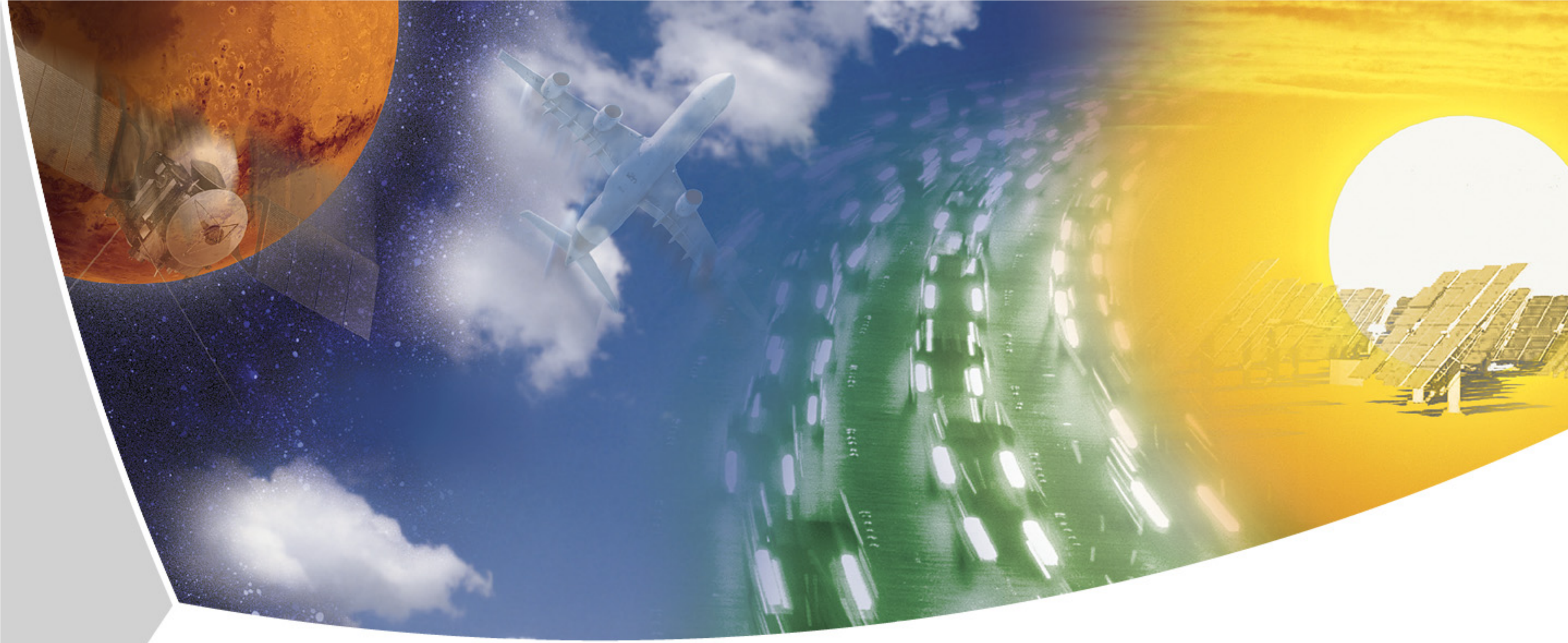


Industrial Applications of Solar Radiation

502. WE-Heraeus-Seminar

Karl-Heinz Funken

DLR, Solar Research, 51147 Cologne, Germany, www.dlr.de/sf

April 02-04, 2012

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Contents

Vision: Solar Research

- **Concentrating solar systems** will generate **power** (and desalinated water) at acceptable cost in the solar belt of the earth and will supply the rapidly growing metropolitan areas
- **German Industry** is developer, supplyer and producer of key componernts
- **Import of Solar Power** (HVDC) will cover part of the European electricity demand
- **Storage of Solar Energy** in thermal and chemical form will allow flexibility and dispatachability

Contents

- Vision: Concentrating Solar Power (CSP)
- **Sustainable Electricity and Water for the MENA Region and Beyond**
- CSP Technology and Recent Examples
  - Test Facilities and Solar Power Plant Development at DLR
- Summary

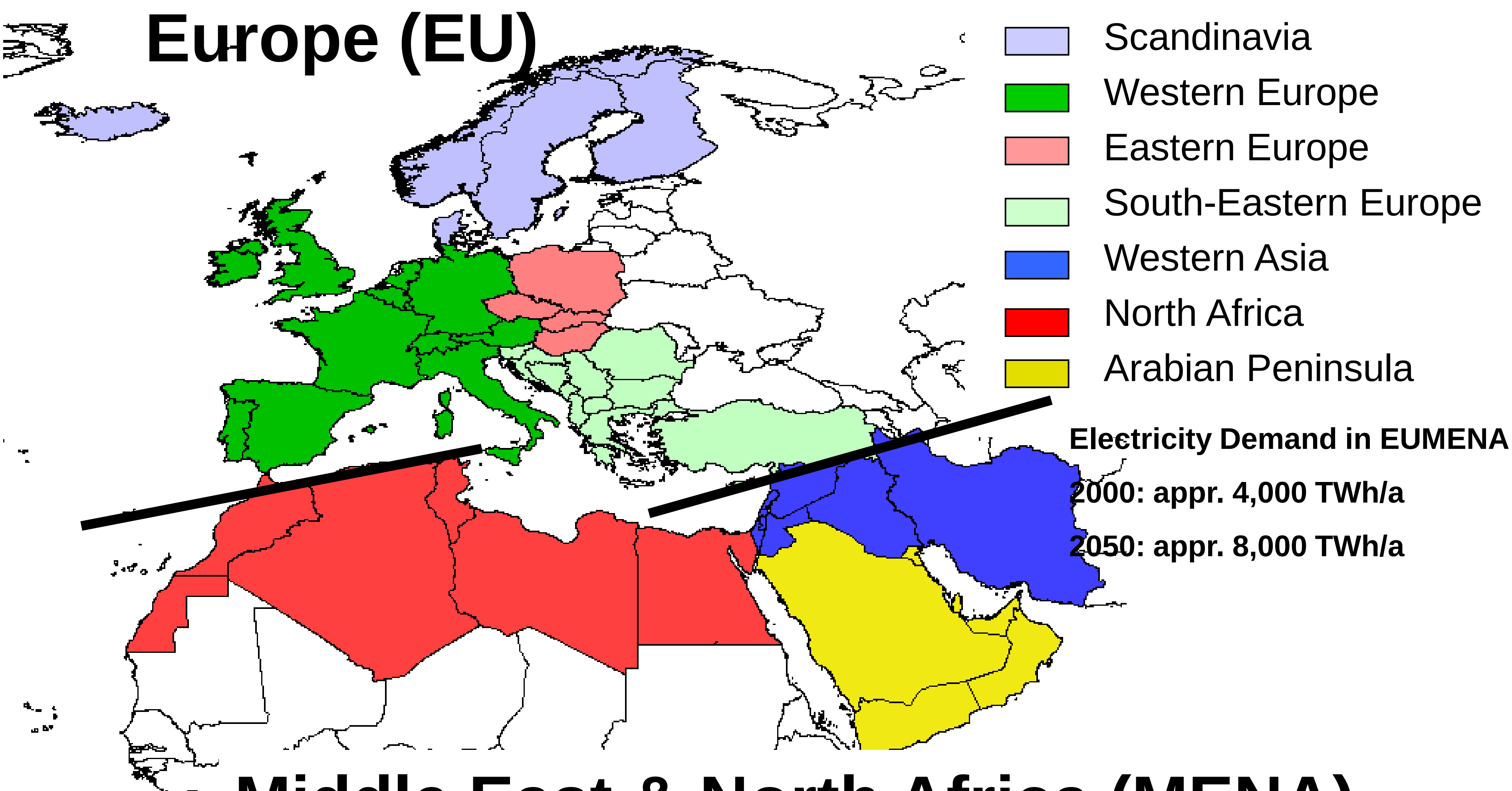
MED-CSP TRANS-CSP AQUA-CSP

Sustainable Electricity and Water for Europe, Middle East, and North Africa

Results of a series of studies comissioned by the Federal Ministry of for the Environment, Nature Conservation and Nuclear Safety

Reports and individual scenarios for countries:
http://www.dlr.de/tt/med-csp
http://www.dlr.de/tt/trans-csp
http://www.dlr.de/tt/aqua-csp

50 Countries in EUMENA analyzed



Electricity Demand in EUMENA

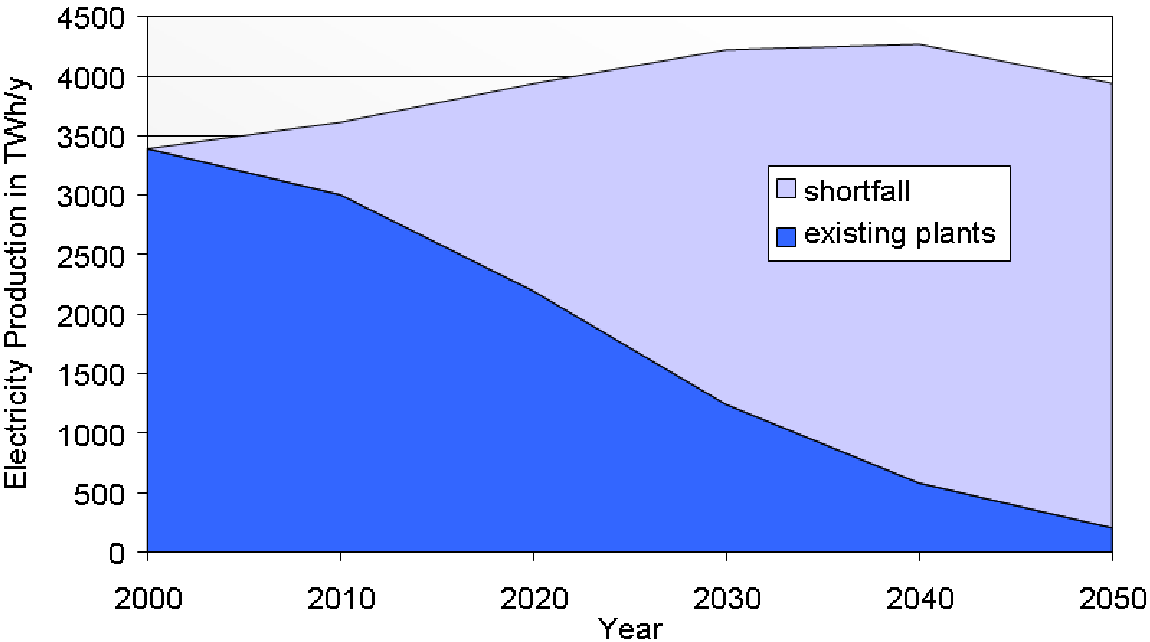
2000: appr. 4,000 TWh/a

2050: appr. 8,000 TWh/a

Middle East & North Africa (MENA)

Development of European electricity demand and its coverage by power plants already existing in 2000

- moderate increase due to efficiency gains and socio-demographic development
- significant investments required to replace “old” plants
- targets for reduced CO_2 emissions and increased renewable sources
- window of opportunity for restructuring of electricity sector
- and to reduce dependency on imported fuels



