MEDITERRANEAN WORKSHOP ON
NEW TECHNOLOGIES OF RECYCLING NON CONVENTIONAL WATER IN PROTECTED CULTIVATION
AGADIR (29 April-1 May, 2008)

SOLAR DESALINATION – RECENT RESEARCH ACTIVITIES OF PLATAFORMA SOLAR DE ALMERIA

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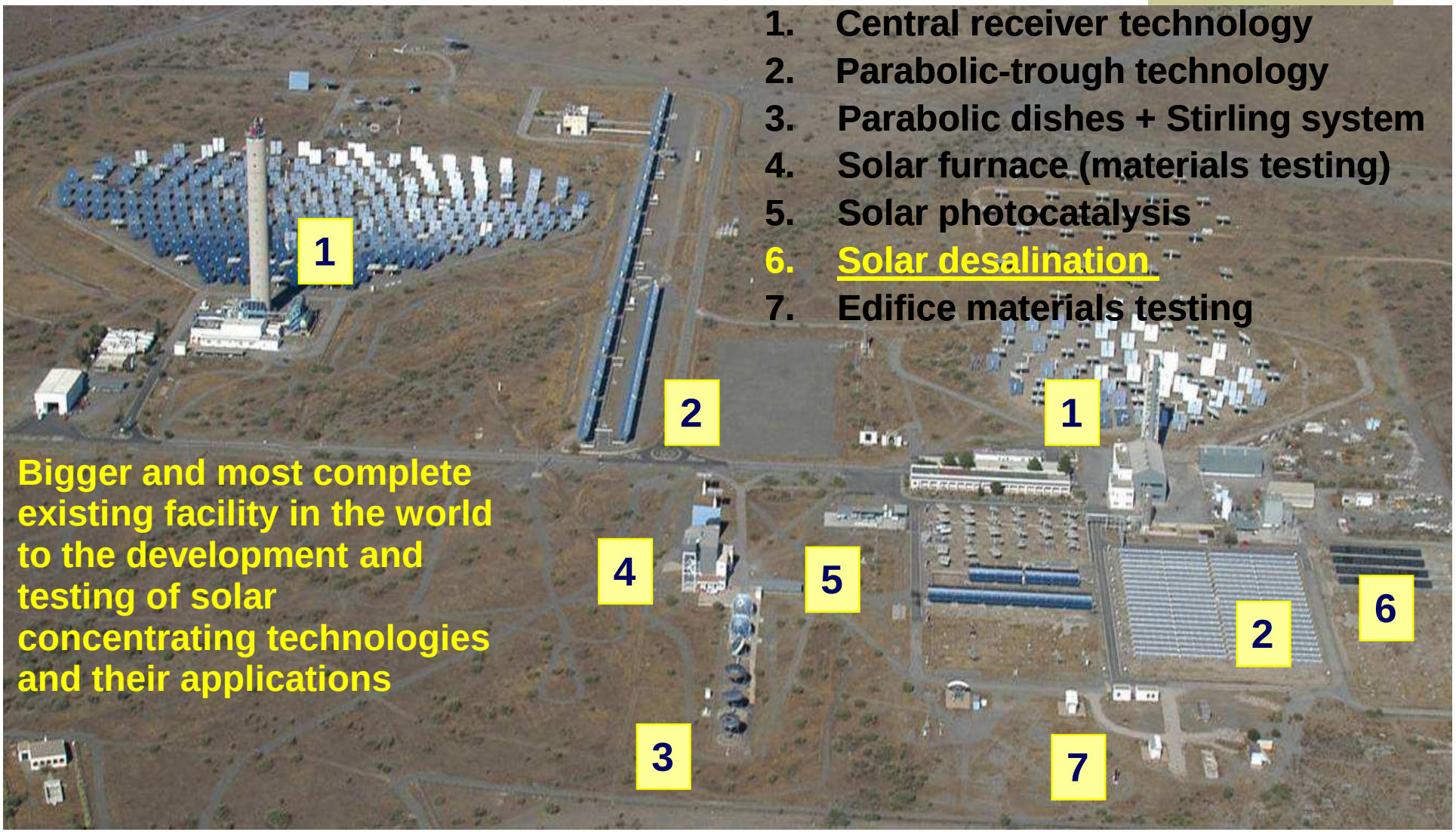
MINISTERIO DE EDUCACION Y CIENCIA

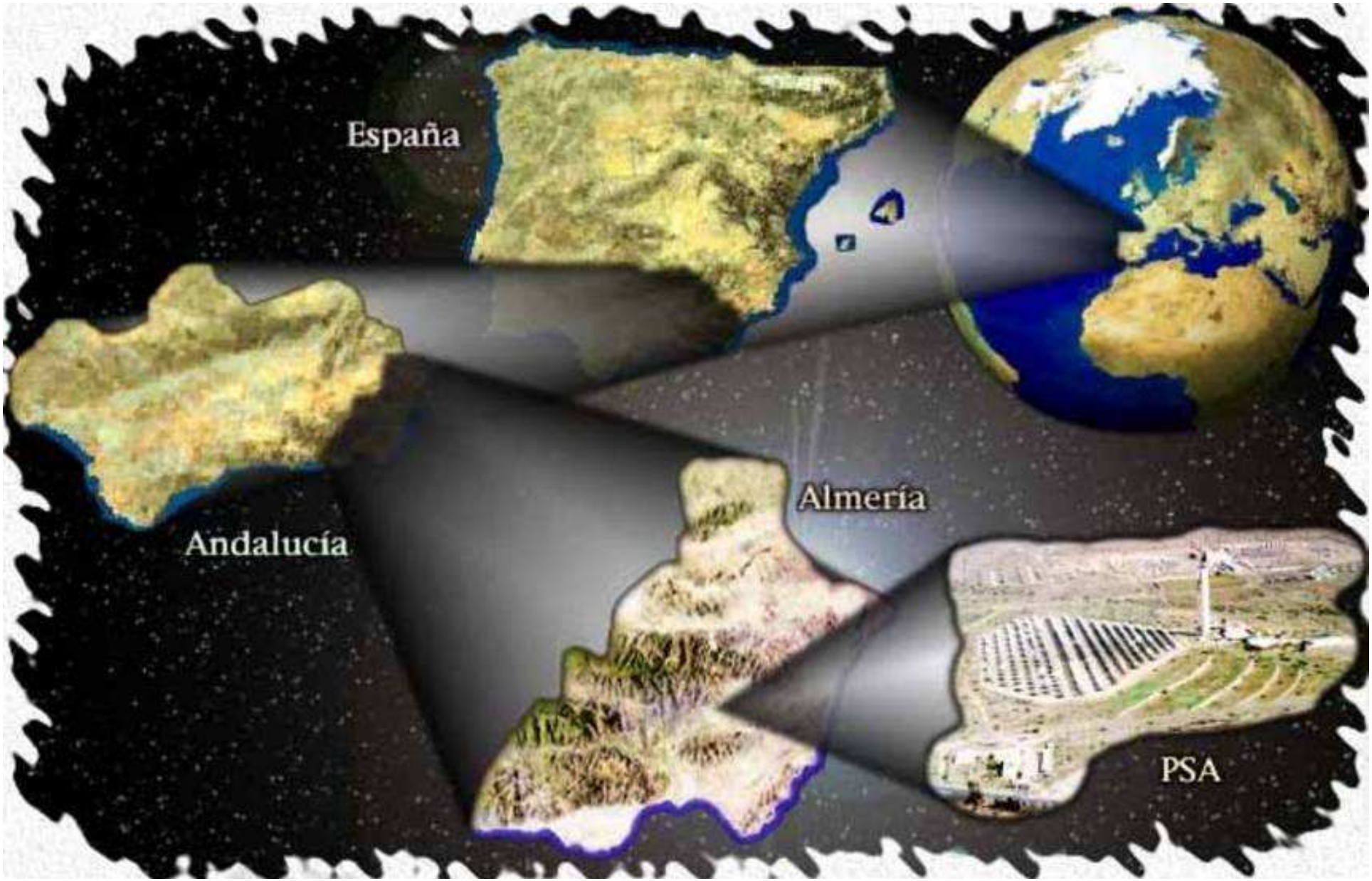
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

PLATAFORMA SOLAR DE ALMERÍA



1. Central receiver technology
2. Parabolic-trough technology
3. Parabolic dishes + Stirling system
4. Solar furnace (materials testing)
5. Solar photocatalysis
6. Solar desalination
7. Edifice materials testing

Bigger and most complete existing facility in the world to the development and testing of solar concentrating technologies and their applications


