SOLARTHERMAL ENERGY R&D AT FRAUNHOFER ISE

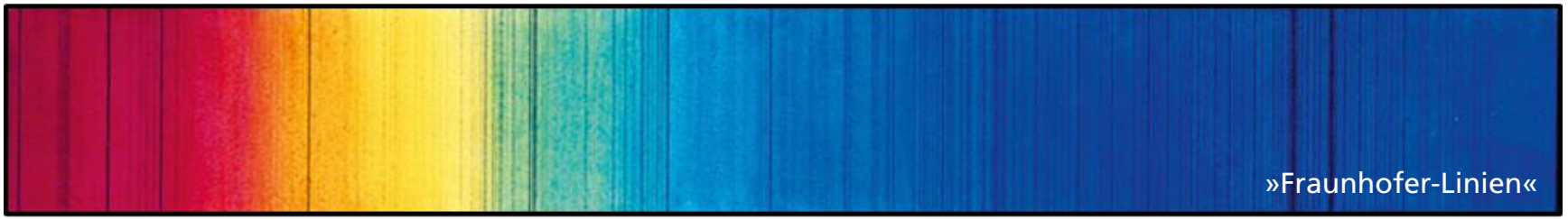
Fraunhofer ISE

The Fraunhofer-Gesellschaft
Mission Statement

- Promotes and undertakes applied research in an international context, of direct utility to private and public enterprise and of wide benefit to society as a whole.
- Helps reinforce the competitive strength of the economy on the regional level, throughout Germany and in Europe
- Offers a platform that enables its staff to develop professional and personal skills

The Fraunhofer-Gesellschaft
Largest Organization for Applied Research in Europe

- 67 institutes and research units
- Staff of more than 23,000
- €2 billion annual research budget totaling
  - Roughly two thirds of this sum is generated through contract research on behalf of industry and publicly funded research projects
  - Roughly one third is contributed by the German federal and state governments in the form of base funding
- International cooperation



Fraunhofer Institute for Solar Energy Systems ISE
Mission Statement

- Fraunhofer ISE conducts research on the technology needed to supply energy efficiently and on an environmentally sound basis. To this purpose, the Institute develops systems, components, materials and processes in the areas of the thermal use of solar energy, solar building, solar cells, electrical power supplies, chemical energy energy storage and the rational use of energy.
- Our work ranges from fundamental scientific research relating to solar energy applications, through the development of production technology and prototypes, to the construction of demonstration systems.

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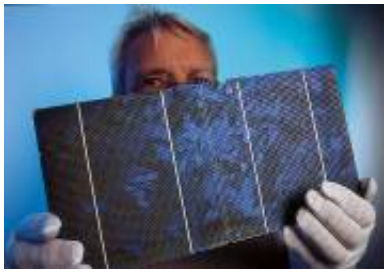
Research, Development and Services

Research
Materials,
Modeling,
Methods



Development
Components,
Prototypes,
Systems, Procedures

Services
Consulting, Tests,
Monitoring,
Quality Assurance

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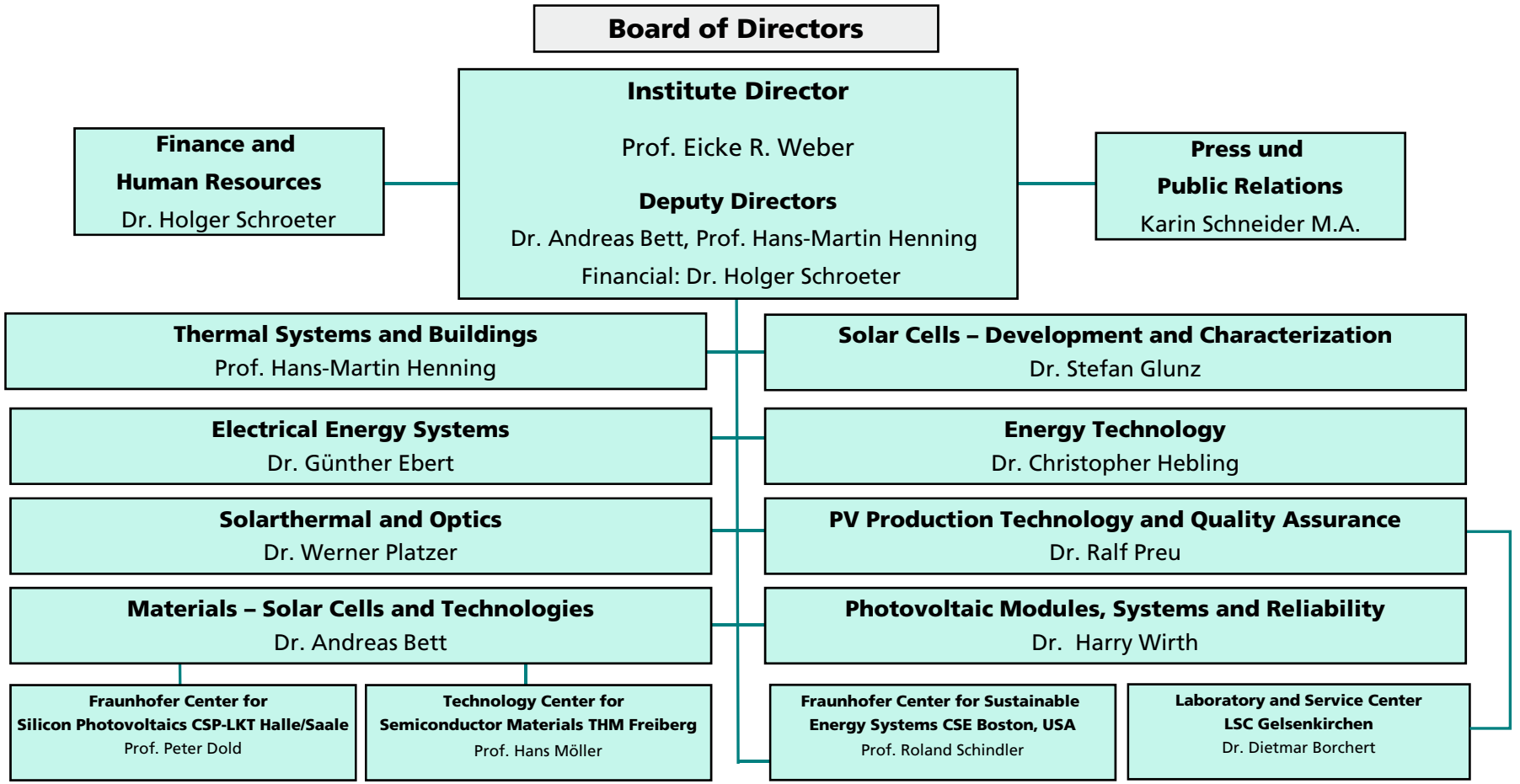
Organizational Structure – 8 Scientific Divisions



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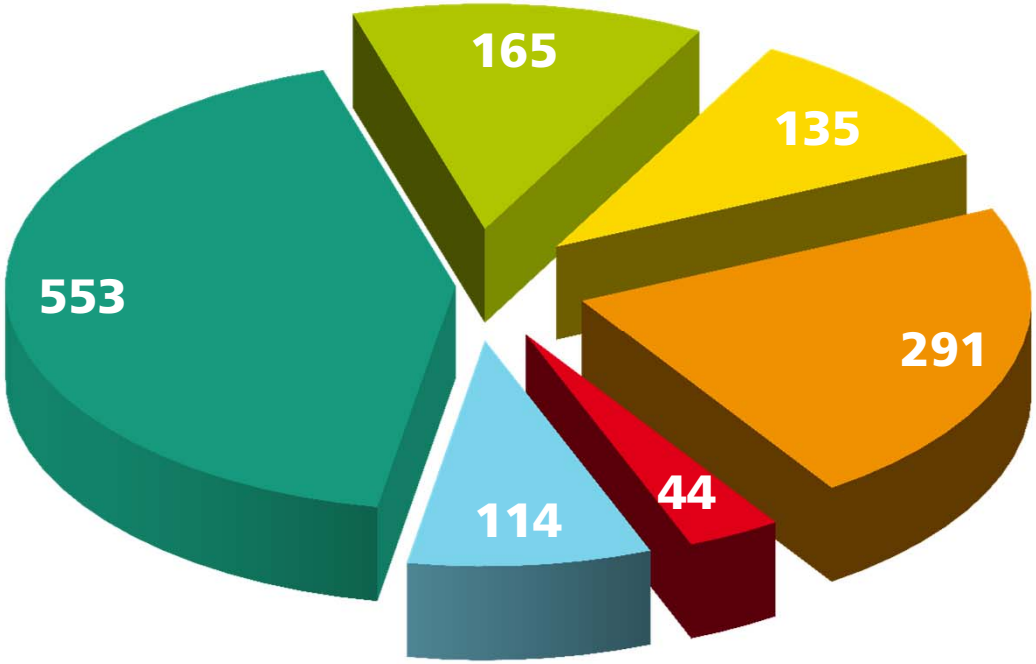
Personnel Structure

- Staff
- Doctoral Students
- Diploma Students
- Scientific Assistants
- Trainees
- Others



Total : 1301

Status : January 2014

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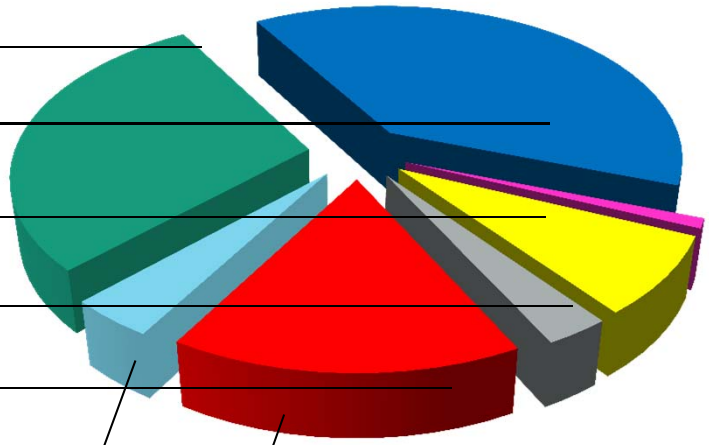
Revenue Structure, Operation 2013

