# DLR German Aerospace Center
# Solar Energy Research

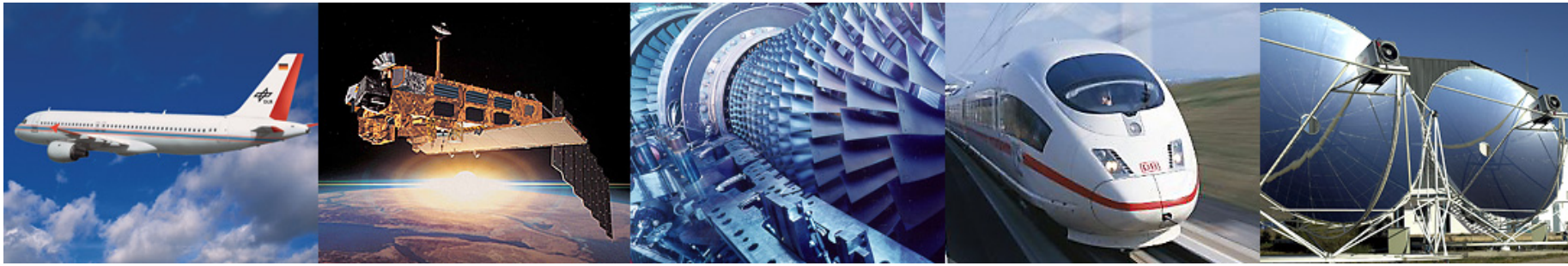
## Institute of Solar Research

## Institute of Engineering Thermodynamics

# Table of Contents



# German Aerospace Center (DLR)



- Research Institution, Space Agency and Project Management Agency
- Research Areas:

  **Aeronautics | Space Research and Technology | Transport | Energy | Defence and Security**
- 8000 employees across 32 institutes and facilities at 16 sites in Germany
- 17 subsidiaries, cooperations and outposts in Germany, the Netherlands and Spain
- Offices in Brussels, Paris, Tokyo and Washington
- Total income 2013: €846 Mio.

# DLR
## Guiding Principles

### Vision

- DLR – one of Europe's leading **public research institutions**, setting trends in its **aeronautics, space, transport and energy** business areas
- DLR – in its **space agency** function, a force that shapes European space activities
- DLR – the umbrella organisation for the most effective and efficient **project management agencies and offices**

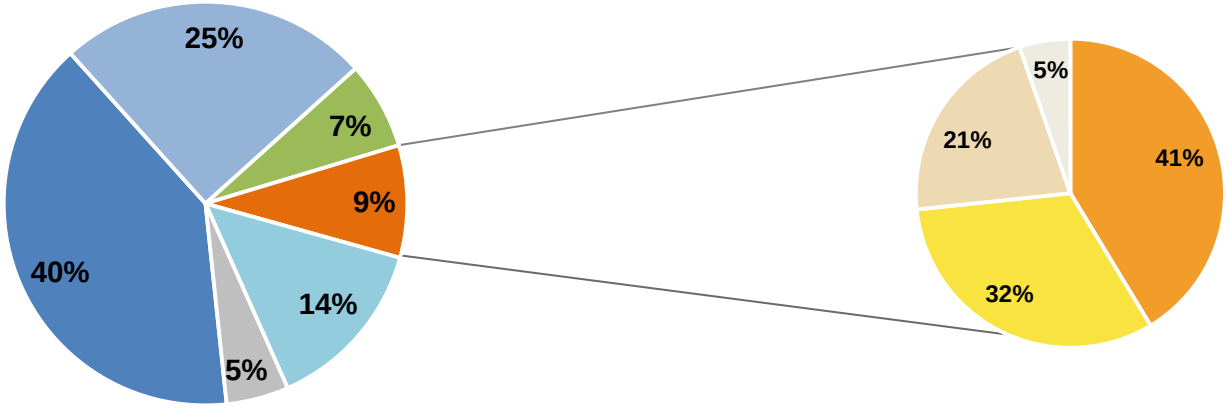
### Mission

- To **explore Earth and the Solar System**; to conduct **research** into the **preservation of the environment**, into **mobility and into public safety**, and to address **societal questions** on behalf of public customers
- To bridge the gap between **basic research** and **innovative applications** and to **transfer knowledge and research results to industry and the political sphere** through **mediation** and **consultation** as well as through the **provision of services**
- To **shape Germany's space commitment** and **represent its interests internationally** as a governmental function
- To make a significant contribution towards **enhancing Germany as a science and business location** as well as to **stimulate growth in the European region**
- To **train young scientists** in order to enhance Germany's innovative capability

# DLR and DLR Energy

## Income 2014 - Research, Operations and Management Tasks

**DLR**




**DLR Energy**




| **Total Income[1)]** | € Mio **871** |
|---|---|
| Space Research and Technology | 351 |
| Aeronautics | 218 |
| Energy | 75 |
| Transport | 62 |
| Space Administration/ DLR Project Management Agency | 119 |
| Other Income/Earnings | 46 |

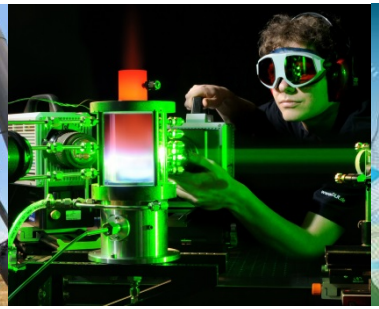
Defence and Security € Mio: 45

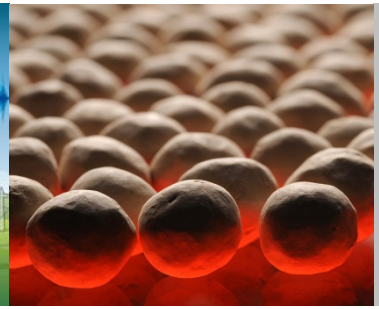
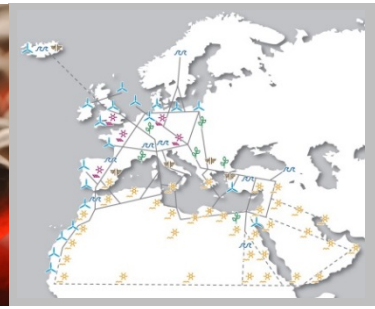
| **Total Income** | € Mio **75** |
|---|---|
| Gas Turbine Technologies | 31 |
| Solar and Wind Energy Technologies | 24 |
| Storage and Fuel Cell Technologies | 16 |
| Energy Systems Analysis | 4 |

[1)] Excluding trustee funding from the Space Administration/DLR Project Management Agency

# DLR Energy Research

## Seven Research Institutes with Sites and Facilities in Germany and Spain

- Institute of Aerodynamics and Flow Technology (Braunschweig, Goettingen)
- Institute of Combustion Technology (Stuttgart, Ulm)
- Institute of Communications and Navigation (Oberpfaffenhofen)
- **Institute of Engineering Thermodynamics (Stuttgart)**
- Institute of Materials Research (Cologne)
- Institute of Propulsion Technology (Cologne)
- **Institute of Solar Research (Cologne, Juelich, Stuttgart, Almería[1])**

[1] Almería (Spain): Permanent team from the Institute of Solar Research at CIEMAT's Plataforma Solar de Almería (PSA)

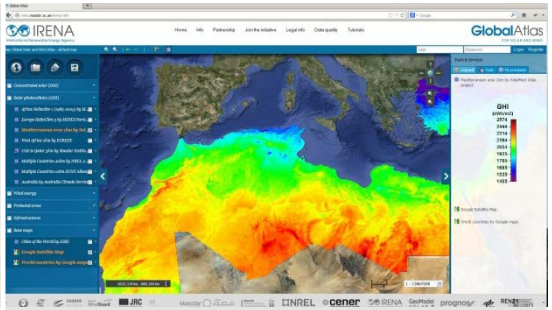
# DLR Energy Research
## Core Competencies

### Efficient Electricity Generation

- Flexible efficient gas turbines
- Biogenic fuels
- Micro gas turbines
- Hybrid power plants
- Concentrated solar thermal power
- Wind energy
- Fuel cells

### Energy Storage

- High-temperature heat storage
- Electro-chemical energy storage
- Chemical energy storage, electrolysis, solar fuels




### System Analysis

- Energy Scenarios
- Integration of renewables
- Solar resource assessment

# DLR Energy Research

## Participation in Professional Energy Associations (1/2)

### International

EERA JP CSP European Energy Research Alliance Joint Programm Concentrating Solar Power

ESTELA European Solarthermal Electricity Assocation

EUREC The Association of European Renewable Energy Research Centres

FCH JU Fuel Cells and Hydrogen Joint Undertaking

IEA – HIA International Engergy Agency Hydrogen Implementing Agreement

SolarPACES The international network of researchers and industry experts for the development and marketing of concentrating **Solar** Thermal **P**ower **A**nd **C**hemical **E**nergy **S**ystems - An Implementing Agreement of the International Energy Agency IEA

SOLLAB Alliance of European Laboratories for Research and Technology on Solar Concentrating Systems

SHC Solar Heating & Cooling Programme
International Energy Agency

# DLR Energy Research

## Participation in Professional Energy Associations (2/2)

### Germany

DCSP German Association for Concentrated Solar Power

FVEE ForschungsVerbund Erneuerbare Energien
Renewable Energy Research Association

