enerMENA

Towards a Sustainable Implementation of Solar Thermal Power Plants Technology in the MENA

The Joint German-Jordanian Workshop 2012
Amman February 27th – 29th

Characterization of Advanced Solar Air Receiver Materials

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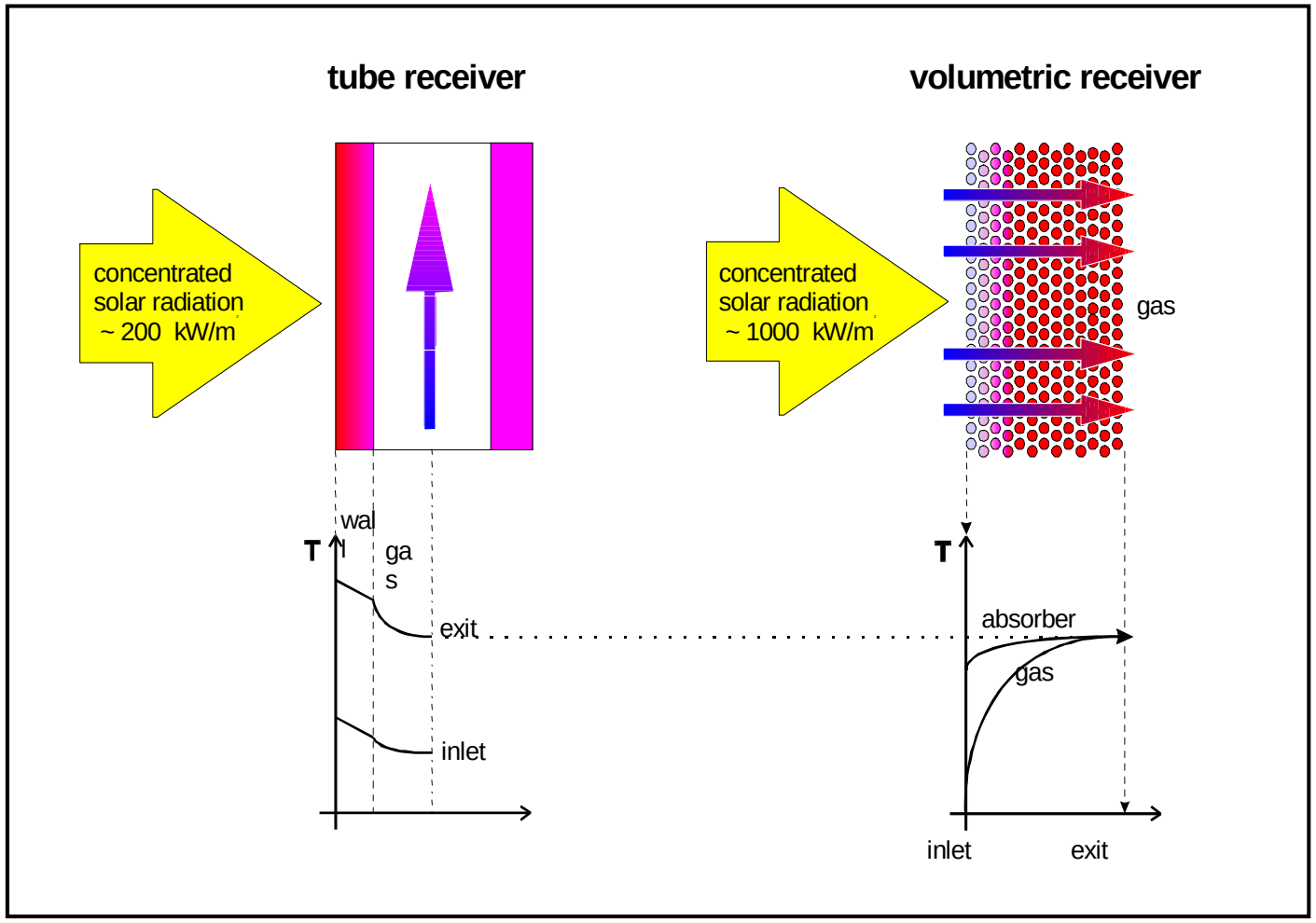
Outline

- Introduction into Volumetric Air Receiver Technology
- Experimental Testing
- Modeling
- Spin-off Applications
- The Solar Tower Jülich

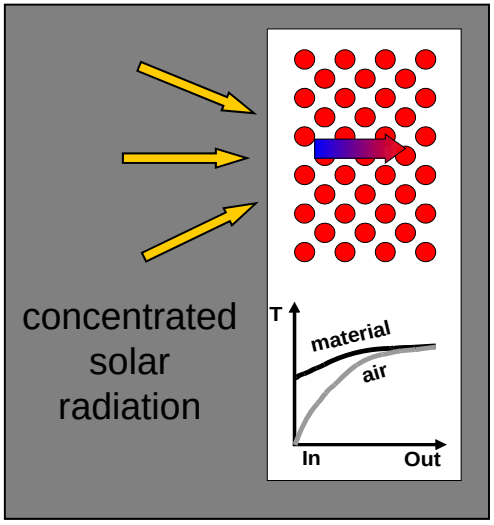
Solar Receiver for Tower Technology: Basic properties

- function: absorption of radiation heat transfer to a fluid
- solar receiver = absorber + heat exchanger
- two basic types
  - tube receiver
  - volumetric receiver

Tube Receiver/Volumetric Receiver



General Requirements of a Volumetric Receiver



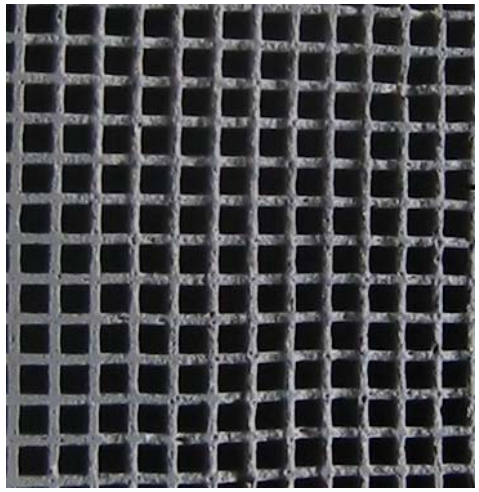
optical - thermophysical requirements

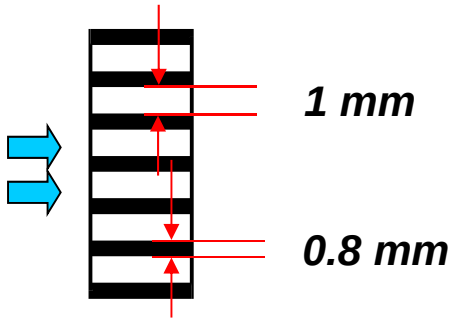
- absorption
- volumetric optical extinction
- heat transfer surface
- high fluxes
- radial heat transport
- char. permeability

material requirements

- dark
- high porosity
- high cell density
- temp. resistance
- thermal conductivity
- 3D-Structure

