Overview of nuclear desalination technologies & costs

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Outlines

- **Introduction**
- **Nuclear desalination technologies**
- **Cost of Nuclear desalination technologies**
- **Conclusion**

Nuclear Desalination

- What is it ?
  - Any co-located desalination plant that is powered with nuclear energy
- Why?
  - Viable option to meet:
    - Increasing global demand for water & energy
    - Concerns about climate change
    - Volatile fossil fuel prices
    - Security of energy supply
- How?
  - Cogeneration concept → 1+1=~~2~~ 1½
  - Extra safety barriers

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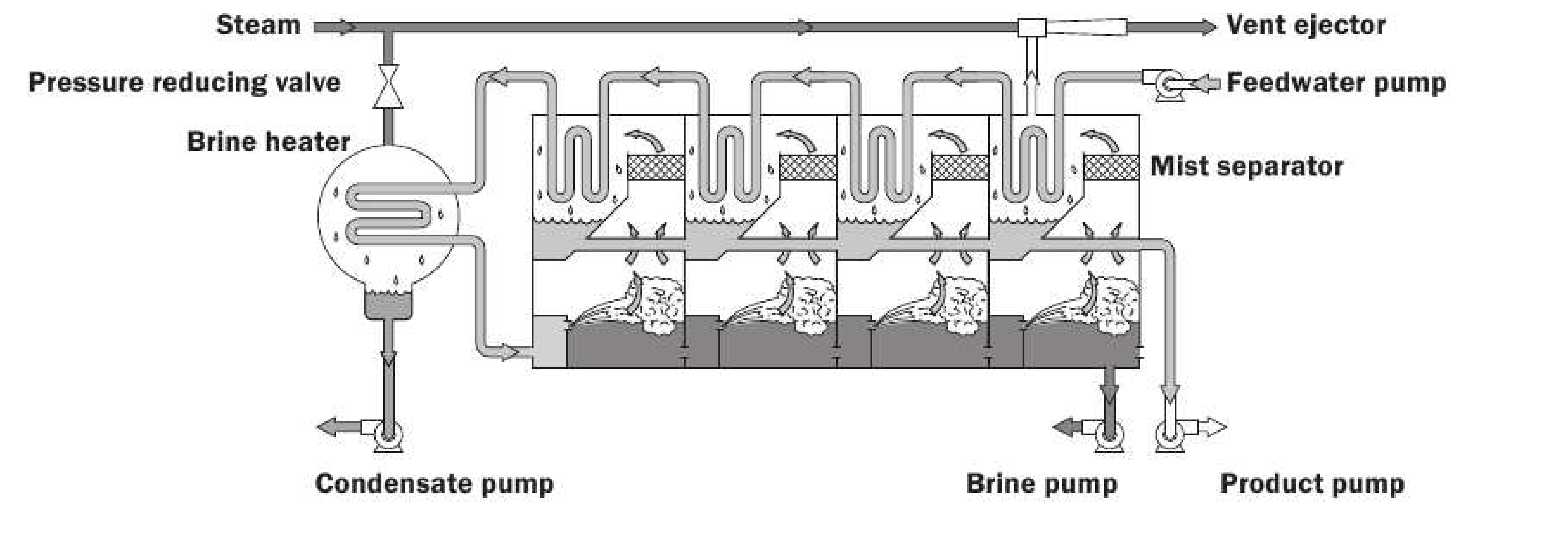
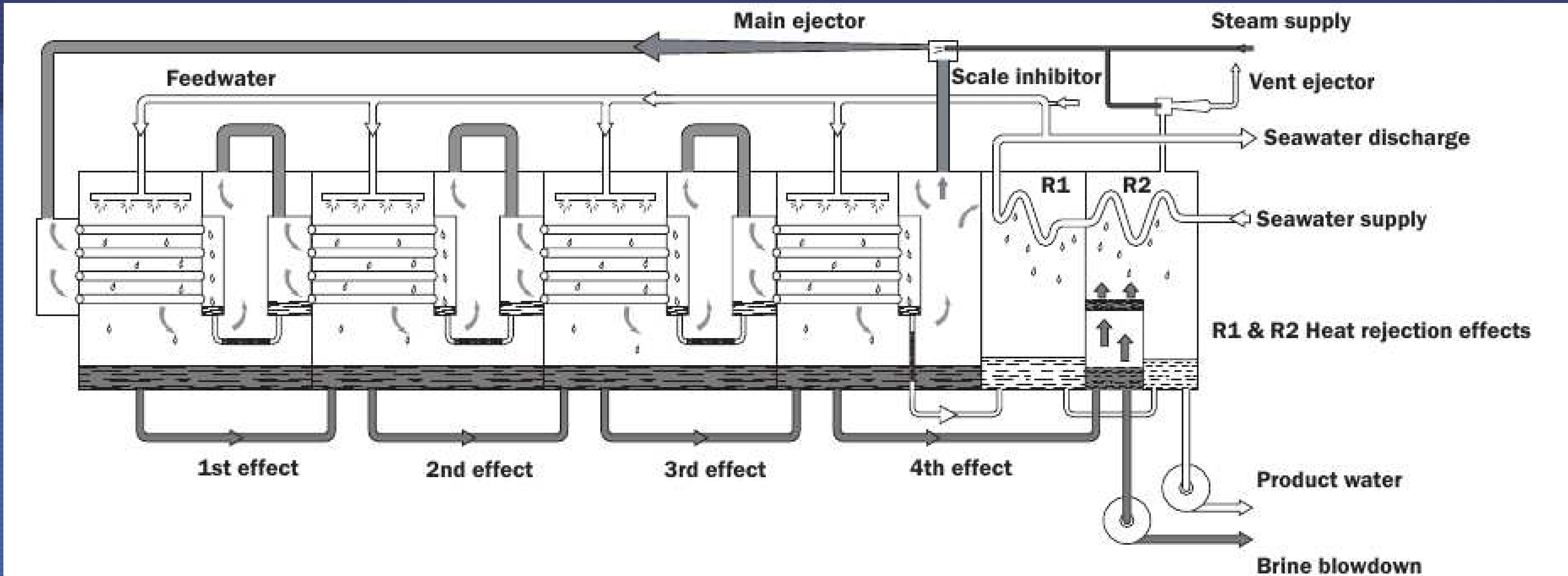
Multi-Stage Flash (MSF) Distillation Plant



