stage RO

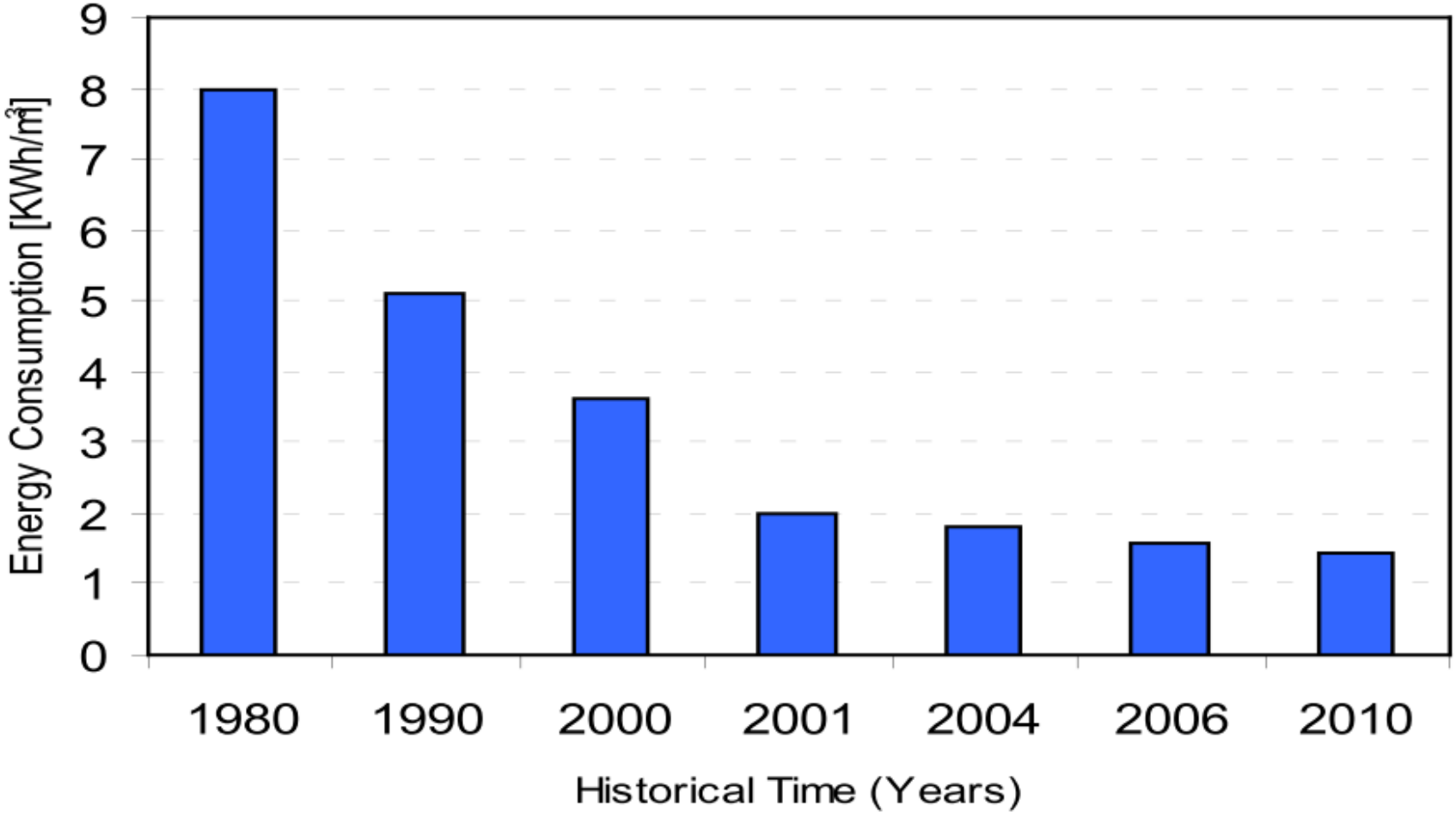


Two-stage Reverse Osmosis

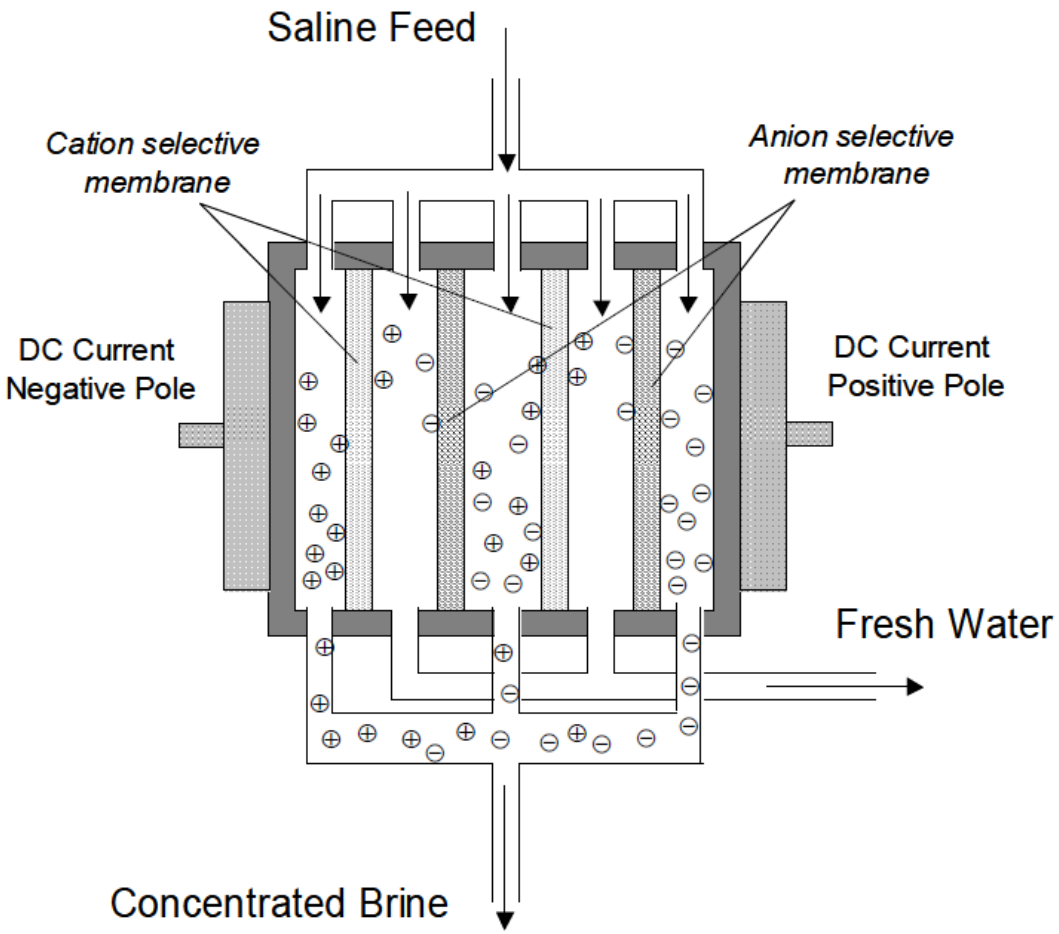


- 1 Stage: 1.56 kWh/m^3
- 2 Stages: 1.28 kWh/m^3
- ∞ stages: 1.06 kWh/m^3
- Best practice: 2kWh/m^3
- Overall consumption: 3-4kWh/m^3

RO process energy consumption



Electrodialysis



James E. Miller, Sandia National Lab 2003

Thermal process economic comparison

Desalination process	Capacity(m^3/day)	Desalination cost ($/$m^3$)
MED	<100	2.5-10
	12,000-55,000	0.95-1.95
	>91,000	0.52- 1.01
MSF	23,000 – 528,000	2.01-2.66
OS	<1000	1.25-18.75
	60,000 - 15,000	0.48-1.62
	100,000 – 320,000	0.45-0.66

