International Symposium on High Temperature Solar Materials

Porous Materials For High-Temperature Solar Absorbers

Sandro Gianella

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  - Point focussing systems
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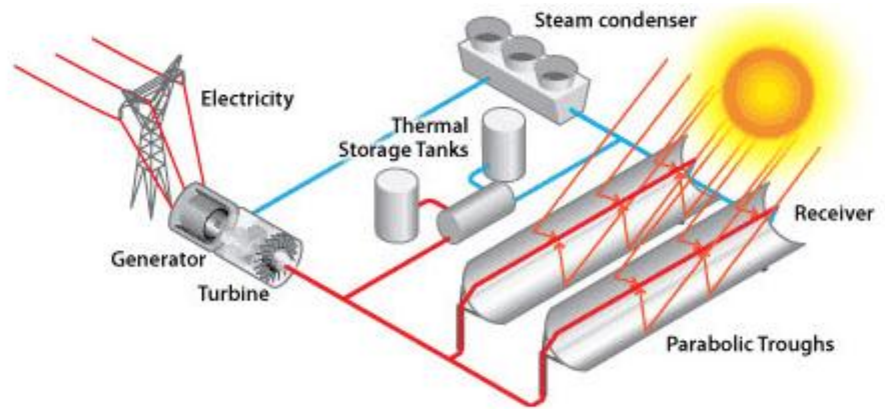
Citation

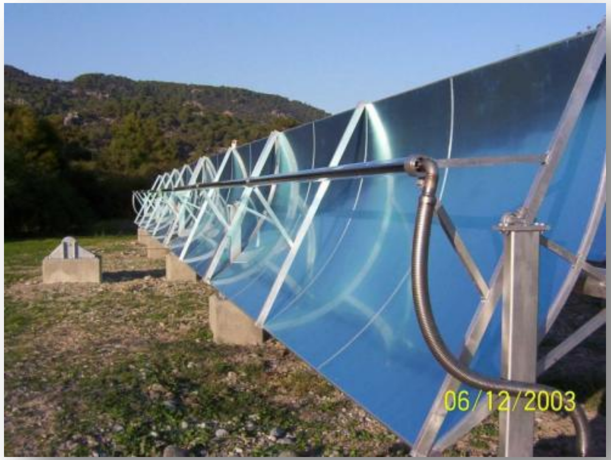
"Using only 0.1% of the earth's land space with solar collectors that operate with a collection efficiency of merely 20%, one could gather more than enough energy to supply the current yearly energy needs of all inhabitants of the planet (~1.2 x 10^{14} kWh)."

A. Steinfeld, A. Meier, Solar Fuels and Materials, Encyclopedia of Energy, Volume 5, 2004, Elsevier

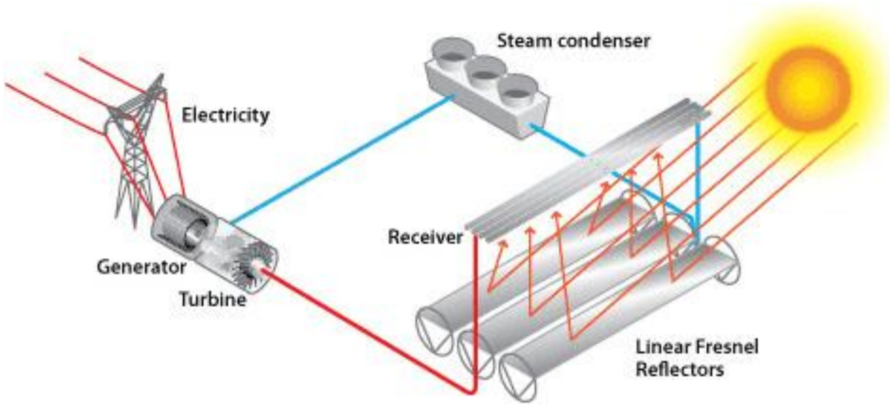
CSP Technologies

Parabolic through

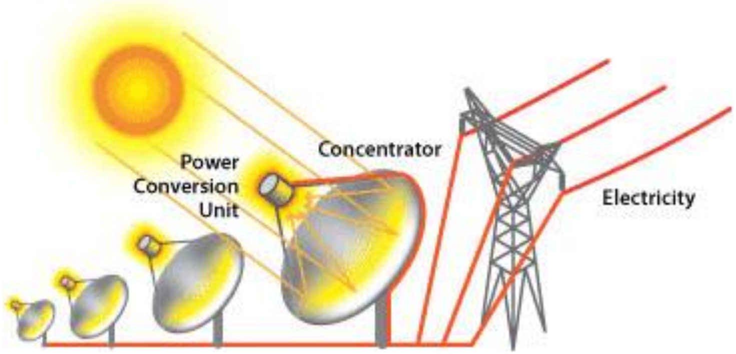




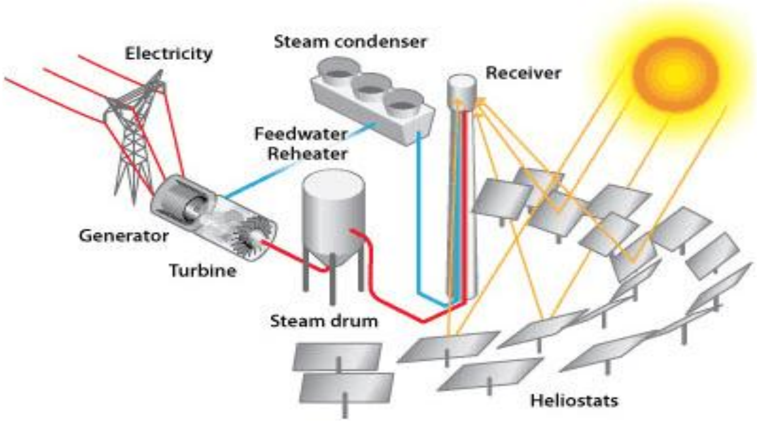
Linear Fresnel



Dish



Solar tower



CSP Technologies

Comparison




	Parabolic Trough	Solar Tower	Linear Fresnel	Dish-Stirling
Typical capacity (ME)	10-300	10-200	10-200	0.01-0.025
Maturity of technology	Commercially proven	Pilot commercial plants	Pilot projects	Demonstration projects
Operating temperature (°C)	350-550	250-565	390	550-750
Plant peak efficiency (%)	14-20	23-35	18	30
Annual solar-to-electricity efficiency (net, %)	11-16	7-20	13	12-25
Collector concentration	70-80 suns	> 1000 suns	> 60 suns	> 1300 suns
Receiver/Absorber	Absorbers attached to collectors	External surface or cavity receiver	Fixed absorber	Absorber attached to collector

Source: IRENA Report, Concentrating Solar Power, Volume 1, Issue 2/5, June 2012

CSP Technologies

Electricity production

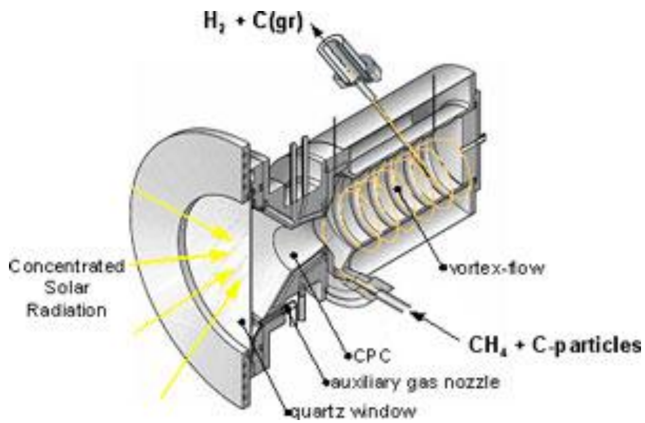
Puerto Errado 2, Fresnel CSP Power Station
30 MW , Novatec Solar

Parabolic-trough power plant, California's Mojave Desert.