- Vapor is produced by heating the seawater close to its boiling temperature and passing it to a series of stages under successively decreasing pressures to induce flashing.
- The vapor produced is then condensed and cooled as distillate in the seawater tubes of the following stage.

Multiple Effect Distillation (MED) Plant



- Vapor produced by an external heating steam source
- Vapor multiplied by placing several evaporators (effects) in series under successively lower pressures,
- Vapor produced in each effect is used as a heat source for the next one.

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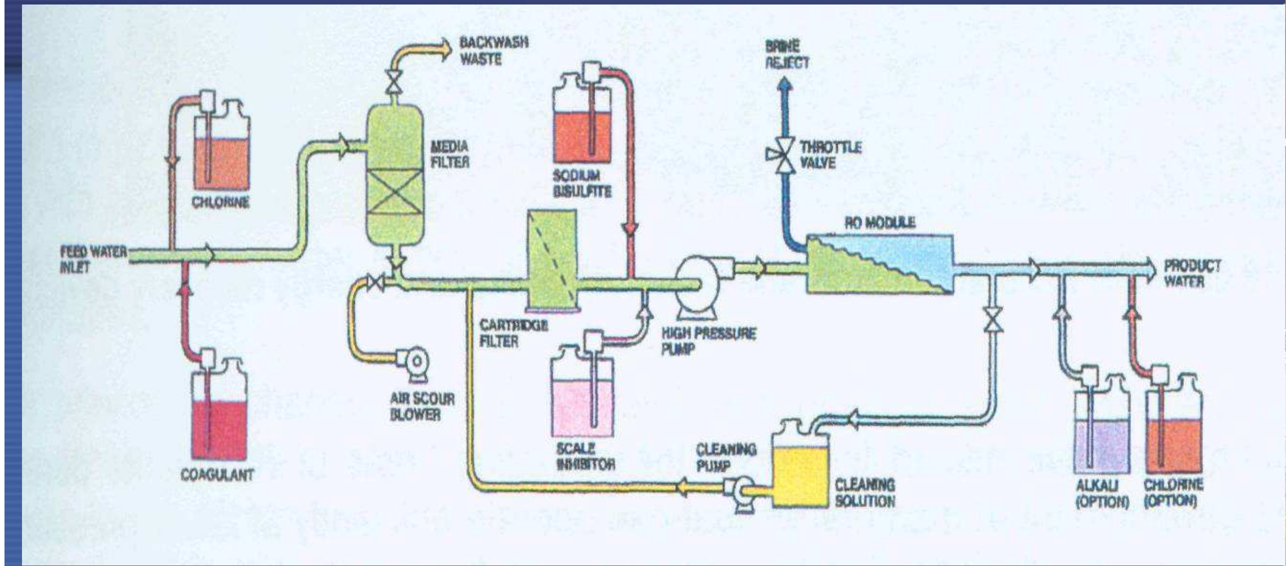
Reverse Osmosis (RO)



- Seawater is forced to pass under pressure through special semi-permeable membranes:
- Pure water is produced & brine is rejected.

The differential pressure must be high enough to overcome the natural tendency of water to move from the **low salt concentration side to the high concentration side**, (as defined by osmotic pressure).