Construction costs of different technologies

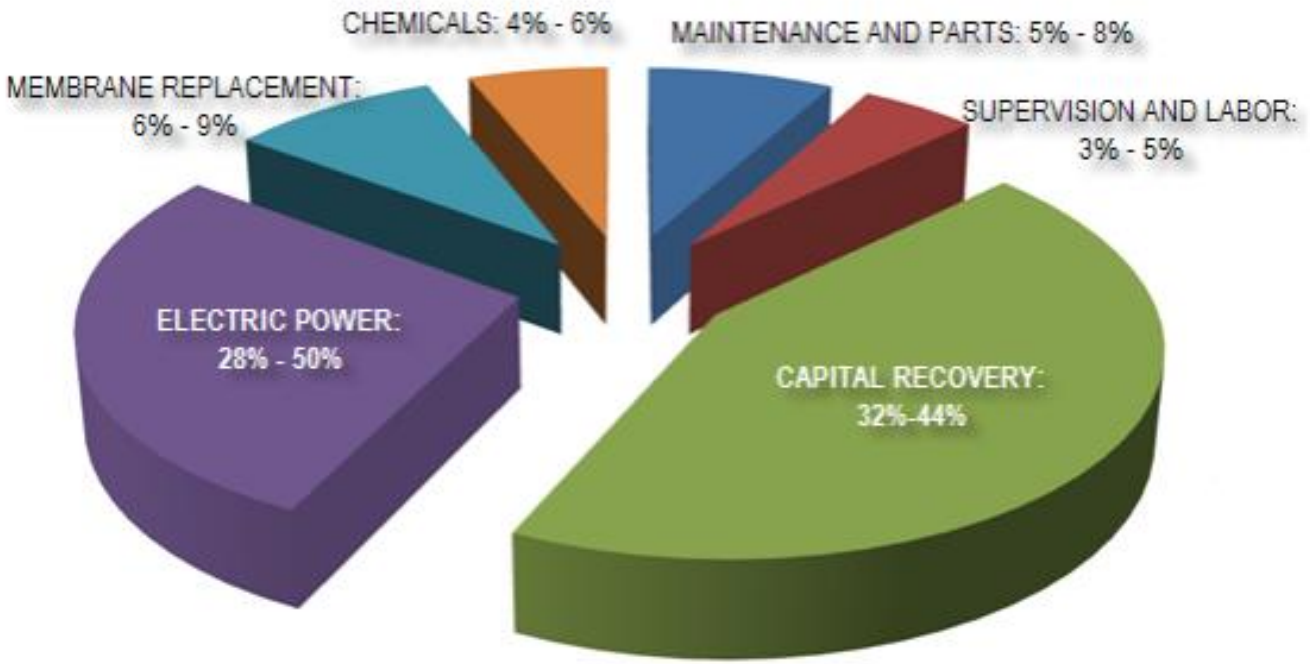
- Qingdao Case (RO):
  - $176m construction cost, 100,000m^3 capacity
  - about $1760 per day per m^3
- Black and Veatch case (MSF):
  - $19m construction cost, 4,000m^3 capacity
  - About $4750 per day per m^3

