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The long-term future of desalination based on solar energy

L'avenir à long terme du dessalement basé sur l'énergie solaire

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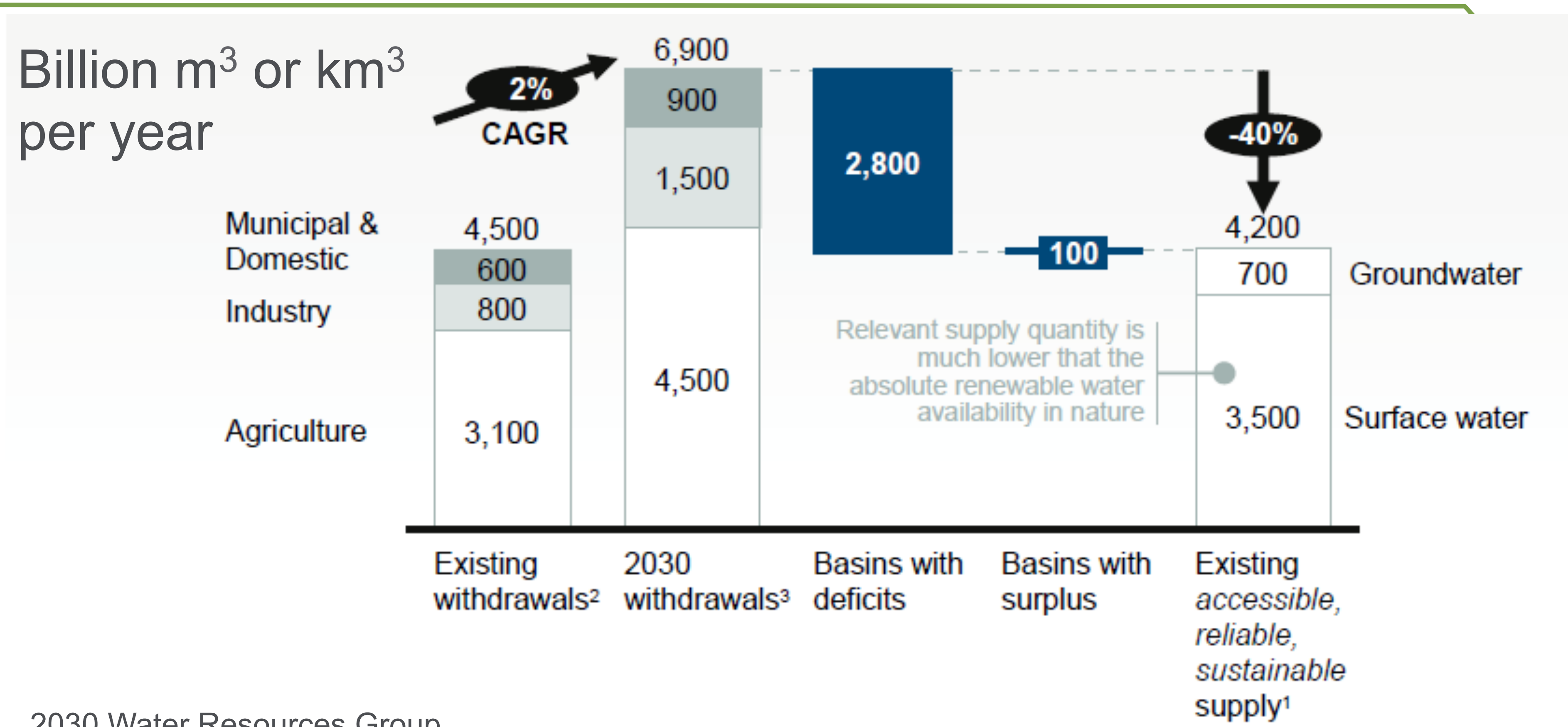
Sharing Knowledge Across the Mediterranean (7) – Tunis – May 2012

Outline

- The need for water: quantity, quality and access
- Main types of desalination technology
- Solar-desalination: what's theoretically possible?
- The performance gap
- Some emerging areas of research
- What's realistically possible?
- Costs relative to other measures
- Recommendations: an integrated approach

Quantity – global water deficit 2030



2030 Water Resources Group

1 Existing supply which can be provided at 90% reliability, based on historical hydrology and infrastructure investments scheduled through 2010; net of environmental requirements

2 Based on 2010 agricultural production analyses from IFPRI

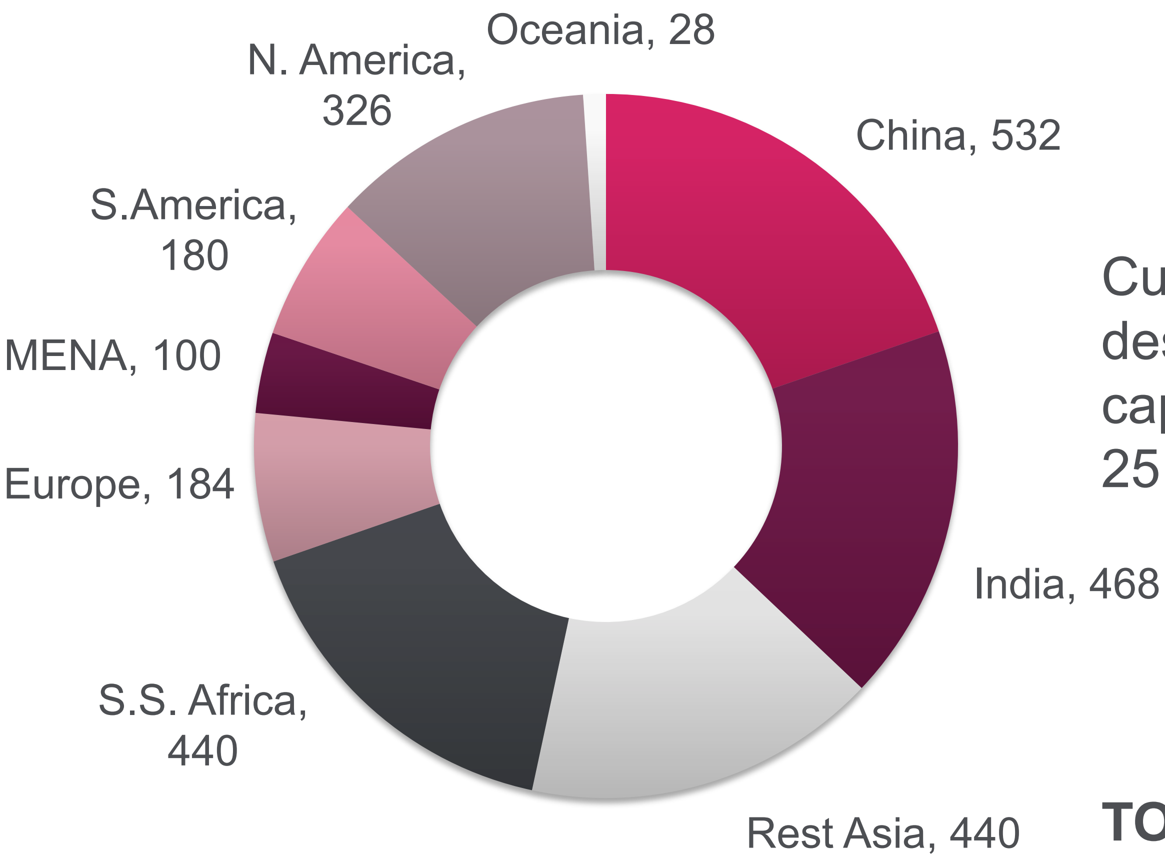
3 Based on GDP, population projections and agricultural production projections from IFPRI; considers no water productivity gains between 2005-2030