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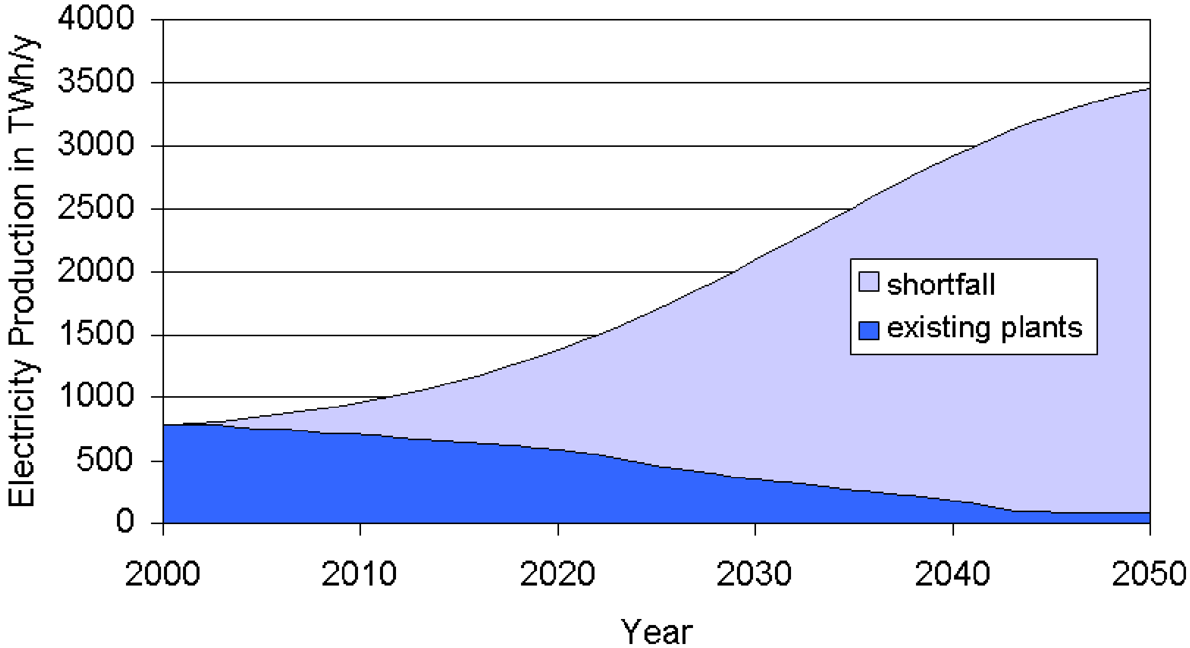
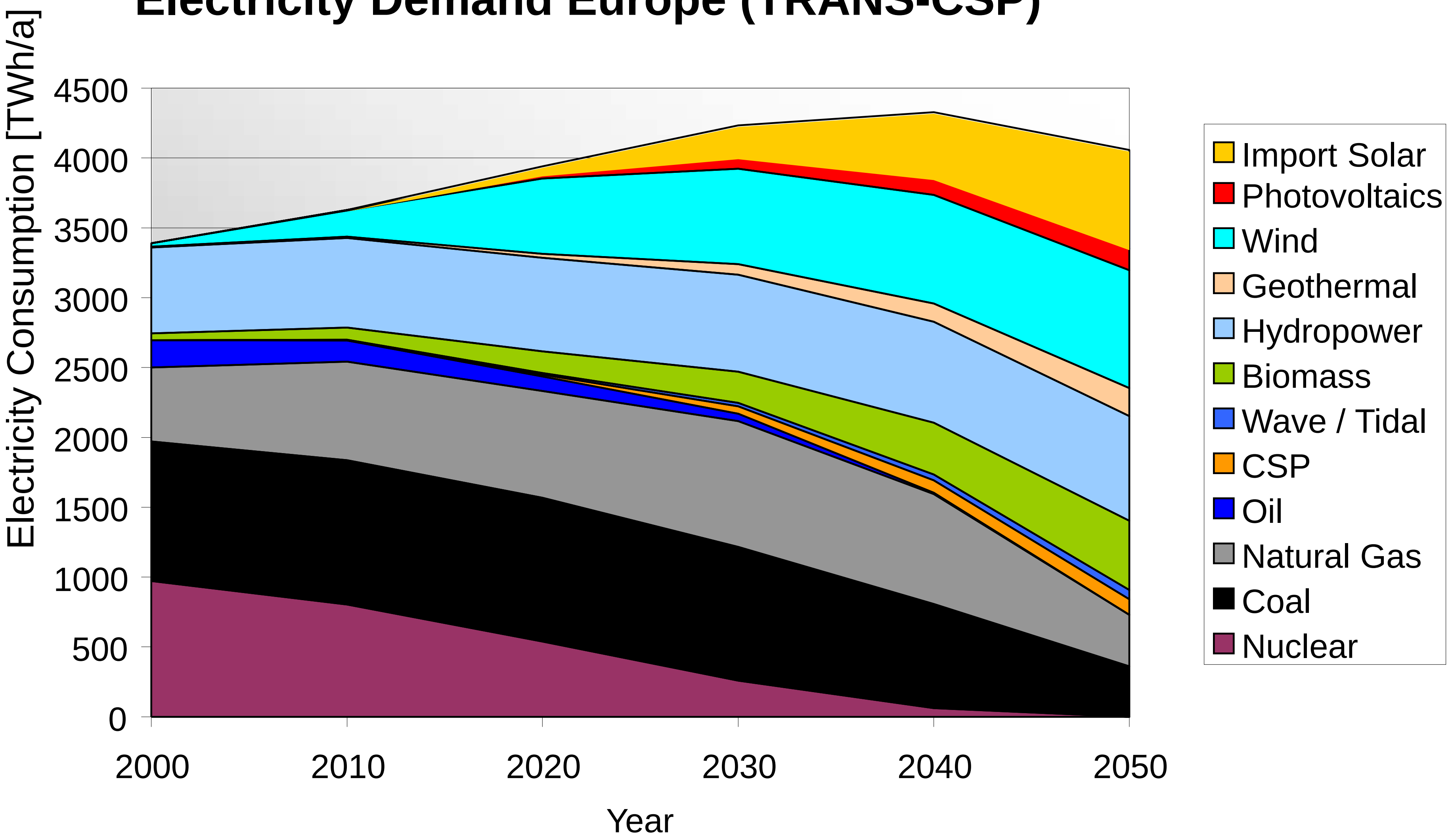
Development of MENA electricity demand, and its coverage by power plants already existing in 2000

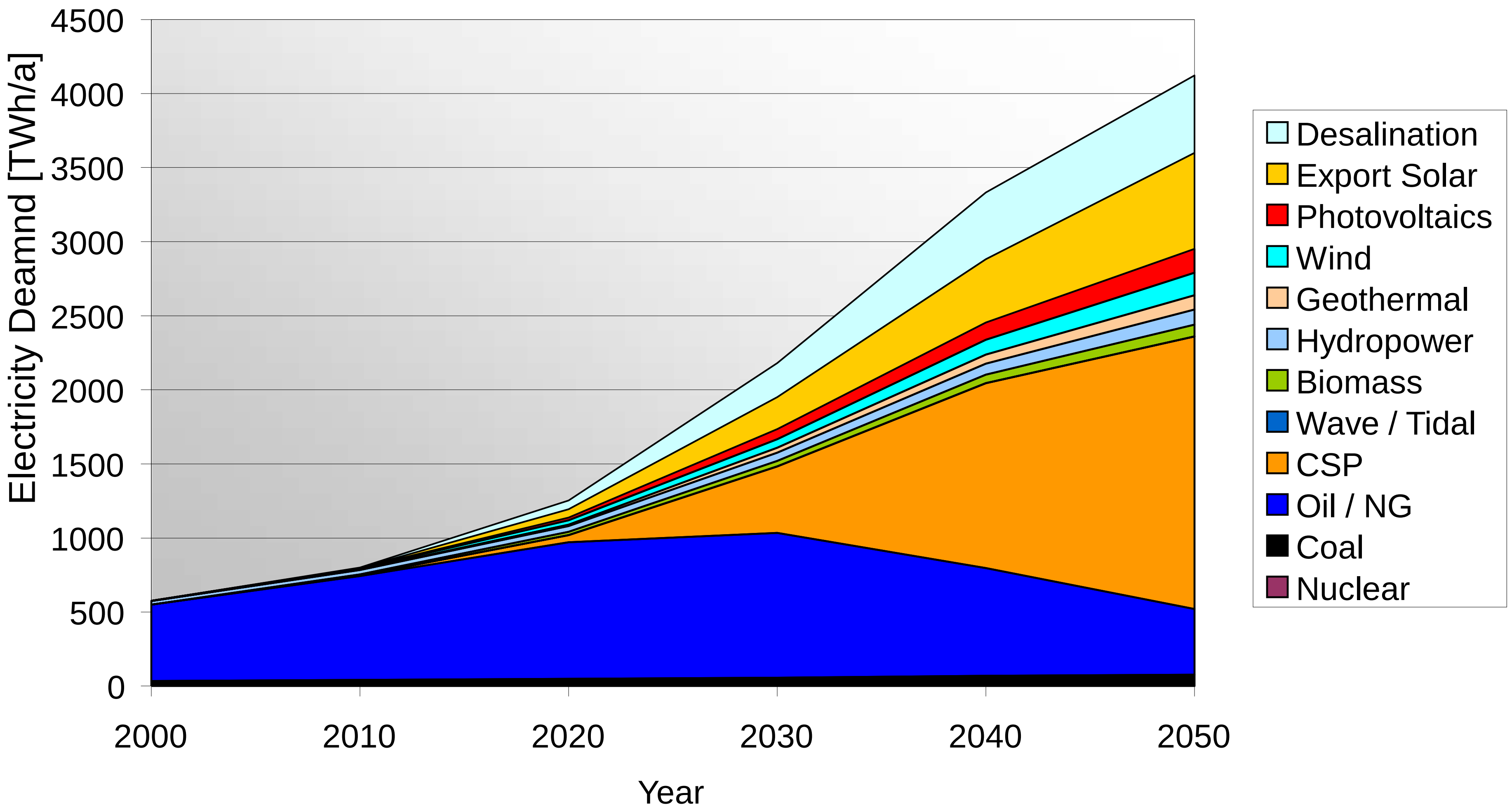
- significant increase due to economic and population growth
- significant investments required for new plants
- window of opportunity for sustainable local electricity and water supply
- potential of future electricity exports
- unique opportunity for closer economic, political and social links with Europe



Electricity Demand Europe (TRANS-CSP)



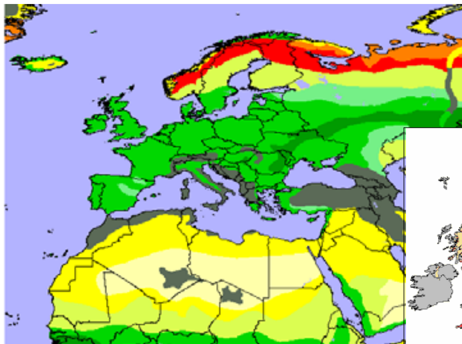
Electricity Demand Middle East and North Africa (MED-CSP)



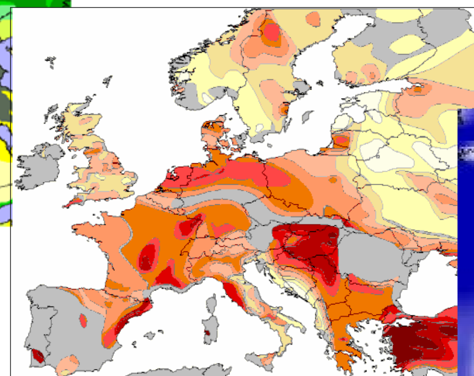
Renewable energy resources in Europe and MENA

in brackets: (range of yield in GWh_{el} / km² / y)

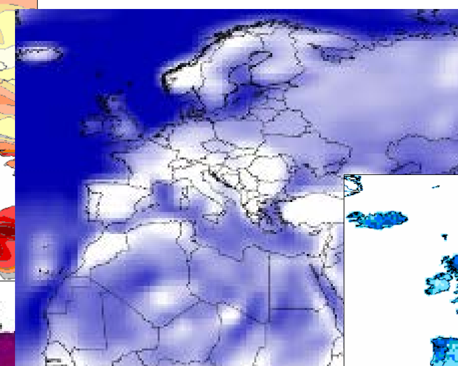
Biomass (0-1)



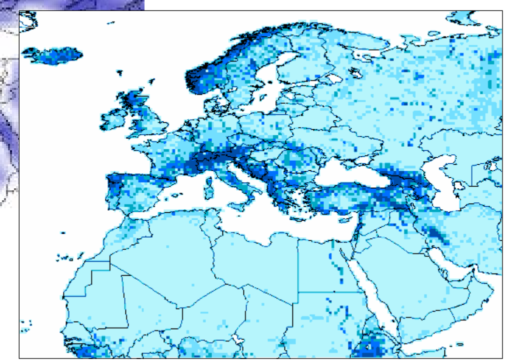
Geothermal (0-1)

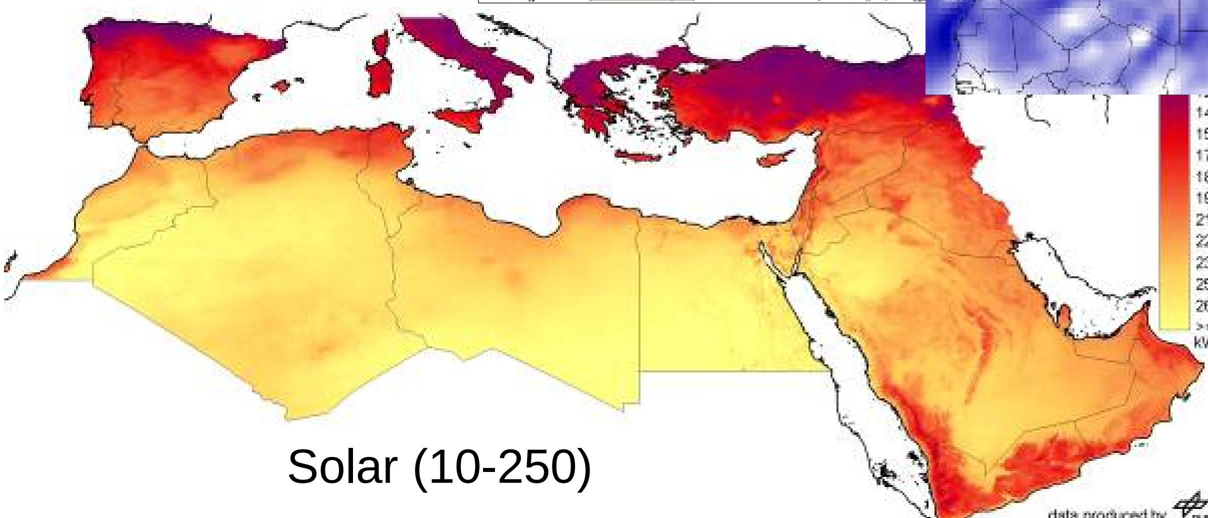


Wind (5-50)



Hydropower (0-50)





Solar (10-250)