Operation	€ 73.2 million
Investment**:	€ 13.5 million
Total:	€ 86.7 million

Industry	29 %
Federal Gov. Projects	39 %
Regional Gov. Projects	1 %
European Union	8 %
Others	3 %
Special Programs, FhG	4 %
Basic Funding*	16 %



* of which 90 % federal and 10 % state funds
** without building investment and economic program

Status : March 2014

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12 Business Areas

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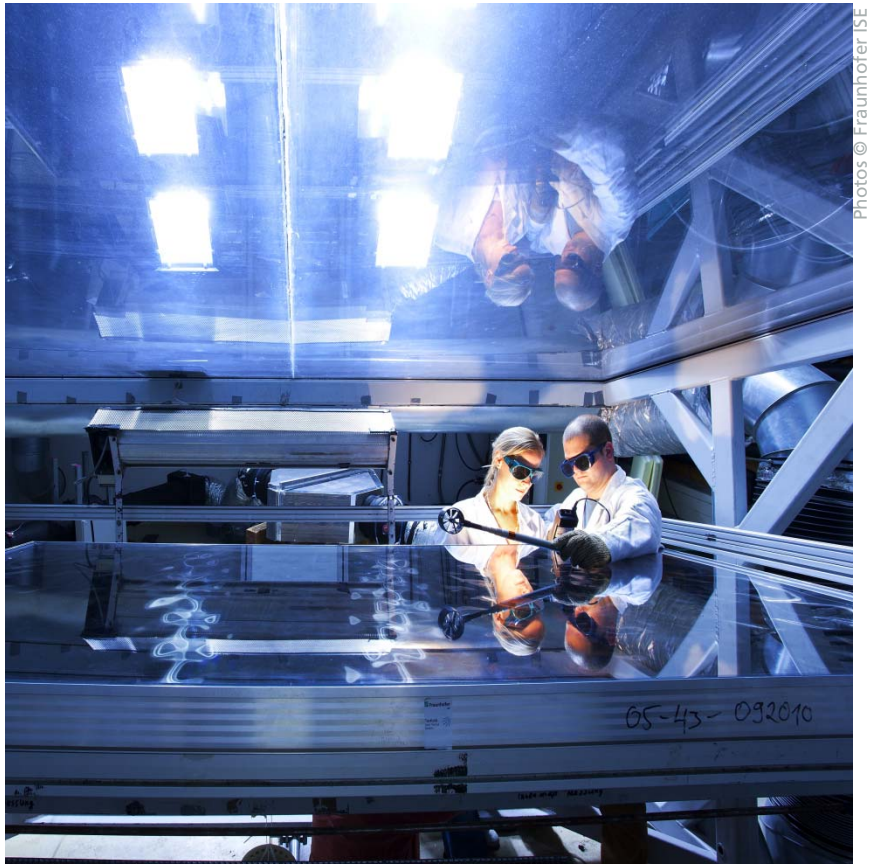
- Energy Efficient Buildings
- Silicon Photovoltaics
- III-V and Concentrator Photovoltaics
- Dye, Organic and Novel Solar Cells
- Photovoltaic Modules and Power Plants
- Solar Thermal Technology
- Hydrogen and Fuel Cell Technology
- System Integration and Grids – Electricity, Heat, Gas
- Energy Efficient Power Electronics
- Zero-Emission Mobility
- Storage Technologies
- Energy System Analysis

Solar Thermal Technology

- Our R&D focuses on innovative materials and components for new approaches and concepts in the collector technology
- Our system technology optimizes the integration and storage of solar heat in the total system.
- Hot water, heating, cooling, process heat, electricity and even clean water can be produced with solar thermal energy.



Photos © Fraunhofer ISE

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Solar Thermal Technology

Photos © Fraunhofer ISE

Domestic Hot Water and Solar Heating

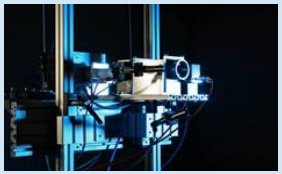
Solar Thermal Façades

Solar Cooling and Refrigeration

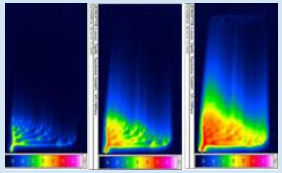
Solar Thermal Power Plants

Solar Process Heat

Decentralized Water Purification Systems



Service Life of Collectors and Components



Heat Transfer and Heat Transport

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Solar Thermal Technology for Heat and Electricity

Optics and Material Science	Solar Thermal Collectors	Solar Thermal Systems Engineering
PVD coatings	Collector development	DHW and heating
Surface analytics	Certified TestLab	Process heat
Vacuum technology	Heat transfer	Solar thermal power
Micro structuring	Concentrator optics	Thermal storage
Degradation	Structural mechanics	Water treatment

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Solar Cooling and Refrigeration

- Research themes
  - Development of sorption materials
  - Adsorption chillers
  - Concentrating collectors
  - Optimization of cold supply systems
- Competence
  - System simulation and optimization
  - Monitoring
  - Performance analysis
  - Assistance in choice of technology

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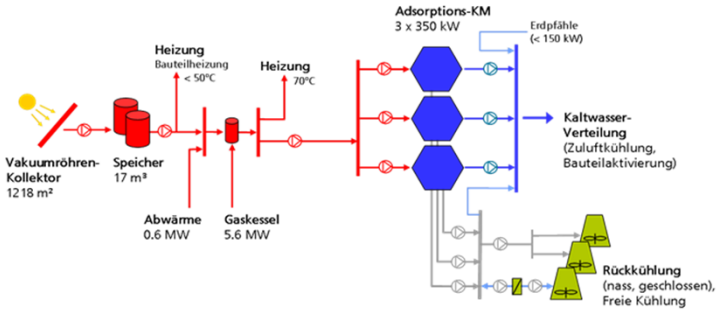

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Solar Cooling and Refrigeration
Examples of Large Installed Systems

CGD Bank Headquarters

- Lisbon
- 1560 m² collector area
- 400 kW absorption chiller

Source: SOLID, Graz/Austria

FESTO Factory

- Berkheim
- 1218 m² collector area
- 1.05 MW (3 adsorption chillers)

Source: Paradigma, Festo

United World College

- Singapore
- 3900 m² collector area
- 1.47 MW absorption chiller *(in planning)*

Source: SOLID, Graz/Austria

Solar Process Heat

- Research themes
  - Medium temperature collectors
  - Integration of solar heat
  - Optimization of system concepts
  - Branch concepts (laundries)
  - Mobile measurements
- Competence
  - Concentrator optics and tracking
  - Dynamic system simulation
  - System monitoring
  - Layout and design

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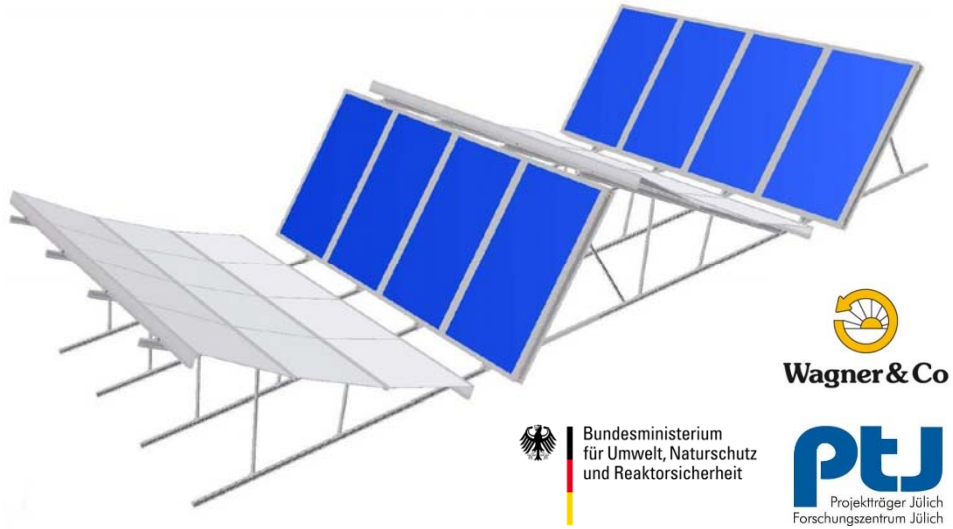
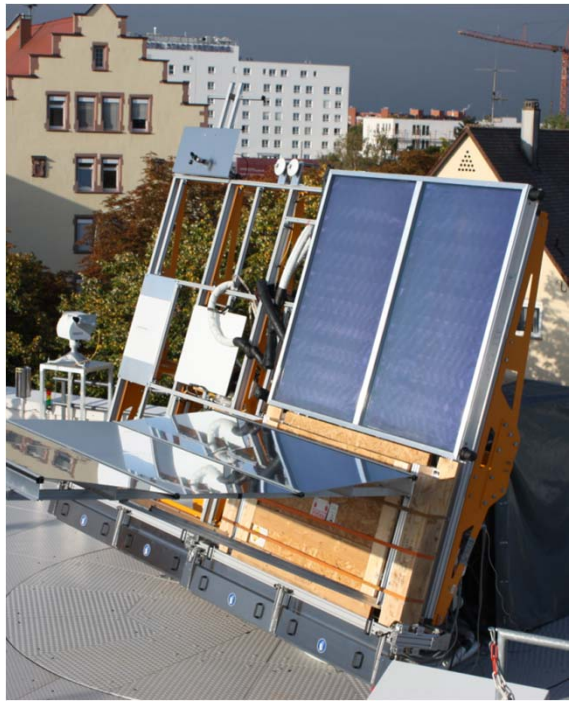
Solare Process Heat
Collector Development