SOURCE: Water 2030 Global Water Supply and Demand model; agricultural production based on IFPRI IMPACT-WATER base case

Quantity – by region

- Projected increase in annual water demand 2005-2030 (km^3/yr)

Nile discharge
90 km^3/yr



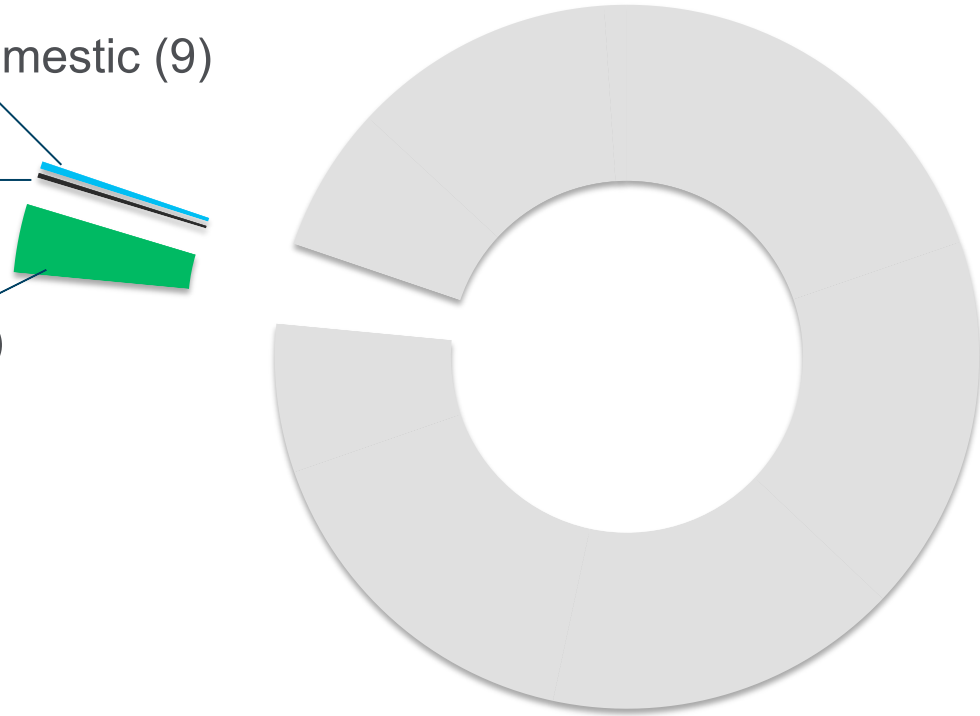
Current global desalination capacity
25 km^3/yr

TOTAL
2700 km^3/yr

Sources: Charting our water future, 2030 Water Resources Group , and GWI

Quantity – MENA breakdown

- Projected increase in annual water demand 2005-2030 (km^3/yr)



Current global desal. capacity 25 km^3/yr

Sources: Charting our water future, 2030 Water Resources Group , and GWI

Quality

- WHO Drinking water standards: microbial, chemical, radiological
- Different requirements for irrigation e.g. boron, sodium absorption ratio
- Surface and groundwater– EU Water Framework Directive: nitrates, phosphates, eutrophication
- Nile delta: salinisation from irrigation drainage and saline intrusion

Suffolk, UK

River Nile

Access

- Quantity and quality do not guarantee access
- Mumbai slum household pays €0.2/litre of **safe** water; earns € 80/month
  Compare France: €0.003/litre – average earning €1700/month
- **Globally 1 billion people have insufficient access to clean water**

shahidul.wordpress.com

Main types of desalination technology

Driven by Pressure

- Reverse Osmosis

Driven by Heat

- Multistage flash
- Multiple effect distillation
- Solar Stills
- Membrane distillation

