تحت رعاية معالي رئيس مجلس الوزراء المصري المهندس شريف إسماعيل
مؤتمر تحلية المياه الحادي عشر في البلدان العربية
UNDER THE PATRONAGE OF THE EGYPTIAN PRIME MINISTER ENGINEER SHERIF ISMAIL
11TH WATER DISALINATION CONFERENCE IN THE ARAB COUNTRIES
18-19 APRIL 2017 • INTERCONTINENTAL CITY STARS - CAIRO - EGYPT

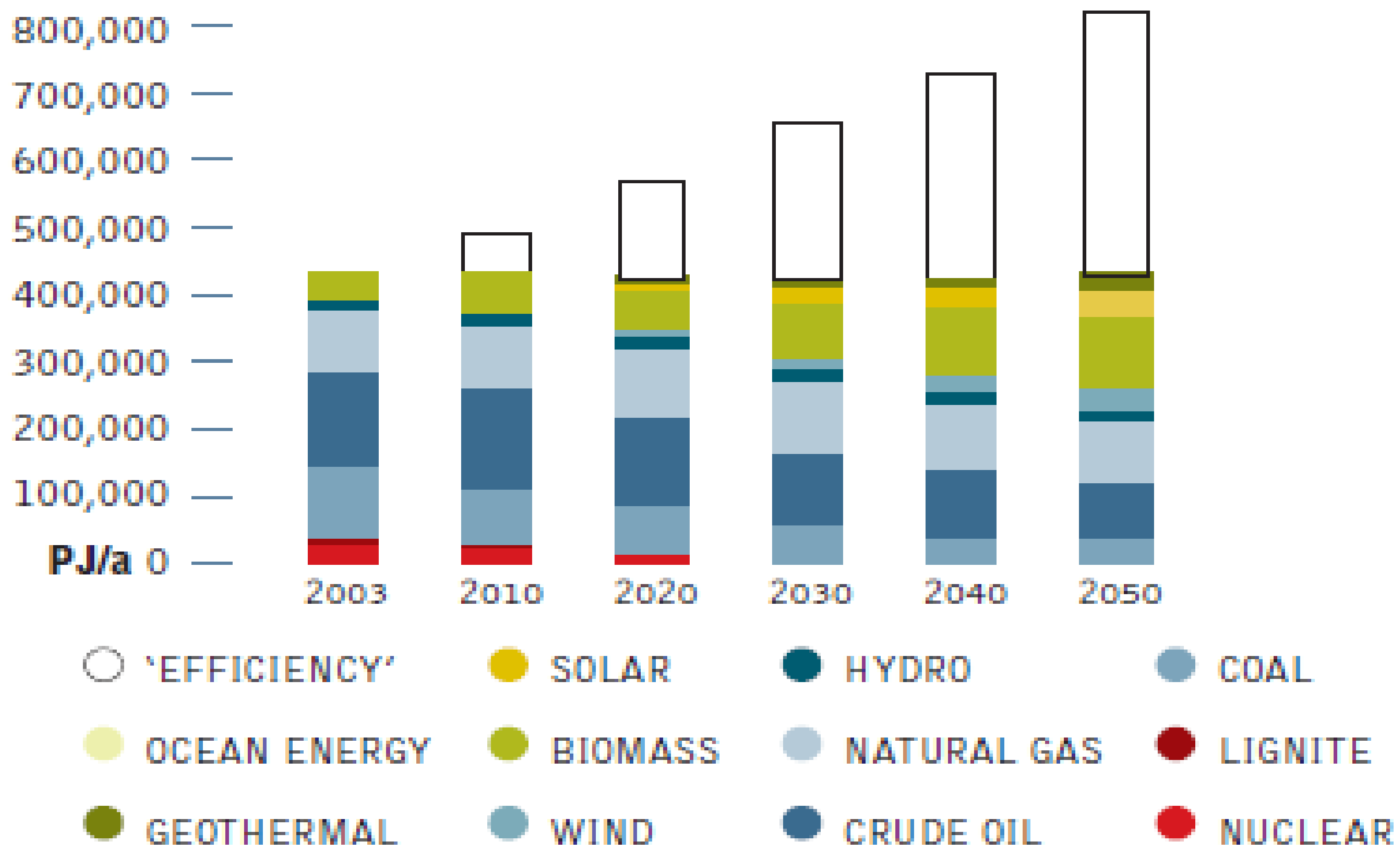
Efficiency improvement and sustainability development in power and desalination industry

Corrado Sommariva
MD generation ILF and member of the board
President IDA 2011-2013
President EDS 2004-2006

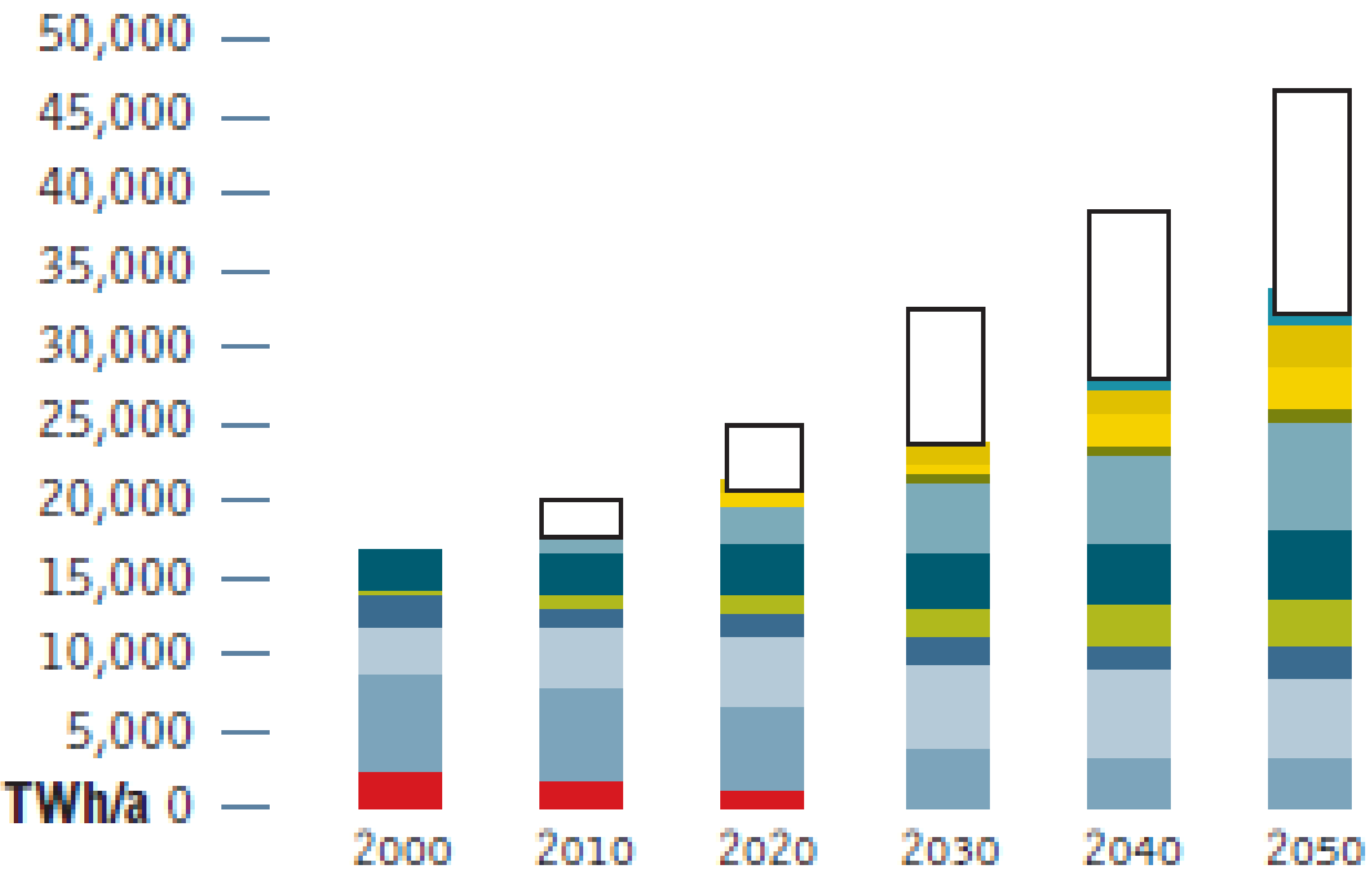
General considerations on efficiency

Half of the climate change problems cold be solved by a smarter use of the existing energy resources

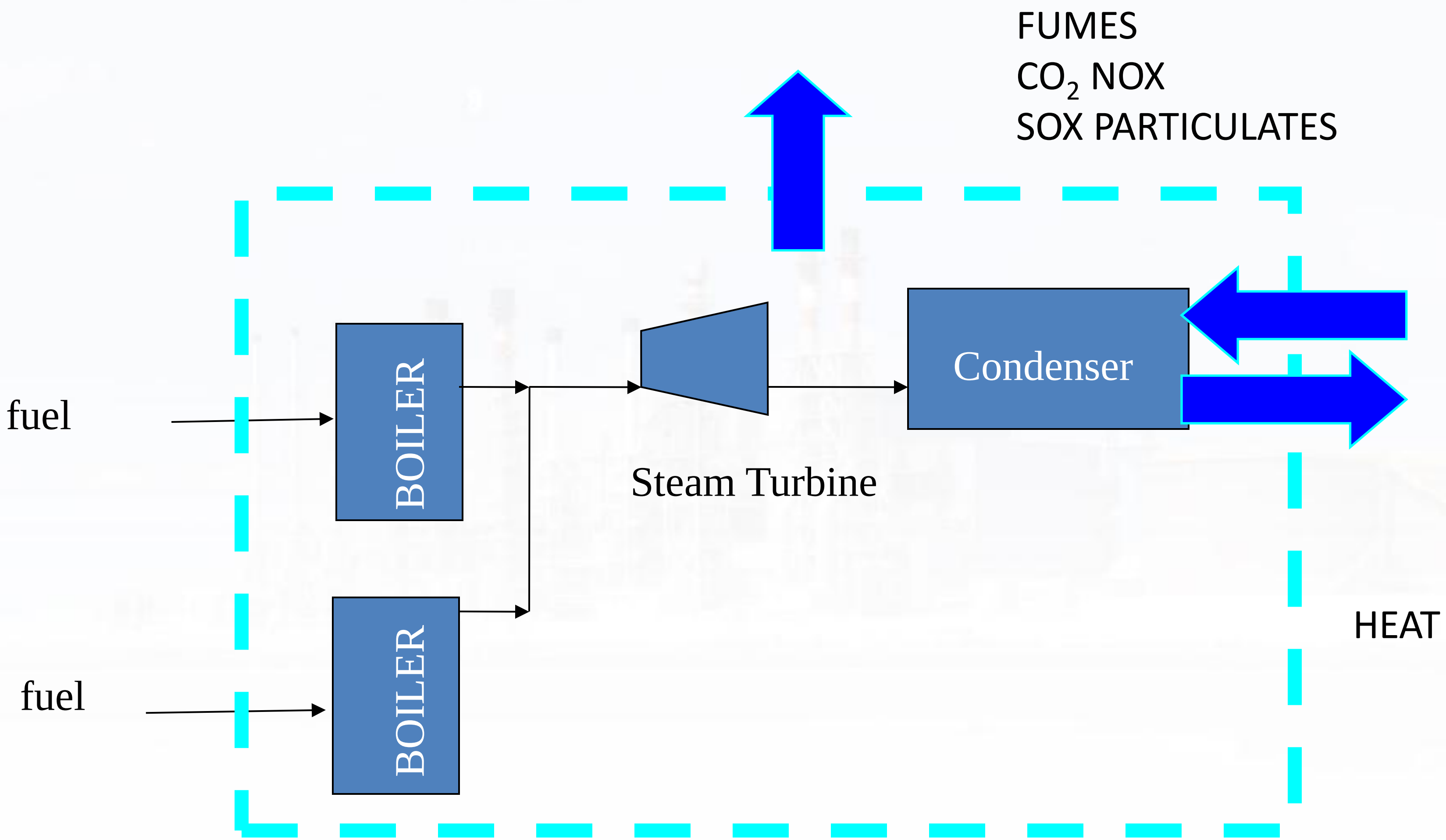
Development of global primary energy consumption under the energy Revolution scenario



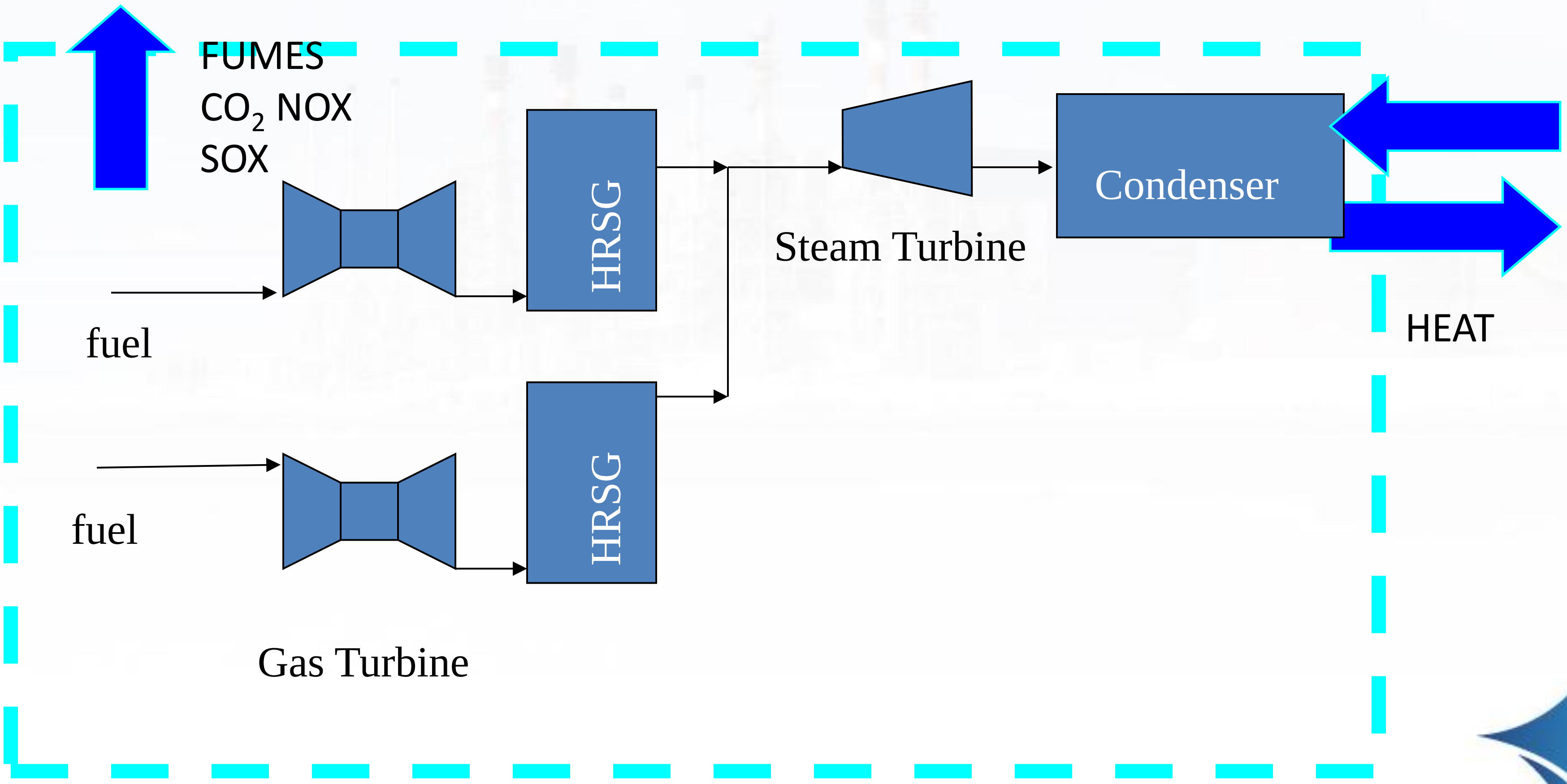
Development of global primary energy consumption under the energy Revolution scenario



Technology 1 = POWER
Conventional Power Plant



Technology 2 POWER
CCGT Power Plant - COMBINED CYCLE POWER PLANT



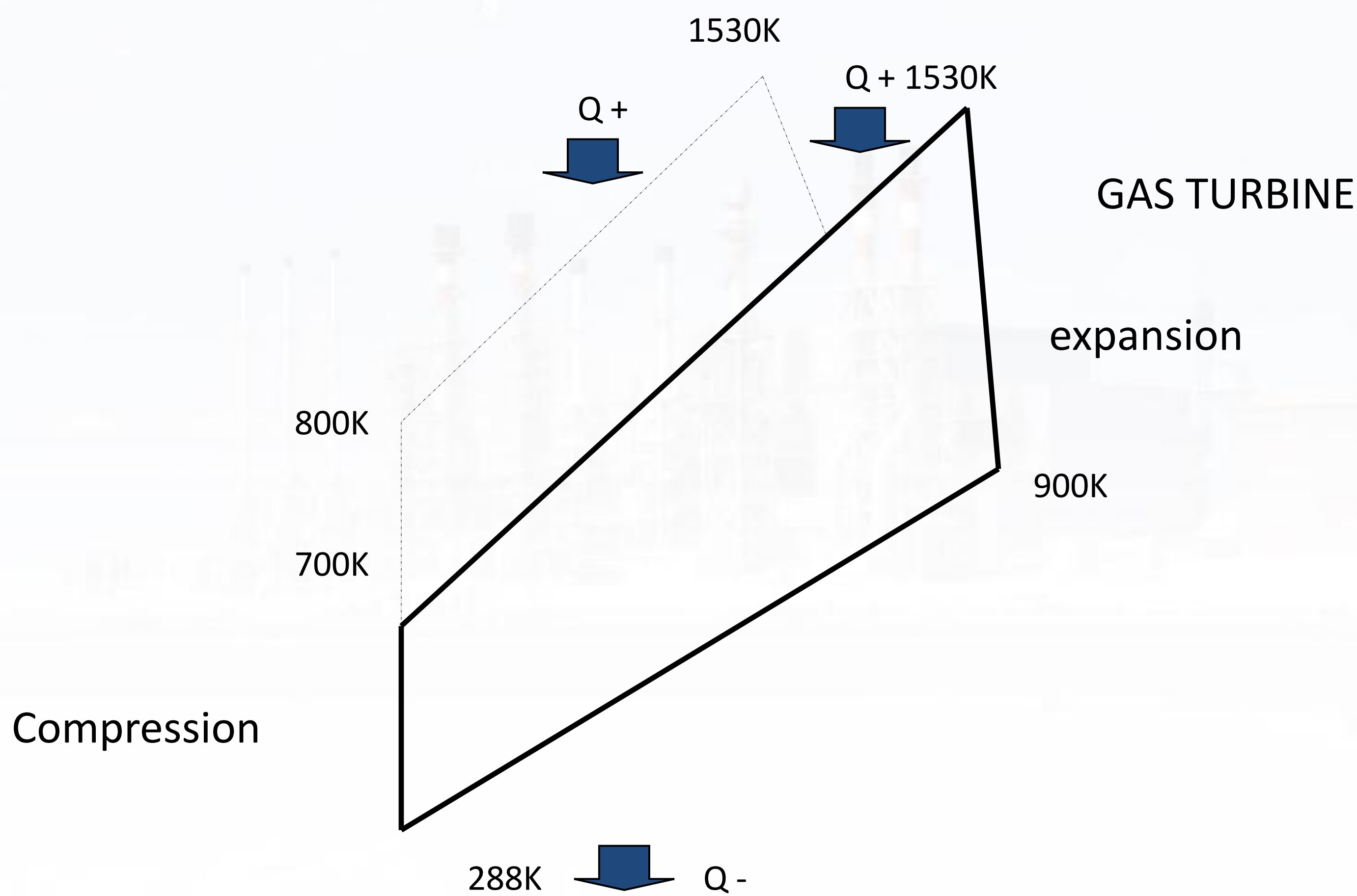
Carnot Efficiency

$$\eta_c = \frac{T_E - T_A}{T_E}$$

T_E Temperature of the energy supplied

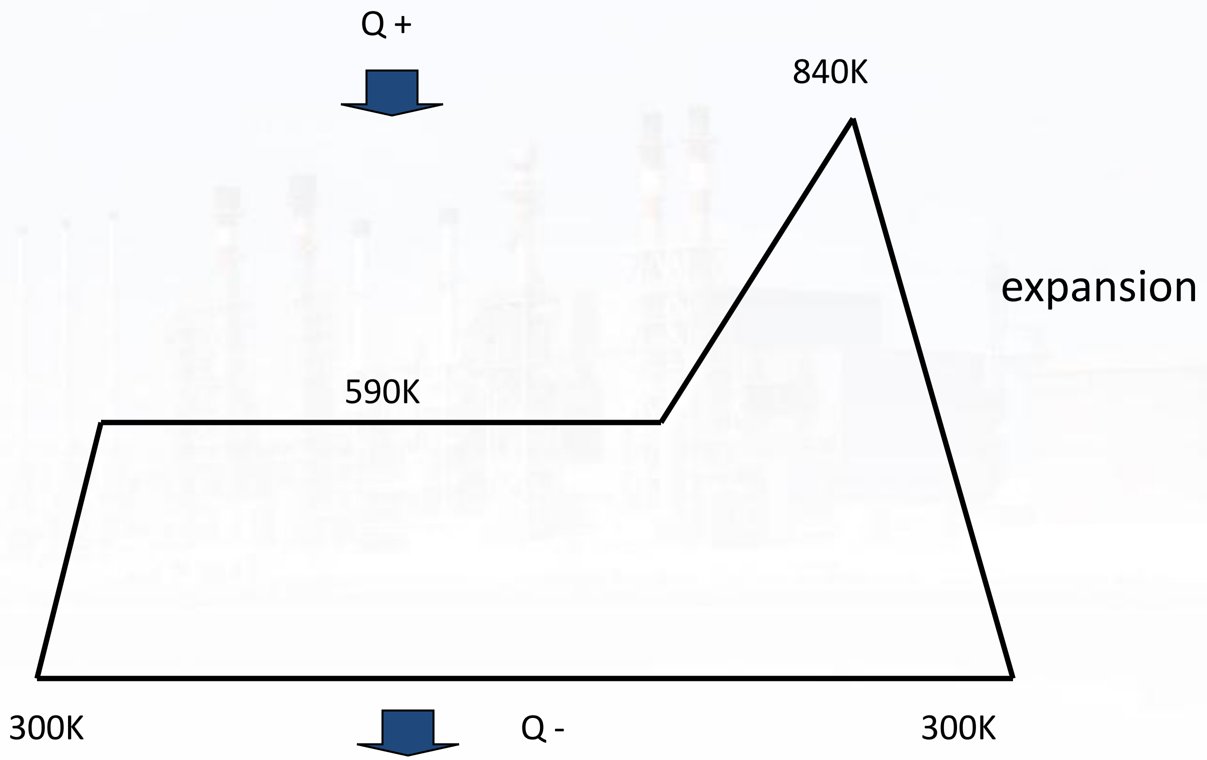
T_A Ambient Temperature

Open cycle Gas Turbine (OCGT)



