# HEAT AND MASS TRANSFER IN HIGH TEMPERATURE SOLAR TECHNOLOGY FOR CEMENT PRODUCTION

**The Presentation for the workshop for Department of Energy Science and Engineering Indian Institute of Technology Delhi Hauz Khas, New Delhi**

Cheilytko Andrii, DLR 26.11.2024 | New Delhy, Indian Institute of Technology Delhi

# SOLAR RESEARCH AT THE GERMAN AEROSPACE CENTER

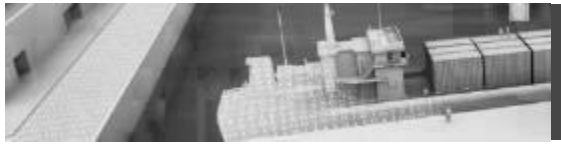
**Part 1 of „Heat and mass transfer in high temperature solar technology for cement production“**

**Presentation by Prof. Dr.-Ing. Robert Pitz-Paal. Institutspraesentation komprimiert: Solar research at the German Aerospace Center. 2023**

Cheilytko Andrii, DLR 26.11.2024 | New Delhy, Indian Institute of Technology Delhi

# German Aerospace Center
## Research Centre + Space Agency + Project Management Agency

| AERONOTICS | SPACE | ENERGY | TRAFFIC |
|---|---|---|---|
|  |  |  |  |



**SECURITY**
Civil & Defence Security Research

**DIGITISATION**
Quantum Technologies & Systems Modelling

# DLR Energy Research: Controllable Sustainable Energy

*Demand*

Households

Mobility

Industry

*Transducer*

*Memory*

*Technology*

Steam turbine

Gas turbine

Fuel cell

System operation

Electricity storage

Heat accumulator

Chemical storage

Reducing agent

Sector coupling

Heat pump

Electrolysis

Thermochemistry

Electricity & Gas Grid Technologies

**Power & Heat**

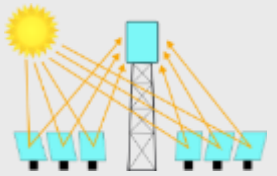
**Fuels**

**Management & Digitalisation**

System analysis

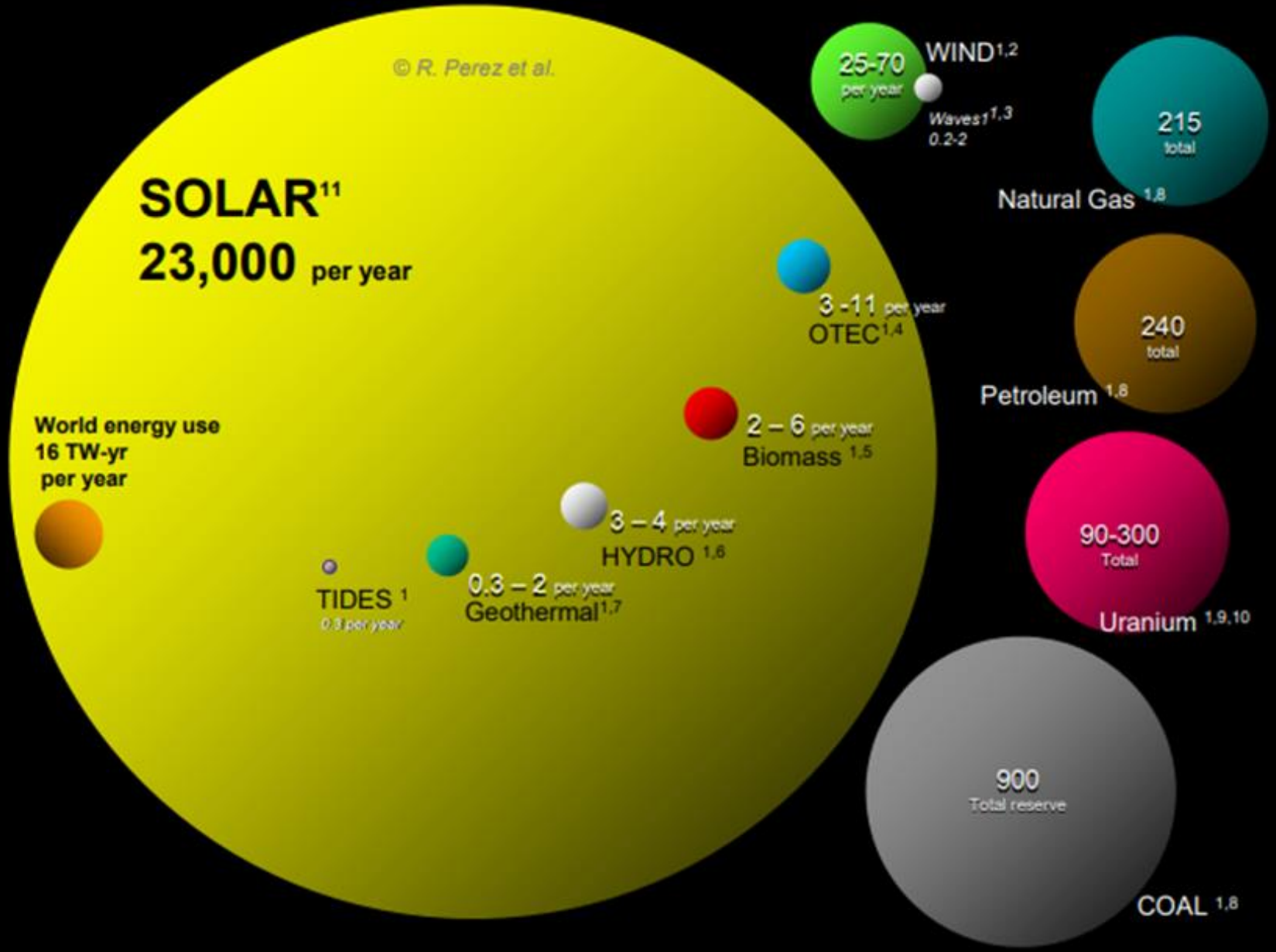
*Sources*

Wind turbines



Concentrating solar systems

# The sun: energy for the future

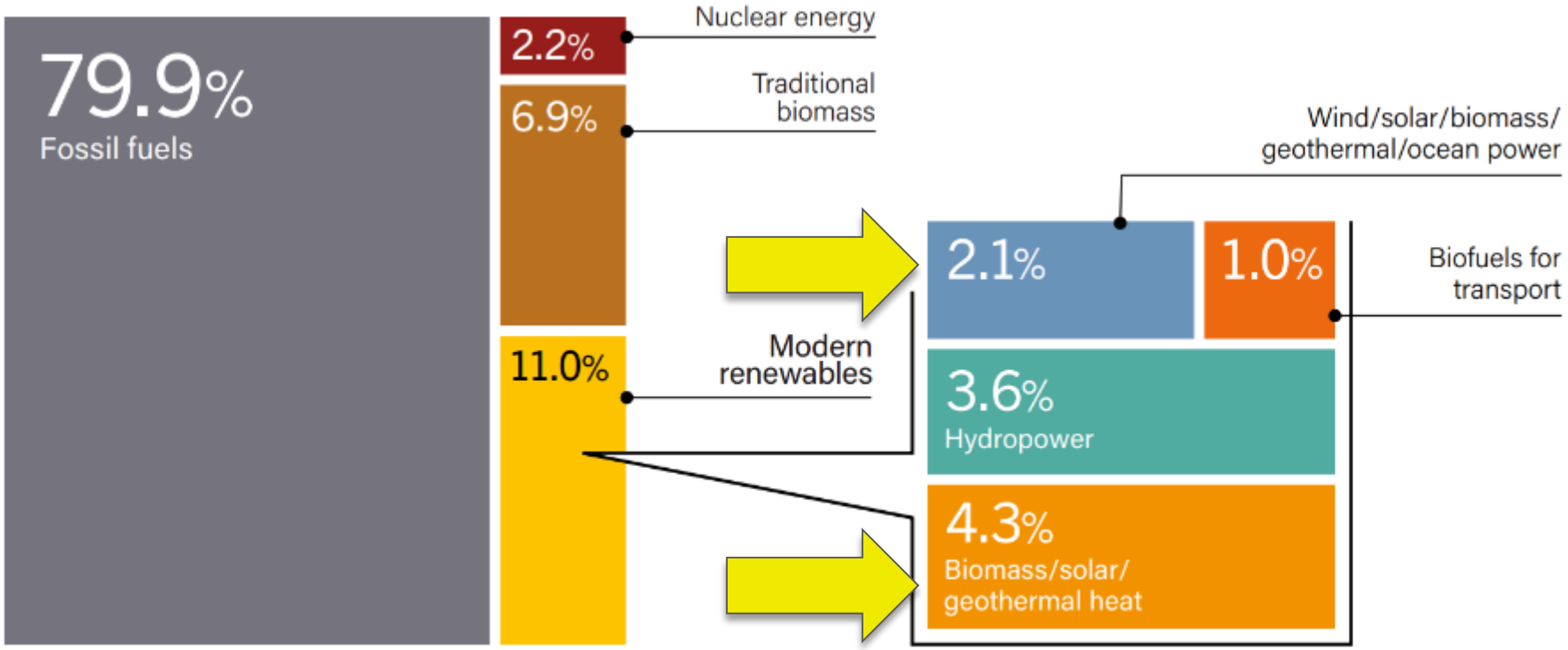



**Available solar energy:**

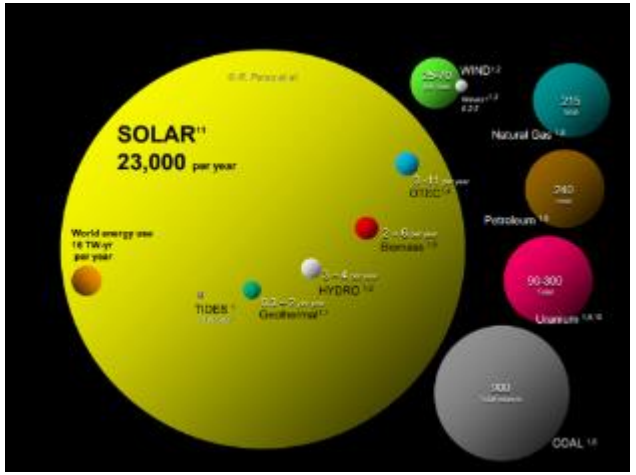
- More than 90% of renewable energy resources
- Energy for 10,000 Earths

Source: Perez et al. (2009). A fundamental look at energy reserves for the planet. The IEA SHC Programme Solar Update, Volume 50, 2009.

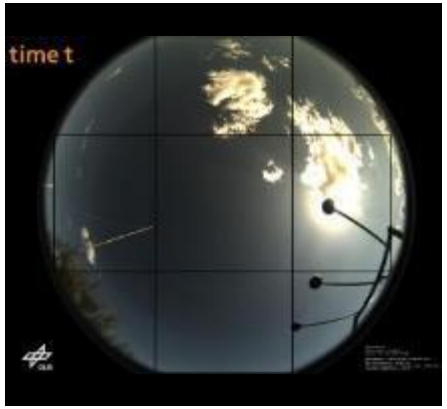
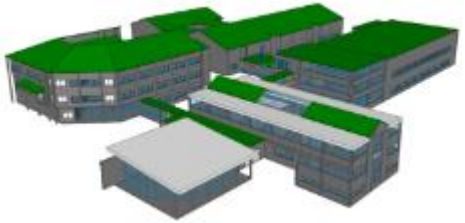
# Energy resources used worldwide



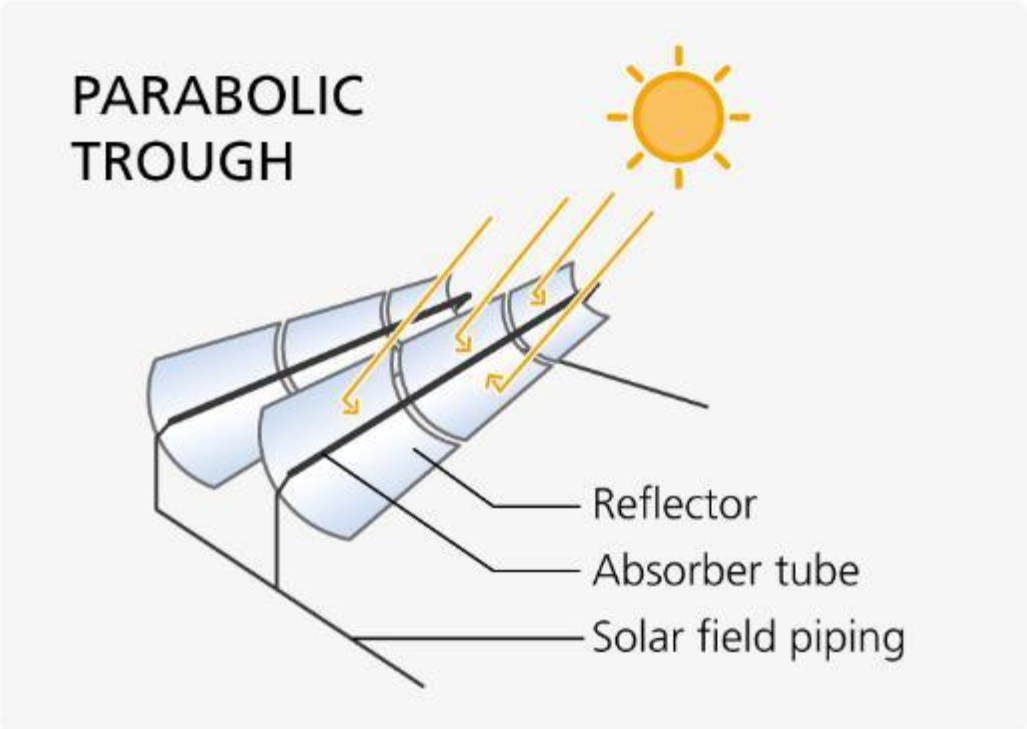

Source: REN21 (2020): Global Stature Report 2020 (figures from 2018).