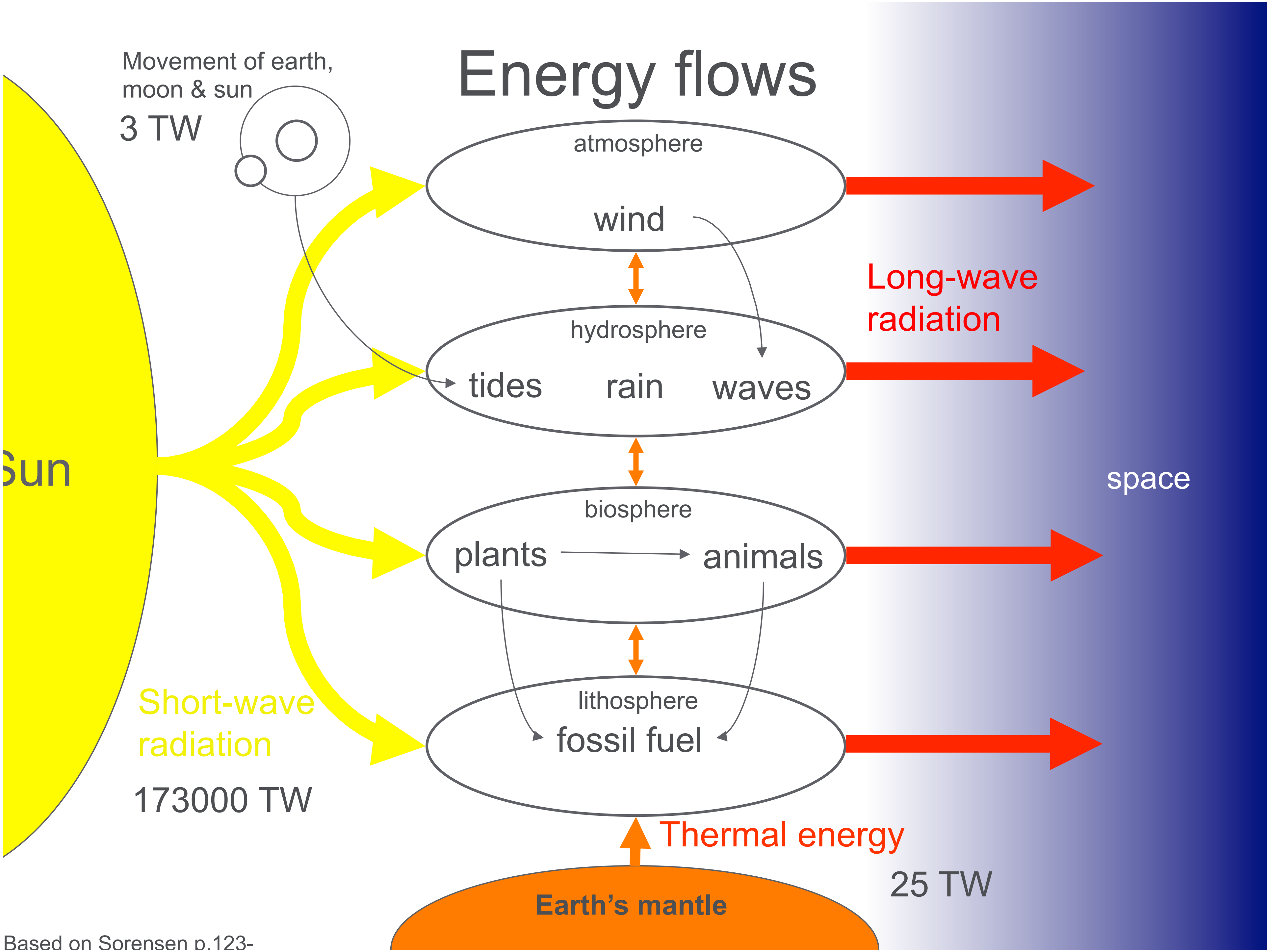
Driven by Electricity

- Capacitive deionisation
- Electrodialysis

The energy of desalination

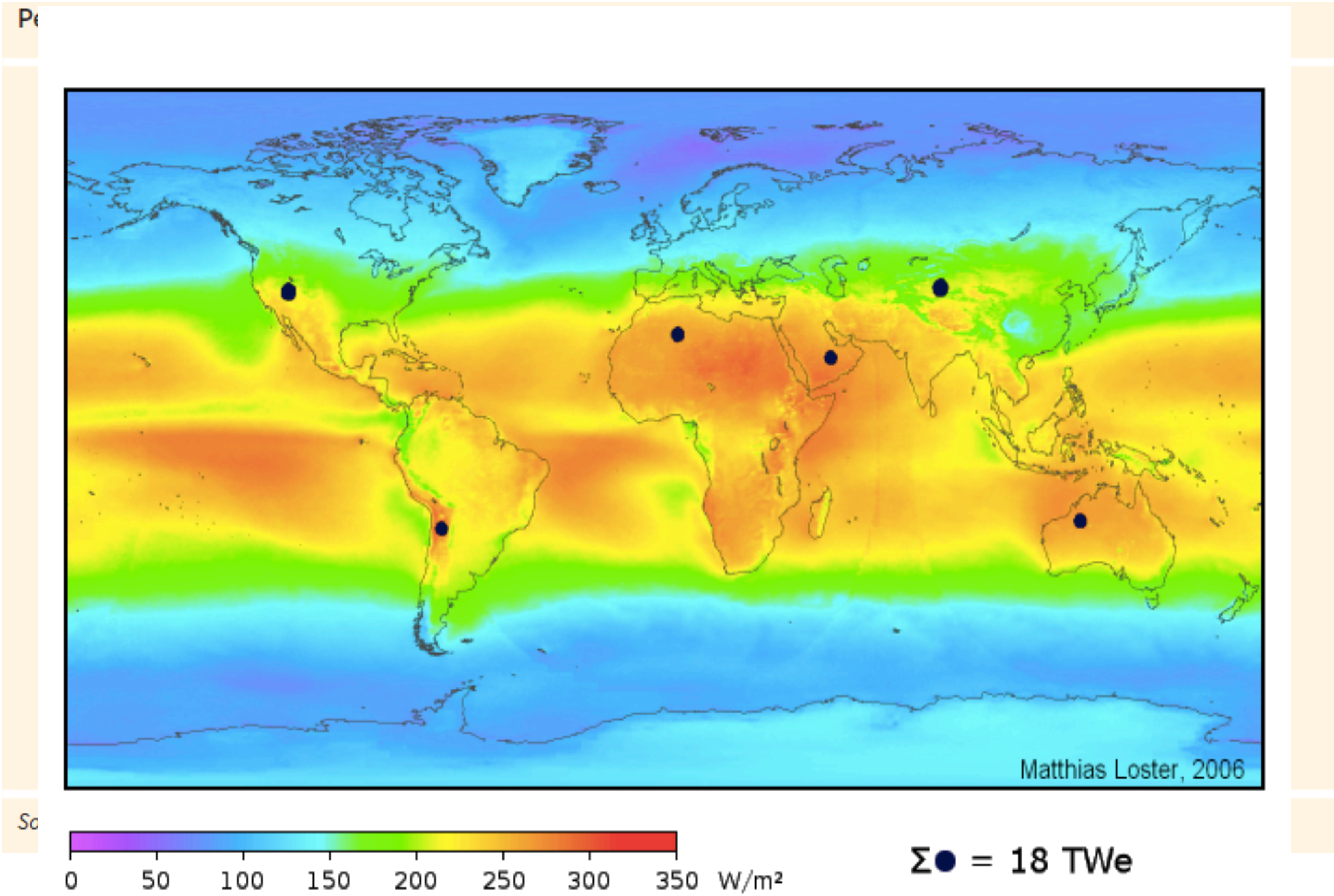
- Desalination is relatively expensive: high energy requirement
- Minimum thermodynamic energy to desalinate seawater ≈ 1 kWh/m^3
- About the same as the energy needed
  - to raise the temperature of 1 m^3 of water by 1°C
  - to lift 1 m^3 of water through a height of 360 m
- BUT **600 times** less than the energy needed to evaporate 1 m^3 of water
- **This may explain why Reverse Osmosis (RO) has emerged as the state of the art in low energy-desalination, in preference to thermal processes requiring phase change (evaporation)**
- Modern reverse osmosis requires 2.5−5 kWh/m^3