Comparison between Major Desalination technologies

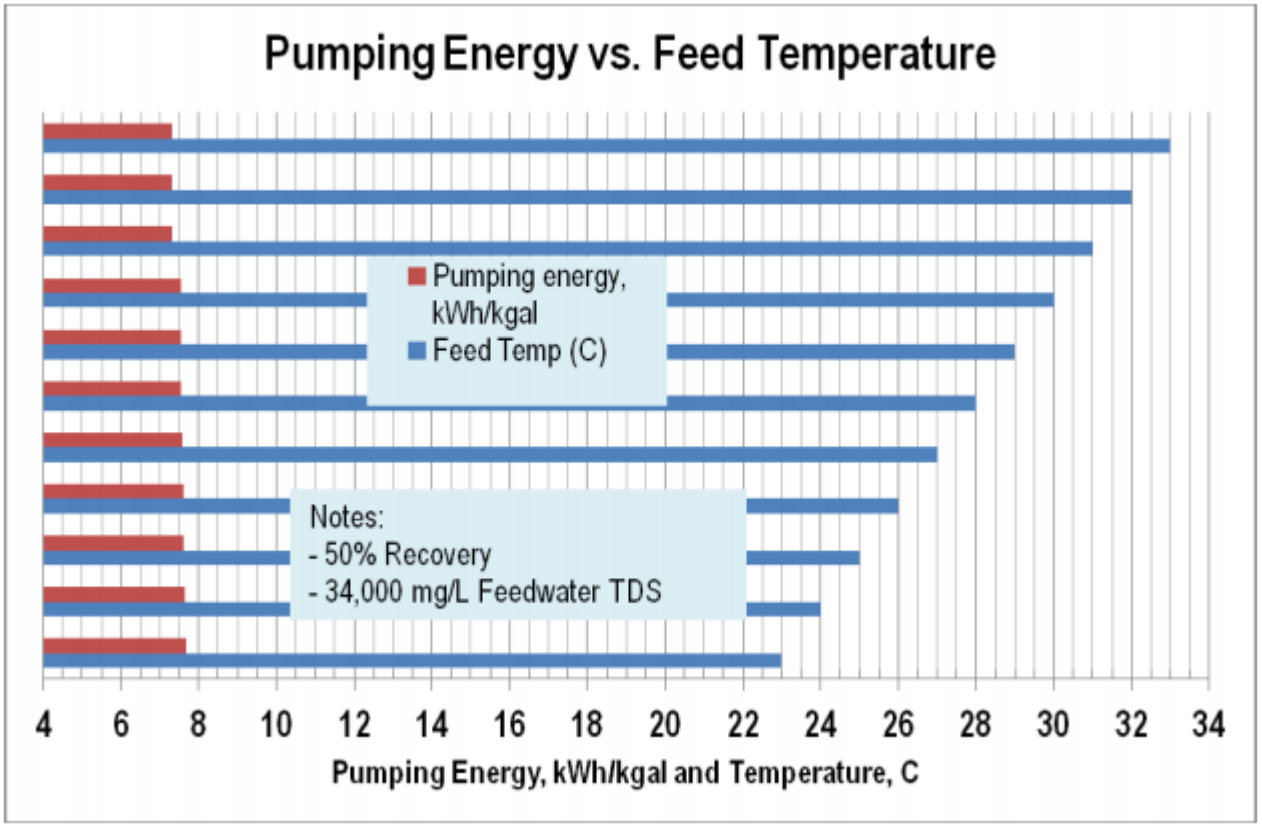
Technologies	Advantages	Disadvantages
MDE	Energy efficient Couple with Cogen and Solar thermal, geothermal	Smaller in scale Vacuum
MSF	Large scale	Less efficient Corrosion
OS	Highly efficient	Use electricity


THANKS

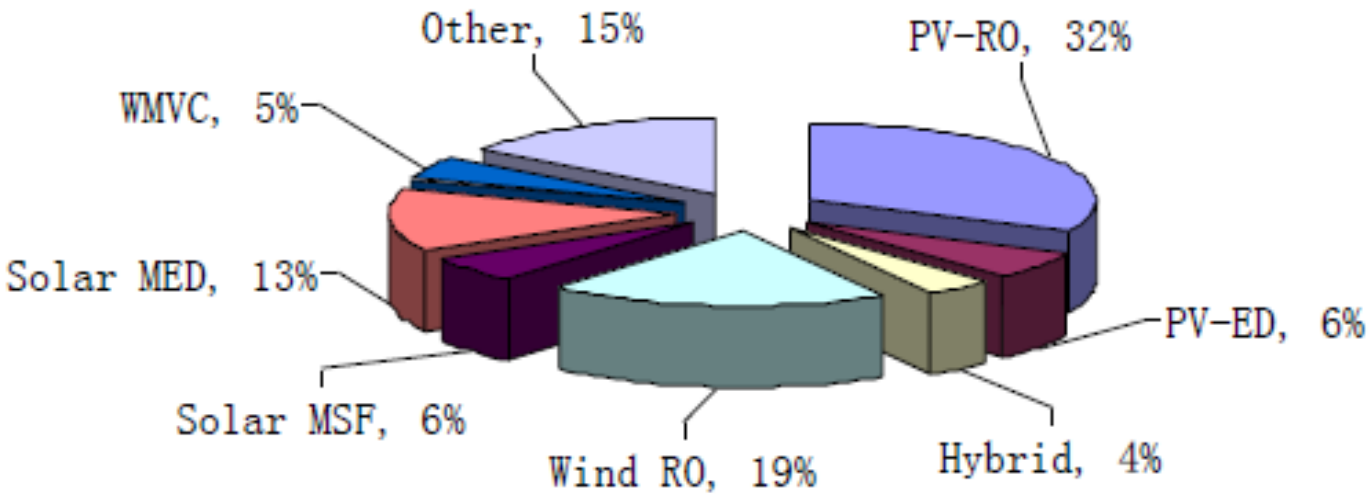
Typical Cost Structure of SWRO



Feed temperature effect



Desalination by Renewable Energy



Mohamed A. Eltawil, *Twelfth International Water Technology Conference 2008*