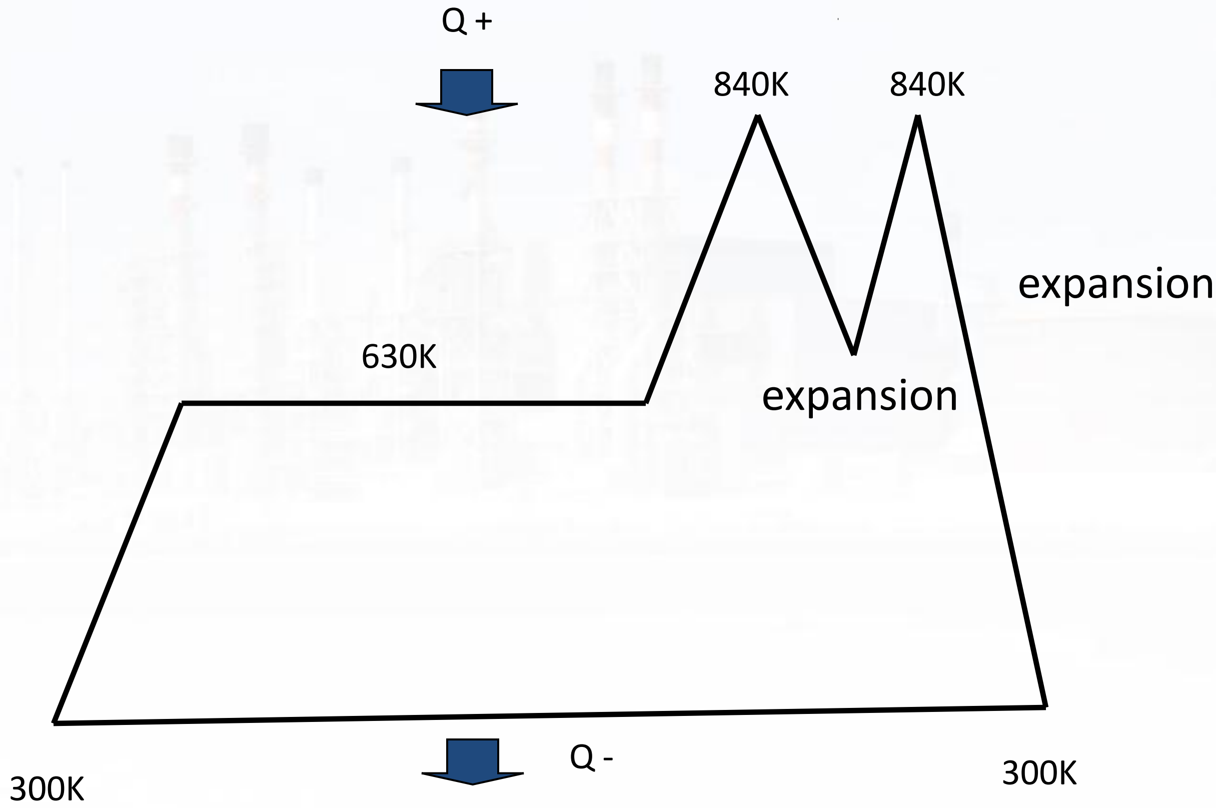
Steam turbine superheat

STEAM TURBINE
RANKINE CYCLE

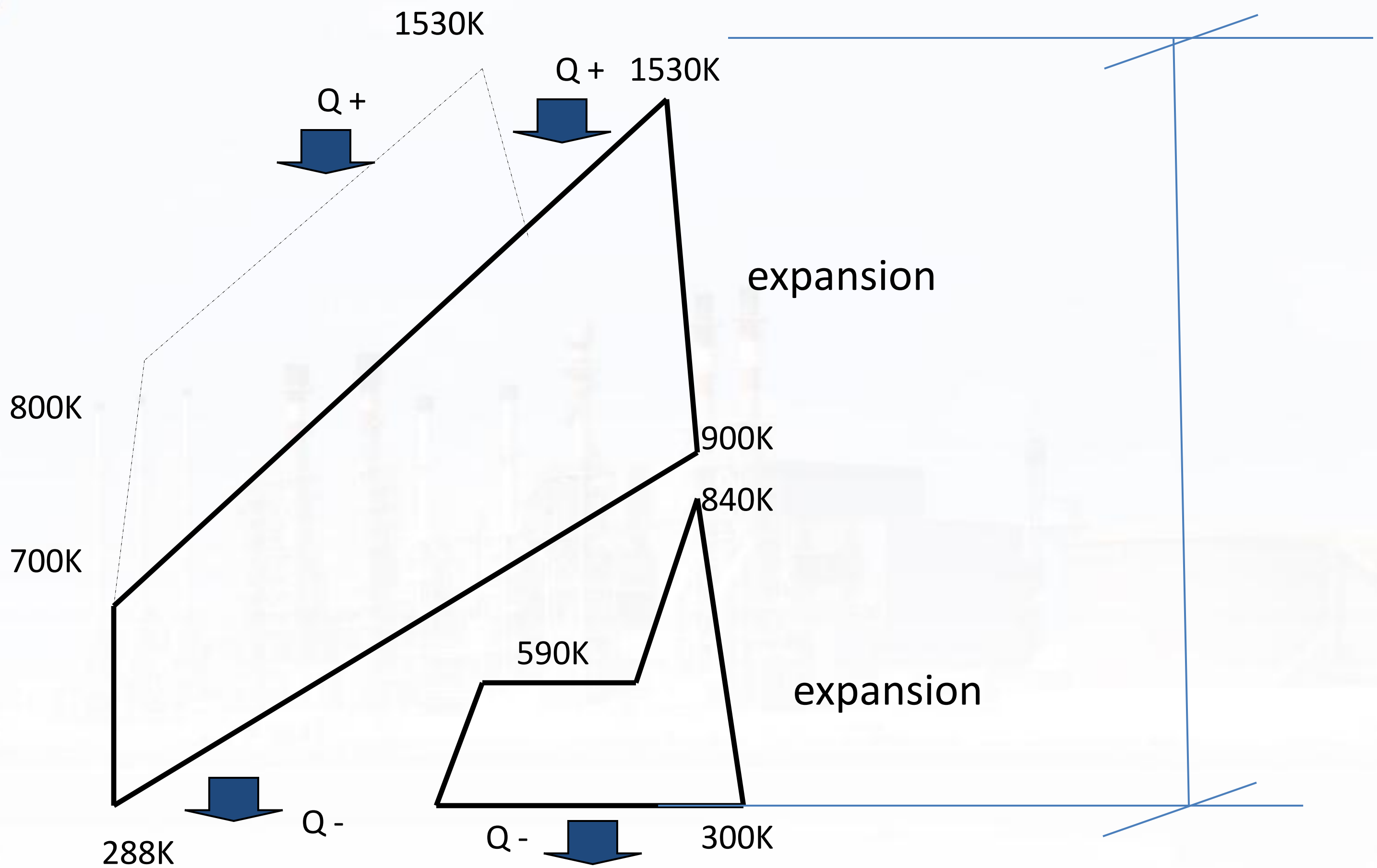


Steam turbine re heat

STEAM TURBINE
RANKINE CYCLE WITH
REHEAT



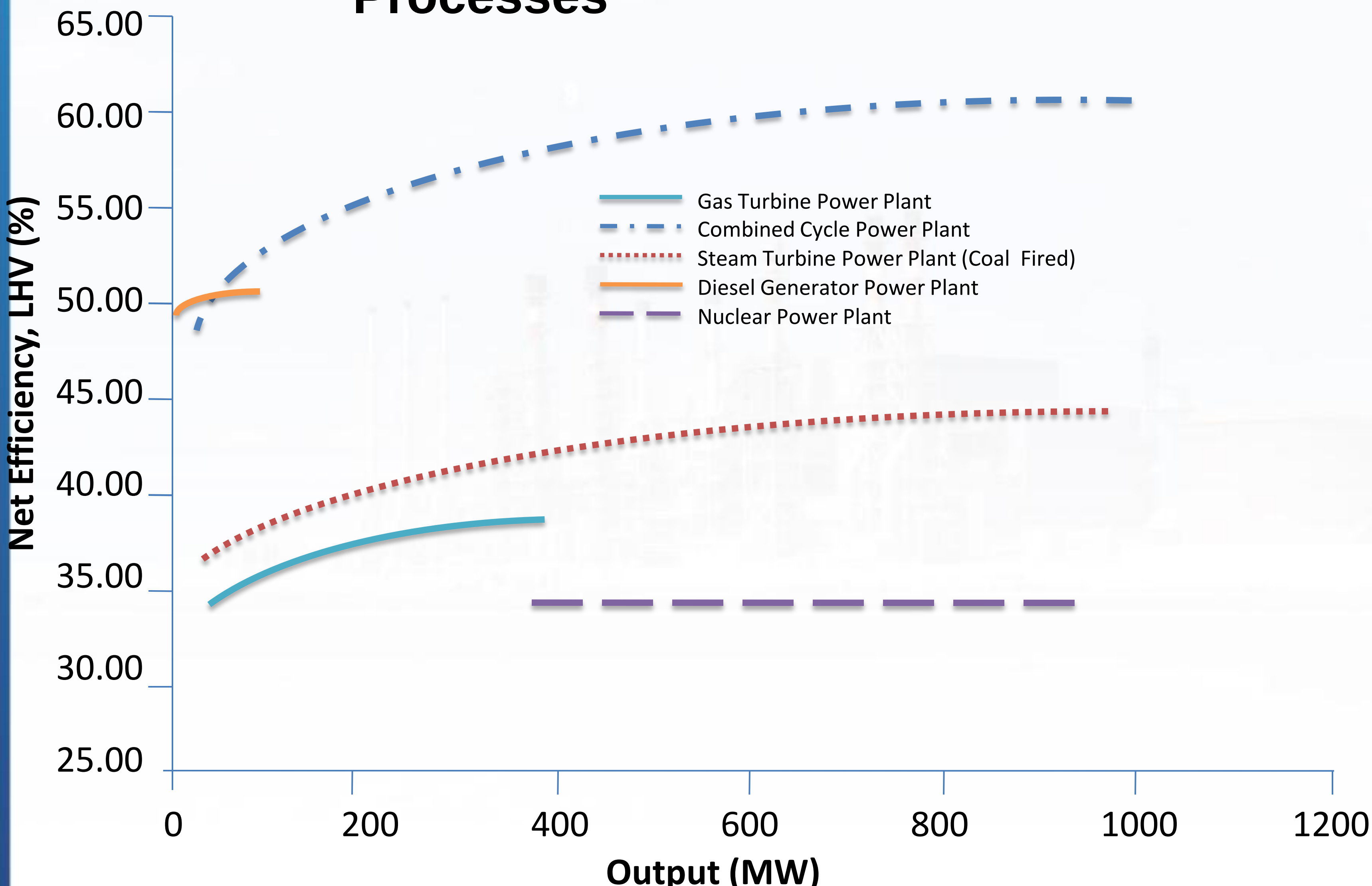
COMBINED CYCLE



Thermodynamic Comparison of Gas Turbine, Steam Turbine and Combined-Cycle Processes

	GT	ST	CC
Average temperature of	1,000 - 1,350	640 - 700	1,000 - 1,350
heat supplied, K (°R)	(1,800 - 2,430)	(1,152 - 1,260)	(1,800 - 2,430)
Average temperature of	550 - 600	300 - 350	300 - 350
dissipated heat, K (°R)	(900 - 1,080)	(540 - 630)	(540 - 630)
Carnot efficiency, %	45 - 50	45 - 57	65 - 78
GT = Gas Turbine Power Plant,			
ST = Steam Turbine Power Plant,			
CC = Combined-Cycle Power Plant			

Thermodynamic Comparison of Gas Turbine, Steam Turbine and Combined-Cycle Processes



Thermodynamic Comparison of Gas Turbine, Steam Turbine and Combined-Cycle Processes

The most environmentally and climate-friendly conventional power plants are combined cycle gas and steam facilities that use natural gas. Such plants have a peak efficiency of more than 58 percent, and their CO_2 emissions per kilowatt-hour (g $CO_{2/}$kWh) are only around 345 grams

The corresponding average figures for coal-fired plants worldwide are 30 percent peak efficiency and 1,115 g $CO_{2/}$kWh

Combined cycle Efficiency (gross)

$$\eta_{cc} = \frac{P_{gt} + P_{st}}{F_{gt} + F_{sf}}$$

P_{gt} power output Gas Turbine

F_{gt} fuel input Steam Turbine

P_{st} power output Steam Turbine

F_{sf} supplementary firing

Combined cycle Efficiency (net)

$$\eta_{ccnet} = \frac{P_{gt} + P_{st} - P_{Aux}}{F_{gt} + F_{sf}}$$

P_{Aux} power required to run the plant auxiliaries and desalination

Overview of conventional main power and desalination technologies

General

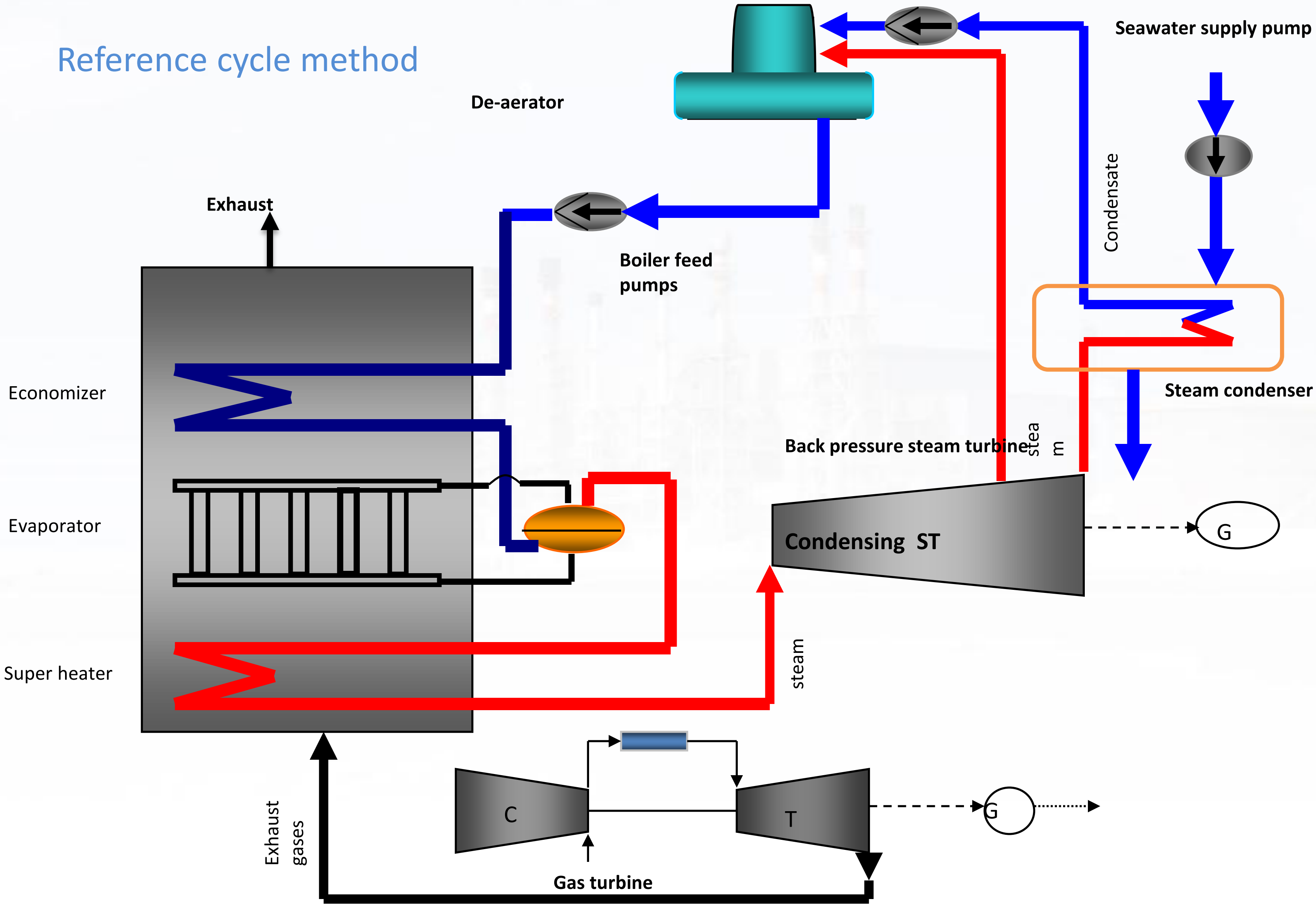
With power and water generation we have two basic options

Cogeneration with thermal desalination option 1

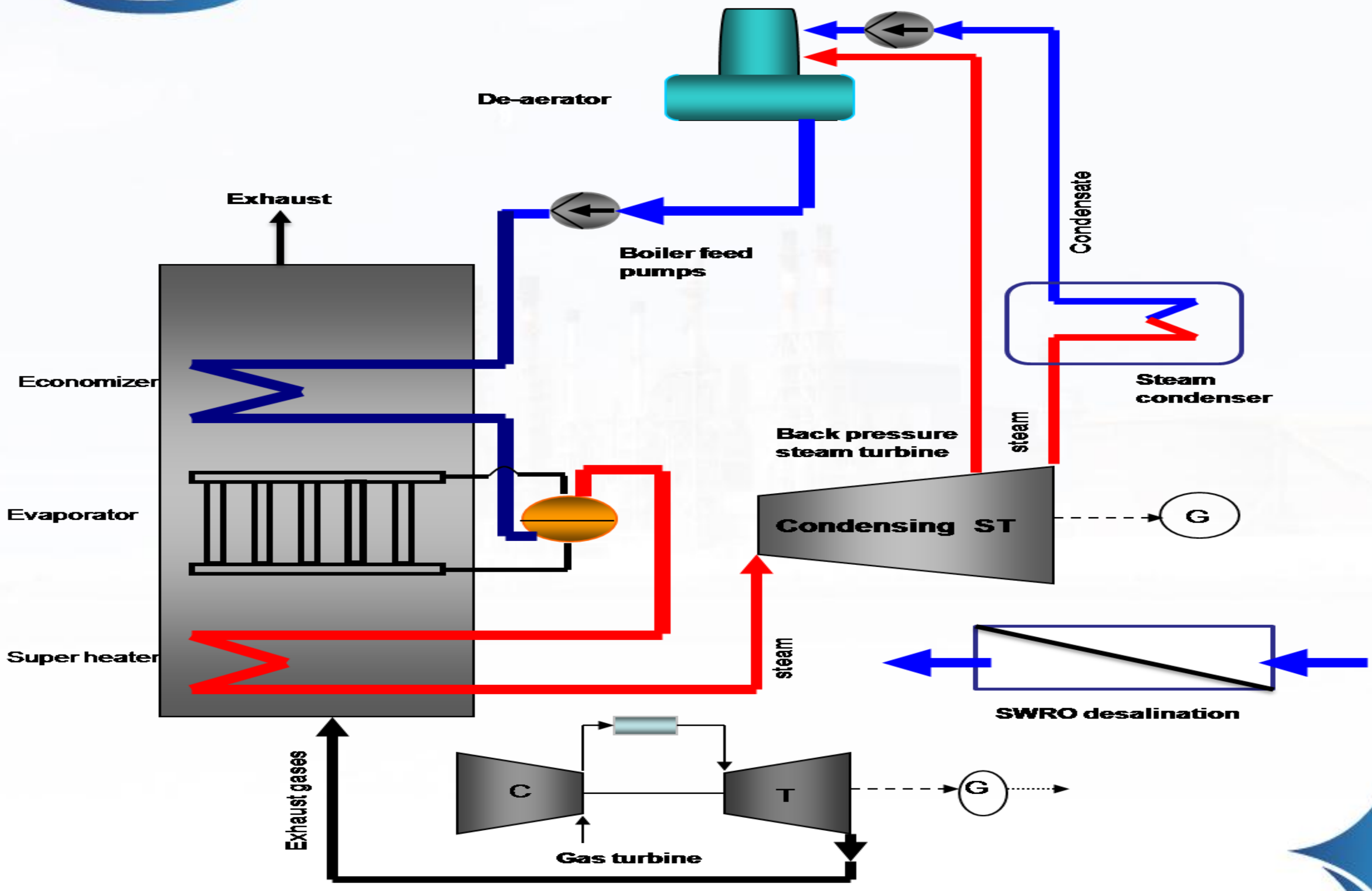
Separate power and SWRO desalination option 2