Visualisation of the RefleC-conzept



Prototype of RefleC-Collector
Nov. 2010 on Tracker-platform
Fraunhofer ISE

- Development of highly efficient Flat-plate collceotrs with reduced heat losses
- Operating temperatures 80 °C to 150 °C

Solare Process Heat
Systems Lab for Medium Temperatures

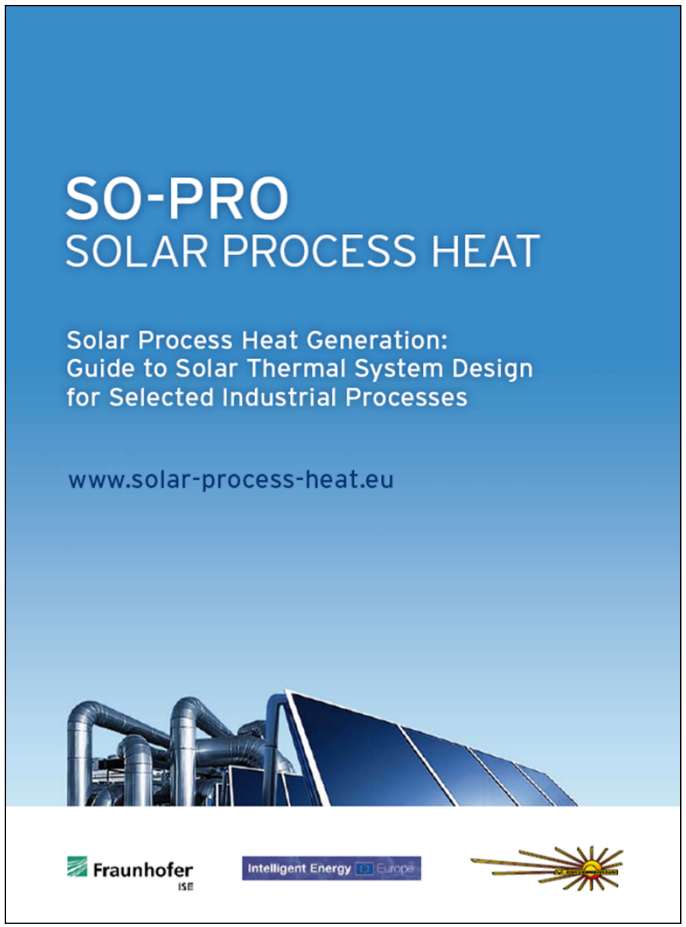
- Heat simulation of 250 kW therm. power
- Water steam and ORC (organic media)
- Limits 300°C and 30 bar

Dynamical testing and investigation of transients:

- Heat engines
- High temp. storages
- Thermal chillers

Solare Process Heat
SO-PRO Design Guideline

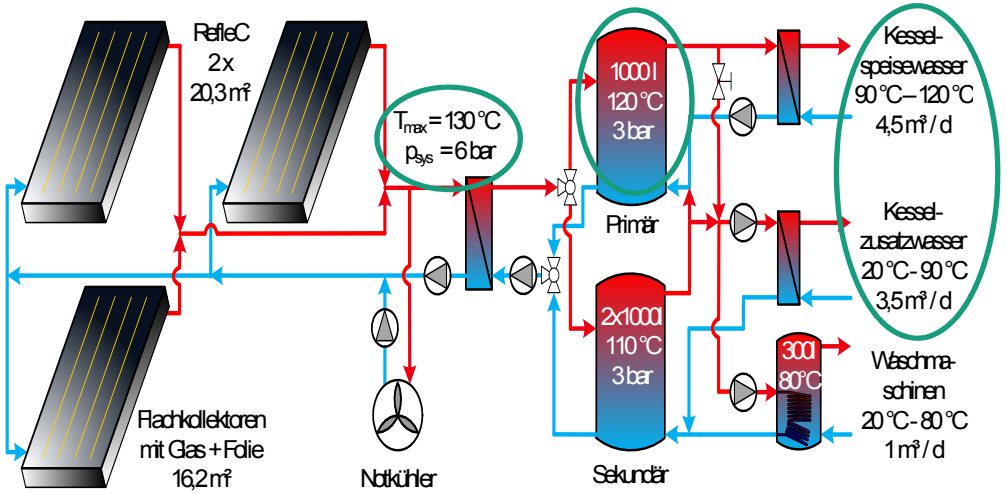
- Aim: Common Understanding for engineering companies, energy consultants and solar companies
- Design rules for four selected applications:
  - Hot water for washing or cleaning
  - Make-up water for open steam networks
  - Baths or vessel heating
  - Drying using hot air
- Holistic design approach with consecutive steps



Solar Process Heat
Pilot System, Laguna Laundry

- System optimization and monitoring
- Comparision of RefleC and standard collectors in operation
- Stagnation prevention with cooler
- Pre-heating of feed water and supplemental water

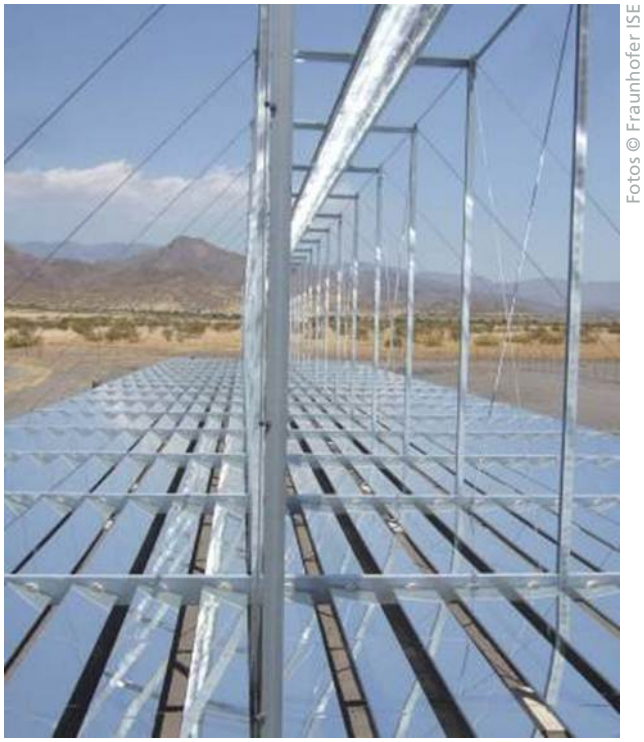
Thermal solar array on roof:
Laguna laundry in Marburg (Lahn)



System Schematic

Solar Thermal Power Plants

- Research themes
  - Linear Fresnel collector
  - Direct evaporation / molten salt
  - Heliostats and solar field arrays
  - High temperature storage
- Competence
  - Absorber and mirror development
  - Collector optimization
  - Simulations and optimized operation
  - Experimental qualification
  - Technological and overview studies



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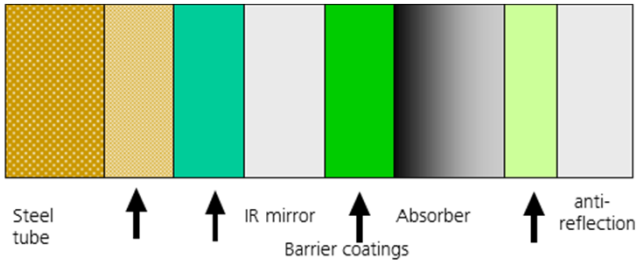
Solar Thermal Power Plants
Absorber Systems and Mirror Coatings

- Stability up to 450 °C in air
- High absorptivity and low emissivity
- Selection of steel material
- Surface pre-conditioning
- Coating materials
- Optimization of layers (thickness, barrier coatings)



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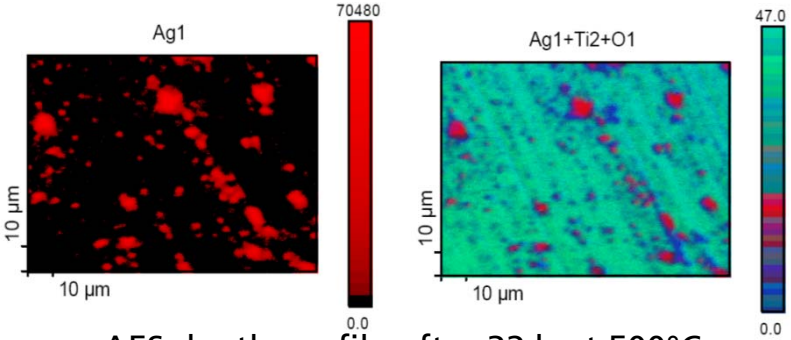
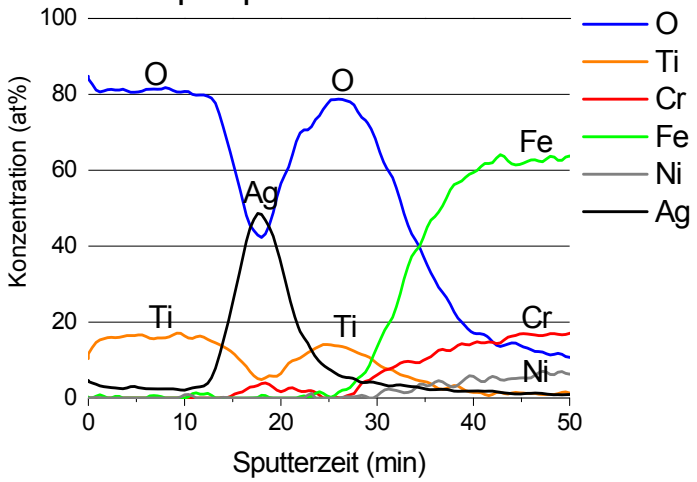
Solar Thermal Power Plants