España
Andalucía
Almería
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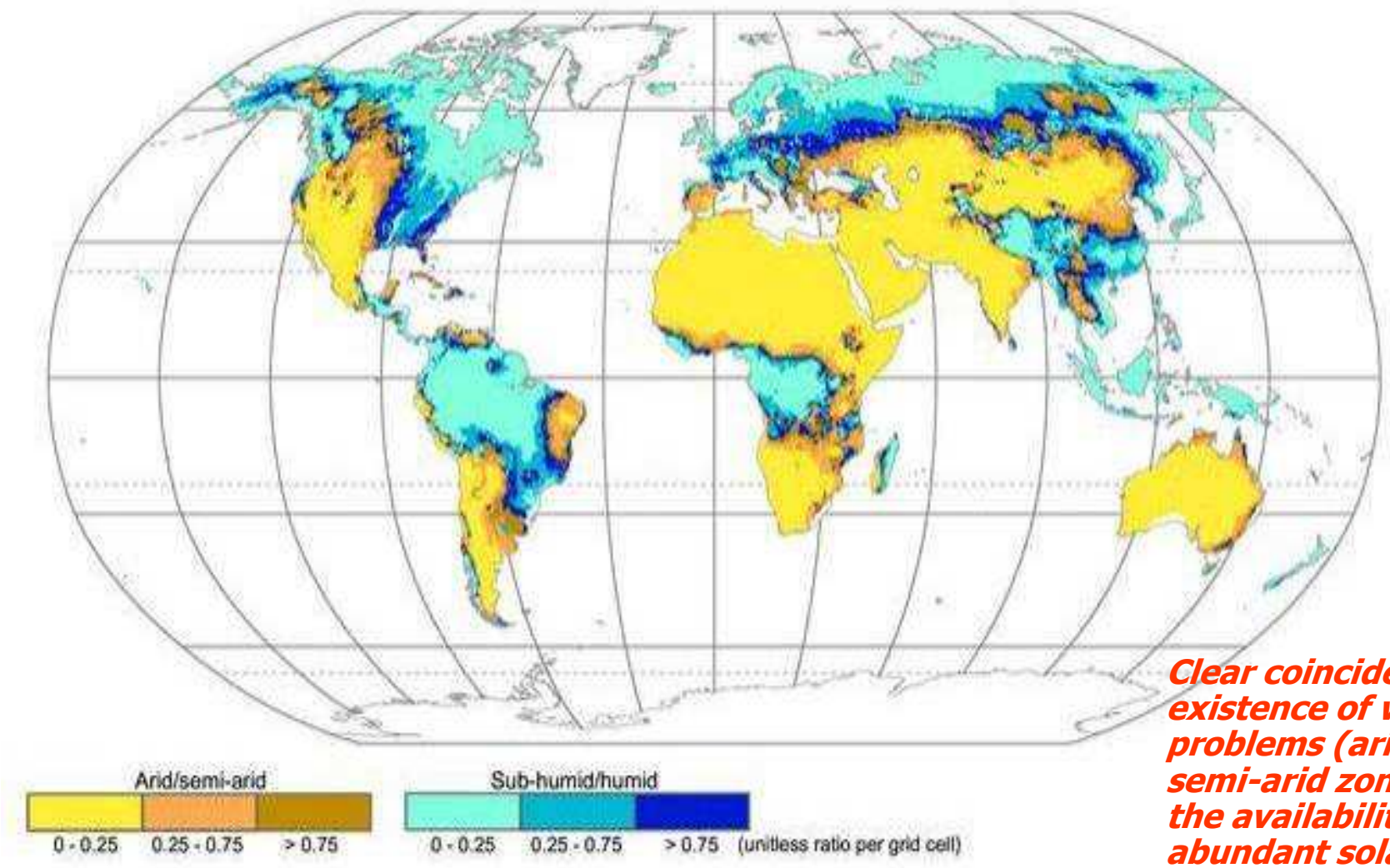
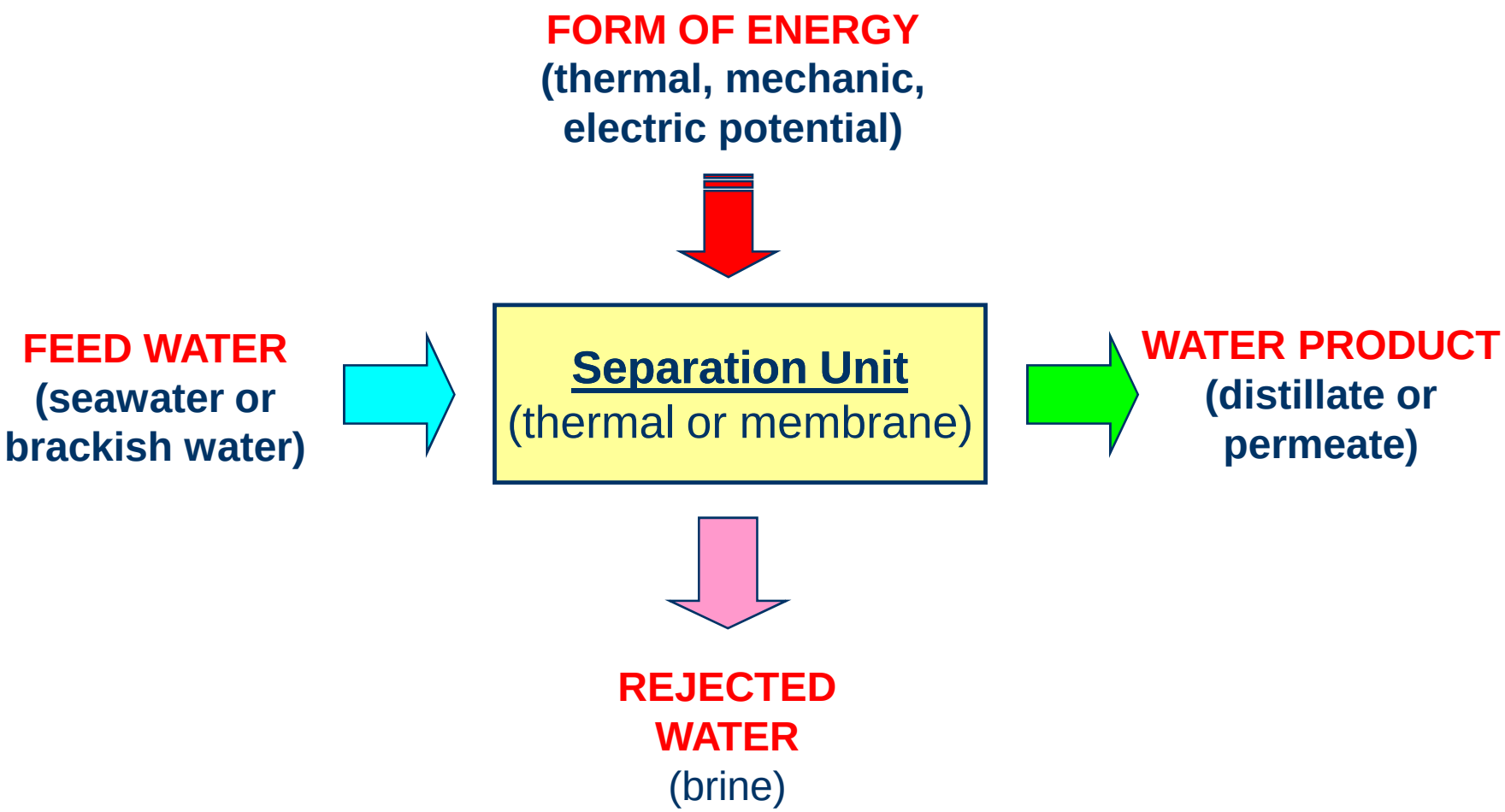
SOLAR ENERGY & ARID ZONES

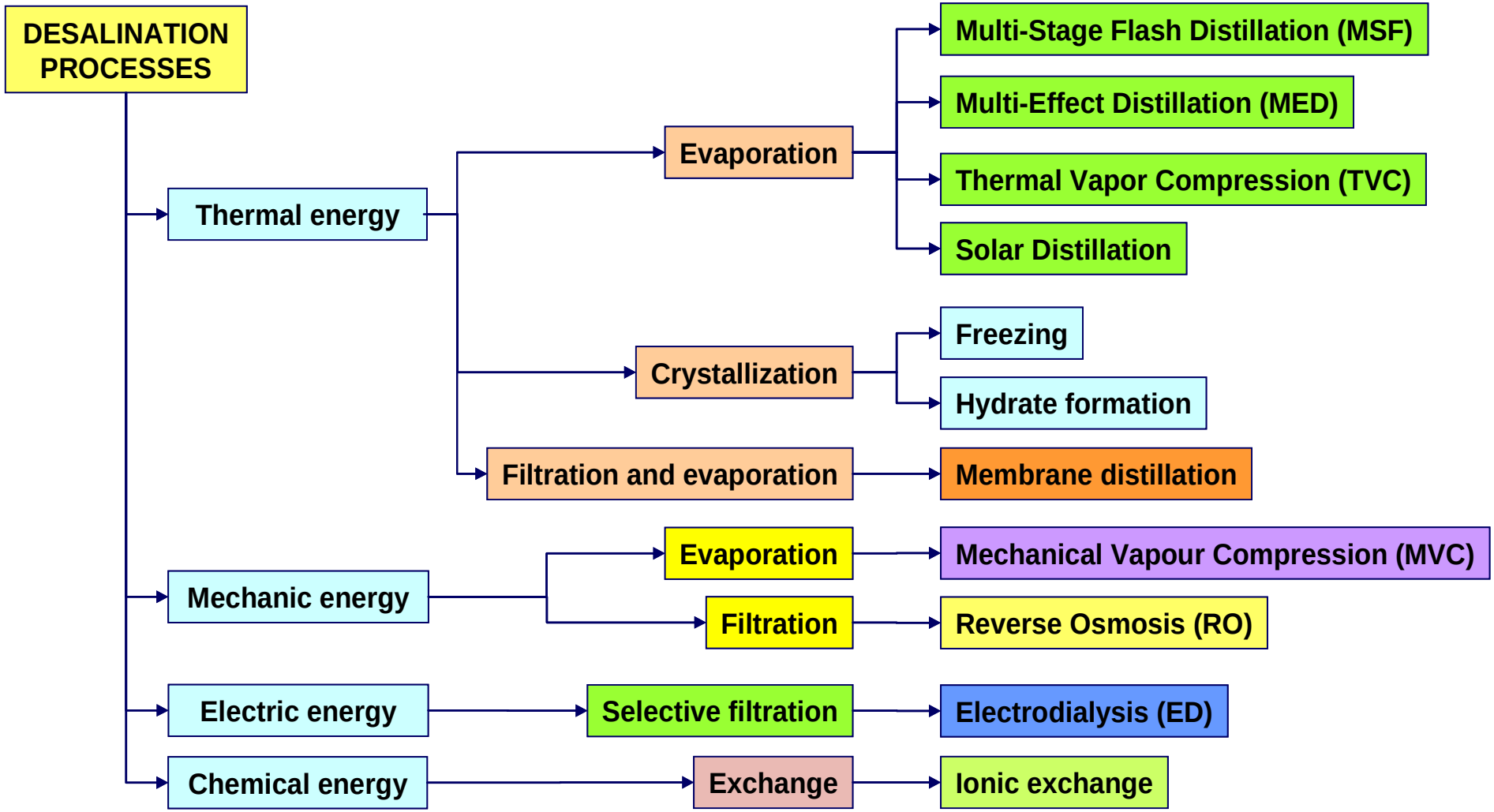


Clear coincidence in the existence of water problems (arid and semi-arid zones) and the availability of abundant solar radiation