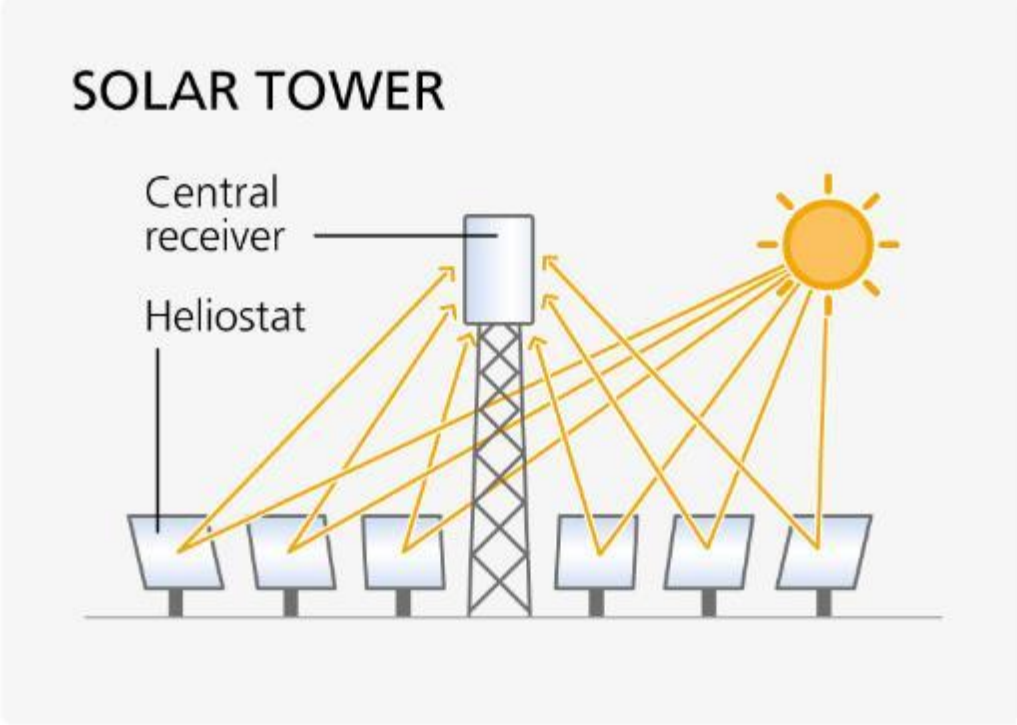


# Institute of Solar Research

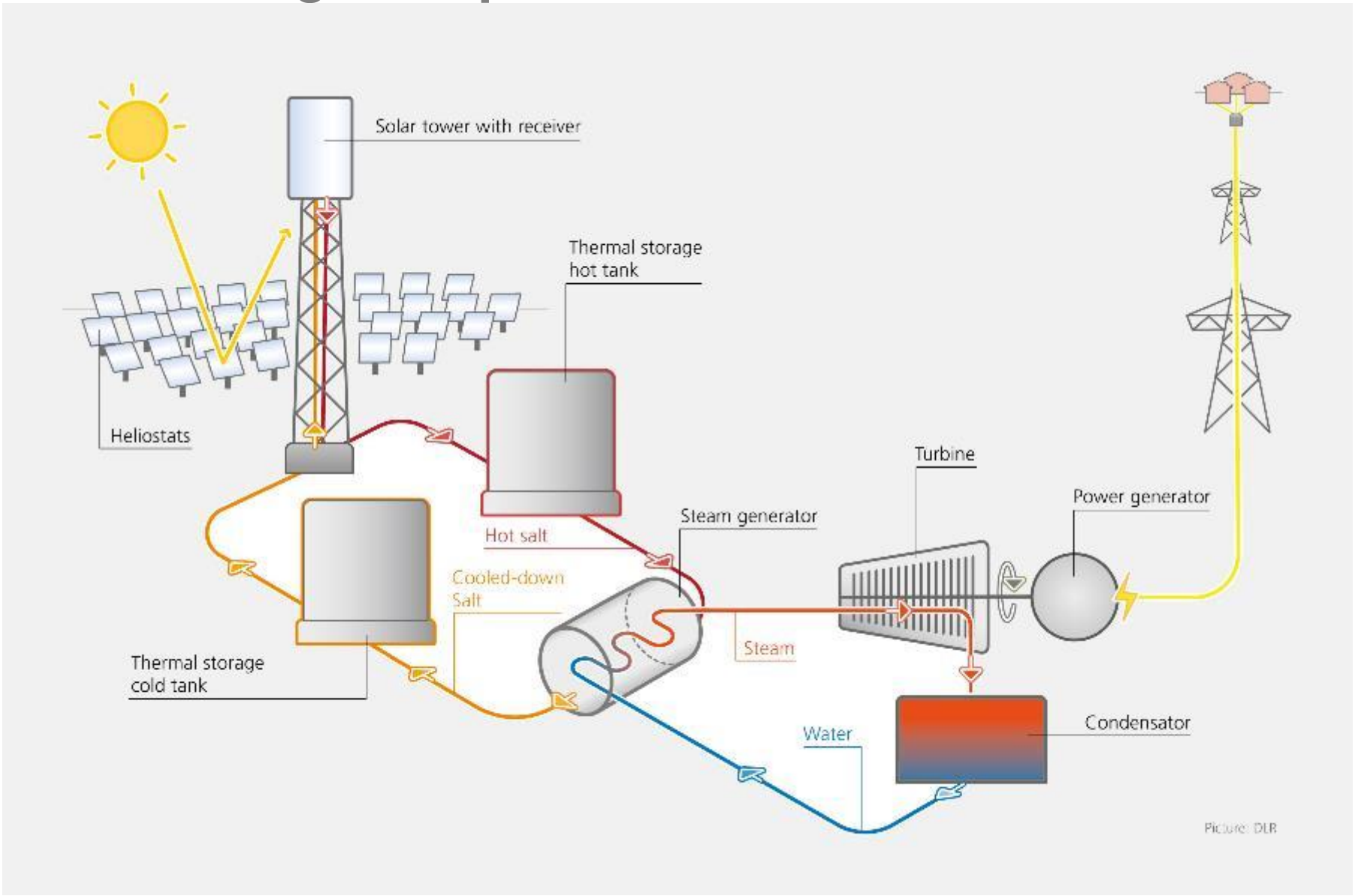
| Concentrating solar technologies | Quality assurance and operational optimisation for solar power plants and photovoltaic systems | Agri Photovoltaics | Solar energy meteorology | Heat transition: Energetic building assessment |
|---|---|---|---|---|
|  |  |  |  |  |

# In a nutshell: How does a solar thermal power plant work?

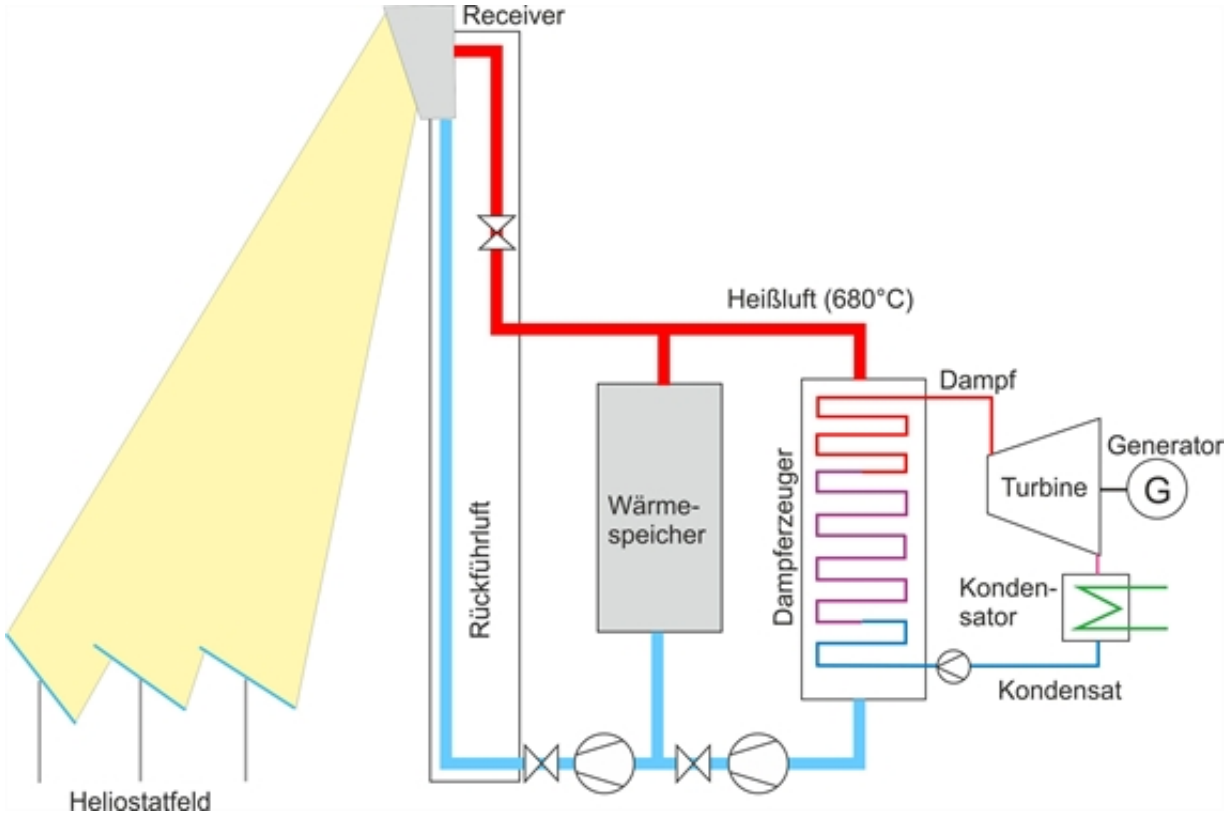


# In brief: from high temperatures to electric current



# Solar tower with air as a heat carrier




# The advantages of CSP technologies in a renewable energy system

- $CO_2$-free
- Sustainable energy storage
- 24/7 Energy
- Adjustable
- Hybrid power plants with PV possible
- Can be used in district heating networks
- Can provide process heat for industrial plants
- Without rare resources

# Milestones of the Institute of Solar Research

**02/2011**

DLR founds **Institute of Solar Research**

**06/2011**

Takeover of the **Jülich Solar Tower**

**03/2017**

Inauguration of **Synlight** in Jülich

**06/2020**

Spin-off of the **Institute of Future Fuels**

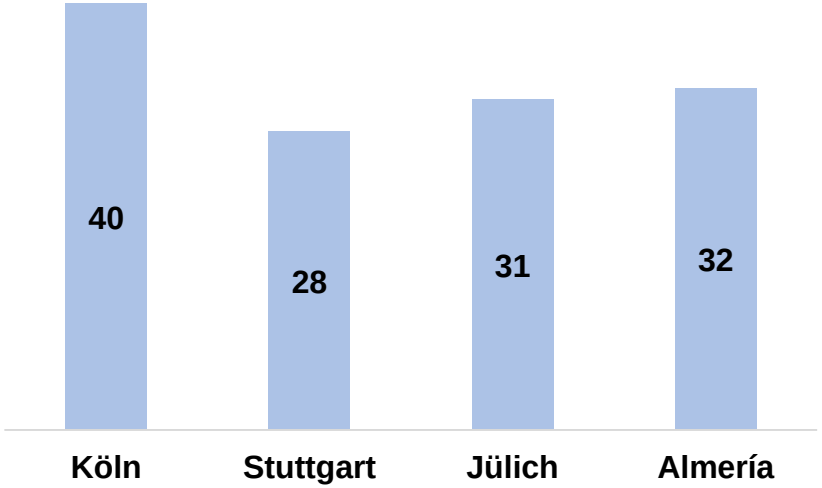
**07/2020**

Inauguration of the Jülich **Multifocus Solar Tower**

# Solar research at our four locations




Almería (Spain)




* As of 01/2022, without student assistants

# Institute of Solar Research

**Departments for the development and optimisation of solar thermal power plants**

Technology development: efficient and economic use of solar energy for the production of electricity, heat and fuels