Energy flows

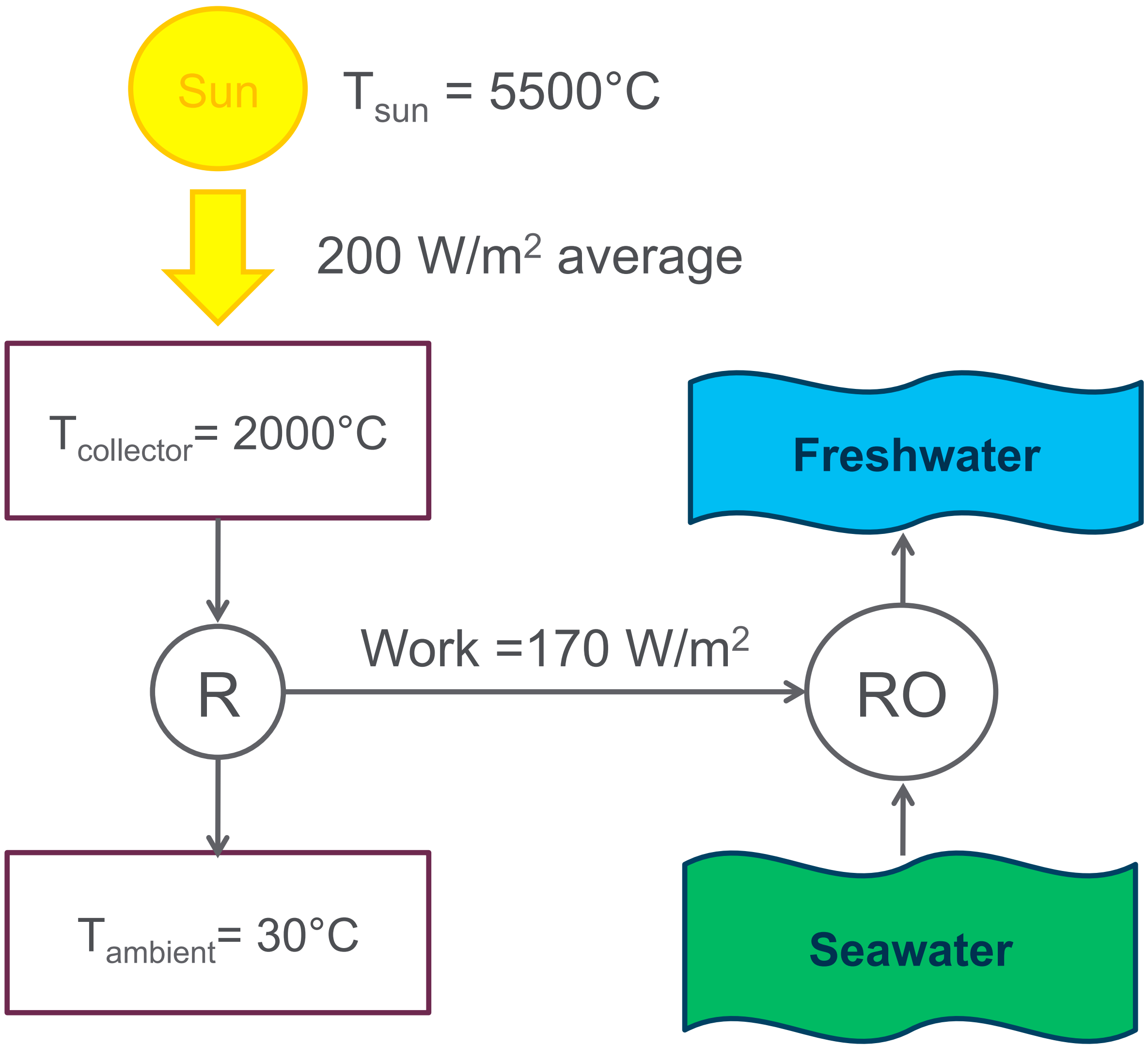


Based on Sorensen p.123-

Coincidence of solar energy with water scarcity



A perfect solar-desalination machine



Output per land area

0.17 m^3/m^2.hour

1500 m^3/m^2.year

Qiu & Davies
Desal.& Water Treatment
35, 14-32

Minimum space required to satisfy MENA deficit (2030) – ideal future technology

Real solar-desalination systems

Instituto Technológico de Canarias

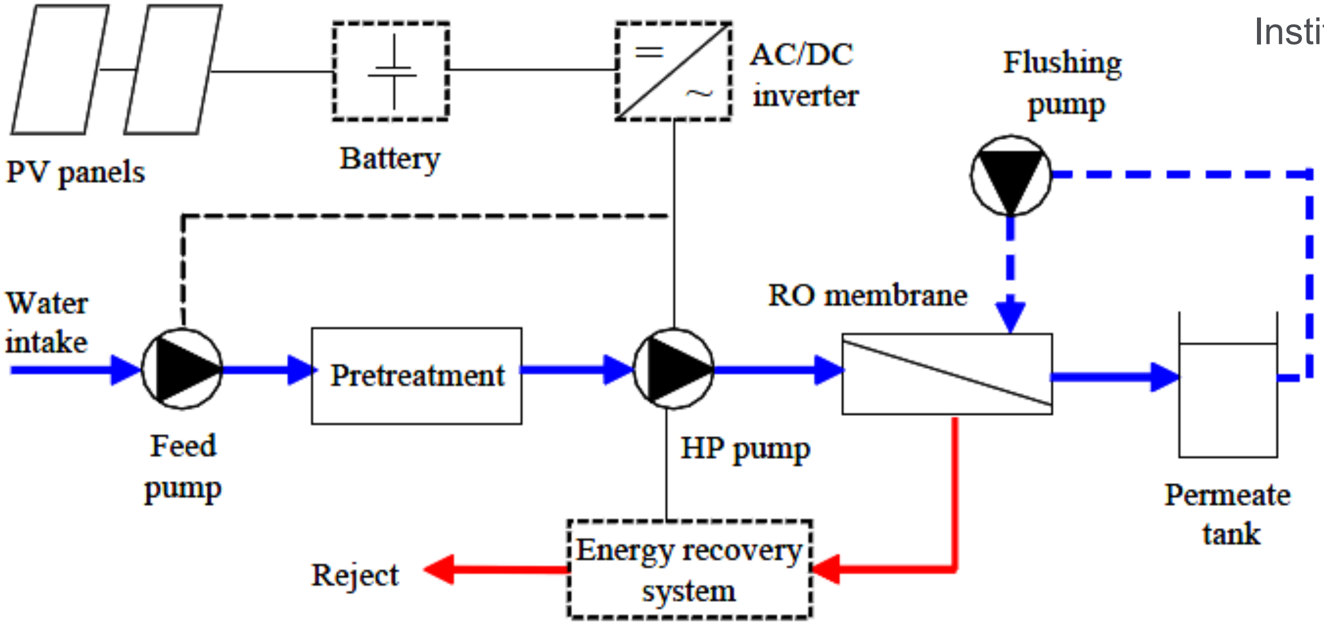
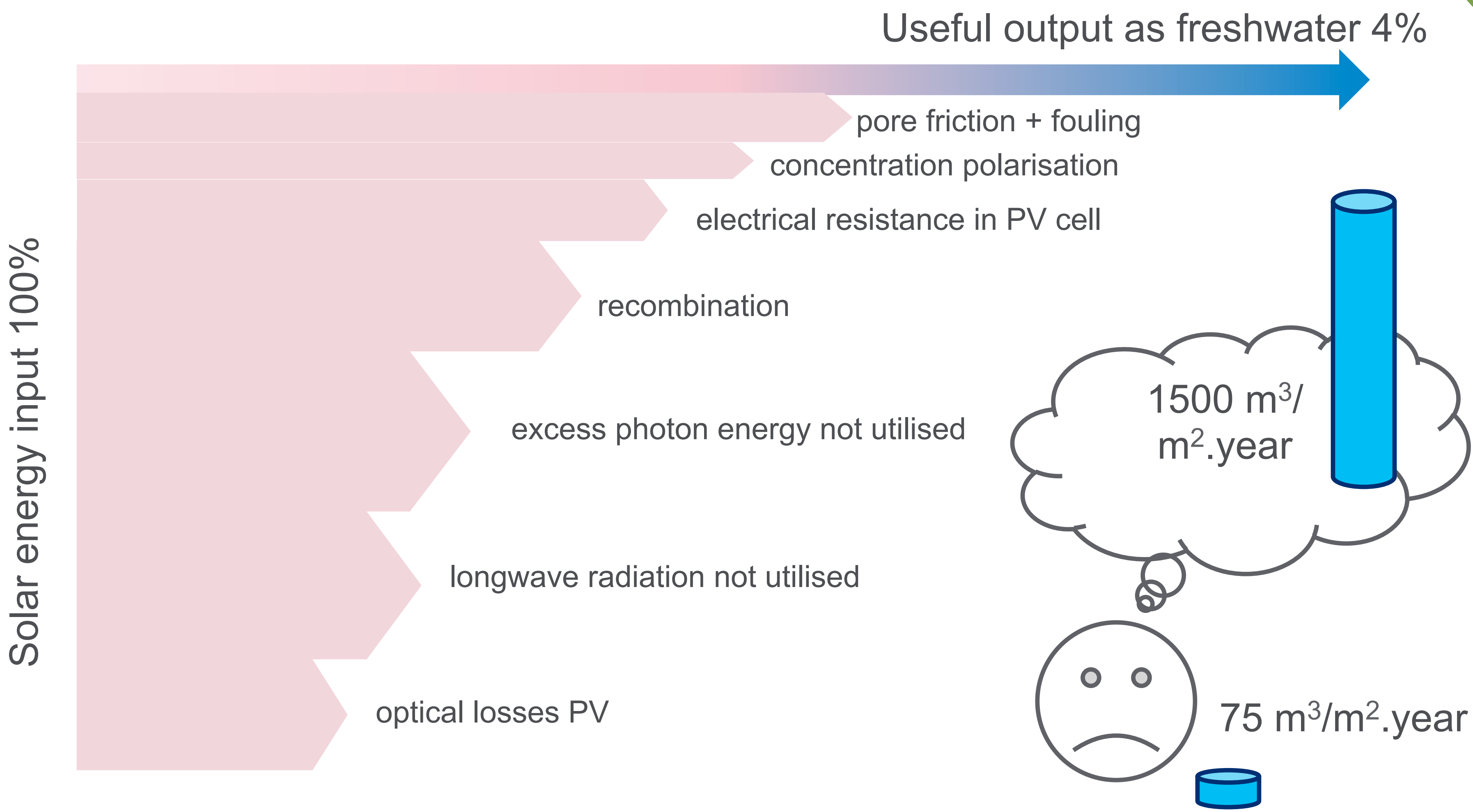