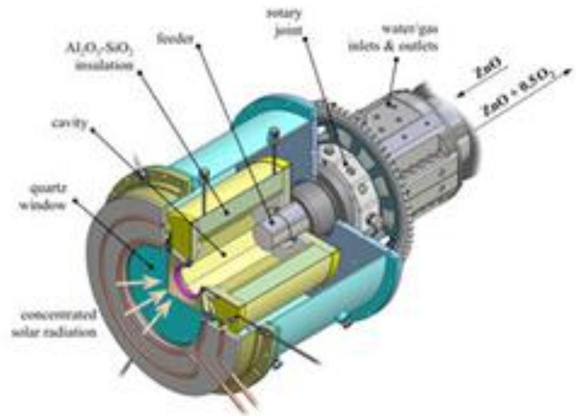
Maricopa Dish Stirling Plant, Peoria, Arizona, 1.5 MW

PS10 and PS 20 solar towers, Sevilla, Spain

Energy carriers production



SOLHYCARB reactor, Methane splitting, ETH Zürich

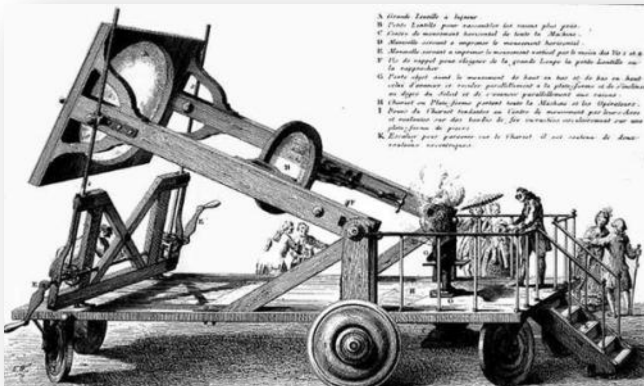


ZnO reactor, Water splitting, ETH Zürich

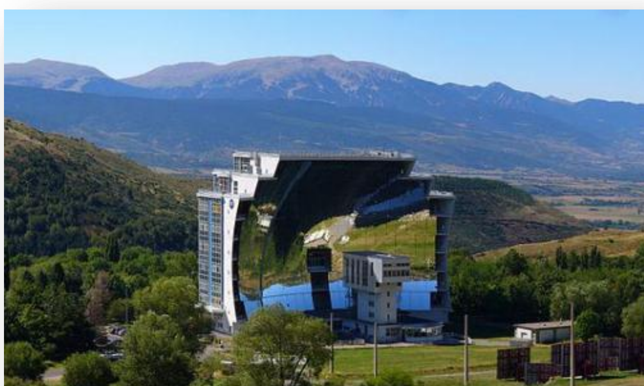
Component tests for SOLHYCARB, PSI

100-kW scale up reactor, ETH Zürich

Process Heat



Lavoisier solar furnace, Paris 1772



Solar furnace of Odeillo, Pyrénées-Orientales, France

Solar Process Heat (SO-PRO)

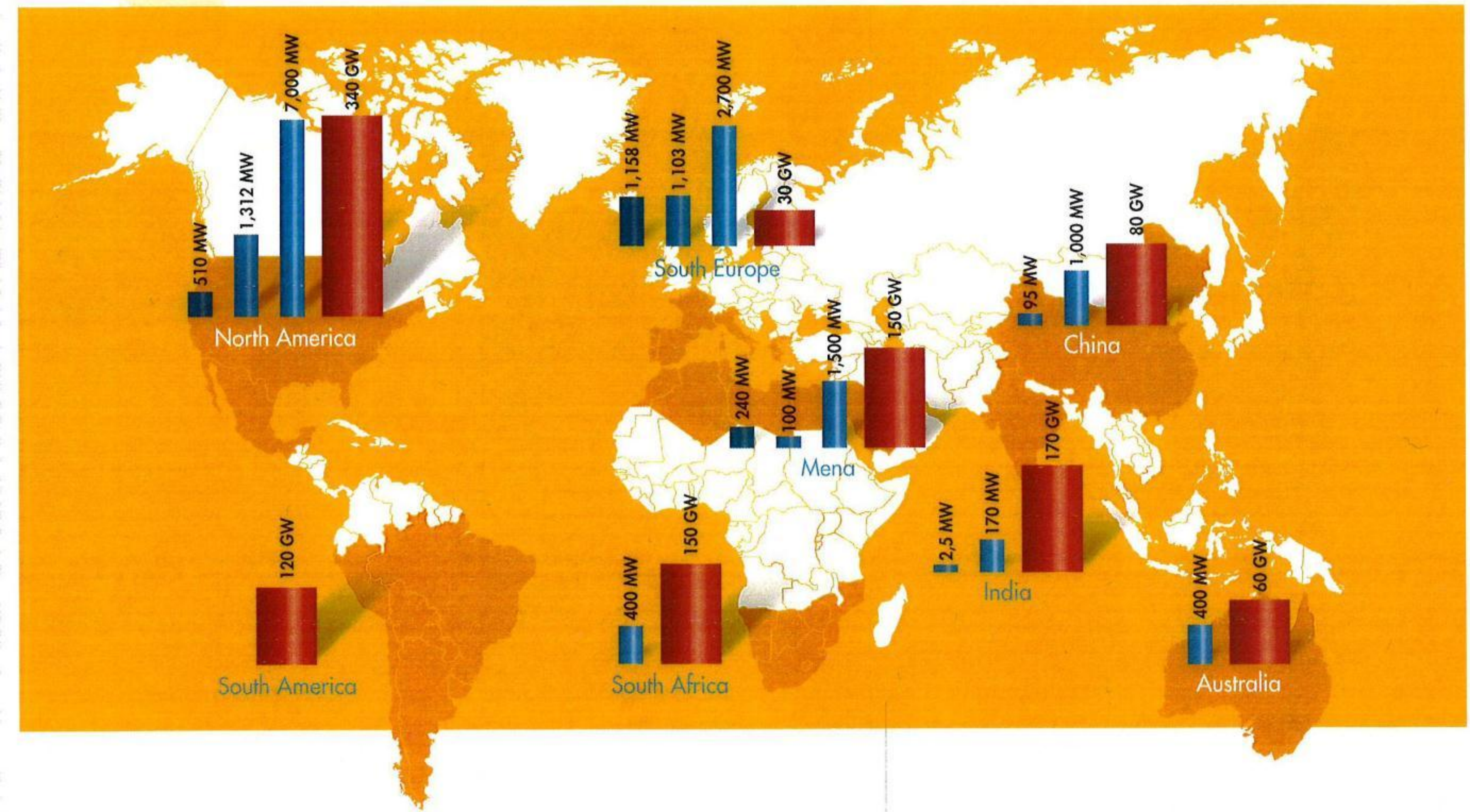
Facts

- Activity re-started after more than 15 years
- By the end of March 2012: 1.9 GW installed CSP capacity
- Leading markets: USA and Spain (90% of current installed CSP capacity)

- Currently dozens of CSP plants in construction
- 20 GW under development worldwide