Volumetric Receiver: Examples





Siliconized Silicon carbide honeycomb structure

(ε>0.9)

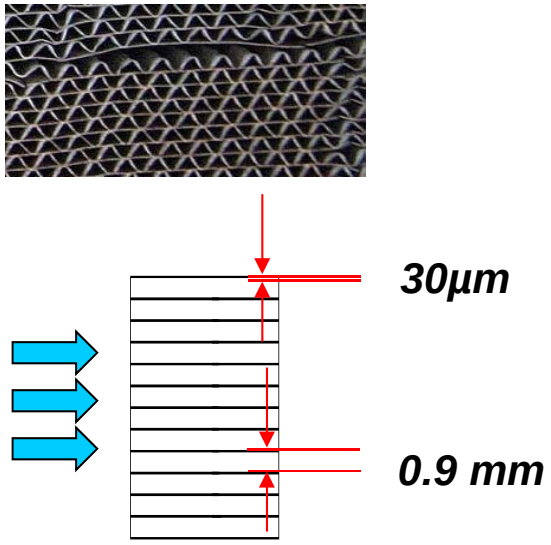
\+ thermal conductivity
(150 W/mK – 30 W/mK)

\+ strength at high temperatures

\- cell density (≈ 1000 m²/m³)

\- porosity (≈ 50%)

Volumetric Receiver: Further Examples

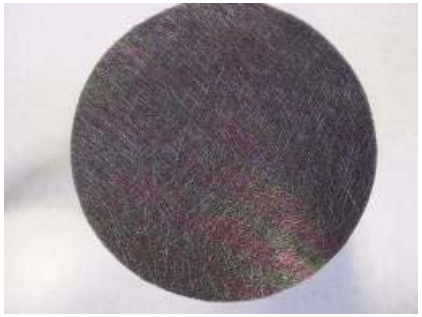


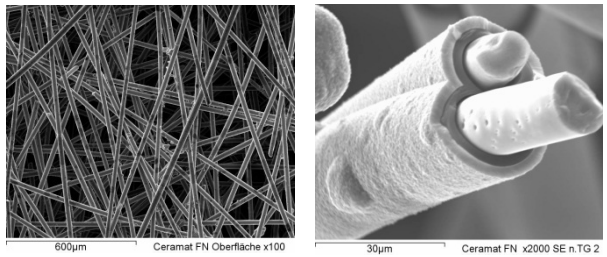
coiled corrugated metal foil
(iron based)

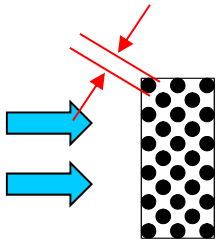
\+ cell density (up to 6000 1/m)

\- limited to 900°C

Volumetric Receiver: Further Examples







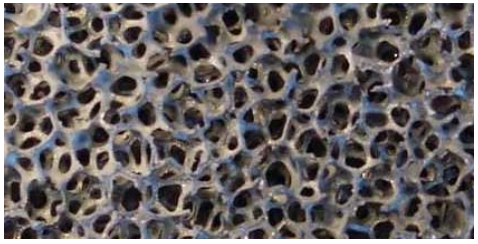
25 µm

SiC fiber mesh (Schott Ceramat)

\+ cell density (>8000 1/m)

\- strength at high temperatures

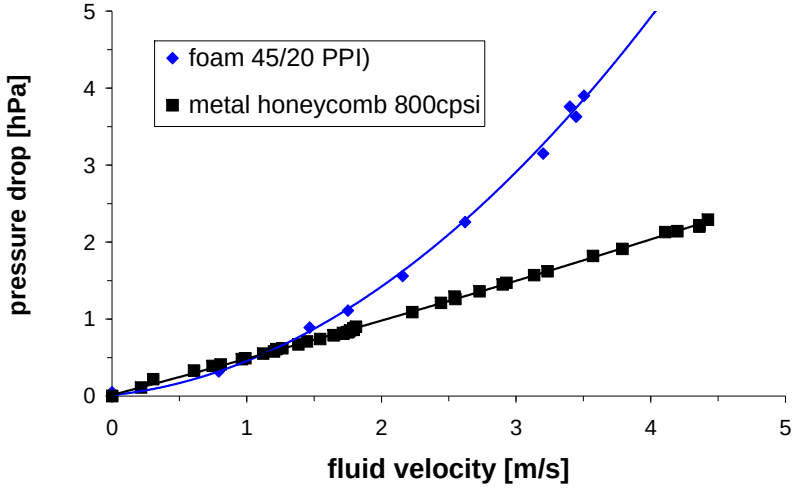
Volumetric Receiver: Further Examples



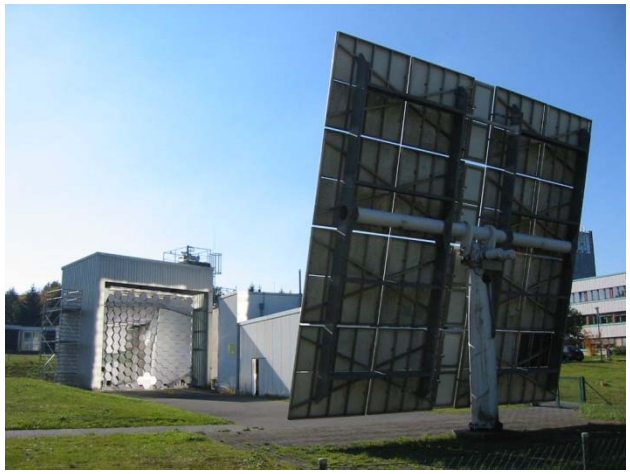
ceramic foams 30-80 ppi
(siliconized Silicon Carbide)

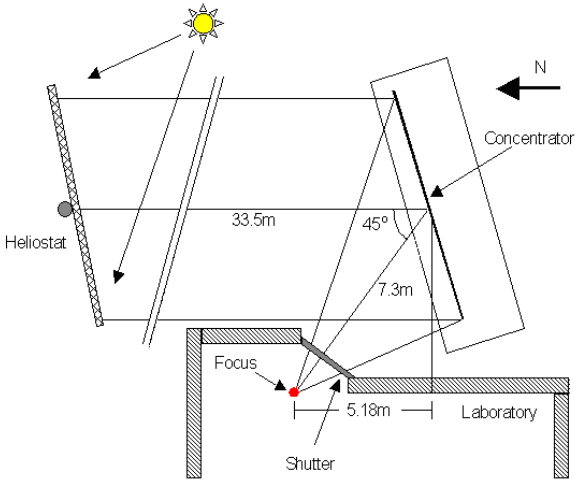
+ cell density (up to 6000 1/m)

