R&D on CSP and Solar Chemistry at DLR

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DLR German Aerospace Center

- Research Institution
- Space Agency
- Project Management Agency

>8000 employees across
32 institutes and facilities at
16 sites.

Energy Program Themes

• Efficient and environmentally compatible fossil-fuel power stations
  (turbo machines, combustion chambers, heat exchangers)

• Solar thermal power plant technology, solar conversion

• Thermal and chemical energy storage

• Wind energy converters

• High and low temperature fuel cells

• Systems analysis and technology assessment
Institutes and Facilities Involved in Energy

**Braunschweig**
Institute of Aerodynamics and Flow Technology
**Goettingen**
Institute of Aerodynamics and Flow Technology
**Cologne**
Institute of Propulsion Technology
**Institute of Solar Research**
Institute of Materials Research
**Juelich**
**Institute of Solar Research**
**Stuttgart** / **Ulm**
**Institute of Technical Thermodynamics**
Institute of Combustion Technology **Oberpfaffenhofen**
Institute of Communications and Navigation

**Almería (Spain)**
Permanent team from the Institute of Solar Research at the Plataforma Solar de Almería (PSA)
Institute of Solar Research
Directors
Prof. Dr. Robert Pitz-Paal/ Prof. Dr. Bernhard Hoffschmidt

- **Point-Focus Systems**
  Dr. Reiner Buck (34 P)

- **Line-Focus Systems**
  K. Hennecke (16 P)

- **Qualification**
  Dr. P. Heller (33 P)

- **Solar Chemical Engineering**
  Dr. C. Sattler (26 P)

- **Facilities and Solar Materials**
  Dr. K.-H. Funken (20 P)
Institute Profile

Mission
• 1/3 fundamental scientific questions to enable next generation technology for electricity, heat, fuel and water using concentrating solar power
• 2/3 applied development task for/with industry to optimize products and technologies

Key data
• Annual turnover >15 Mio€ (in CSP related activities)
• More than 160 people (among Top 5 worldwide)
• Teams in Germany (Cologne, Stuttgart, Jülich) and Spain (Almería)
• Unique Infrastructure
• Active coordination of national and international networks in CSP

Track record
• Awarded as DLR Centre of Excellence 2006, 2009 and 2013
• Several license agreements with industry on DLR Patents (Receivers, measurement technology)
• 2 Spin-off companies founded in the last 6 years
• CSP Component Qualification Centre QUARZ™ is market reference
Large scale facilities

Tower Research Facility
Jülich

Research Plattform 500 kW

Solar Furnace

Solar Simulator
Department “Line Focus Systems”

Klaus Hennecke
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ANDASOL 1: Start of operation 2008
State-of-the-art parabolic trough power plant technology
Plant schematic Andasol (50 MW)
Integrated Solar Combined Cycle plant

Projects in
- Algeria
- Egypt
- Morocco
- Mexico

Solar share limited by
- solar steam parameters
- turbine ability to accept additional steam

Transition technology build confidence
Egypt, 146 MW ISCCS, 30 MW Solar Field

Developer NREA New & RenewableEnergy Agency
EPC financed by JBIC and NREA with 50Mio Grant
984GWh per year, of which 64.5GWh solar
Awarded to Iberdrola (CC) and Orascom/Flagsol (Solar Field)
Direct Steam Generation Research

- Understand thermohydraulic phenomena
- Validate numerical models
- Develop and test operating concepts and control algorithms
- Test components in real scale
- Demonstrate technical feasibility
- German/Spanish Collaboration PSA DISS test facility: 1000 m collector loop up to 100 bar / 500°C
Direct Steam Generation commercial applications

- **TSE1 Kanchanaburi, Thailand**
  - Developer: SOLARLITE
  - Operational 11/2012
  - 5 MWe
  - 30 bar / 330°C

- **PE2 Puerto Errado, Spain**
  - Developer: NOVATEC
  - Operational 8/2012
  - 30 MWe
  - 55 bar / 270°C

DLR support portfolio:
- concept design
- construction supervision
- commissioning
- acceptance testing

Foto: Solarlite
Conclusions on DSG

• For short to mid-term, technology ready for:
  • CSP plants without or with small storage
  • Integrated Solar Combined Cycle (ISCC) or fuel saver plants
  • Industrial process steam applications

• For long term DSG perspective, R&D requirements:
  • Development of economic PCM storage system
  • Development of once through process (DUKE Project at PSA)
Molten Salt R&D: HPS2 Project