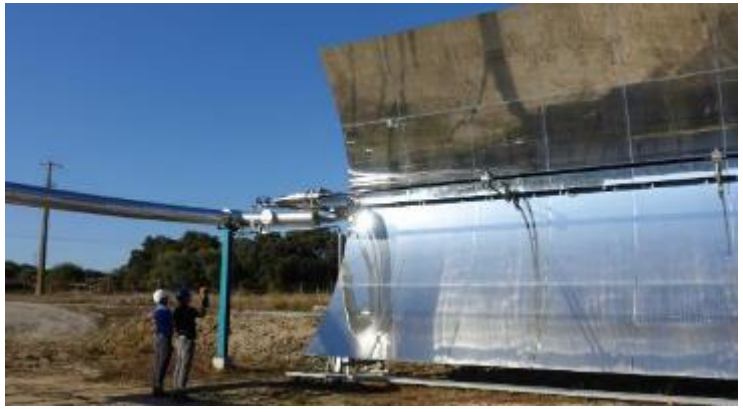
| Solar high temperature technologies | Solar power plant technology | Qualification | Chairs in Aachen |
|---|---|---|---|




# Department Solar High Temperature Technologies

Head of Department: Dr.-Ing. Reiner Buck

**"Fluid Systems"**
**Dr.-Ing. Jana Stengler**

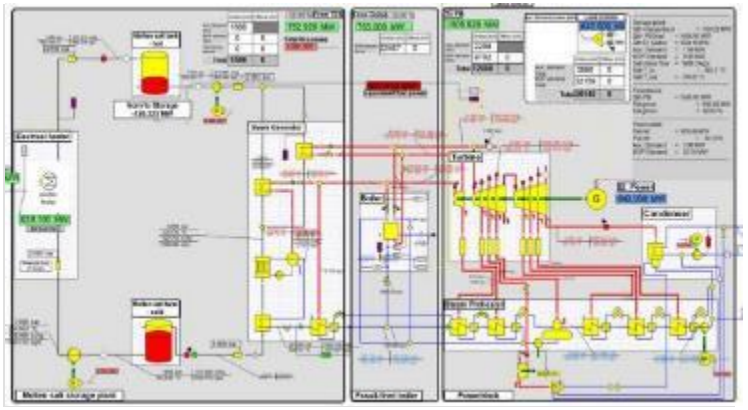


- Heat transfer in liquids and gases
- Operation of liquid salt plants
- Solar process heat

**"Particle systems"**
**Dr.-Ing. Luka Lackovic**

- Heat transfer in particles
- Development of particle receivers and heat exchangers
- CFD/FEM/DEM modelling

**"System Modelling“**
**Dr.-Ing. Tobias Hirsch**



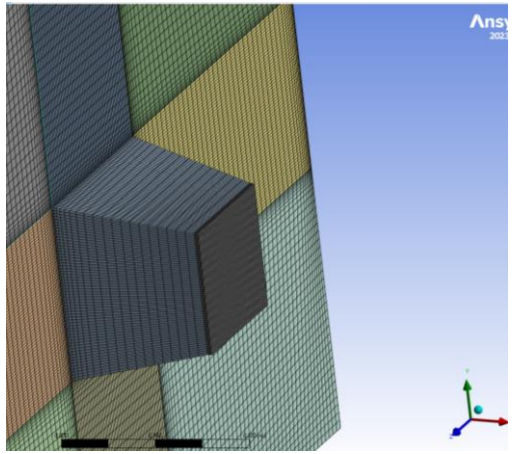
- System modelling and design
- Techno-economic evaluation
- Operating behaviour and control of parabolic trough systems

- 30 employees at the locations and plants in Stuttgart, Cologne and Évora (Portugal)

# Department Solar Power Plant Technology

Head of Department: Dr.-Ing. Kai Wieghardt

**"Simulation and Open Volumetric Recievers"**
**Peter Schwarzbözl**



- Controls for CSP and heliostat arrays
- Automation, dyn. simulation
- Flux density measurements

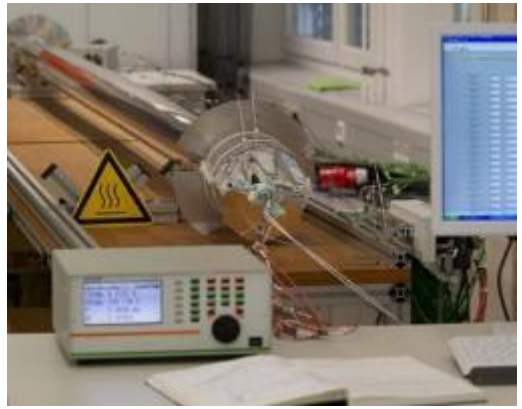
**"Jülich Solar Tower Power Plant"**
**Felix Göhring**

- Trial operation of the plants:
- Jülich experimental solar thermal power plant
- Multifocus Tower Jülich

- Employees at the Jülich site

# Department Qualification

Head of Department: Dr.-Ing. Peter Heller

| "System qualification"<br>Dr.-Ing. Marc Röger | "Solar Energy Meteorology"<br>Dr. Stefan Wilbert | "Materials, Layers, Components"<br>Dr.-Ing. Florian Sutter | "Buildings and Quarters"<br>Dr. Jacob Estevam Schmiedt |
|---|---|---|---|
|  |  |  |  |
| • Opt. qualification of solar fields<br>• Thermal characterisation of receiver systems | • Determination of meteorological parameters<br>• Analysis of the impact on CSP | • Test methods and tests of components<br>• Durability of materials and components | • Energy analysis of buildings<br>• Basis for rehabilitation planning |

- 40 employees at the sites in Cologne, Jülich, Oldenburg and Almería (Spain)

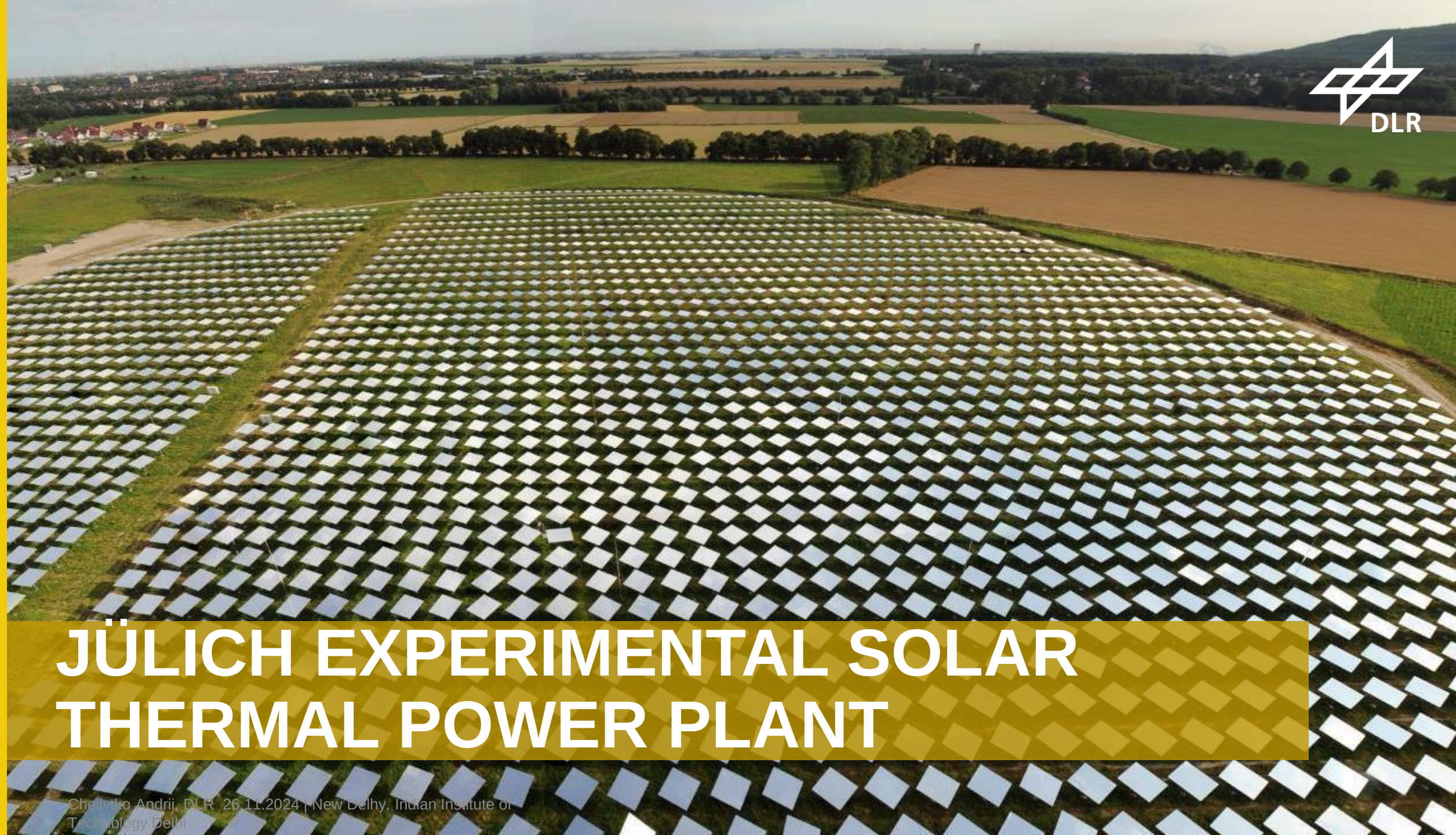
# PLATAFORMA SOLAR DE ALMERÍA

**OWNER AND OPERATOR: CIEMAT**

# PROCESS HEAT TEST FACILITY

Cheilytko Andrii, DLR 26.11.2024 | New Delhy, Indian Institute of Technology Delhi

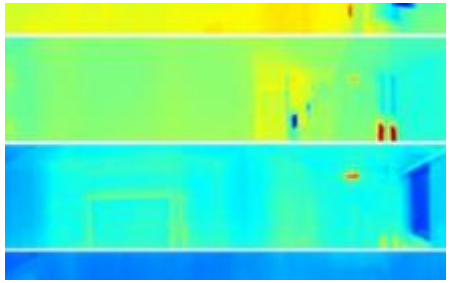
# EVORA MOLTEN SALT PLATFORM



# JÜLICH EXPERIMENTAL SOLAR THERMAL POWER PLANT

Chelyt'ko Andrii, DLR 26.11.2024 | New Delhy, Indian Institute of Technology Delhi

# Spin-offs of the Institute of Solar Research

| 2007 | 2016 | 2017 | 2019 | 2020 |
|---|---|---|---|---|
| cspservices | HELIOKON | HELIOHEAT | LUMOVIEW | Volateq |
| Optimising solar field performance and maximising system lifetime | Heliostat design and control. Today Synhelion Germany | Particle receiver technology. Today part of Heliogen | 3D capture and energy-efficient analysis of buildings | Fully automatic condition monitoring of CSP and PV plants |
|  |  |  |  |  |

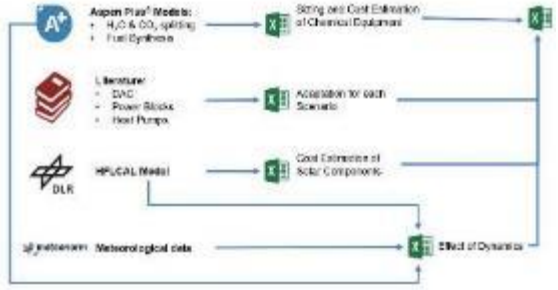
# Institute of Future Fuels

Institut für Future Fuels

- Development of alternative fuels

**Technology development for the efficient and economic production of energy sources for a global, renewable energy economy**

| Solar chemical processes | Material and component design | Demonstration | Evaluation |
|---|---|---|---|



# THE THEORY OF HEAT AND MASS TRANSFER PROCESSES IN SOLAR ABSORBER

**Part 2 of «Heat and mass transfer in high temperature solar technology for cement production»**

Cheilytko Andrii, DLR 26.11.2024 | New Delhy, Indian Institute of Technology Delhi

# The theory of heat and mass transfer processes in solar absorber

## Purpose

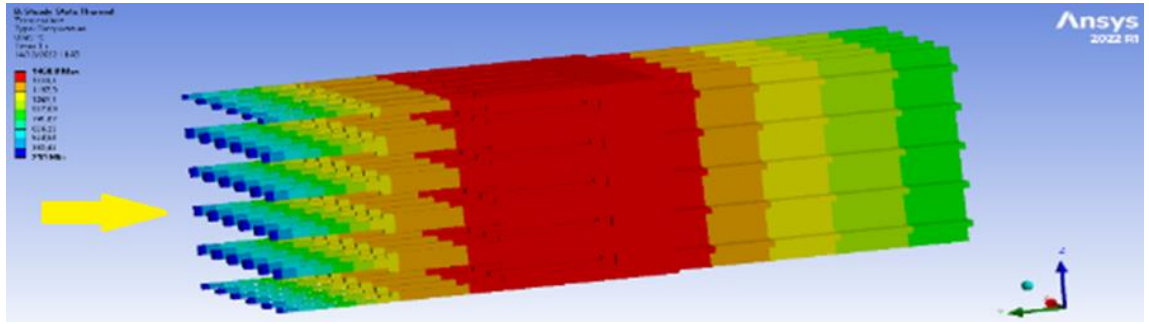
- Improve the quality and accuracy of existing calculations of heat and mass transfer processes in solars receivers.