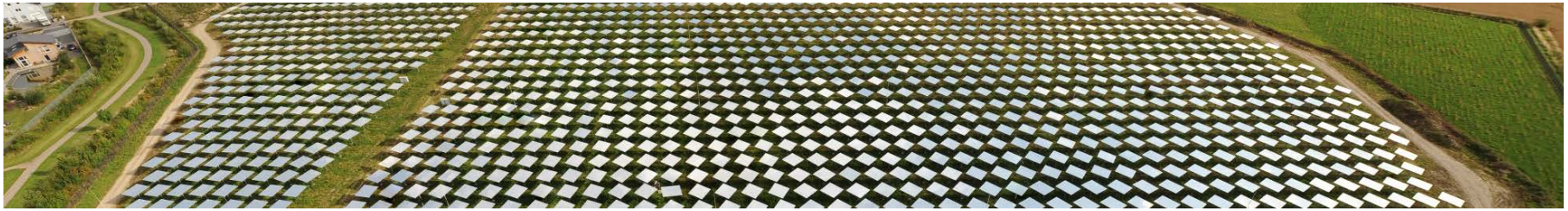
HELMHOLTZ Association

Kompetenznetzwerk Kraftwerkstechnik NRW
Netzwerk Brennstoffzelle und Wasserstoff NRW
EnergyAgency.NRW - Climate protection made in North Rhine-Westphalia

Rhein Ruhr Power
EnergyAgency.NRW - Climate protection made in North Rhine-Westphalia

# Institute of Solar Research

## Concentrating Solar Systems for Power, Heat and Fuel generation



- Germany's largest research entity in the field of concentrating solar systems for the generation of heat, electricity and fuel
- Research Areas:

  **Line Focus Systems | Point Focus Systems | Qualification**
  **Solar Energy Meteorology | New Materials | Solar Chemical Engineering**

- Services and consulting for industry clients
- Annual revenue in 2013: 17,6 €Mio
- Staff: approx. 140 people at the four sites Cologne, Juelich, Stuttgart, Almería (Spain)
- Spin-off companies: CSP Services GmbH, Sowarla GmbH

# Institute of Solar Research
## Guiding Principles

### Vision

- We are the **leading german research institution for concentrating solar systems** and a **worldwide prime mover** for the **development and qualification** the associated technologies
- Our findings provide an indispensible contribution to the **protection of the environment** and to a **sustainable worldwide energy supply**
- **Concentrating solar systems** will be an essential pillar of a **future energy supply**

### Mission:

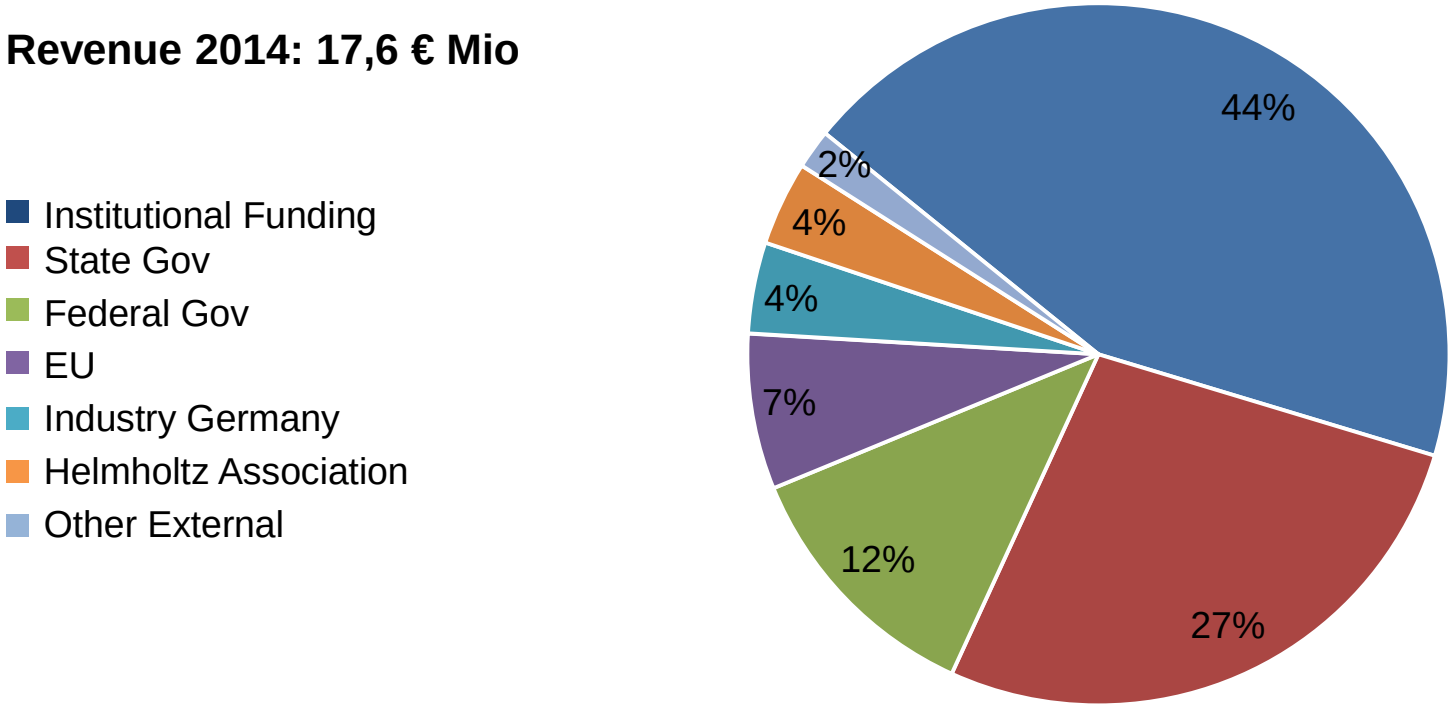
**Foster CSP technologies' worldwide market penetration** by

- Answering basic questions on **technical feasability**, **increase of efficiency**, **quality ensurance** and **cost reduction**
- Supporting **industry partners** with **R&D solutions** for specific application-oriented requirements