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Main SW Desalination Technologies

	Advantages	Weaknesses
MSF	• Simplicity, reliability, long track record • Minimum pretreatment • Large unit sizes • On-line cleaning	• High energy requirements • Not appropriate for single purpose plants
MED	• Minimum pretreatment • Low TDS product water • Less electrical energy than MSF • Lower capital cost than MSF	• Complex to operate • Small unit sizes
RO	• Less energy needed than thermal • Less feed water needed • Lower capital costs	• Extremely dependent on effectiveness of pretreatment • More complex to operate than thermal • Low product purity • Boron issues to be addressed

Main parameters for desalination

- ***Capacity*** → Production of water (usually in m^3/d)
- ***Quality*** → Water quality expressed by amount of total dissolved solids (TDS) in the product (in ppm)

Specific for thermal

- ***Gain Output Ratio*** → The ratio of the amount of steam needed to produce one kg of product water. It is used as a measure of efficiency (the bigger the better)
- ***Top Brine Temperature*** → The maximum temperature of the brine in the first stage/effect. Defines the quality of heat needed and affects GOR.

Specific for membrane

- ***Pressure*** → The feedwater pressure used to pump the feedwater through the membrane. Usually related with the membrane type and mechanical properties.

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Process Comparison

Parameter	MSF	MED (TVC)	SWRO
Pretreatment required	Minimum	Minimum	Critical
Chemical consumption	Low	Low	Higher
Sludge production	None	None	Some
Scaling	Low	Low	Lowest
Fouling	Low	Low	Higher
Operational simplicity	Lowest	Low	Higher
Reliability / Robustness	Highest	High	Pretreatment dependent
Capital cost	Highest	High-medium	Lower
Electricity consumption (kWh/m^3)	3.5	1.2	4
Steam consumption (GOR)	10:1	7:1	n/a
Concentration factor (Brine/Feed)	1.7	1.7	1.9
Top brine temperature (°C)	110	65	N/A
Feedwater pressure (bar)	2	2	65
Feed : Product flow	8:1	8:1	2.2:1
Product TDS, (ppm)	<25	<25	450
Max capacity per unit/train (m^3/d)	78,700	37,850	240,000

Source: GWI DesalData

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Various types of nuclear desalination systems

Reactor type	Country	Desalination process	Status
LMFR	Kazakhstan	MED, MSF	Decommissioned (1999) after 26 reactor-years
PWRs	Japan	MED, MSF, RO	Operating more than 150 reactor-years
	Korea, Argentina	MED, RO	Design stage
	Russia	MED, RO	Design stage
PHWR	India	MSF, RO	Operating since (2002+2010)
	Canada	RO	Design stage
	Pakistan	MED	Operating since (2010)
BWR	Japan	MSF	Installed
HTGR	South Africa	MED, MSF, RO	Design stage
NHR	China	MED	Design stage

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Cost of Nuclear desalination technologies

Role of economic assessment of ND project: is to assist in making decisions based on:

- Criteria
  - Cost of product ($/m3)
  - Percentage of local currency
  - Value of the product to the customer
- Compare options
  - Nuclear vs Fossil
  - Thermal vs Electrical

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Typical cost parameters

	Capital Costs ($/kWe)	Fixed O&M ($/kW)	Variable O&M ($/MWh)	Fuel ($/MWh)
Nuclear	4500	70	4	8
Coal	2400	40	7	40
CCGT	850	15	5	80
Wind	2000	30	0	0
PV	4000	25	0	0

References:

- WNA (2010), The Economics of Nuclear Power
- EIA (2010), Annual Energy Outlook 2011
- Du and Parsons, (2009), Update on the cost of Nuclear Power, EIA, Annual Energy Outlook
- MIT, (2009), Update of the MIT 2003 Future of Nuclear Power Study
- Economic Modelling Working Group (EMWG) of the GIF (2007), Cost Estimating Guidelines for Generation IV nuclear energy systems Rev 4.2
- Global Water Intelligence (2010), Desalination Markets 2010 : Global Forecasts and analysis
- Global Water Intelligence (2011), IDA Desalination Plant Inventory

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Key factor

Most useful criterion to measure the performance of a given combination of an energy source and desalination plant is the ***lifetime levelised unit cost*** of the water produced ($/m^3) or ($/kWh)

- Levelised cost $= \dfrac{Total\ water\ production\ cost}{Total\ amount\ of\ water\ produced}$