## Tasks

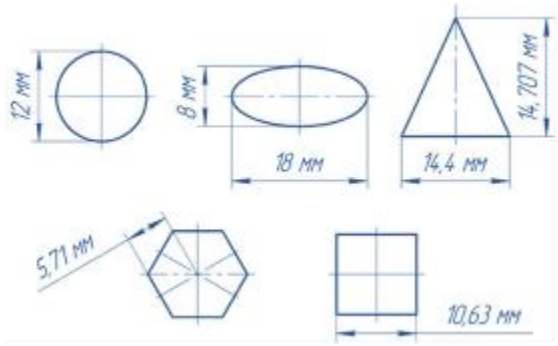
- AP 1 Basics
- AP 2 Modeling
- AP 3 Related technical tasks
- AP 4 Support to projects
- AP 5 Analysis of potential

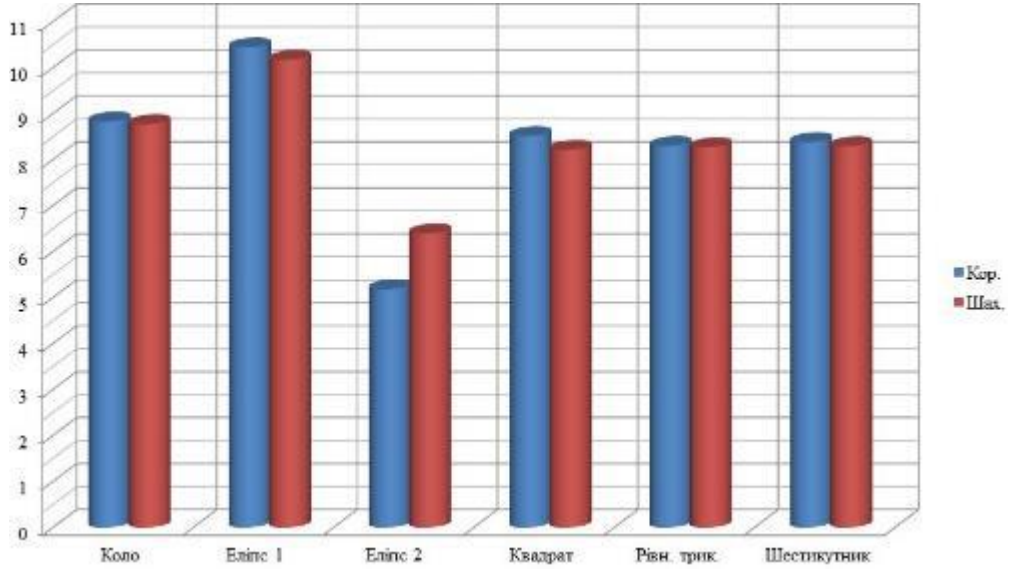
$$\rho_s (c_p)_s \frac{\partial T_s}{\partial \tau} = \frac{\partial}{\partial x}\left(\lambda_s \frac{\partial T}{\partial x}\right) - \alpha A_v (T_s - T_f) + q_{source}$$

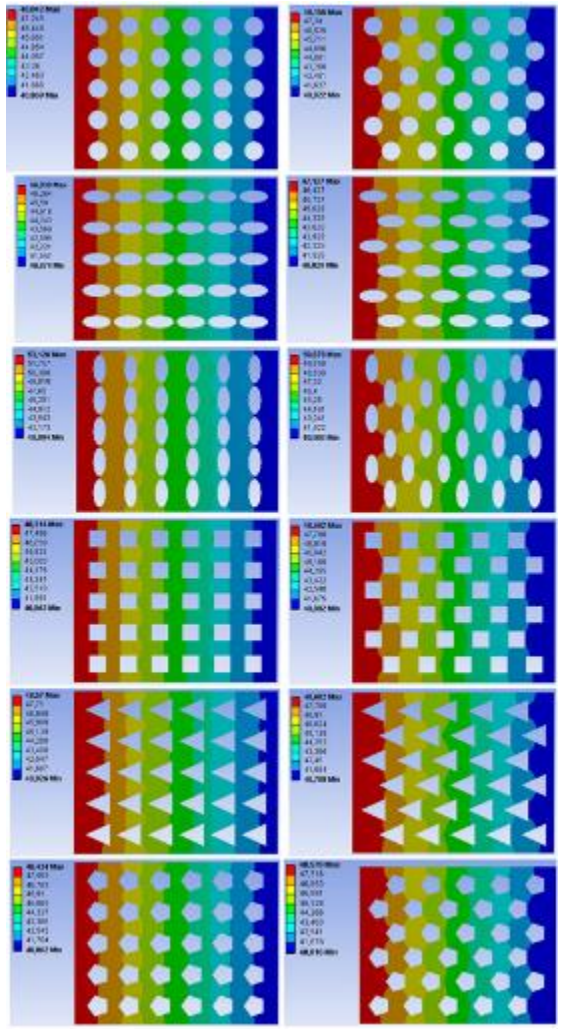
$$\rho_f (c_p)_f \left(\frac{\partial T_f}{\partial \tau} + u T_f\right) = \frac{\partial}{\partial x}\left(\lambda_f \frac{\partial T}{\partial x}\right) + \alpha A_v (T_s - T_f) + q_{source}$$



# Study of the influence of pore shape on the thermal conductivity coefficient of porous structures and thermal protection structures without taking into account convection inside the pores

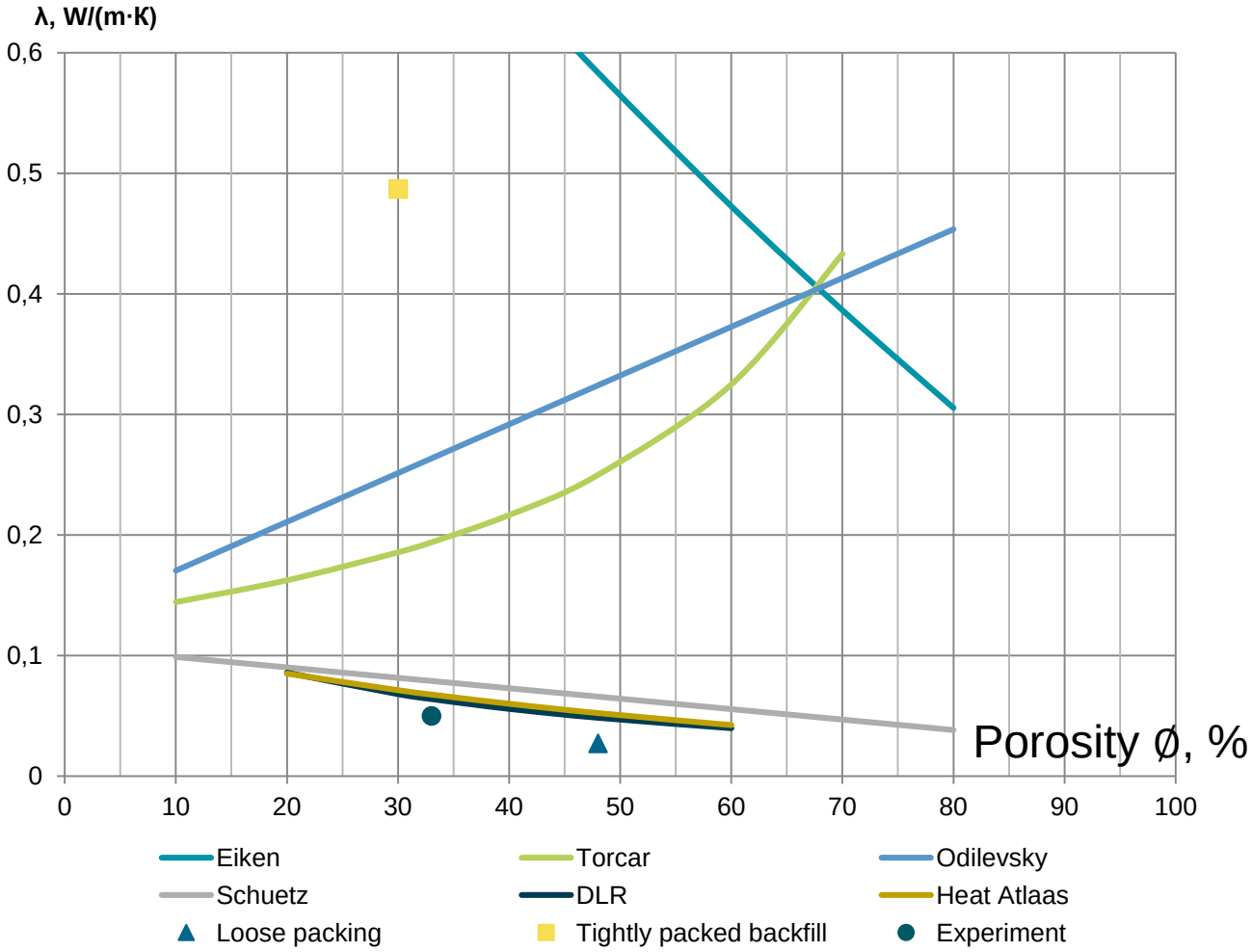


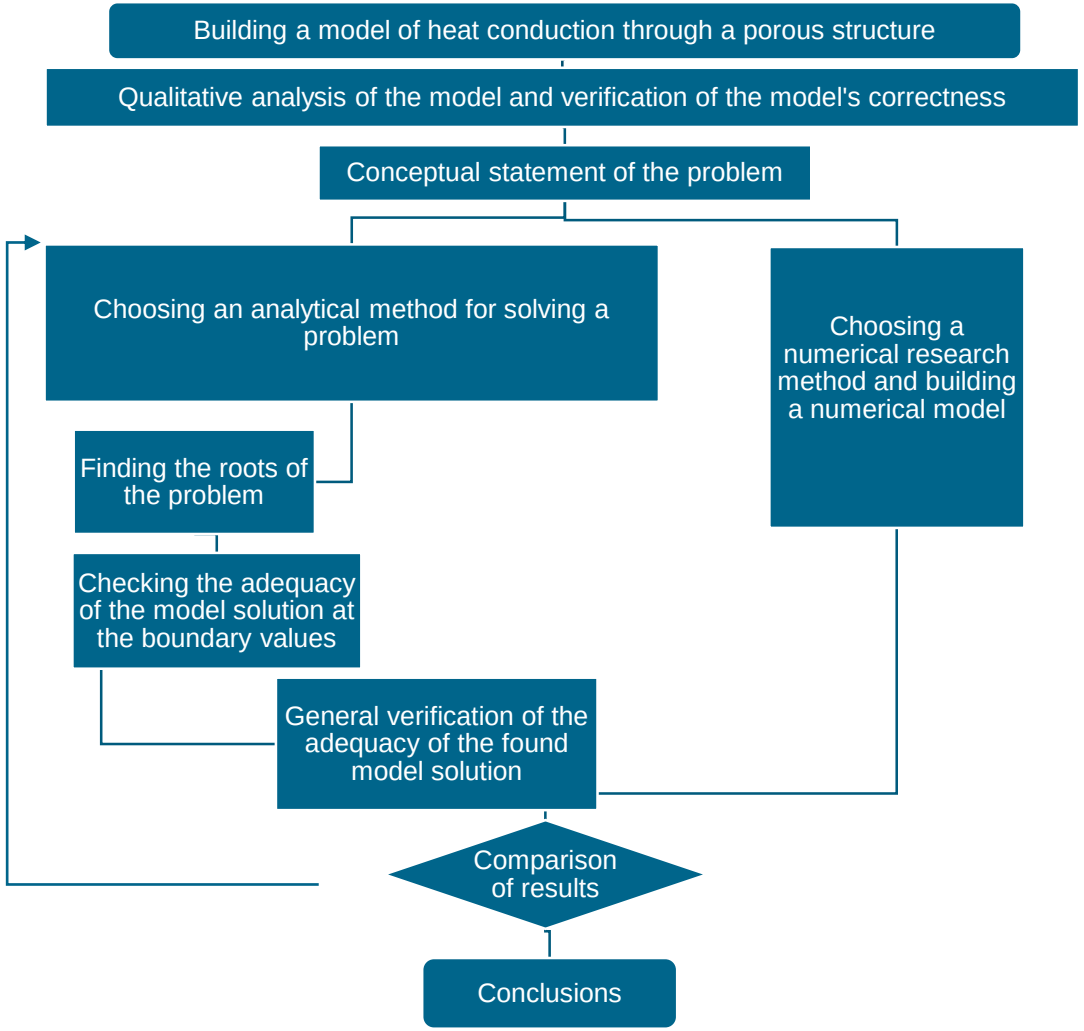



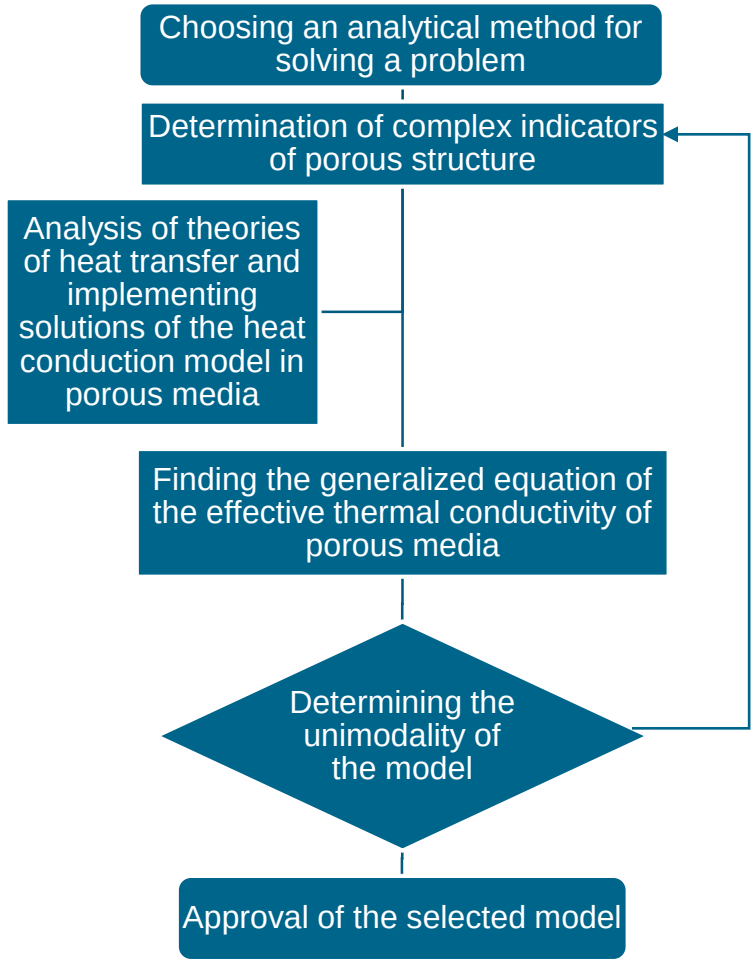
Thermal conductivity coefficients of porous materials and products with different pore shapes