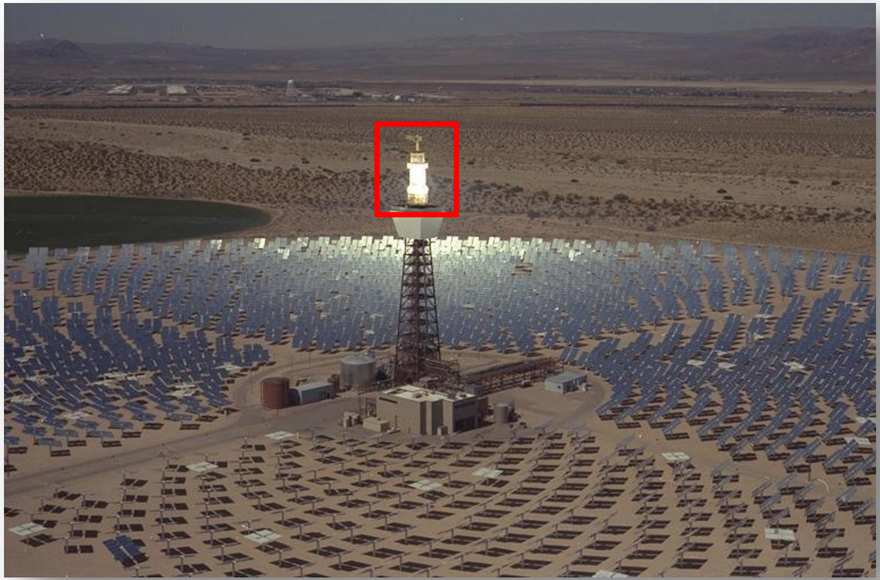
- Capacity distribution:
  - 1.8 GW parabolic through (94%)
  - 70 MW solar tower
  - 31 MW Fresnel reflector

Source: *Photon International, 2009, NREL, 2012, and AEIST, 2012*

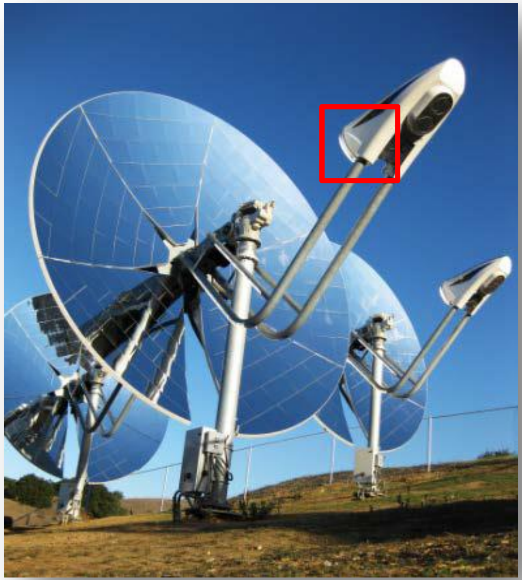


Source: European Solar Thermal Electricity Association (ESTELA), The First Five Years Of ESTELA Report, 2011

High Temperature Absorbers

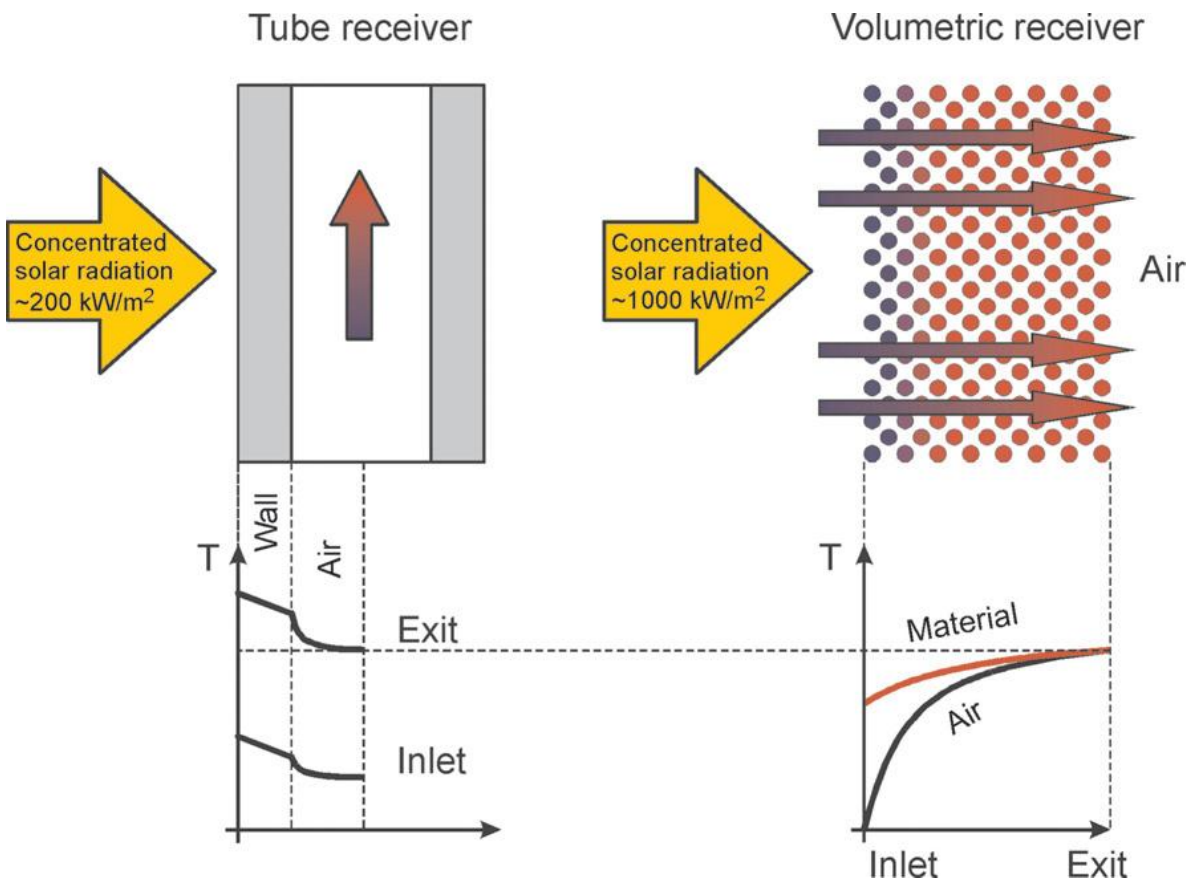


Solar tower, molten salt



Parabolic Dish, stirling engine

High Temperature Absorbers

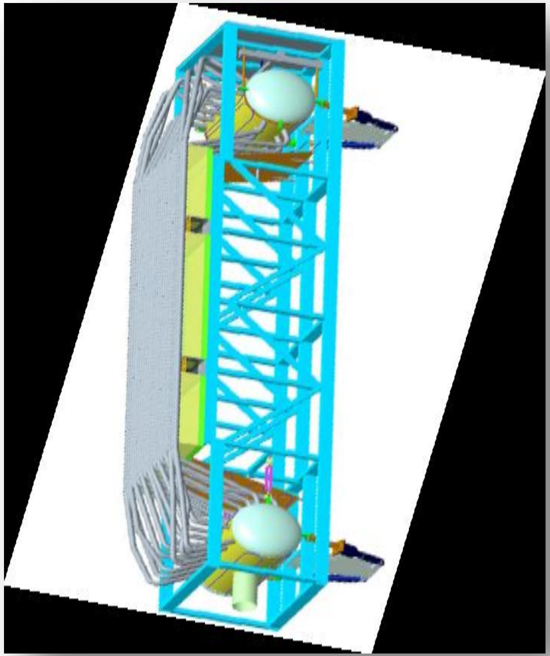


Tube receiver and volumetric receiver concept.