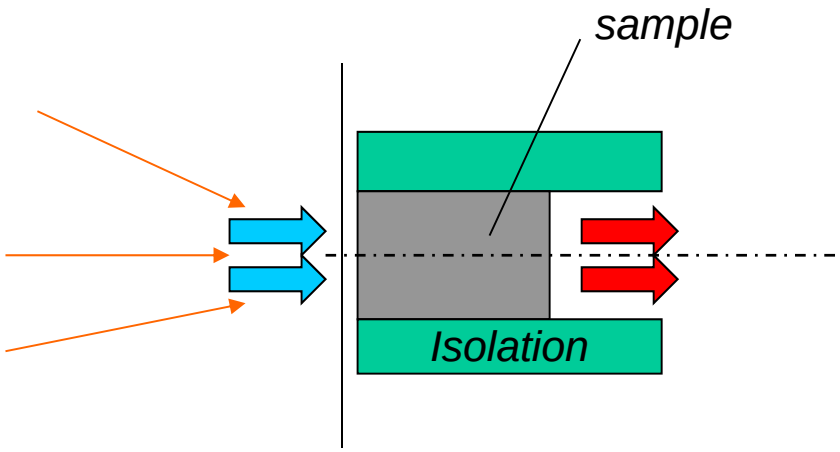
+ permeability characteristics



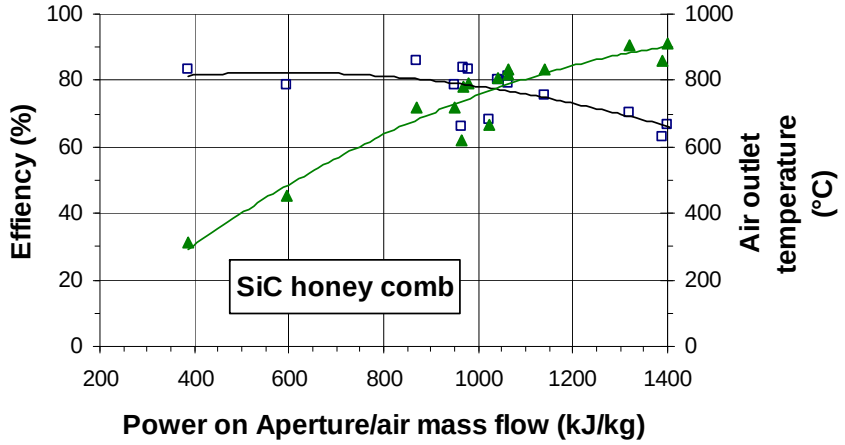
Testing: Thermal Efficiency in the Solar Furnace