Fig. 2. Simplified general design scheme of a PV–RO desalination plant. Dashed lines identify components and connections that may be absent.

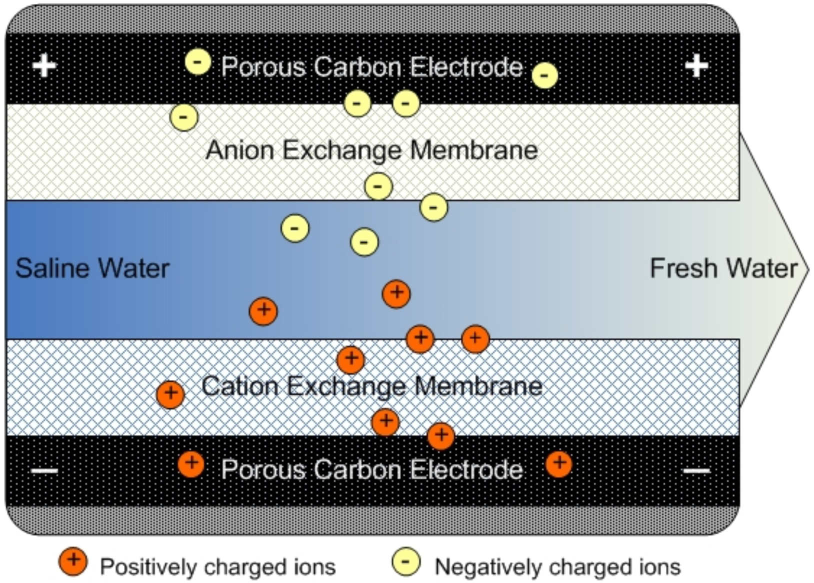
Ghermandi & Messalem: Desal. Water Treatment, 7, 285-296

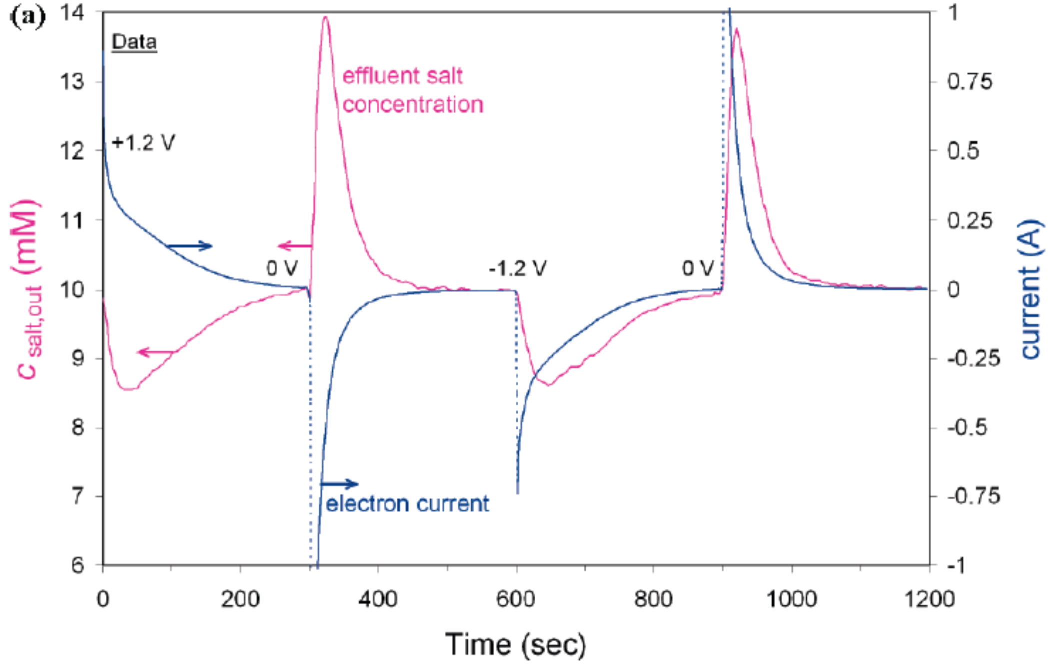
Losses in a real system



Developments to close the performance gap

- Capacitive de-ionisation: no pressure, no phase change...