Source: T. Fend, High porosity materials as volumetric receivers for solar energetics, *Optica Applicata, Vol. XL, No. 2, 2010*

Solar tower tube receiver

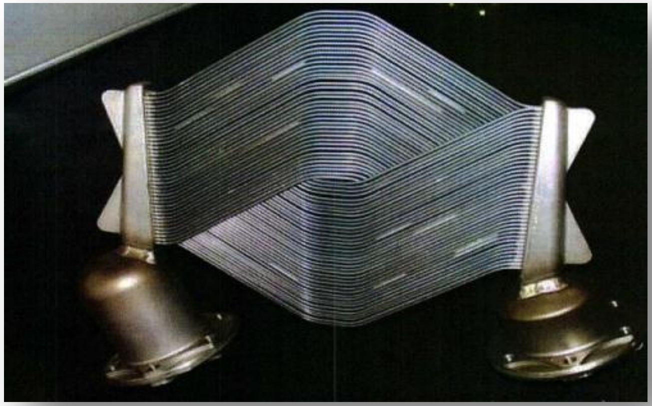
- Metallic tubes (special alloy)
- Steam or molten salt carrier
- Max. 650°C (flow temperature)
- Tube outside temperature < 900°C
- Corrosion and deterioration
- Special coatings



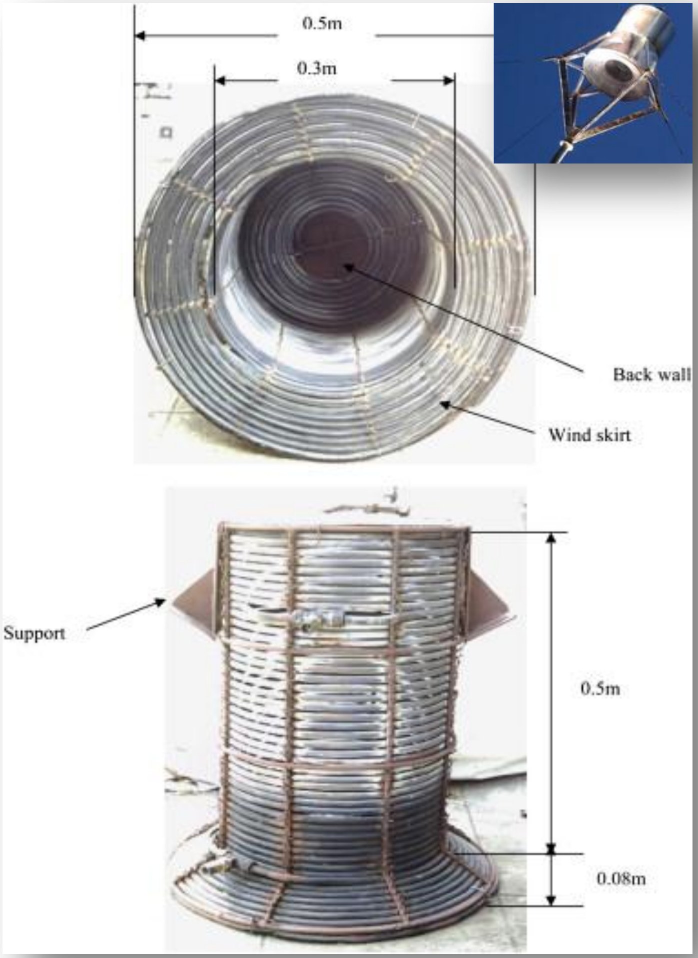
Solar Two in Daggett, California, 10-MW solar thermal electric power plant

Parabolic dish tube receiver

SES SunCatcher solar receiver

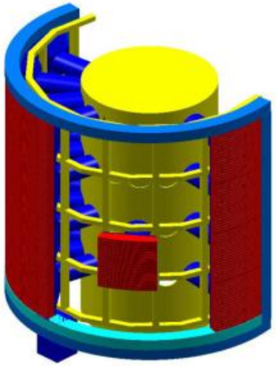


Eurodish receiver material, Solo Stirling GmbH

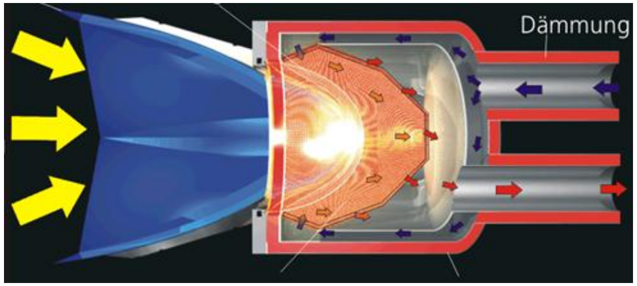


Metallic tube receiver for parabolic dish.

Solar tower volumetric receiver

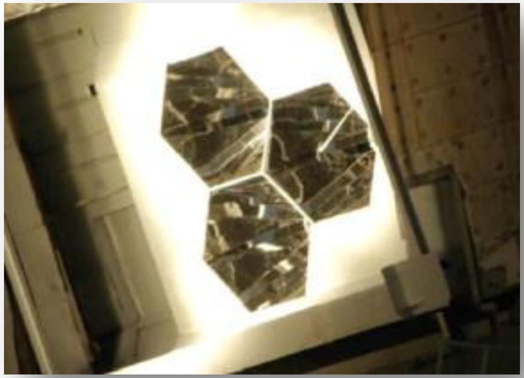


Open volumetric receiver HiTRec, DLR



Closed (pressurized) volumetric receiver REFOS, DLR and CIEMAT, Spain

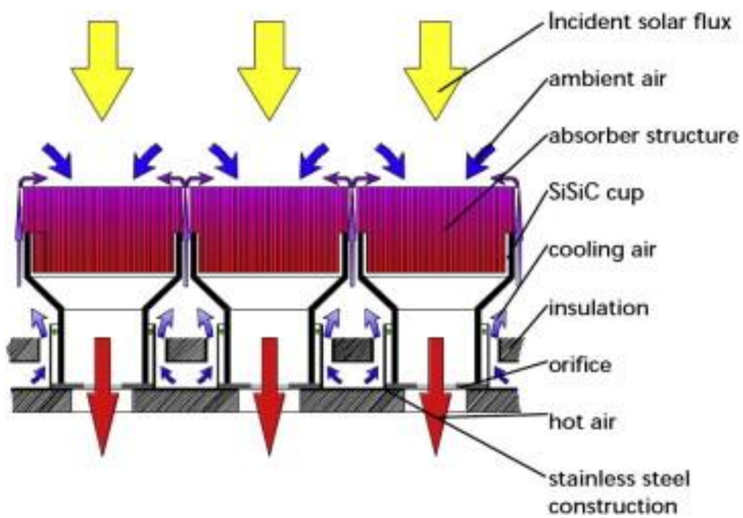
Implementation, KAM, Jülich



Implementation, Plataforma Solar de Almeria, Spain

Open volumetric receiver material

- Si-SiC honeycomb
- Up to 1000ºC air temperature achieved
- 80% efficiency from solar to air