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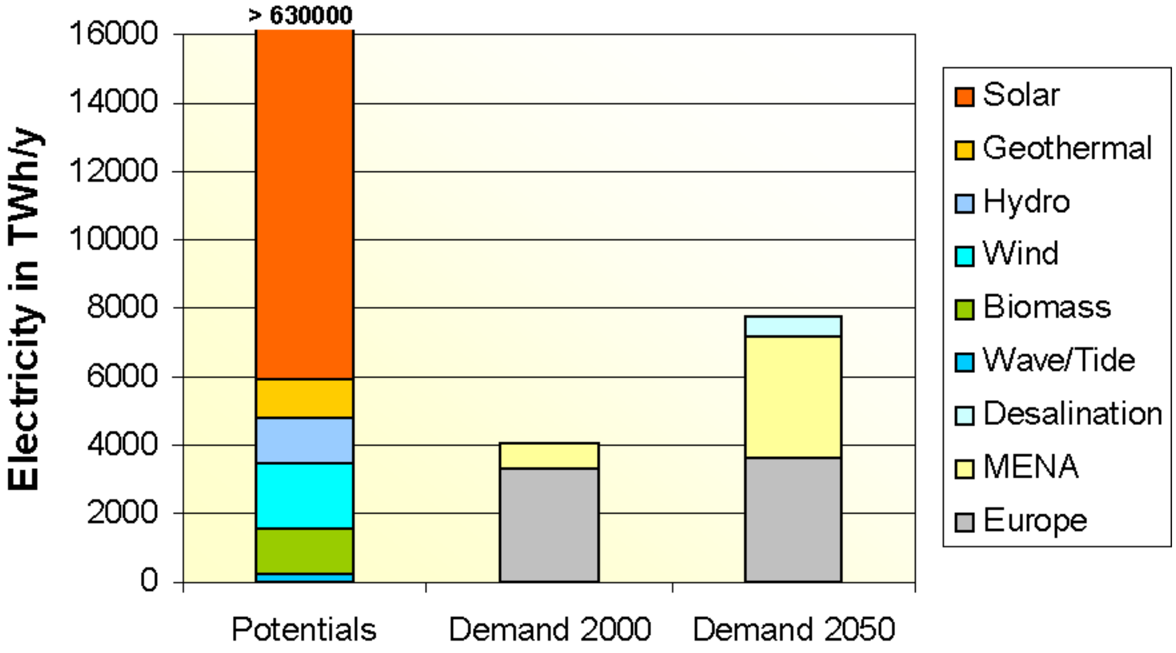
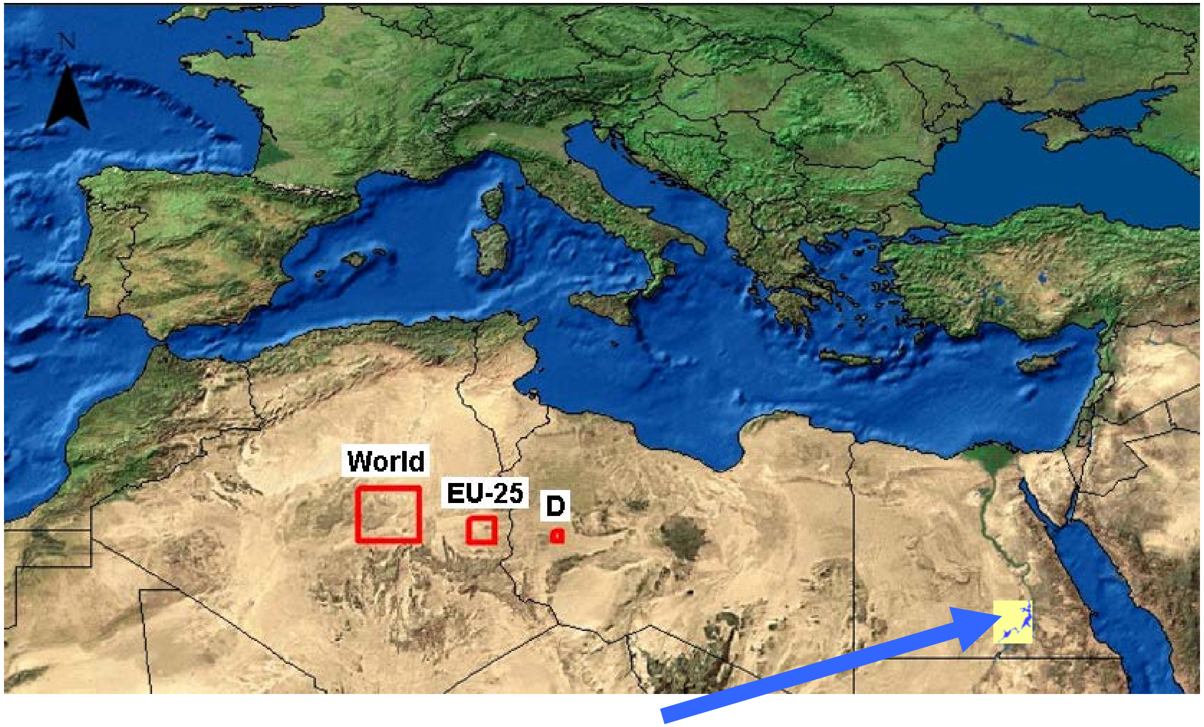
Economic renewable electricity potentials vs. demand in Europe and MENA

- renewable resources greatly exceed the present and future electricity demands
- solar radiation is by far the most abundant source of energy



Required Area for CSP Power Supply of the World, EU-25, Germany

- renewable resources greatly exceed the present and future electricity demands
- solar radiation is by far the most abundant source of energy
- 1 km² of desert land may generate 50 MW of electricity
- 1 km² of desert land may produce 200 - 300 GWh_{el} / year
- 1 km² of desert land may avoid 200,000 tons CO_2-emisssions / year
- Solar thermal power plants are the most effective technology to harvest this vast ressource

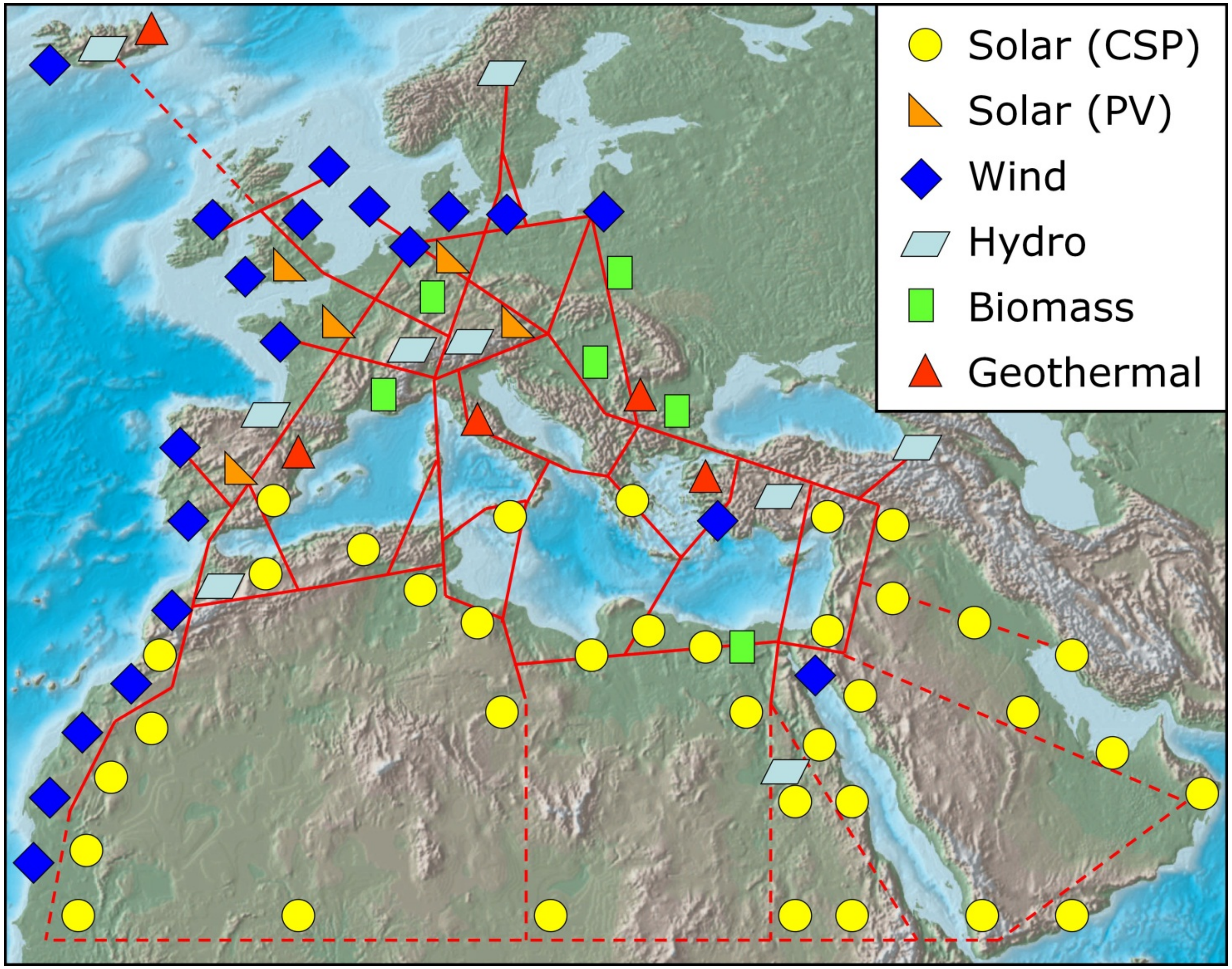


The electrical energy produced by a solar power plant with the size of Lake Nasser equals the total Middle East oil production

The Vision: Interstate Highways for Renewable Electricity: Trans-Mediterranean High Voltage Direct Current Electricity Grid

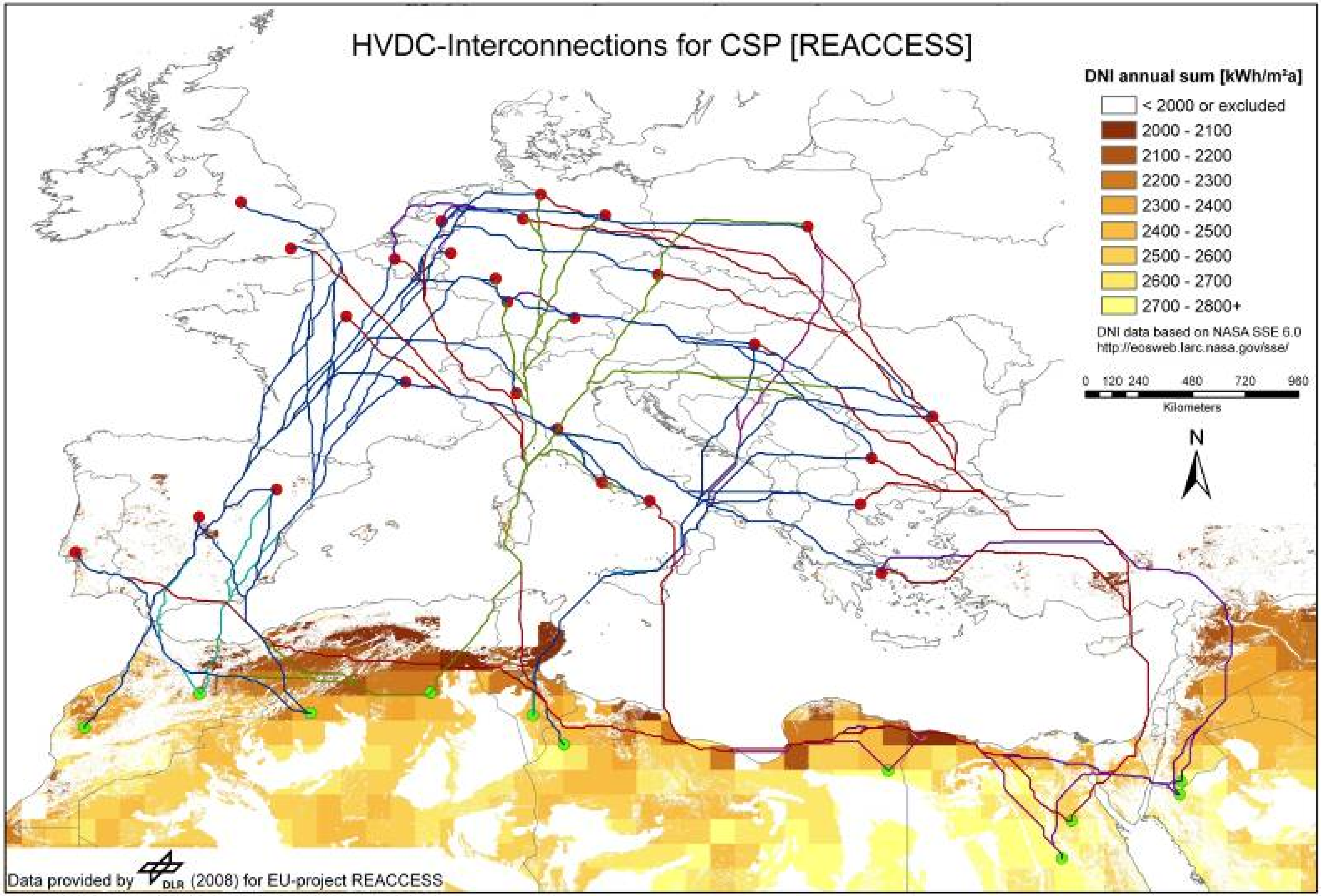
TREC
Clean Power from the Deserts
Trans-Mediterranean
Renewable Energy Cooperation
In conjunction with The Club of Rome

THE CLUB OF ROME



www.desertec.org

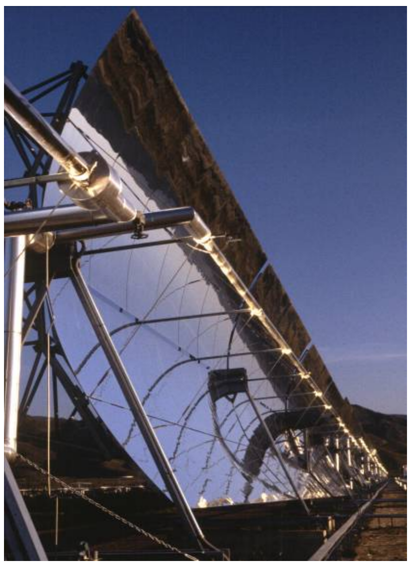
HVDC-Interconnections as Solar Energy Corridors



Contents

Concentrating Solar Power (CSP)

By means of concentrating solar collectors and absorbers process heat is generated, transferred to a heat transfer fluid to drive steam turbines, gas turbines, or piston engines, for thermo-mechanical production of power or combined heat and power.