# Effect of porosity on the effective coefficient of thermal conductivity for backfills made of borosilicate glass




# Methodology for finding the equation of effective thermal conductivity

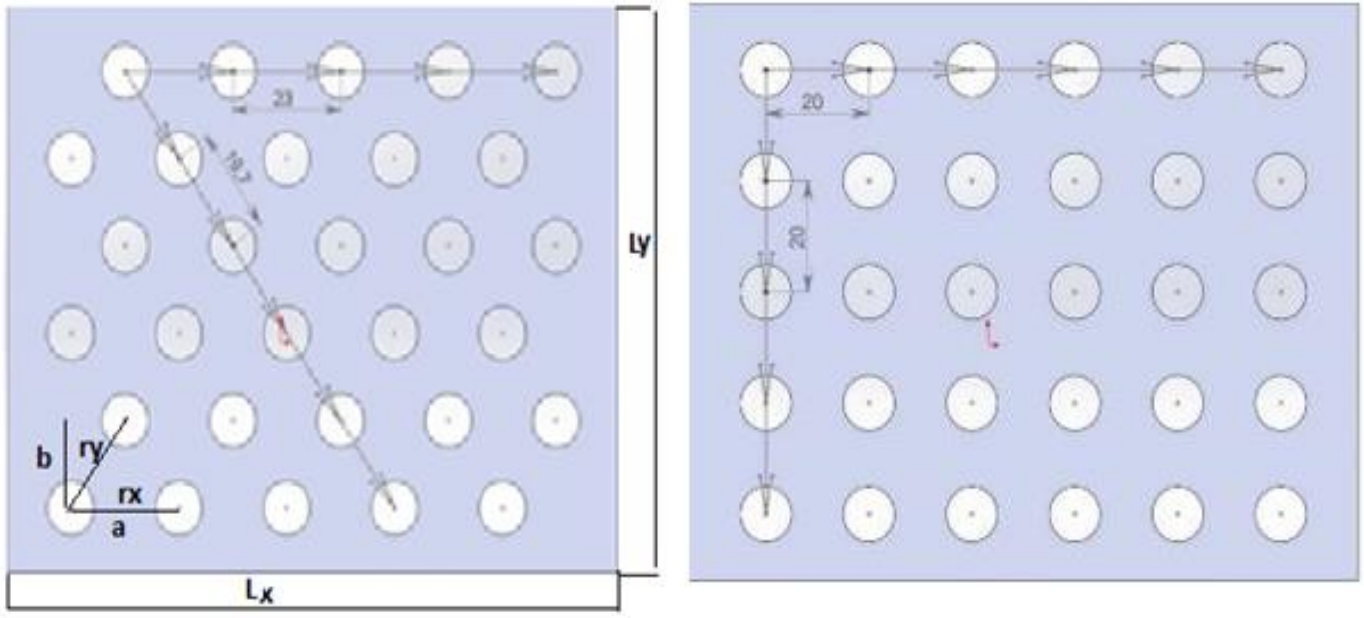


# The dislocation vector

The volume of a unit cell can be calculated from the constant lengths and angles of the lattice. If the sides of the cell are represented as vectors, the volume is equal to the scalar triple product of these vectors

$$V_{cell} = \text{asb}\sqrt{1 + 2cos\alpha cos\beta cos\gamma - cos^2\alpha - cos^2\beta - cos^2\gamma}$$




$$\left(\bar{k}_y\right)_y = n_y\langle r_y\rangle / L_y$$

$$\left(\bar{k}_y\right)_x = n_x\langle r_x\rangle / L_x$$

Locations with vectors on them $k_y$=1.182 (left), $k_y$ =1 (right)

# New equation

Equation DLR of the effective coefficient of thermal conductivity

$$\lambda_{eff,s} = \frac{\frac{\lambda_f \lambda_s}{\lambda_s \emptyset + \lambda_f (1-\emptyset)}}{\frac{\lambda_s}{\lambda_f}\emptyset + 2\Psi + \frac{\lambda_f}{\lambda_s}(1-\emptyset) + 1}\left[\frac{\lambda_s}{\lambda_f}\emptyset + (1-\emptyset) + \Psi\right]\left[\emptyset + \frac{\lambda_f}{\lambda_s}(1-\emptyset) + \Psi\right]$$

$\Psi$ - indicator of porous structure;

For different models of heat transfer, the solution of this model has different roots $\Psi$.

For open channel structure

$$\Psi = \frac{1}{k_y}(\emptyset - 1)\frac{(\lambda_s - \lambda_f)}{\lambda_s \lambda_f}[\lambda_f(\emptyset - 1) - \lambda_s(\emptyset)]$$

For porous mesh or catalyst, the following solution is recommended (this equation considers the uncertainty of $k_y$)

$$\Psi = (\emptyset - 1)\frac{1 - \frac{\lambda_f}{\lambda_s} + \sqrt{\left(1 - \frac{\lambda_f}{\lambda_s}\right)^2 + 4}}{2} + \emptyset\frac{1 - \frac{\lambda_s}{\lambda_f} + \sqrt{\left(1 - \frac{\lambda_s}{\lambda_f}\right)^2 + 4}}{2}$$

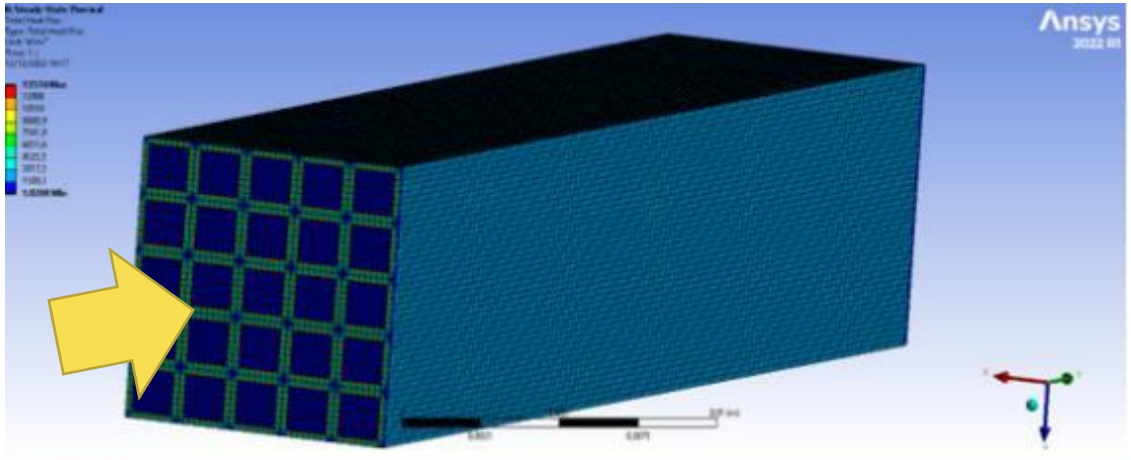
For fluid in the LTNE model

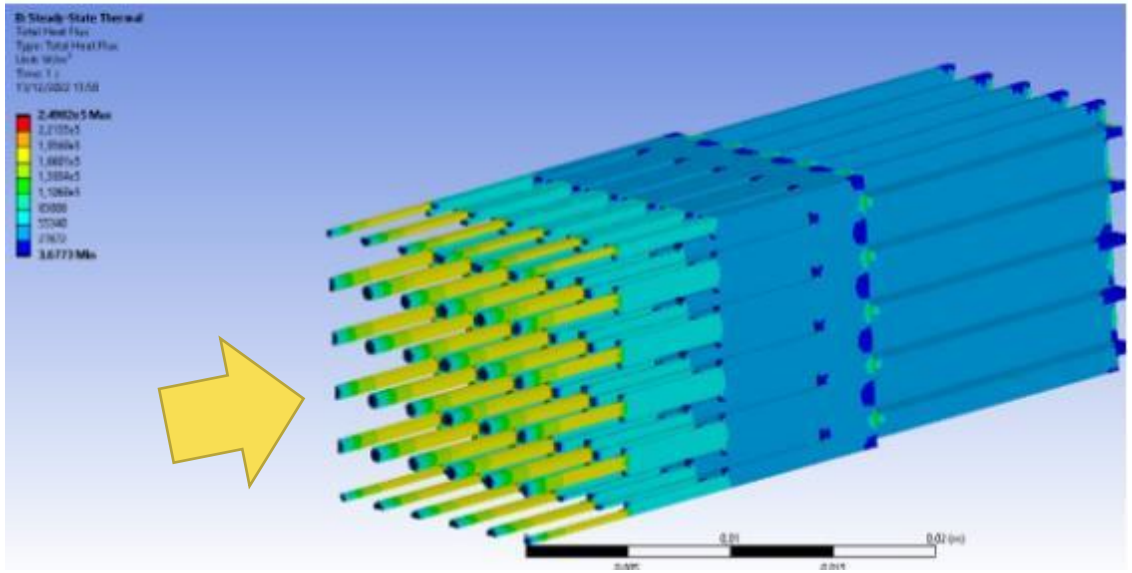
$$\Psi_f = \left(k_y\frac{1 - \frac{\lambda_f}{\lambda_s} + \sqrt{\left(1 - \frac{\lambda_f}{\lambda_s}\right)^2 + 4}}{2}\right)^{1-\emptyset} \times \left(k_y\frac{1 - \frac{\lambda_s}{\lambda_f} + \sqrt{\left(1 - \frac{\lambda_s}{\lambda_f}\right)^2 + 4}}{2}\right)^{\emptyset}$$

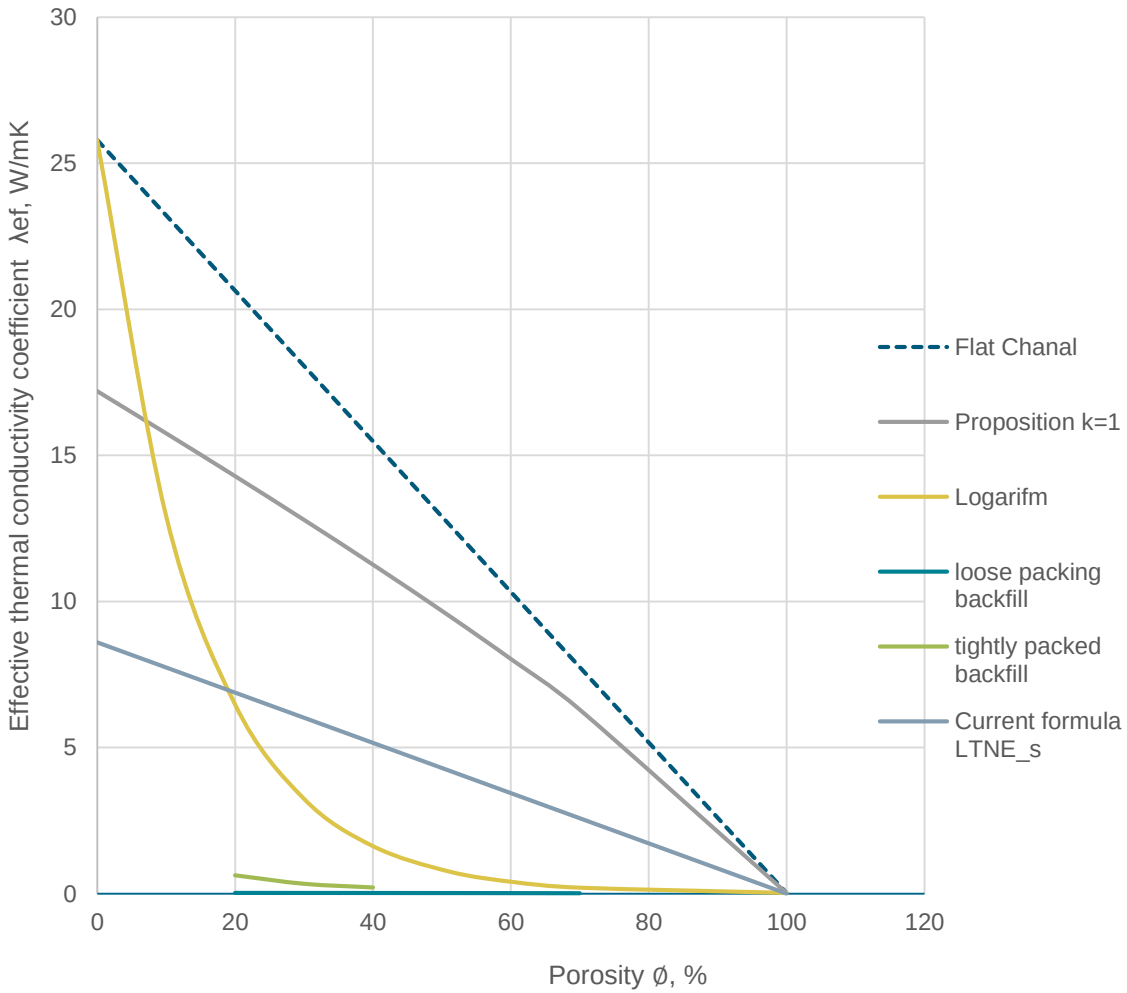
For porous open absorbers in the LTNE model

$$\Psi_s = \frac{1}{k_z}(\emptyset - 1)\frac{(\lambda_s - \lambda_f)}{\lambda_s \lambda_f}[\lambda_f(\emptyset - 1) - \lambda_s(\emptyset)]$$