Cogeneration with thermal desalination option 1

Reference cycle method



Separate power and SWRO desalination option 2



Separate power and SWRO desalination option 2

CLASSROOM DISCUSSION

Some example air emissions

CASE 1 600 MW + 40 MIGD

HEAT RATE 8181 KJ/KW hr

FUEL CONSUMPTION 33.6 Kg/s

Equivalent CO2 emissions

4.4 million Tons/yr

CASE 2 600 MW + 40 MIGD

HEAT RATE 7387 KJ/KW hr

FUEL CONSUMPTION 30.4 Kg/s

Equivalent CO2 emissions

3.8 millions Tons/yr

10% LOWER air emissions

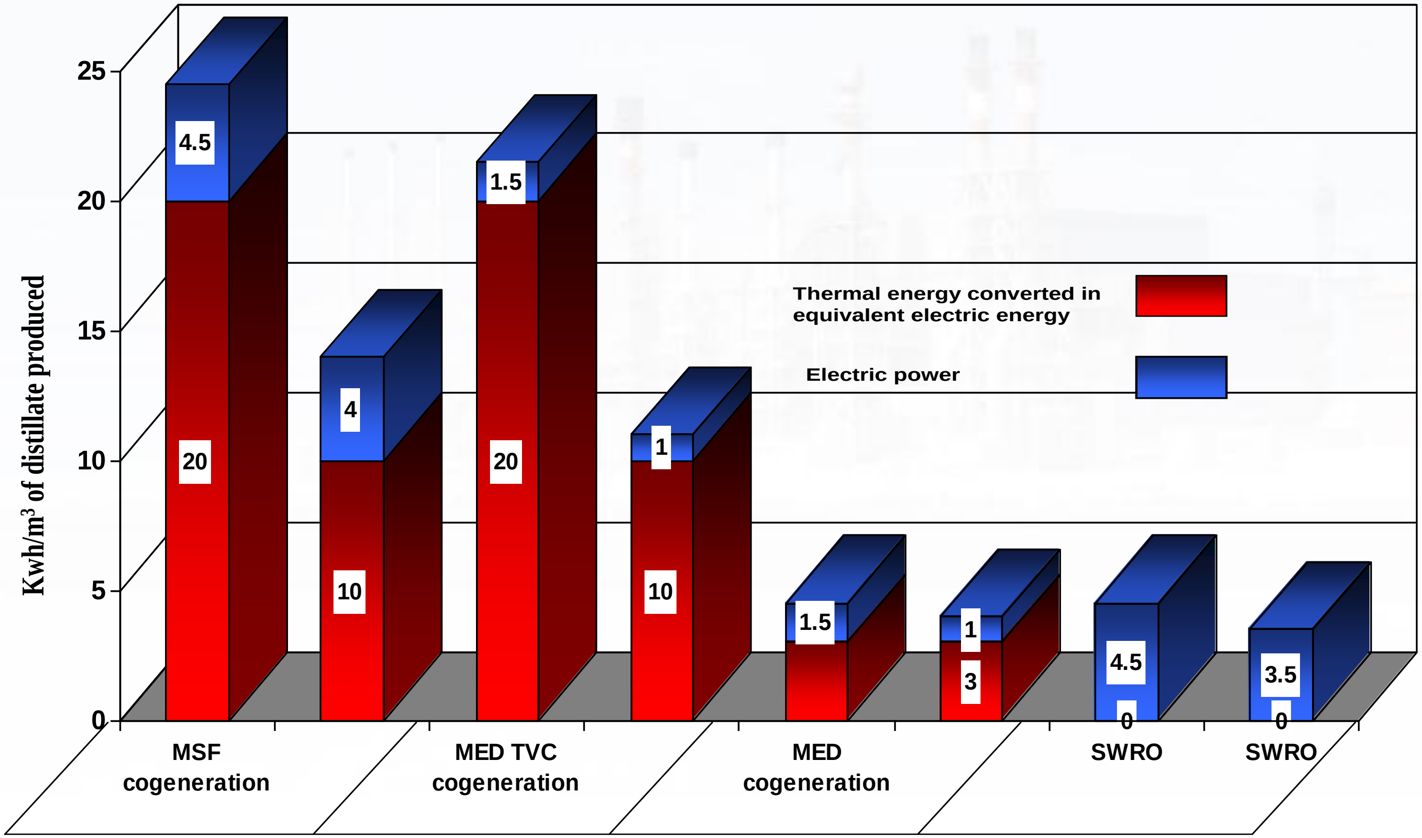
ANYTHING MORE ?

Technologies and efficiency comparison

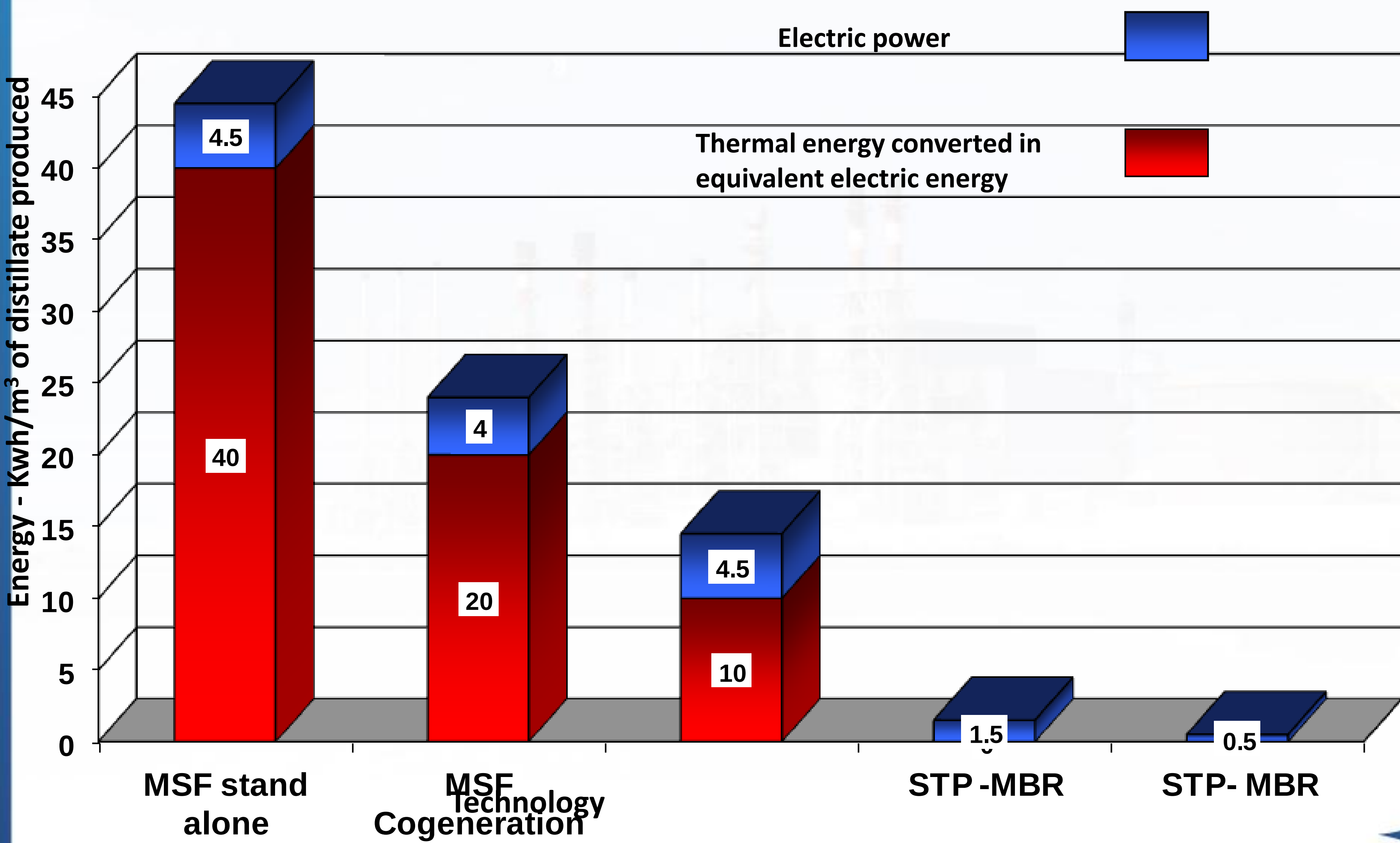
Energy consumption per technology

Energy consumption of status of art desalination projects

Desalination plants are very energy intensive processes !!!



Energy consumption per technology



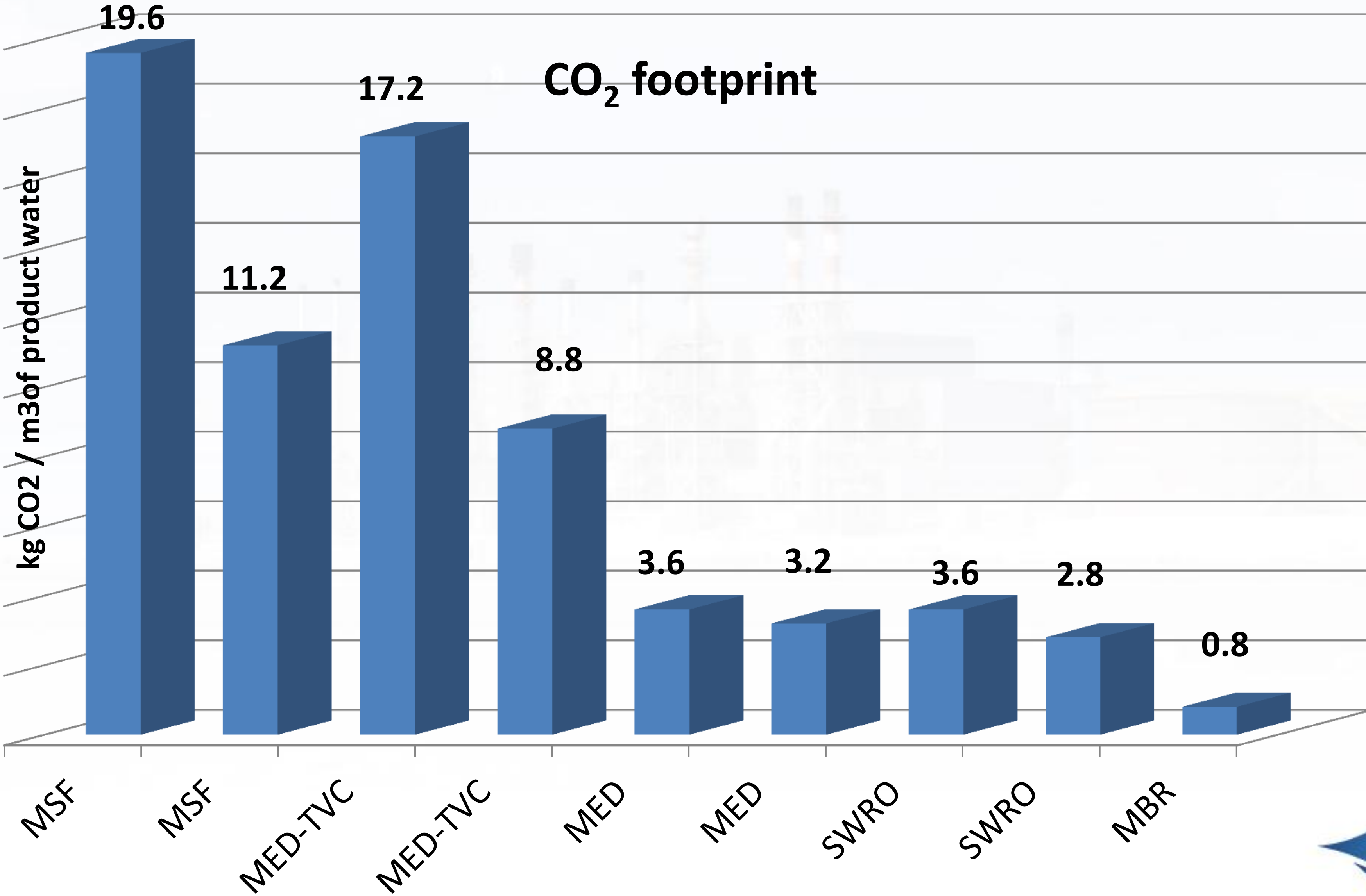
Energy consumption per technology

CO_2 footprint

Grid emission Factor

- In parts of the world that are heavily reliant on coal the grid emission factor is somewhere near 0.8TCO_2/MWH.
- Whereas where there is lots of new and efficient system the grid it tends to be lower e.g 0.5TCO_2/MWH

Energy consumption per technology

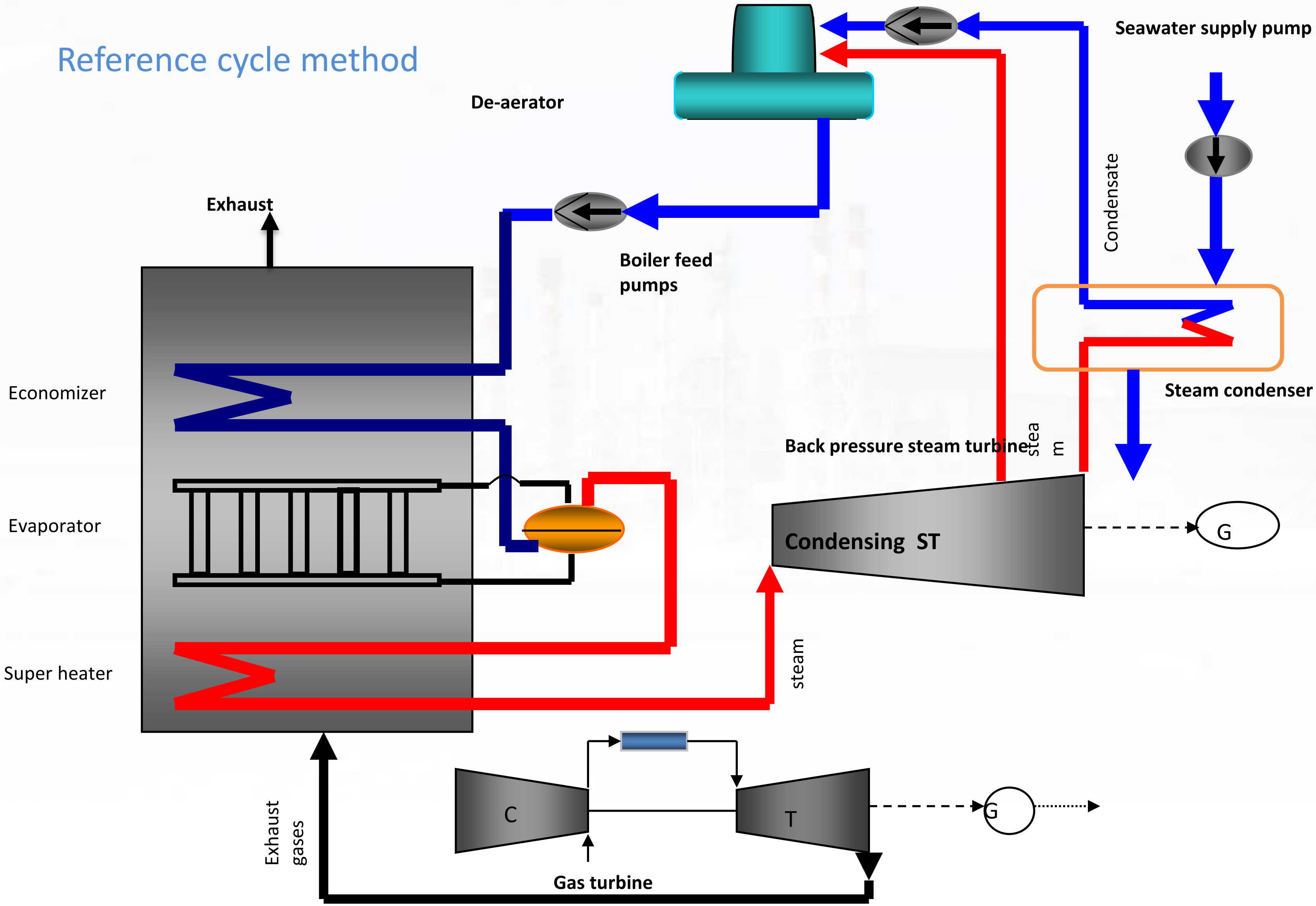


Energy apportionment options

- Energy that could be produced with the steam used for the thermal desalination plant in cogeneration (reference cycle)
- Energy required in a stand alone (and that could be produced with the steam)
- Energy that has been used to produce that amount of steam
- Energy that could be rendered by the heat at the given temperature