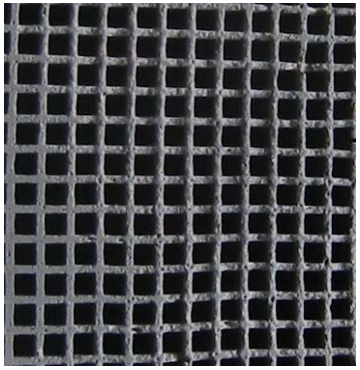


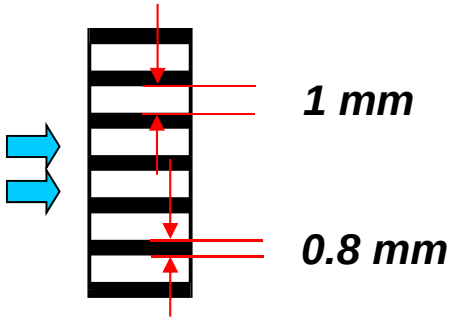


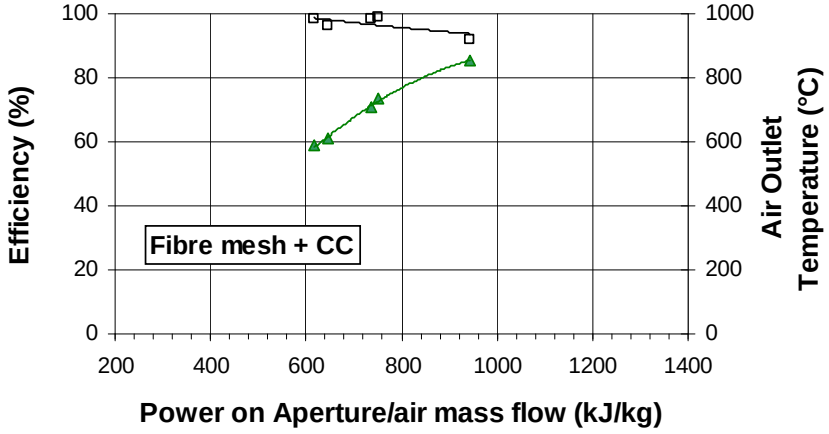


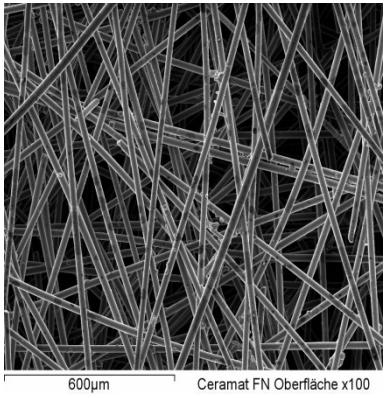
Efficiency Tests: Examples

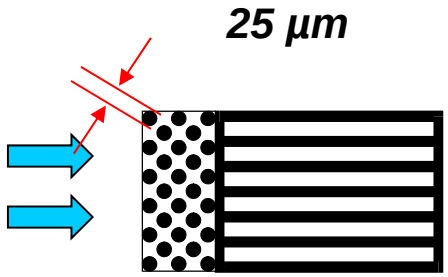




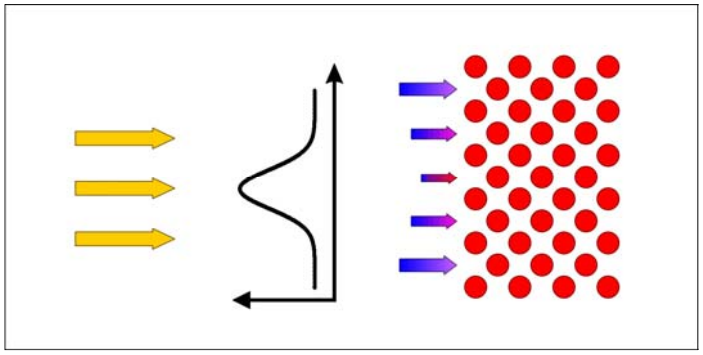








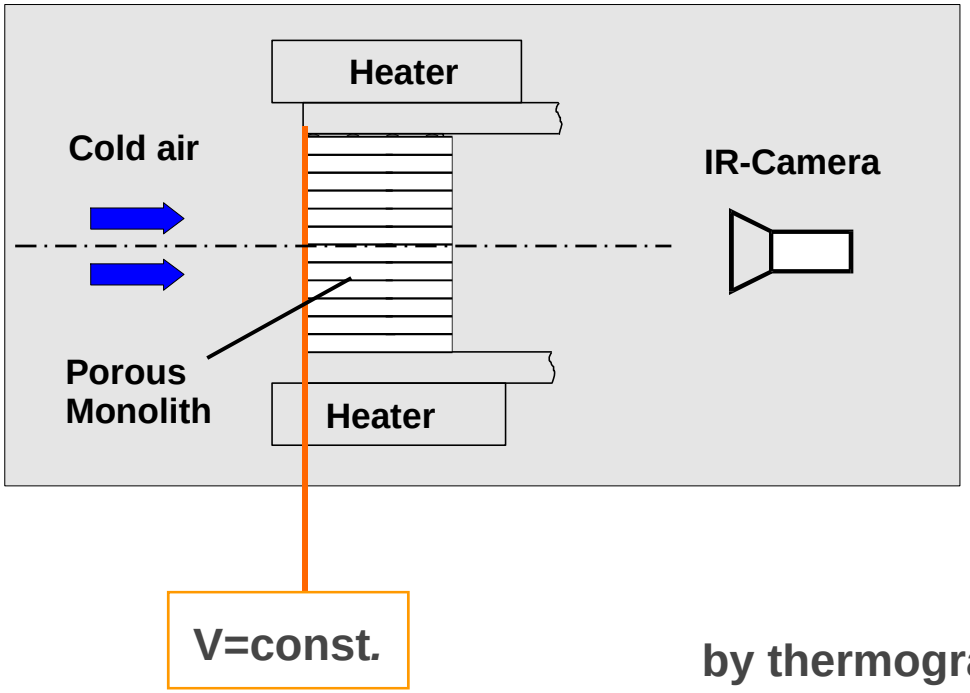
Physical Problems and Constraints

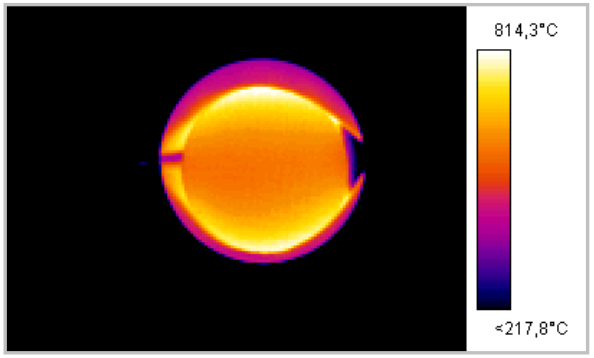


- viscosity increases with increasing temperature
- hot zones are badly cooled

- local hot spots
- → instable flow at
  - high temperatures
  - linear pressure drop characteristics
  - low thermal conductivity

How can instable flow be visualized?