THE DESALINATION PROCESS

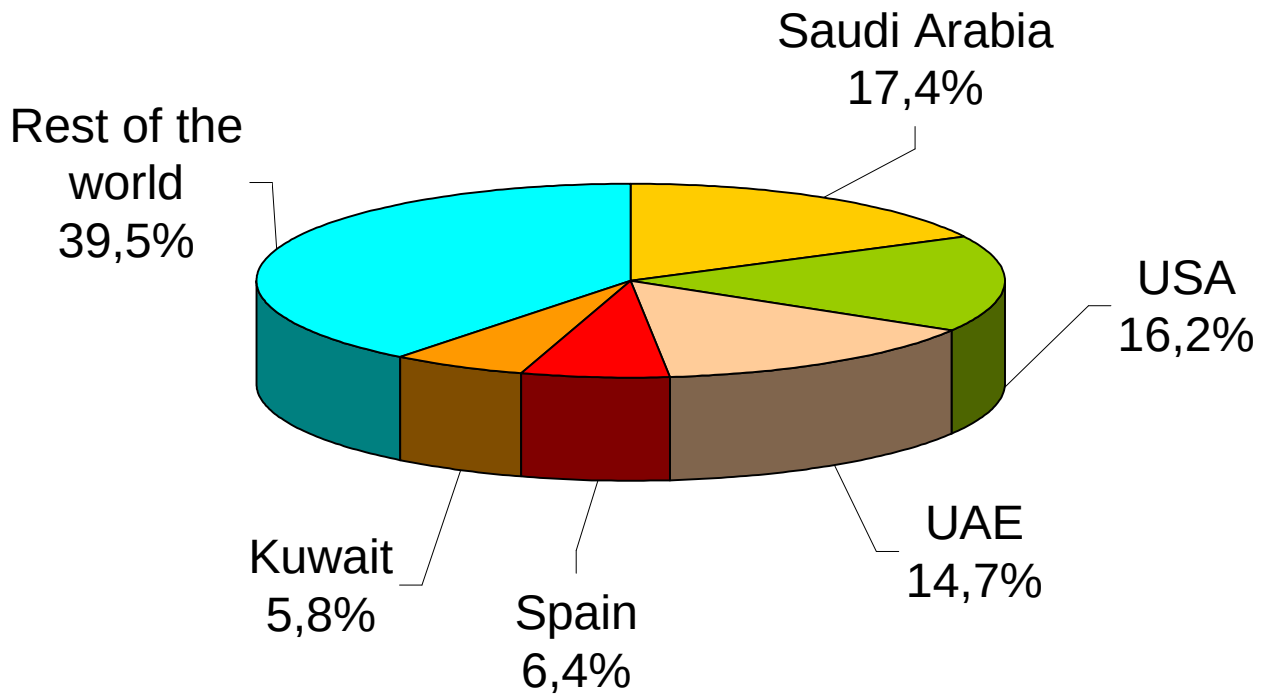


DESALINATION PROCESSES



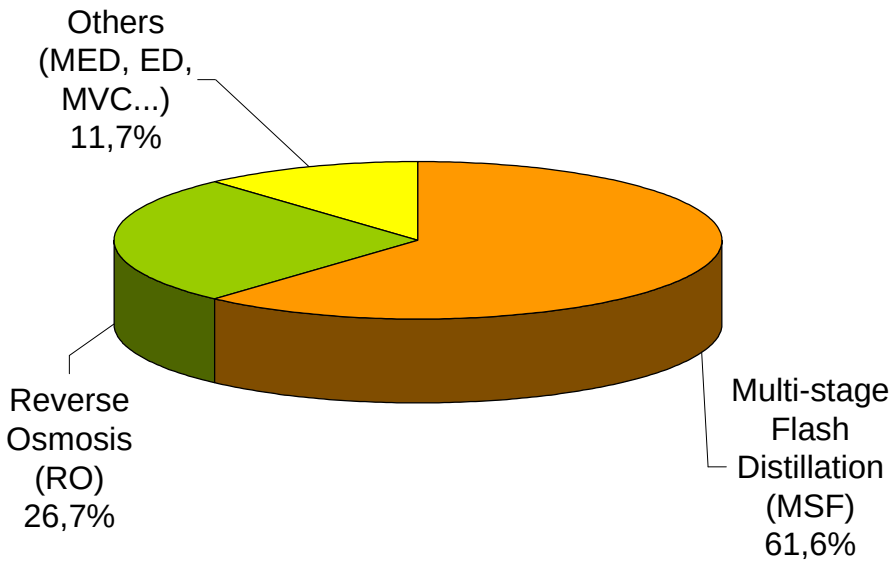
WORLD CAPACITY DISTRIBUTION

Five countries (Saudi Arabia, USA, UAE, Spain and Kuwait) share more than 60% of the world production capacity of desalinated water.