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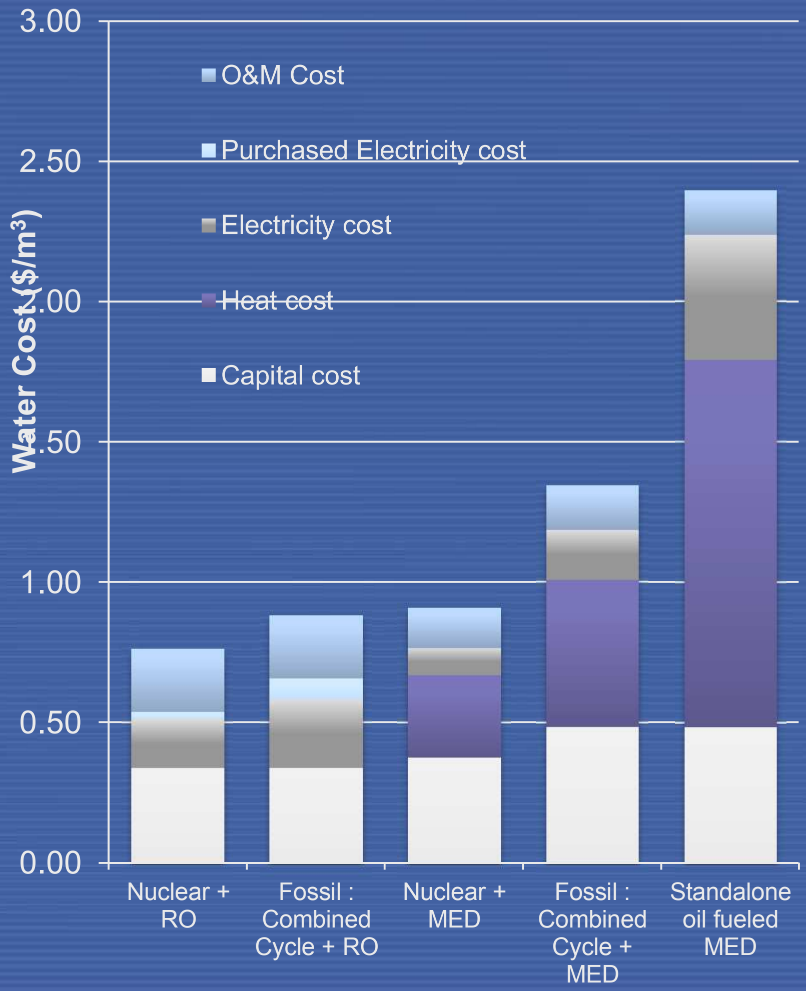
Current cost estimation of ND



Very site specific:

- **Site characteristics**
  - Availability of adequate land
  - Pumping requirements
    - Geological nature of the terrain may also be a factor
    - Proximity to the water source and of the concentrated brine discharge
  - Land cost ←local regulatory requirements and the costs associated with the acquisition of permits etc.
- **Plant capacity**
  - Specific water cost decreased with bigger plants
  - Modularity of system
- **Feed-water quality**
  - Lower salinity → lower energy consumption of the system.
  - → High conversion rates
  - → Less dosing of antiscalant chemicals.
  - → Less costly pre-treatment eg. surface waters will be more costly as compared to brackish ground water or water from beach-wells.

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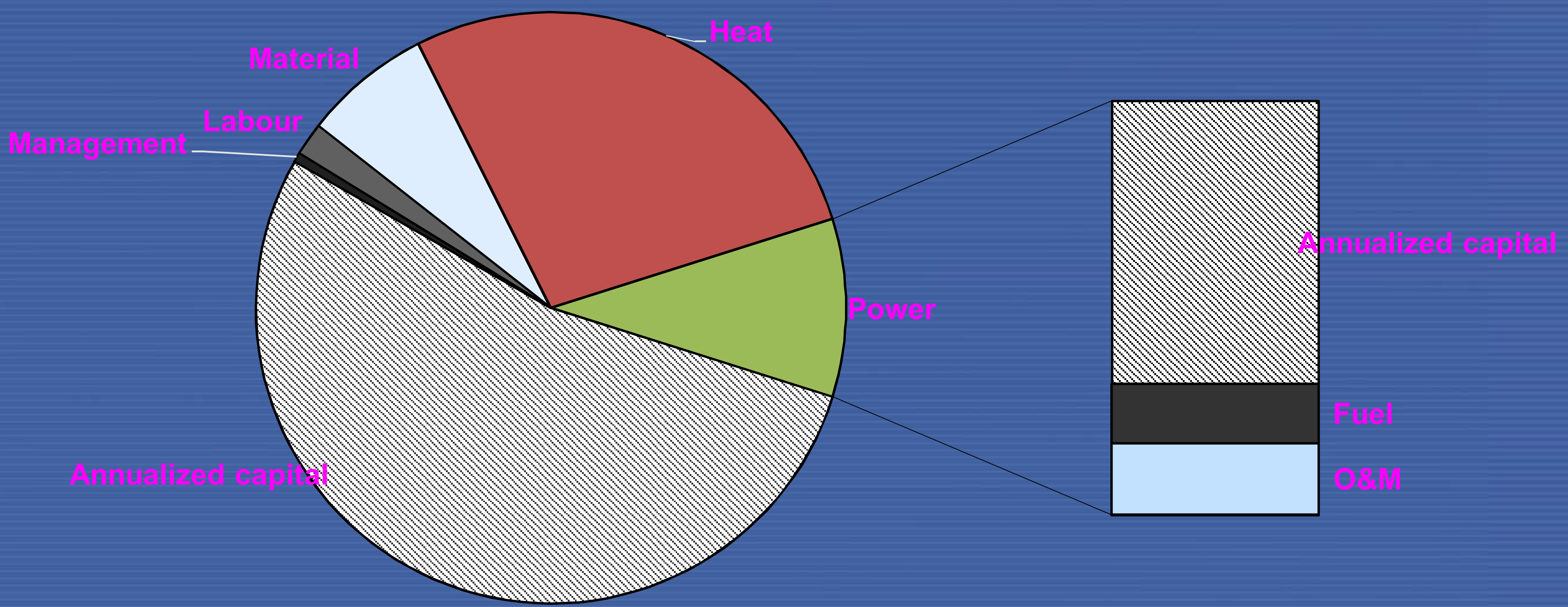
Typical water cost breakdown