Steam

Power

Conc. Solar Collector

Steam Turbine & Generator

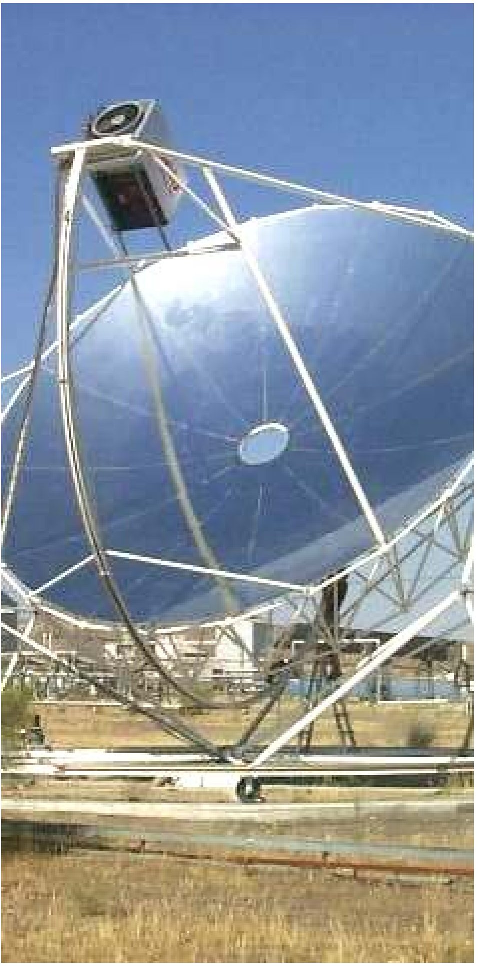
Grid

Why solar thermal power plants ?

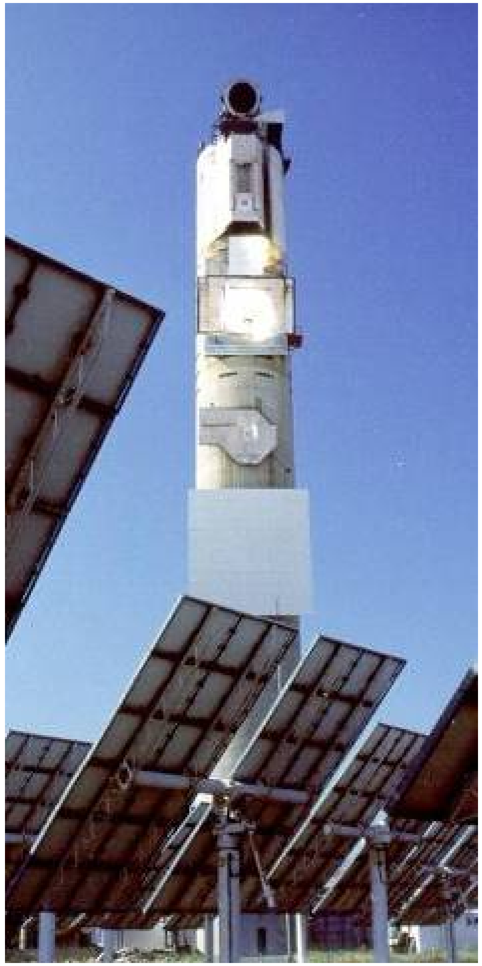
Solar thermal power plants

- can be integrated into conventional thermal power plants
- provide firm capacity (thermal storage, fossil backup)
- serve different markets (bulk power, remote power, heat, water)
- have the lowest costs for solar electricity
- have an energy payback time of 6-12 months

Types of Concentrating Solar Thermal Technologies

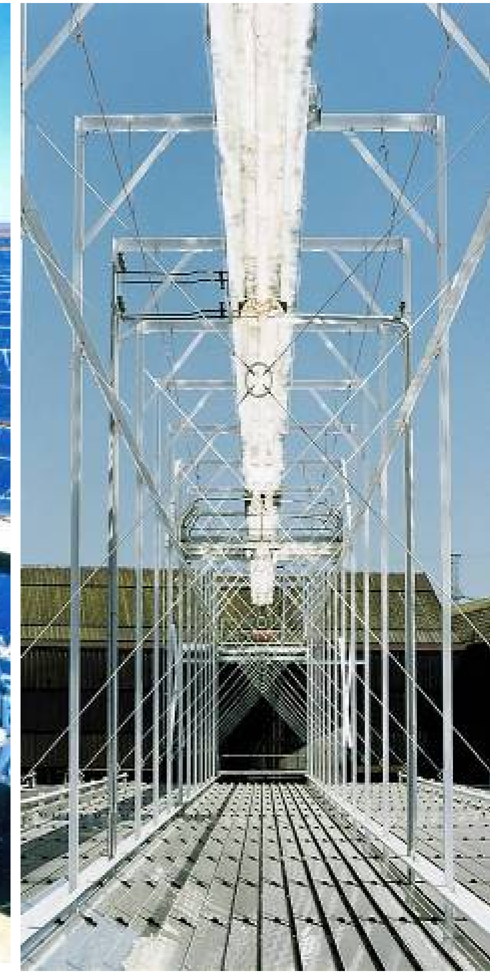


Dish-Stirling



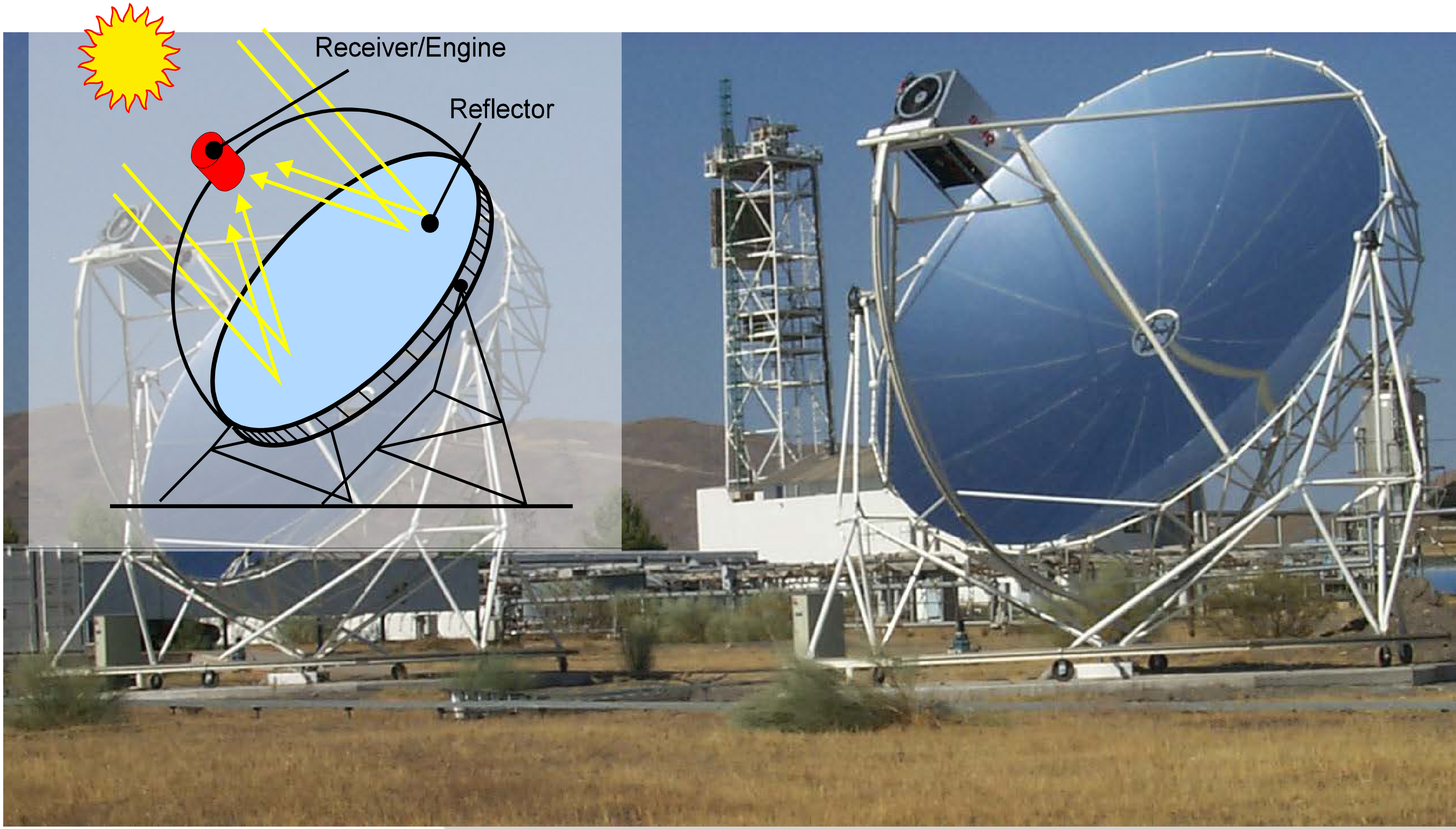
Solar Power Tower

Parabolic Trough

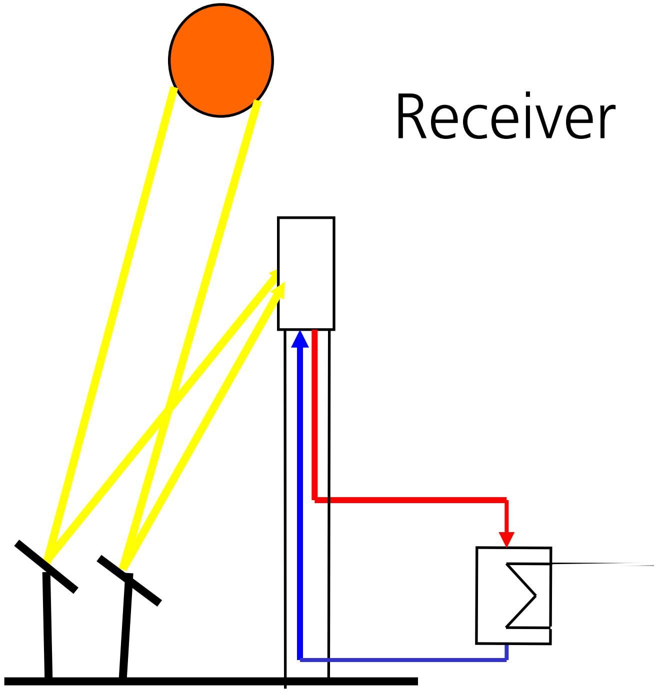


Linear Fresnel

Principle: Dish/Stirling Technology

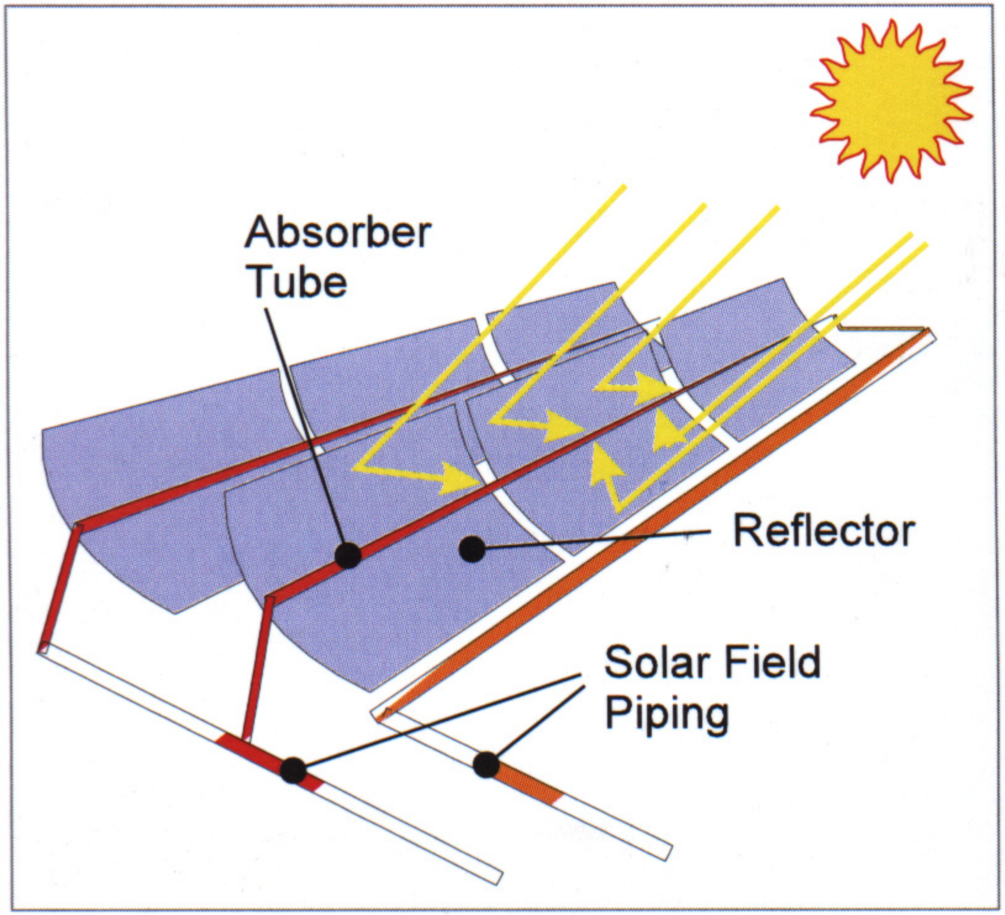


Principle: Solar Tower Power Plants



PS-10 (11 MWe): Start of Operation 2007

Principle: Parabolic Trough Solar Power Plants



Nevada Solar One (64 MW_e), 2007

ANDASOL 1 (50 MW; 7,5 h Storage), 2009

1,9 km^2 Ground area
0,5 km^2 Collector area
209.664 Parabolic mirrors
22.464 Absorber tubes → 90 km
2.000 t Thermal oil
28.500 t Storage medium
Ca. 180 GWh/a Electricity production → 200.000 people