Analysis of degradation of deposited layers

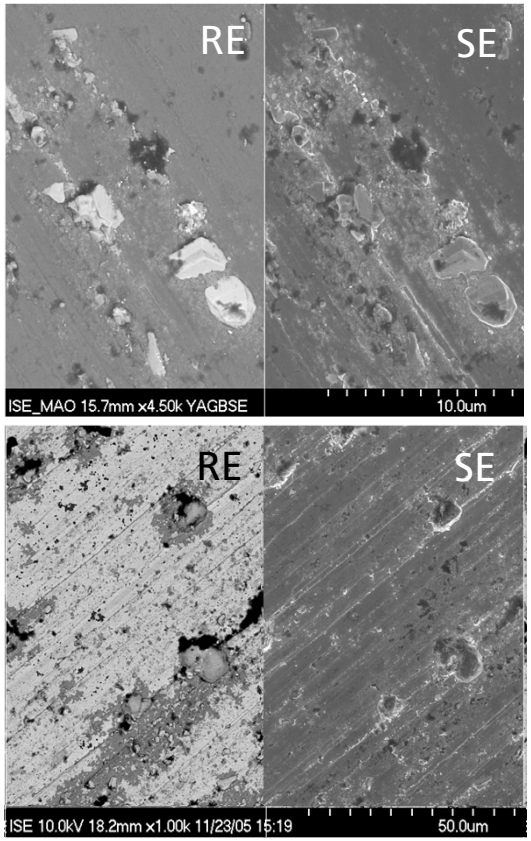
AES-Mapping after 32 h at 500°C



AES depth profile after 32 h at 500°C



REM-images after 32 h at 500°C



5 keV

10 keV

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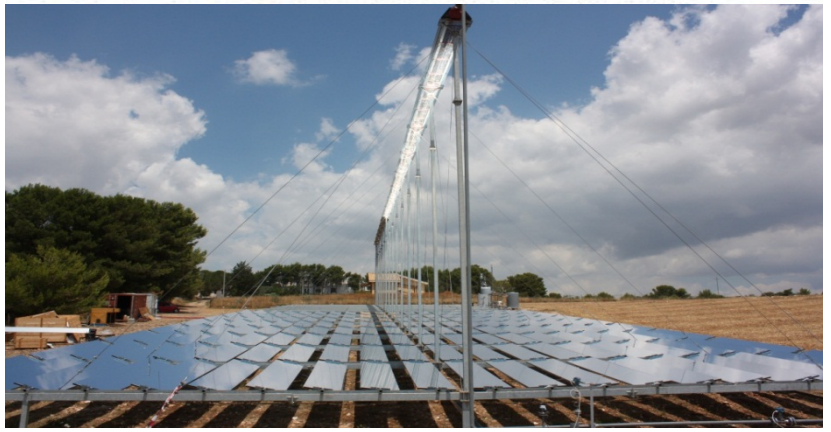
Solar Thermal Power Plants
Linear Fresnel Collectors

- Cost-effective flat mirrors
- Stationary receiver tube
- Low wind loads
- High concentration factors
- Direct evaporation / molten salt
- Supplementary use of the area: parking lot, supermarket, agriculture
- Local adaption and regional value chain development



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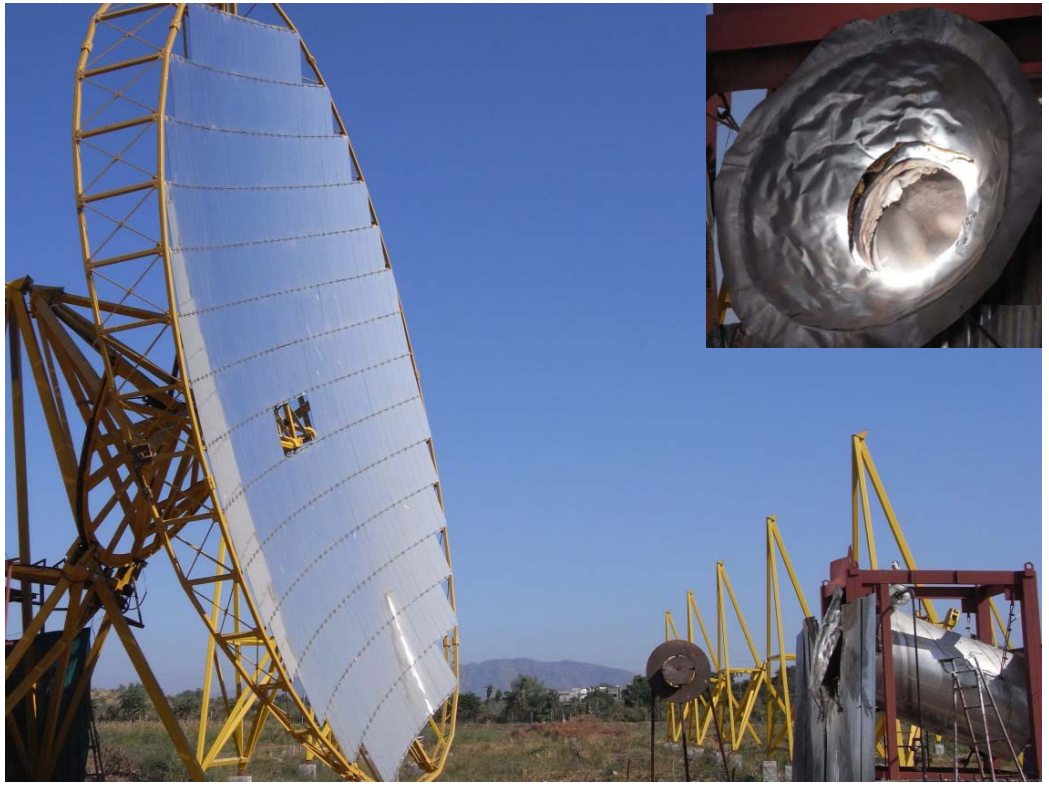
Solar Thermal Power Plants
Scheffler Reflector

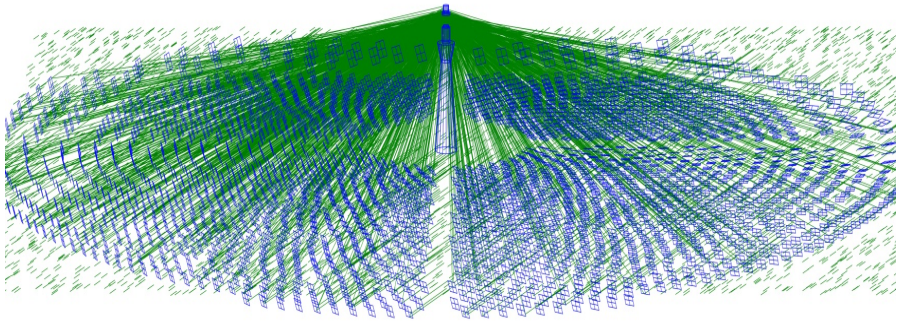
- Main technical data:
  - 770 Scheffler dishes with fix focus (60 m^2 each)
  - Reflector area: 45.000 m^2
  - 1 MW_{el} (Siemens turbine, 255 °C, 41 bar)
  - 3.5 MW_{th} (hot water grid)
  - Metal core storage for continuous operation

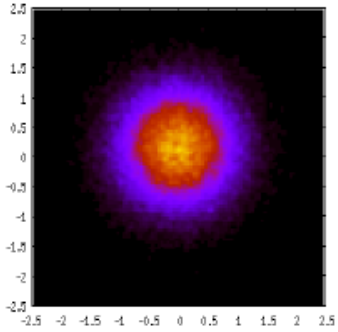


- www.india-one.net

Solar Thermal Power Plants
Solar Tower

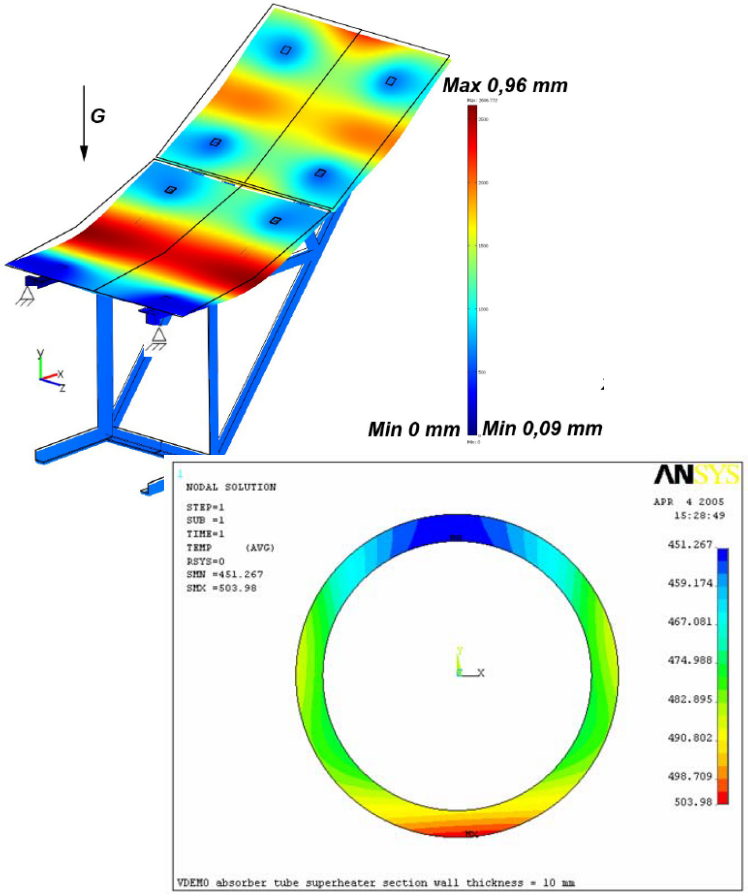
- Performance assessment of optical systems applied to a solar tower system
- Optimization of optical components: Receiver, heliostat field, heliostats, reflector, secondary concentrator, etc.
- Integration of storage models
- Modelling and simulation of planned or real solar tower plants





Solar Thermal Power Plants
Optimization of the Collector Construction

- FEM analysis of primary reflectors
  - Deformation due to gravity
  - Deformation due to wind loads
  - Integrate result in optimization of secondary reflector
- CFD analysis of receiver cavity
  - Temperature distribution in secondary reflector and on the receiver pipe
  - Input to secondary reflector development