Of a nuclear desalination plant



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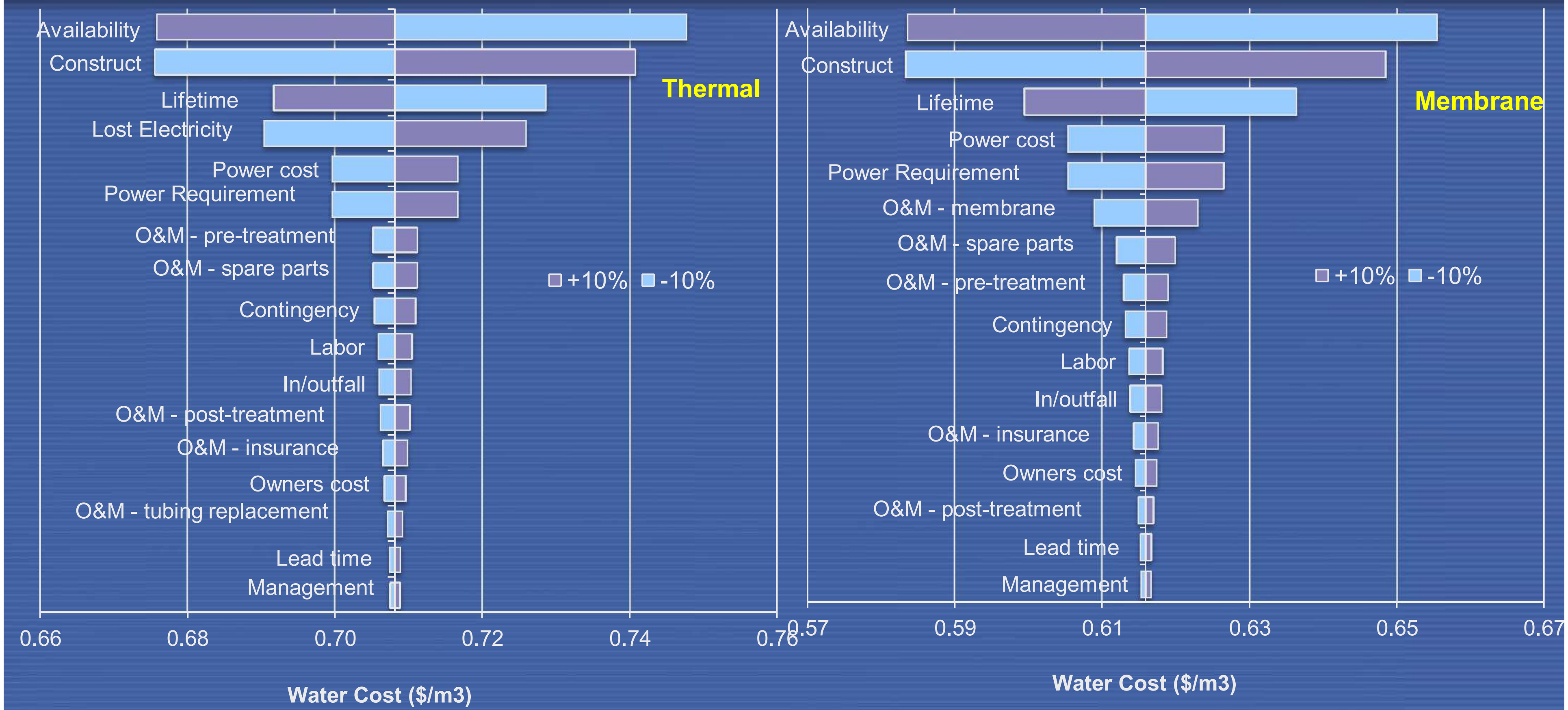
Sensitivity Analysis for ND