Andasol 1 -3

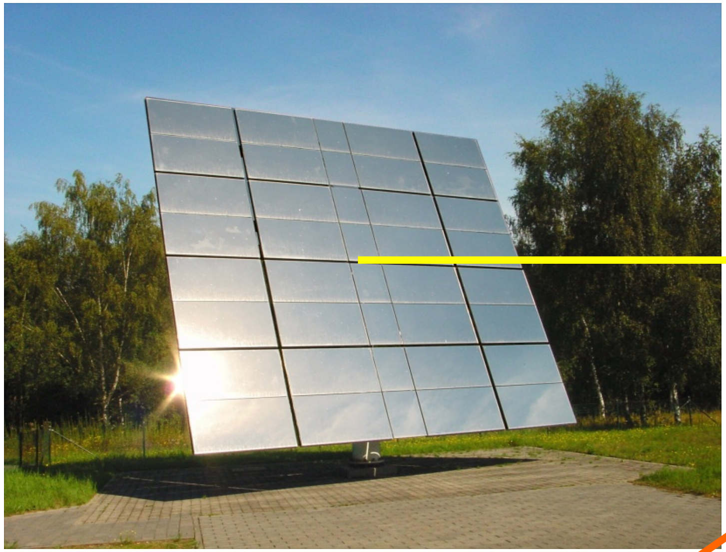
Contents

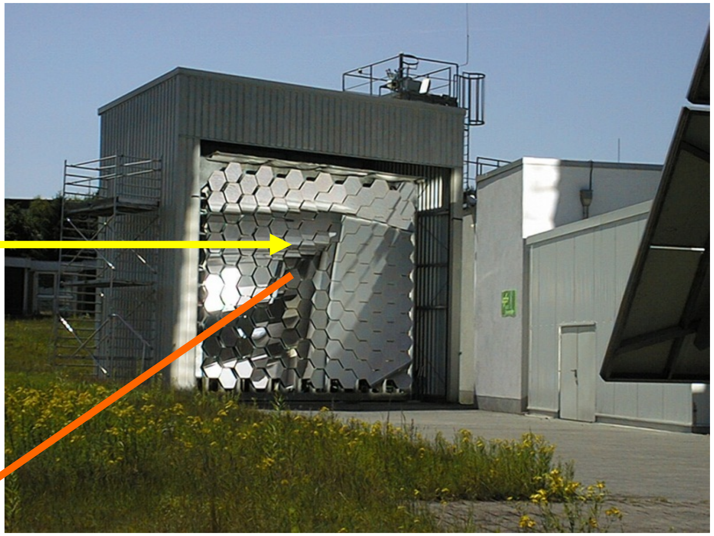
- Introduction
- 4 Challenges
- Sustainable Electricity and Water for the MENA Region and Beyond
- CSP Technology and Recent Examples
    - **Test Facilities and Solar Power Plant Development at DLR**
- Summary and Conclusions

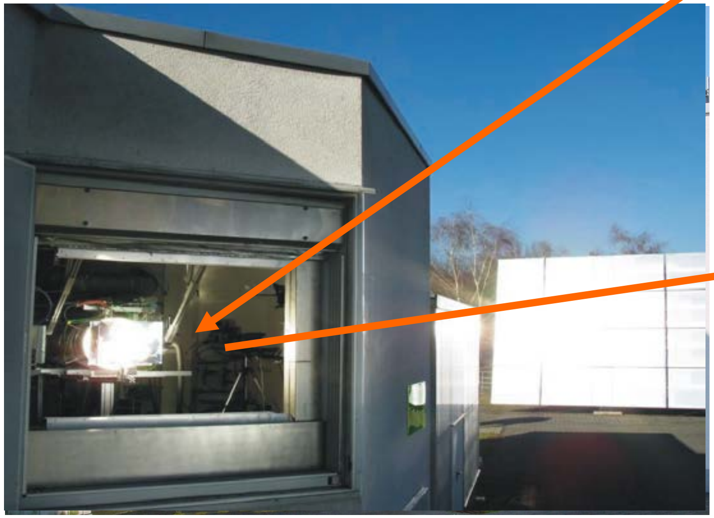
Facilitiy: High Flux Solar Furnace

- Max. Power at Focal Plane: up to 25 kW
- Max. Irradiance up to 5 MW/m^2
- Spectrum similar to natural sunlight

Facilitiy: High Flux Solar Furnace



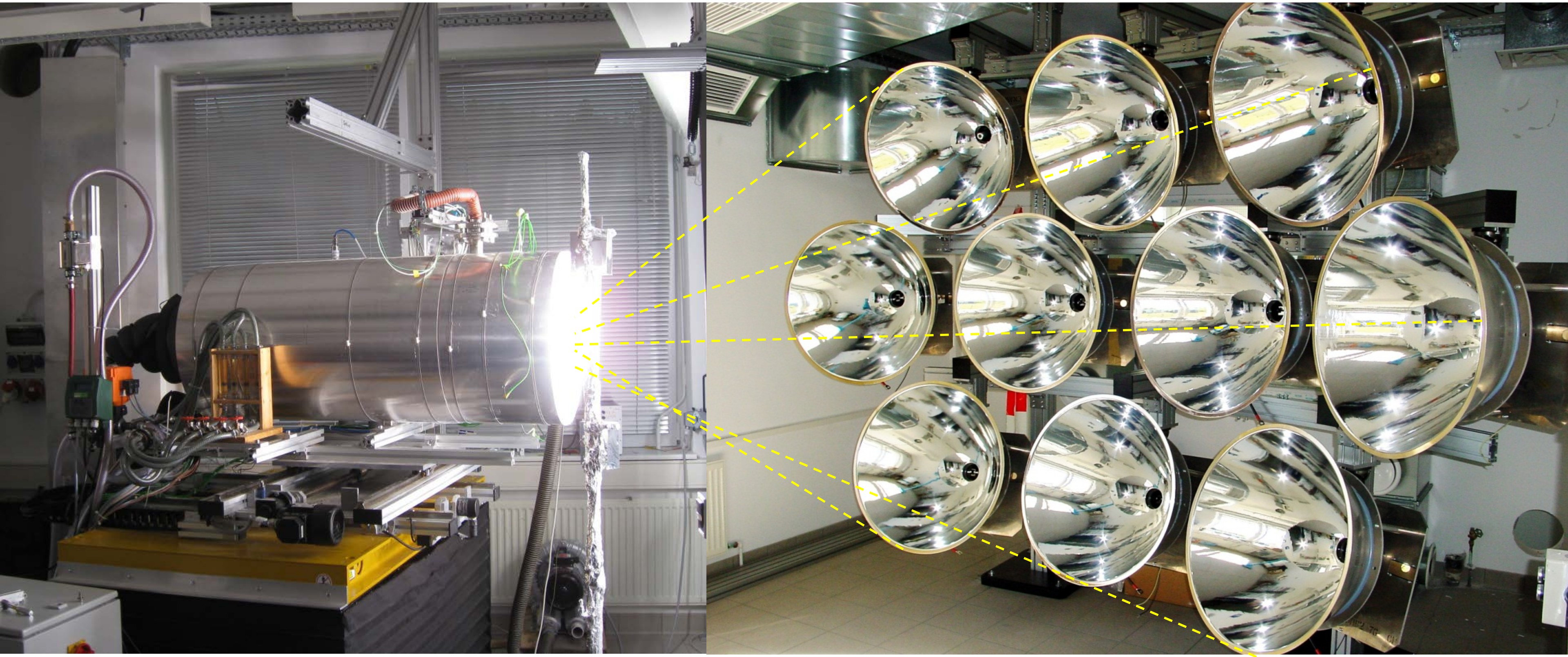




High Power Solar Simulator

- **Electric Power Input: 60 kW**
- **Max Radiant Power at Focal Plane: ca. 20 kW**
- **Artificial Light with a Spectrum similar to Natural Sunlight**

Application of the High Power Solar Simulator for the Qualification of Receiver Materials



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Classification of Solar Processes

- **High Temperature and / or high Irradiance required, without Requirement in Power**

- **High Temperature and / or high Irradiance required and high Requirement in Power**

Solar Processes without Requirement in Power

- Heat Treatment of Materials at T > 1000 °C
- Testing of Materials in a High Vacuum at High Irradiances
- Testing of Materials to Simulate and Accelerate Aging Processes with Concentrated Natural UV-Radiation
- Kinetic Studies of High Temperature Processes

  - Evaporation Rates of Solids

  - Dissociation Rates

  - Formation Rates of Solids

Solar Processes with high Requirement in Power

- **Solar Photochemical Syntheses of Commodities and Specialities**
- **Solar thermal Fuel Production**
- **Solar thermal Power Production**

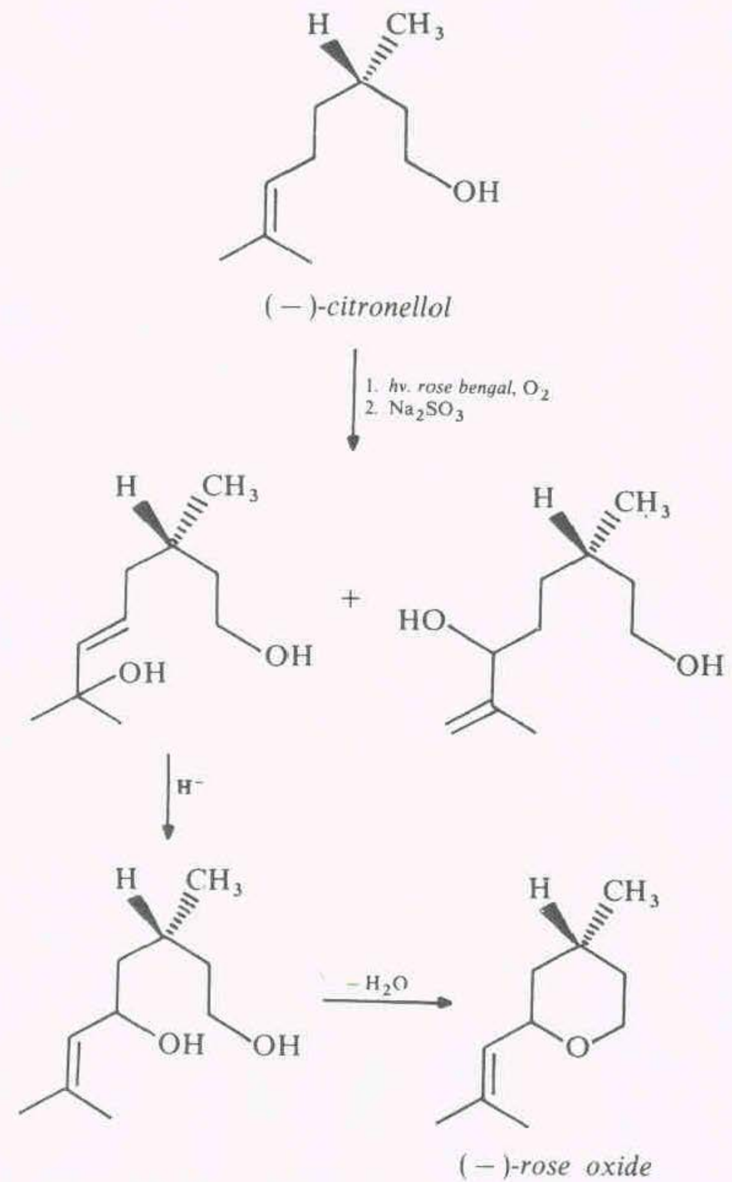
Solar Photochemical Technology for Synthetic Applications

- **Photooxygenations (Singlet-Oxygen)**
- **Photoisomerizations**
- **Photo-Bönnemann-Reactions**
- **Photo-Friedel-Crafts-Acylations**
- **Paternò-Büchi-Reactions**
- **Photooximations**

Sensitized Photooxyenations (4/5)

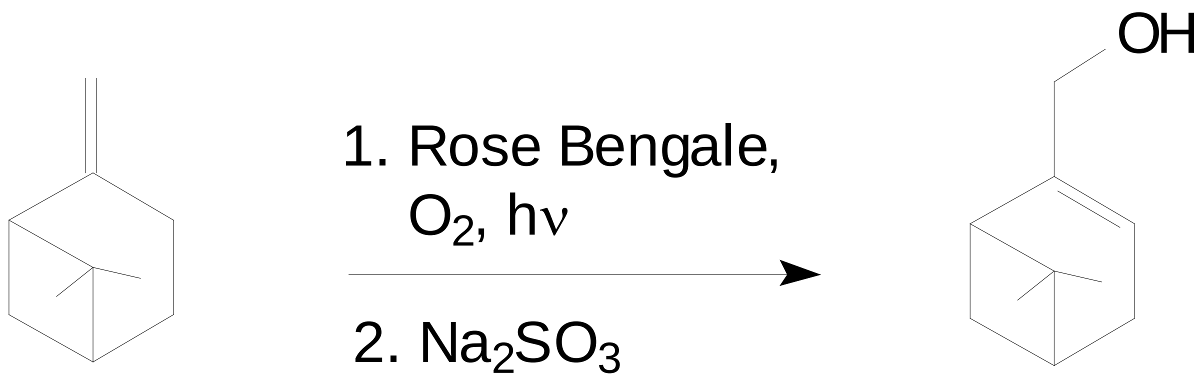
Ene-Reaction von (-)-Citronellol in the Industrial Synthesis of (-)-Rose Oxide

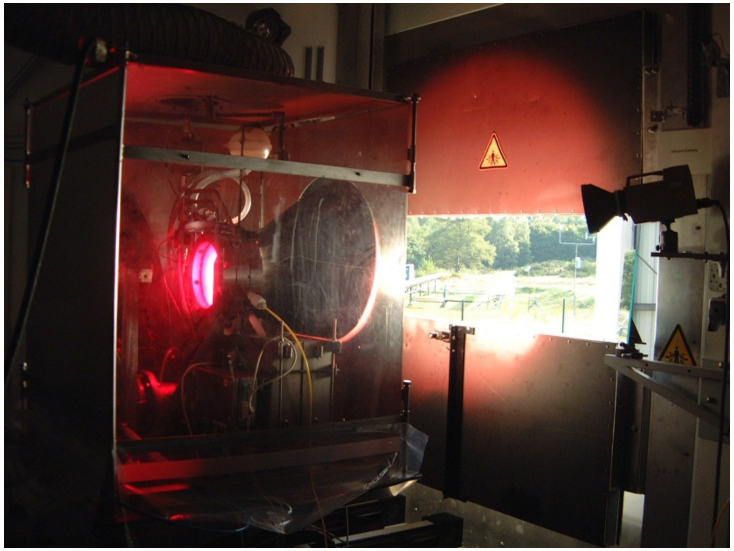
Ref. Scharf et al., Demuth et al., Funken et al.