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Solar Thermal Power Plants
Quality assessment of key components

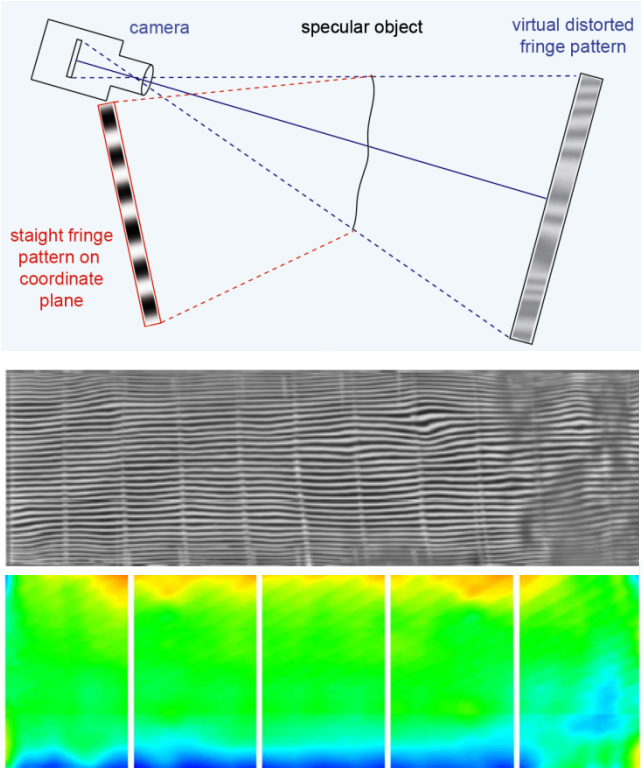
TestLab
Solar Thermal
Systems

DIN Geprüft

- Thermal qualification
  - Thermal receiver testing in the lab and outdoors
  - Dynamical characterization of collector performance
- Optical qualification of mirrors
  - Reflectivity and scattering of different materials
  - Shape assessment and concentration
- Durability and lifetime estimation
- Certification of products

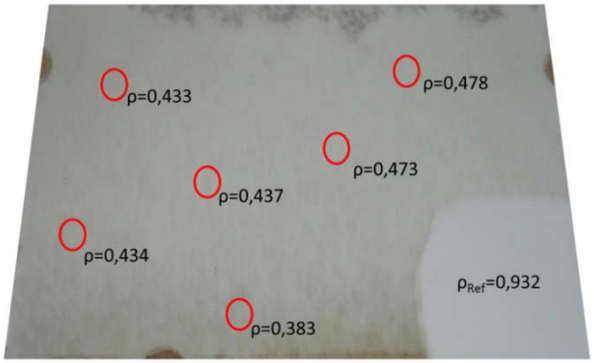
Concentrating Collectors
Deflectometry

- Shape measurement of focussing mirrors in the lab

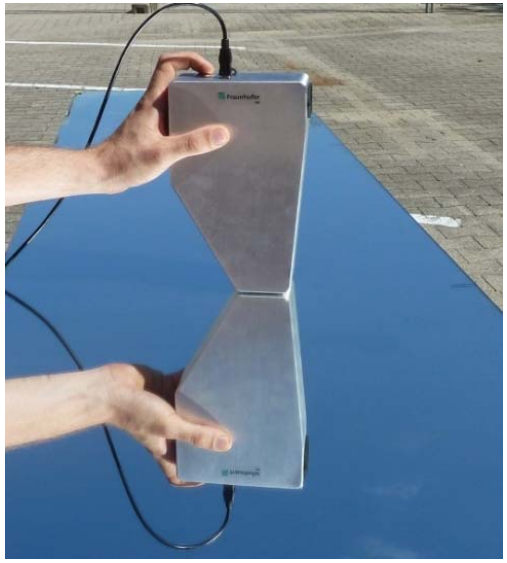


Concentrating Collectors
Soiling of Reflector Mirrors

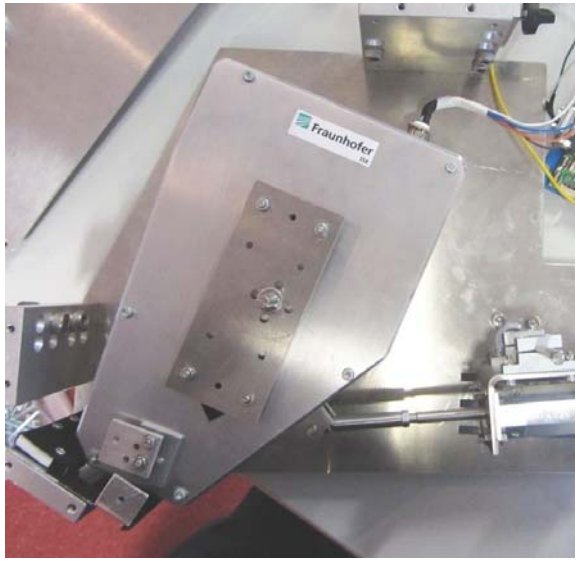
- Development of optical measurement devices
- Studies on soiling, cleaning procedures and impact on economics



Investigation of soiling at 3 locations



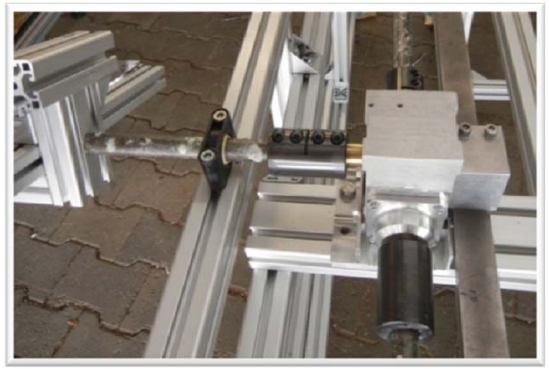
Mobile spectral reflectance measurement

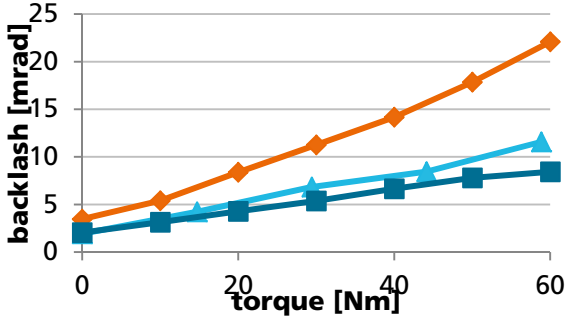


Device mounted in cleaning robot
Source: Novatec/ISE

Concentrating Collectors
Tracking and Controls

- Testing of tracking accuracy and drive back lash

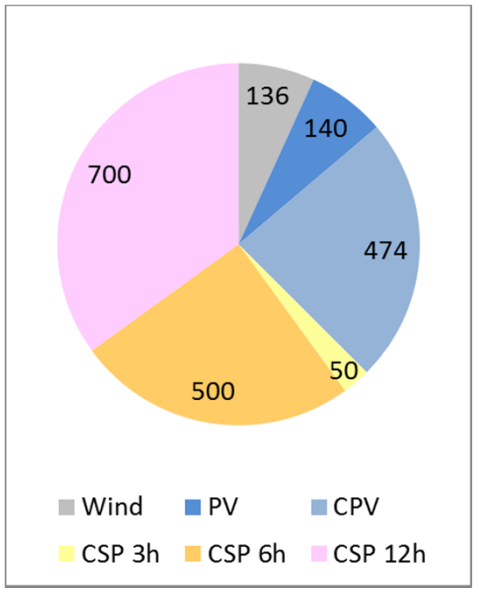




Solar Thermal Power Plants

Project Shagaya – 2GW-Solar-Wind-Park in Kuwait

- Zubau von PV, Wind und CSP Kraftwerken bis 2030 optimiert unter Berücksichtigung von Stromgestehungskosten, lokaler Lastverteilung und flächenspezifischem Ertrag
- CSP favorisiert wegen Speicherfähigkeit und Planbarkeit der Erzeugung