- Most sensible variables in both thermal and electrical: capital costs and availability
- Thermal Desalination is affected a lot by electricity penalty

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Water cost volatility: ND vs. Fossil

- Most dominant factor in power cost
  - Nuclear: Capital cost ($/kW)
  - Fossil : Fuel cost ($/bbl, $/ton)

	Nuclear	Fossil
Capital	**65%**	15%
O&M	20%	10%
Fuel	15%	**75%**

- Water costs less volatile due to the fact that they are not so much dependent on fuel costs
  - A doubling in the price of uranium would cause only **5%** increase in the total cost of generation
  - Similar increase in the price of Oil/NG would lead to **70%** increase

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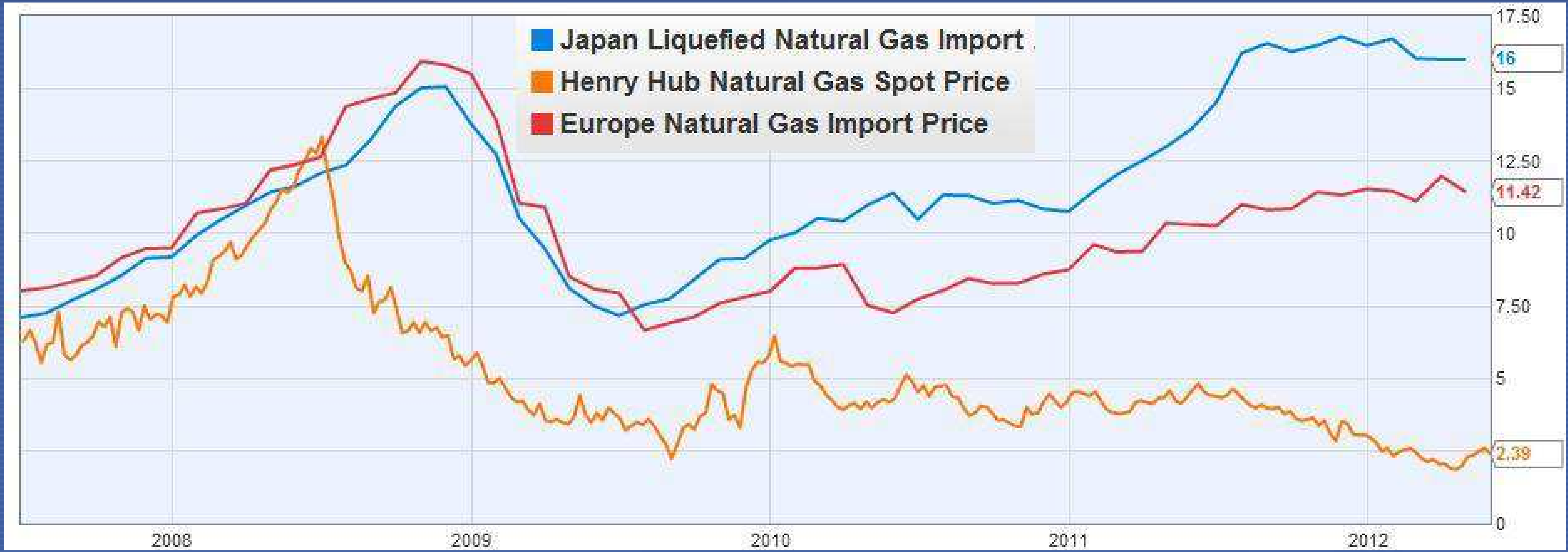
Natural gas prices



	Natural Gas Price ($/mmBTU) (March 2013)	Desalination cost (estimated by DEEP) ($/m3)
Europe	11.7	1.35
Asia	16.6	1.65
USA	3.6	0.81