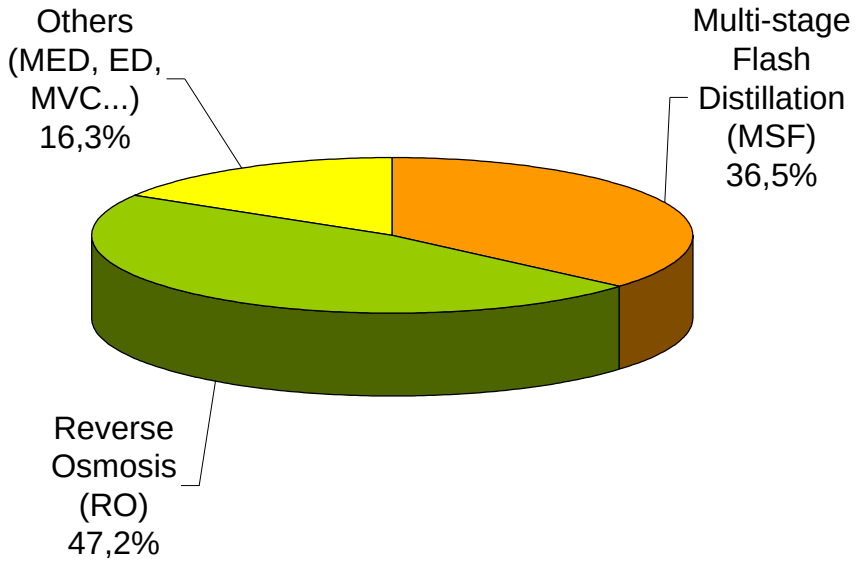


PROCESS DISTRIBUTION CAPACITY

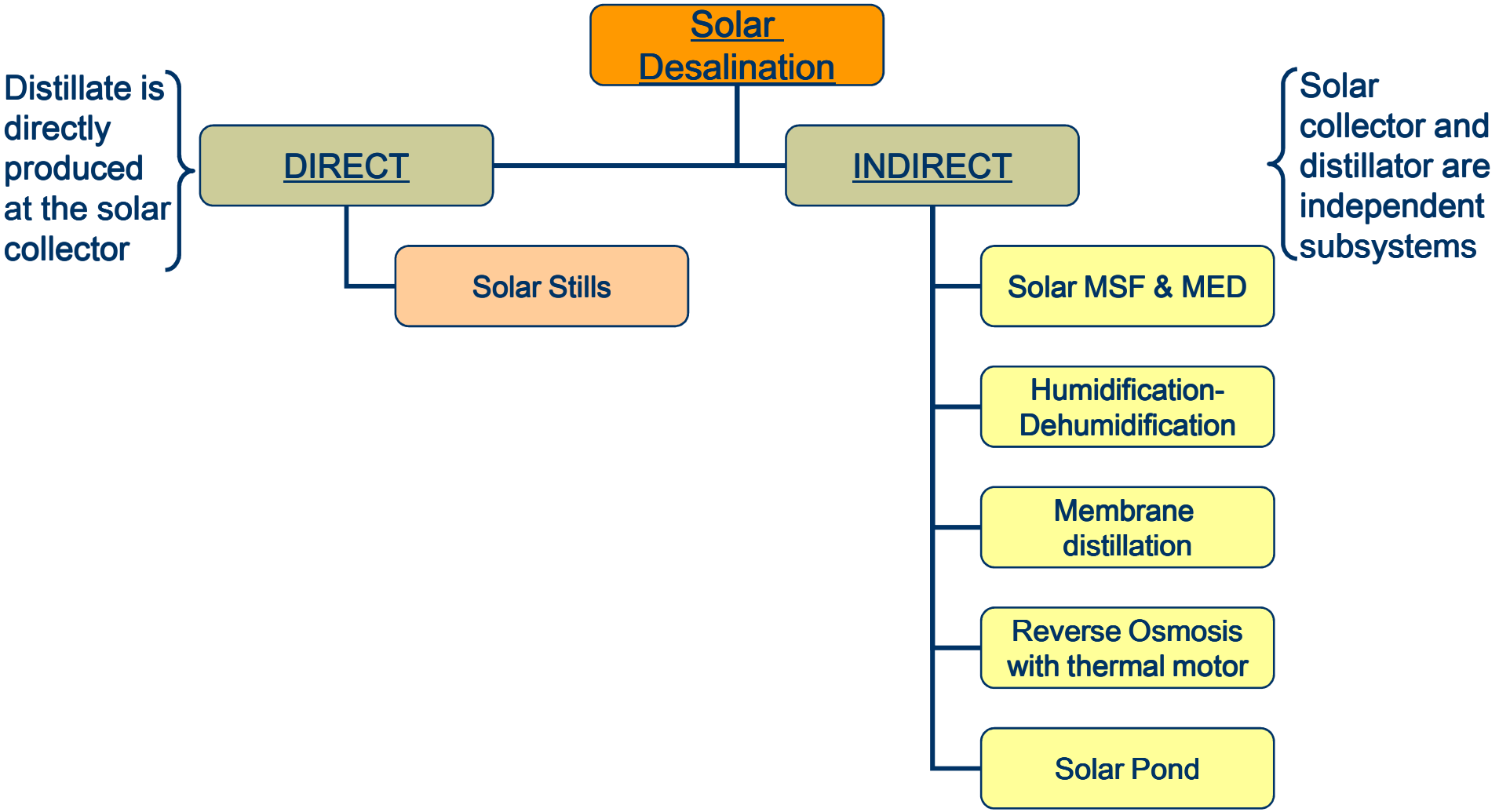
Sea water



Sea water + brackish water



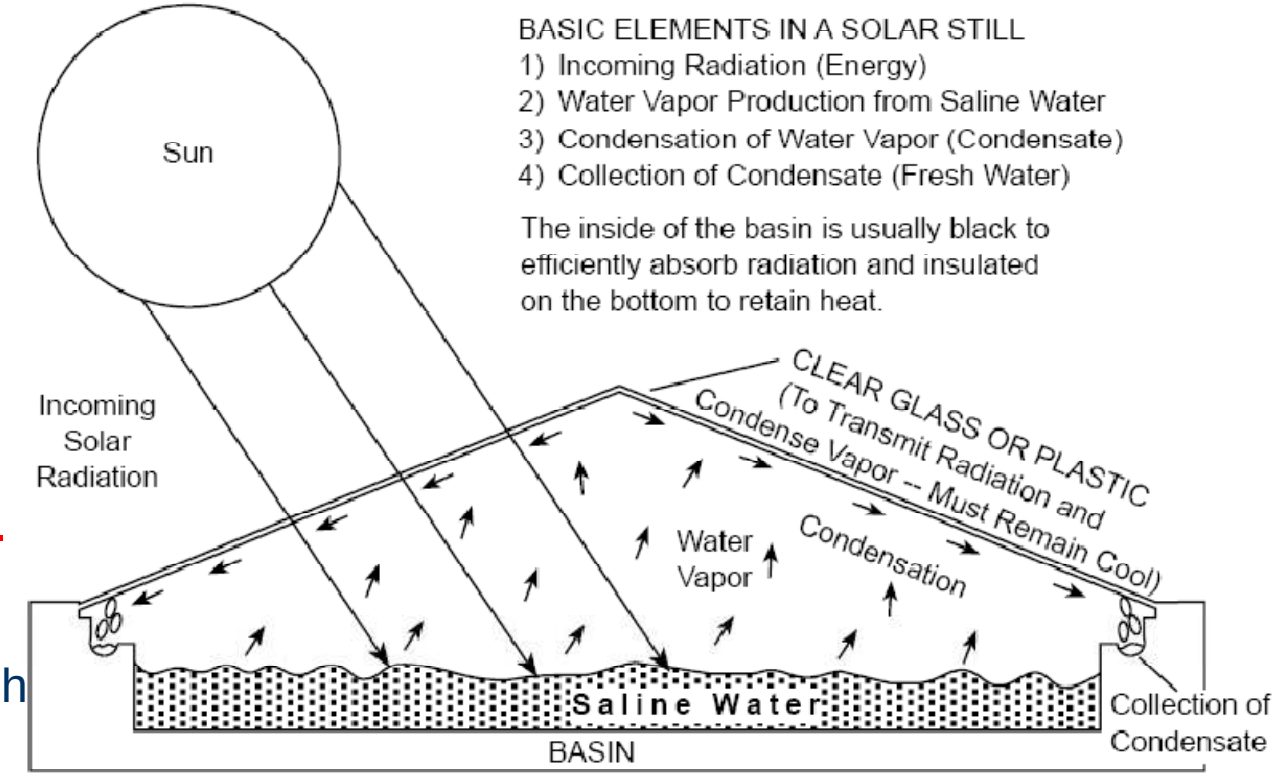
SOLAR THERMAL DESALINATION



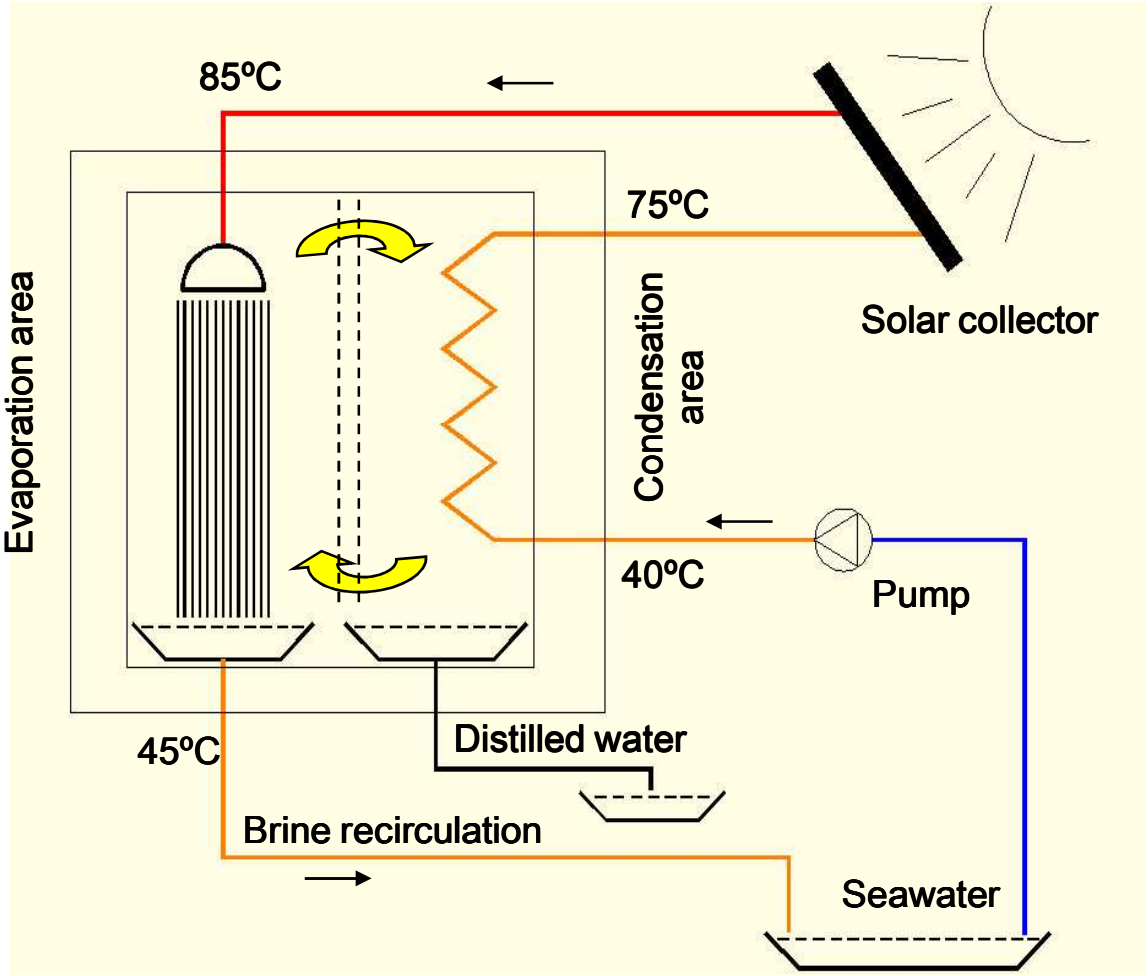
SOLAR STILLS

Parameters that affect efficiency of solar stills include water depth, solar radiation intensity, cover inclination and material, and feed water temperature.

Solar Still present a low distillate production per surface unit (between **1 and 4 L/m2/d**). Typical **Performance Ratio** of a solar still is about **0.53**, which means that **4652 kJ** are required to produce one kilogram of desalted water.

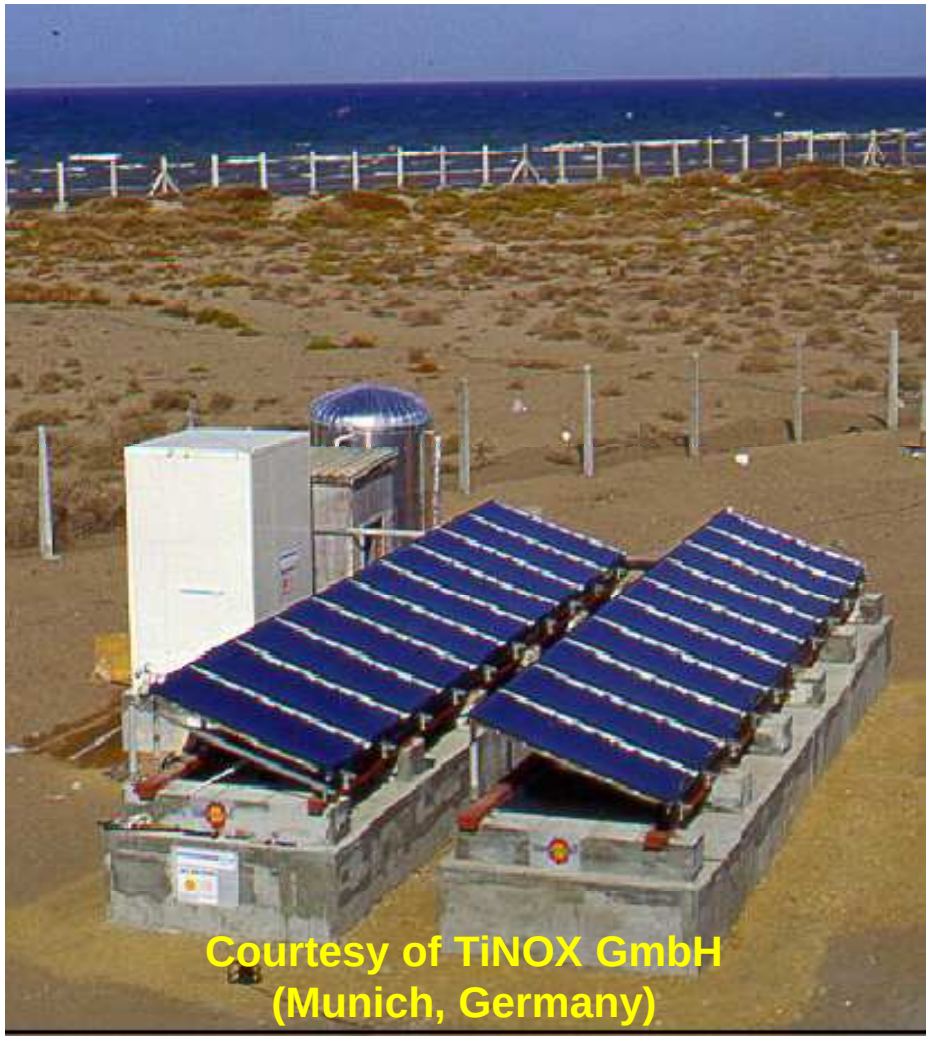


HUMIDIFICATION-DEHUMIDIFICATION



Desalination process based on the **increase of water saturation capacity of air with temperature**. Thermal energy can be provided by flat solar collectors. Typical distillate production: **10 to 20 L/m²** (of solar collector) **and day**

HUMIDIFICATION-DEHUMIDIFICATION

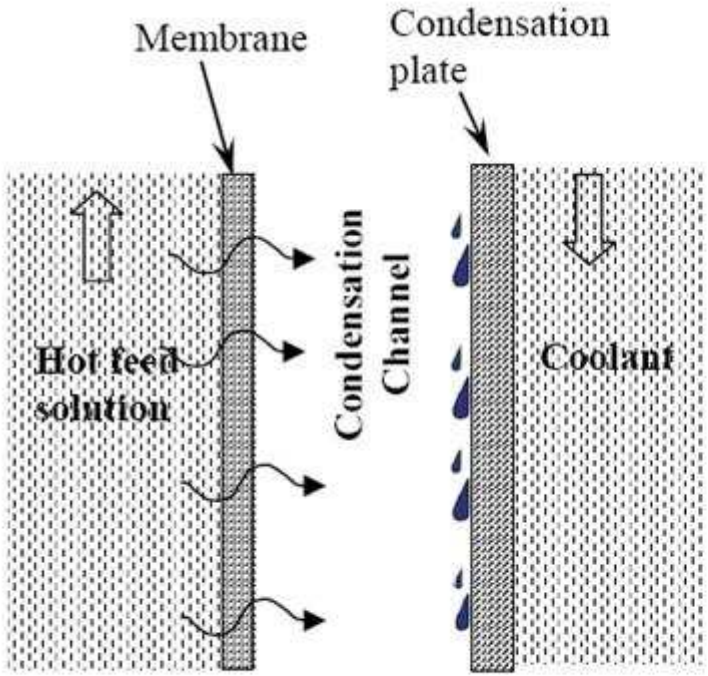


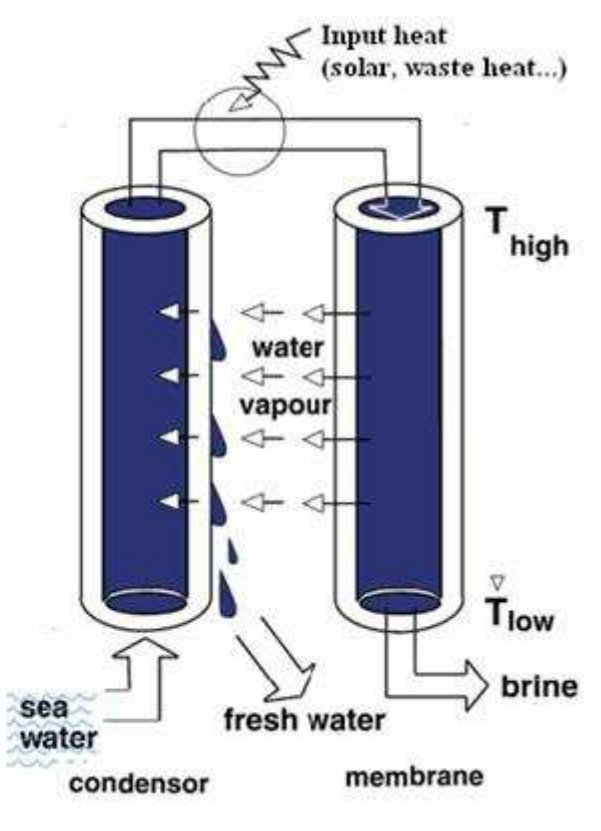
TiNOX GmbH (Germany) is currently manufacturing 3 systems based on the multi-effect humidification-dehumidification process with nominal production of: 1000, 5000 and 10000 L/day.