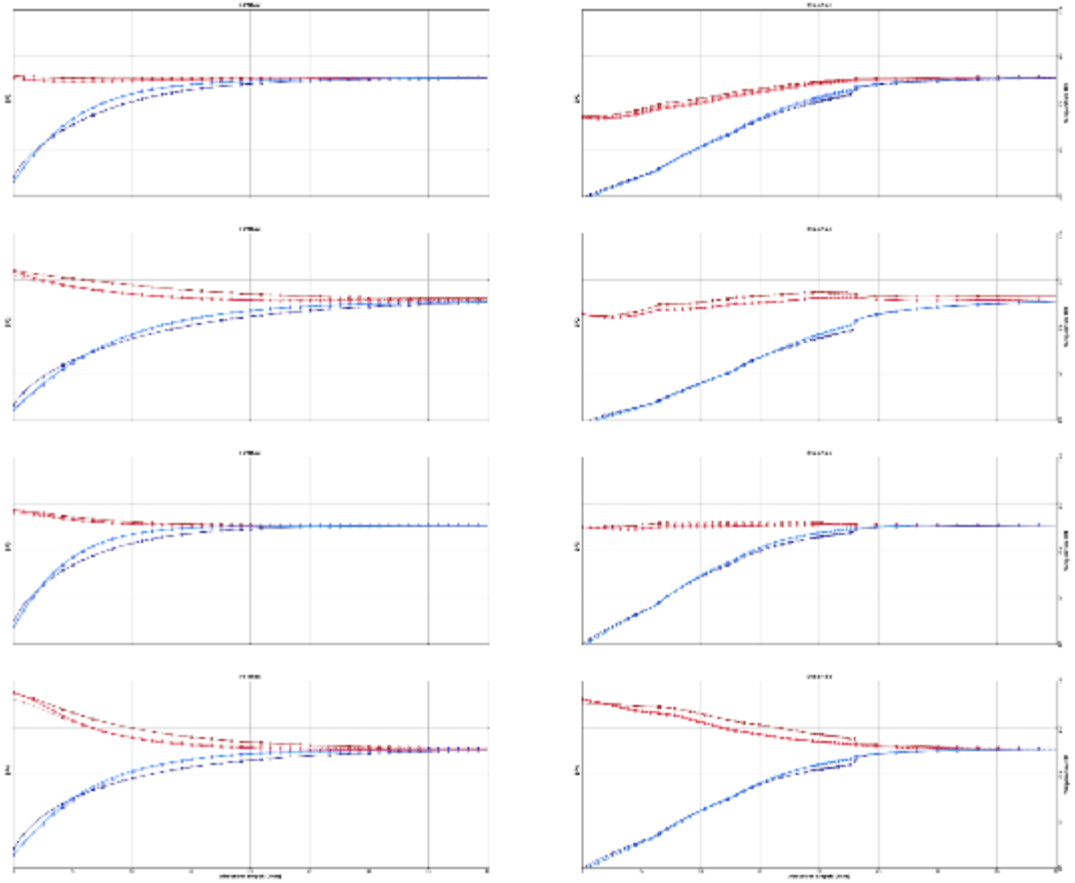
# Comparison of different models of calculation of the effective coefficient of thermal conductivity





# Nu vs. Pe dependences for the StepRec type absorber with the capillary effect and effect from the thickness of the thermal layer and with considering the heat exchange of internal layers



*Depth dependence of air (blue) and solid (red) temperatures of HiTRec (left) and StepRec (right) absorbers for four different operating points (different angle and power of the irradiation energy*

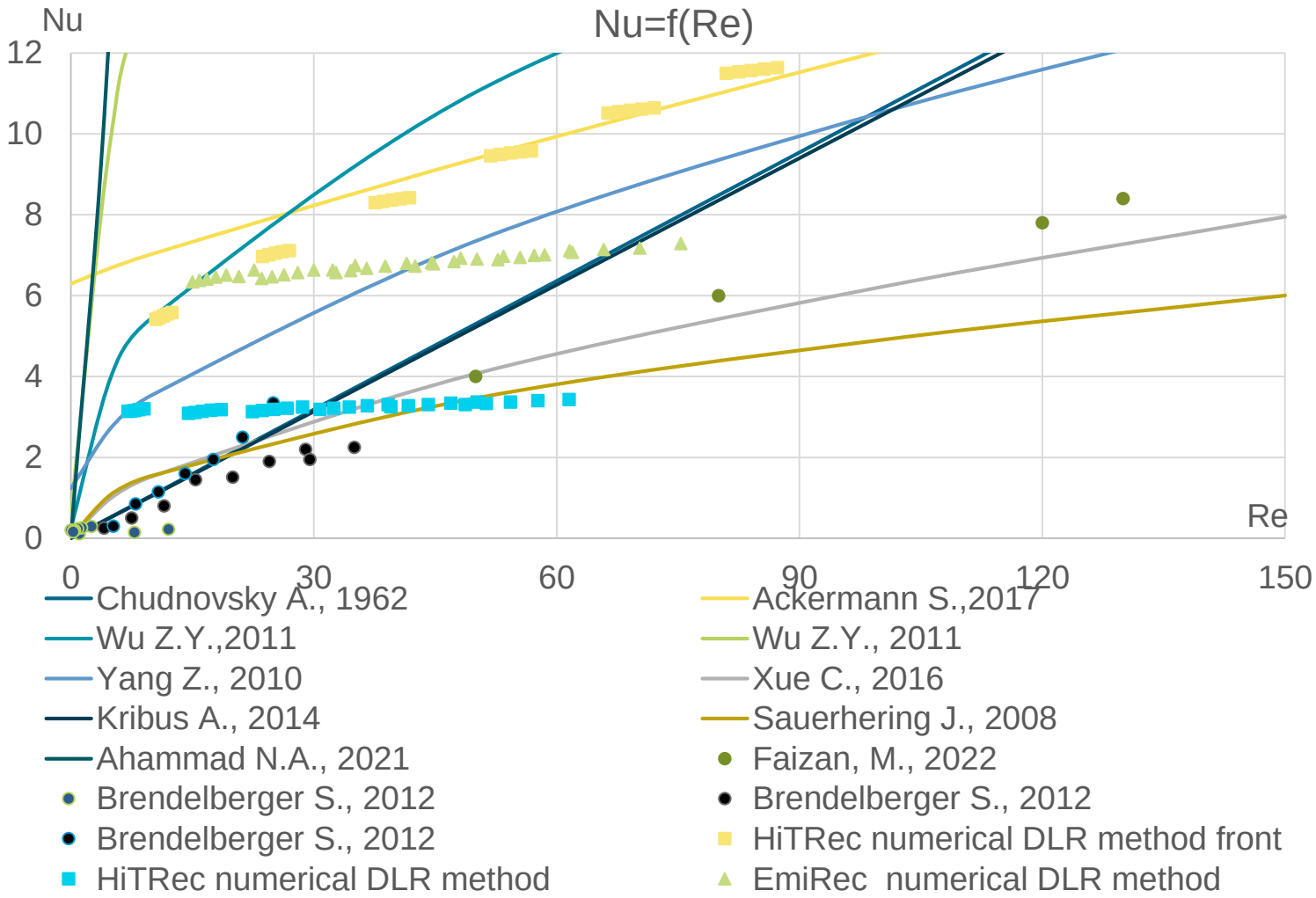
# Volumetric solid-fluid convective heat transfer coefficient

$$\frac{\partial}{\partial x}\left(\lambda_{s\_ef}\frac{\partial T}{\partial x}\right) - \alpha A_v\left(T_s - T_f\right) = 0$$

$$\frac{\partial}{\partial x}\left(\lambda_{f\_ef}\frac{\partial T}{\partial x}\right) + \alpha A_v\left(T_s - T_f\right) = 0$$

$$\alpha_v = \frac{Nu \cdot \lambda_f}{\langle d_{pore} \rangle}$$

$$Nu = \frac{Nu_0}{\tanh\left(2.43 Pr^{\frac{1}{6}} X^{\frac{1}{6}}\right)}$$



# How to determine the heat transfer coefficient?

The heat flux can be determined by the temperature gradient in the body or by the power of the electric heater. The wall temperature can be measured. The temperature of the liquid at a distance from the wall is a conditional value

Liquid temperature - average mass temperature in the channel

$$\overline{T} = \frac{\int \rho C_p w T dS}{\int \rho C_p w dS}$$

$$Nu = cRe^n Pr_f{}^m \left(\frac{Pr_f}{Pr_s}\right)^{0.25}$$

$$c = f(\emptyset),\ n = f(d_e, \overline{u_b}),\ m = f(d_e)$$

$$lnNu = f(\emptyset) + f(d_e, \overline{u_b}) lnRe + f(d_e) lnPr_f + 0{,}25 \ln\left(\frac{Pr_f}{Pr_s}\right)$$

$\left(\frac{Pr_f}{Pr_s}\right)^{0.25}$ Mikheev amendment

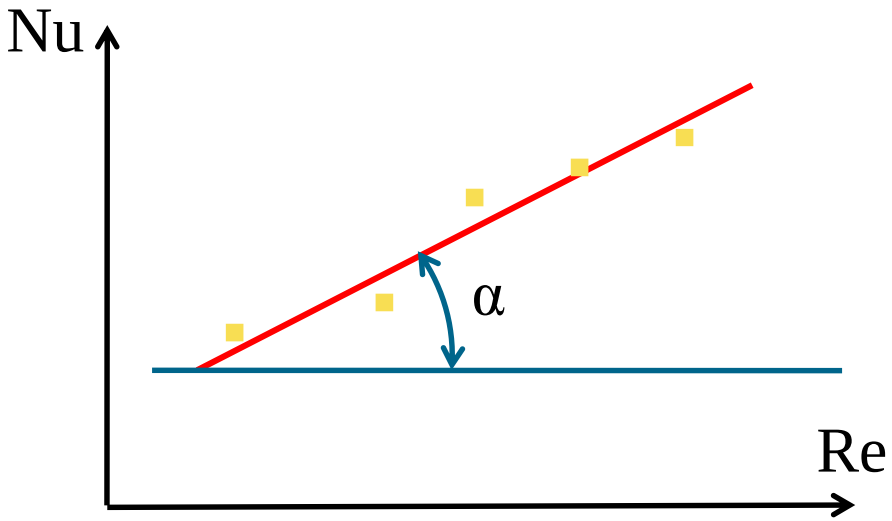
**The average heat transfer coefficient on any surface F:**

$$\bar{\alpha} = \frac{\bar{q}}{\overline{\Delta T}} = \frac{\int_F q dF}{\int_F \left(T_{ж} - T_{cm}\right) dF}$$