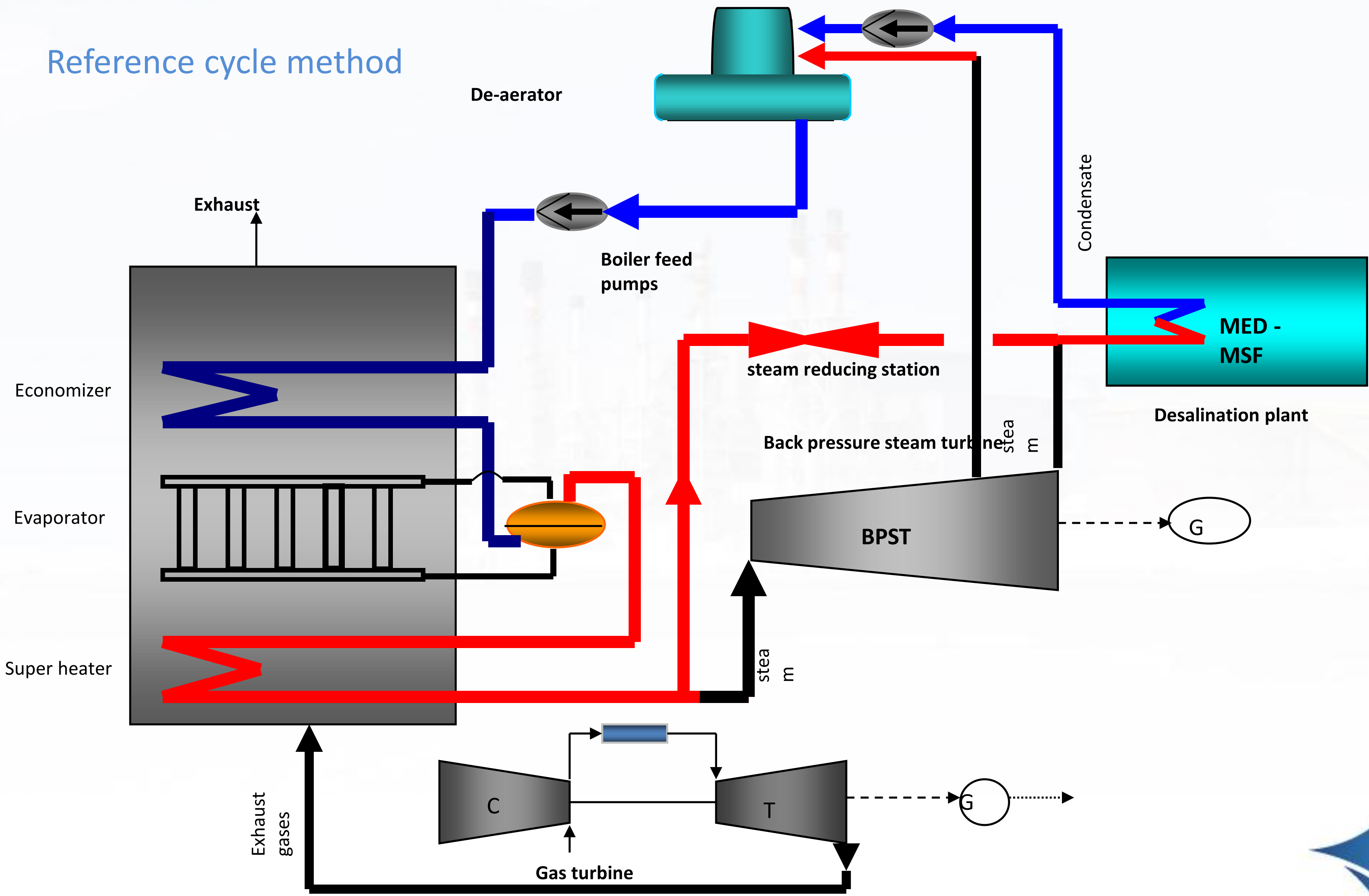
Thermal Energy apportionment criteria

Reference cycle method

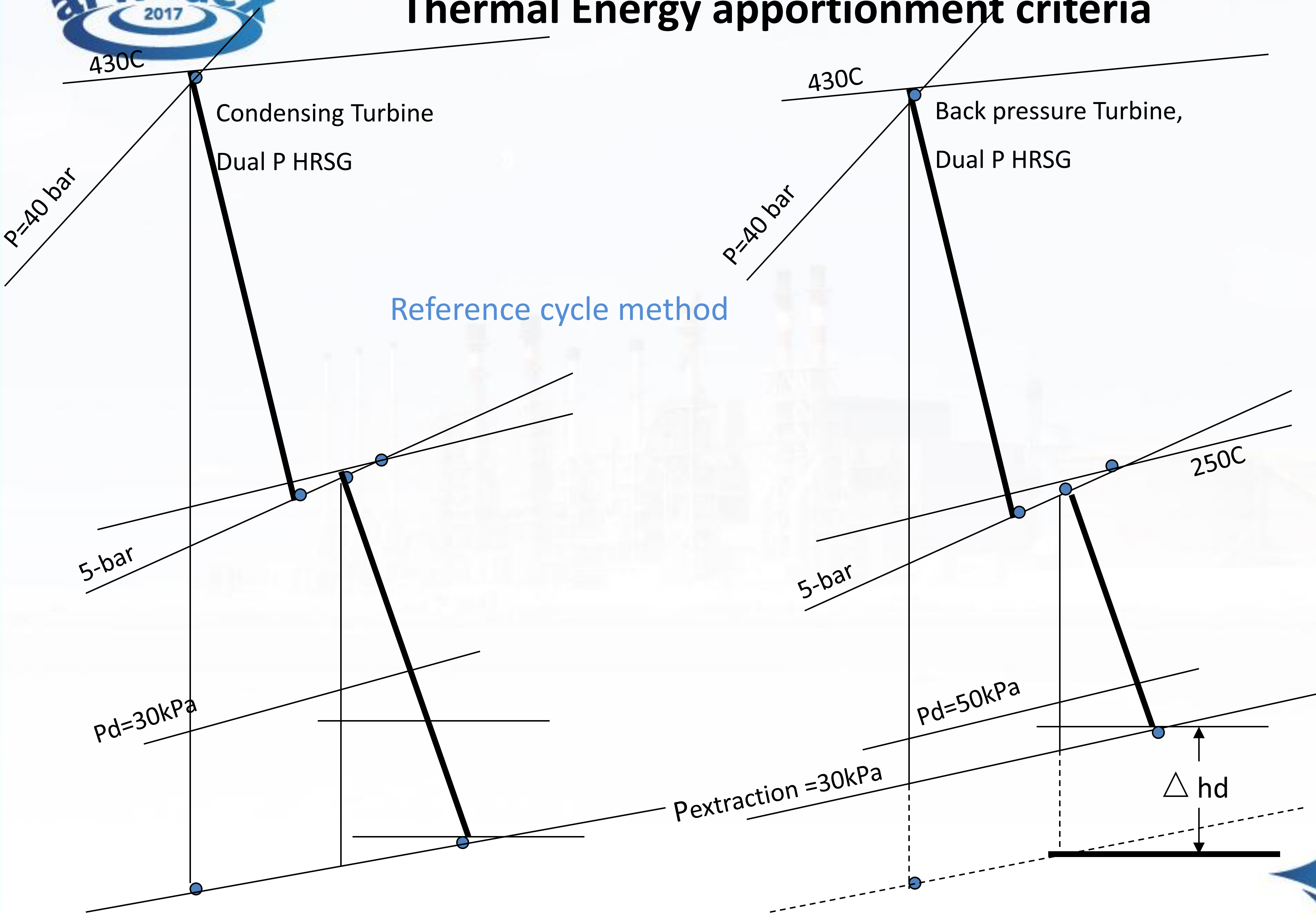


Thermal Energy apportionment criteria

Reference cycle method



Thermal Energy apportionment criteria

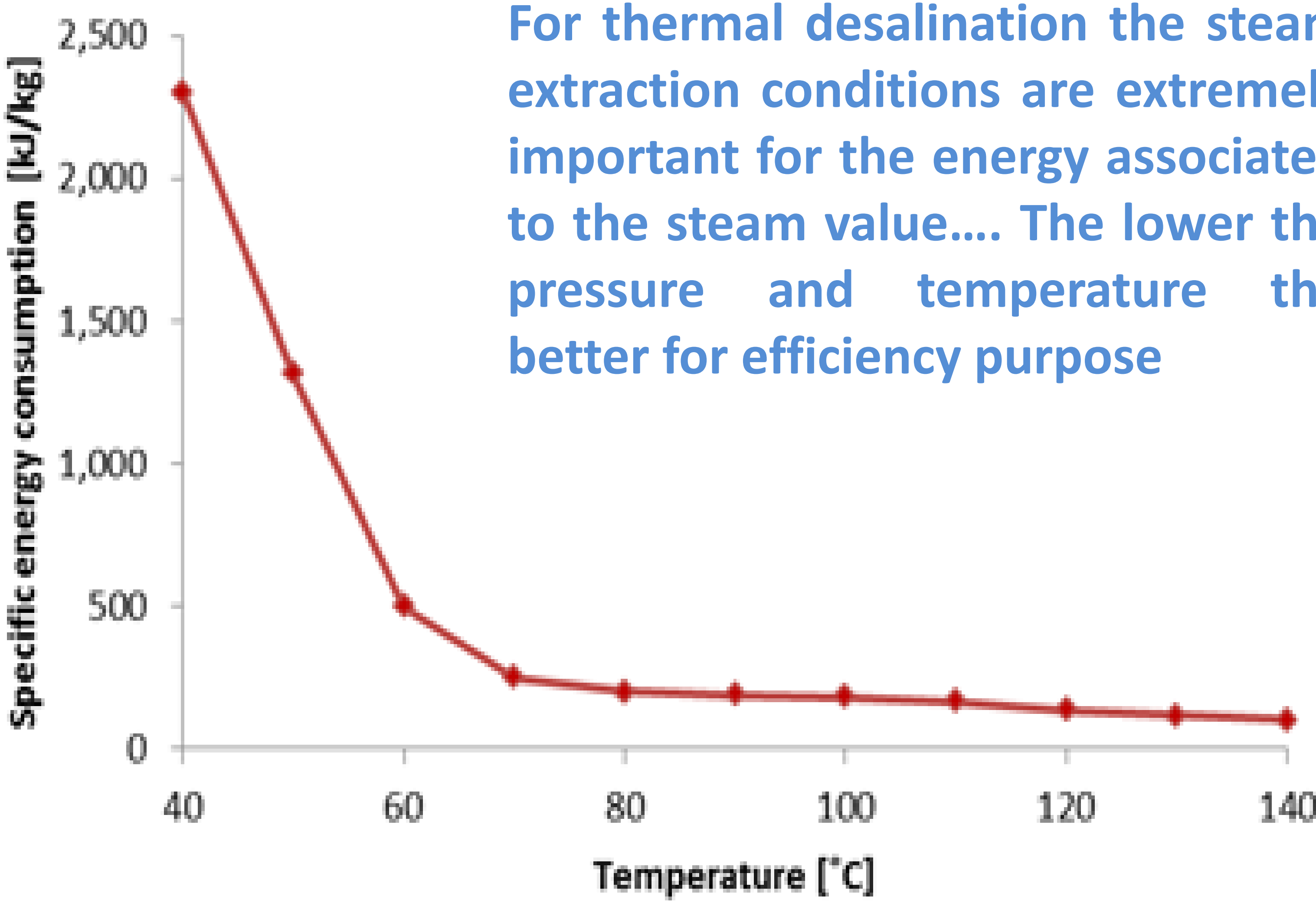


Thermal Energy apportionment criteria

Desalination technologies energy consumption thermal and electric power cogeneration

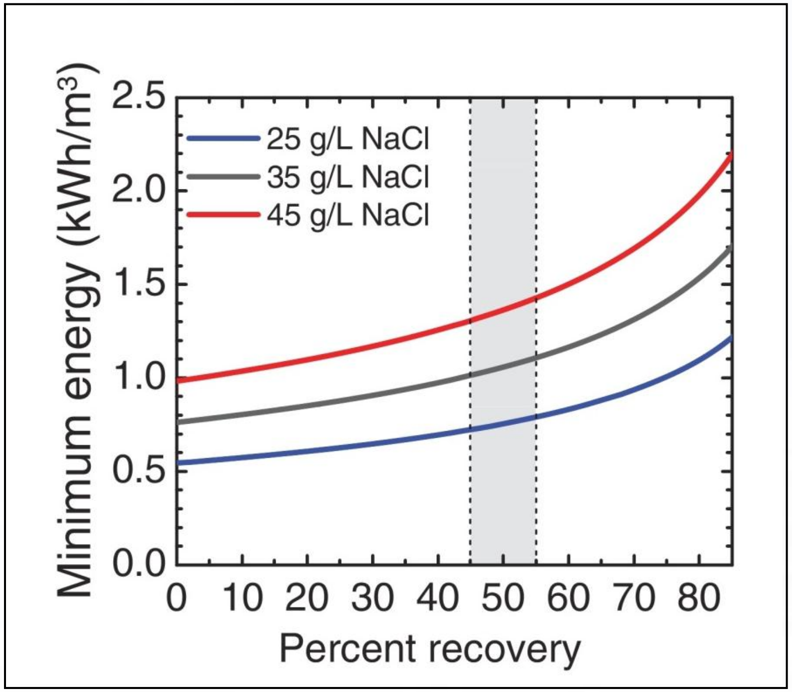
	Specific electric power Kwh/m^3	Specific heat consumption kJ/kg	Steam Extraction pressure Bar abs	Thermal energy Thermal kwh/m^3	Equivalent power loss Electric kwh/m^3	Total Energy requirements kwh/m^3
SWRO (Mediterranean Sea)	3.5	0	N.A.	0	0	3.5
SWRO (Gulf)	4.5	0	N.A.	0	0	4.5
MSF	4.5	287	2.5-2.2	78	10-20	14-25
MED-TVC	1.0-1.5	287	2.5-2.2	78	10-20	11-21.5
MED	1.0-1.5	250	0.35-0.5	69	3	4-4.5

Thermal Energy apportionment criteria

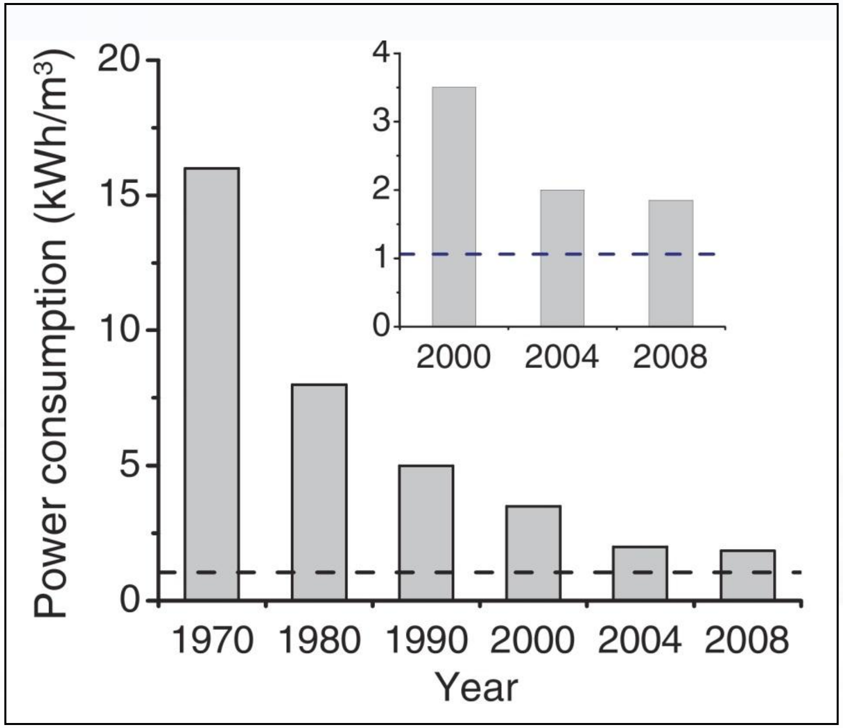


For thermal desalination the steam extraction conditions are extremely important for the energy associated to the steam value…. The lower the pressure and temperature the better for efficiency purpose

Theoretical thresholds



Source: Science Magazine, Elimelech and Phillip



Theoretical minimum: 3.5% SW, 50% recovery ~ 1.56 kWh/m^3

Thermal Energy apportionment criteria

The problem is ….

$$\Delta H = K_t \cdot A \cdot \Delta T_{ml}$$

ΔH = energy exchanged kJ/sec

K_t = overall heat transfer coefficient kJ/m²°C

A= overall heat transfer area m²

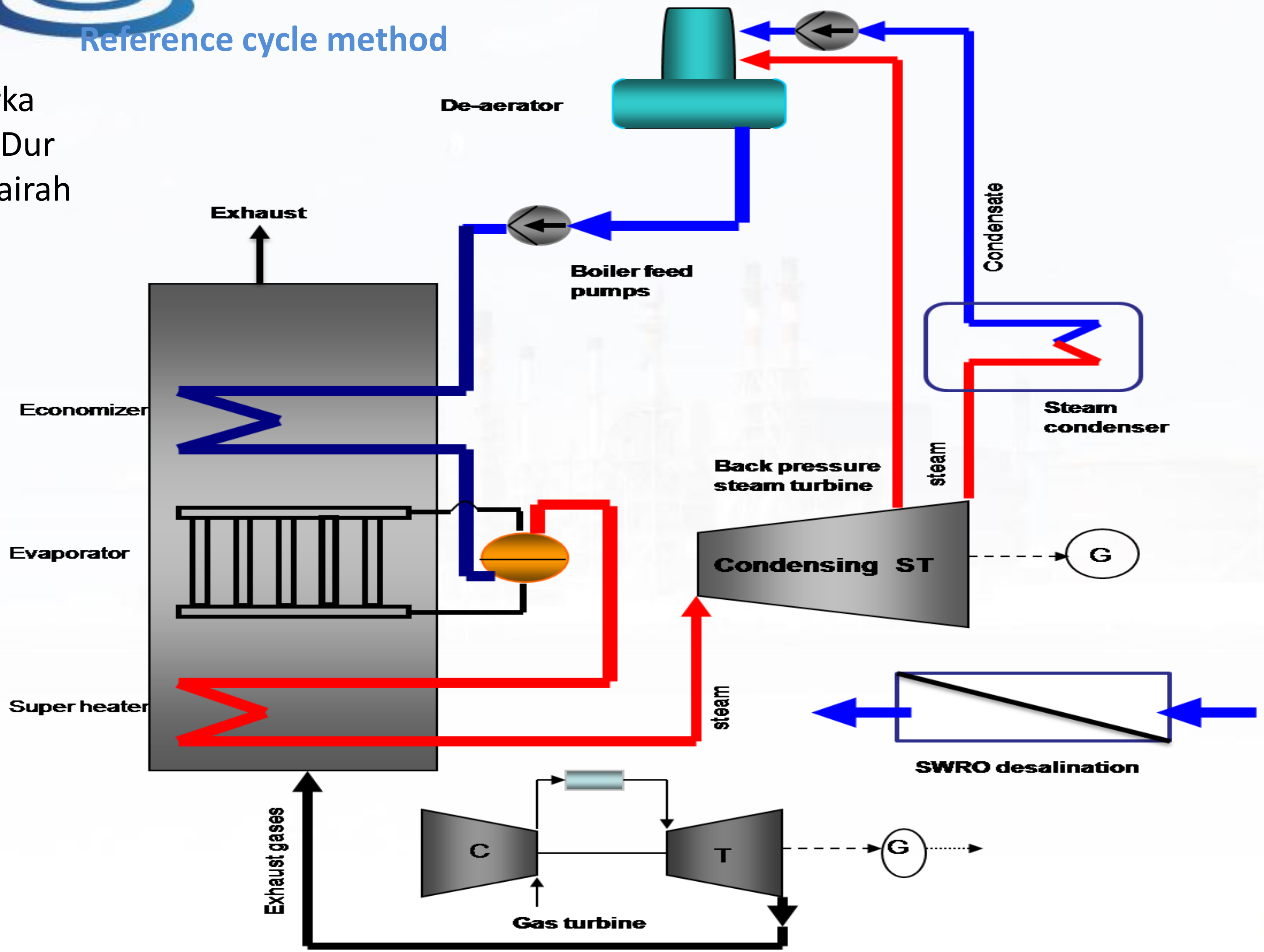
ΔT_{ml} = Delta Temperature (media logarithmic) between the streams °C