# Institute of Solar Research

## Revenue

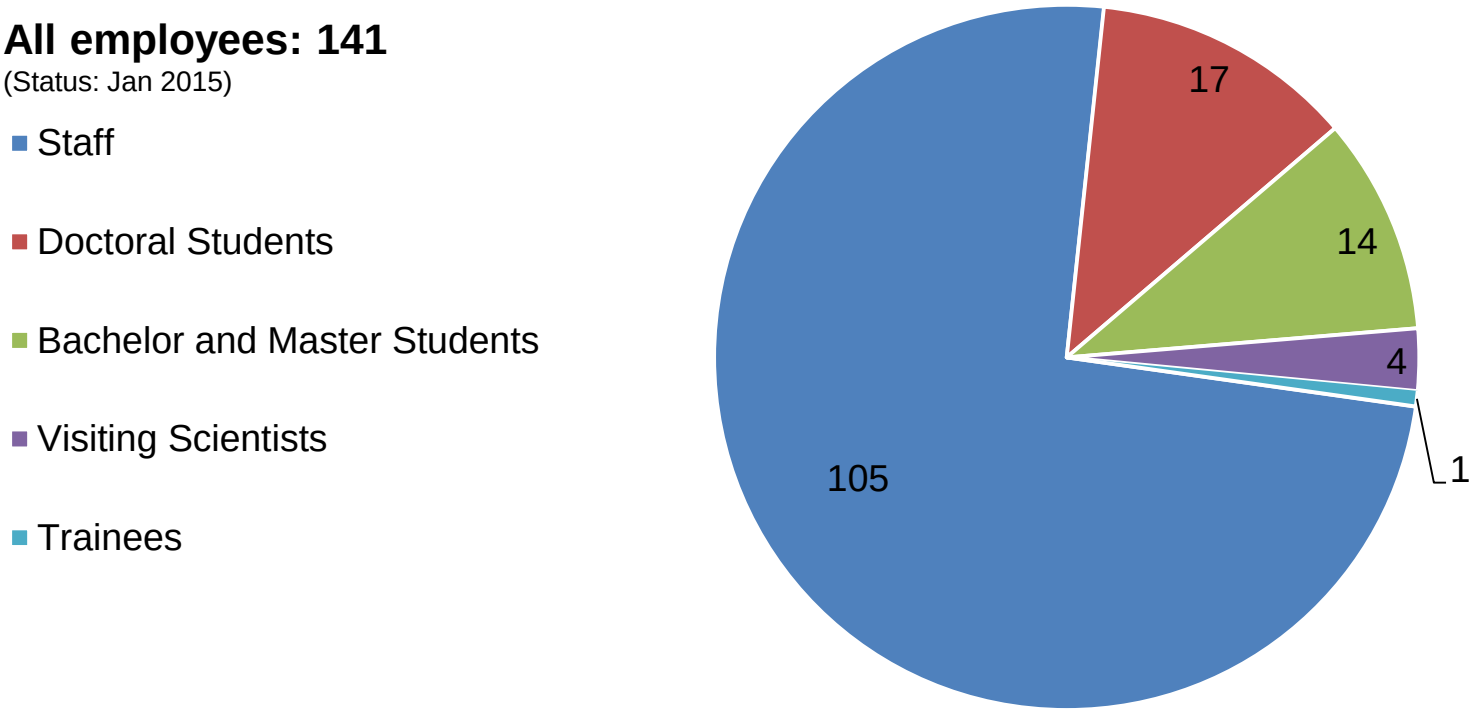
**Revenue 2014: 17,6 € Mio**




# Institute of Solar Research

## Personel Structure

**All employees: 141**
(Status: Jan 2015)




# Institute of Solar Research

## Organizational Structure

**Directors**
Prof. Dr.-Ing. Robert Pitz-Paal
Prof. Dr.-Ing. Bernhard Hoffschmidt

Public Relations
Elke Reuschenbach

Quality Management
Dr. Jan-Peter Säck

**Line Focus Systems**
Klaus Hennecke

**Administration**
Annette Broicher

**Point Focus Systems**
Dr. Reiner Buck

**Solar Chemical Engineering**
Dr. Christian Sattler

**Qualification**
Dr. Peter Heller

**Facilities and Solar Materials**
Dr. Karl-Heinz Funken

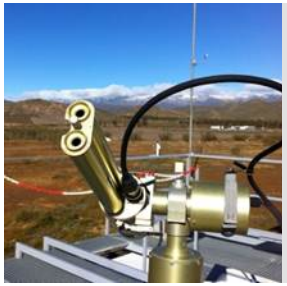
# Institute of Solar Research

## Research & Development

**Point Focus Systems**
- Heliostats
- High temperature receivers
- System technology

**Qualification**
- Components
- Component durability
- Systems

**Line Focus Systems**
- Heat transfer media
- Collector development
- Industrial process heat



**Solar Energy Meteorology**
- Solar radiation measurement and modelling
- Radiation nowcasting
- Other meteorological influences

**New Materials**
- Absorber materials
- Hight temperature redox systems
- Photocatalysts
- Heat transfer fluids

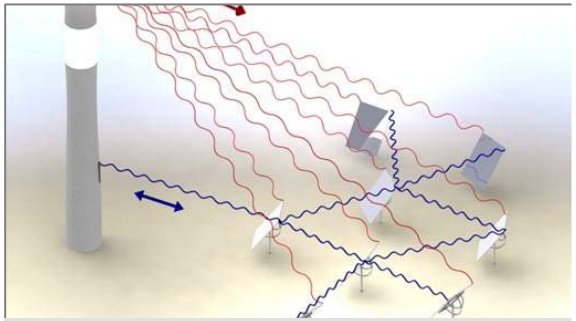
**Solar chemical engineering**
- Solar fuels
- Solar water treatment

# Institute of Solar Research

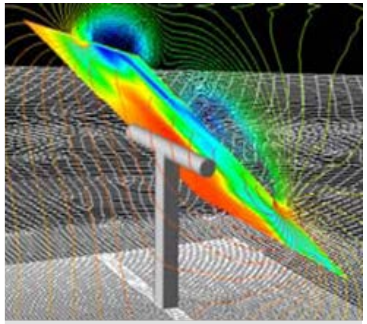
## Research & Development **> Point Focus Systems**

**Heliostats** • High temperature receivers • System technology

- Development of autonomous heliostats
  - AutoR: Autonomous light weight heliostat with rim drives
  - Aim: 30% cost reduction of heliostats
  - Partners: Trinamic Motion Control GmbH, Institute of Telematik, TU Hamburg Harburg
- Examination of wind force impact on heliostat structures



AutoR: Autonomous heliostats



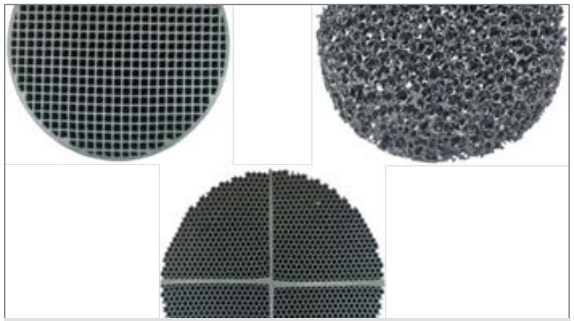
Wind force examination

# Institute of Solar Research

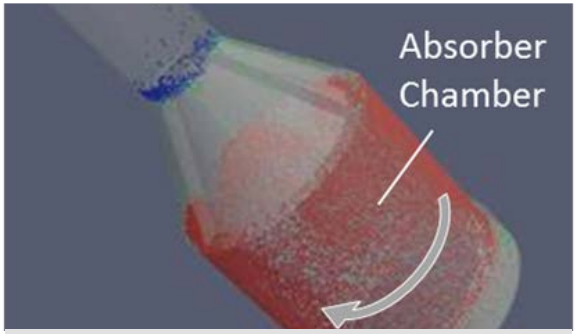
## Research & Development **> Point Focus Systems**

Heliostats • **High temperature receivers** • System technology

- Development and technology transfer to industry partners
- Open volumetric air receivers:
  - Development of volumetric absorber structures
  - Support of commercial realization
- Pressurized air receivers
- R&D of liquid heat transfer media:
  - Molten salt
  - Liquid metals
- Direct absorption receivers:
  - Centrifugal particle receiver
  - Falling film particle receiver



Volumetric absorber structures



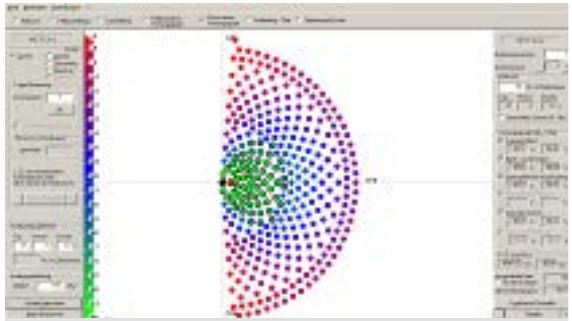

Centrifugal particle receiver (CentRec)

# Institute of Solar Research

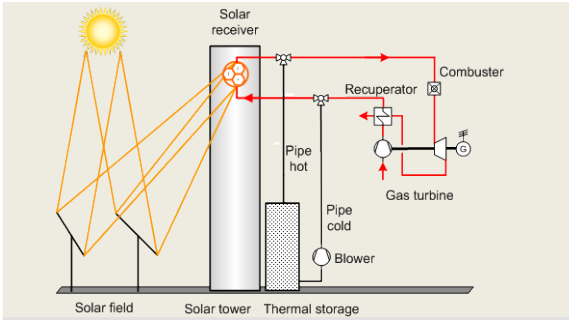
## Research & Development **> Point Focus Systems**

Heliostats • High temperature receivers • **System technology**

- Pre-feasibility studies
- Detailed annual performance simulation
- Cost estimates
- LCoE calculation
- Simulation tool development: STRAL - calculation of radiation flux density (ray tracing)
  HFLCAL - heliostat field layout and optimisation



Performance optimization with HFLCAL




Solar power plant process scheme

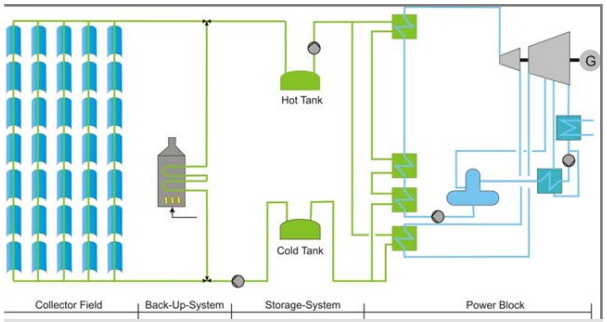
# Institute of Solar Research

## Research & Development **> Line Focus Systems**

**Process improvements** • Collector development • Innovative applications

- Application of new heat transfer media to increase operating temperatures
  - Direct steam generation in the collectors
    - Two-phase flow, high pressure, non-uniform heat transfer characteristics
    - No cost-effective heat storage yet, preferable for hybrid systems and decentralized applications
  - Molten salt
    - Freeze protection, corrosion prevention, system draining and filling
    - Heat transfer medium = storage medium; de-coupling of solar collection and power generation
- Dynamic process modelling: development of advanced control algorithms and operating strategies

Cloud passage over ANDASOL 1-3




Molten salt plant schematic

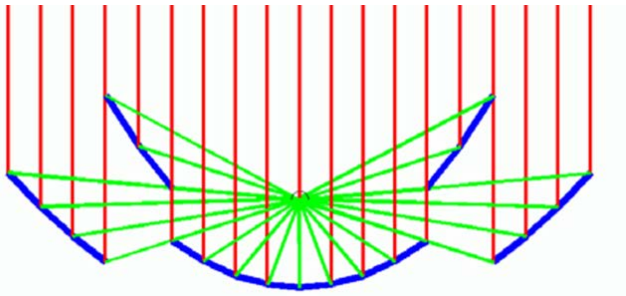
# Institute of Solar Research

## Research & Development **> Line Focus Systems**

Process improvements • **Collector development** • Innovative applications

- Collectors adapted to special requirements of
  - Direct steam generation
  - Molten salt
- Collector cost reduction by
  - Increased aperture
  - New materials
  - Design for Manufacturability