Sensitized Photooxygenations (5/5)

Production of Myrthenol by Photooxidation of β-Pinene

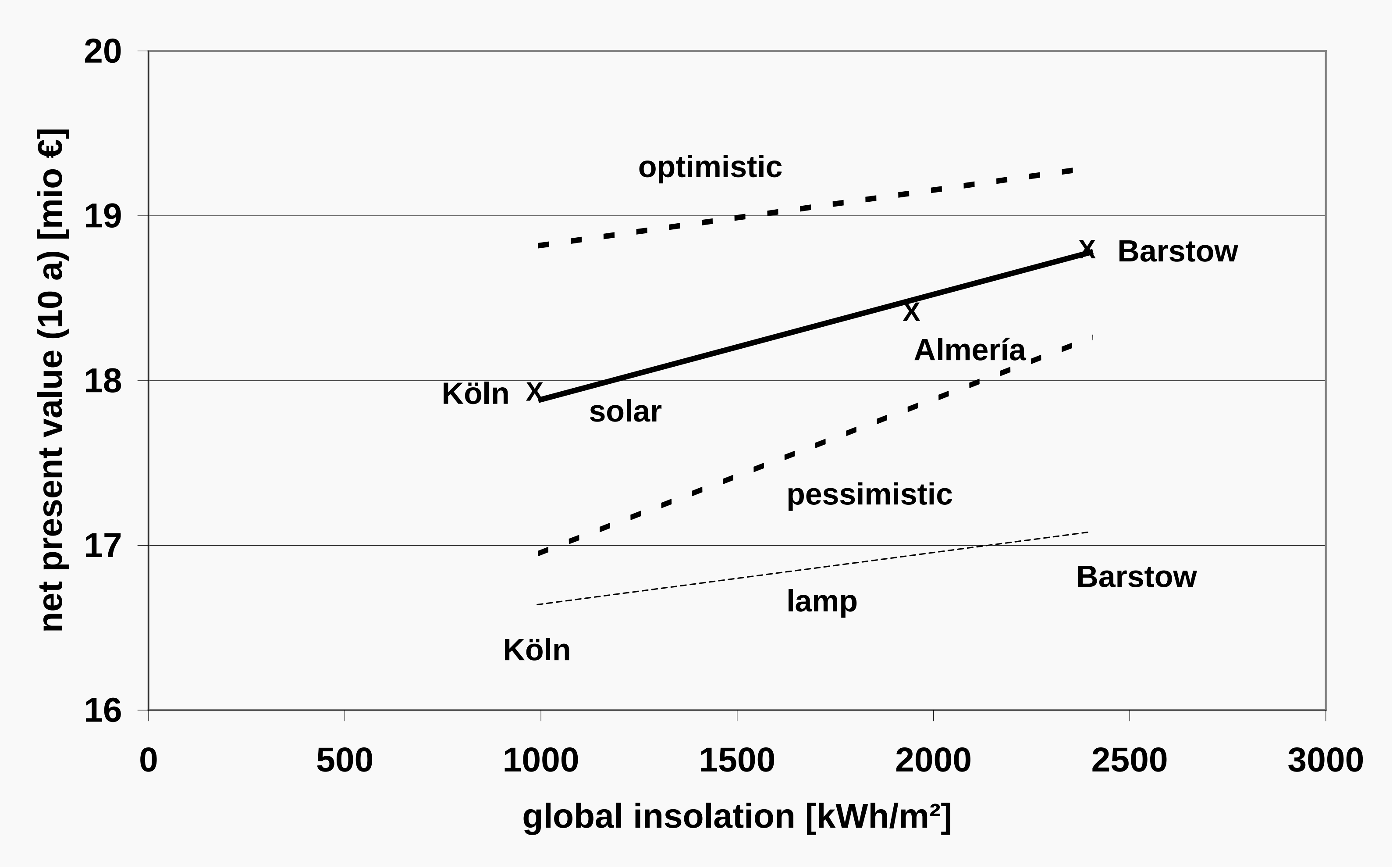




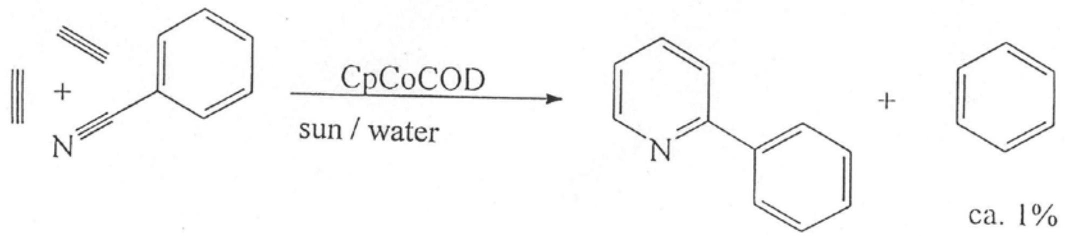
Ref.: Scharf et al.

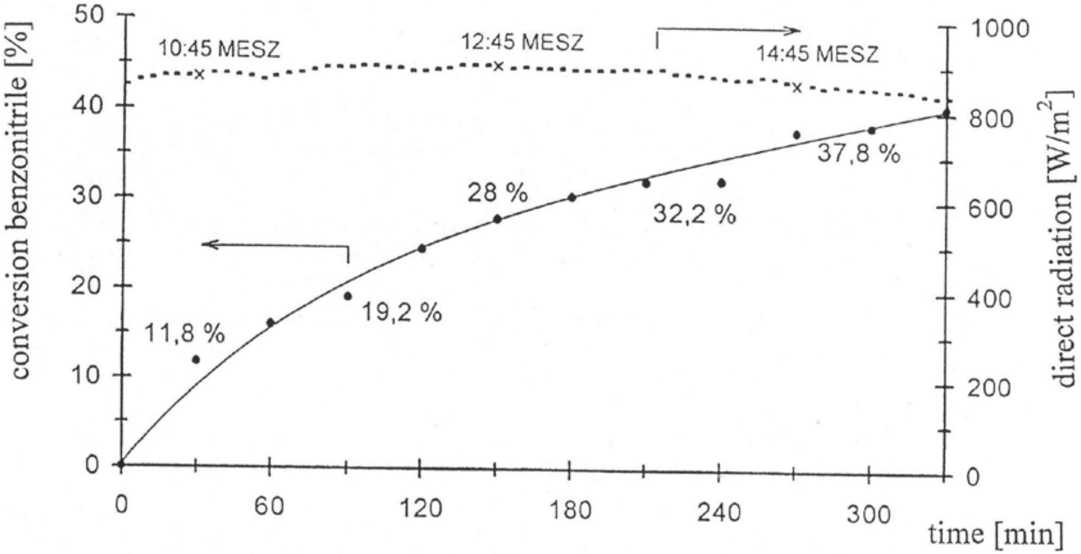
Solar Photoreactors: Tests of Photooxygenations, DLR

Evaluation of Investment: Production of Rose Oxide



Photocatalytic Heterocyclisation

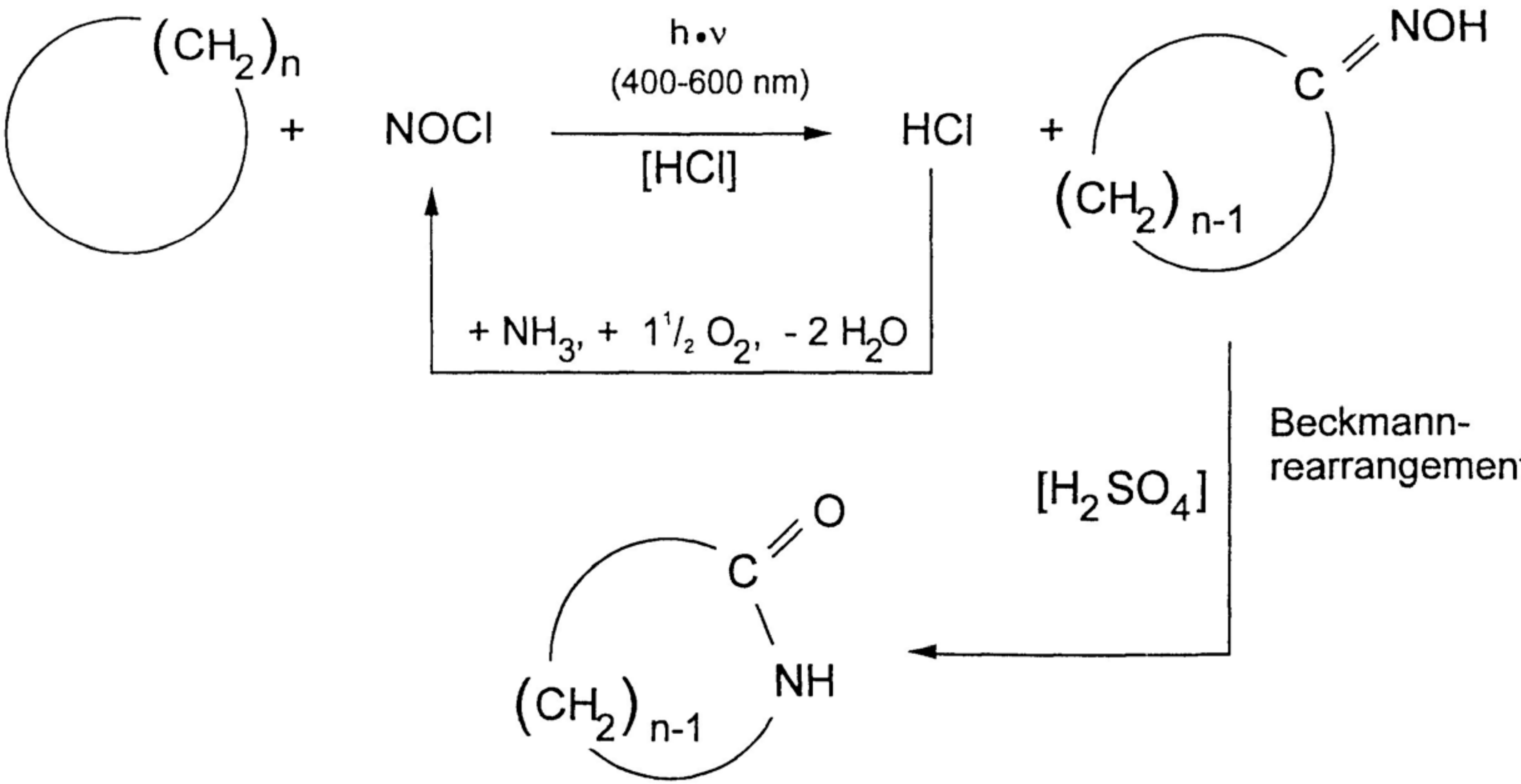




model reaction for solar heterocyclizations

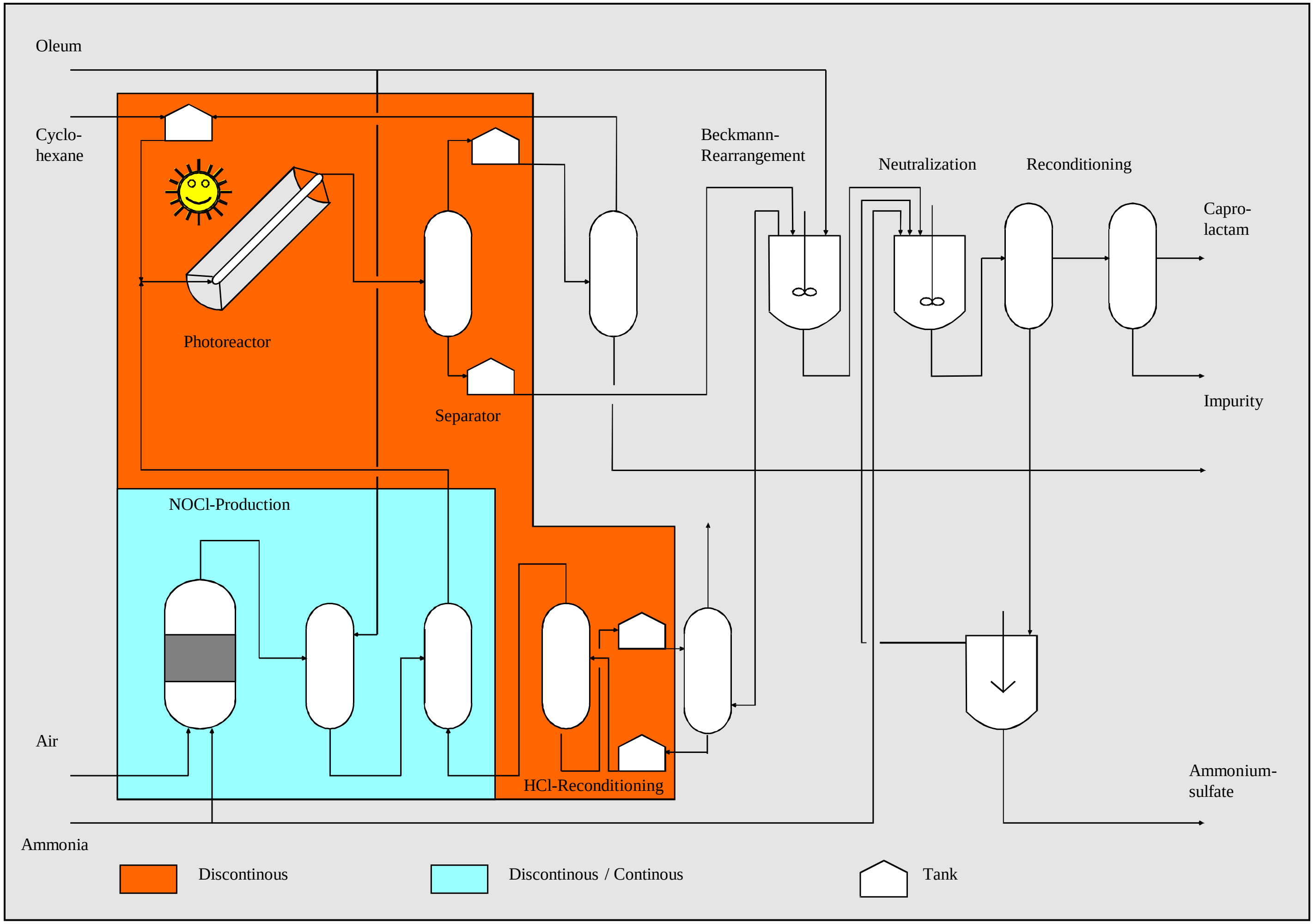
P. Wagler, B. Heller, J. Ortner, K.-H. Funken, G. Oehme, Chem.-Ing.-Tech. 68 (1996) 823