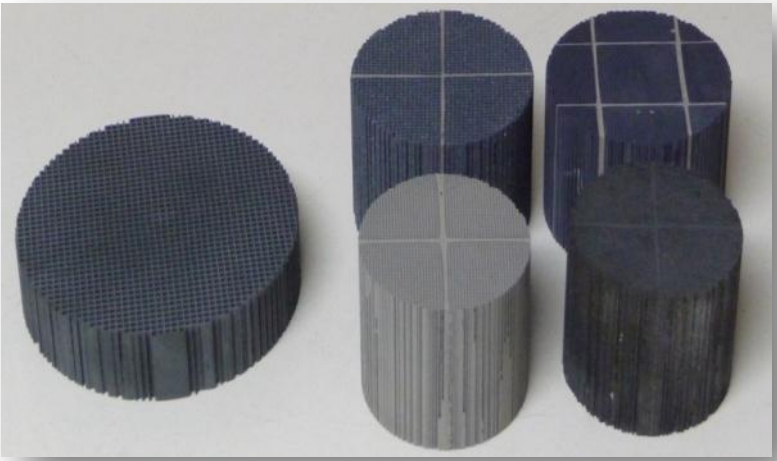


HiTRec receiver, DLR

Stobbe SiSiC receivers

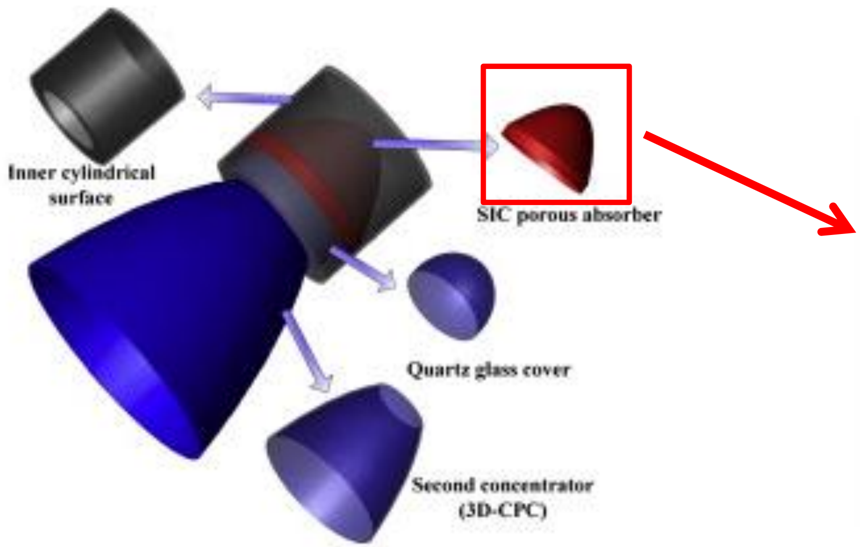
Open volumetric receiver material

- Diesel particulate filter technology
- Mass product
- Relatively cheap



First commercial open volumetric absorber material, St. Gobain

Closed volumetric receiver material

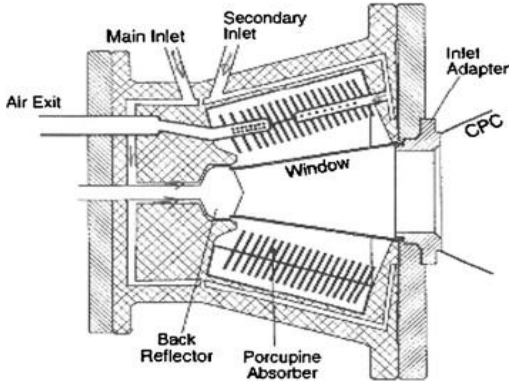


Decomposition diagram of REFOS receiver

SiC foam as radiation absorber material

Parabolic dish closed volumetric receiver material

- The Porcupine receiver, developed by Karni et all. at Weizmann Institute, Israel
- Cross flow
- SiC foams as absorber material

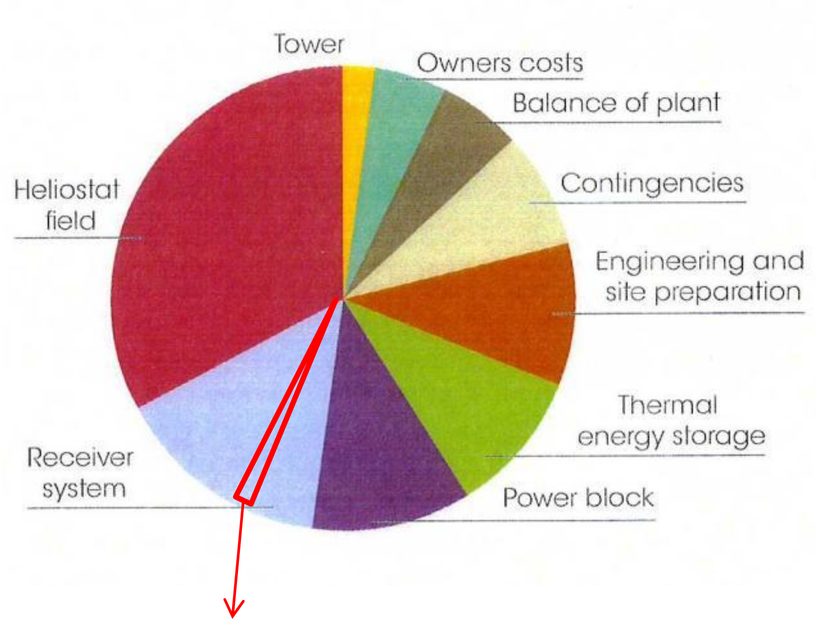


Porcupine solar receiver, Weizman, Israel

Parabolic dish receiver by HelioFocus, Israel

Porcupine implementation by HelioFocus, Israel

- First transformation point, radiation to heat
- Higher absorption + higher transmission to flow →lower LCOE
- Very low cost contribution, big effect



Contribution of absorber material

"One of the most promising developments for towers relies on the ***development of receivers*** *that can operate with alternative fluids which can lead to higher operating temperatures."*

Source: ATKearney, ESTELA, Solar Thermal Electricity 2025, June 2010

Absorber Optimization

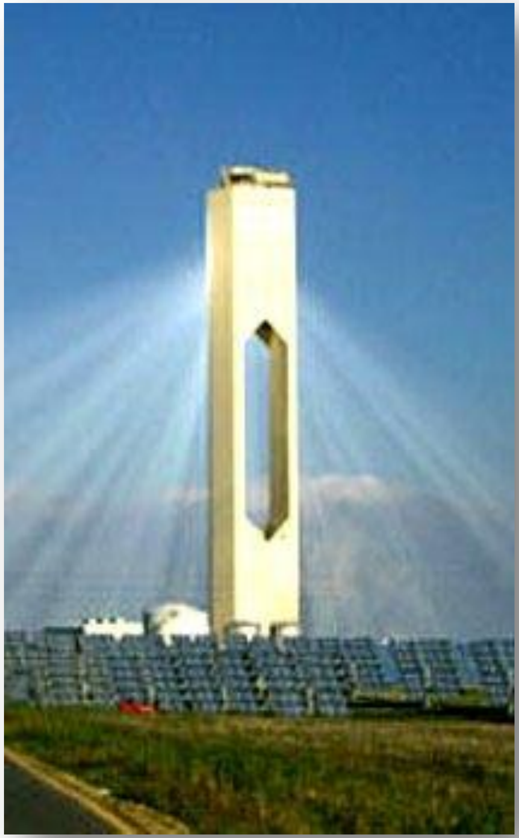
Absorber Optimization

- Resistance up to 1200°C (air)
- Support radiation flux densities >1,000 kW/m2

- Thermal shock resistance (>200 °C/min)
- Thermal cycle resistance
- High thermal conductivity