Parabolic trough sandwich mirror



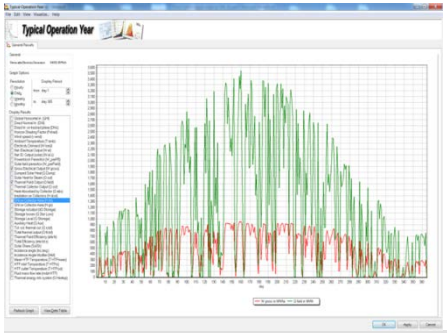
Innovative fix-focus collector geometry

# Institute of Solar Research

## Research & Development **> Line Focus Systems**

Process improvements • Collector development • **Innovative applications**

- Consulting services to assist technology transfer and CSP project development
  - Feasibility studies
  - Due dilligence
- Support for industrie partners in design and installation of pilot plants
  - Project example: 5 MWe direct steam generation plant TS1 (Kanchanaburi, Thailand) with Solarlite GmbH, Germany
- Development and demonstration of concepts for new applications
  - Project example: Solar process steam integration at ALANOD GmbH & Co. KG, Germany




System performance simulation

Solar steam generator at ALANOD

# Institute of Solar Research

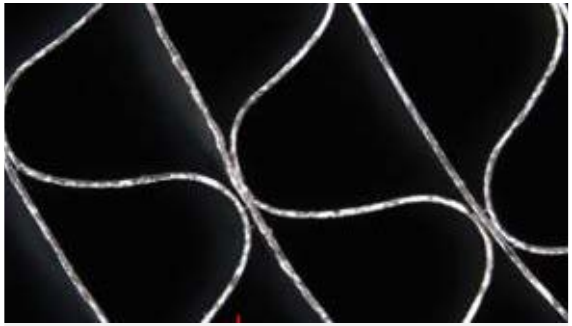
## Research & Development **> New Materials**

**Absorber Materials** • High temperature redox systems • Photocatalysts • Heat transfer fluids

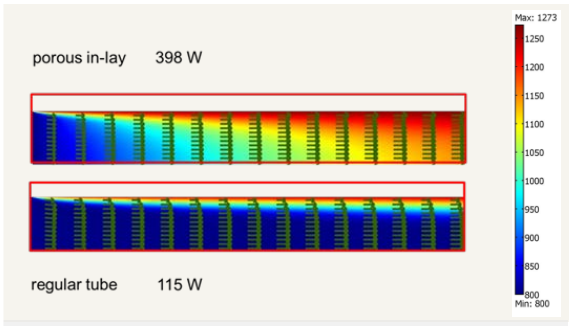
Evaluation and testing of cellular solids for high temperature receivers and spin-off-applications:

- Experimental determination of thermophysical, optical, heat transfer and permeability properties
- Co-development of innovative cell-structures and engineered composites
- Prediction and experimental testing of component performance in service conditions
- Co-development of spin-off applications (e.g. particle filters, catalysts)

Engineered cellular SiC tubes from SUPSI and Yeungnam University tested for solar gas turbine application



Corrugated metal foil structures from EMITEC tested for volumetric receiver application




Predicted heat transfer of a tubular receiver with a porous in-lay compared with a regular tube

# Institute of Solar Research

## Research & Development **> New Materials**

Absorber Materials • **High temperature redox systems • Photocatalysts • Heat transfer fluids**

- High temperature redox systems:
  Synthesis, evaluation and application of new materials for water and $CO_2$ splitting
- Photocatalysts:
  Evaluation and application of photocatalysts for fuel production and water and air treatment
- Heat transfer fluids:
  Evaluation of innovative heat transfer fluids, high pressure test facilities for degradation analysis


Laboratory for redox system development

The SOCRATUS test facility for photo catalysis evaluation

# Institute of Solar Research

## Research & Development **> Qualification**

**Components** • Component durability • Systems

Evaluation of quality and performance parameters[1)]

- Mirrors:
  - Shape and reflectivity measurement
  - Deformation analysis
- Receivers:
  - Optical efficiency
  - Thermal characteristics
- Collectors:
  - Peak efficiency
  - Thermal characteristics
  - Incident angle modifier, behavior under different load conditions
- Development of test and evaluation standards

Mirror shape measurement

Receiver performance test

[1)] In the QUARZ® laboratory, Cologne

# Institute of Solar Research

## Research & Development > Qualification

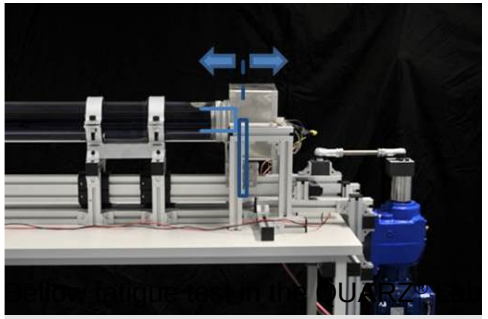
Components • **Component durability** • Systems

Evaluation of durability parameters

- Mirrors[1)]
  - Corrosion tests: e.g. Salt Spray NSS/CASS ISO9227, UV/humidity ISO11505, Damp Heat IEC 62108 test 10.7b, Humidity Freeze IEC 62108 test 10.8, Condensation ISO 6270-2 (CH), thermal cycling with condensation
  - Abrasion tests: Taber Abrasion test, cleaning, dust and sand storm simulation
  - Outdoor exposure at desert and coastal sites - three sites in Spain, five sites in Morocco
- Receivers
  - Overheating and thermal cycling
  - Bellow fatigue tests
  - Anti-reflective coating of glass envelope
- Standards for durability assessement

[1)] Joint activity with CIEMAT in OPAC laboratory at CIEMAT's Plataforma Solar de Almería

Outdoor weathering at PSA, Spain



Bellow fatigue test bench

# Institute of Solar Research

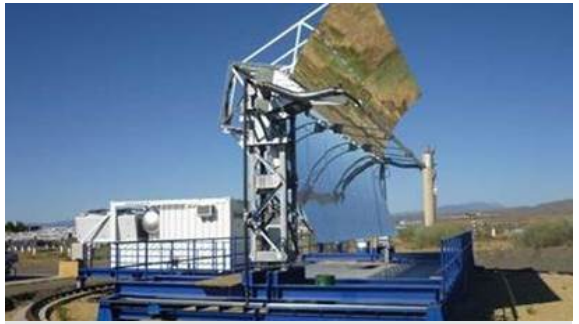
## Research & Development **> Qualification**

Components • Component durability • **Systems**

Collector and heliostat qualification

- Optical characterization (shape, torsion, tracking, raytracing)
- Optical and thermal outdoor testing
- Rotary test bench for parabolic trough collectors and receivers (KONTAS) [1)]
- Testing facility for rotating and expansion performing assemblies (REPA) in preparation[1)]
- Facility to measure HTF properties (*cp*) under operation conditions

[1)] at CIEMAT's Plataforma Solar de Almería, Spain



Rotary test bench (KONTAS)

Aerial verication with quadcopter

Mobile field laboratory for efficiency measurements

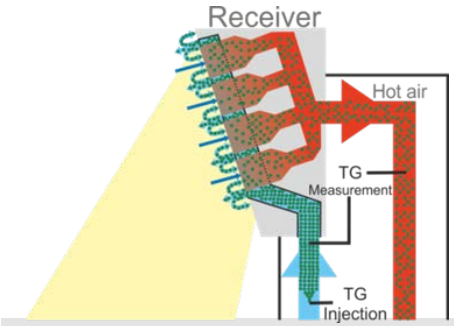
- Clamp-on ultrasonic flow meter
- Clamp-on temperature sensors
- Irradiance measurement station
- Camera equipped quadcopter
- Inclinometers

# Institute of Solar Research

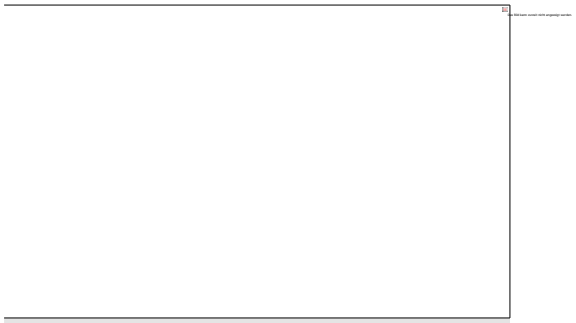
## Research & Development **> Qualification**

Components • Component durability • **Systems**

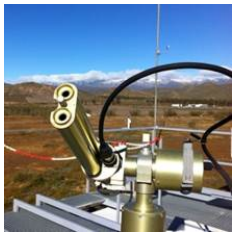
- In-field receiver qualification to determine
  - Heat loss of parabolic trough receivers
  - Air return ratio of open volumetric receivers
  - Solar flux distribution and input power of solar receivers
  - Receiver efficiency
- Development of quality inspection tools integrated in production-line, e.g. for concentrators
- Standardization
  - Optical measurement techniques and protocols for mirrors/concentrators
  - Solar plant performance testing




Open volumetric receiver:
Determination of air return ratio



Parabolic trough receiver:
heat loss measurement



# Institute of Solar Research

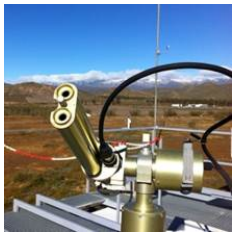
## Research & Development > **Solar Energy Meteorology**