Using low temperature involves a lot of heat transfer….. costs

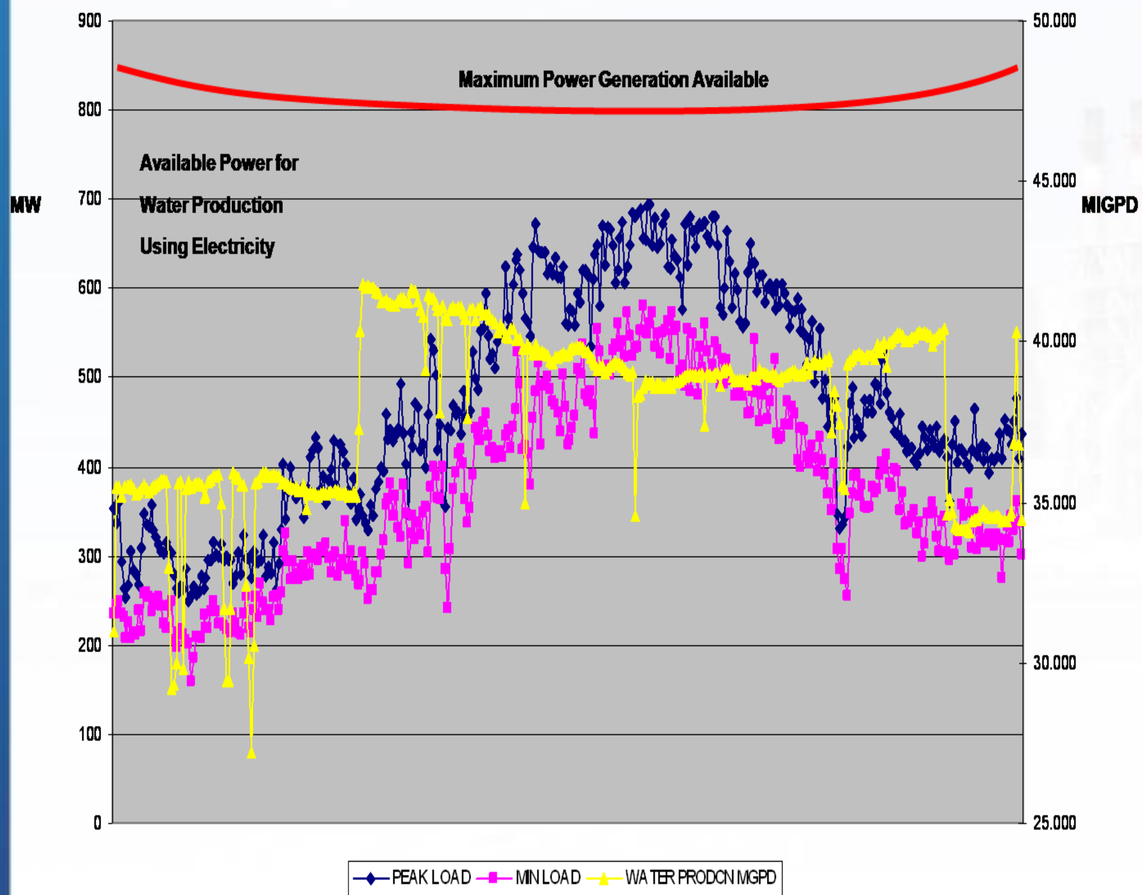
Thermal Energy apportionment criteria

Reference cycle method

Barka
Ad Dur
Fujairah



The energy situation



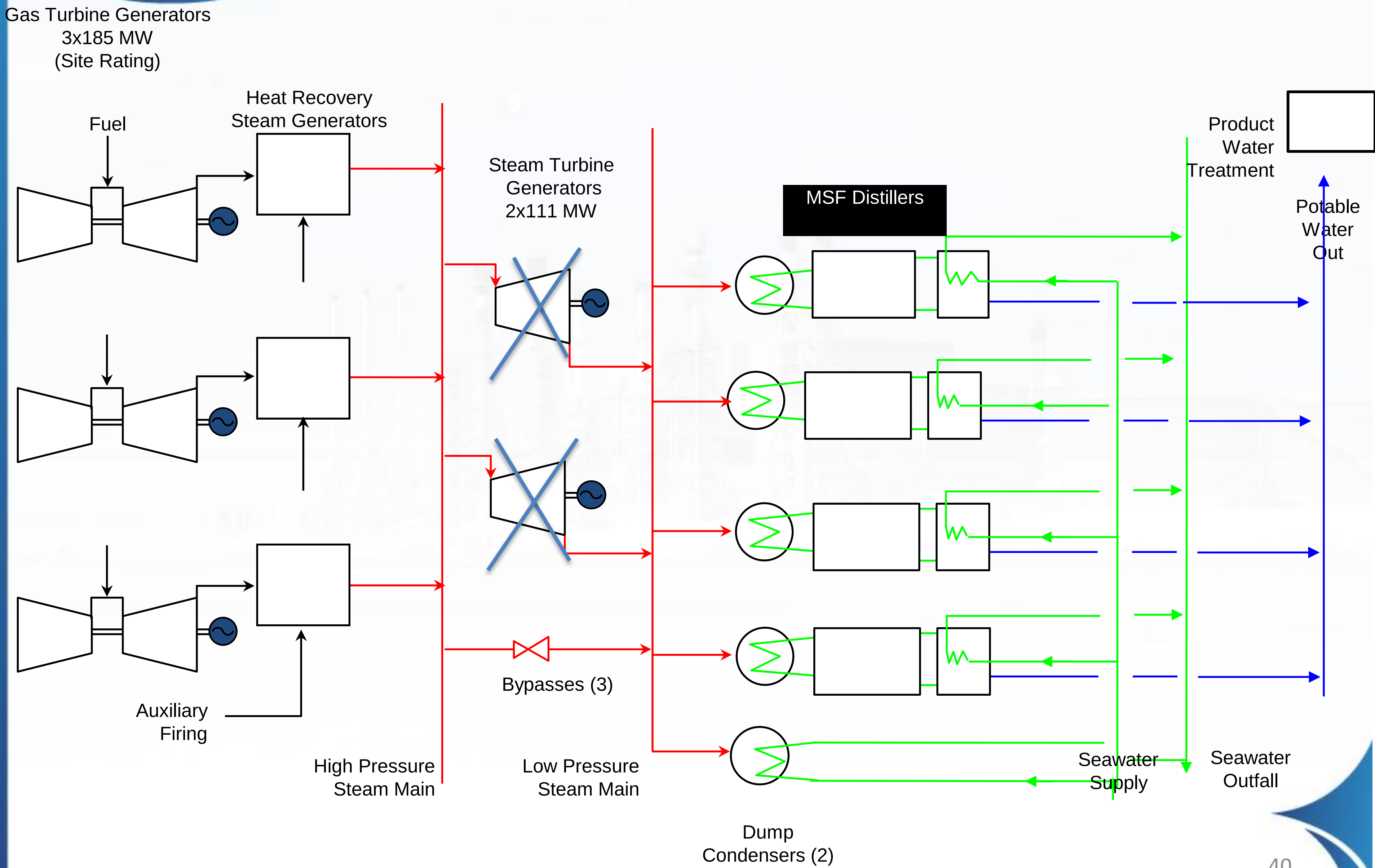
Data Courtesy of SEWA Layyah Power Plant

Despite all thermal desalination plant are installed as cogeneration the winter summer unbalance of water and power demand generate tremendous inefficiencies

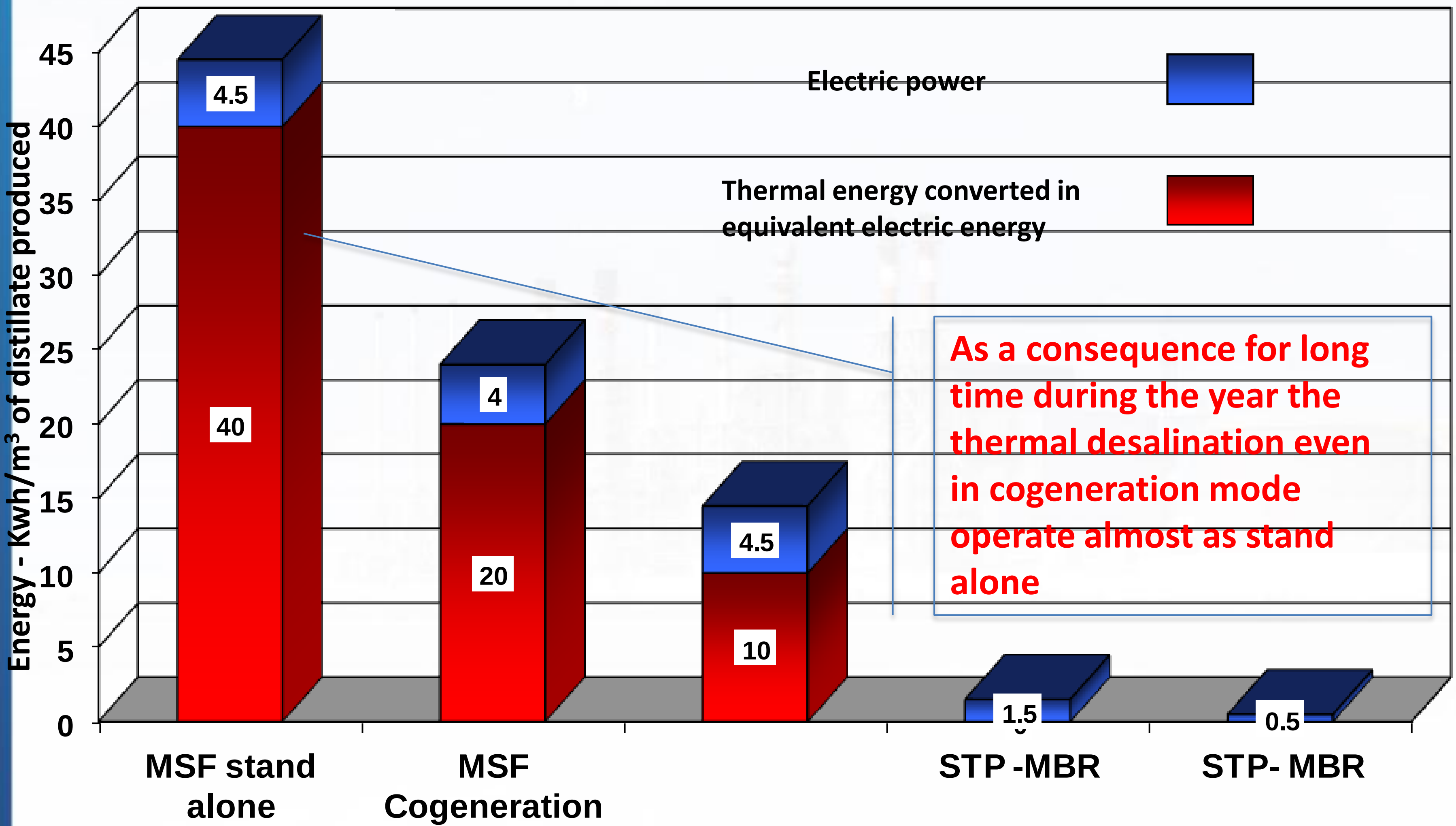
Thermal Energy apportionment criteria

Since power is no required but water demand keeps almost constant the only solution with thermal desalination is to feed the thermal plant bypassing the steam turbine through steam reducing station

Thermal Energy apportionment criteria



Thermal Energy apportionment criteria

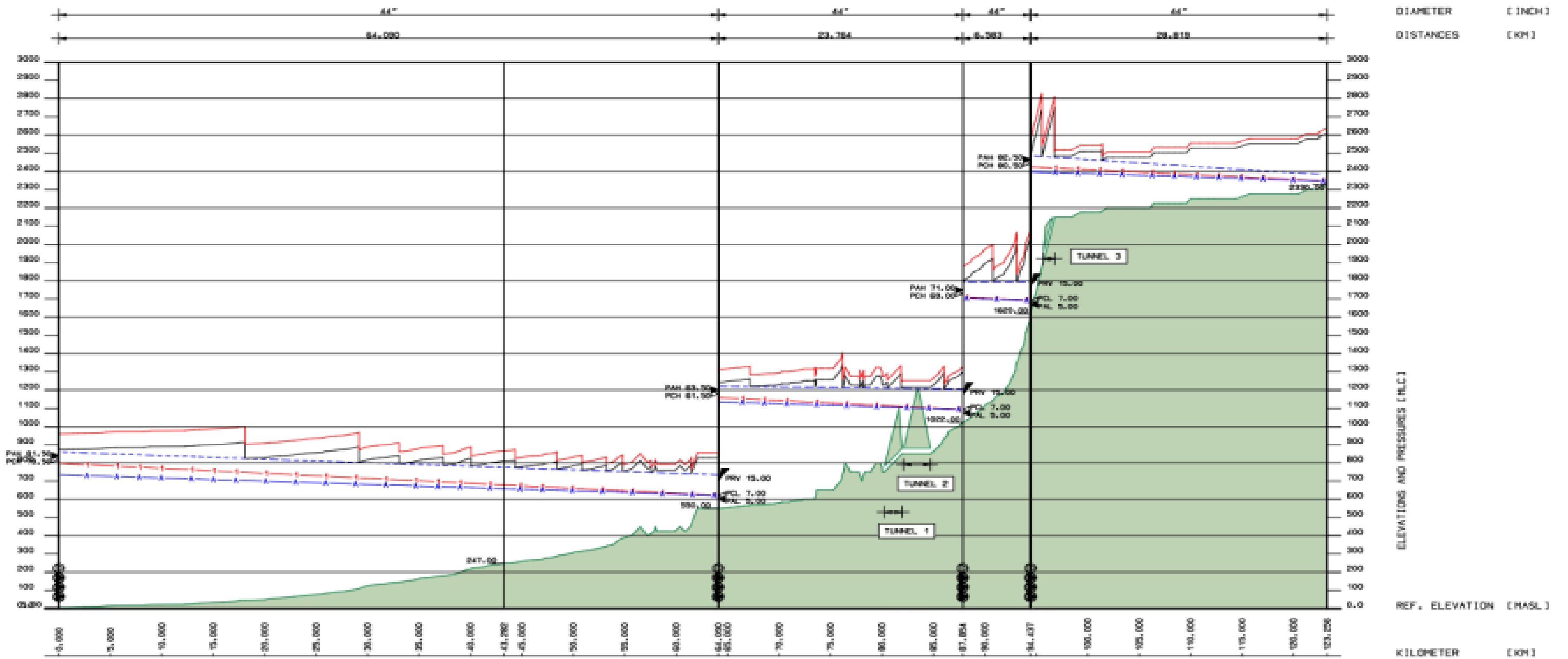


Synergies with WW reclamation to reduce the desal needs and water transmission needs

Desalination plant technology	Destination	Generation footprint	Transmission footprint	Total footprint
MSF	East Coast Riyadh	25-30 kWh/m^3	5 kW h/m^3	30-35 kWh/m^3
RO	East Coast Riyadh	7 kW h/m^3	5 kW h/m^3	13 kW h/m^3
MSF	West Coast Abha	25-30 kWh/m^3	10 kW h/m^3	35-40 kW h/m^3
RO	Abha	6kW h/m^3	10 kW h/m^3	16kW h/m^3

Synergies with WW reclamation to reduce the desal needs and water transmission needs

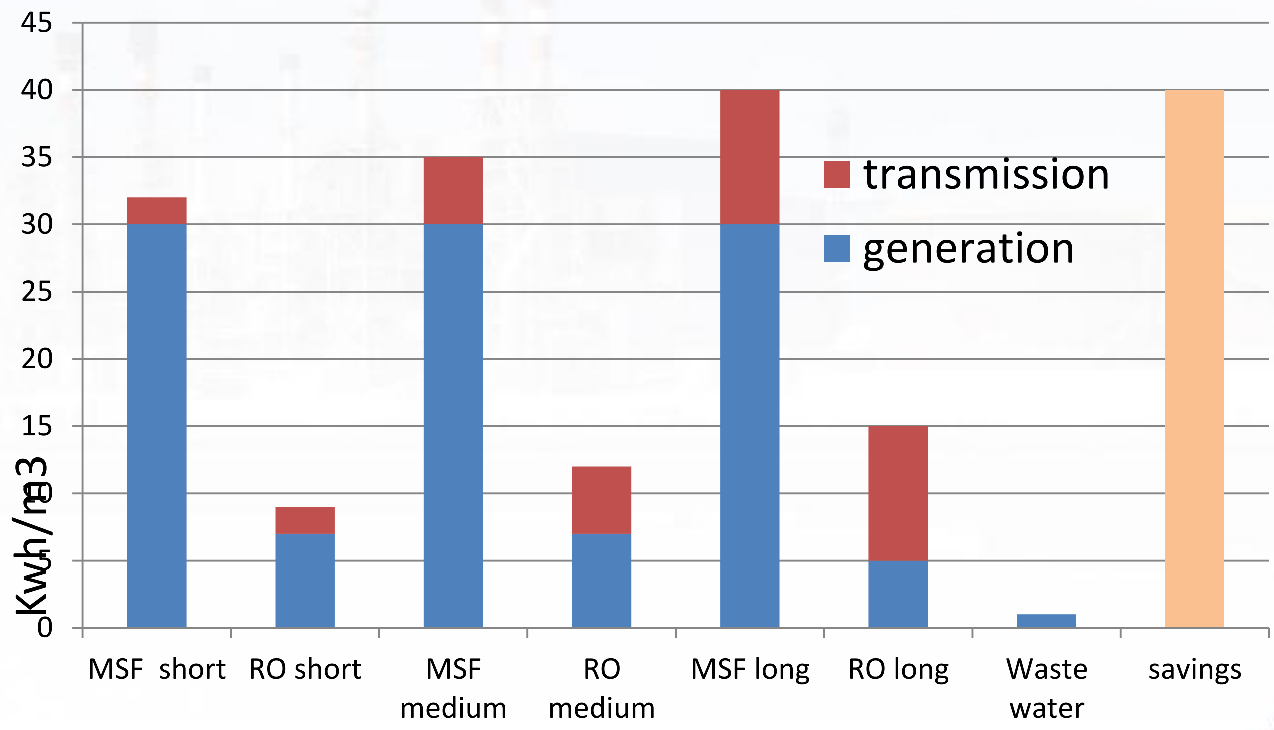
Hydraulic Profile, Shuqaiq – Abha Pipeline



Importance of water re-use for sustainability and energy efficiency

Not only for saving water but most importantly to save energy.

Several large size power generation assets could be saved if this concept was adopted extensively



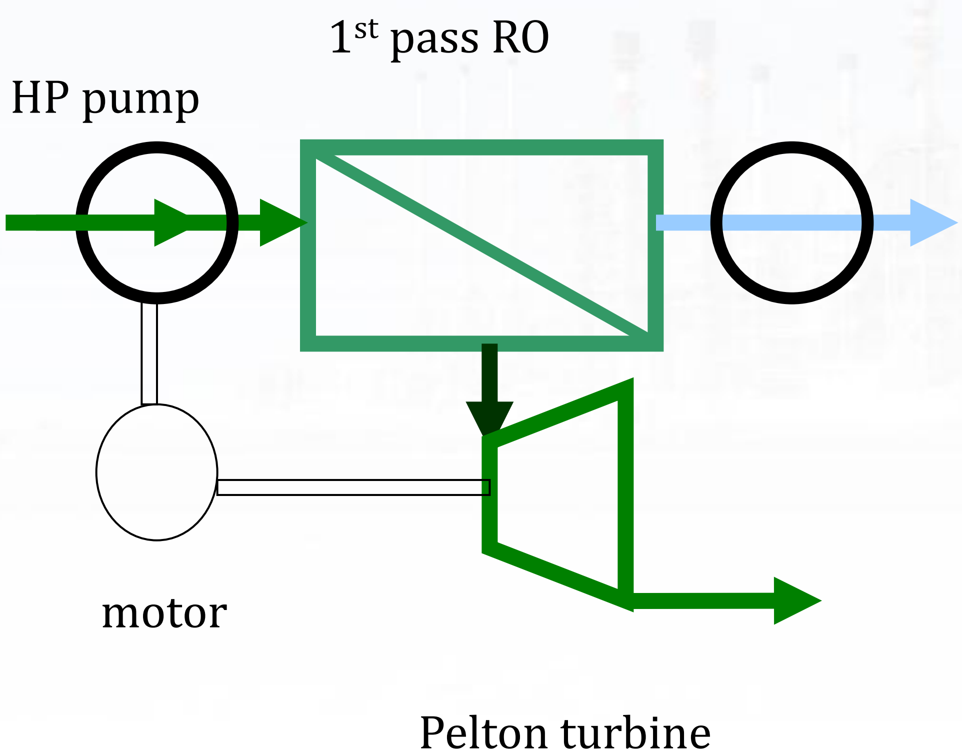
Examples of energy efficiency retrofits

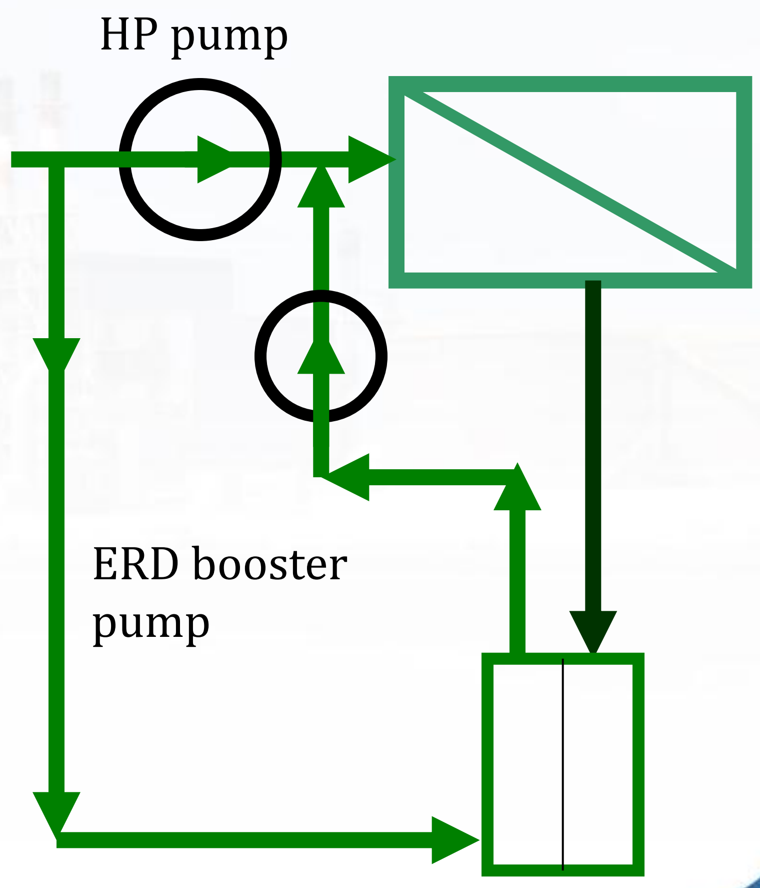
Examples of energy efficiency retrofits

Technology	Thermal	SWRO	Potentials
Optimization of extraction pressure to the heat input source	√		Above 2-3 MW per 5 MIGD installed
Retrofit of isobaric ERD against traditional Pelton wheel		√	Up to 1 MW per 5 MIGD installed
Retrofit of higher efficiency solution for pumping system	√	√	Depending on the original efficiency
Converting brine extraction to blowdown extraction	√		Up to 1 MW per 5 MIGD installed
Redesigning hydraulic circuit for major process pump	√	√	Extremely high potentials up to 3 MW for 5 MIGD installed particularly for old operations
Intermediate extraction of Distillate	√		Depending on the configurations up to 0.5 MW per 5 MIGD installed
Using MSF/MED drain as feed for SWRO		√	Up to 2 MW per 5 MIGD installed
Others			

Examples of energy efficiency retrofits

Pelton Wheel to isobaric device





Examples of energy efficiency retrofits

Tordera SWRO Plant, Spain. Expansion Retrofit.

Original capacity 28,000 m^3/d, 4 trains 7,000 m^3/d each.

Expanded capacity 64,000 m^3/d. 4 trains, 16.000 m^3/d each.