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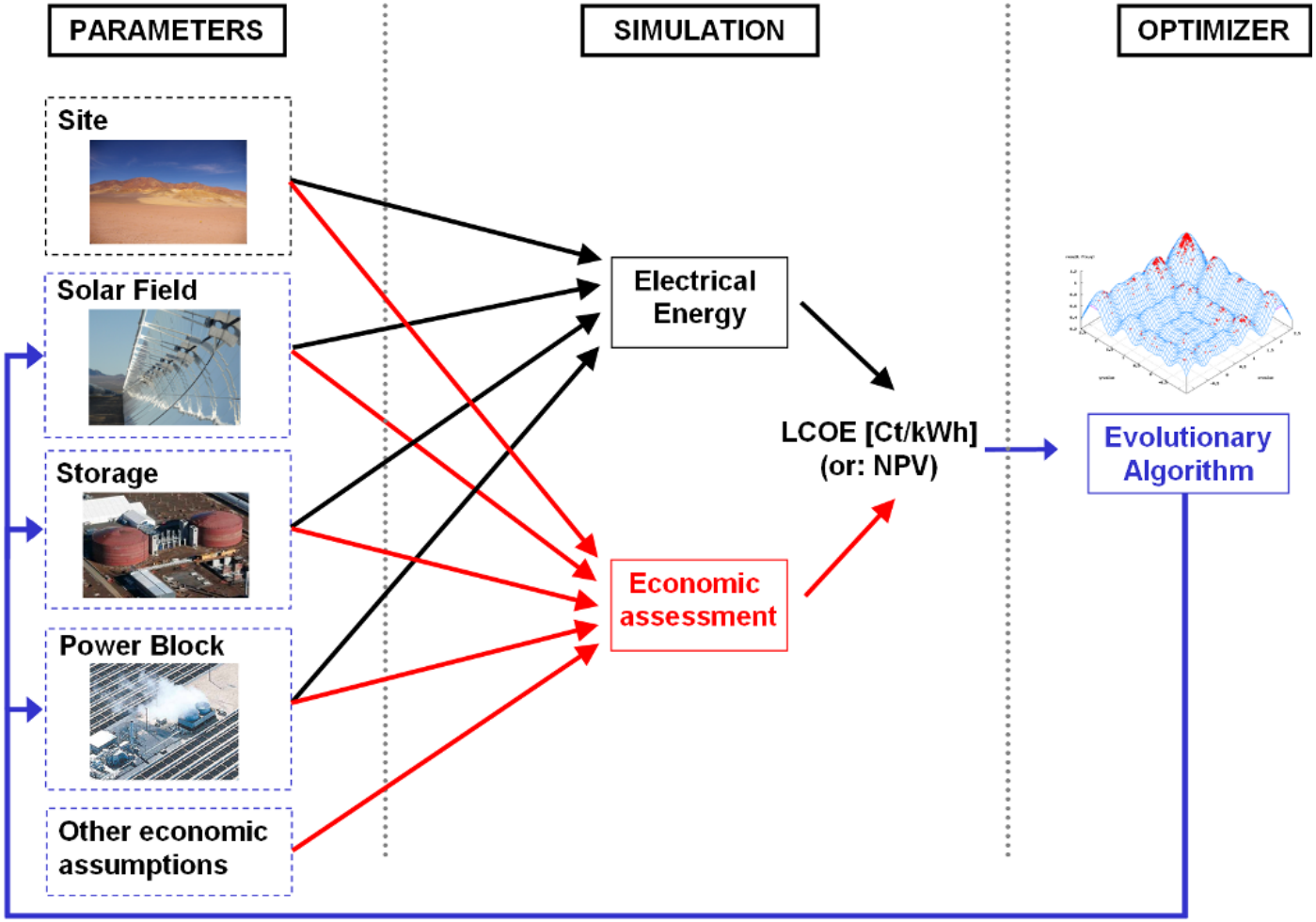
Integrated Model for energetic and economic plant simulation and optimisation



Decentralized Water Purification Systems

- Research themes
  - Membrane optimization
  - Membrane destillation with solar heat and waste heat
  - PV reverse osmosis
  - Ultrafiltration
  - Industrial material separation
- Competence
  - Membrane characterization
  - Heat/material transport simulations
  - MD Module construction
  - System monitoring and evaluation

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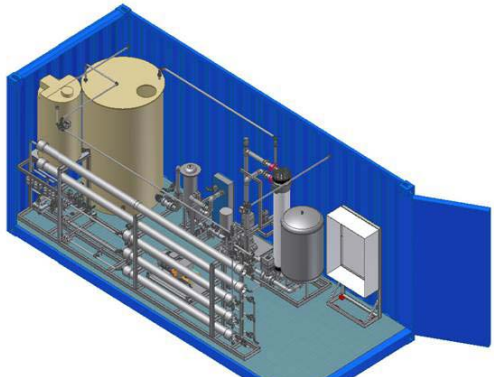
Decentralized Water Purification Systems
Photovoltaic Desalination Systems (PV-RO)

Development of PV-RO systems without batteries and chemical water treatment:

- Capacity: 5 m³/day (for seawater with 28 000 ppm salt content)
- Pilot plant location: Cyprus
- 3 RO modules (RO=Reverse Osmosis)
- Pretreatment: Ultrafiltration
- 34 PV modules, nominal power 7.65 kWp



Decentralized Water Purification Systems
Thermal Membrane Destillation (MD)

- Driven by waste heat from diesel generator
- Capacity: 5m³/day
- Raw water: Seawater with 28 000 ppm salt content
- Operation: 24h/day (no heat storage)

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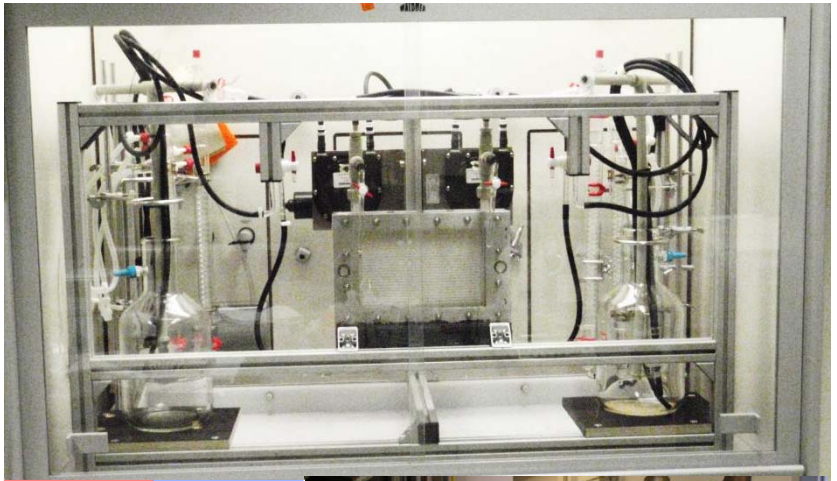
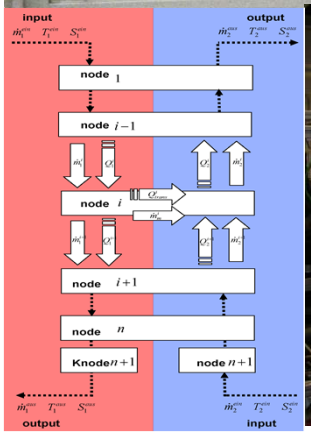
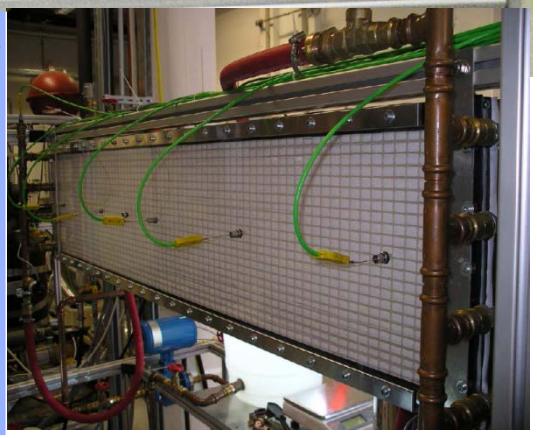
Membrane Destillation
Test Cells for Membrane Characterisation

- Membrane characterisation
  - Heat transfer
  - Mass transport
  - Thermal efficiency
- Model validiation
- Membrane optimization
- Process characterisation
- Application on new substances
  - Sea and brackish water
  - Chloric acid, sodium hydroxide, ammonia, …







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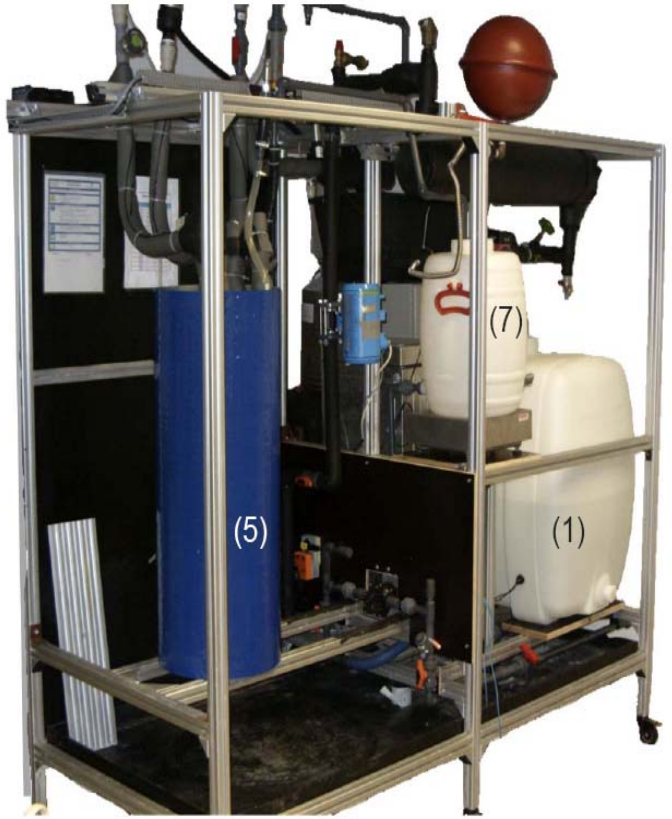
Membran Destillation

Building and Testing of Axially Wound Modules



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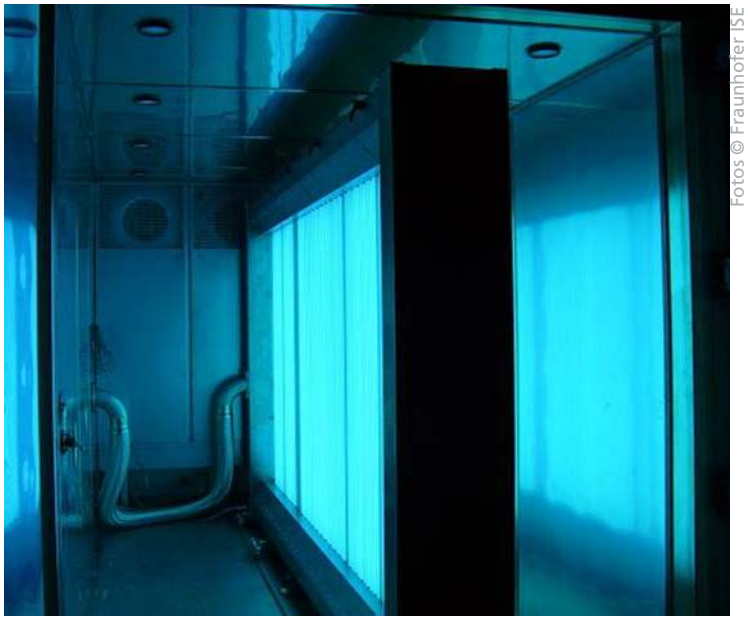
Service Life of Solar Thermal Components

- Research themes
  - Degradation of polymers and other materials
  - Model development for lifetime estimates
  - Development of test procedures for accelerated aging
- Competence
  - Testing facilities
  - Analytics for material investigations
  - Exposure assessment



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Service Life of Solar Thermal Components
Testing of durability and degradation

- Durability testing

  Coated samples are being investigated in accelerated testing with extreme climatic conditions (heat, humidity, UV).