10 main concerns regarding safe and efficient operation of molten salt systems to be dispelled by erection, commissioning and operation of a Demonstration Loop with Ultimate Trough collectors at Evora, Portugal:

1. Filling and draining of the plant
2. High thermal effort during anti-freeze operational mode (high parasitic load, added costs for the required heating through the year)
3. Danger of freezing during various operation modes (reliability of impedance heating, failure current of impedance heating, valve heating, …)
4. Blackout scenarios
5. Material requirements, high corrosion
6. Performance of the SCA (receiver performance, Behavior of receiver with collector) a. thermal performance, b. optical performance, c. mechanical properties
7. Flexible connection: Proof of functionality and tightness
8. Steam Generating System: internal leakage due to defect of heat exchanger tubes
9. Maintenance procedures, Handling of disturbances (complete draining and re-filling, treating of blockages)
10. Stability of salt mixtures (time stability, thermal stability)
Parabolic Trough Power Plant with Molten Salt

Advantages

• High efficiency of the solar collector at high operating temperature
  => high overall efficiency of the power station
• Direct storage of the collected heat
• Full-decoupling of the solar field operation and the electricity production
• Commercial plants with capacity factors of over 5500 full load hours
• Potential to save up to 40 % of LCoE in comparison to state-of-the-art solar thermal power stations (at highly irradiated locations)
• 100 % renewable and fully storable energy
Overview of DLR CSP simulation tools

- DLR simulation tools cover all levels of CSP simulation

**GREENIUS**: analysis of performance / economics of renewable energy systems

**ebsSolar®**: detailed performance analysis of CSP systems

**Component layout:**
- concentrators (parabolic trough, Fresnel, heliostats)
- receivers

**System layout optimization:**
- solar field, receiver
- power block
- storage

**Transient system simulation:**
- real-time, high resolution performance simulation
- coupling of components and control
Greenius Overview

• software tool developed at DLR for fast and simple annual performance calculations of renewable energy plants

• based on datasets for individual subsystems like collector, solar field, powerblock, etc.

• uses steady-state simulations in hourly time steps

• offers tools for economical analysis and illustration of result

• a free version is available at www.FreeGreenius.dlr.de
1. Greenius
Implemented technologies

- most renewable energy systems
- CSP:
  - parabolic trough
  - linear Fresnel
  - solar tower
  - Dish Stirling
  - optional: thermal storage
- process heat generation
- solar cooling with absorption chillers
- PV and concentrating PV
- wind turbines
- fuel cells
Detailed System Performance Simulation using Ebsilon®

- „All in One“ solution for detailed power plant modelling
- for development, acquisition und planning of all kinds of power plants and thermodynamic processes
- design and development of single components, subsystems and complete systems
- development of new solar library EbsSolar (steag and DLR):
  - thermodynamic modelling and yield analysis (e.g. annual yields)
  - components of solar thermal power plants
    (Dialog for time series calc., transient calc. for energy storage, fluid properties for solar applications)
  - 2010: library for line focussing systems
    - Parabolic Trough
    - Linear Fresnel
  - 2011: library for Solar Tower systems
  - currently more than 70 licences of EbsSolar are used
Summary / Conclusion

DLR simulation competence
• covers all levels of detail
• cover all CSP technologies
• coupling of different tools
• collaboration experience with industry and R&D institutions

Options for collaboration
• technology-independent consulting
• subcontracted work
• joint development of tools
• adaptation of tools specific tasks and conditions
• licensing of tools, incl. training and support
Department “Point Focus Systems”
Thematic Orientation

Goal: Cost Reduction of CSP Plants (Solar Tower, Dishes)
  • performance optimization
    • heliostat field, receiver, system
  • cost reduction
    • component cost, O&M cost

R&D topics:
• receivers
• heliostats
• system aspects
• control
• simulation tools

Contact:
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Receiver Technology R&D

- development / technology transfer
  - open volumetric air receivers
  - pressurized air receivers

- extension to liquid heat transfer media
  - e. g. molten salt

- innovative concepts: direct absorption receivers

particle receiver test to 900°C
Open Volumetric Air Receivers

- development of volumetric absorber structures

- optimization of air receiver system

- support of commercial realization
  - development of scalable designs
  - layout of prototype plants
  - know-how transfer to industry
SOLUGAS: Solar-hybrid Plant Demonstration

co-funded by the EC under FP7

project lead: Abengoa
SOLUGAS Project: Solar-hybrid Gas Turbine System
Solar Tower with Molten Salt