- High absorptivity
- High surface area
- Low pressure drop

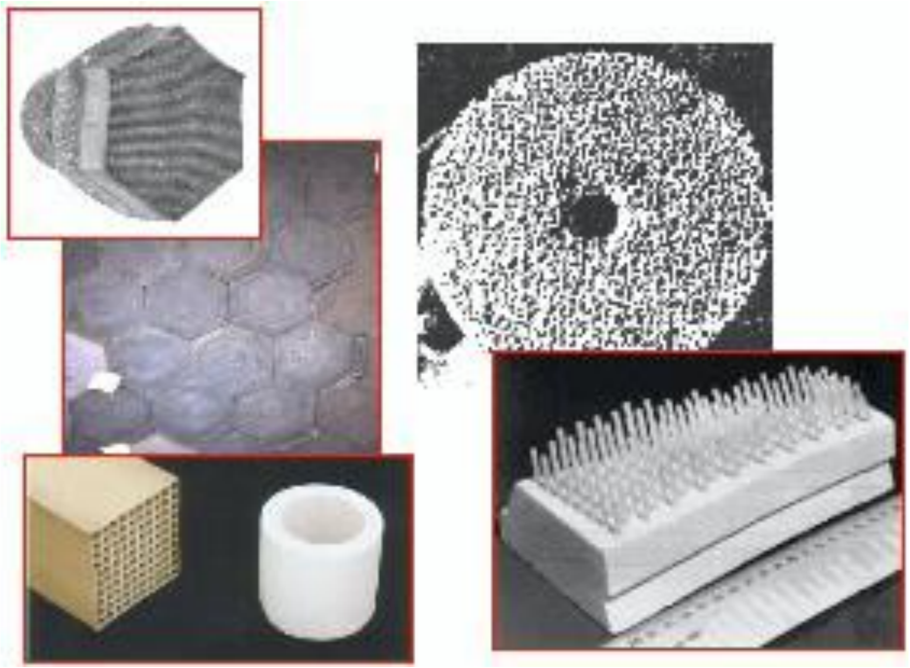
- Low cost
- Long life span



Solar Power Plant, Sevilla, Spain

Absorber Optimization

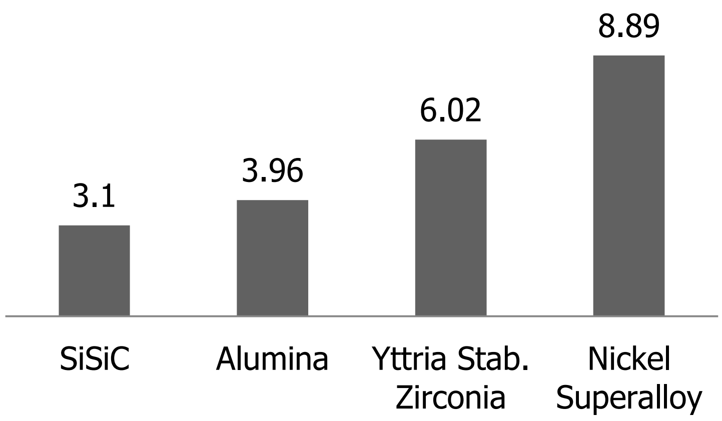
- Physical, thermal and mechanical properties
- Architecture
- Life span
- Cost



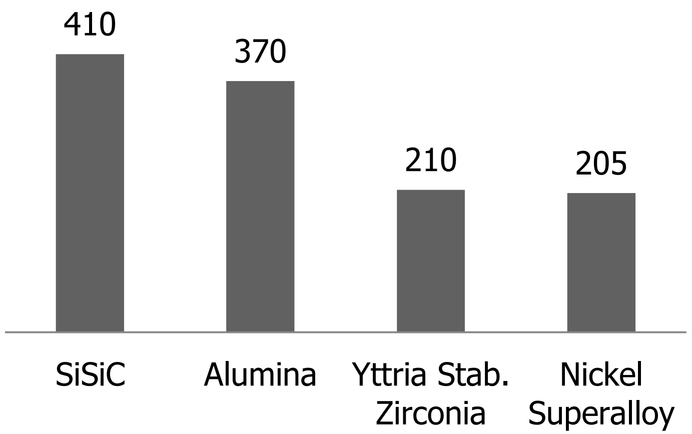
Potential absorber materials

Absorber Optimization

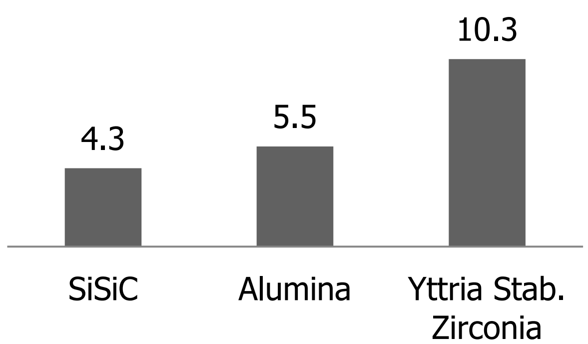
Material properties



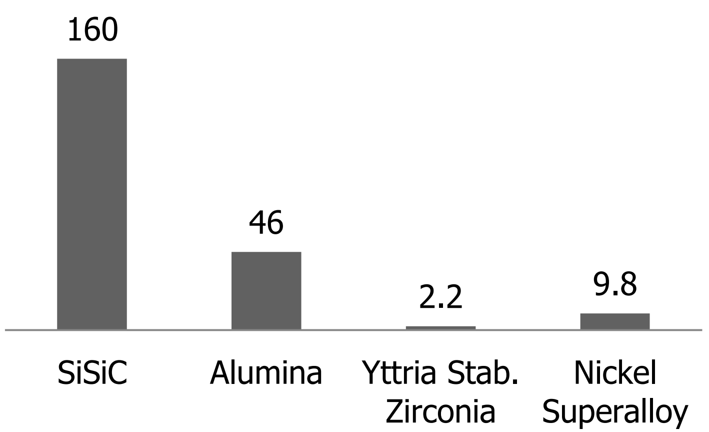
Density [g/cc]



Modulus of elasticity [GPa]



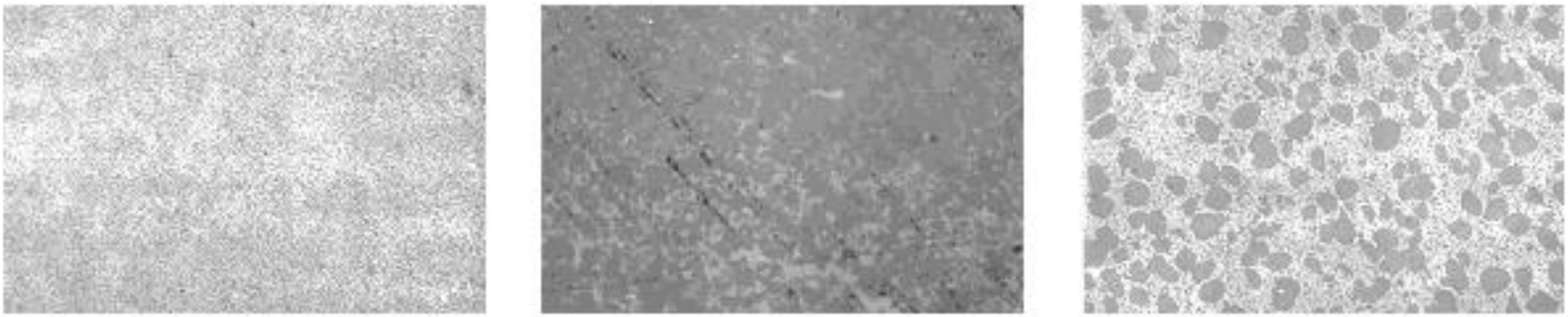
CTE linear at 25°C [µm/m-°C]



Thermal conductivity [W/m-K]

Absorber Optimization

Material microstructure



SEM-images of different Si-SiC microstructures

- Two different sizes of particles homogeneously distributed in fused Silicon
- Microporosity: ~0%
- Passive oxidation layer
- Low crack formation