5000 L/day system installed on Jeddah, (Saudi Arabia) with 140 m^2 of solar collectors and a 10 m^3 thermal storage tank at 90ºC

MEMBRANE DISTILLATION

Distillation driven by partial pressure difference on the two sides of a hydro-phobic membrane which permit the flow of vapor but not the liquid water





MEMBRANE DISTILLATION

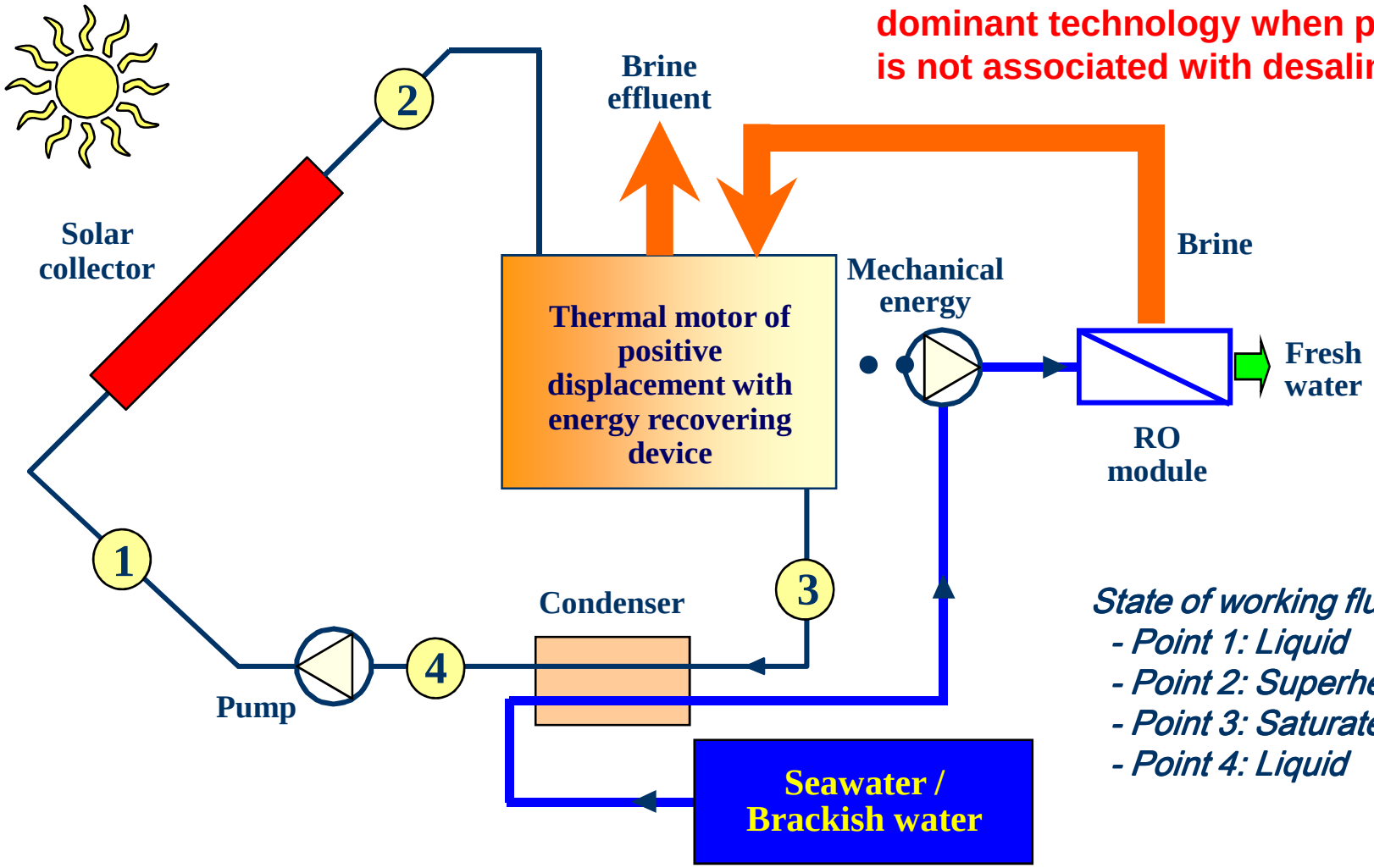
The Fraunhofer Institut (Germany) is working on the development of two systems based on this process: **100 L/day** (1 membrane, 6 m^2 of solar collectors) and **1000 L/day** (4 membranes, 72 m^2 of solar collectors). Typical distillate production: **15 to 20 L/m^2** (of solar collector) **and day**.

Membrane Distillation system installed at Prof. Dr. Hassan Fath facilities in Alexandria, Egypt (July 2005).

Fraunhofer Institut (Germany)

THERMAL MOTOR + REVERSE OSMOSIS

Reverse Osmosis is the current dominant technology when power plant is not associated with desalination

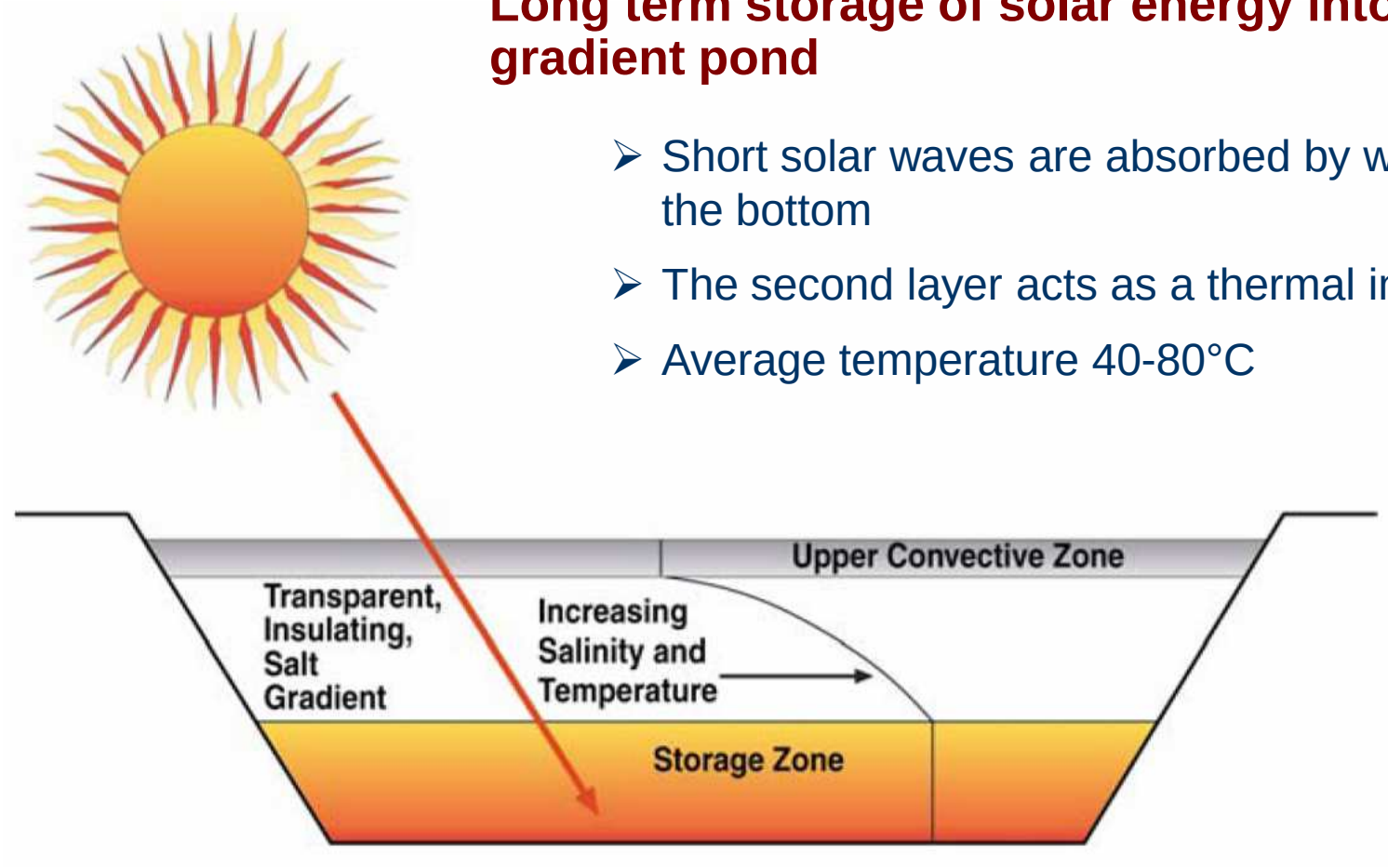


State of working fluid:
- *Point 1: Liquid*
- *Point 2: Superheated vapour*
- *Point 3: Saturated vapour*
- *Point 4: Liquid*