Recovery 45%, 15 PX-260 units per train

Courtesy of ERI

Before SEC with Pelton wheels: 3.06 KWh/m^3

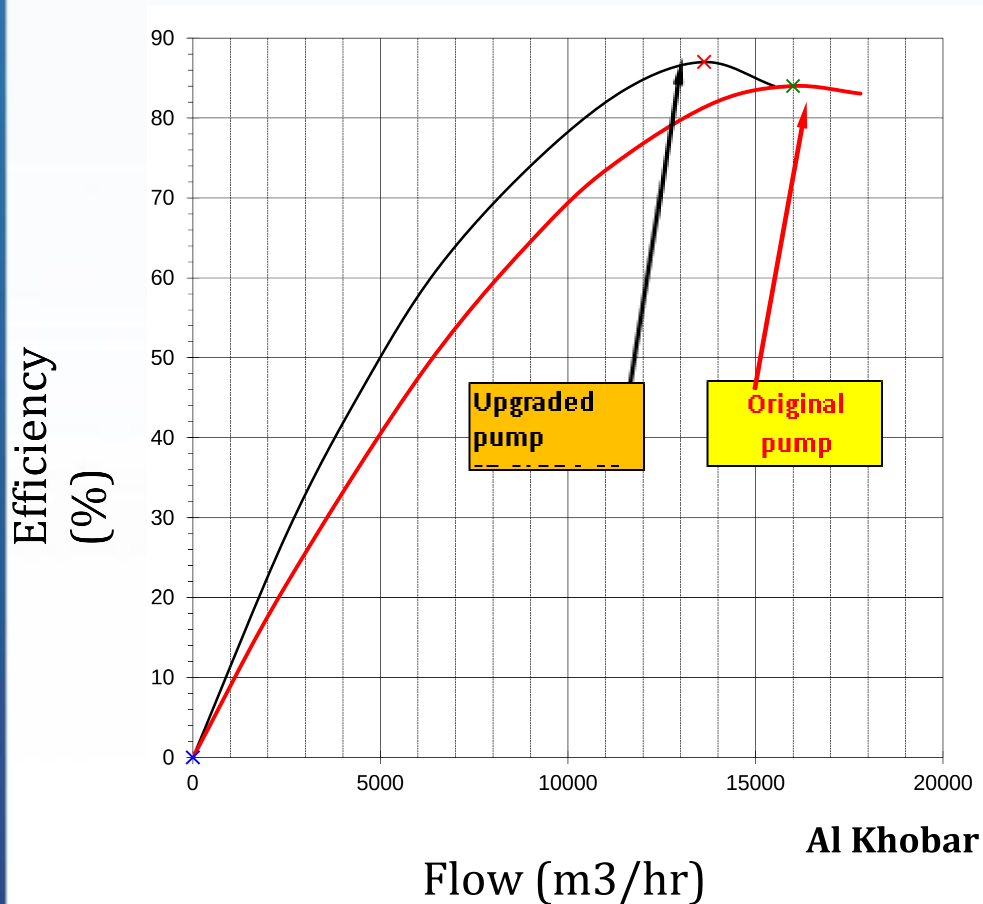
After: 2.56 KWh/m^3

16.3% reduction in SEC

Same HPP, new motor, new membranes in the new trains, same membranes in half of the plant.

Examples of energy efficiency retrofits

Retrofit of higher efficiency solution for pumping system



Al Khobar Power and Desalination Plant, Phase II

Examples of energy efficiency retrofits

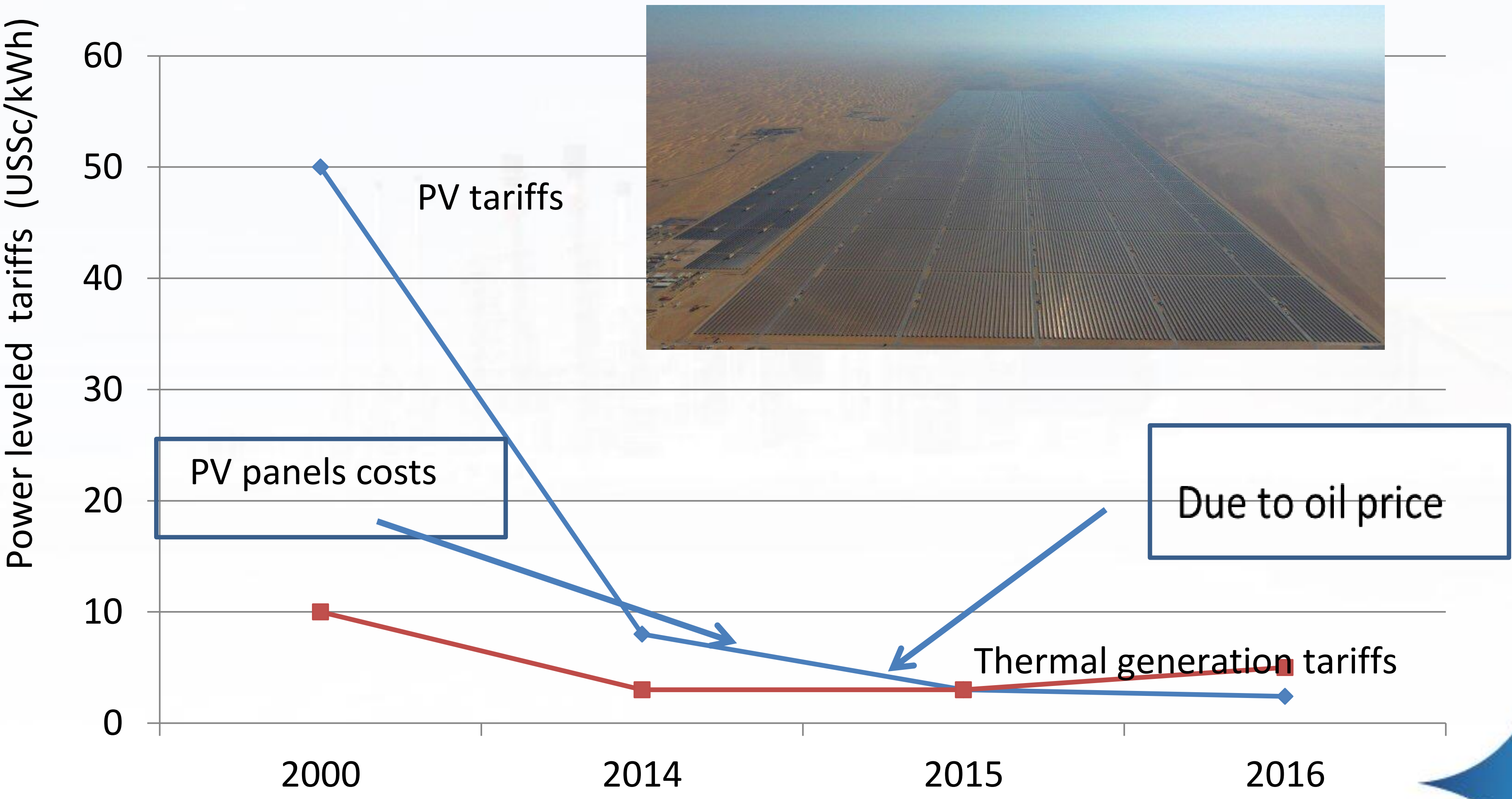
Efficiency is also in managing your plant !

Poor seawater screening equipment performance bring about and increase in steam condenser pressure

Seawater screening system retrofit has solved the problems
Jubail +0.5 MW per steam turbine increase in power output

Overview of renewable energy technology and comparison

Evolution of PV system tariff IPP



Evolution of PV system tariff IPP

Renewable energy tariffs

Year	project	US$c/kWh
	Previous pilots- and small installations	20-50
2014	100 MW SOLAR PHOTOVOLTAIC INDEPENDENT POWER PROJECT - PHASE II	8
2016	800 MW SOLAR PHOTOVOLTAIC INDEPENDENT POWER PROJECT - PHASE II	3
2016	350 MW solar photovoltaic plant Shweihan ADWEA	2.4

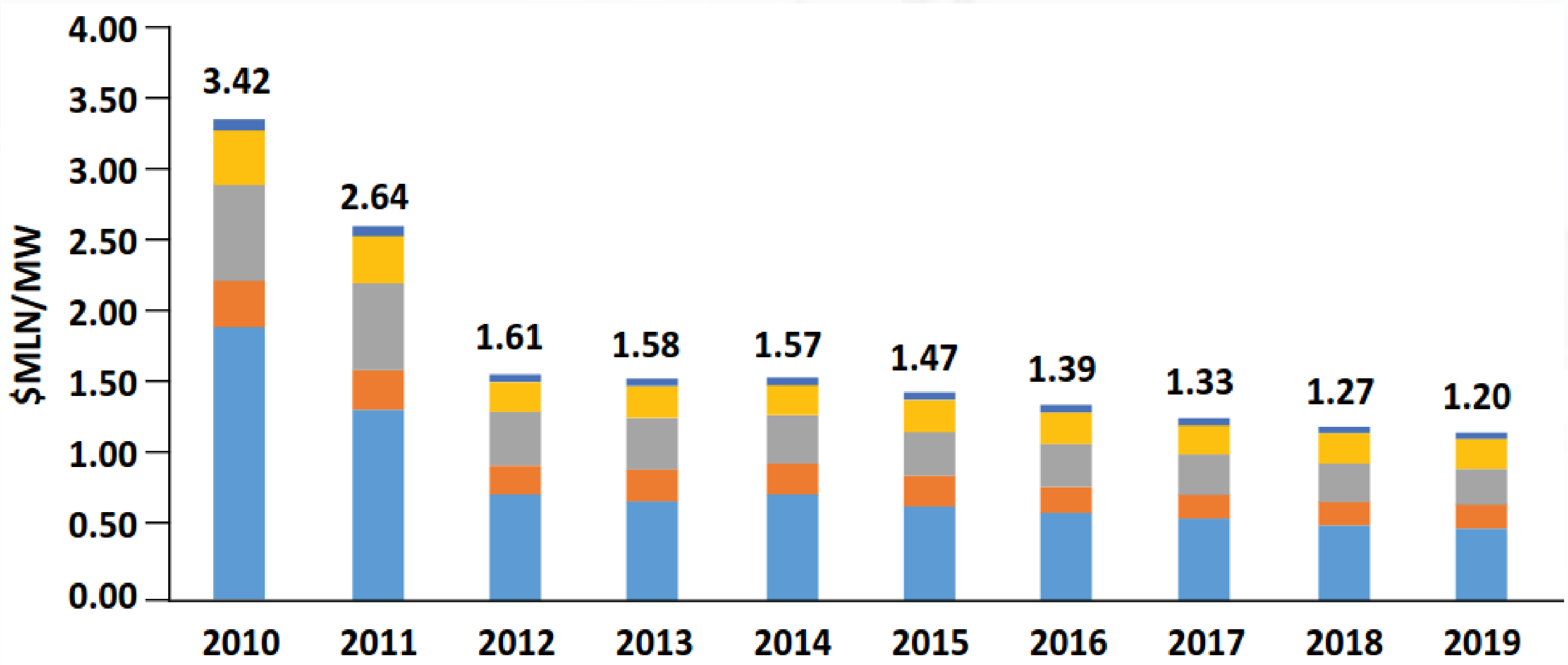
Evolution of PV system tariff IPP

Variables affecting tariffs long terms	
Renewables	Thermal power generation
Land use	Energy costs
Storage	Land cost
	New emission limits

Opportunities for new tariffs	
Renewables	Thermal power generation
Better efficiencies	Technology development new more efficient machines
New installations	

Evolution of PV system

- Significant module Price declines from 2010 to 2020
- Historical Data from more developed markets (Europe, North America, Asia)
- Forecast can be used for other markets for benchmarking purposes



Evolution of PV system

Main Developments in Crystalline and Thin Film Technology:

- **Crystalline: 300 µm**

  Polycrystalline silicon (p-Si), Monocrystalline silicon (m-Si); high peak efficiency – 21 %

- **Thin Films: 1 to 3 µm**

  Amorphus silicon (a-Si), Copper Indium Diselenide (CIS), Cadmium Telluride (CdTe); lower peak efficiency – 16 %

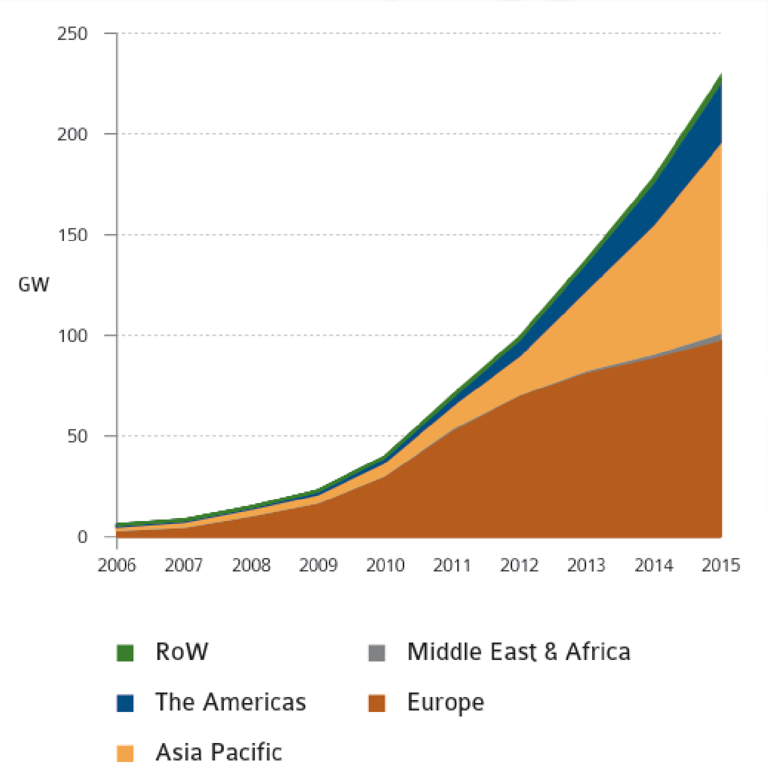
Source: ILF

Source: IEA

Yearly Production of Thin-Film and Wafer-based Modules

Evolution of PV market

- Installed PV Power until 2015 worldwide: 228GWp
- Strong Increase in Europe and Asia Pacific region in the last 5 years
- Forecast until 2020: 400GW installed power worldwide

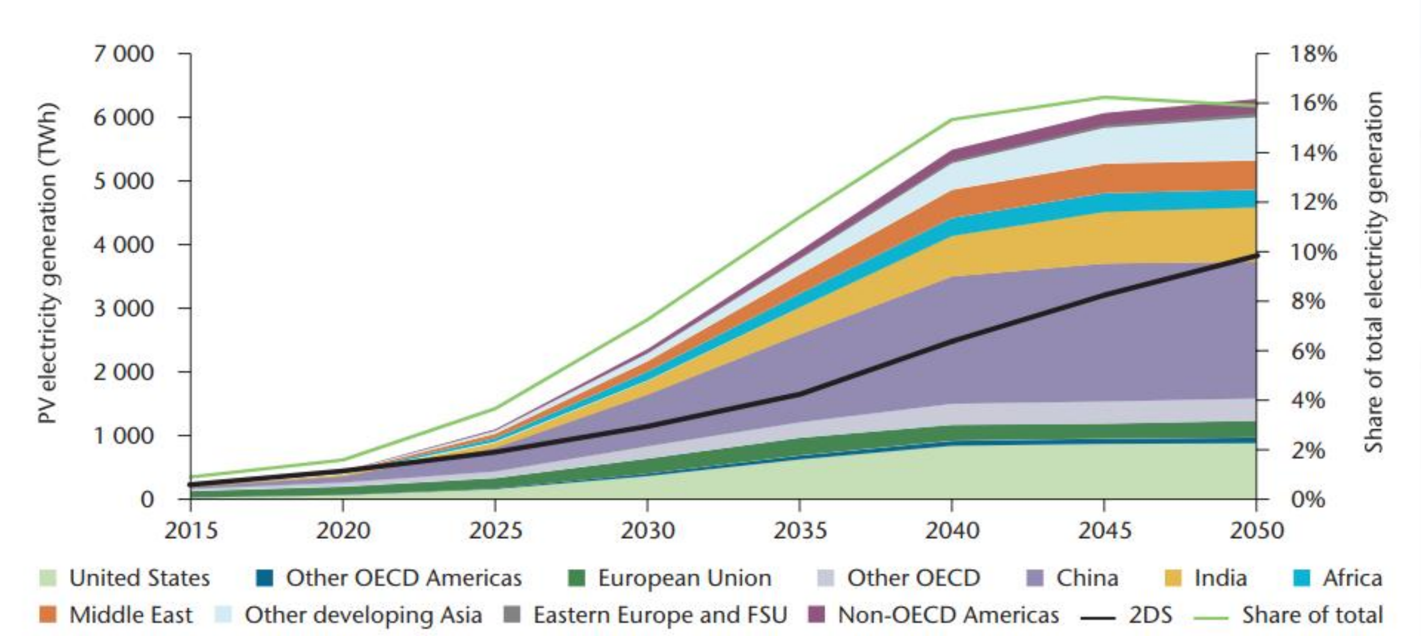


Source: IEA

Evolution of PV market

- Forecast for high renewable Energy scenario

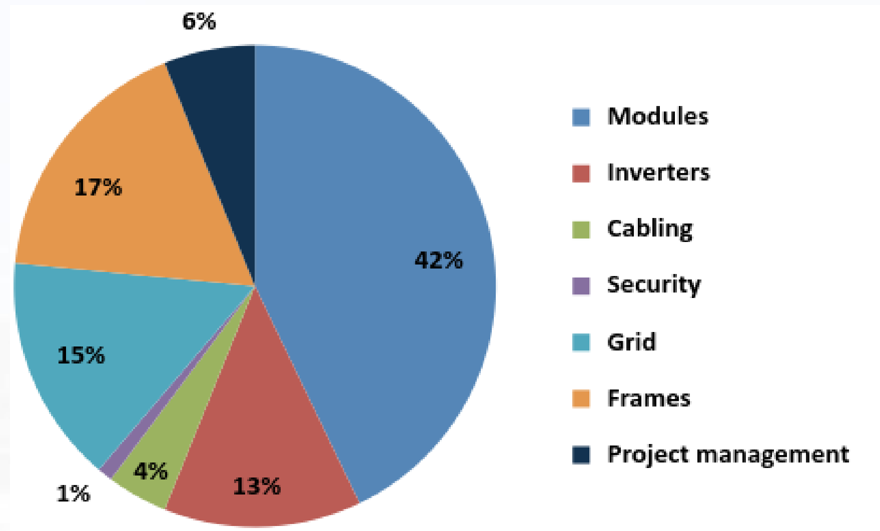
  (Based on 2°C Scenario with high deployment of renewable Energies)
- PV provides 16% of global electricity generation (energy) in 2050



Evolution of PV market

- Average CAPEX costs in 2014: **1.6 million $/MW**
- CAPEX and OPEX depend strongly on the considered world region

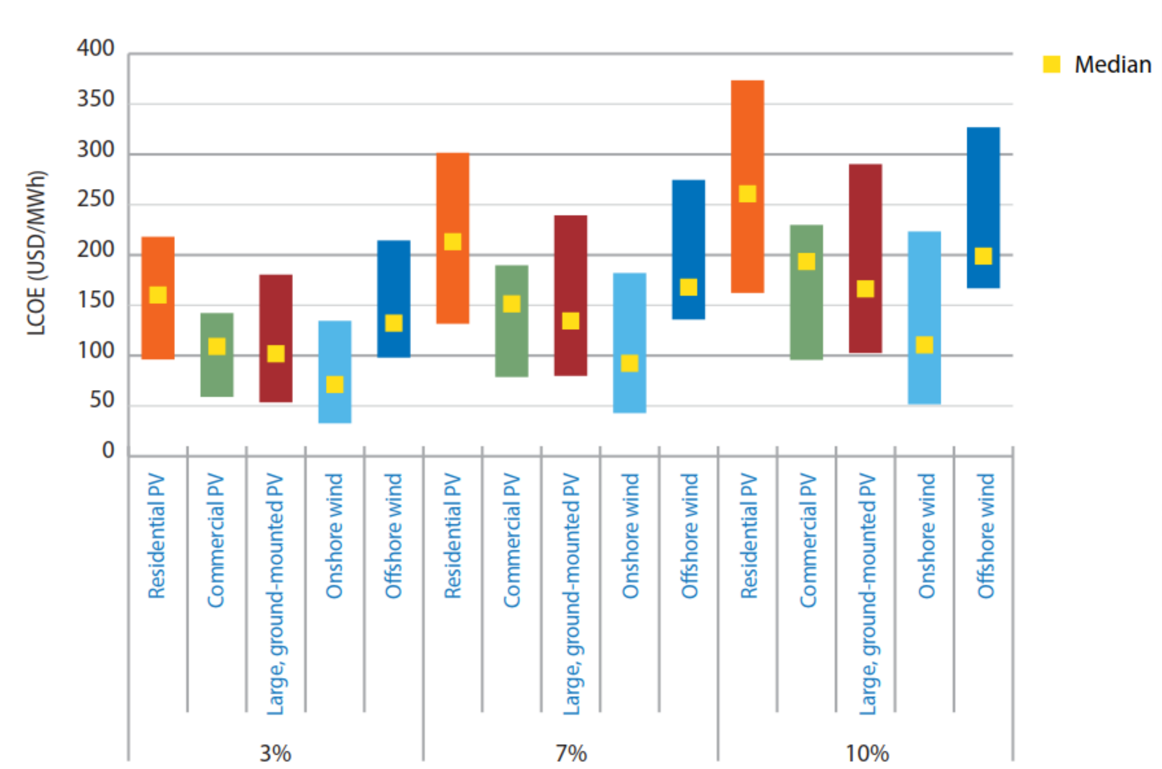
→ High Variation in costs



Variability of CAPEX and OPEX costs observed during 2013 and 2014

Evolution of PV market

- Comparison of LCOE of different PV and Wind energy systems for different discount rates
- Medium LCOE for large, ground-mounted PV systems: **100 - 170 USD/MWh**



Source: IEA

Evolution of PV market

- Forecast for LCOE based on 2°C Scenario:

  Two different scenarios for high and standard deployment of renewable energies

- Global Average for Utility-scale systems:

  - **83 USD/MWh** for 2DS Scenario

  - **75 USD/MWh** for 2DS hi-Ren Scenario

Table 9.6: LCOE for solar PV in 2015 and 2030

Scenario	Technology	LCOE 2015 (USD/MWh)	LCOE 2030 (USD/MWh)	Capacity 2030 (GW)
2DS	Utility-scale systems	110-294 (164 global average)	68-173 (83 global average)	841
	Rooftop systems	125-499 (186 global average)	77-389 (110 global average)	
2DS hi-Ren	Utility-scale systems	110-294 (164 global average)	52-129 (75 global average)	1 920
	Rooftop systems	125-499 (186 global average)	59-214 (94 global average)	

Notes: LCOE calculations are based on a discount rate of 7%. Ranges reflect regional differences in costs and solar conditions.