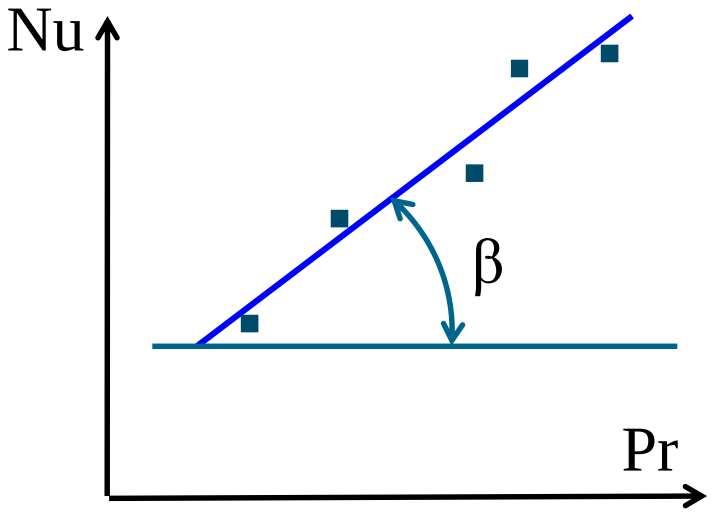
# Example of experimental data processing: at forced convection usually

$$\mathrm{Nu} = C\,\mathrm{Re}^{n}\,\mathrm{Pr}^{m}$$

$$\ln\mathrm{Nu} = n\ln\mathrm{Re} + m\ln\mathrm{Pr} + C_1$$



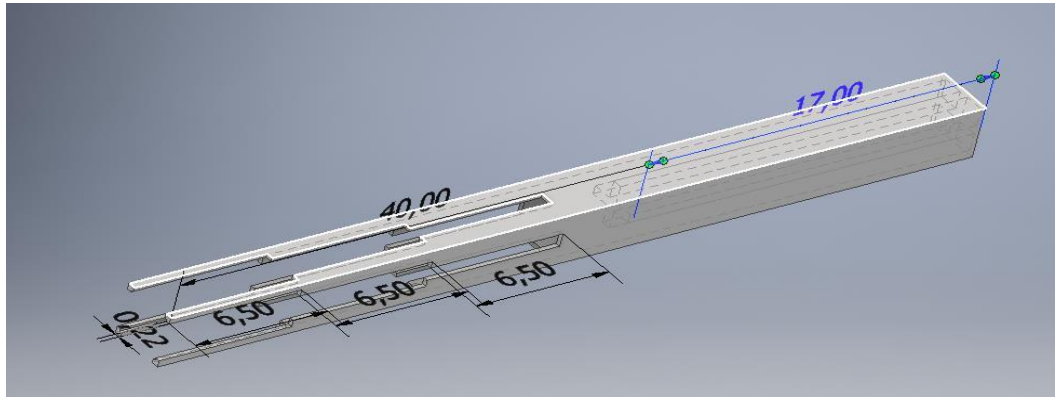

Pr = const

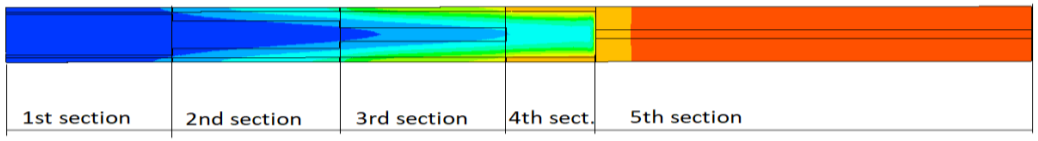


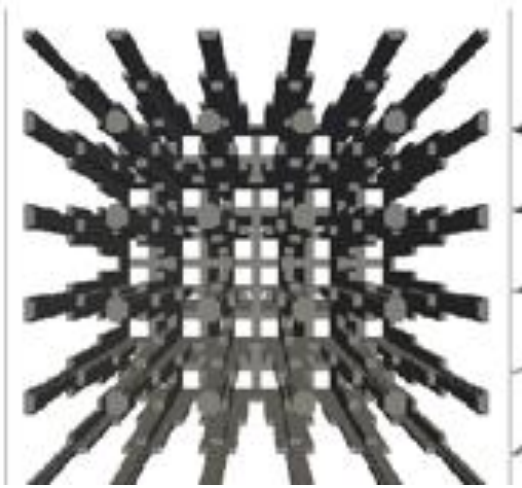

Re = const

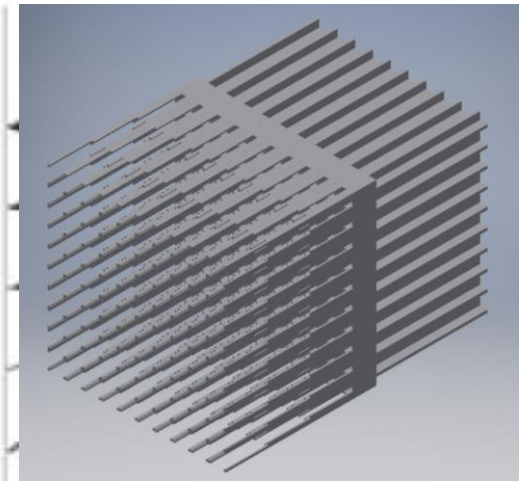
$$n = \mathrm{tg}\alpha \qquad m = \mathrm{tg}\beta \qquad C = \frac{\mathrm{Nu}}{\mathrm{Re}^{n}\,\mathrm{Pr}^{m}}$$