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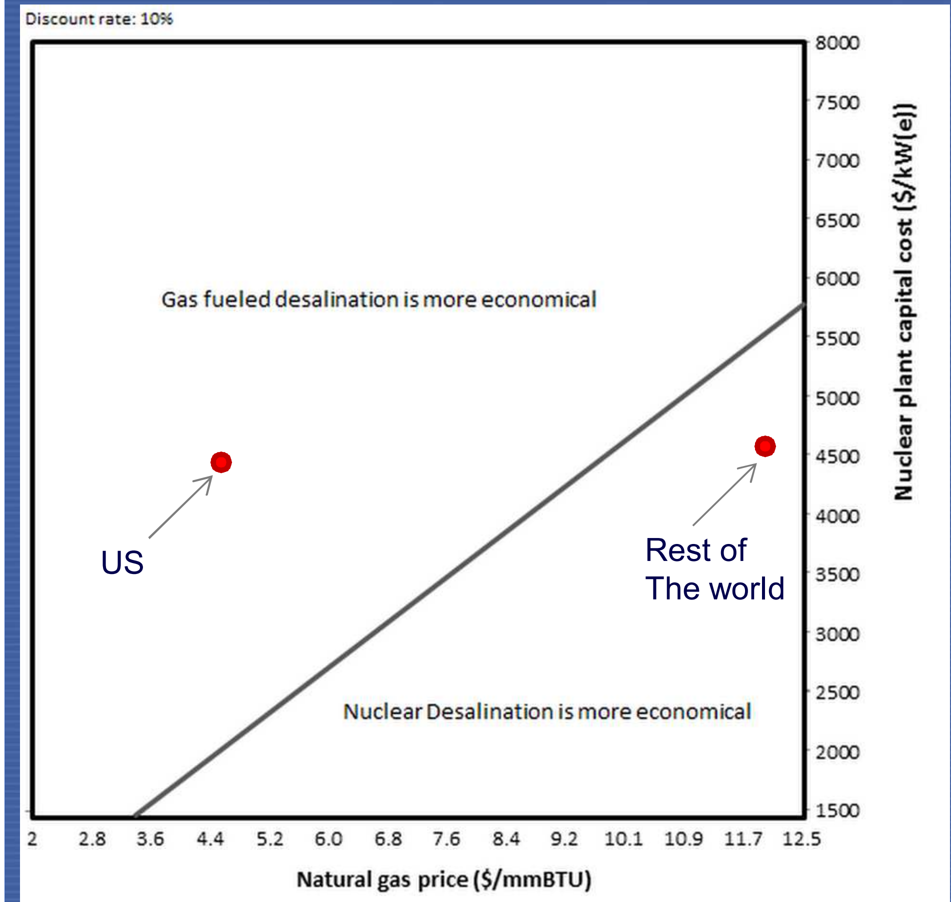
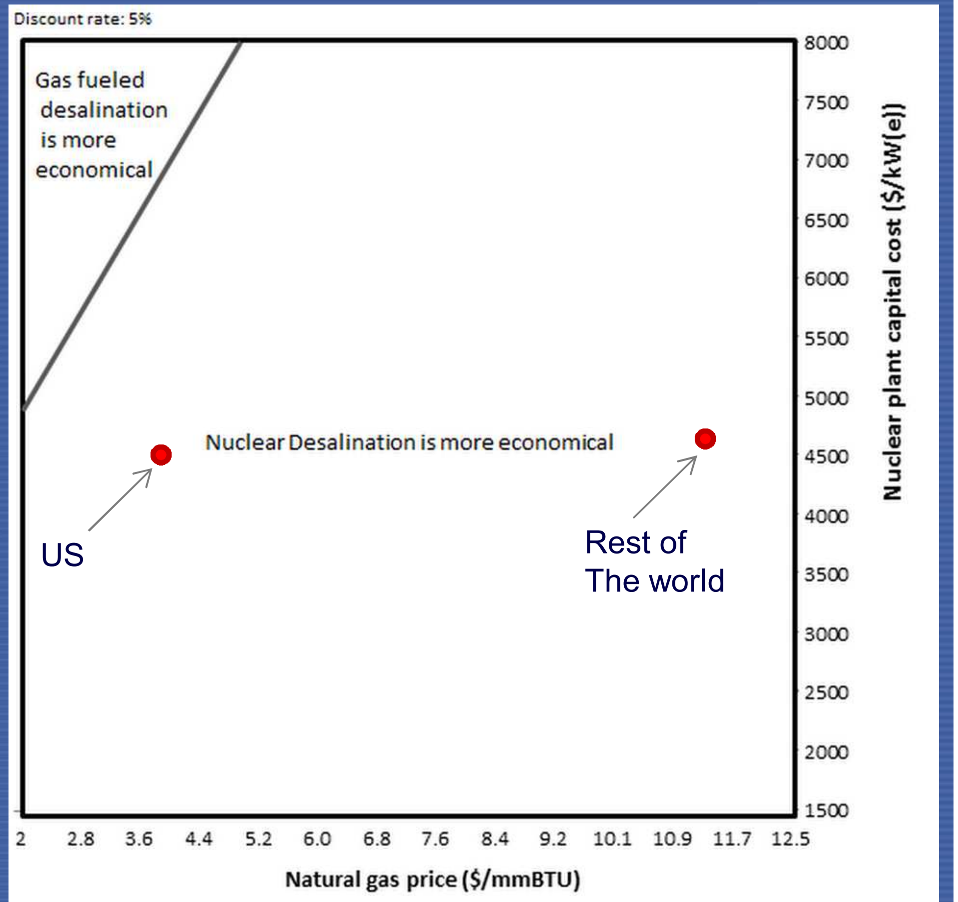
Mapping the influence of the cost for the two most important variables