Improvement of molten salt solar tower systems

- next generation technology:
  - increased HTF temperature
  - higher power block efficiency
  - reduced LCoE
- industry participation
- tests planned at
  Solar Tower Jülich
Heliostat R&D

- heliostat and field simulation
- structural analysis
- load analysis
- qualification
- control
- operation strategy
System Analysis and Optimization

- pre-feasibility studies
- detailed annual performance simulation
- cost estimates
- LCoE calculation
Simulation Tool Development for Solar Tower Systems

- heliostat field layout

- performance simulation
  - flux distribution
  - aim point strategy
  - efficiency
Simulation Tool Development for Solar Tower Systems

- heliostat field analysis

- real-time optimization of operation strategy
  - dynamic field simulation
  - dynamic receiver simulation

measured heliostat surface

solar heat flux

measurement

simulation

aim point strategy
Department of “Qualification”
Motivation: Qualification for Improved Performance

- Solar field has a high share of the total investment
- It is a long-term investment
- It is of big extent (corrections are expensive)
- Yearly plant output strongly depends on optical quality of collector field
  - Measurements showed that without proper quality assurance 3-10% and in some cases even more of the field performance can be lost
- Quality assurance and final acceptance tests of collector fields are necessary for control of subcontractors and warranty claims

→ Quality assurance of collector field assembly is indispensable and makes economic sense

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Motivation

Efficiency Chain, Example: Parabolic Trough

Example ANDASOL:
1% less optical quality means for investors:
→ 0.5 million € less revenues per year
→ 10 million € less revenues per lifetime
QUARZ® – Center
Test and Qualification Center for CSP Technologies

• Strong impact on the performance and cost efficiency:
  • CSP component quality and durability
  • their interaction in the overall system
  • and the meteorological conditions each

• Development of measurement techniques and devices
• Evolution of guidelines and standards
  • testing methods
  • quality criteria

• Customer oriented services
  → Fundamental information for industry to
    • Improve quality, performance → competiveness
    • Proof of product quality → successful market entry / bankability
  → Consulting and training
Solar Resource Assessment

Measurements:
- Solar Radiation
- Soiling of components
- Aerosols
- Beam attenuation, Extinction
- Sunshape
- Nowcasting (prediction of DNI for next 30 min.)

Services:
- Calibration of sensors
- Analysis of effects on Plant design, Operation, System performance
Mirror / Collector Shape Accuracy

Evaluation of quality and performance parameters:
- Methods: deflectometry, photogrammetry
  (in laboratory, in the collector, in the solar field)
- Analysis of reflector deformation
  (sag, interaction with support structure)
Mirror Reflectance

Evaluation of quality and performance parameters:
- Spectral hemispherical reflectance
- Specular reflectance
Mirror Durability

Accelerated ageing tests
- Laboratory: humidity, salt spray, UV, temp. cycling, aggressive corrosion
- Outdoor ageing tests in different climatic regions
Receiver Performance

Receiver performance parameters:
- Optical efficiency \( \eta_{\text{opt,rec}}(T) \)
- Thermal loss power \( P_{\text{th,loss}}(T) \)
(non-destructive measurements)
Receiver Durability

Durability tests:
- Overheating and Thermal Cycling
- Bellow fatigue tests
- Operability tests under real solar conditions (Kontas at PSA, Spain)
Performance testing – collector module

Collector quality features:
- Peak efficiency, thermal losses
- Incident angle modifier
- Behavior under different load conditions (tracking quality, deformation, torsion)
Performance testing – collector loop

Mobile Field Laboratory:
- Clamp-on ultrasonic flow meter
- Clamp-on temperature sensors
- Irradiance measurement station
- Camera equipped quadcopter

Benefits
- Detecting optimization potential of solar field
- Accurate performance parameters lead to reliable results of system simulations
<table>
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<th>Phases</th>
<th>R&amp;D Phase</th>
<th>Production Phase</th>
<th>O&amp;M Phase</th>
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<td>Objects</td>
<td>Prototypes</td>
<td>Mass Product</td>
<td>Commissioned Plant</td>
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<tr>
<td>Concentrator</td>
<td>Parabolic Trough Coll.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Heliostats</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Receiver</td>
<td>Parabolic Trough Receiver</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Central Receiver</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Several manufacturing specific quality control measures</td>
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<tr>
<td>Materials</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Several manufacturing specific quality control measures</td>
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Qualification in Different Phases
Summary