Source: IEA

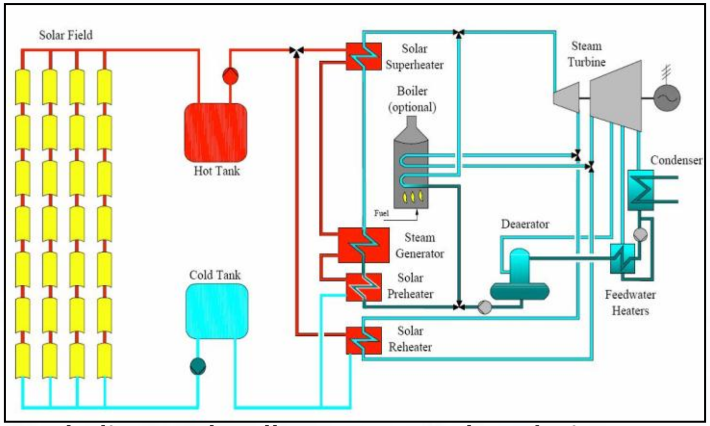
Evolution of CSP technology

1. Parabolic trough systems, most common worldwide

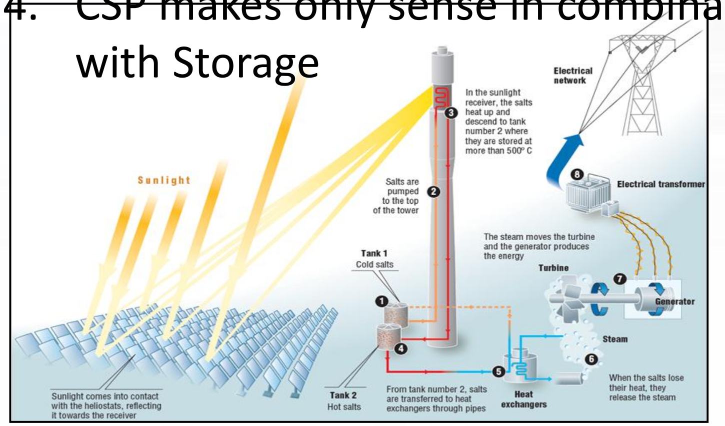
2. Solar Tower, highest efficiency

3. Linear Fresnel, for industrial applications

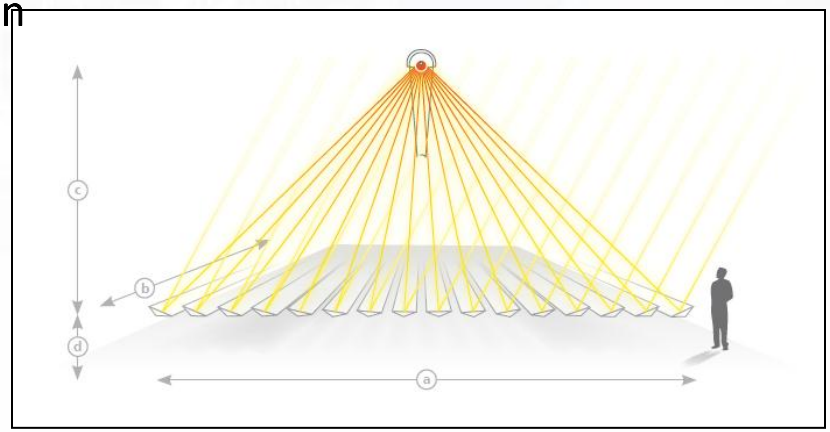
4. CSP makes only sense in combination with Storage



Parabolic trough collector power plant design



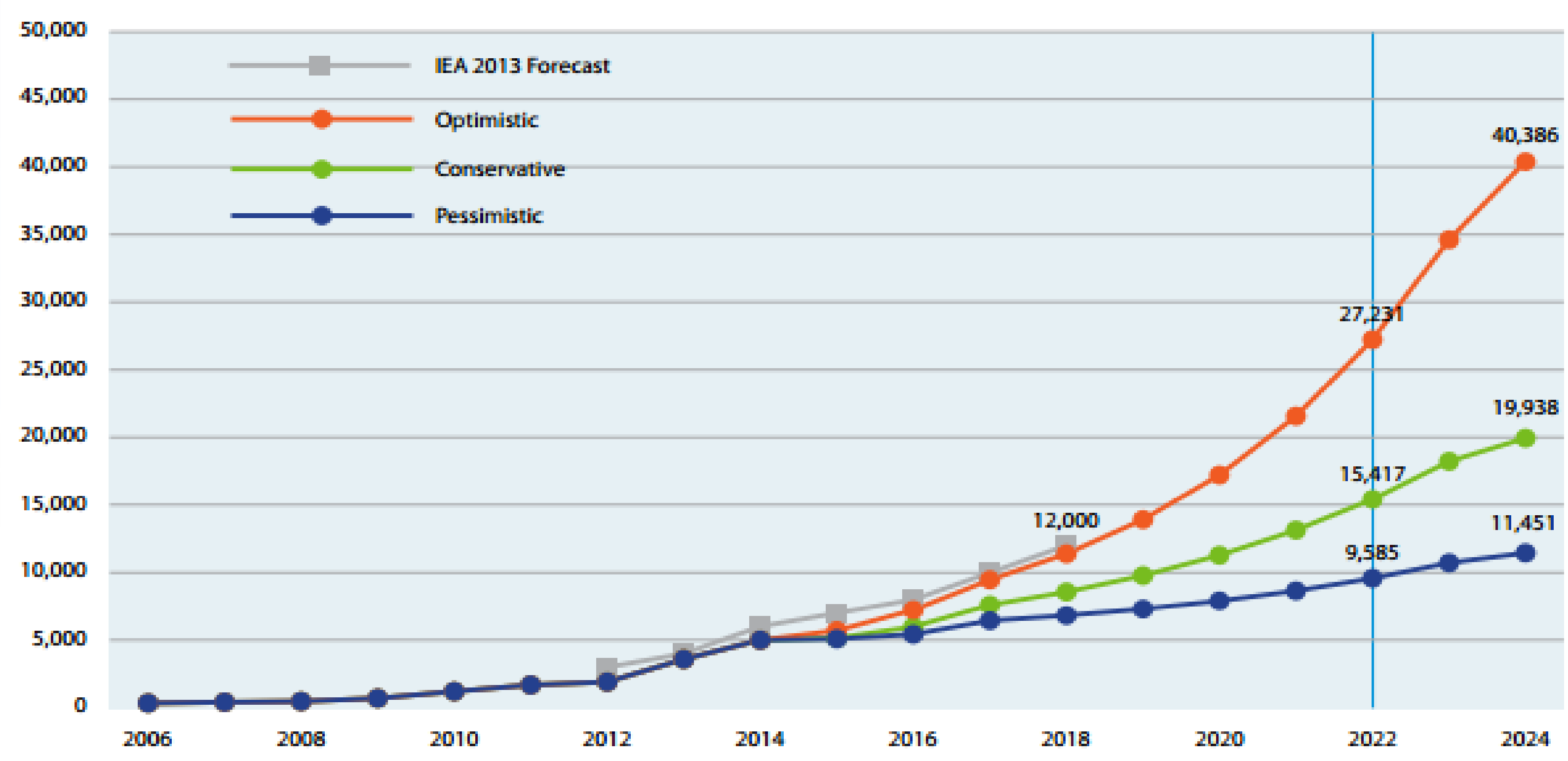
Solar Tower power plant design



Linear Fresnel system

Evolution of CSP technology

- Installed PV Power until 2015 worldwide: 5 GWp
- Increase in China, South Africa, Morocco, UEA, India
- Forecast until 2020: 10 GW installed power worldwide



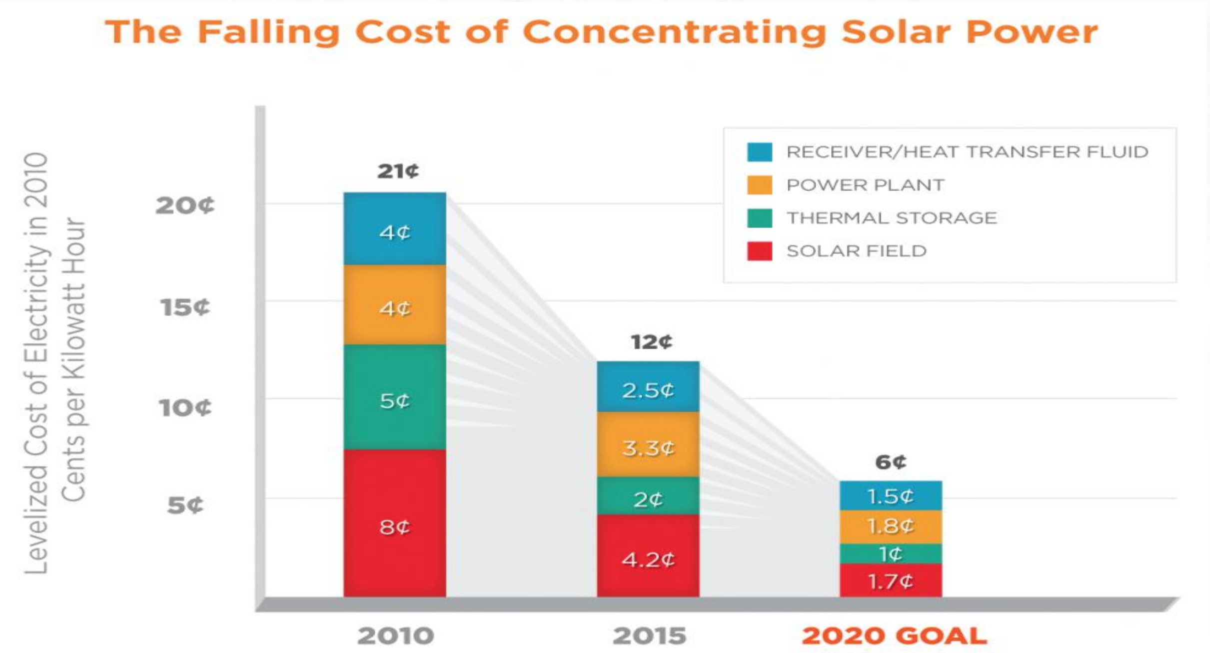
Evolution of CSP technology

- Average CAPEX costs in 2015 for a Parabolic trough system with 10 h of storage, good DNI around 2400kWh/m²a = **approx. 5200 USD / kW**
- Average CAPEX costs in 2015 for a SolarTower system with 10 h of storage, good DNI around 2400kWh/m²a = **approx. 6000 USD / kW**

- **Potential reduction of CAPEX for Parabolic trough system until 2020 ~ 6%**
- **Potential reduction of CAPEX for Solar Tower system until 2020 ~ 32%**

Evolution of CSP technology

- Current LCOE for large scale CSP power plants 2015: **130-210 USD/MWh**
- Medium LCOE for large CSP systems in 2020: **80 - 160 USD/MWh**
- Forecast of Sunshot initiative even more agressiv; current offers in Chile for 60 USD / MWh available, UAE is heading towards 80 USD / MWh for 200 MW power plant
- Market is volatile and hardly predictable



Source: Sunshot

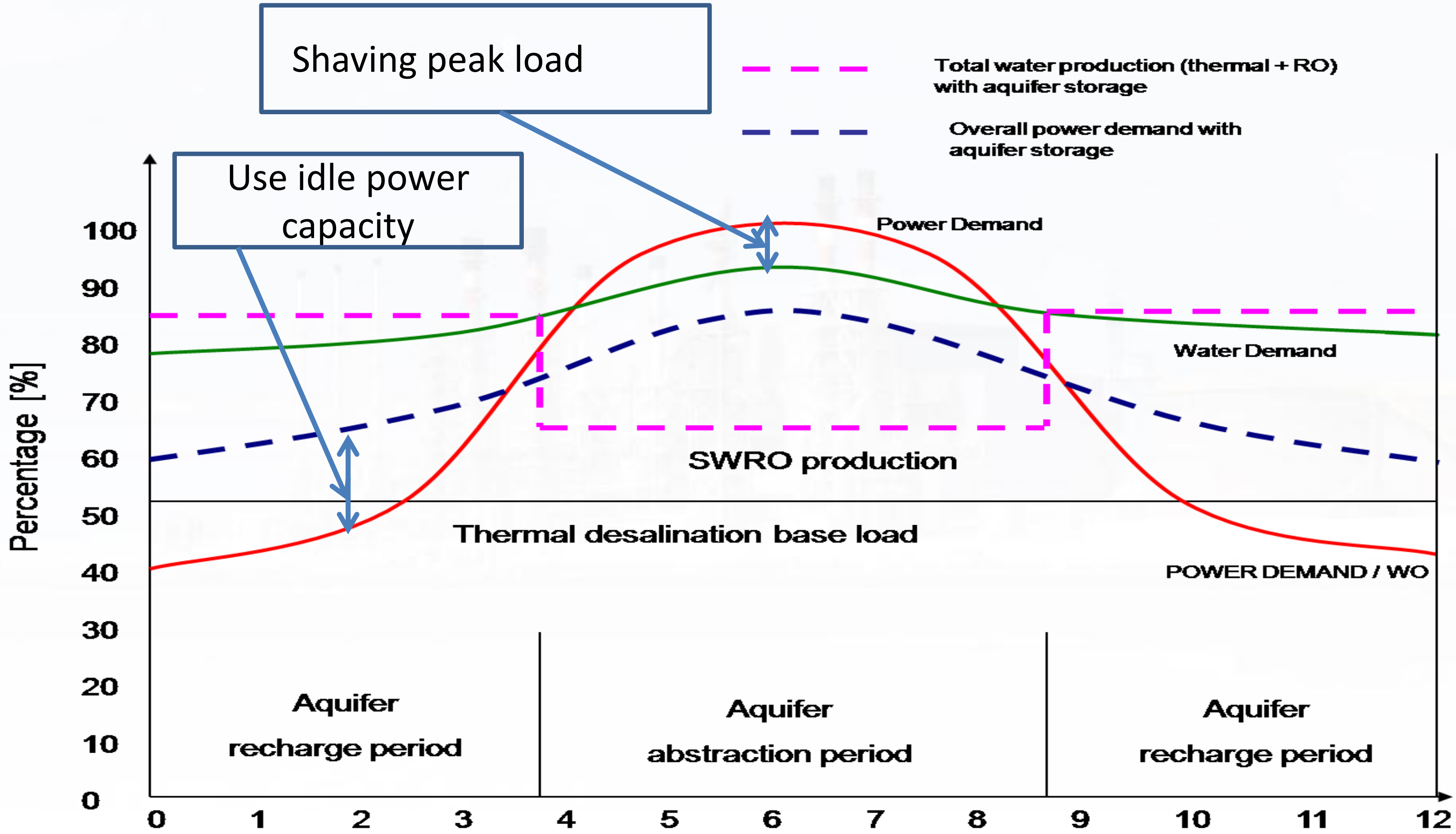
Efficiency by Energy storage

Harmonizing generation and supply

Nuclear and renewable plants must operate at baseload therefore during the Winter months there may not be sufficient electricity generation at co-generation stations to maintain water production of the thermal plants.

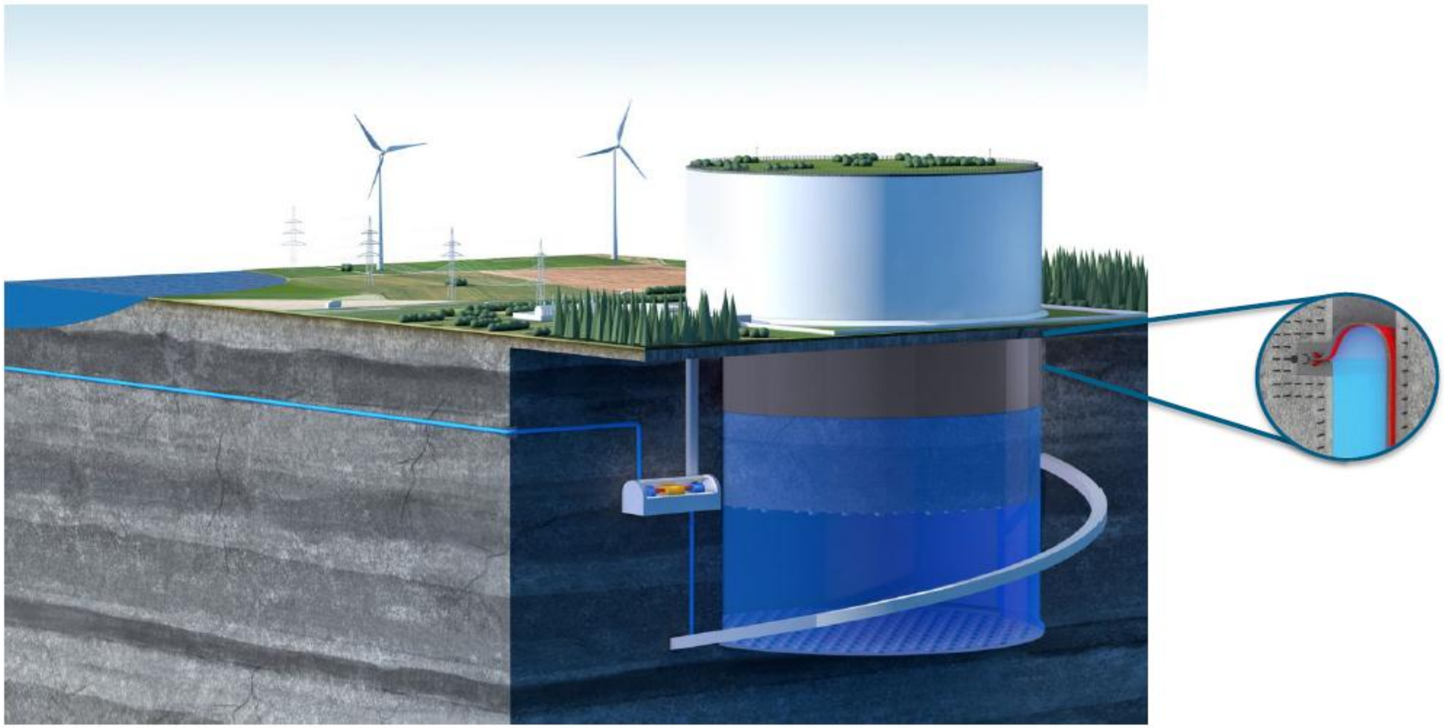
A gradual switch of the desalination technology from thermal to SWRO obviously would offer the solution to this problem as SWRO offers the possibility of absorbing part of the idle power load in winter time and can be completely disengaged from the thermal power mode of operation.