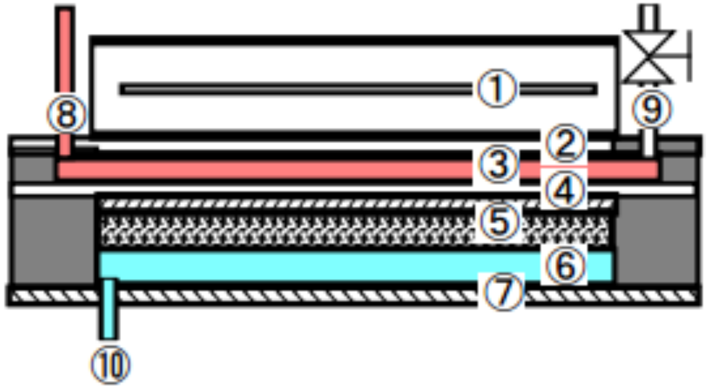




P. M. Biesheuvel *J. Phys. Chem. C* 2009, *113,* 5636–5640

Hybrid PV – Membrane Distillation

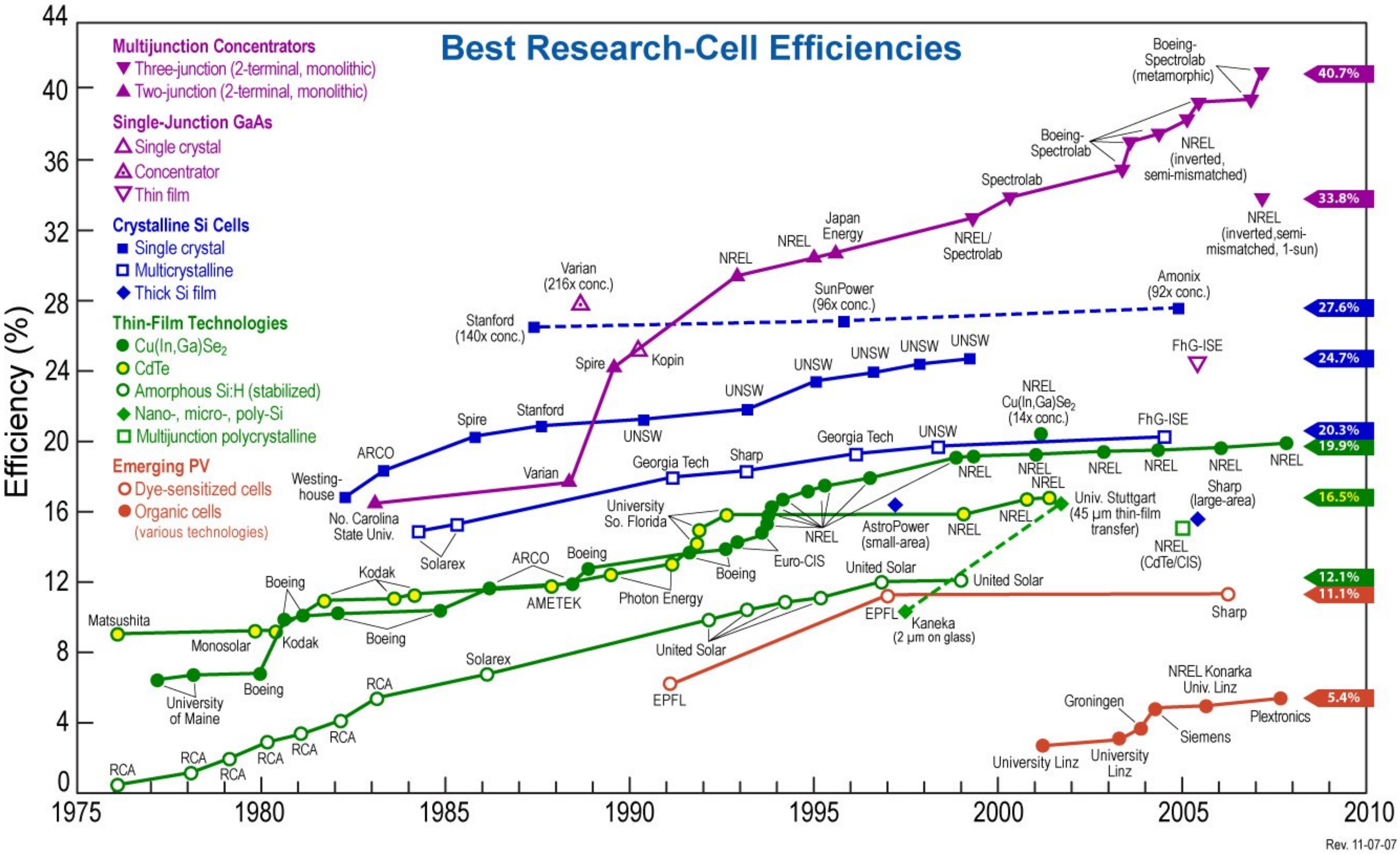
2. Experimental set-up



① Double glass solar cell (KANEKA)
② Black coulored PET Sheet
③ Saline water
④ PTFE membrane (NITTO DENKO)
⑤ Polyethylene mesh (fine & Coarce)
⑥ Distillated water
⑦ Stainless plate for radiation
⑧ Feed
⑨ Discharge of air
⑩ Drain of distillated water

Figure 1. A schematic cross section hybrid solar distillator

Murase et al.,
World Renewable Energy Conf., 2011



Best Research-Cell Efficiencies
Efficiency (%)
Multijunction Concentrators
Three-junction (2-terminal, monolithic)
Two-junction (2-terminal, monolithic)
Single-Junction GaAs
Single crystal
Concentrator
Thin film
Crystalline Si Cells
Single crystal
Multicrystalline
Thick Si film
Thin-Film Technologies
Cu(In,Ga)Se2
CdTe
Amorphous Si:H (stabilized)
Nano-, micro-, poly-Si
Multijunction polycrystalline
Emerging PV
Dye-sensitized cells
Organic cells
(various technologies)
40.7%
33.8%
27.6%
24.7%
20.3%
19.9%
16.5%
12.1%
11.1%
5.4%
Boeing-Spectrolab (metamorphic)
Boeing-Spectrolab
NREL (inverted, semi-mismatched)
NREL (inverted,semi-mismatched, 1-sun)
Spectrolab
NREL/Spectrolab
Japan Energy
NREL
Varian (216x conc.)
Stanford (140x conc.)
SunPower (96x conc.)
Amonix (92x conc.)
Spire
Kopin
FhG-ISE
UNSW
Stanford
ARCO
Westing-house
Varian
No. Carolina State Univ.
Solarex
Georgia Tech
Sharp
NREL Cu(In,Ga)Se2 (14x conc.)
University So. Florida
Euro-CIS
AstroPower (small-area)
Univ. Stuttgart (45 μm thin-film transfer)
Sharp (large-area)
NREL (CdTe/CIS)
Boeing
Kodak
AMETEK
Photon Energy
United Solar
Matsushita
Monosolar
University of Maine
EPFL
Kaneka (2 μm on glass)
RCA
NREL Konarka
Univ. Linz
Groningen
Siemens
Plextronics
University Linz
1975
1980
1985
1990
1995
2000
2005
2010
Rev. 11-07-07