QUARZ – Benefits for our customers

- Detecting **optimization potential** helps to **improve products**
- Accurate performance parameters → **reliable results** of system simulations
- Source of **data** for a plant’s **cost-benefit analysis**

- **Customer oriented services**
  → Fundamental information for industry to
    - **Improve** quality, performance → **competiveness**
    - **Proof** of product quality → successful **market entry / bankability**

- **Trainings and Seminars**
  in all CSP Relevant Topics
Summary (II)
Possible Cooperations

Meteorology / Solar Resource Assessment
- DNI, Sunshape, Soiling Rate, Beam Attenuation in Solar Towers

Solar Towers
- Receivers and Heliostats R&D, System Optimization

Qualification of Systems and Components
- Receivers, Heliostats, Collectors, Mirrors, etc.
- Production Inline Quality Control

Durability Issues of Mirrors and Receivers
- Ageing by UV Radiation and Corrosive Environments (Salts)

Capacity Building
- Consulting and training in all CSP Relevant Topics
Department of Solar Chemical Engineering

Head
Organisation
Strategy
Representation in boards

Group
High temperature CE
Solar tower >500°C

Group
Low temperature CE
Reactors up to Parabolic troughs < 500°C

Solar Fuels
Solar Materials

Heat transfer fluids
Solar fuels
Water treatment
SOWARLA GmbH

25 Co-workers + 10 Students, 65% external funding
Competences

Development of components and processes

and

scientific, technologic and economic evaluation
Three examples to achieve the goals

• High Potential Product
  • Jet-Fuel

• Business Case
  • Integration of concentrated solar radiation to enhance existing processes

• Continuity
  • Developments to a certain scale needs time (unfortunately there is no Manhattan Project for solar fuels yet)
H$_2$O/CO$_2$-Splitting Thermochemical Cycles

Solar Production of Jet Fuel

- EU-FP7 Project SOLAR-JET (2011-2015)
- SOLAR-JET aims to ascertain the potential for producing jet fuel from concentrated sunlight, CO$_2$, and water.
- SOLAR-JET will optimize a two-step solar thermochemical cycle based on ceria redox reactions to produce synthesis gas (syngas) from CO$_2$ and water, achieving higher solar-to-fuel energy conversion efficiency over current bio and solar fuel processes.

- First jet fuel produced in Fischer-Tropsch (FT) unit from solar-produced syngas!
SOL2HY2 – Solar To Hydrogen Hybrid Cycles
https://sol2hy2.eurocoord.com

- FCH JU project on the solar driven Utilization of waste SO$_2$ from fossil sources for co-production of hydrogen and sulphuric acid
- Hybridization by usage of renewable energy for electrolysis
- Partners: EngineSoft (IT), Aalto University (FI), DLR (DE), ENEA (IT), Outotec (FI), Erbicol (CH), Oy Woikoski (FI)
- 100 kW demonstration plant on the solar tower in Jülich, Germany in 2015

Outotec™ Open Cycle (OOC)

- Utilization of waste SO$_2$ from fossil sources
- Co-production of hydrogen and sulphuric acid
- Hybridization by renewable energy for electrolysis
Investments vs. revenues

- Reduction of initial investments
- Financing of HyS development by payback of OOC
- Increase of total revenues
HYDROSOL, HYDROSOL 2, HYDROSOL-3D, HYDROSOL Plant

- 2002 Start HYDROSOL, EU FP5
- 2004 First solar hydrogen, DLR
- 2005 Quasi-continuous solar hydrogen, DLR
- 2008 HYDROSOL 2, EU FP6, 100 kW demonstration CRS Tower PSA, Spain
- 2013 HYDROSOL-3D, FCH JU, Design of a 1,5 MW demonstration plant ready
- 2014 HYDROSOL PLANT, FCH JU
- 2015 750 kW Demonstration plant, CRS Tower, PSA, Spain

APTL (GR), DLR (DE), CIEMAT (SP), StobbeTech (DK), Johnson Matthey (UK), HyGear (NL), HELPE (GR)
Next Step: Specific Solar Fuel Demonstration Tower needed!

- High concentration > 1000
- Heliostats fit to receiver size
- Field control adapted to fuel production processes
Thank you very much for your attention!