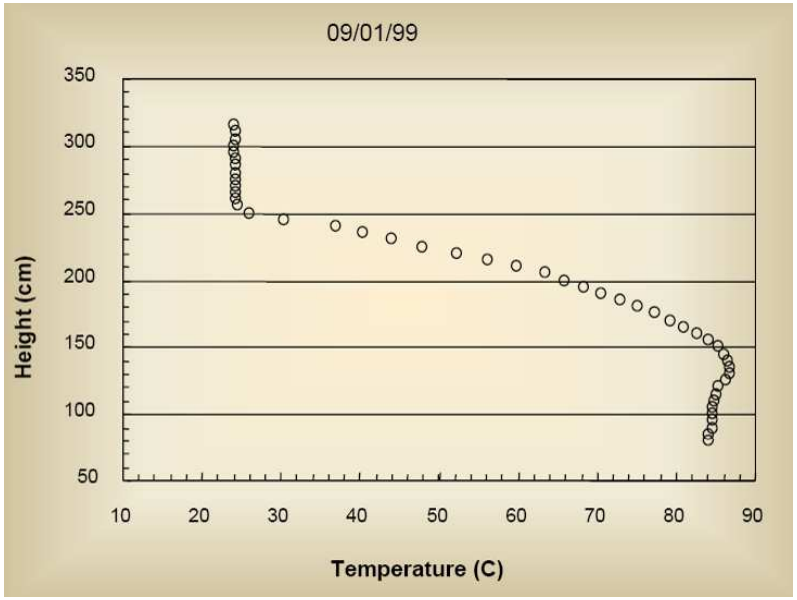
SOLAR PONDS

Long term storage of solar energy into a salt-gradient pond

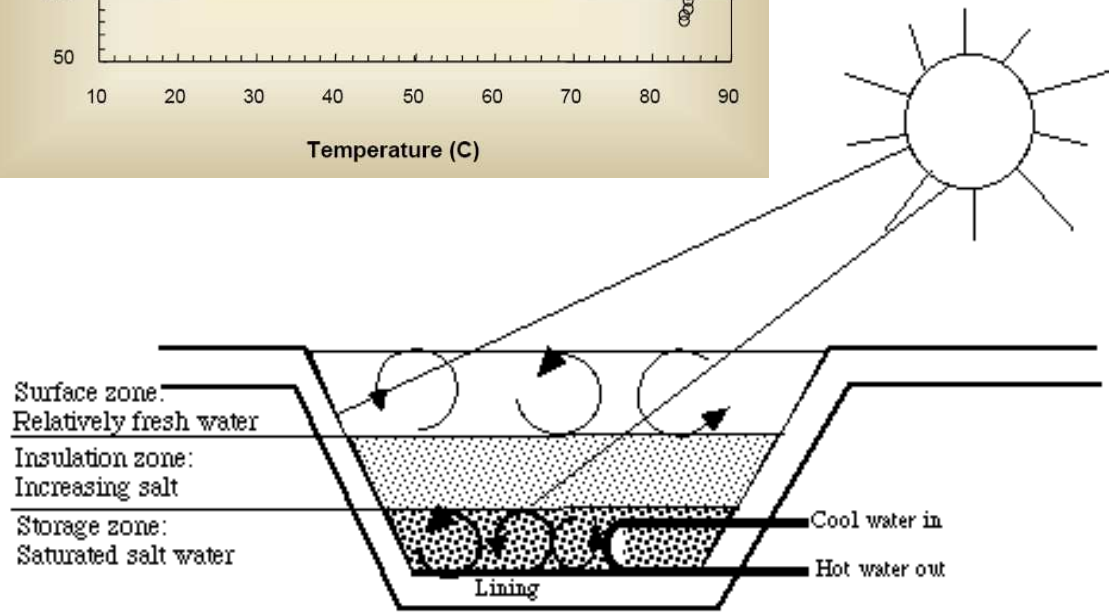
- Short solar waves are absorbed by water at the bottom
- The second layer acts as a thermal insulator.
- Average temperature 40-80°C



SOLAR PONDS



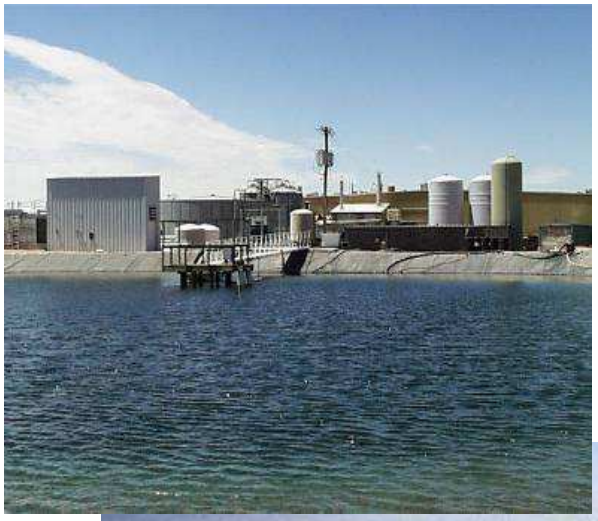
Temperature distribution at Solar Pond of ENIT (Tunisia), 1500 m^2 and 3,5 m deep



Solar Pond of ENIT (Tunis)

SOLAR PONDS

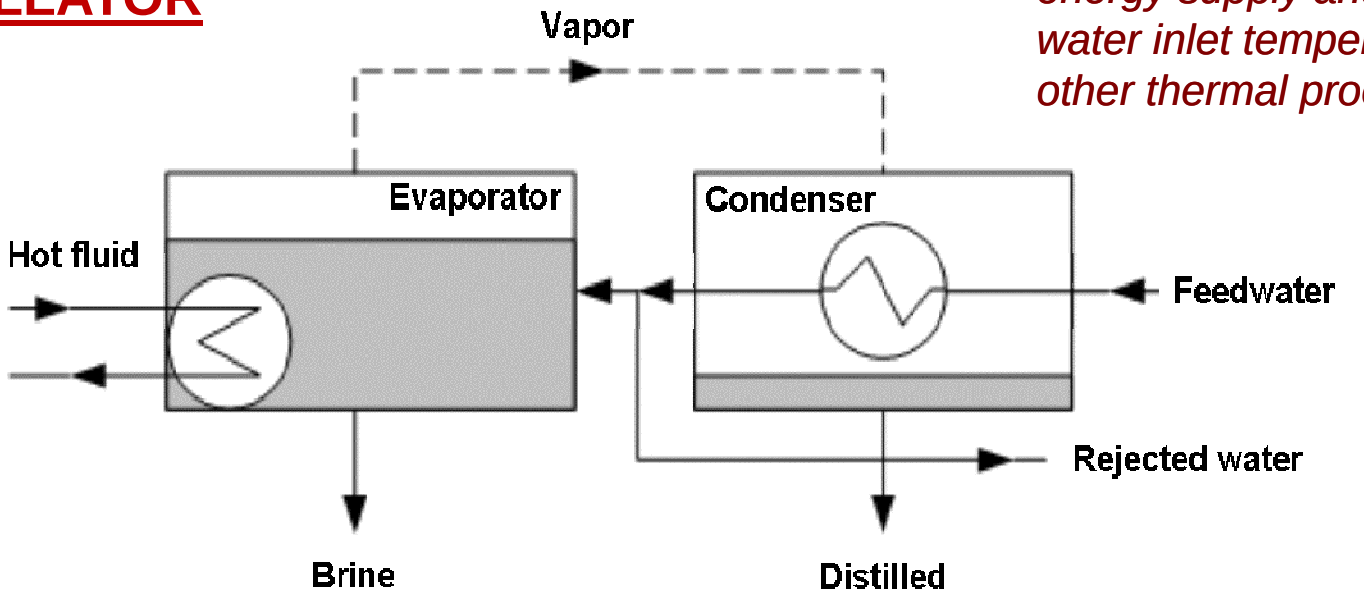
Solar Ponds near Lisbon (Portugal) → 1024 m^2 with heat exchanger at the bottom



Solar Ponds at El Paso (Texas) → one of 210,000 m^2 and another of 1,900,000 m^2

MULTI-EFFECT DISTILLATION (MED)

ONE EFFECT DISTILLATOR



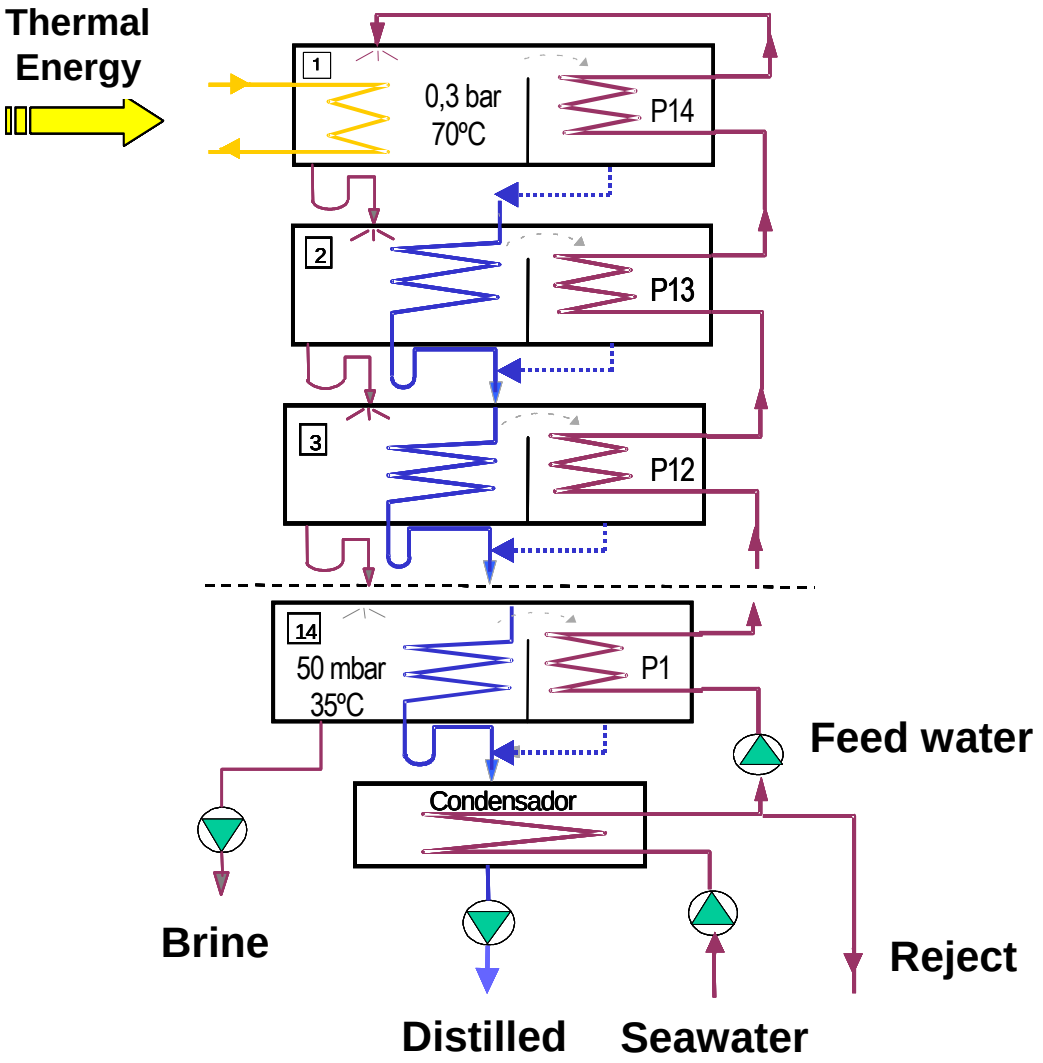
MED process required lower energy supply and lower feed water inlet temperature than other thermal processes

MULTI-EFFECT DISTILLATION (MED)

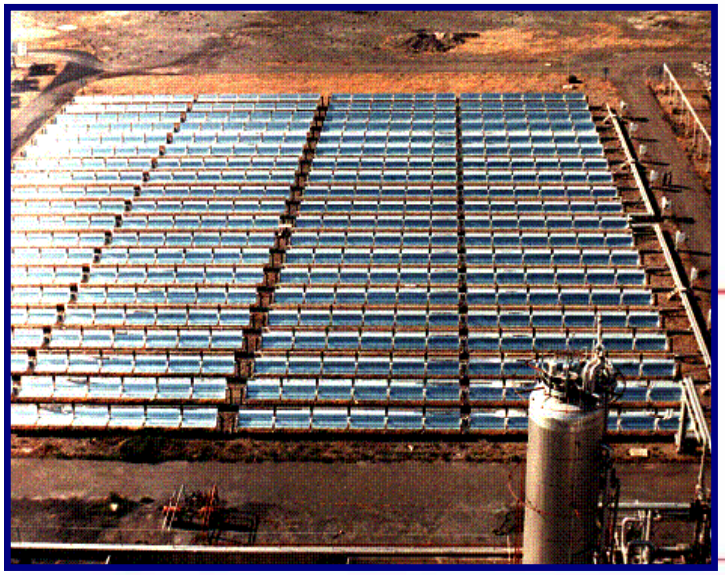
The Performance Ratio **is higher** when the **number of effects** is **increased** (**MULTI-EFFECT DISTILLATION**) because successive consecutive evaporations can be performed at decreasing temperatures, recovering the latent heat of evaporation.