Discount Rate : 10 %



Discount Rate : 5 %

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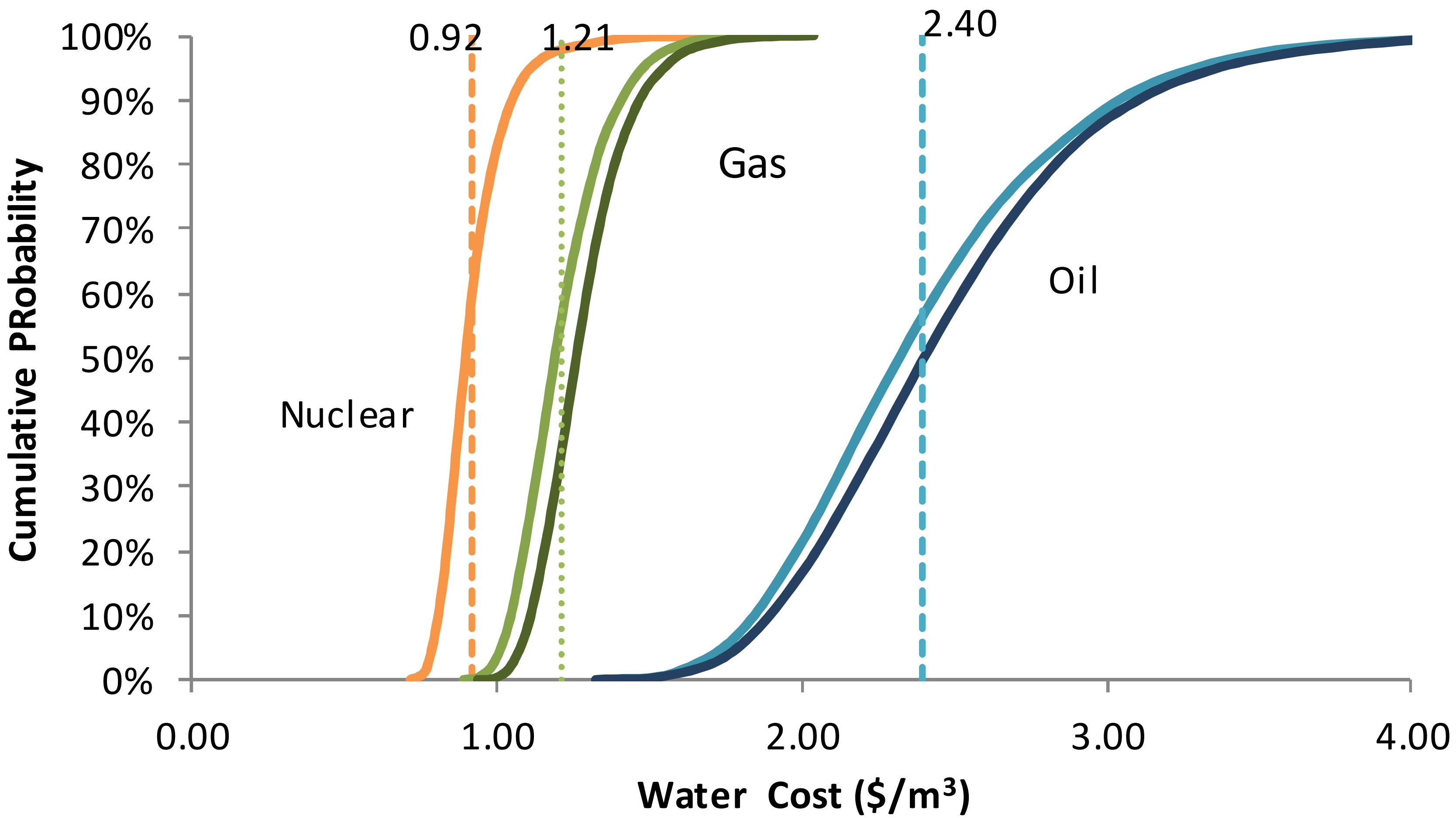
Risk



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative PRobability
0.92
1.21
2.40
Gas
Oil
Nuclear
0.00
1.00
2.00
3.00
4.00
Water Cost ($/m³)

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Conclusion

- Electrical-driven desalination is in general cheaper than thermal but produces worst quality of water and is very sensitive the the quality of the feedwater
- Even with increasing capital costs, nuclear can be cheaper than fossil fuel considering the extra risk due to the volatility of the fossil fuel prices

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…Thank you for your attention