**Solar radiation measurement & modelling** • Nowcasting • Other meteorological influences

- Direct Normal Irradiance (DNI) measurement methods
  - Calibration of irradiance sensors, evaluation of accuracy and robustness, rotating shadowband irradiometers
- Sunshape measurements (see picture at bottom left)
- Aerosol optical depth measurements
  - Spectral irradiance modelling, AERONET (Aerosol Robotic Network)

Equipment for sunshape measurement: Visidyne's SAM (left) and CIMEL sunphotometer (right) at the Plataforma Solar de Almería

Twin Rotating Shadowband Irradiometer
*Credit: CSP Services GmbH*

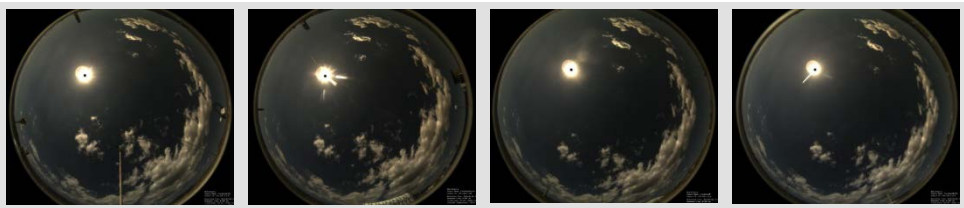


# Institute of Solar Research

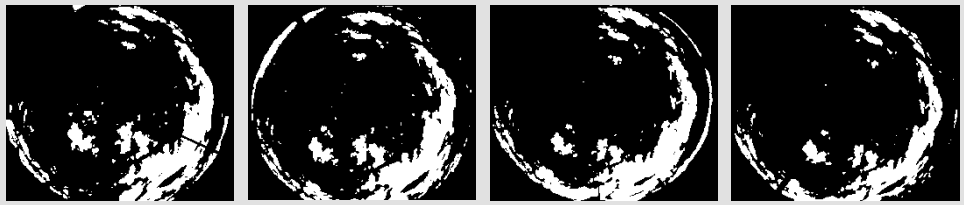
## Research & Development **> Solar Energy Meteorology**

Solar radiation measurement & modelling • **Nowcasting** • Other meteorological influences

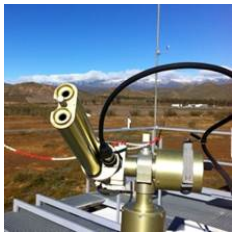
- Direct normal irradiance maps for solar field sites:
  - Spatially resolved, prediction based on all sky images
  - Reconstruction of 3D cloud coordinates
  - Cloud tracking
- Cloud height determination with ceilometer or cameras
- Validation with highly resolved solar irradiance measurements



All sky images, taken from four different sites at CIEMAT‘s PSA (Spain)



Results of cloud detection



# Institute of Solar Research

## Research & Development **> Solar Energy Meteorology**

Solar radiation measurement & modelling • Nowcasting • **Other meteorological influences**

- Solar beam attenuation between heliostat and receiver - modelling and measurement
- Soiling of plant components:
  - Mirrors
  - Entrance windows
  - Absorbers
- Wind measurement
- Sand storms
  - Particle properties
  - Velocity


1 Transmissometer
2 TraCS soiling sensor
3 Sand trap
4 Visibility sensor
5 Particle Counter

Height resolved aerosol extinction measurement with LIDAR (Light detection and ranging)

# Institute of Solar Research

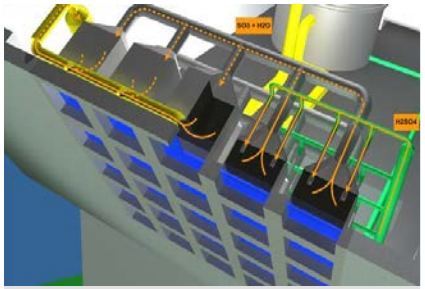
## Research & Development **> Solar Chemical Engineering**

**Solar Fuels** • Solar Water Treatment

### Technical Development in All Dimensions

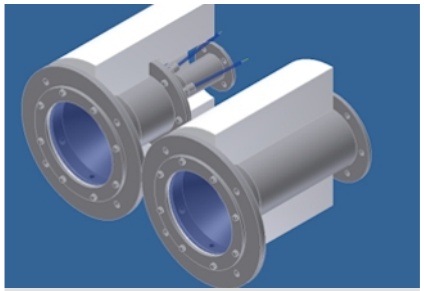
**Solar Plant**

- Site assessment
- Solar field simulation
- Environmental impact



**Receiver**

- Design
- Simulation
- Construction
- Testing
- Next generation development

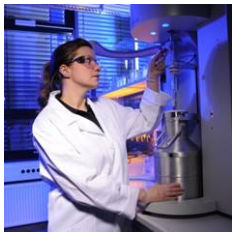


**Receiver Components**

- Materials
- Design
- Heat and mass transport
- Simulation
- Testing and Development

**Reactive Systems**

- Simulation
- Synthesis
- Chemical characteristics
- Physical characteristics



# Institute of Solar Research

## Research & Development **> Solar Chemical Engineering**

### Solar Fuels • **Solar Water Treatment**

- 20 years of experience in solar powered advanced oxidation processes
- Scale-up into industrial scale
- Technology is commercially distributed through Sowarla GmbH, Eberstadt/Germany

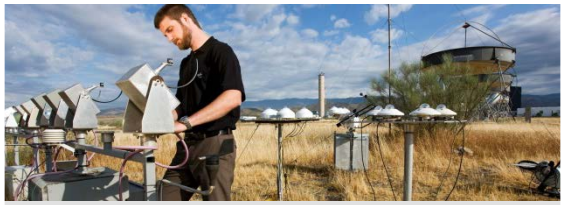
SOWARLA‘s demonstration plant in Eberstadt


# Institute of Solar Research

## Services

**Qualification Services**

For Components and Plants:
- Determination of quality caracteristics and performance parameters
- Aging Tests



**Resource Assessment & Forecasting**

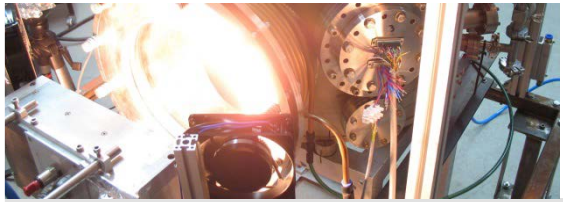
- Solar radiation, soiling and aerosol measurements
- Sensor calibration and characterization
- Nowcasting of irradiance


**Solar Water Treatment**

- Technology
- Consulting


**Software Tools for CSP Plants**

- Greenius: yield calculation for renewable energies
- STRAL: calculation of radiation flux density (ray tracing)
- HFLCAL: heliostat field layout and optimisation



**Technology Assessment/F&E-Support**

- Measuring equipment
- Test installations
- Provision of highly concentrated light, UV/IR resources for radiance tests
- Design reviews
- Feasibility studies

# Institute of Solar Research

## Research Facilities in Cologne and Juelich (Germany)

**Solar Tower Juelich**
Experimental solar power plant, Germany‘s unique solar tower

**QUARZ®**
Test and qualification center for CSP technologies

**CeraStorE®**
Competence center for ceramic materials and thermal storage technologies in energy research

**High-flux Solar Furnace and Xenon High-flux Solar Simulator**

**Outdoor Test Installations**

# Institute of Solar Research

## Joint facilities of DLR and CIEMAT

CIEMAT‘s Plataforma Solar de Almería, Spain

DLR and the spanish research center CIEMAT, owner and operator of Plataforma Solar de Almería (PSA) are close partners in the field of CSP R&D for more than 30 years.
Since the start of their collaboration, DLR and CIEMAT have been working jointly on research, industry projects and training at the PSA.
The installations shown below have been set up by DLR and CIEMAT as joint investments.

**DLR’s and CIEMAT’s joint research and test installations at PSA**

Meteorological station for solar technologies (METAS)

Rotary test bench for parabolic trough collectors (KONTAS)

Optical laboratory (OPAC)

# Institute of Engineering Thermodynamics

## Future Energy Systems, Energy Storage and Efficient Energy Conversion

- Research entity in the field of energy storage, thermal management and heat transfer
- Research Areas:

  **System Analysis and Technology Assessment | Thermal Process Technology | Electrochemical Energy Technology | Computational Electrochemistry**
- Services and consulting for industry clients and politics
- Annual revenue in 2014: 21,4 € Mio
- Staff: approx. 180 people at the four sites Stuttgart, Ulm, Cologne, Hamburg

# Institute of Engineering Thermodynamics
## Guiding Principles

### Vision

- Leading German research institution of energy storage, thermal management and heat transfer as well as a scientific pioneer of the energy storage industry.
- Our research helps to conserve resources and to break new ground in energy production, storage and efficient utilization.
- Efficient energy conversion and storage will play a crucial role in the flexible energy system of the future be a major part for a functioning energy supply system