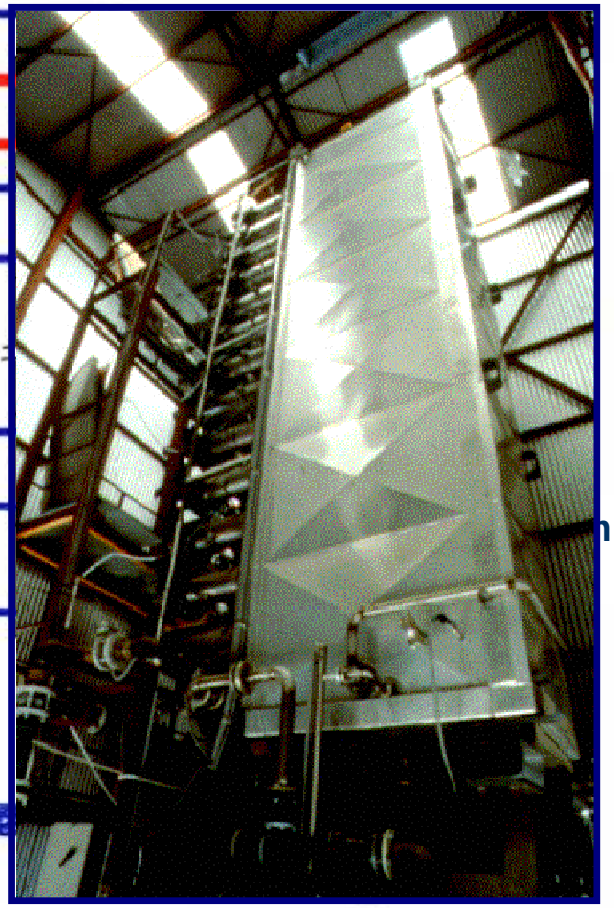
Due to technical and economic reasons, MED commercial plans usually have between **4 and 8 effects**.

The distillation plant installed at the PSA is a forward-feed, vertically-stacked, multi-effect distillation unit with **14 effects**.



MULTI-EFFECT DISTILLATION (MED)





Conceptual scheme of MED plant coupled to solar collector field, developed at PSA during the 90's. Estimated water cost: 1.80 – 2.20 €/m³

Final condenser seawater cooling (12 m³)

Brine (5 m³)

Seawater input (20 m³)

AQUASOL PROJECT

Enhanced Zero Discharge Seawater Desalination using Hybrid Solar Technology (AQUASOL, FP5-EVK1-CT2001-00102) partially funded by the European Commission within the Energy, Environment and Sustainable Development Programme. Development of an environmentally-friendly improved cost- and energy efficient seawater desalination technology based on the multi-effect distillation process:

14 effects MED plant (150 kW_{th}, 2.5 m^3/h distillate prod.)

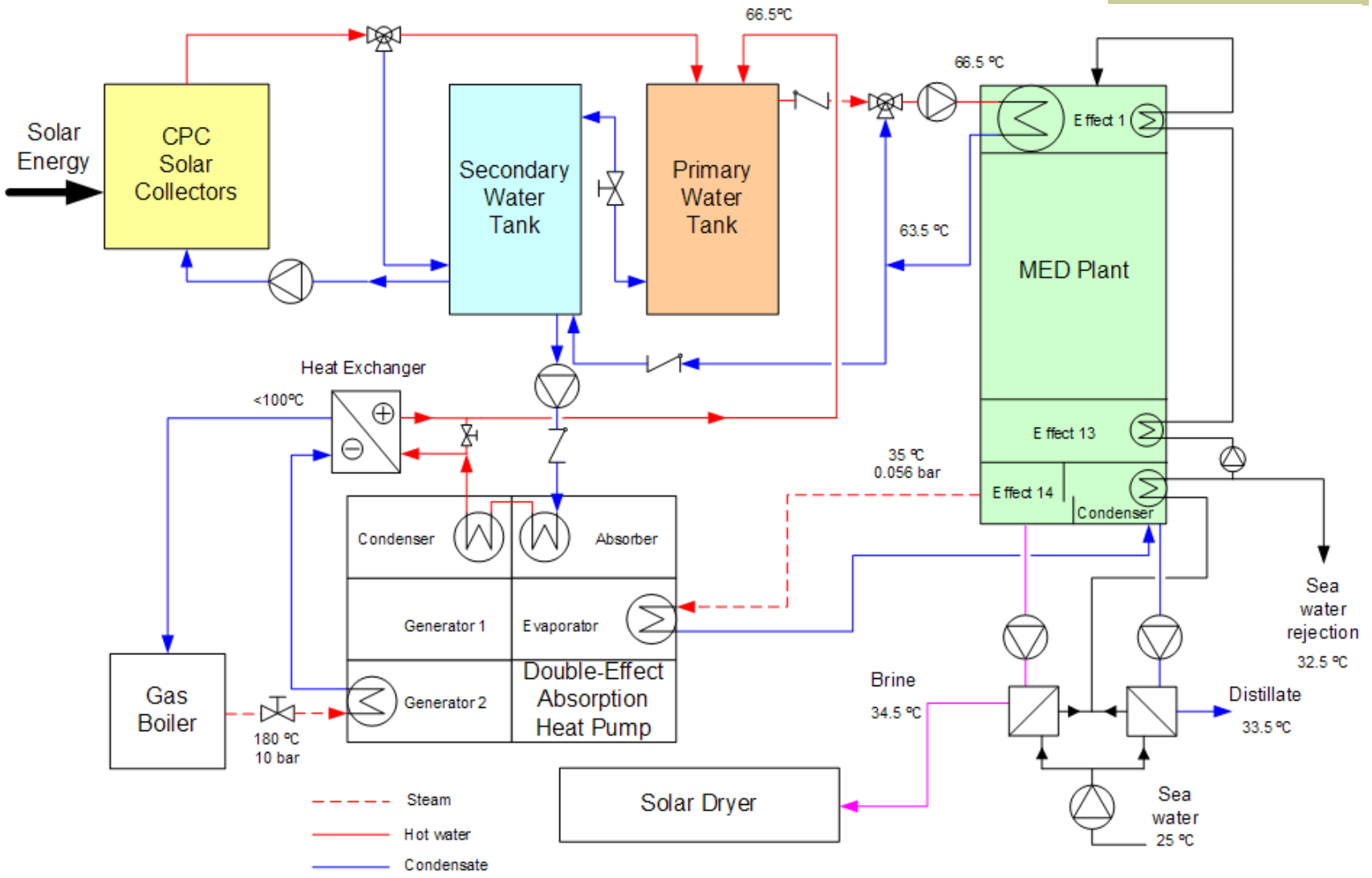
- **Stationary CPC solar collector field**
- **Thermal storage system (water, 24 m^3)**
- **Double-effect (LiBr-H_2O) absorption heat pump**
- **Smoke-tube gas boiler**
- **Solar dryer for final treatment of the brine**

AQUASOL OPERATING MODES

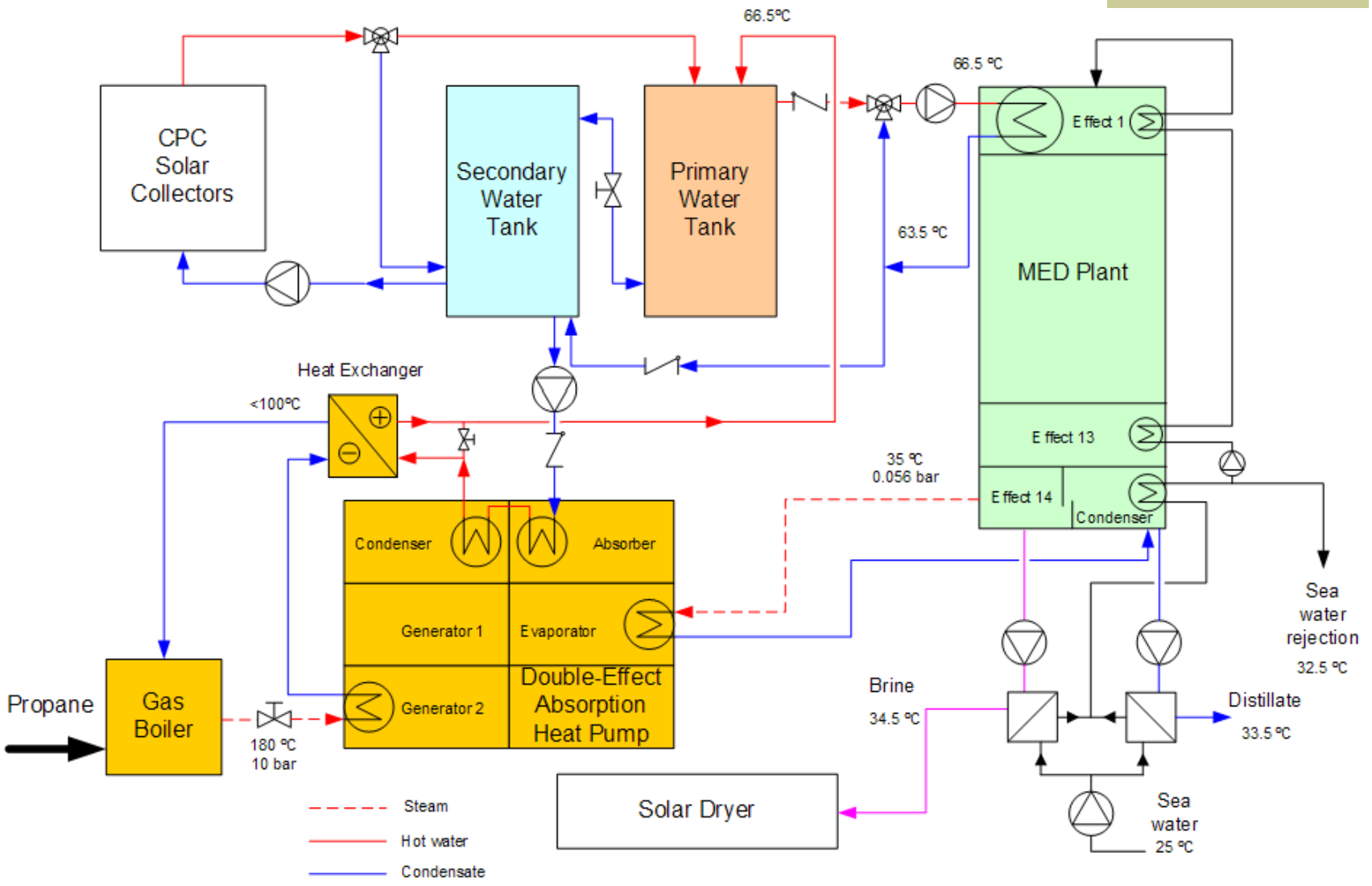
Three desalination system operating modes are possible depending on where the desalination unit energy supply comes from:

- **Solar-only mode**: energy to the first distillation effect comes exclusively from thermal energy from the solar collector field.
- **Fossil-only mode**: the double-effect heat pump supplies all of the heat required by the distillation plant.
- **Hybrid mode**: the energy comes from both the heat pump and the solar field. Two different operating philosophies are considered:
  - The heat pump works continuously 24 hours a day with a 30% minimum contribution.
  - Start-up and shutdown of the pump when requested, depending on the availability of the solar resource.