Application

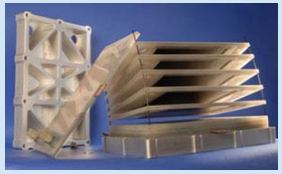
- Inherent in and required for any product development

Storage Technologies

Photos © Fraunhofer ISE

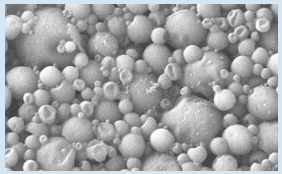
Battery Systems

Storage for Low Temperature Solar Thermal



Redox Flow Batteries

High Temperature Storage



Latent Heat Storage

Membrane Electrolyzers and Hydrogen Storage Systems

Cold Storage

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High Temperature Storage

- Development of new high temperature storage concepts for applications between 200-600°C
- Measurement, characterization and optimization of molten salt storage
- Development of heat exchangers for molten salt storage
- Cost-benefit optimization of high temperature storage concepts
- Modeling and simulation of storage performance

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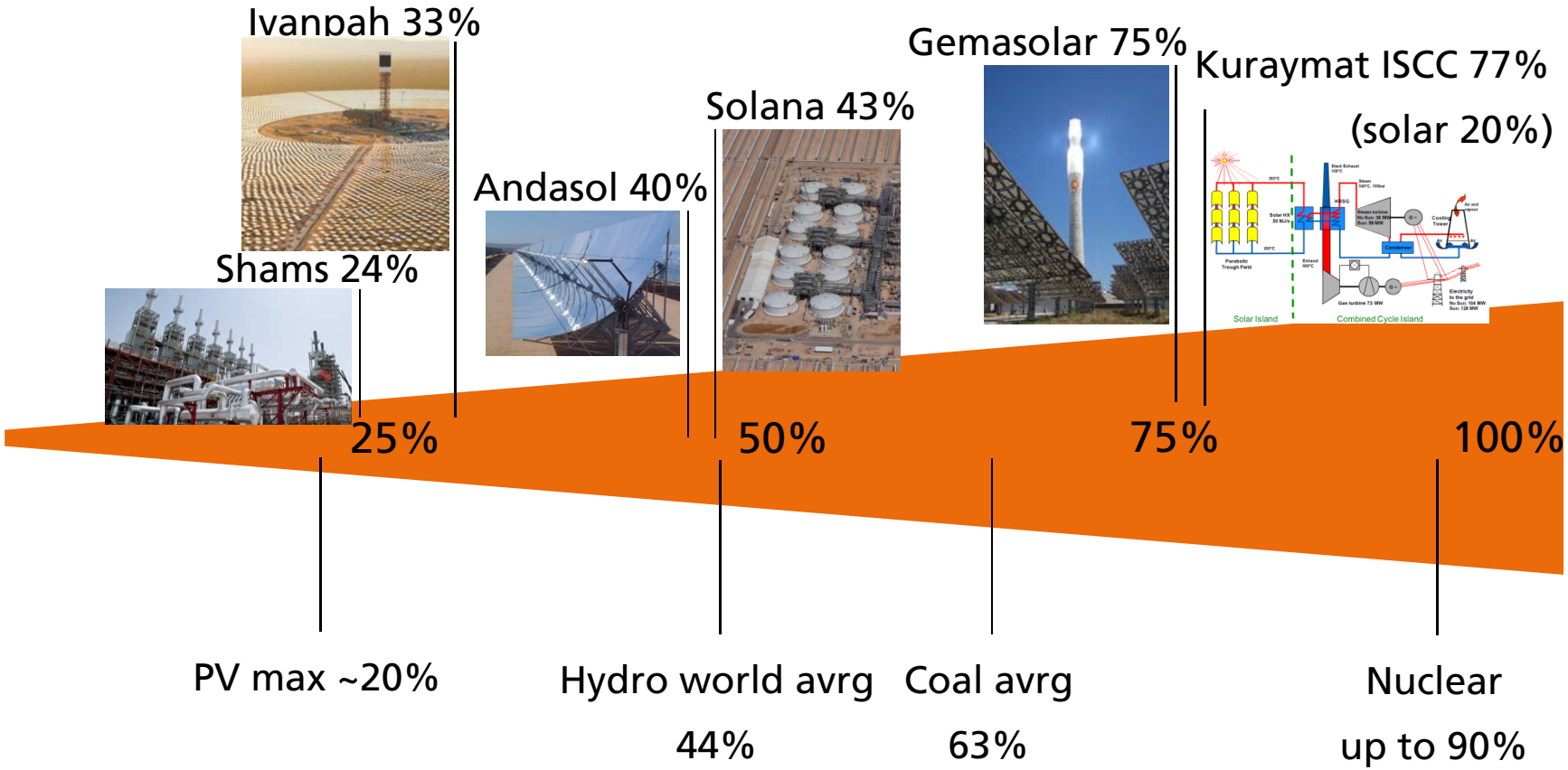
Screw heat exchanger used with phase change materials for latent heat storage

High Temperature Storage

CSP provides wide range of plant types with different CF



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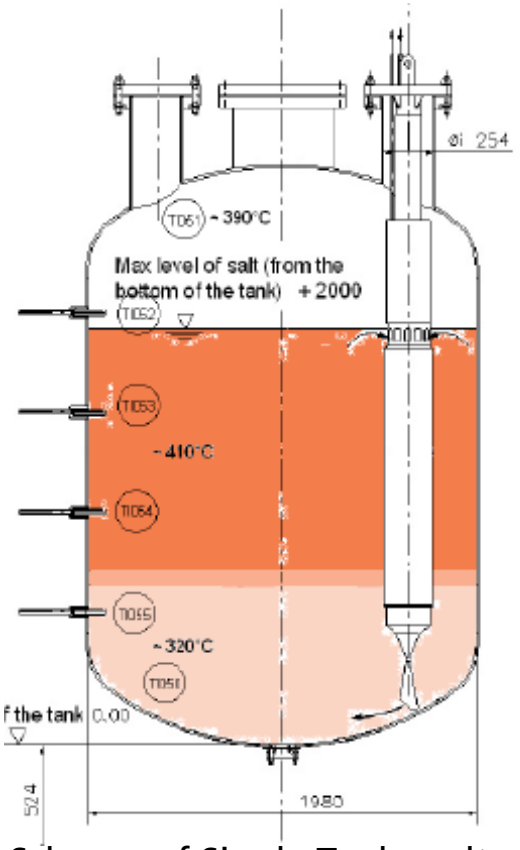
High Temperature Storage
Optimization of Systems and Storage

Development of high-temperature storage, molten salt technology and further development of simulation and optimization tools

- 1 MW Solar thermal power plant using single tank storage and MED desalination in Egypt - MATS (EU FP7)
- Direct steam generator in single tnak molten salt storage - OPTS (EU FP7)
- Latent storage uisng a screw heat exchanger unit - INNOLAT (EIRI)
- Evaluation of storage concepts and innovative storage types - Supergrid (FhG)



Scheme of Single Tank molten salt storage using integrated steam generator

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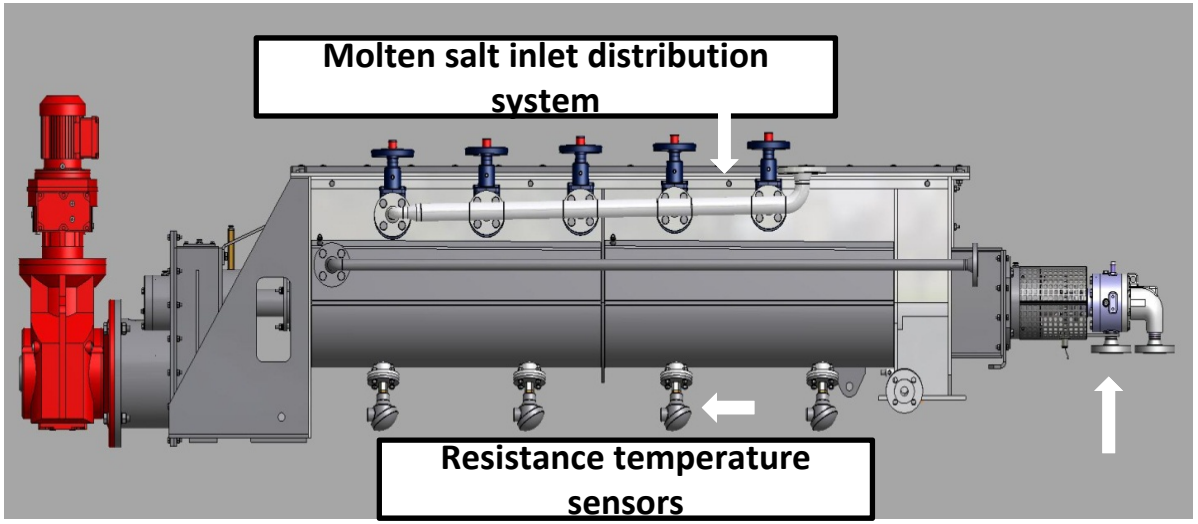
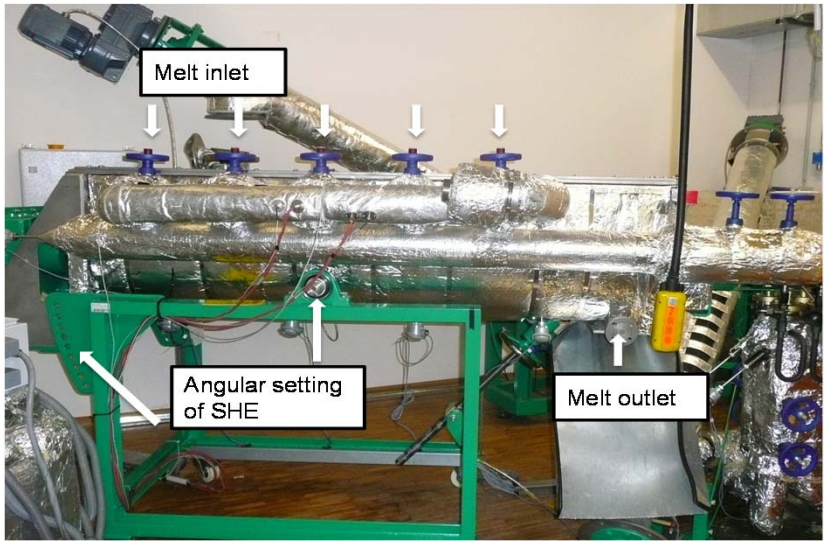
High Temperature Storage
Principle of new PCM storage system