Source: NREL

Multi-layer PV cells

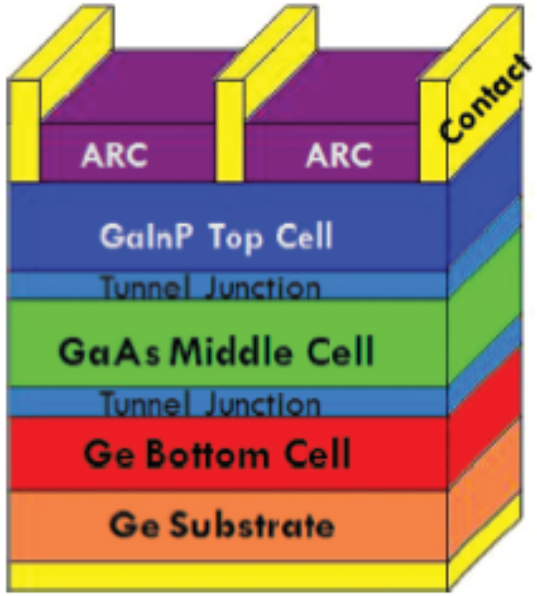
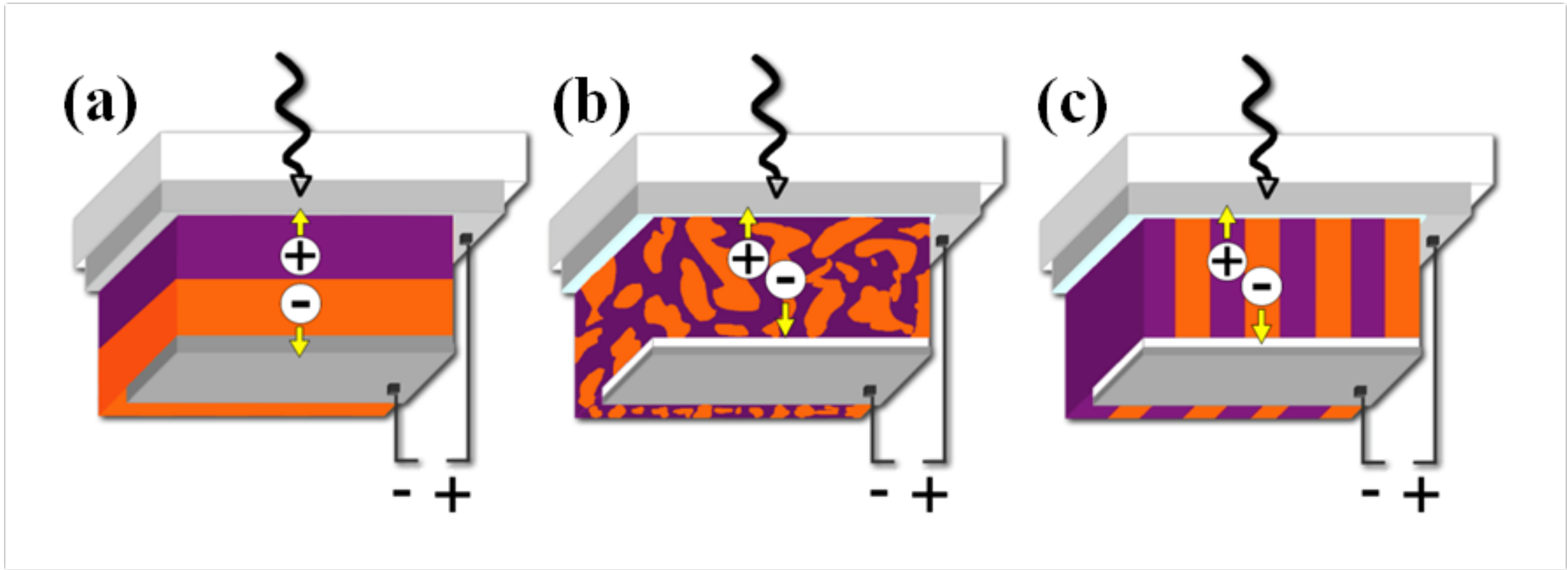


Fig. 12. A multi-junction solar cell.

Polymer solar cells

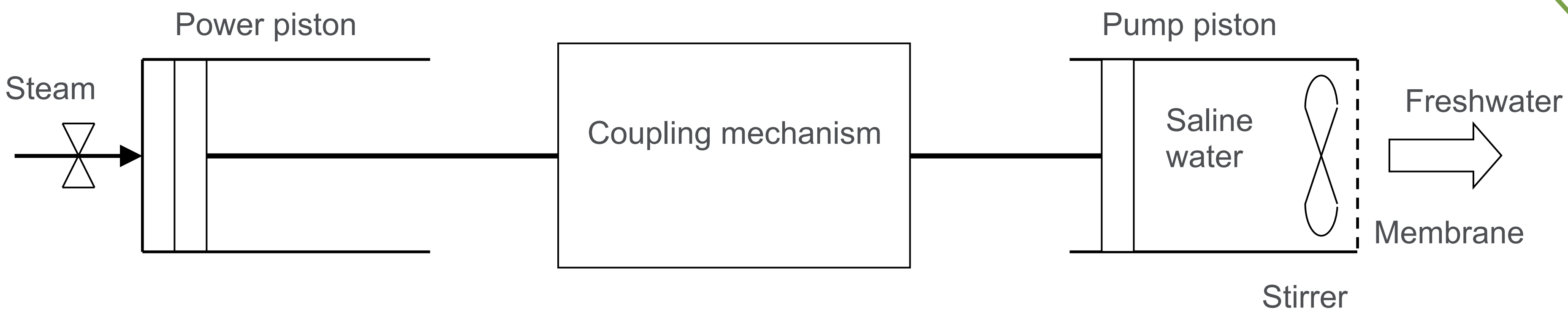


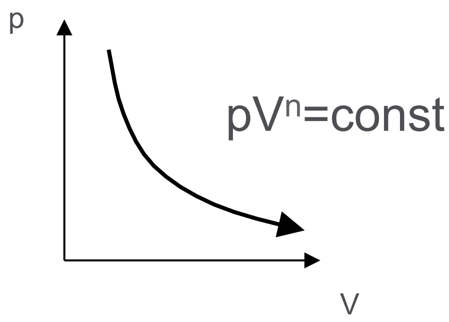
Bi-layer structure   Bulk hetero-junction   Block co-polymers

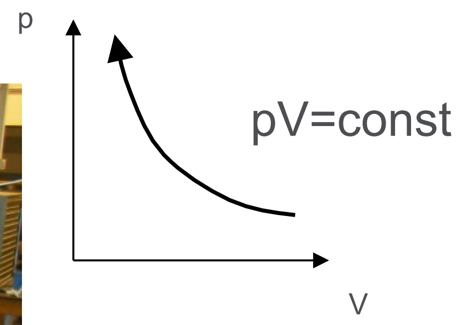
- Polymers can be custom designed – huge number of possibilities!