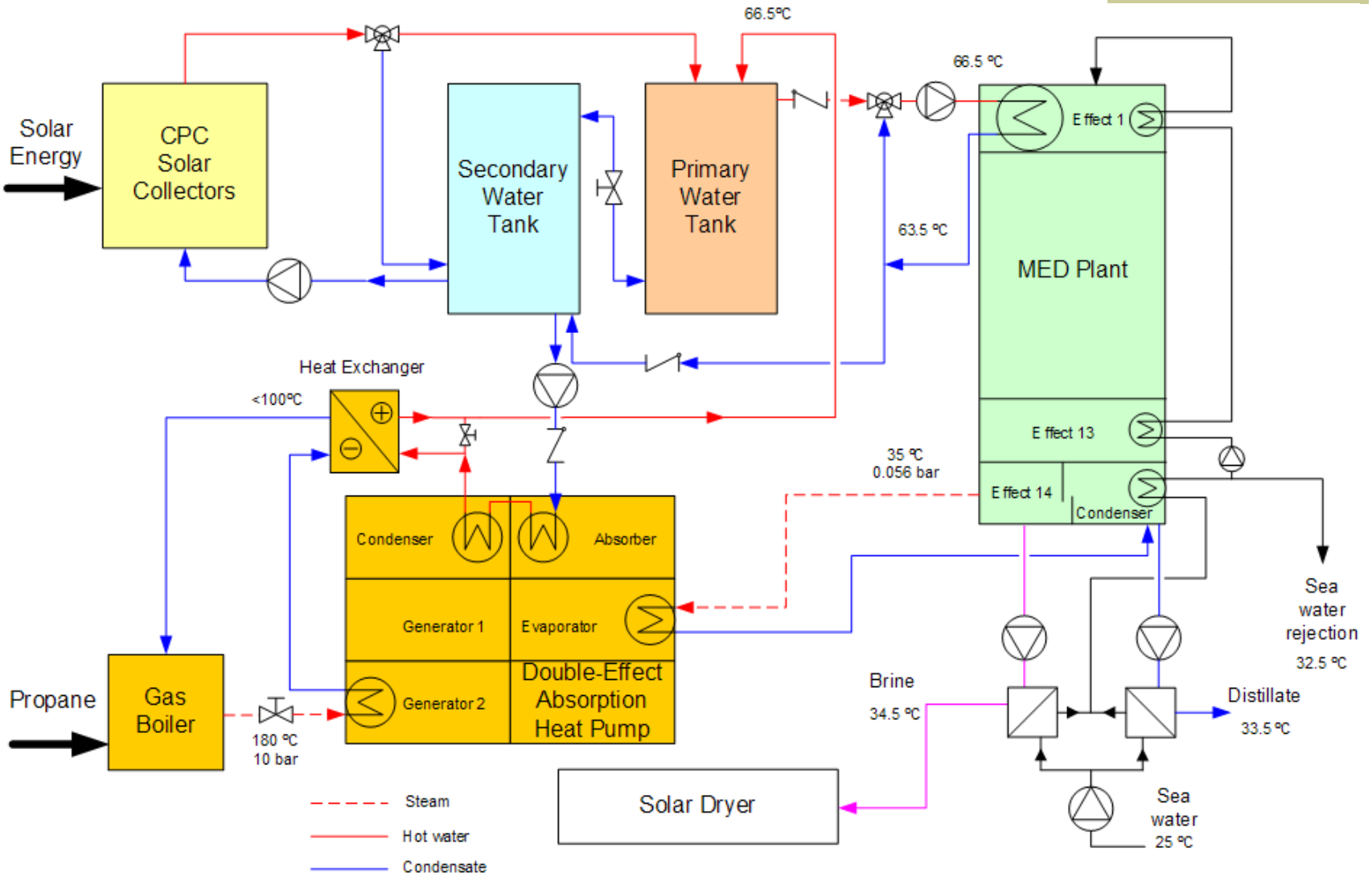
AQUASOL OPERATION: SOLAR MODE



AQUASOL OPERATION: FOSSIL MODE



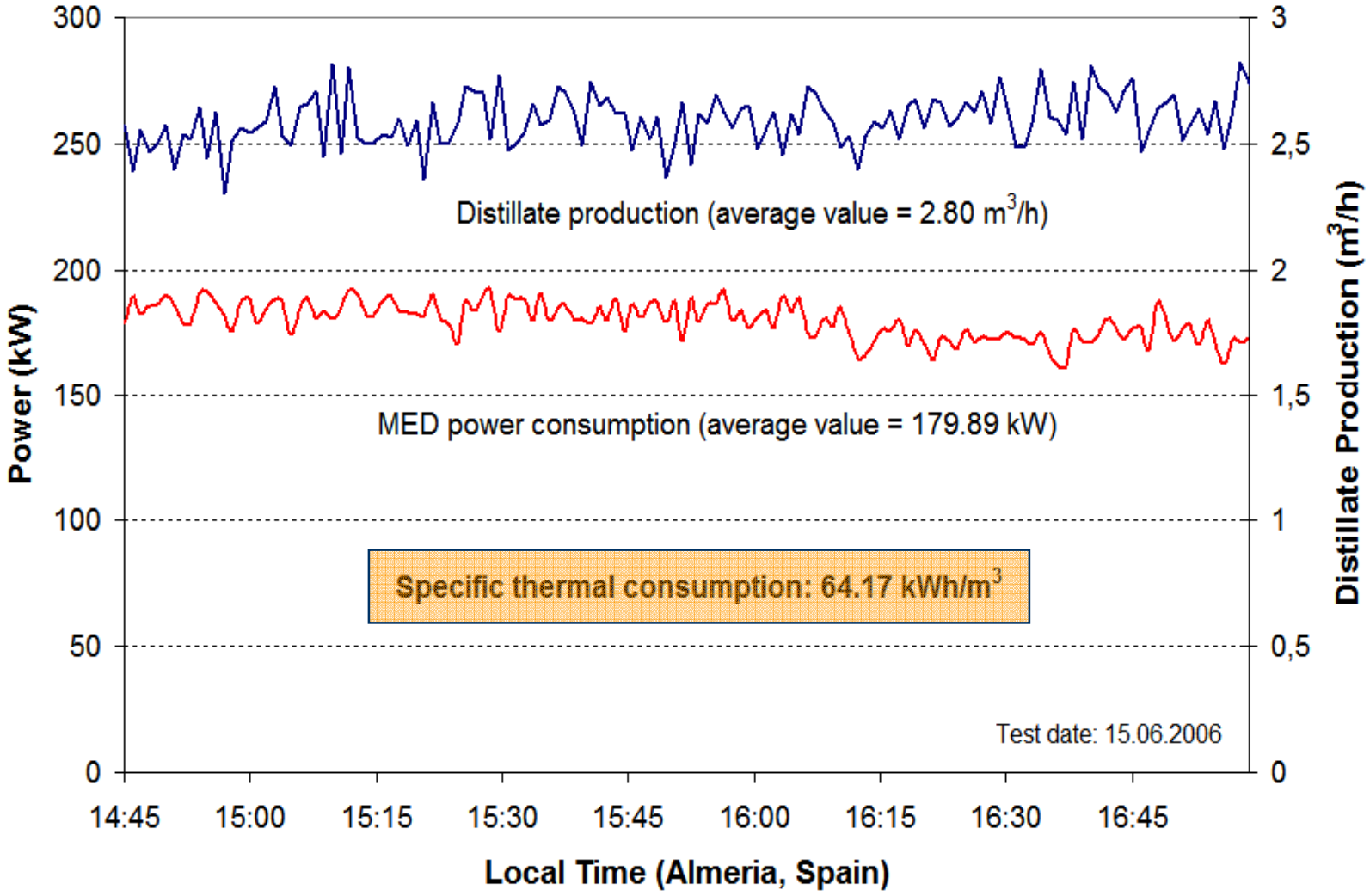
AQUASOL OPERATION: HYBRID MODE



CPC SOLAR COLLECTOR FIELD

The solar field is made up of 252 stationary solar collectors (CPC Ao Sol 1.12x) with a total surface area of 500 m^2 arranged in four rows of 63 collectors.

SOLAR-ONLY MODE



Distillate production and global thermal energy consumed by AQUASOL plant in SOLAR-ONLY MODE

CONCLUSIONS & COST ESTIMATIONS

- Plant specific consumption of thermal energy, in the solar-only mode, is in the range of **60 to 70 kWh** per m^3 of distillate produced. These values are reduced to about 30 kWh per cubic meter when the absorption heat pump is working in fossil-only mode.
- The feasibility of a hybrid mode operation was demonstrated. The absorption machine presents a high thermal inertia but no problems have been detected during transients. However, further research in control should be done in order to keep the heat pump operation at maximum efficiency.
- AQUASOL production of 30 m^3 (from 09:00 to 21:00 h) → **60 L/m^2** (winter day). Summer day: about **90 - 100 L/m^2**. 1 Ha with a land occupation factor of 50% (5,000 m^2 of solar collectors) would yearly produce about a **160,000 m^3**
- Cost of AQUASOL produced water: 8.12 €/m^3 (PSA plant / 2.5 m^3/h) → **0.93 €/m^3** (extrapolation to a **12,000 m^3/day** plant). Land cost not considered.
- Current environmental and energy scenarios makes unlikely that Solar Desalination will not play a major role in the coming years. It is reasonably expected that full industrial involvement would substantially reduce this cost.

ACKNOWLEDGEMENTS

- Institute of Agronomy and Veterinary Hassan II
- EUROPEAN UNION
- CYCLER-SUPPORT PROJECT
- INNOVAMED PROJECT

On-going projects at PSA about solar desalination

- **POWERSOL. EC, FP6, 032344 (INCO)**
- **MEDESOL. EC, FP6, 036986 (GOCE)**
- **OSMOSOL. ENE2005-08381-C03.**

http://www.psa.es/webeng/areas/quimica/proyectos.html