Solar Photooximation of Cyclic Alkanes for the Production of Nylon-Precursors

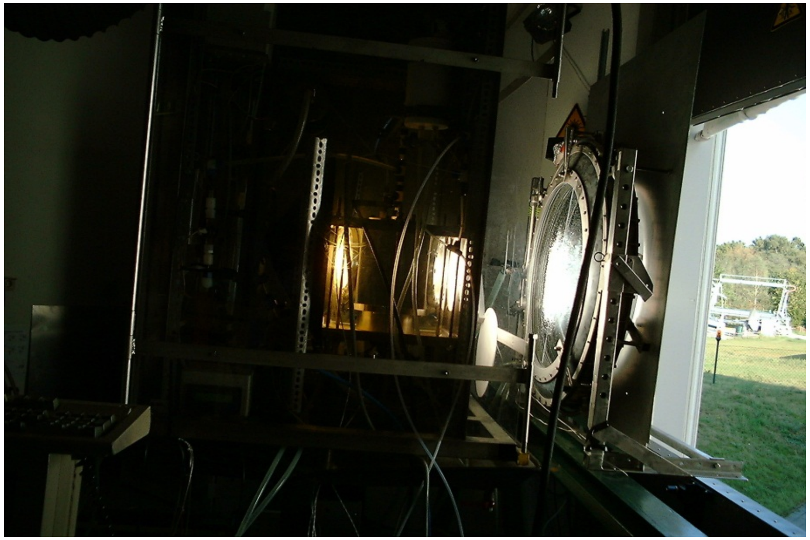


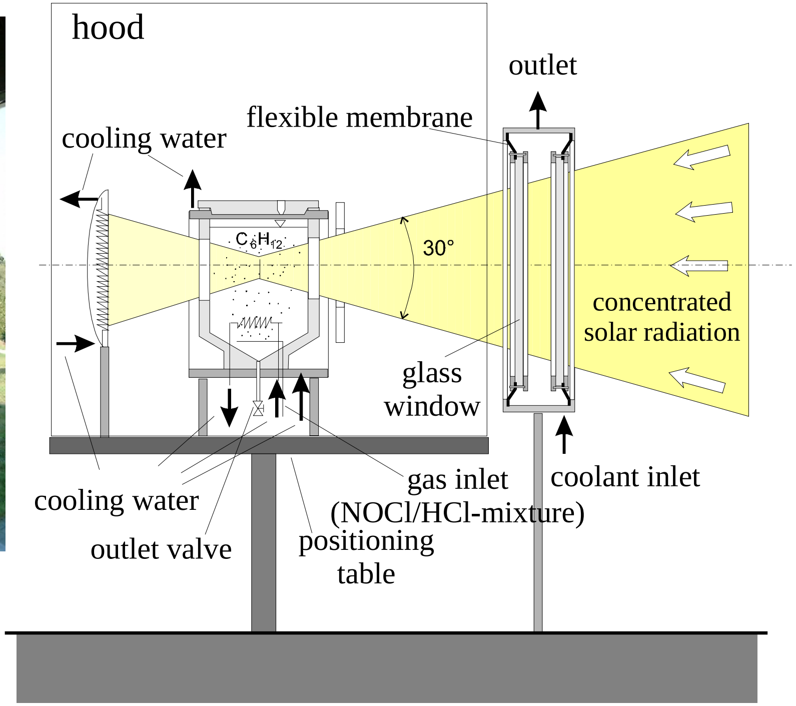
n=6: ε–Caprolactam, n=12: laurylllactam

Block Diagram of a Solar Caprolactam Production Plant



Solar Photochemistry: Photooximation of Cyclic Alkanes for the Production of Nylon-Precursors



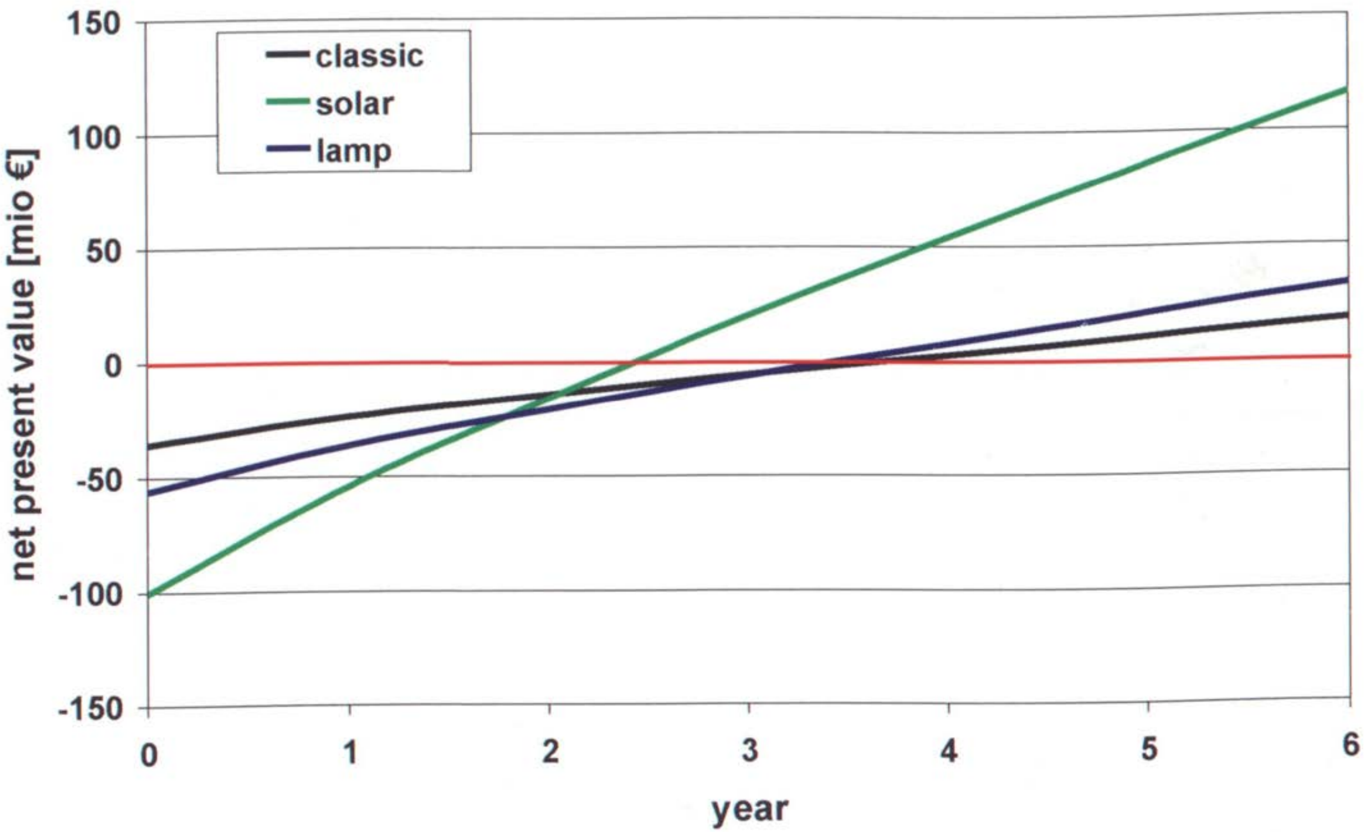


Ref. Riffelmann, Funken, DLR

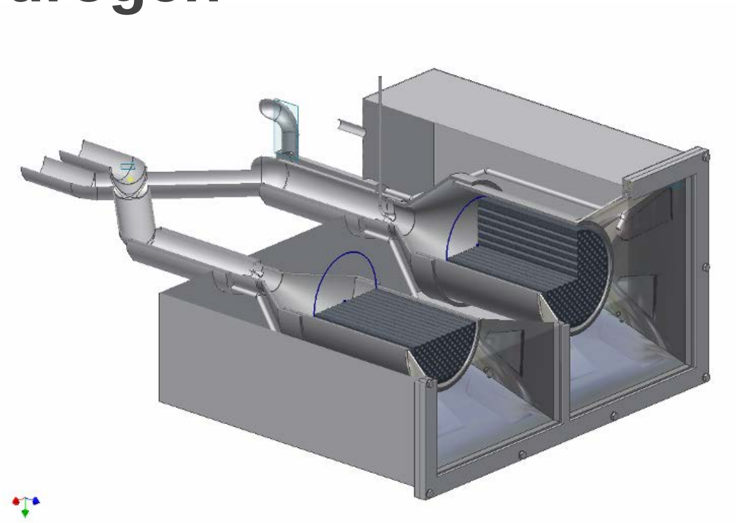
Comparison of Production Costs (10,000 t/a)

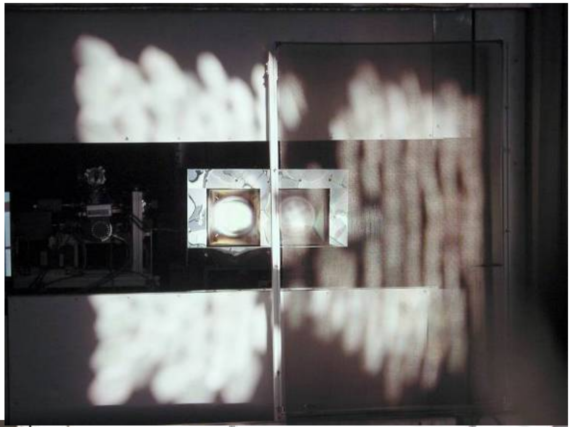
	Solar		Lamp	
	[1000 $]	[%]	[1000 $]	[%]
Fixed Cost				
(labor, annuity etc.)	3440	**52,0**	1960	22,8
Variable Cost				
Electricity	240	3,5	950	**11,1**
Chemicals	3850	58,3	3850	44,8
Cooling	180	2,6	1440	**16,8**
Sale $(NH_4)_2SO_4$	-1110	-16,8	-1110	-12,9
Production Cost 1	6630		7090	
Lamp Replacement	0	0,0	1500	**17,5**
Production Cost 2	6630		8590	

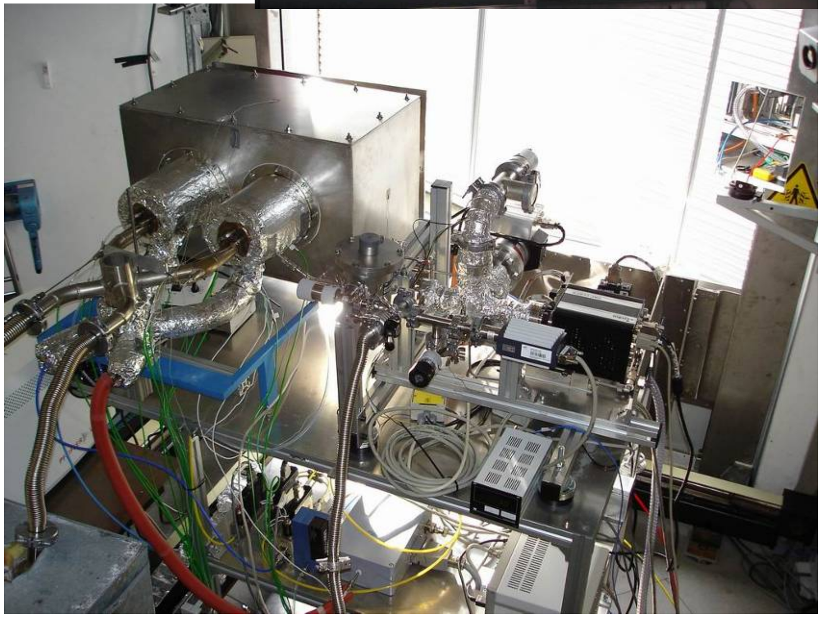
Economic Evaluation of different Caprolactam Routes