Opportunities for energy optimization



Harmonizing generation and supply

Hydraulic Rock Storage pushes storage of electricity in a new dimension of efficiency



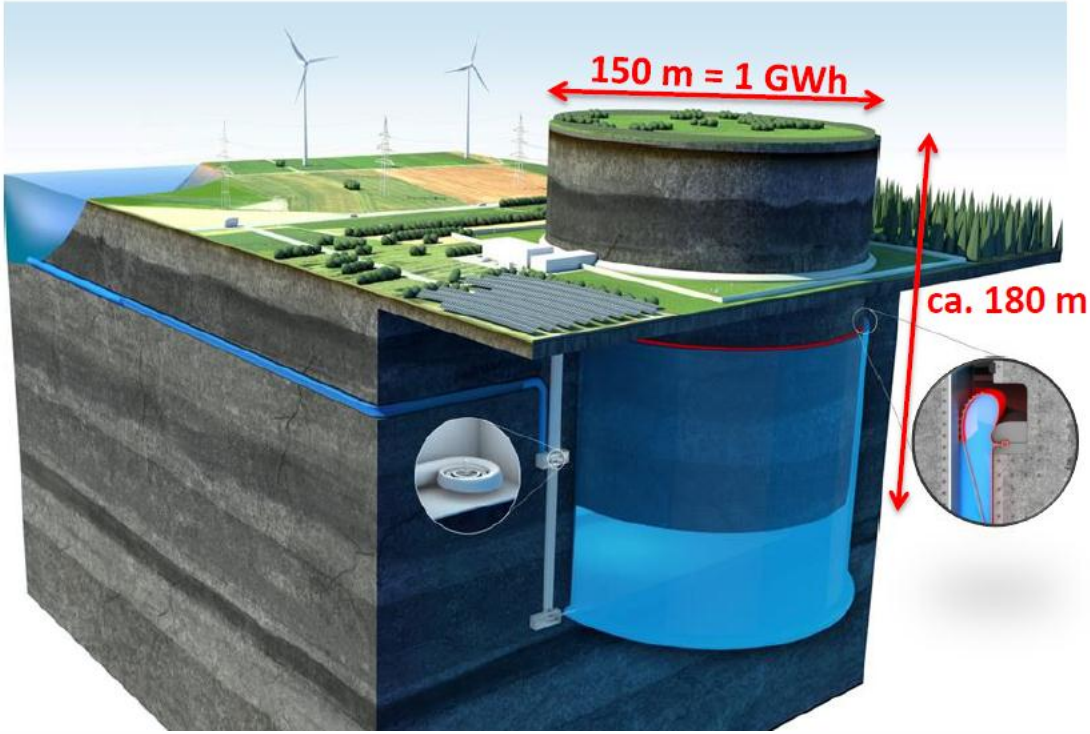
Functionality: A piston of rock that has been exposed from its natural surroundings, is raised up using water pressure, and when power is needed, the water is released and routed to turbines.

The concept of hydraulic hydro storage (HHS) offers an innovative solution because it can store large amounts of energy for a long time.

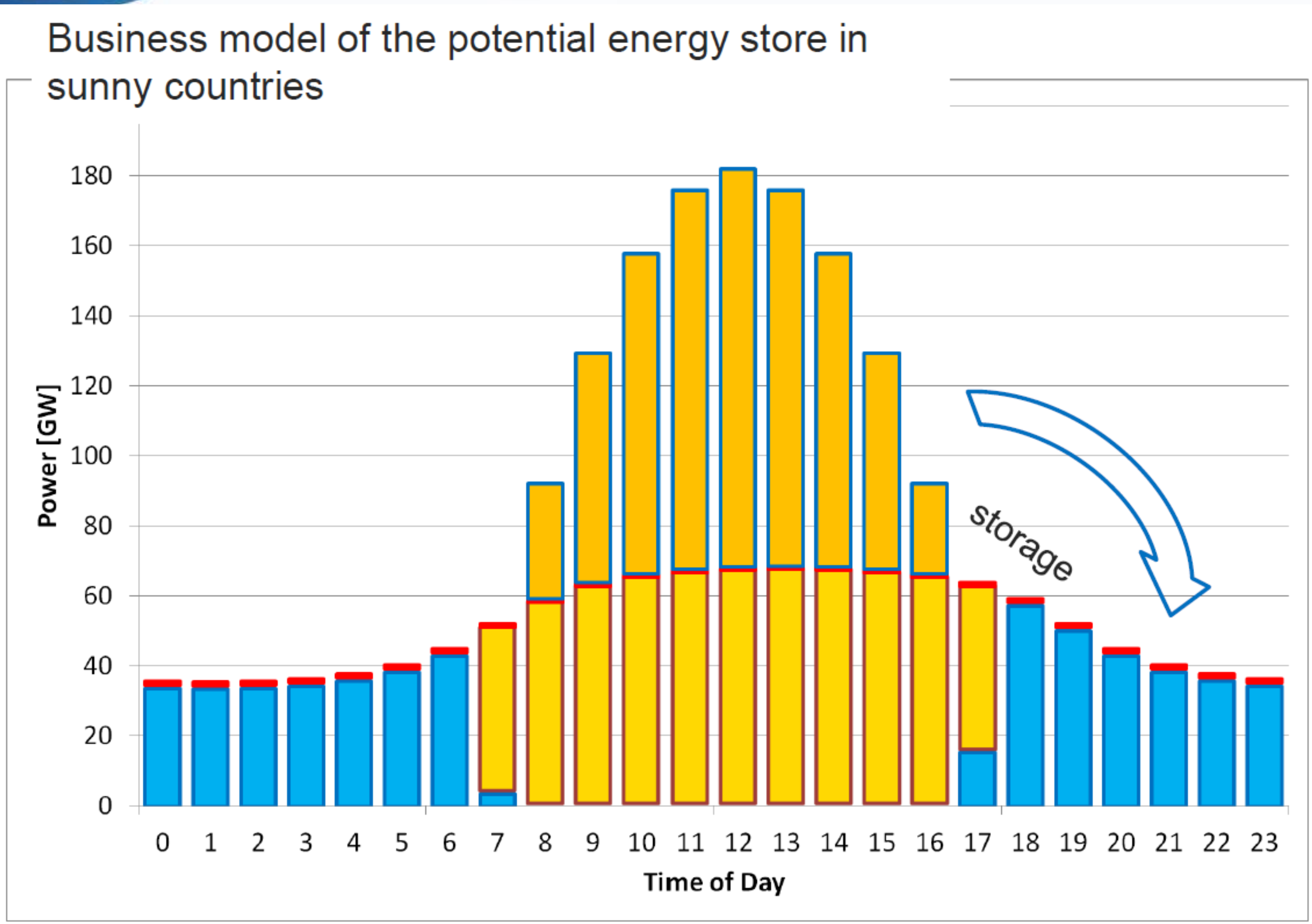
Harmonizing generation and supply

- The rock piston needs to be dismantled from its side walls using rock cutting technology.
- All exposed surfaces will be sealed with geomembranes against environmental impacts and water.
- The piston wears a sealing ring, which is flexible to compensate inaccuracies of the piston wall.
- The storage can be constructed with approved technologies from mining and tunnel constructions.

1. Build tunnel to access the bottom
2. Separating bottom of piston
3. Separating side walls by blasting (parallel to 1, 2)
4. Sealing the surfaces
5. Installing sealing system
6. Installing pumps, turbines and generators etc.



Harmonizing generation and supply



Innovative and advanced desalination technologies and renewable desalination

Advances and new desalination technologies

Thermal		Membrane	
Process	Status	Process	Status
Low energy application to MED technology	Proven in small to medium size pilot plant	Forward Osmosis	Proven in small industrial plant, contracted for new larger applications
LTD desalination	Proven to medium size industrial plant	Biomimetics	Production of initial membranes under further development
Membrane distillation	Proven in small scale pilot	High efficiency membranes	Under further study: laboratory
Forward Osmosis With associated thermal energy for draw solution separation	Proven in small industrial plant, great potentials	Carbon Nanotube	Production of initial membranes under further development
		Pressure Retarded Osmosis (PRO)	Demonstration plant: lab scale
		Carbon Nanotube (CNT)	Production of initial membranes under further development

Advances and new desalination technologies

Thermal			
Process	**Energy requirement**		**Energy optimisation Development outlook**
	Thermal [kJ/kg]	Electric energy [kwh/m^3]	notes
Low energy application to MED technology	200 Required at 70°C in form of hot water or steam therefore at low exergy value	1.0- 1.5	Relatively limited. However the thermal energy footprint could be reduced to 150 kj/kg.
LTD desalination	250 kj/kg Required at 70°C down to 50°C in form of hot water or steam	0.8- 3.0 (*)	Potentially very high. However the thermal energy footprint could be reduced to 100 kj/kg.
Membrane distillation	300-400 kj/kg Required at 70°C down to 50°C in form of hot water or steam	1 - 2.0 (*)	Potentially very high. However the thermal energy footprint could be reduced to 100 kj/kg with multistage installation and proper development of MD membranes
Forward Osmosis With associated thermal energy for draw solution separation	80-100 kj/kg Required at 90°C in form of hot water or steam	2-3	Specific power consumption development outlook could decrease to 1-1.5 through the development of a dedicated FO membrane

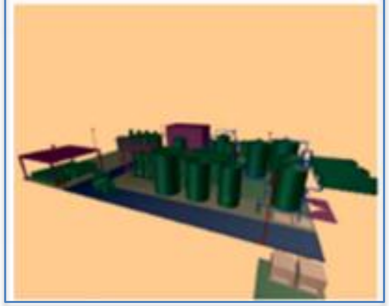
The Ghantoot experience

- The demonstration includes **5 pilot plants** located in Ghantoot, Abu Dhabi. Each pilot plant will be operated over 18 months;
- Masdar implements the program in **close collaboration** with the Abu Dhabi governmental agencies in the water sector;
- The 5 pilot plants demonstrate different **advanced and innovative** desalination technologies.

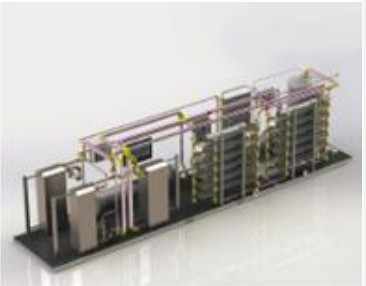
ABENGOA
Reverse Osmosis
+ Membrane Distillation
1000 m^3/d

SIDEM/VEOLIA
Reverse Osmosis
300 m^3/d

SUEZ
Reverse Osmosis
+ Ion Exchange
100 m^3/d



TREVI SYSTEM
Forward Osmosis
50 m^3/d



MASCARA NT
Off-grid
Reverse Osmosis
30 m^3/d

The Ghantoot experience

ABENGOA

Abengoa desalination pilot plant

suez

Suez desalination pilot plant

TREVI SYSTEMS

Trevi Systems desalination pilot plant

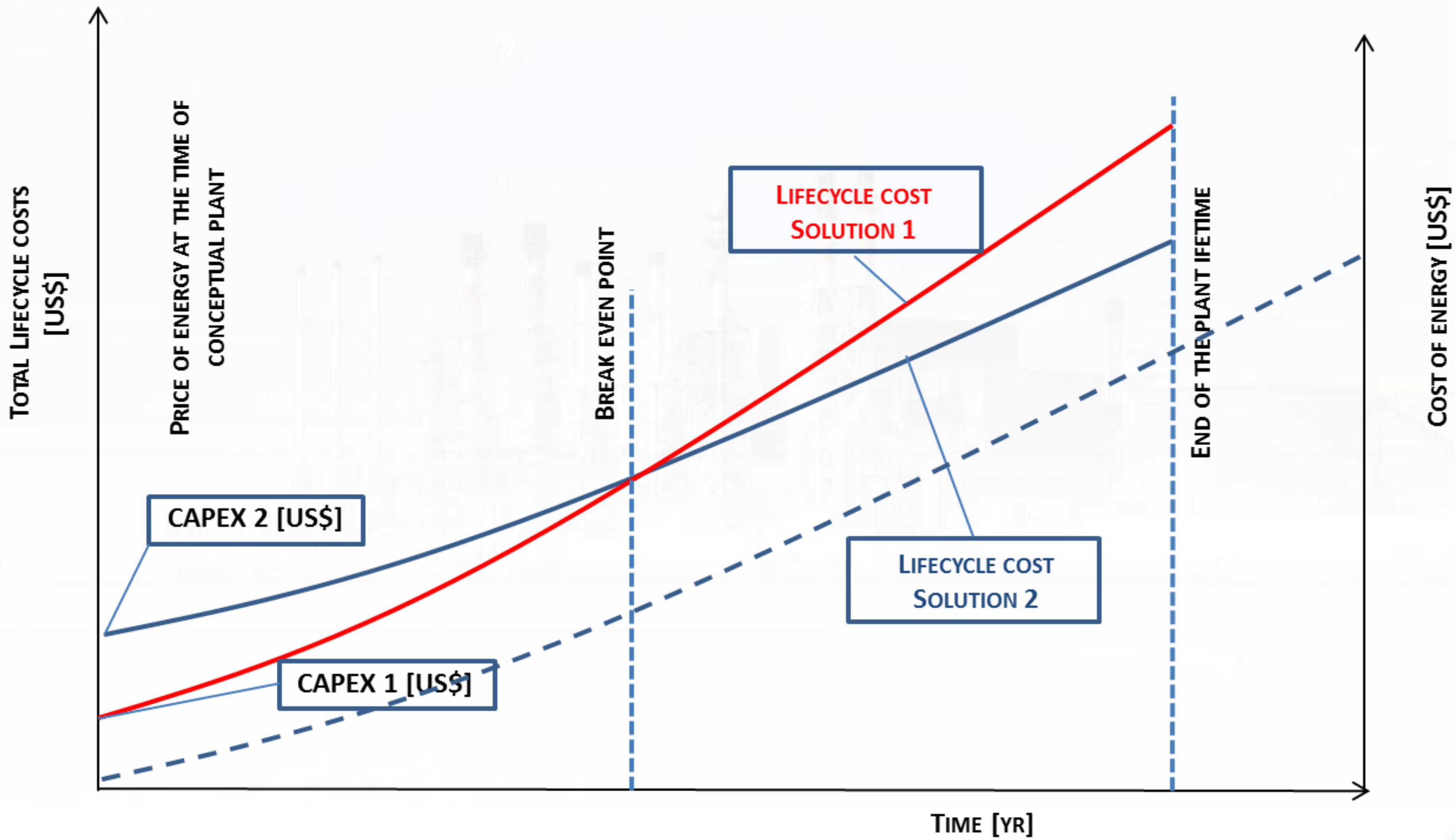
SIDEM VEOLI

Veolia desalination pilot plant

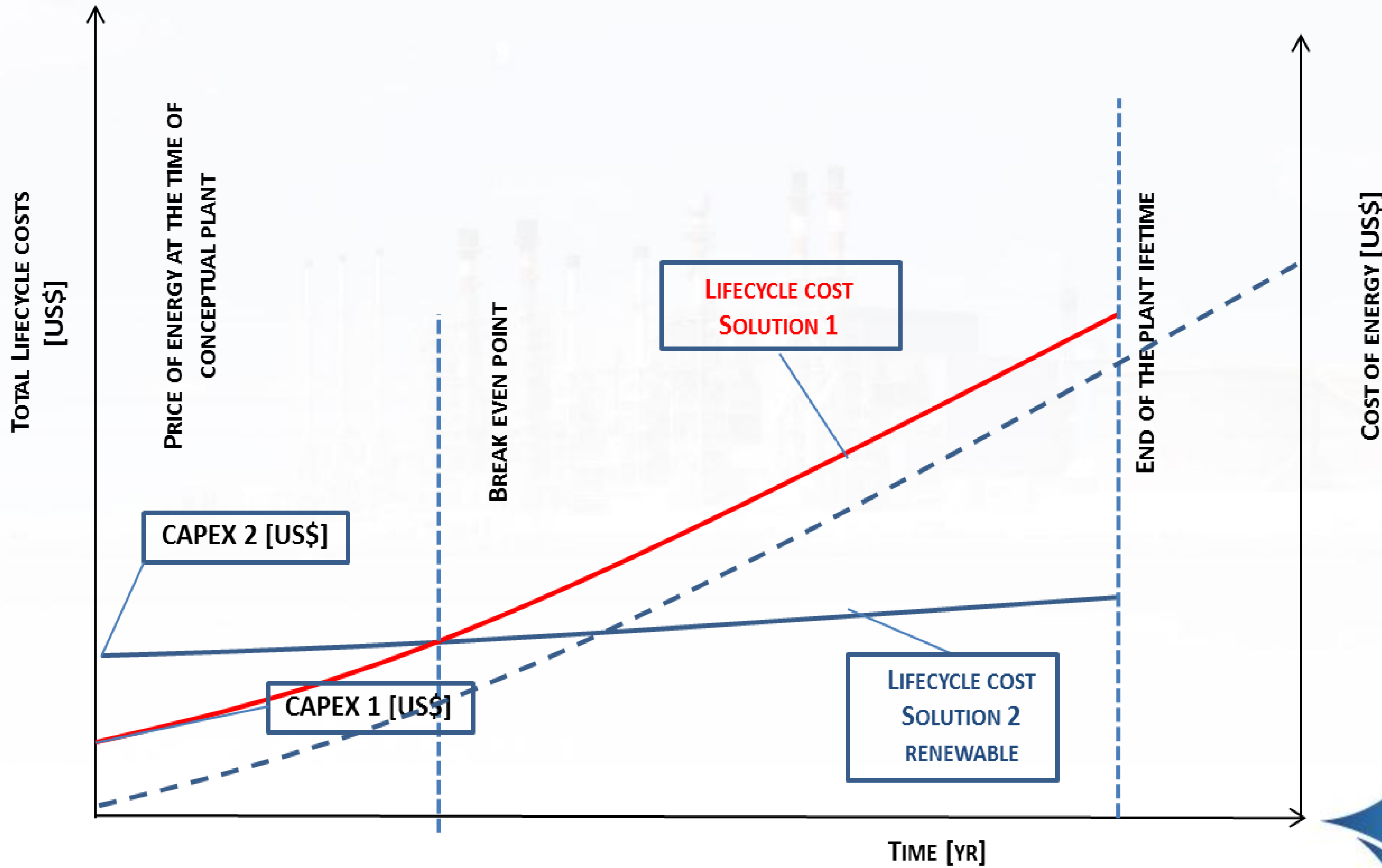
Mascara
L'eau renouvelable

Economics of sustainability and green development

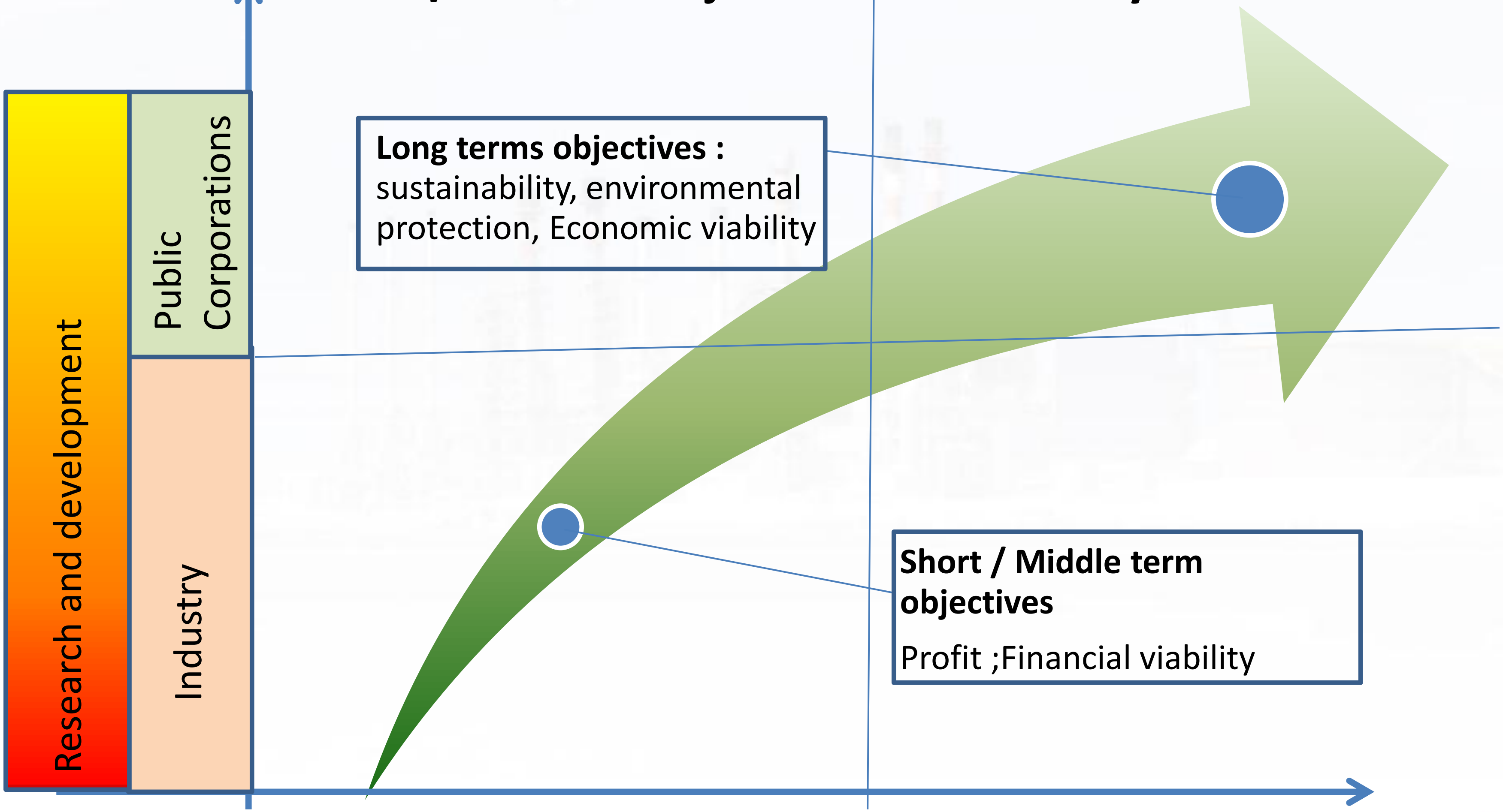
Lifecycle examples… sustainable is not always more expensive



Lifecycle examples… sustainable is not always more expensive



Public/ Private Objectives Dichotomy



End of the course

Thanks !!!!!