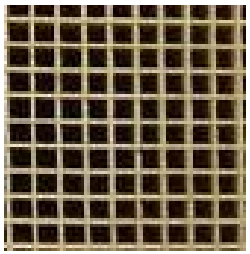


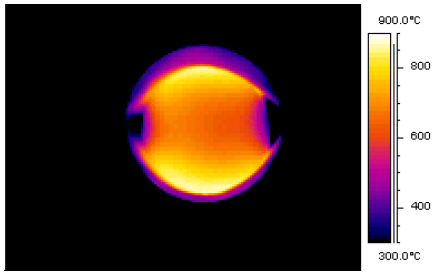


by thermograph monitoring of

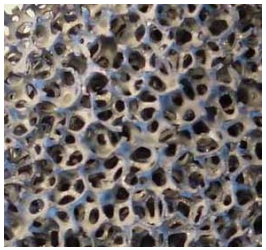
the cooling of a heated porous monolith

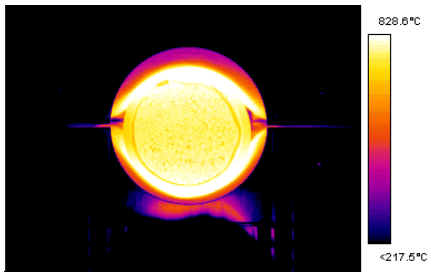
cordierite honey comb



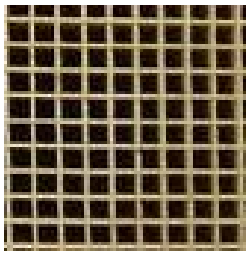


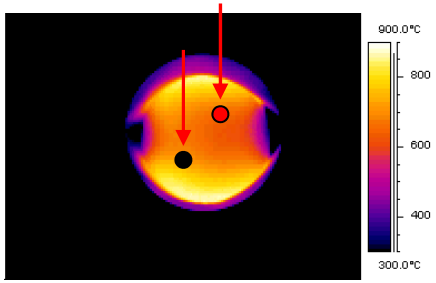
SiC foam

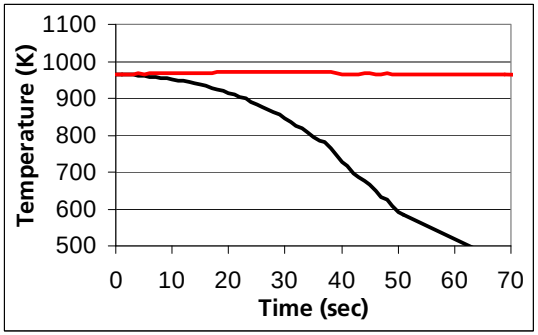




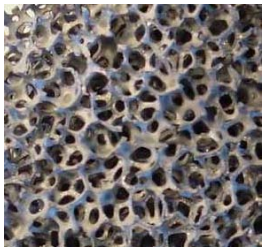
cordierite honey comb

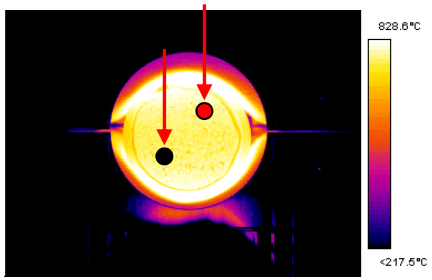


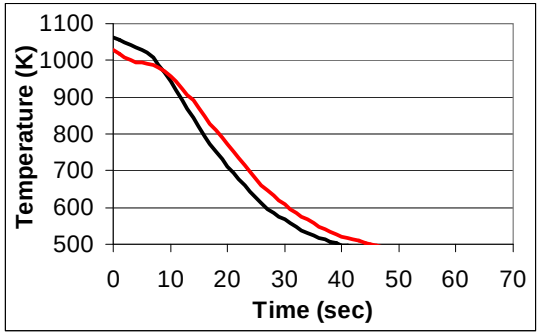


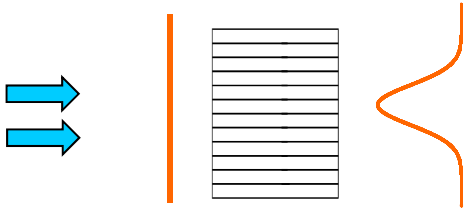


SiC foam







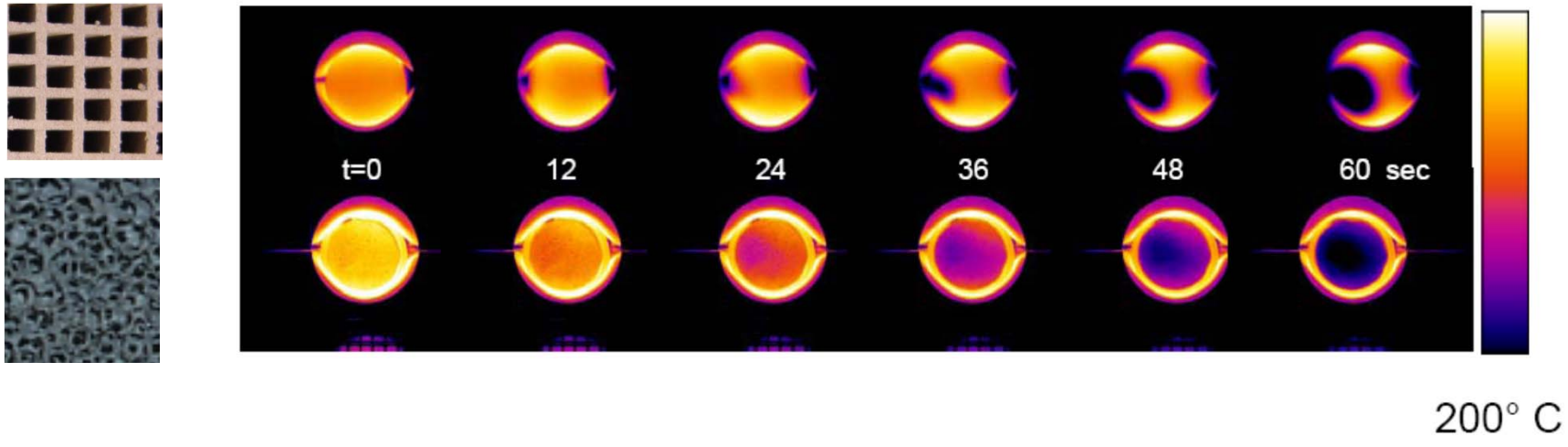


v = const.

v = 0
in hot
channels

geometry/pressure loss
characteristics influences
flow stability

heat conductivity influences
flow stability


800° C
t=0
12
24
36
48
60 sec
200° C

Modeling: which basic mechanisms are involved

k: permeability
λ: effectice heat conductivity
αAv: vol. heat transfer coeff.
a: absorption
e: extinction

- heat conduction in the solid grid
- solid to fluid heat transfer
- fluid flow through the network of open porosity

$$\lambda_{eff} \nabla^2 T_S = 0$$

heat conduction law

$$\lambda_{eff} \nabla^2 T_S - \alpha A_v (T_S - T_F) = 0$$

$$\dot{m} C_P \frac{dT_F}{dx} + \alpha A_v (T_S - T_F) = 0$$

energy conservation

- quantities to be determined experimentally
- effective quantities/homogeneous material

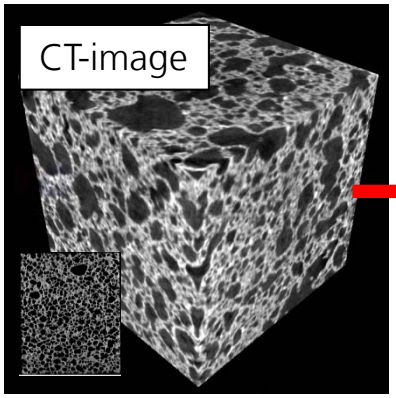
$$\frac{\Delta p}{l} = \frac{\eta_{DYN}}{K_1} v - \frac{\rho}{K_2} v^2$$

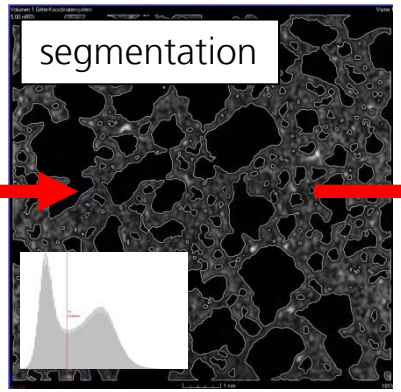
extended Darcy Law

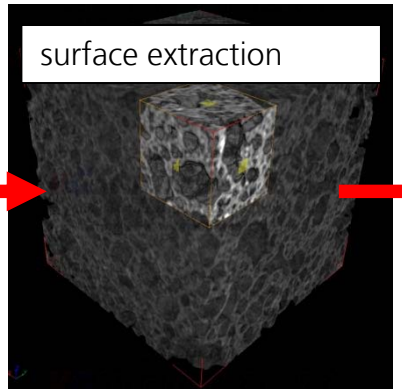
Determination of Material Properties

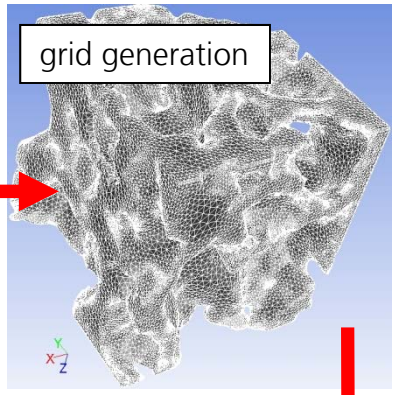
- **permeability**
  - simple pressure loss measurement
- **extinction**
  - modeling the absorber material
  - optical measurements
- **absorption**
  - UV-VIS-NIR Spectrometer
- **effective thermal conductivity**
  - Transient Plane Source technique
- **volumetric convective heat transfer**
  - transient flow technique after Younis/Viskanta