*Regenerator Heat Storage*

### Mission

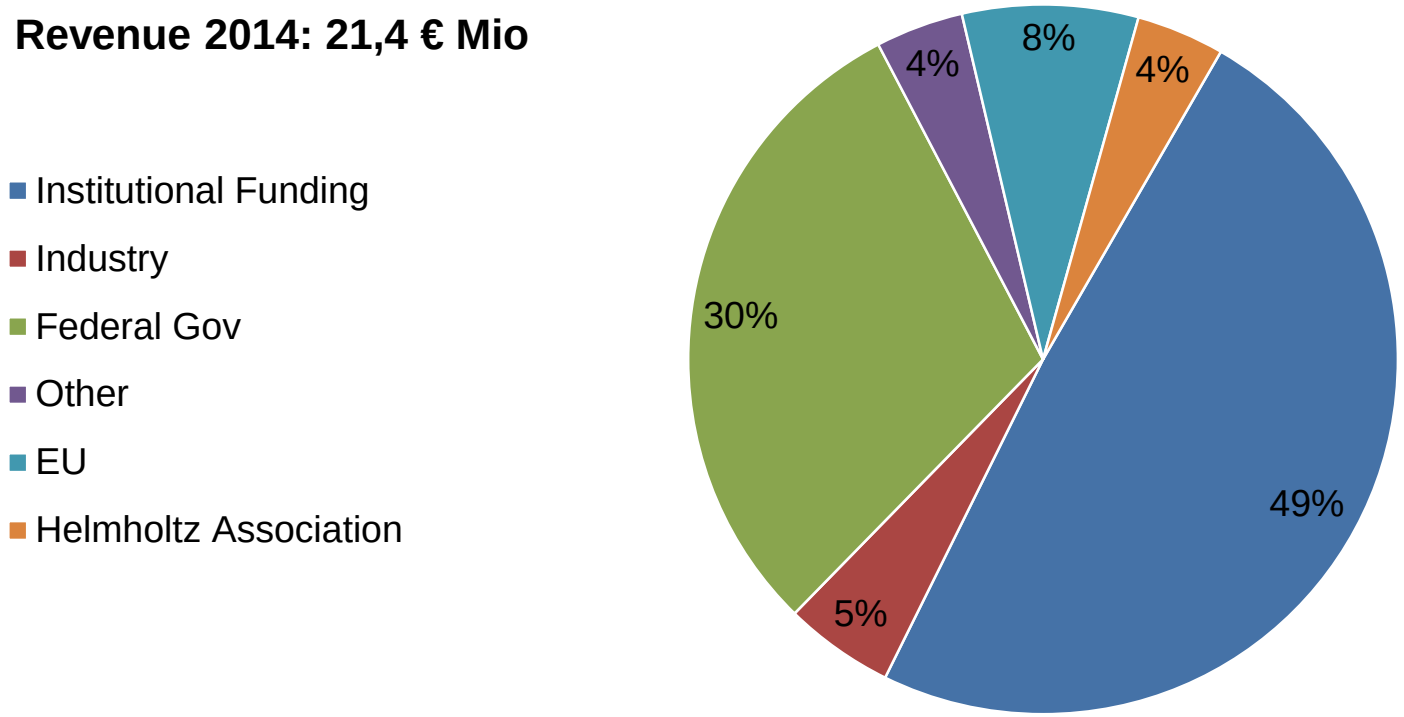
- Perform research in the field of efficient energy storage systems that conserve natural resources and next-generation energy conversion technologies
- Support industry partners with R&D solutions for specific application-oriented requirements and advise governments and companies on energy issues


*Latent Heat Storage*

# Institute of Engineering Thermodynamics

## Revenue

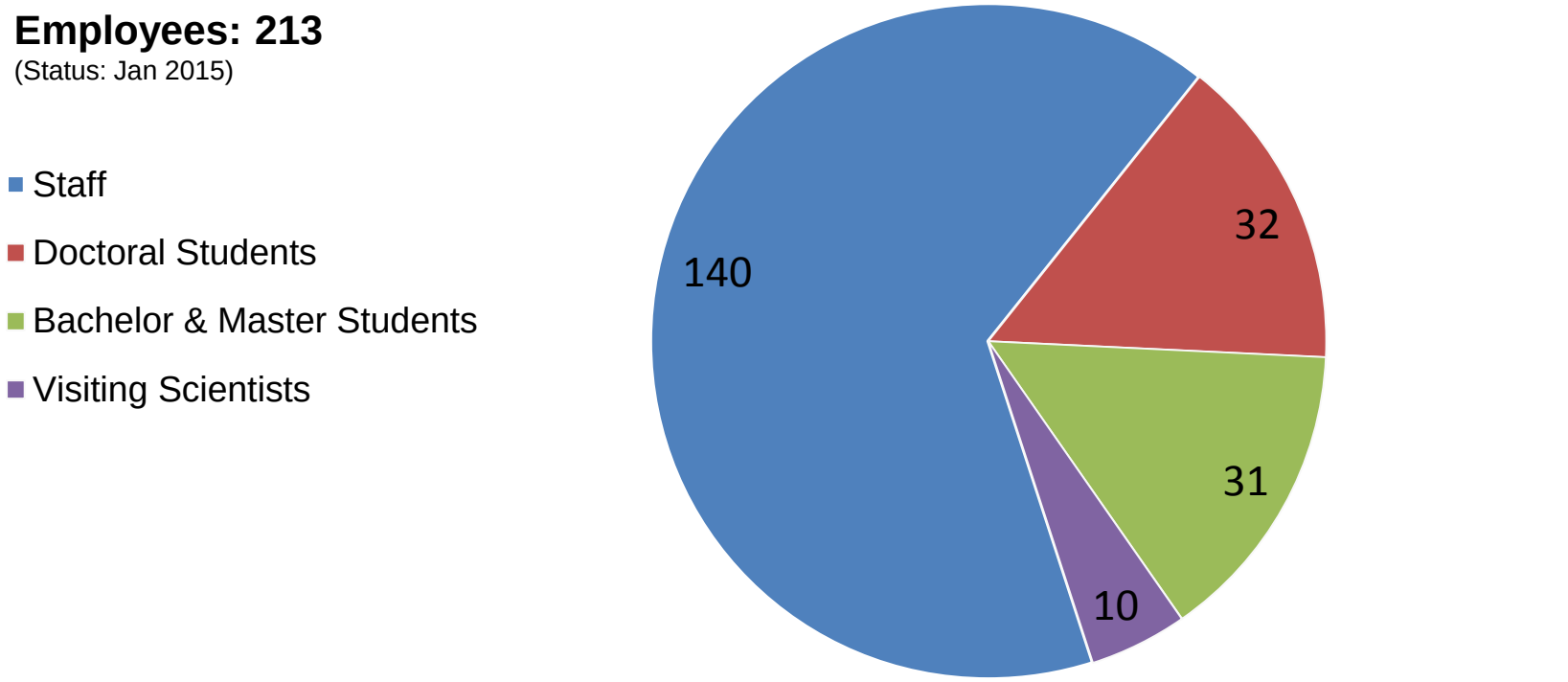
**Revenue 2014: 21,4 € Mio**




# Institute of Engineering Thermodynamics

## Personnel Structure

**Employees: 213**
(Status: Jan 2015)




# Institute of Engineering Thermodynamics

## Organizational Structure

**Director**
Prof. Dr. André Thess

**Deputy Director and Administration**
Jörg Piskurek

**Thermal Process Technology**
Dr. Antje Wörner

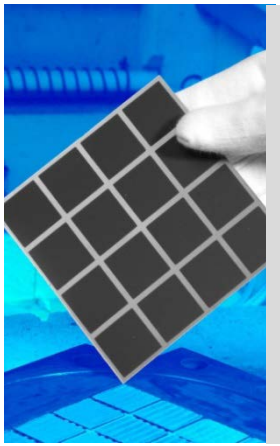
**Systems Analysis and Technical Assessment**
Dr. Christoph Schillings / Carsten Hoyer-Klick

**Computational Electrochemistry**
Prof. Dr. Arnulf Latz

**Electrochemical Energy Technology**
Prof. Dr. Andreas Friedrich

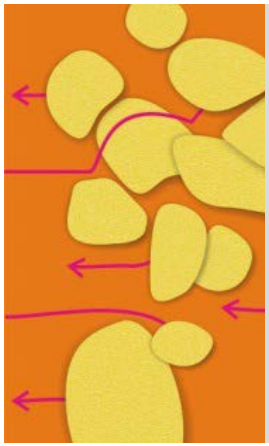
# Institute of Engineering Thermodynamics
## Research & Development

**System Analysis & Technical Assessment**
- Energy system modelling and scenarios
- Resources and potentials
- Incentive programs and economic aspects
- Market strategies for solar thermal power plants



**Electrochemical Energy Technology**
- Battery Technology
- High Temperature Electrochemistry
- Polymer Oriented Electrochemistry
- Electrochemical Systems

**Thermal Process Technology**
- High temperature sensible storage
- Molten Salt Storage
- Latent heat storage
- Thermochemical systems
- Alternative Fuels



**Computational Electrochemistry**
- Multi-scale and multi-physics modeling
- Numerical methods and electrochemical impedance simulation

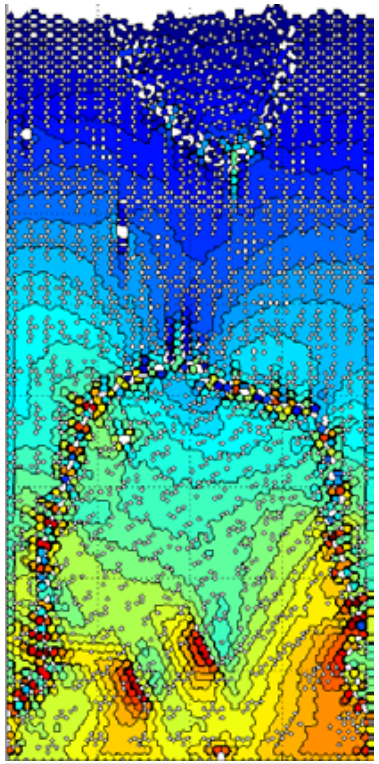
# Institute of Engineering Thermodynamics