P. D. Topham et al. JOURNAL OF POLYMER SCIENCE PART B: POLYMER PHYSICS 2011

Eliminating energy conversion steps







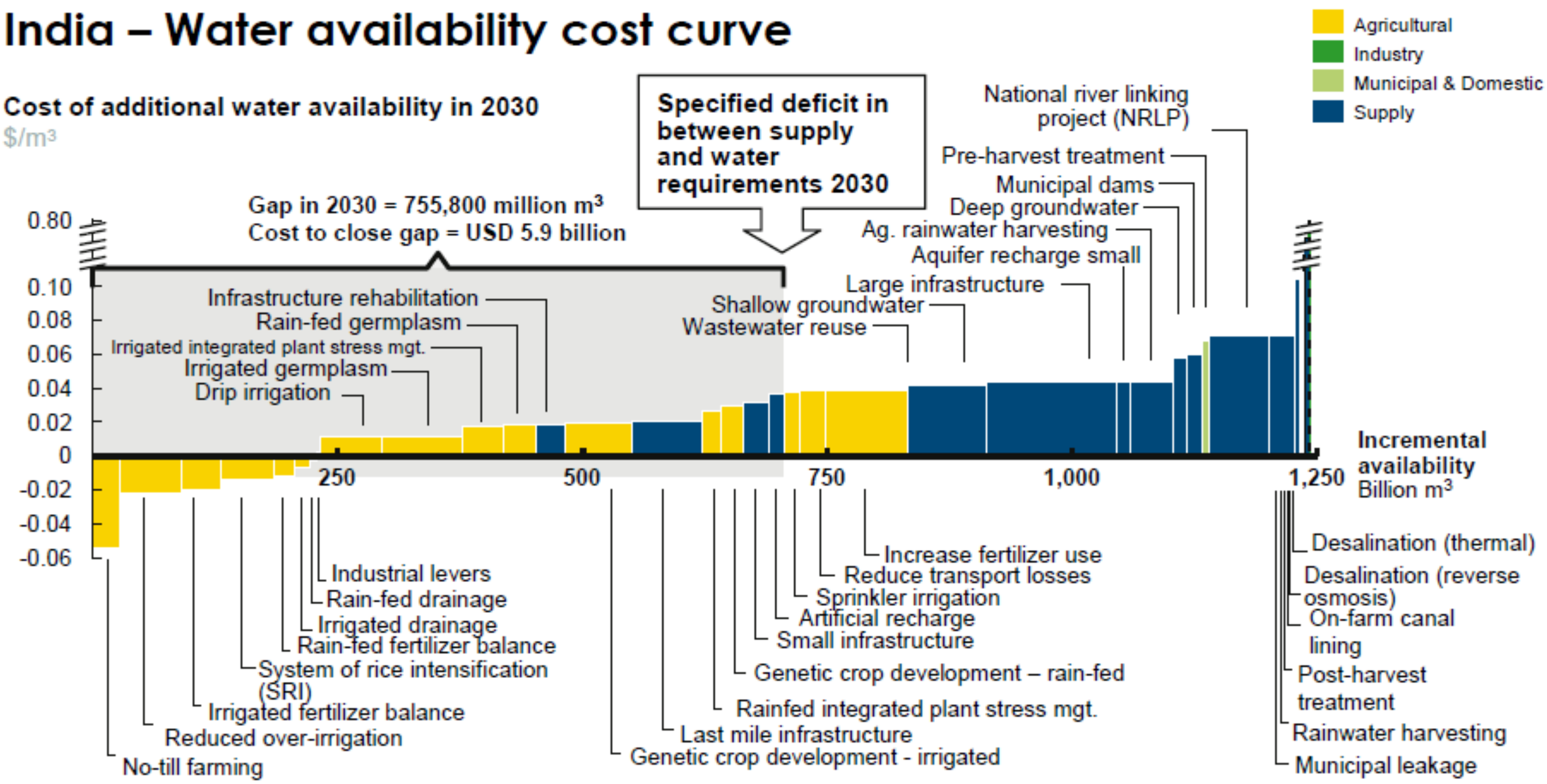
Davies:
Desalination, 271, 72-79 (2011)

Other important research areas

- New membrane materials and pre-treatments to prevent fouling
- Energy recovery from brines and wastewater by forward osmosis
- Zero discharge, valorisation of salts
- Interaction with ocean at inlet and discharge: algal blooms
- New system configurations, batch flow, closed-loop...
- Boron prevention and removal
- Small scale, appropriate technology: humidification/dehumidification
- Rankine cycle, working fluids
- Polygeneration

Space required to satisfy MENA deficit (2030) with today's technology

What about the cost?



SOURCE: 2030 Water Resources Group

Water footprint

www.waterfootprint.org

- Some water footprint figures....

Oranges
560 litres/kg

Chicken
4300 litres/
kg

Green beans
322 litres/kg

Rice
2500
litres/kg

Milk
1000
litres/kg

Energy to water to food to stomach

3 kWh electricity		**LOSSES:**
↓		
1000 litres of water	→	Evapotranspiration
↓		
1 kg of food at farm	→	Post harvest, quality rejection
↓		
0.46 kg of food on shelf	→	Past sell by date
↓		
0.39 kg in fridge	→	Perished, discarded
↓		
0.32 kg on plate	→	Not eaten
↓		
0.3 kg in stomach		

Research by R. Proctor

Asparagus
Water footprint
2150 litres/kg

Buy One Get One Free

No regrets?

Conclusions

- Desalination powered by solar energy can, on technical grounds, make an important contribution to meet the emerging water gap in the MENA region and elsewhere
- But desalination (especially with renewable energy) remains expensive compared to other ways of providing or saving fresh water
- In the long term, the sea offers a virtually limitless supply of water, so researchers should continue to improve and innovate with regard to efficiency and cost (in case the cheaper options get exhausted). **Efficiency of solar-desalination could be improved 20 times**.
- Researchers, policymakers and implementers in different disciplines must work together to develop integrated approaches to effective management of energy and water resources to ensure universal access to vital drinking water, sanitation and food…

Thank you...Merci!

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