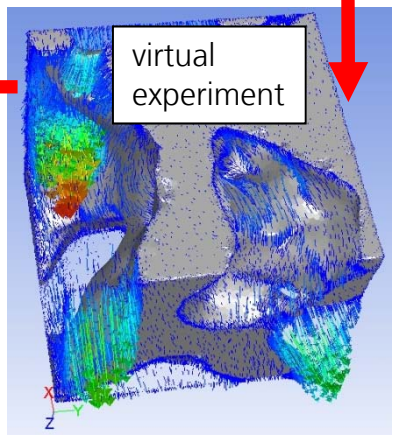
Multiscale Approach to Determine effective Properties from Computer-Tomography (CT)

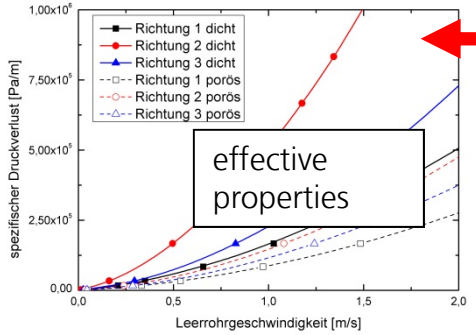




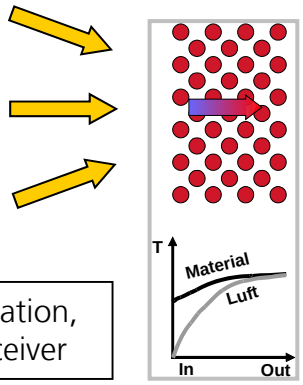






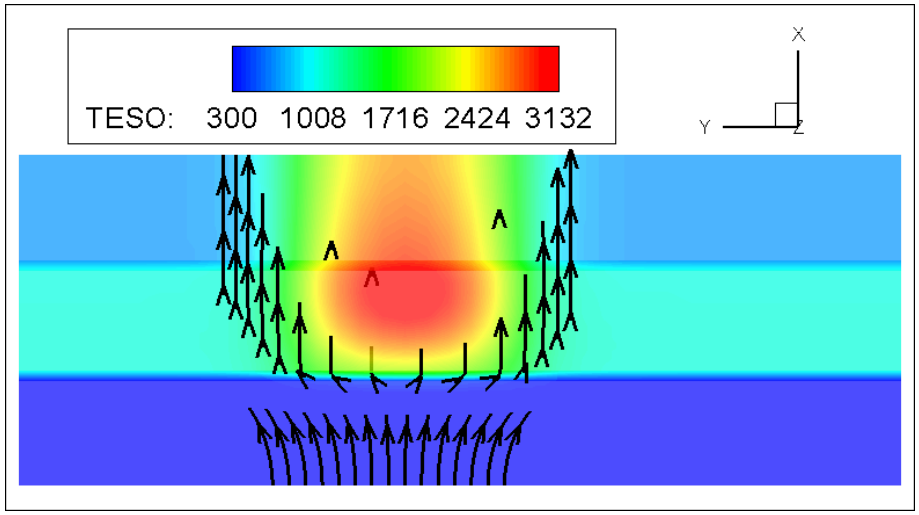


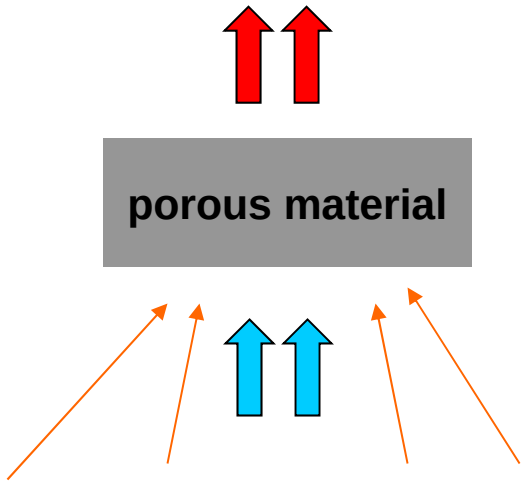
component design: continuum-model



application, air receiver

Results of a Numerical Approach





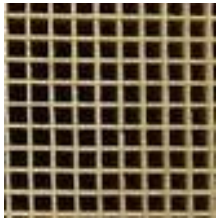
air out

air in

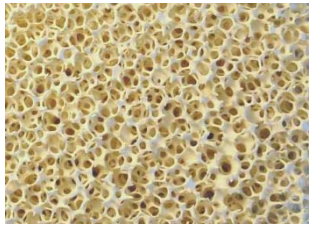
(Results by LSTM/Uni Erlangen within SOLPOR)

Results: When do Hot Spots May Occur?

- temperature distribution at cross section 2mm behind inlet (I = 1 MW/m²)



pressure drop characteristics b/a [10^{-6}m]

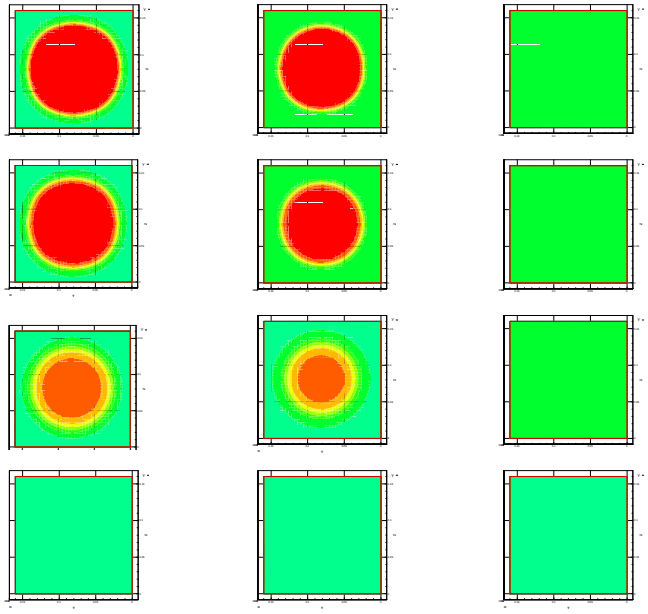


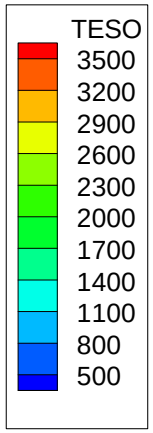
b/a = 0 *b/a = 1* *b/a =10*

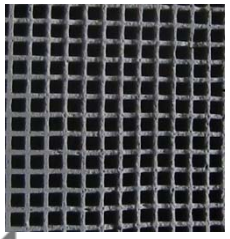
λ=0.01

heat conductivity λ [W/mK]