Quasi-continuous Solar Thermal Production of Hydrogen



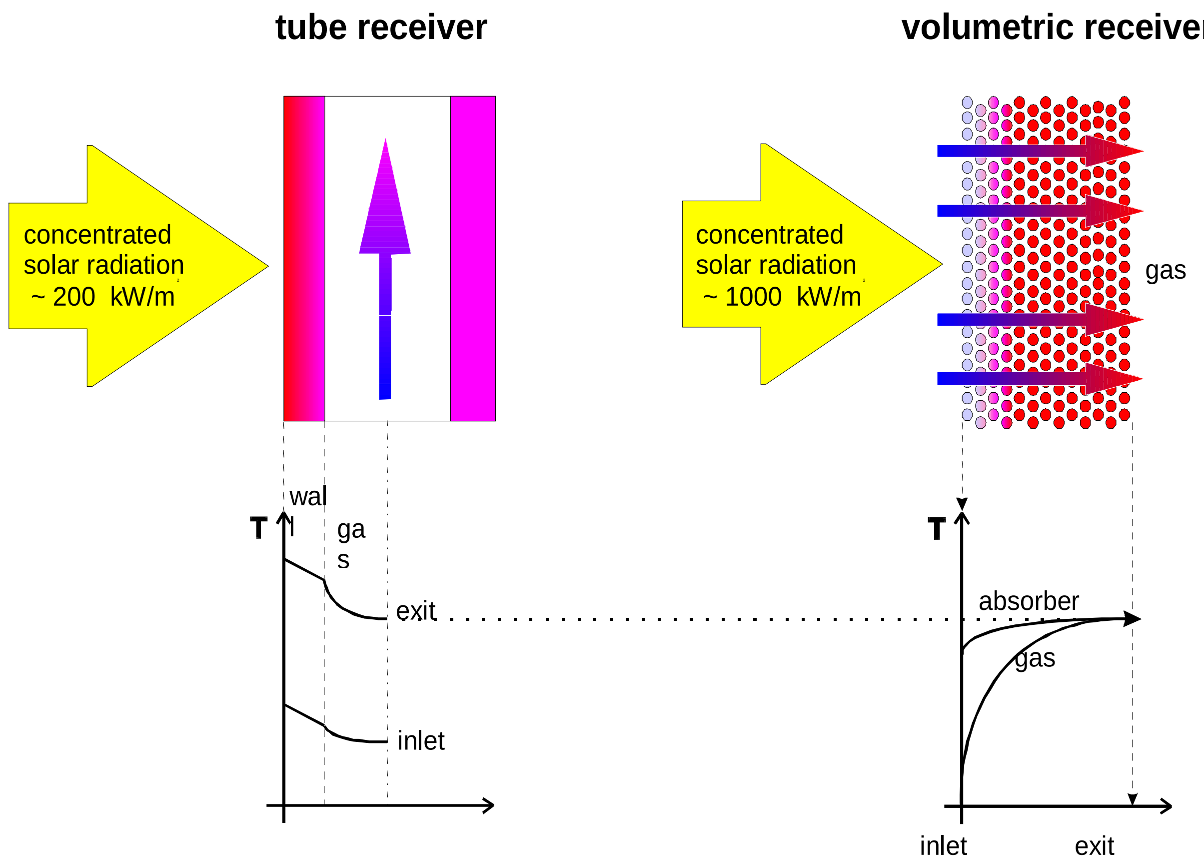




Ref. Sattler, Roeb et al., DLR

Pilot Plant for Solar Thermal Production of Hydrogen at the Plataforma Solar de Almería, Spain

Techology of the Open Volumetric Air Receiver (DLR) as Demonstrated in Jülich



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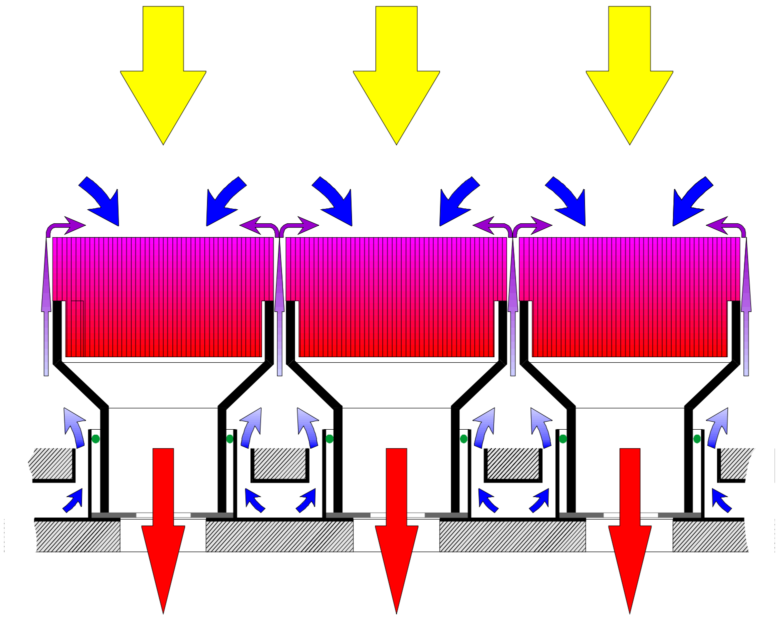
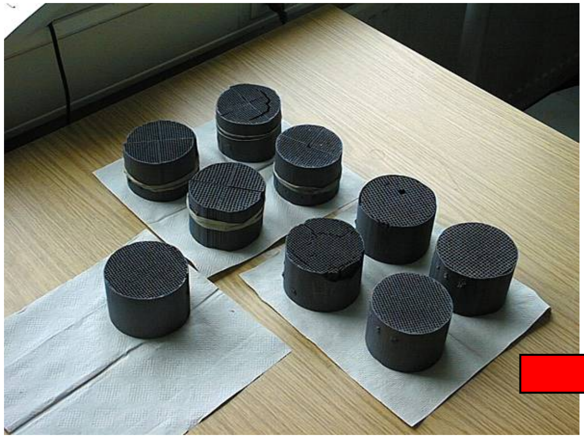
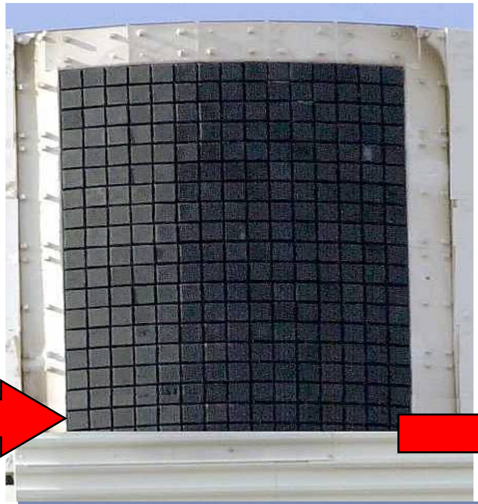
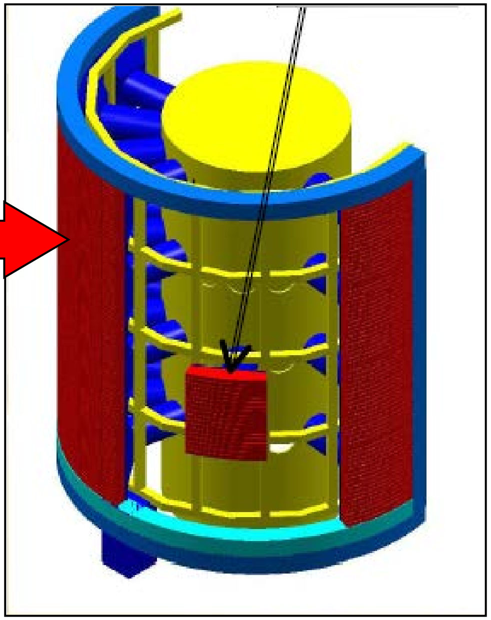
High Temperature Receiver (HiTRec)



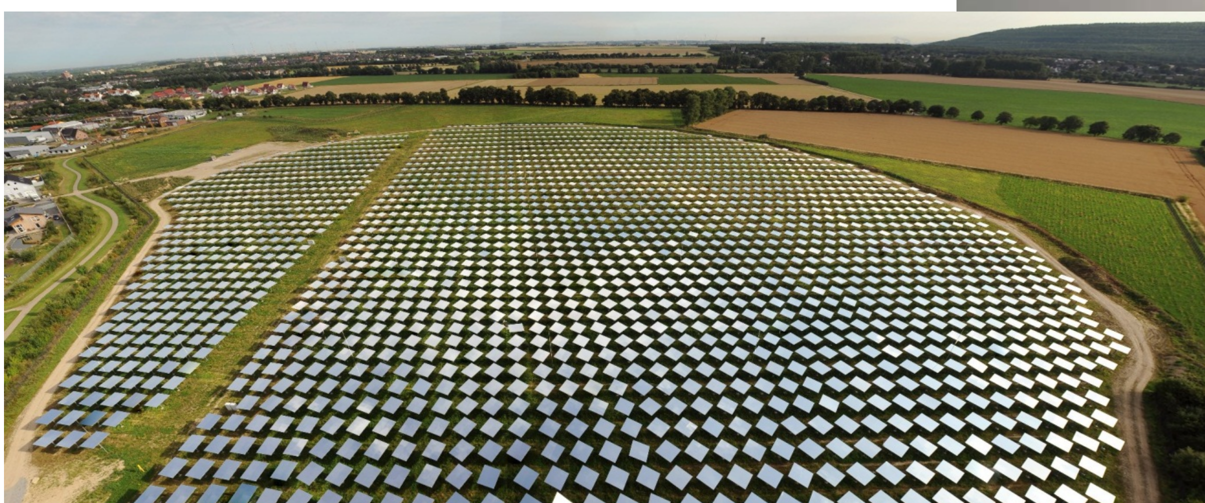
HiTRec Receiver Development







Solar Thermal Test and Demonstration Power Plant Jülich (STJ)



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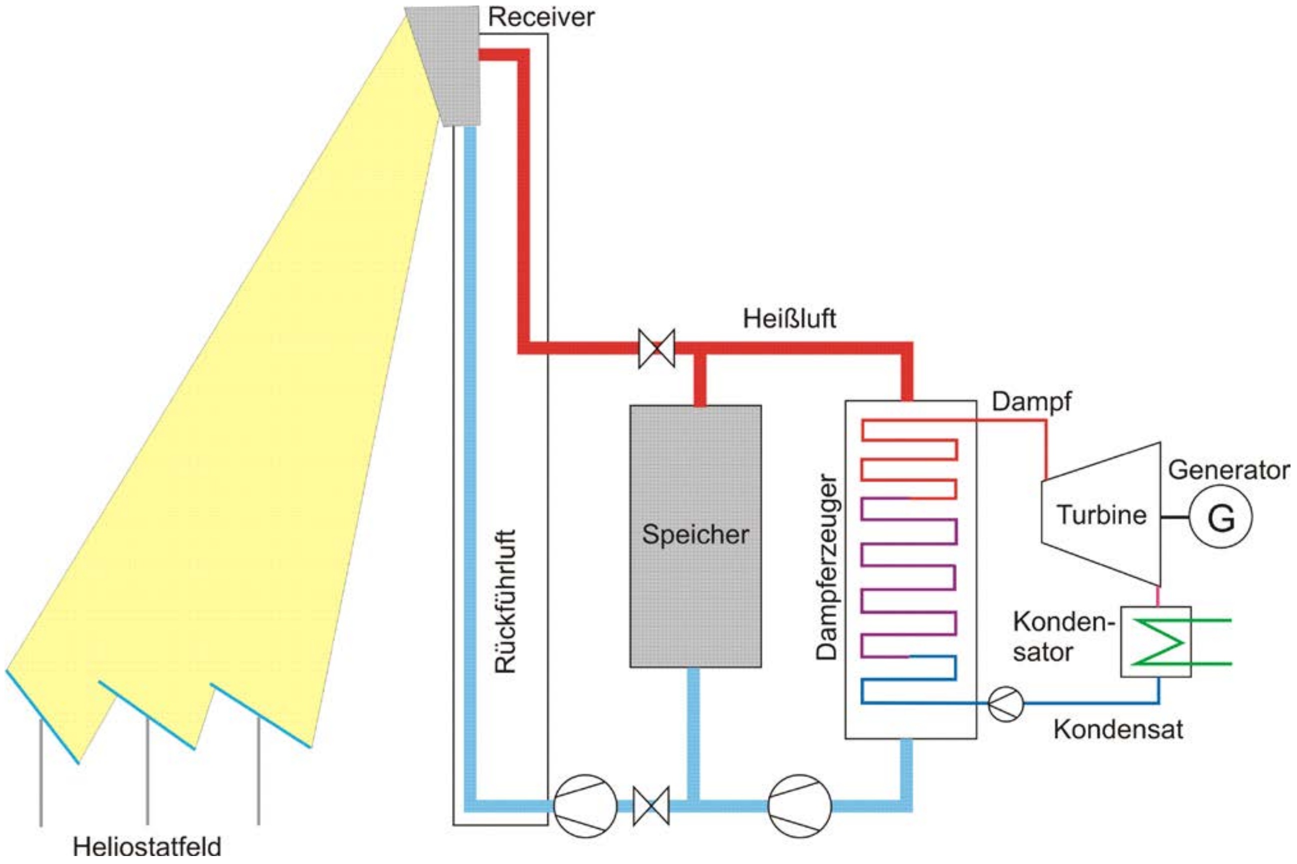
Solar Thermal Test and Demonstration Power Plant Jülich (STJ)

- Start of construction: 2007, Delivery of plant: 2009
- Some technical data:
  - Land - ca. 17 ha
  - Total mirror area - ca. 18.000 m^2
  - Tower height - ca. 60 m
  - Receiver area - ca. 22 m^2
  - Nominal power - 1,5 MW_{el}
  - Thermal storage capacity - ca. 1 hour full load

Solar Thermal Test and Demonstration Power Plant Jülich (STJ)



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Summary: Features for CSP

- Sufficient areas of flat landscape available
- Ability for thermal storage to create smooth operation on the grid and produce electricity outside sunny hours
- Possibility of hybrid operation with fossil or bio fuels
- Possibility of co-generation (power plus desalination)

Thank You For Your Attention