Absorber Optimization

Material architecture

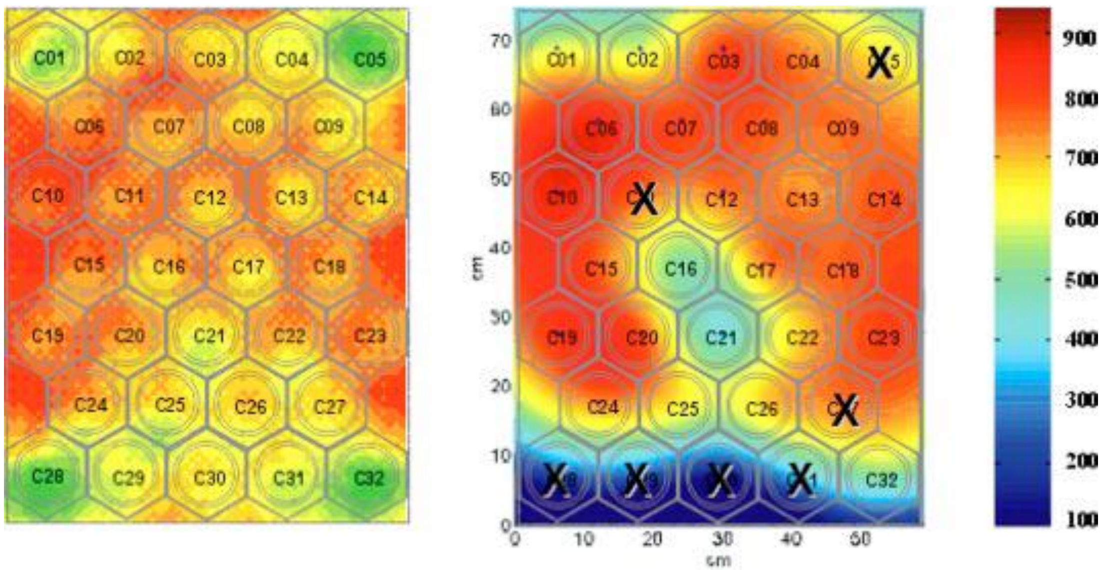
Honeycombs:

- 2-Dimensional flow
- Hot spots
- Mass product

Foams:

- 3-Dimensional flow
- Better temperature distribution
- Not yet a mass product

Honeycombs



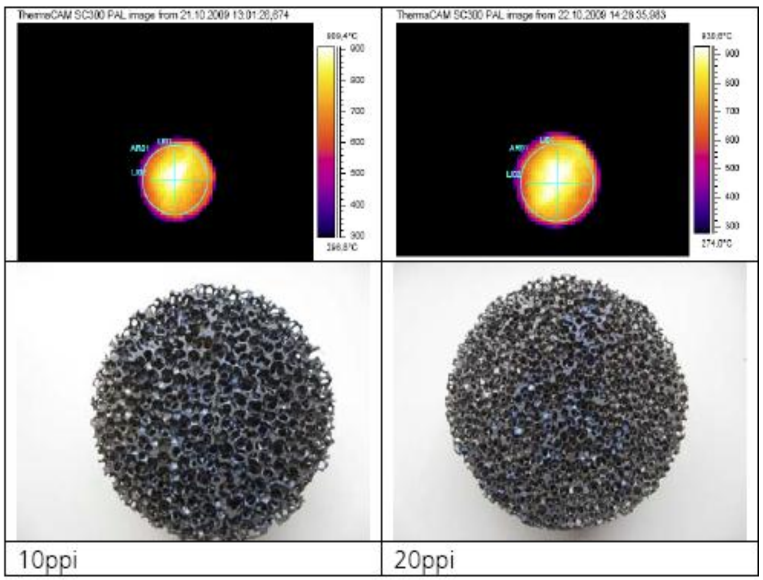
Comparison of measured (left) and 2-D interpolation (right) thermal maps (in °C) of HiTRec-II

Failure of absorber module

Source: B. Hoffschmidt et all., Performance Evaluation of the 200-kWth HiTRec-II Open Volumetric Air Receiver, Journal of Solar Energy Engineering, Vol. 125, 2003, ASME

Absorber Optimization

Foams



IR-Camera analysis of ErbiSiC foams at DLR, Germany

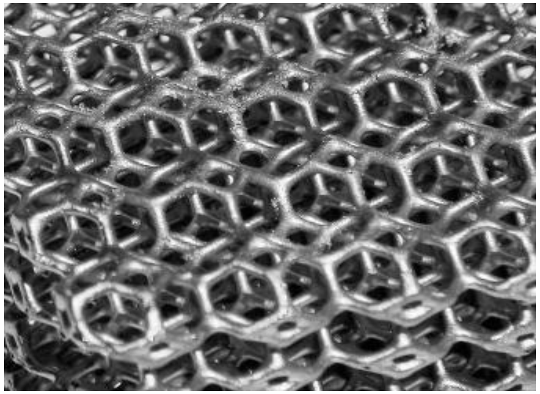
Solar simulation lamps, DLR, Germany

Absorber Optimization

Other architectures

Reticulated Foam (ErbiSiC R)

Filamentous structure (ErbiSiC F)

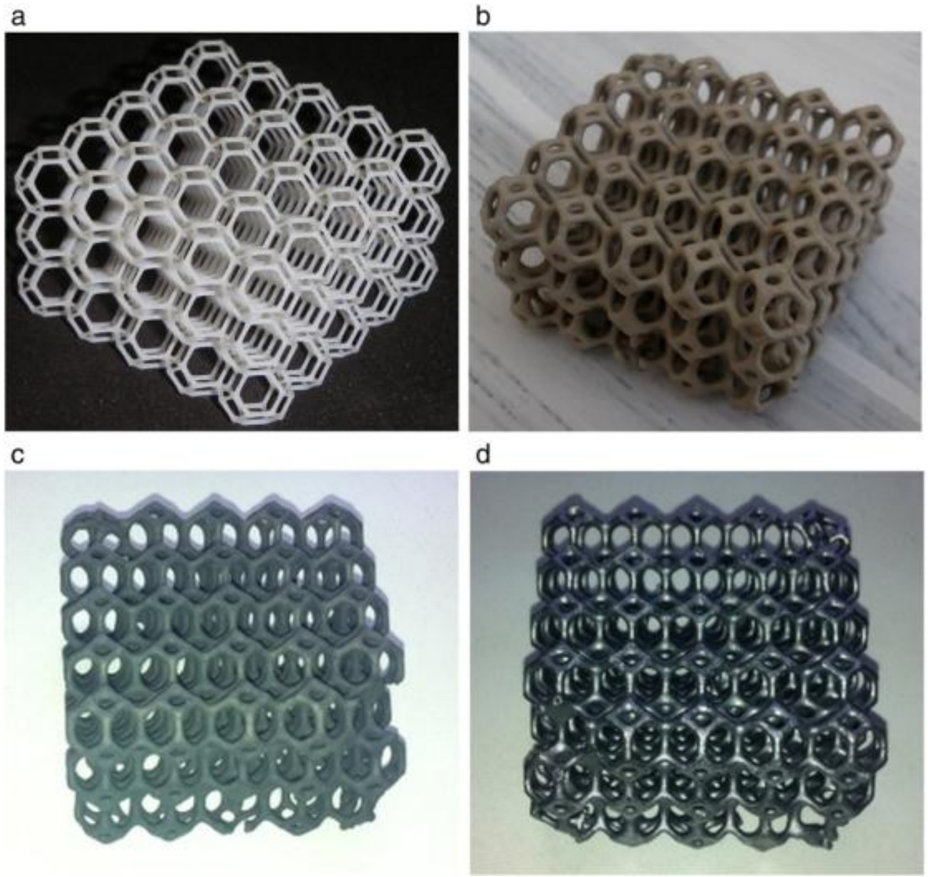


Custom-designed structure

Custom designed architectures

- Simulate phenomena and operation
- Design best structure
- Produce template with rapid prototyping
- Ceramize