λ=10



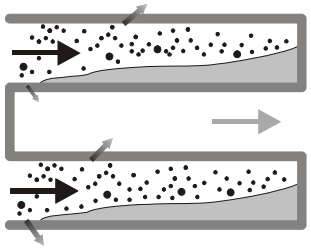


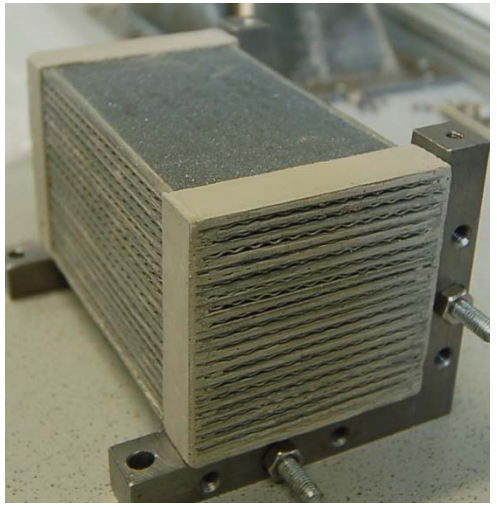


(Results by LSTM/Uni Erlangen within SOLPOR)

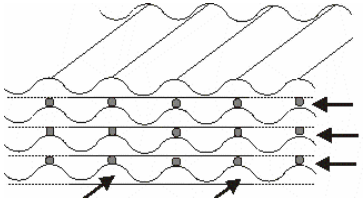
Spin-off Applications

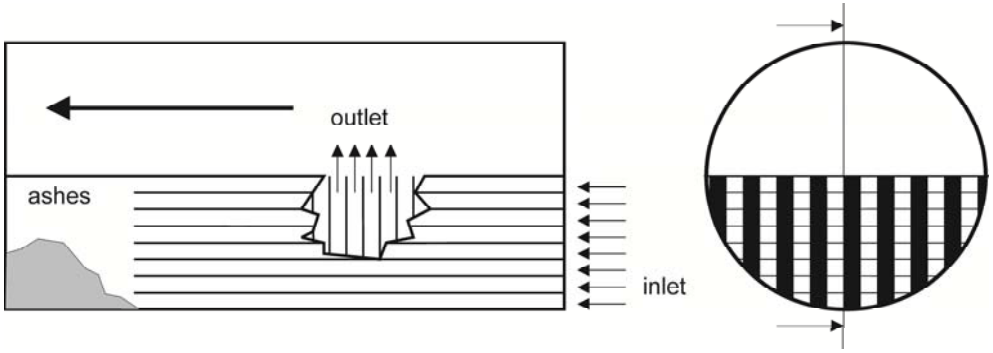
- cross flow particle filter





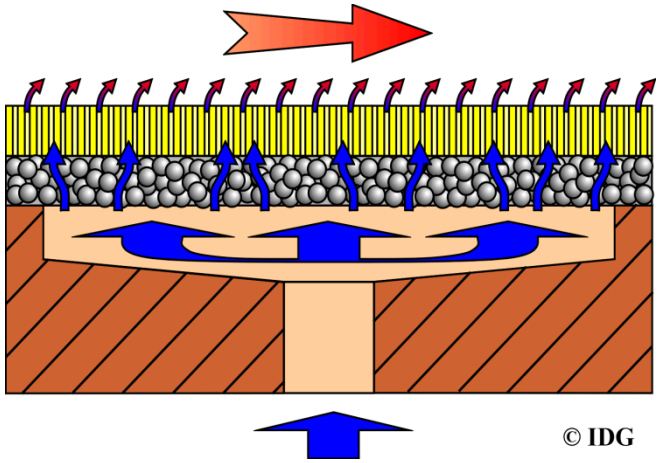
state-of-the-art

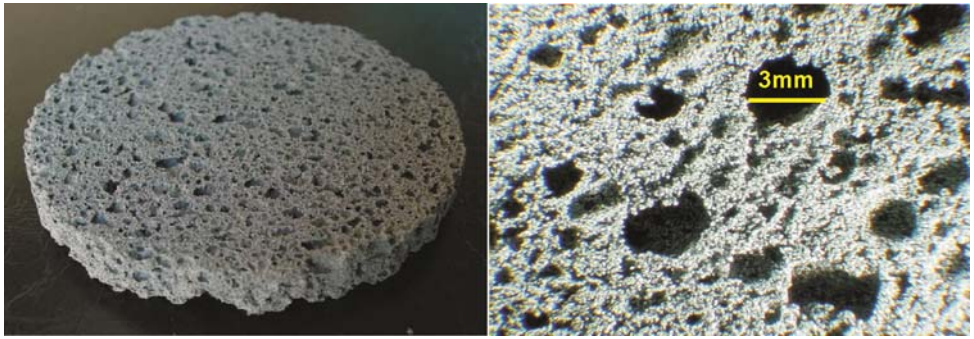




Metal foam as porous combustion chamber wall element: effusion cooling

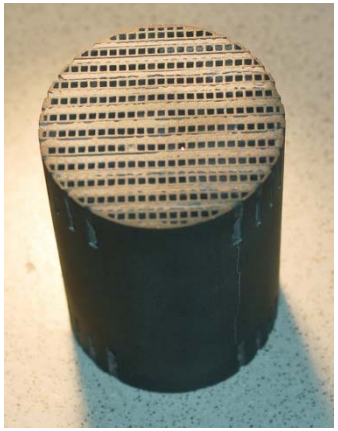
- characterization of flow and heat transfer





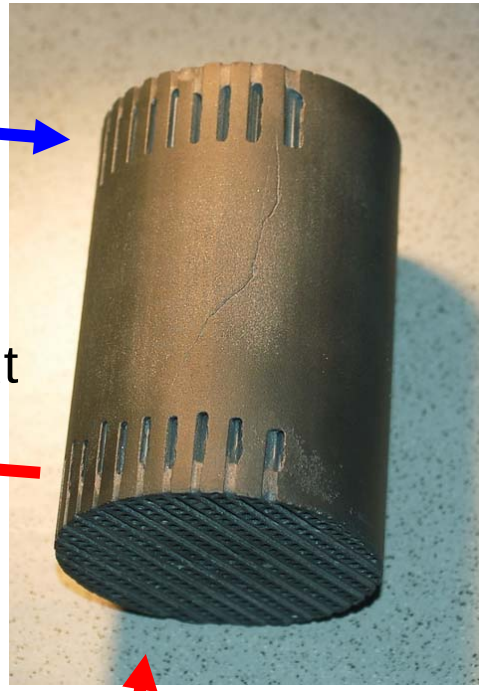
- SFRS-technology by University of Aachen, Institute of Ferrous Metalurgy