## Research & Development **> High Temperature Sensible Storage**

**Regenerator-type storages** • Particle-based heat exchangers

- Simulation and experimental validation of thermomechanical behavior of packed bed design
- Design concepts for cost efficient and durable layout of pressurized storage vessels with direct heat transfer to/from gaseous medium
  - Temperatures up to 600 ºC
  - Pressures up to 65 bar
- Qualification and durability of storage and insulation materials

Inner chamber of testbed with storage material



Mechanical stresses within the storage bed

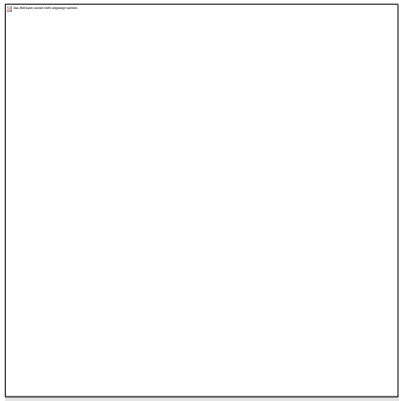
# Institute of Engineering Thermodynamics

## Research & Development **> High Temperature Sensible Storage**

### Regenerator-type storages • **Particle-based heat exchangers**

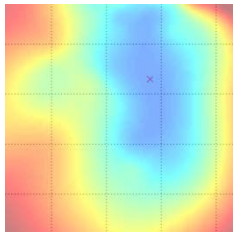
- Particles serve as heat transfer and heat storage medium at the same time
- Discharging of the heat from the particles for steam generation

- Design concepts for efficient heat extraction from the particles within moving bed configuration
- Simulation of fluid dynamics for various heat exchanger setups
- Experimental validation of flow pattern with PIV techniques (cold measurements)
- Experimental validation of heat transfer behavior in heat exchanger setup under real conditions



PIV measurements of heat exchanger configuration

Test facility for particle based heat exchanger for steam generation

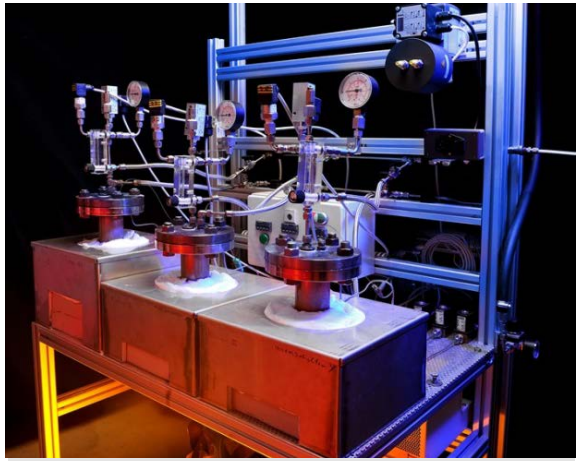


# Institute of Engineering Thermodynamics

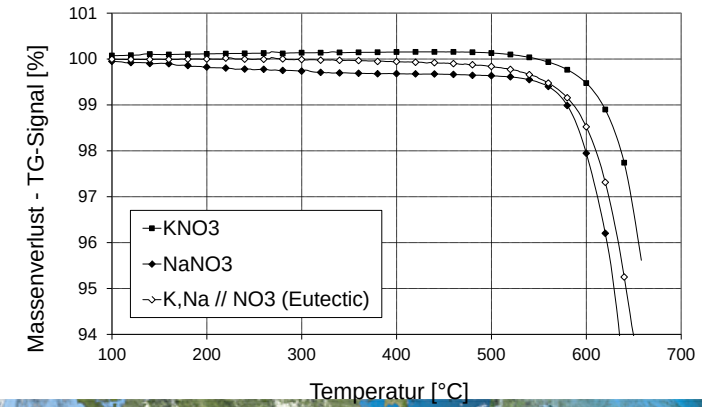
## Research & Development **> Molten Salt Storage**

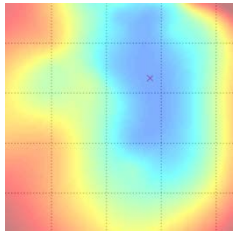
**Improved Salt Formulations** • Storage Tank Concepts

- Development of alternative salt systems
  - Reduced melting temperature < 140 °C
  - Therm. stability at temperatures up to 700 °C
- Investigation of the thermal stability of nitrates salts (i.e. in closed atmosphere)
  - Chemical reactions at higher temeperatures
  - Interaction with vessel materials
  - Influence of the operating parameters and atmosphere
- Investigation of chlorides
  - Handling
  - Chemical stability



Experimental set-up and eutectic mixture



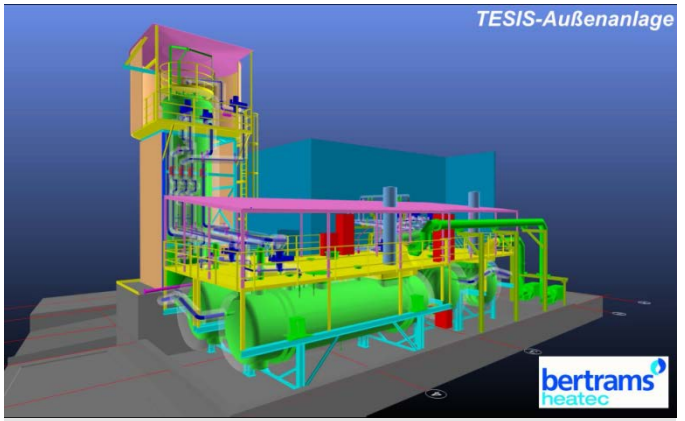



# Institute of Engineering Thermodynamics

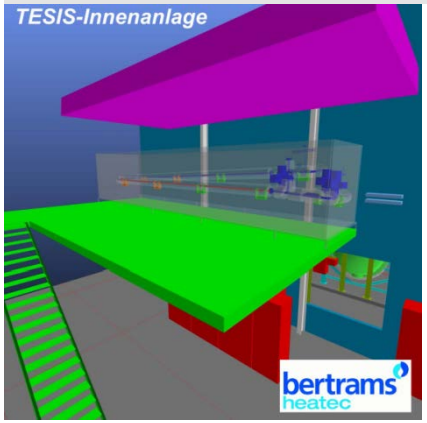
## Research & Development **> Molten Salt Storage**

### Improved Salt Formulations • **Storage Tank Concepts**

- Testing infrastructure for the investigation of molten salt storages and its components at a realistic scale
  - Salt Inventory: max. 135 tons
  - Storage volume: 20 $m^3$
  - Salts: Nitrates/Nitrites, Solar Salt ($NaNO_3$-$KNO_3$)
  - $T_{operation}$: 150 to 560 ºC
  - Heating/Cooling Power: max. 420 kW
  - Capacity ($\Delta T$ = 250 K): ca. 200 kWh/$m^3$
  - Mass flow: 4 / 8 kg/s
  - Commissioning in 2017




Molten Salt Storage Testing Facility TESIS

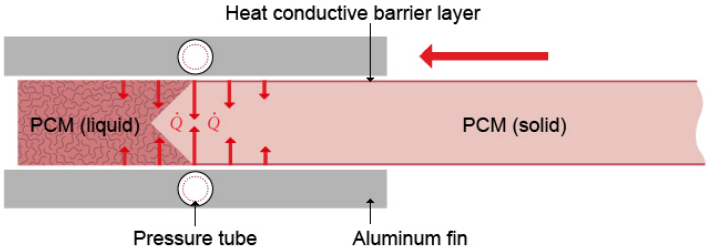



# Institute of Engineering Thermodynamics

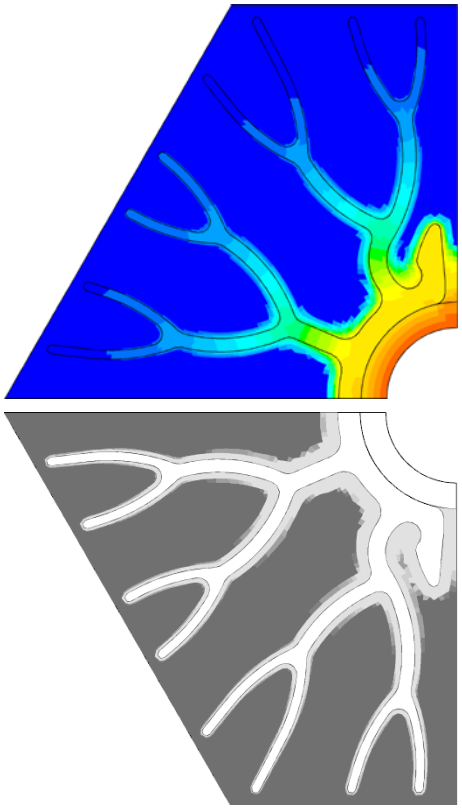
## Research & Development **> Latent Heat Storage**