➡ Get best suited architecture



Custom-designed structure produced by Erbicol SA

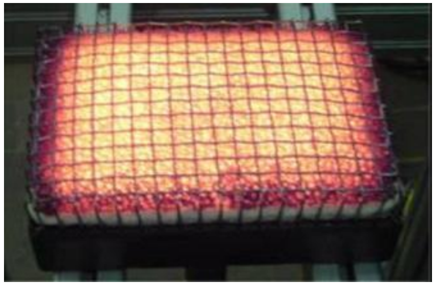
Life span

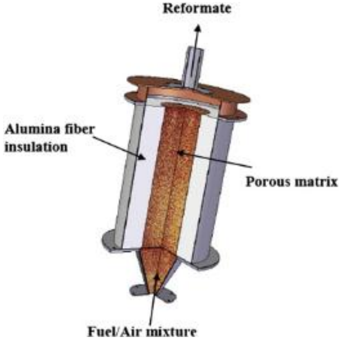
Life Span

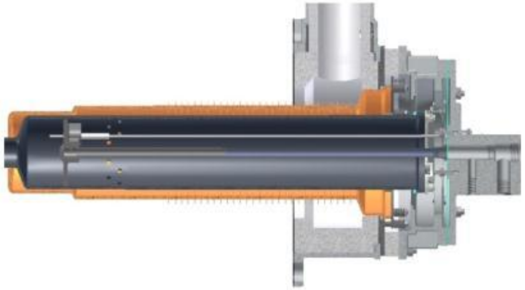
ErbiSiC

Applications of Si-SiC open-cell materials

- Porous burner
- Catalyst support
- Reforming
- Structural materials
- High-temperature heat exchanger
- Static mixer







Life Span

Situation

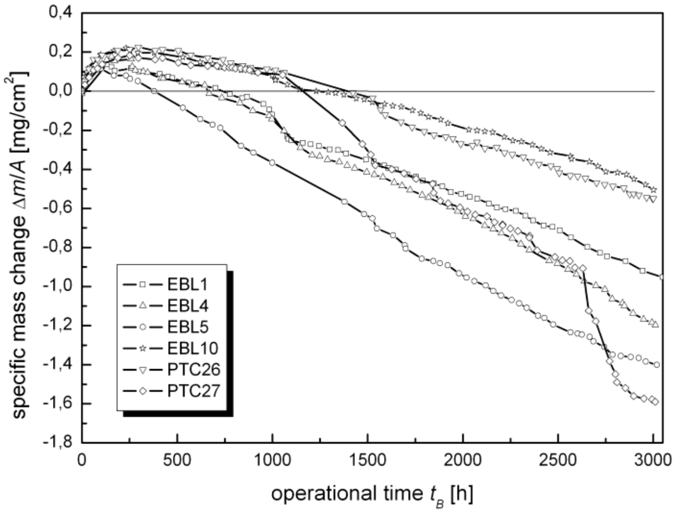
- No accelerated life time test is possible
- Barrier between active and passive oxidation (1400°C)
- Real application conditions are needed

Analysis and prediction

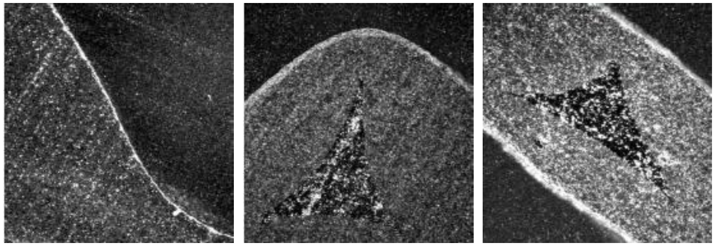
- Main phenomena that influence the life time of foams:
  - Oxidation
  - Crack formation
- Investigate cycled ceramics using:
  - Mechanical analysis: flexural strength and/or compression
  - Mass difference
  - Microanalysis
  - Tomography
  - SEM and SEM-EDS
  - XRD

Life Span

Mass evolution



Passive oxidation layer



As produced   After 100h   After 1000h

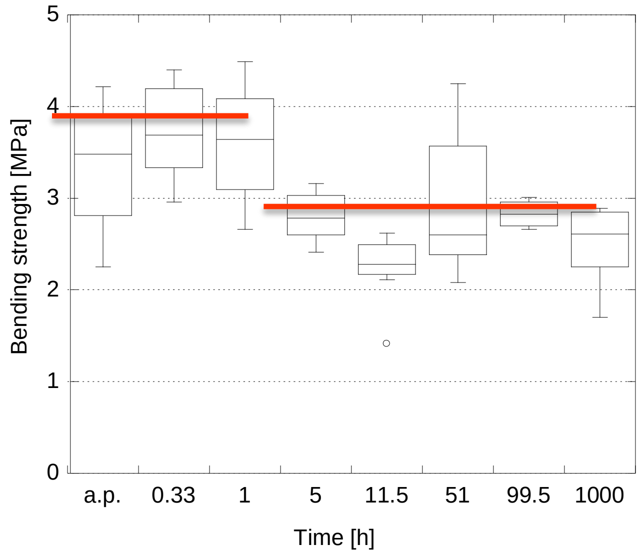
Mass gain ⇒ passive oxidation

Mass loss ⇒ active oxidation and spalling

R. A. Mach, F. v. Issendorff, A. Delgado A. Ortona, Experimental investigation of the oxidation behavior of Si-SiC-foams Advances in Bioceramics and Porous Ceramics: Ceramic Engineering and Science Proceedings, Volume 29, Issue 7, 299-311, 2009, WILEY

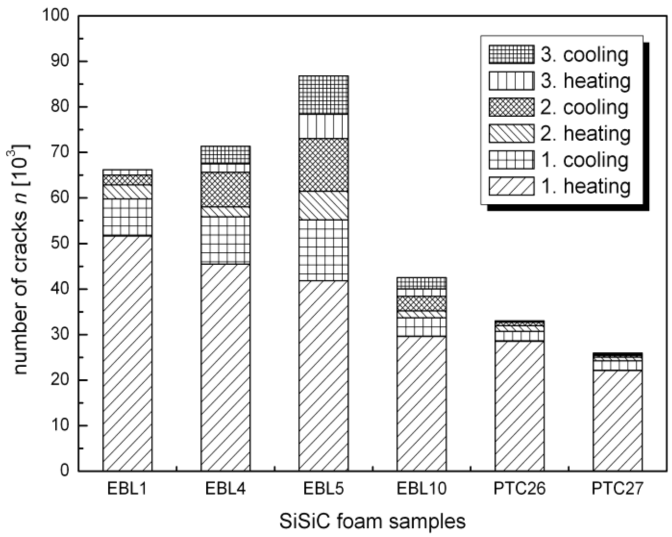
Life Span

Bending strength



- Decrease in first hours
- Almost constant thereafter

Number of cracks



- First three ON/OFF cycles
- Crack formation decreases drastically

Source: R. A. Mach, F. v. Issendorff, A. Delgado A. Ortona, Experimental investigation of the oxidation behavior of Si-SiC-foams Advances in Bioceramics and Porous Ceramics: Ceramic Engineering and Science Proceedings, Volume 29, Issue 7, 299-311, 2009, WILEY

Long time behaviour → **Look at first hours**

- Silica layer formation
- Maximal crack formation during first operation hours
- Mechanical strength decreases 30% during the very first hours of operation

Summary

Summary

- Increase and differentiation of CSP market increases size for solar absorbers
- Absorber material performance is key to LCOE decrease
- Key features of absorbers: high temperature, high absorption, high thermal conductivity, low cost, long life span
- Ceramic open cell materials have potential as solar absorber
- Custom designed structures probably will allow best performance

Sandro Gianella
Managing Director
Porous Ceramics Dept.

Erbicol SA
Viale Pereda 22
6828 Balerna
Switzerland

Phone: 0041 (0)91 697 63 60
Fax: 0041 (0)91697 63 69
Mail: sandro.gianella@erbicol.ch
Web: www.erbicol.ch