Cross-flow/Counterflow Heat-exchanger



cold gas I out

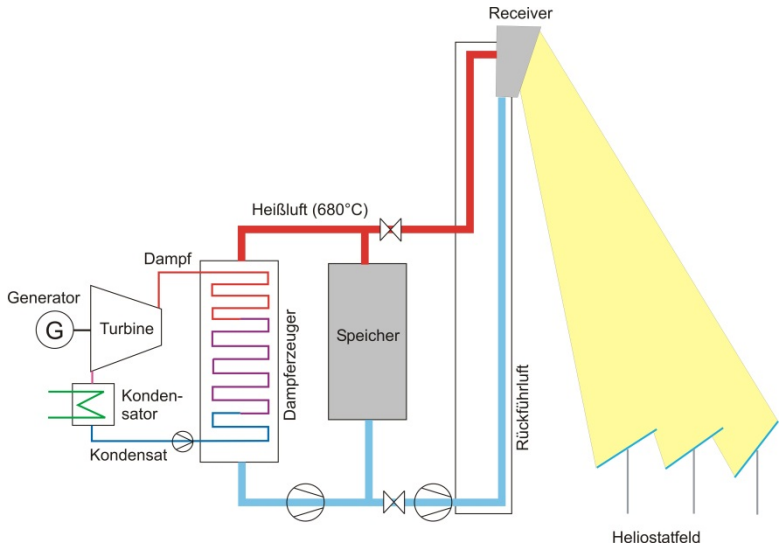
cold gas II in

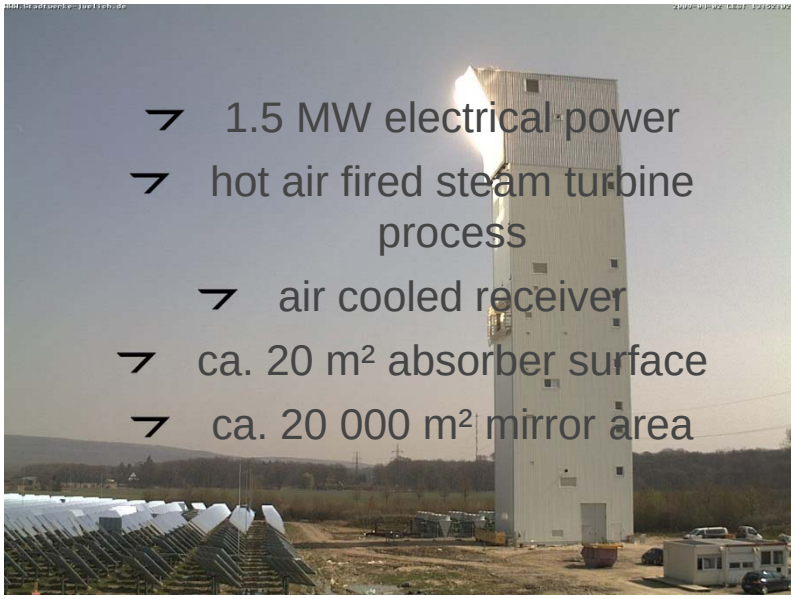


hot gas II out

hot gas I in

Solar Tower Jülich





- 1.5 MW electrical power
- hot air fired steam turbine process
- air cooled receiver
- ca. 20 m² absorber surface
- ca. 20 000 m² mirror area

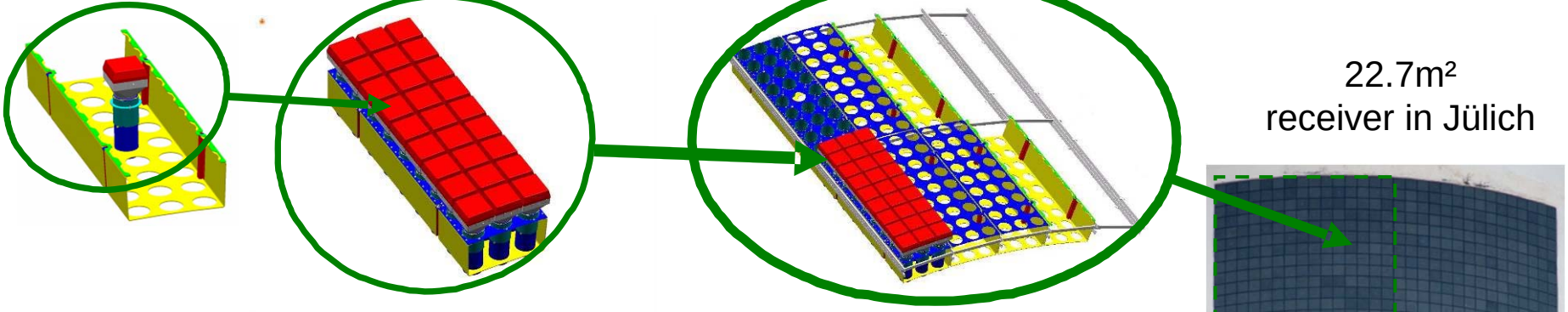
HITREC technology: modular concept

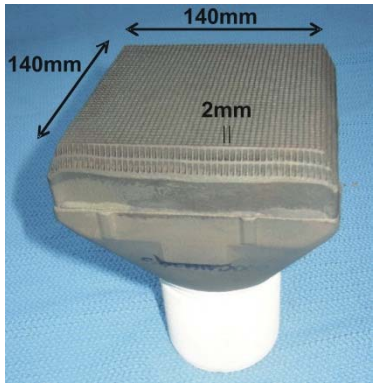
0.02 m²
absorber

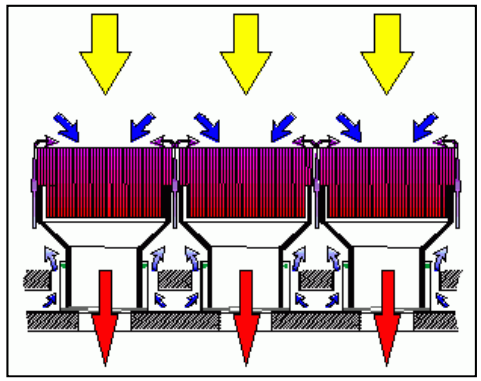
0.57 m²
submodule

5.7 m²
solair receiver testet within SOLAIR

22.7m²
receiver in Jülich







*http://*www.solarturm-juelich.de/de