### **Concepts for Improved Heat Transfer** • Prototype Testing

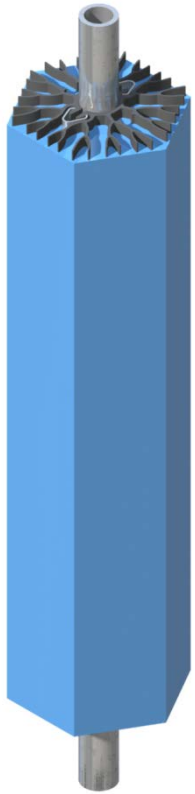
- Identification and characterization of suitable phase change materials with melting temperatures between 140 °C and 300 °C
- 2-dimensional finite volume analysis of charging and discharging process, taking natural convection into account
- Development of design concepts to guarantee for improved heat transfer (i.e. finned tubes, moving bed concept PCMFlux)
- Cost effective fabrication with industrial partners




PCMFlux concept for constant heat flux



Temperature distribution in fins



Extruded fins

# Institute of Engineering Thermodynamics

## Research & Development **> Latent Heat Storage**

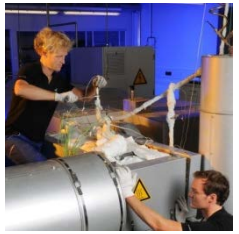
### Concepts for Improved Heat Transfer • **Prototype Testing**

- Design tools for latent heat thermal energy storages and their integration into power plants and industrial processes

Examples for realizes prototypes:

- Demonstration of a pilot-scale storage system and integration into a steam plant in Spain:
  - 700 kWh latent heat storage with 14 tons of sodium nitrate salt
  - 300 kWh concrete storage
  - 3000 hours of operation, 100 cycles
- Integration of 6 MW storage into a cogeneration plant to supply back-up of superheated steam for industrial customer
  - 1.5 MWh storage capacity
  - 30 tons of sodium nitrate salt
  - Commissioning in 2016


Pilot-scale storage system in Spain

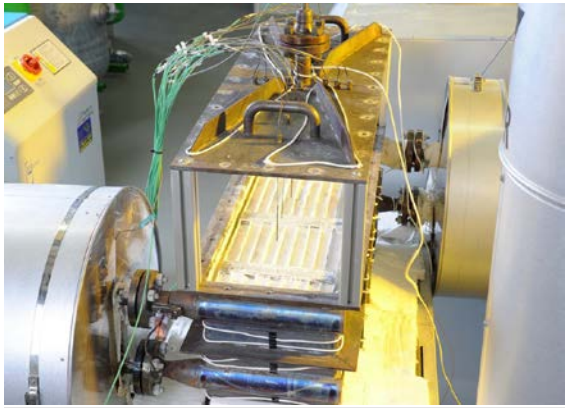


# Institute of Engineering Thermodynamics

## Research & Development **> Thermochemical Systems**

### **Heat Storage** • Heat Transformation

- Characterization and modification of storage material (thermodynamic equilibrium, reaction kinetics, bulk properties, particle size)
- Modelling of heat and mass transfer in the bulk during reaction
- Development of moving bed reactor concepts
- System integration for solar thermal power plants, industrial process heat and seasonal storage



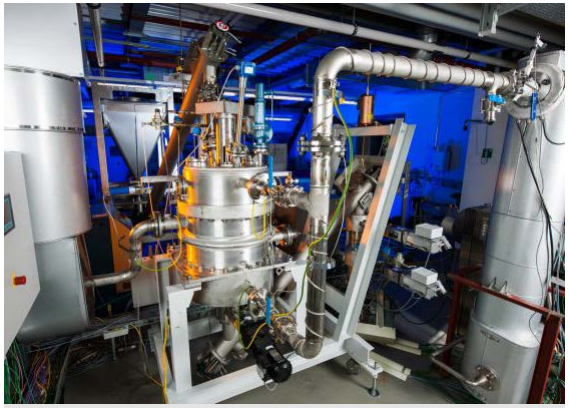
10 kWh plate heat exchanger test setup

endothermic

$$Ca(OH)_2 + \Delta H \rightleftharpoons CaO + H_2O$$

exothermic

Gas-solid reaction for thermochemical energy storage between 400 and 600 ºC



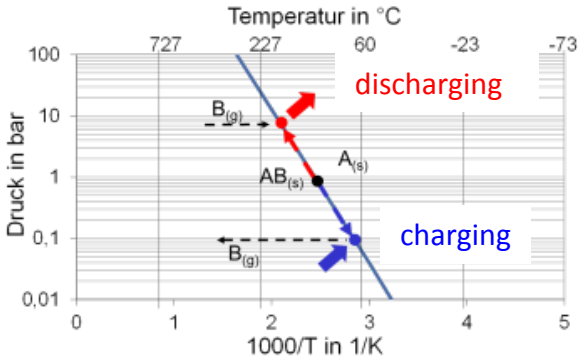
100 kWh moving bed test setup

# Institute of Engineering Thermodynamics

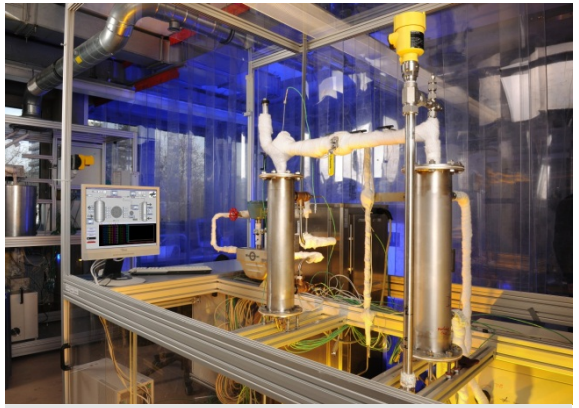
## Research & Development **> Thermochemical Systems**

### Heat Storage • **Heat Transformation**

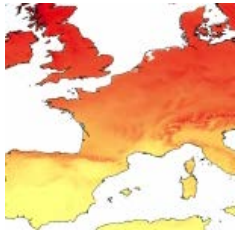
- Utilization of pressure and concentration differences (i.e. waste steam vs. ambient air) to realize thermal upgrade
- Characterization of suitable reactions systems
  - Thermo-physical properties
  - Reaction kinetics
  - Bulk properties
- Modelling of thermal, chemical and physical behavior in 2D
- Development of specific reactor concepts for small temperature gradients
- System integration for low temperature waste heat and high temperature heat pump applications




Van't Hoffs plot for thermal upgrade



Test bench for salt hydrates

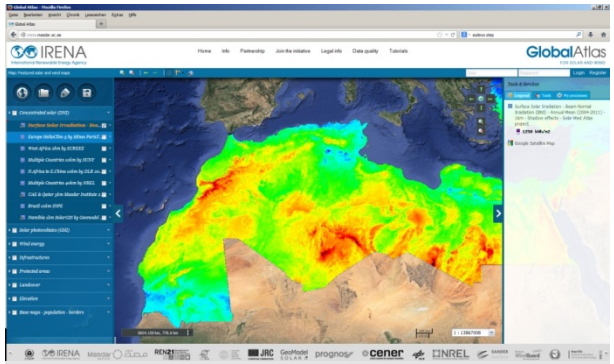


# Institute of Engineering Thermodynamics

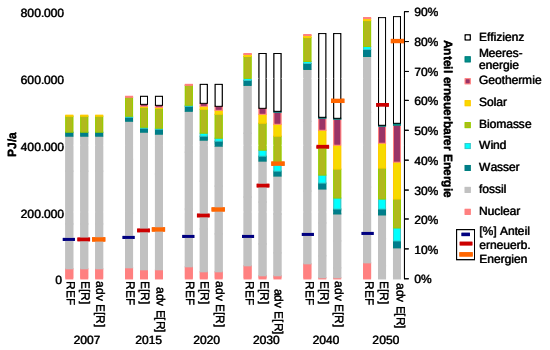
## Research & Development **> Market Strategies for CSP Plants**

- Analysis and scenarios for the enrollment of CSP technologies in the MENA Region
  - MED-CSP, TRANS-CSP, AQUA-CSP studies
- Energy system modelling and investigation of the theoretical and economical potential of renewable energies with high local and temporal resolution
- Identification of ideal sites for CSP plants
- Analysis of the potential of new technologies for seawater desalination and synthetic hydrocarbon

CSP import scenario for Europe




High resolution data for MENA region



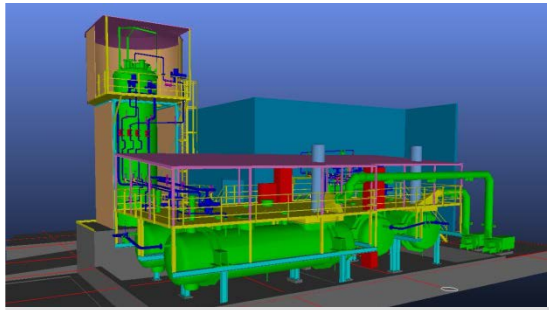

Energy mix with renewable share

# Institute of Engineering Thermodynamics

## Research Facilities in Stuttgart and Cologne (Germany)

**HOTREG**
Test bed for high temperature thermal energy storage

**CellFlux**
Modular test bed for cost-efficient sensible storage



**TESIS**
Molten salt test facility (in operation by 2017)

**Skoop**
Latent heat storage test facility for temperatures up to 400 °C

**TCS-Testbed**
Thermochemical storage test facility for temperatures up to 1000 °C

# Contact

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