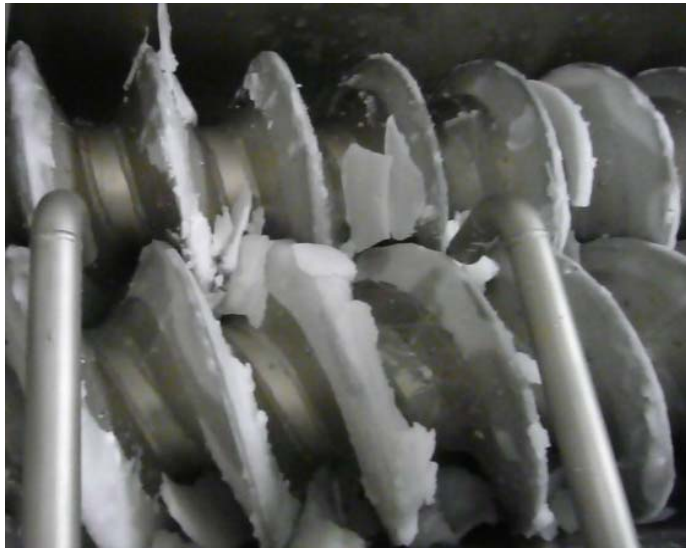
- Solid granular material and molten material are stored in separate tanks
  - Transport of PCM through screw heat exchanger (SHE)
  - Phase change inside SHE
- Size of thermal power and storage capacity are not coupled



Design of lab prototype

High Temperature Storage
Prototype and commissioning





- Inclination for crystallization not necessary
- Crystallization of salt in SHE $\dot{m}$ = 150 kg/h
- Bulk density improved to ρ = 950 kg/m³

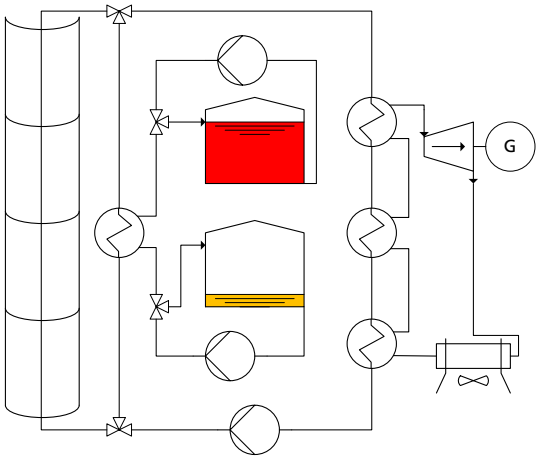
=> Proof of concept has been successful
=> Heat transfer experiments with varying parameters (e.g. mass flow, rotation speed,..

High Temperature Storage

Evaluation of molten salt storages

Two-tank indirect

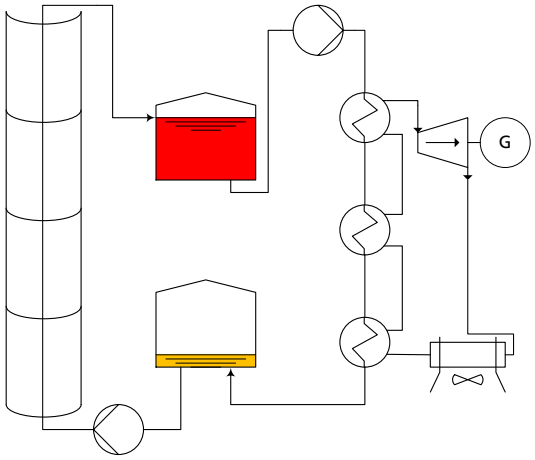
- Temperature (T) loss due two double HX
- T limited by oil
- One tank is empty



- Andasol

Two-tank direct

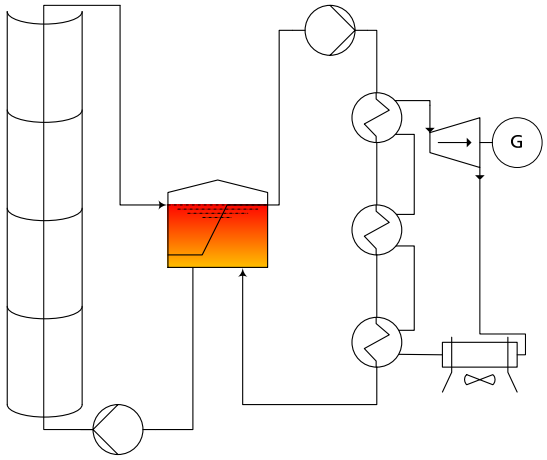
- Molten salt also in collector
- Higher T possible
- Less loss & equipment



- Gemasolar

Single thermocline tank

- One tank less
- Integration of HX
- Use of filler material reduces amount of salt



- Testing / Pilots

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Energy System Analysis

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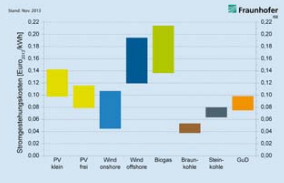

Techno-Economic Assessment of Energy Technologies

National and Regional Energy Supply Concepts

Market Analysis and Business Models

Modeling of Energy Supply Scenarios

Planning and Operating Strategies of Power Plants

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Techno-Economic Assessment of Energy Technologies

- Analysis of technology developments: competitiveness, applications, trends and learning curves
- Studies on lifetime costs and costs of generating electricity and heat (LCOE)
- Evaluation of value chain of renewables
- Photovoltaic production technology through to the business planning
- Technology analysis for investment decisions

Fotos © Rainer Sturm

Market Analysis and Business Models
All Solar Technologies

- Market analysis – players, technologies, applications, competitiveness
- Market role for the different players
- Operating strategy and niche markets for various energy technologies
- Analysis of the technological trends

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Techno-Economical Assessment

Levelized Cost of Electricity (LCOE) for Renewables

- Market analysis of photovoltaics (PV), solar thermal power plants (CSP) and wind turbines
- Economic modeling
  - technology specific
  - for different power plant designs and site conditions
  - based on financing costs and risk mark-up as usual in the market
- Sensitivity analyses of technology and financing parameters
- Prognosis thru 2030

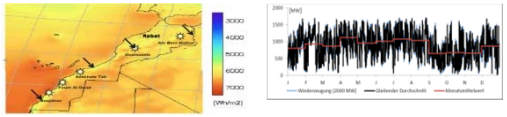
Fotos © Fraunhofer ISE

Quelle: C. Kost, T. Schlegl et al, Fraunhofer ISE, 2013

Optimization Tool for Energy Systems

RESlion – System Integration, Invest & Operation

Wind and Solar Resources



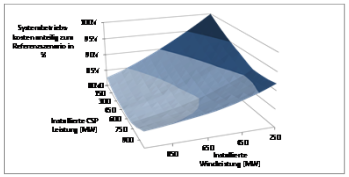
Power Plants
Fuels
Transmission Capacity
Demand Forecast

Technology Model for Renewable Energy

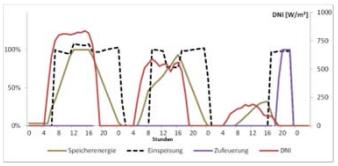
RESlion – Optimization Tool for Planning Investment and Operation

Locations, Demand, Resources

Technology Mix



Operation Strategies



Export Option

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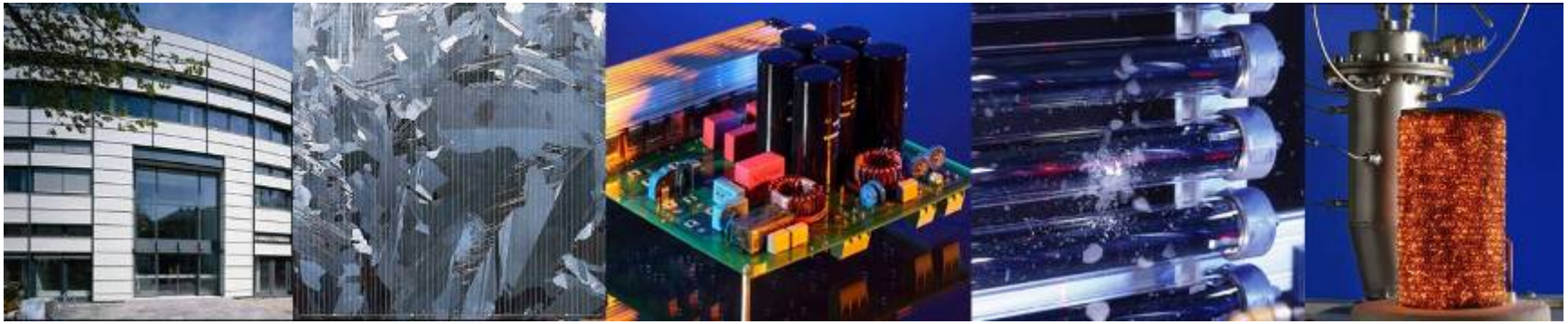
Thank you for listening!



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