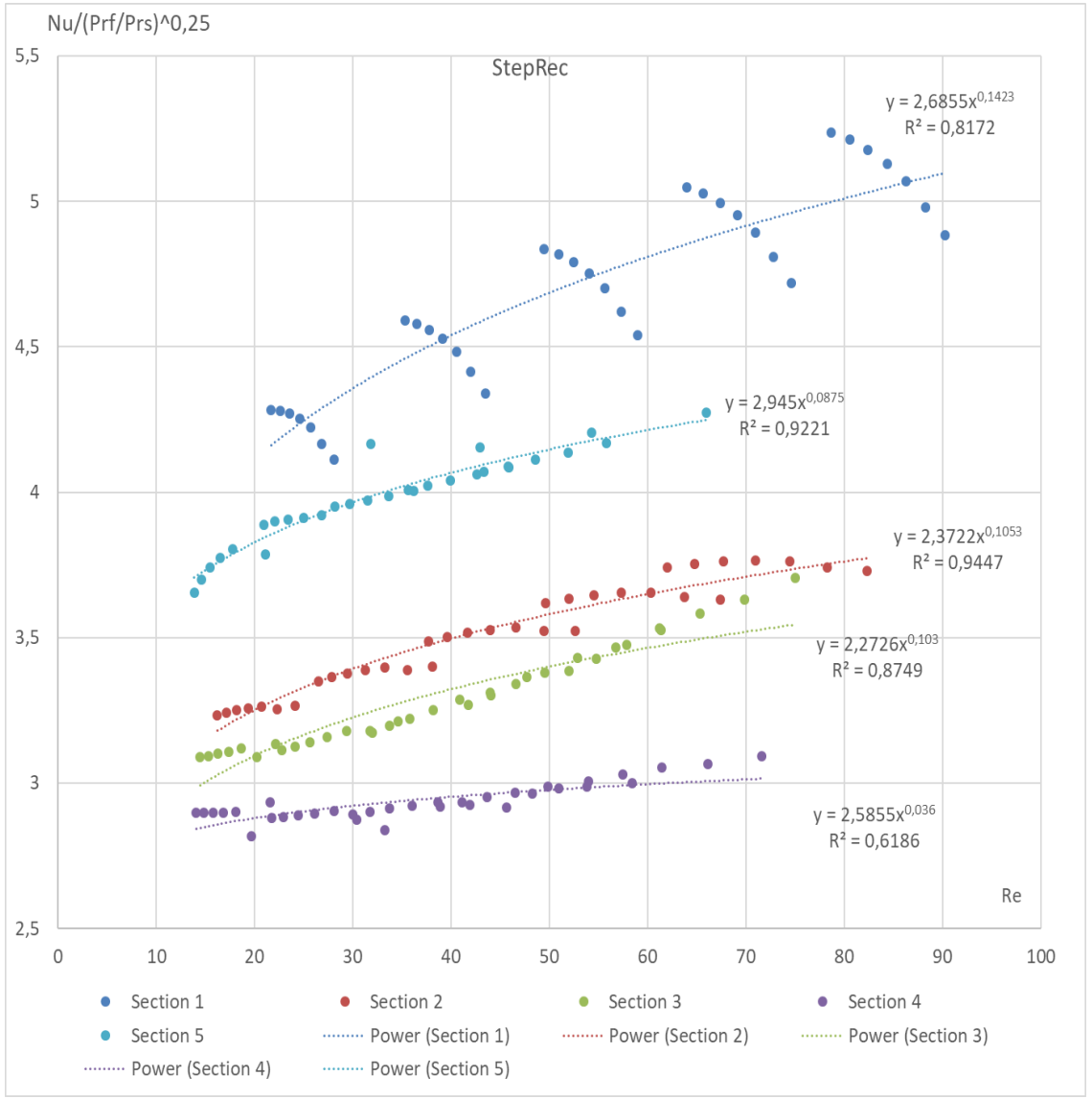
# Probleme


17,00
40,00
6,50
6,50
6,50
10
12

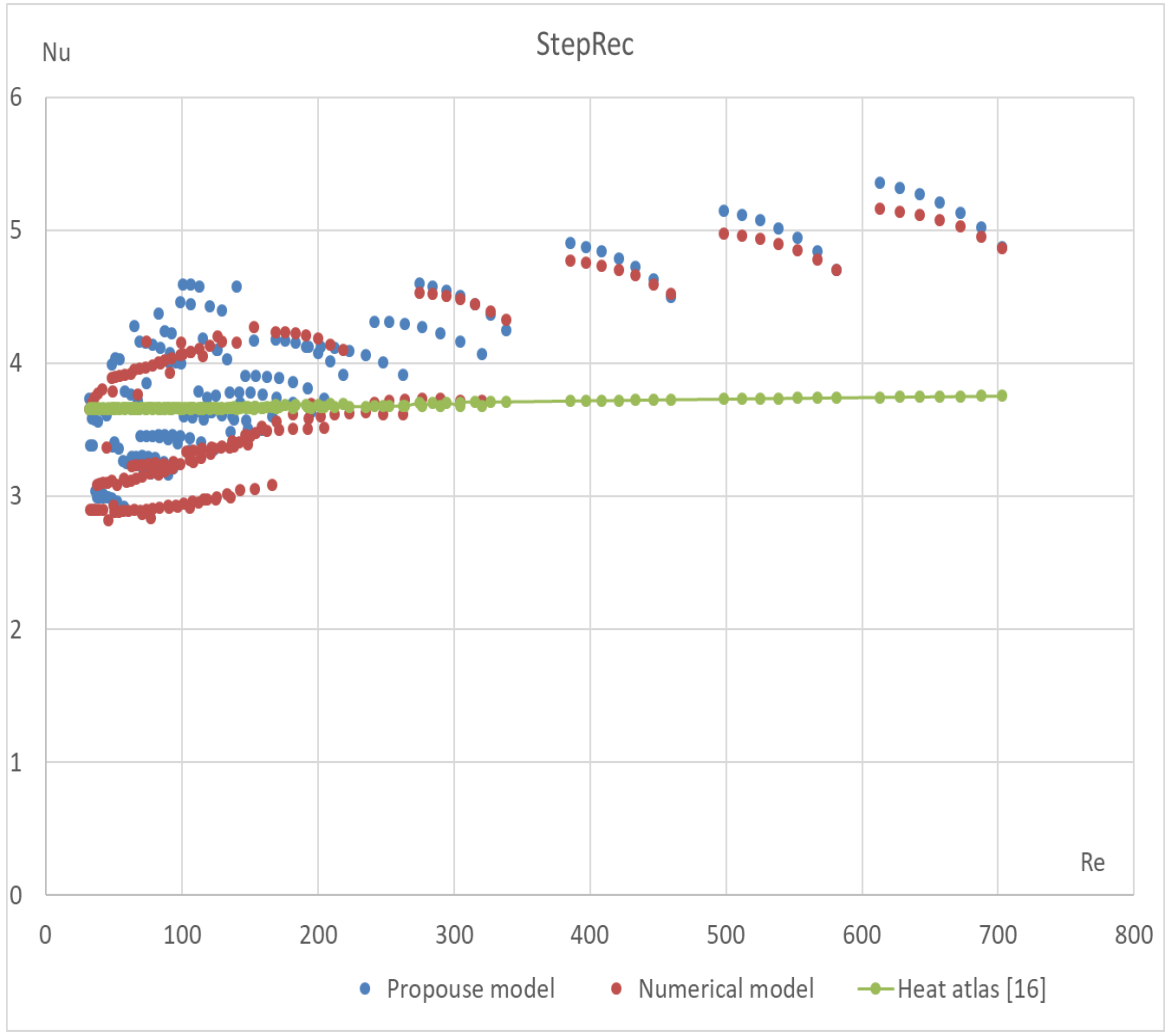

1st section
2nd section
3rd section
4th sect.
5th section

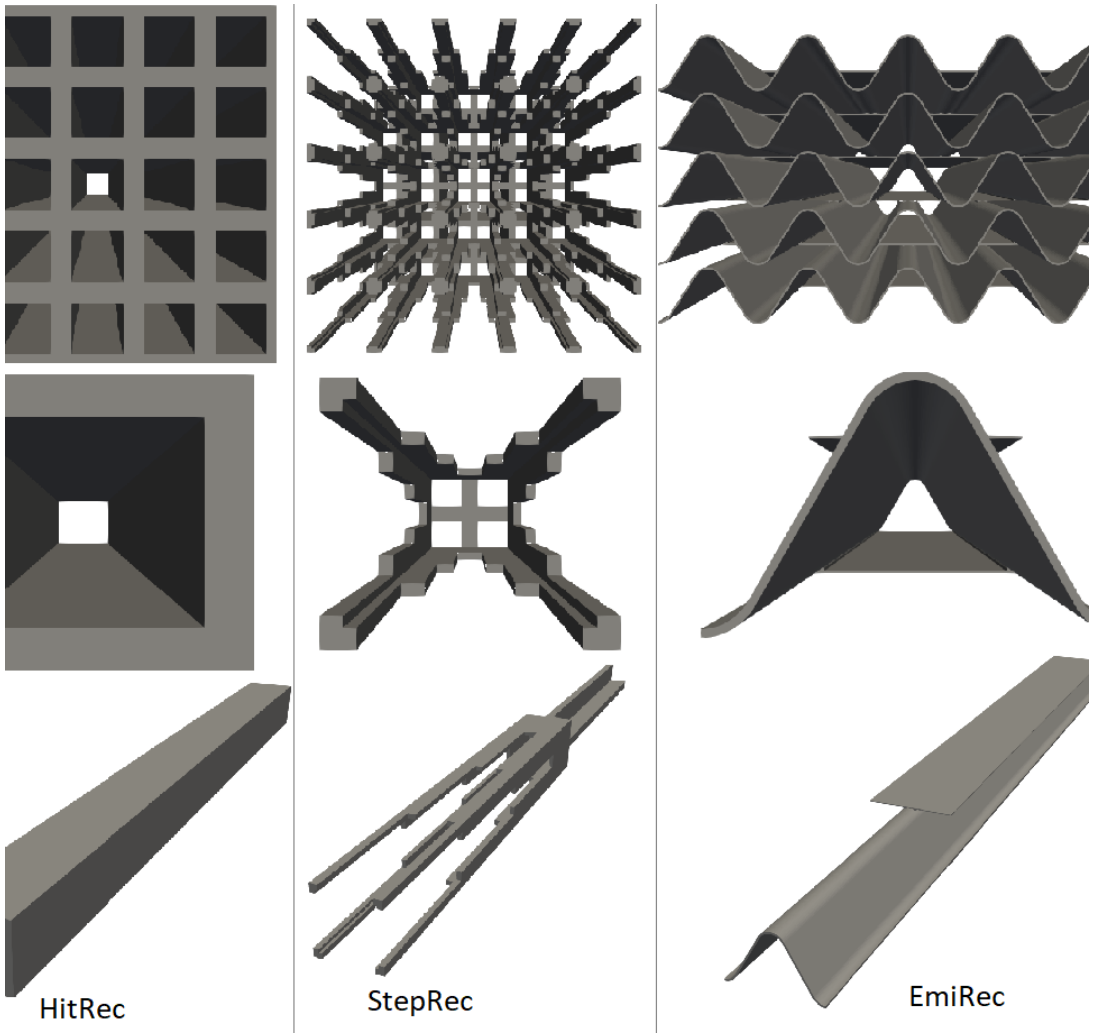





Nu/(Prf/Prs)^0,25
StepRec
y = 2,6855x^0,1423
R² = 0,8172
y = 2,945x^0,0875
R² = 0,9221
y = 2,3722x^0,1053
R² = 0,9447
y = 2,2726x^0,103
R² = 0,8749
y = 2,5855x^0,036
R² = 0,6186
Re
5,5
5
4,5
4
3,5
3
2,5
0
10
20
30
40
50
60
70
80
90
100
Section 1
Section 2
Section 3
Section 4
Section 5
Power (Section 1)
Power (Section 2)
Power (Section 3)
Power (Section 4)
Power (Section 5)

# Receiver´s absorber



# Analytical Determination of Nusselt Numbers for Convective Heat Transfer Coefficients in Channel Macroporous Absorbers

$$Nu = \mathrm{c} \cdot K^{stability} \cdot \mathrm{Exp}\left(-0{,}5\frac{T_{in}}{T_w}\right) \cdot \frac{\mathrm{d}_e}{l_t} \cdot Re^{n} \cdot {Pr_f}^{0.33} \cdot \left(\frac{Pr_f}{Pr_s}\right)^{0{,}25},$$

$$\mathrm{c} = \mathrm{c}_1 \cdot exp\left(\mathrm{c}_2 \cdot tan\left(\frac{1-\emptyset}{\emptyset}\right)\right),$$

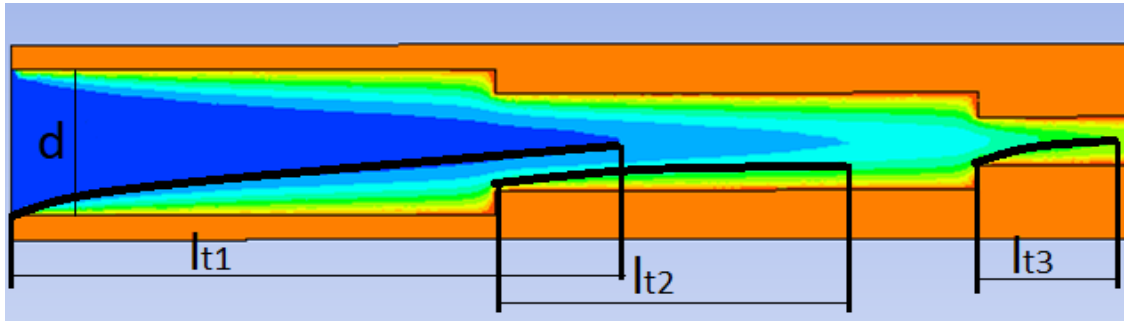
$$K^{stability} = \begin{cases} 1 \; if \; l_t^{previous} < L^{previous} \\ 1 - 0{,}1\dfrac{l_t^{previous} - L^{previous}}{L} \\ 0{,}9 \; if \; l_t^{previous} > L^{previous} \end{cases},$$

$$\mathrm{n} = 0{,}015\mathrm{Ln}\left(\frac{\mathrm{d}_e}{L}\right) + \mathrm{c}_3\left(\frac{c}{\emptyset}\xi_{Shape}\right)^{\mathrm{c}_4},$$

$$\xi_{Shape} \approx \frac{\mathrm{d}_e}{d_e^{previous}} + 1 + \frac{\mathrm{d}_e}{d_e^{next}}.$$

$$l_T = k_T \cdot Re \cdot d \cdot Pr_{\bar{f}}$$

$$k_T = 0{,}07$$




where $\xi_{\mathrm{Shape}}$ - coefficient changes shape of channel;

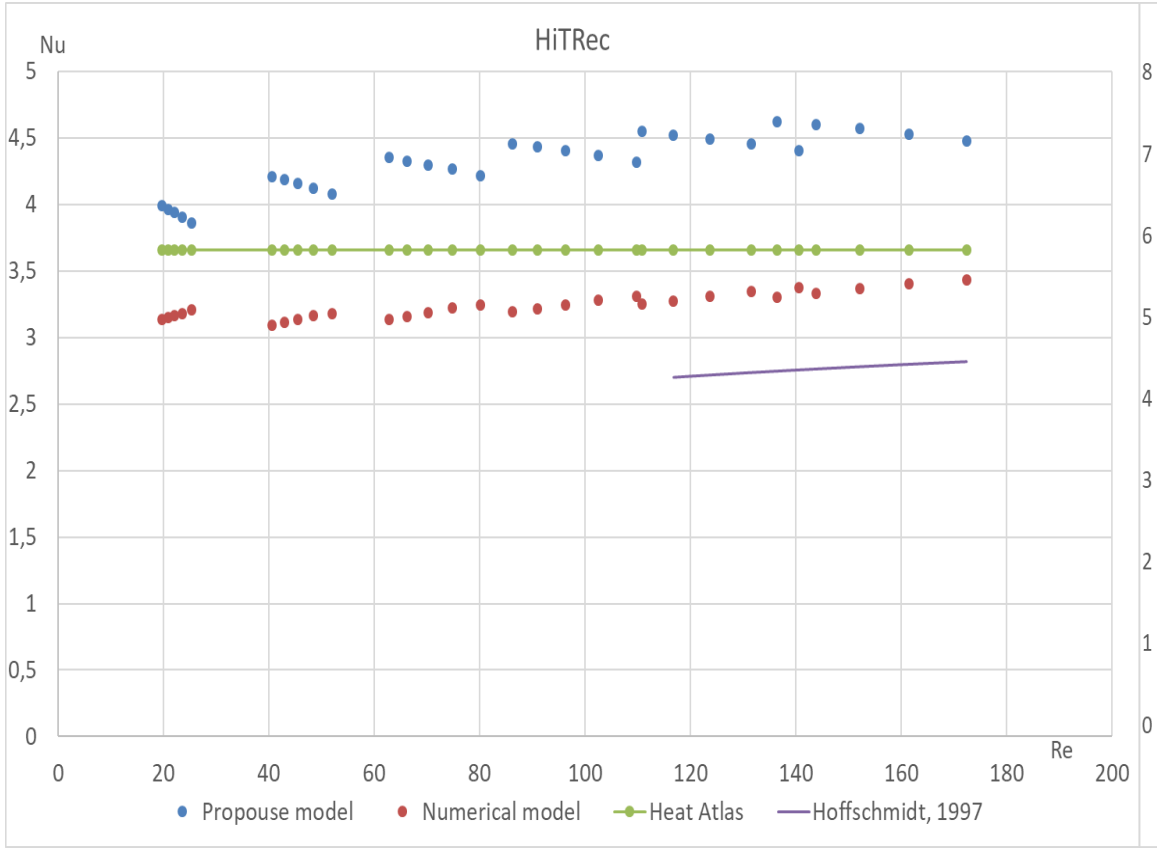
for first section $\xi_{\mathrm{Shape}} = \emptyset + 1 + \frac{\mathrm{d_e}}{\mathrm{d_e^{next}}}$ ;

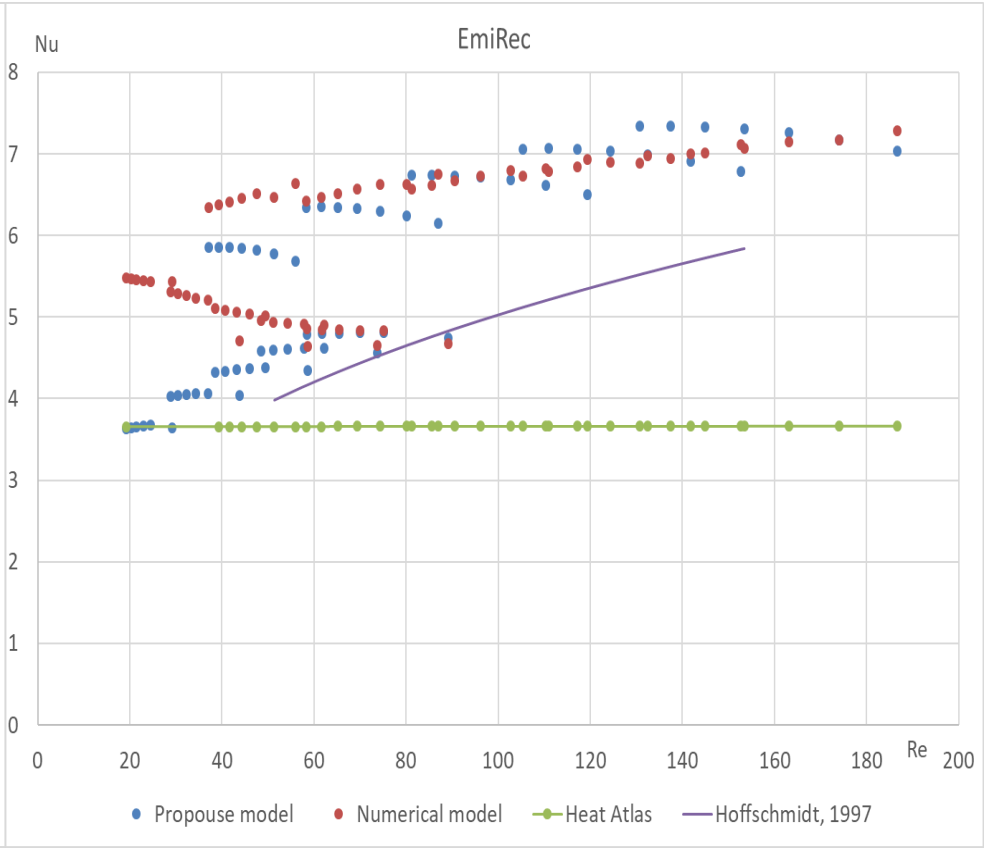
for last section $\xi_{\mathrm{Shape}} = \frac{\mathrm{d_e}}{\mathrm{d_e^{previous}}} + 1 - \emptyset$;

L – length of the channel;
lt – length of the thermal boundary layer
de – hydraulic diameter.

$\mathrm{c}_1 = 0{,}1;\ \mathrm{c}_2 = 0{,}525;\ \mathrm{c}_3 = 1{,}1;\ \mathrm{c}_4 = -0{,}09$ are structural constants.

# Validation of the Nu number of the dependence on Re for all sections of absorbers with 30 different modes



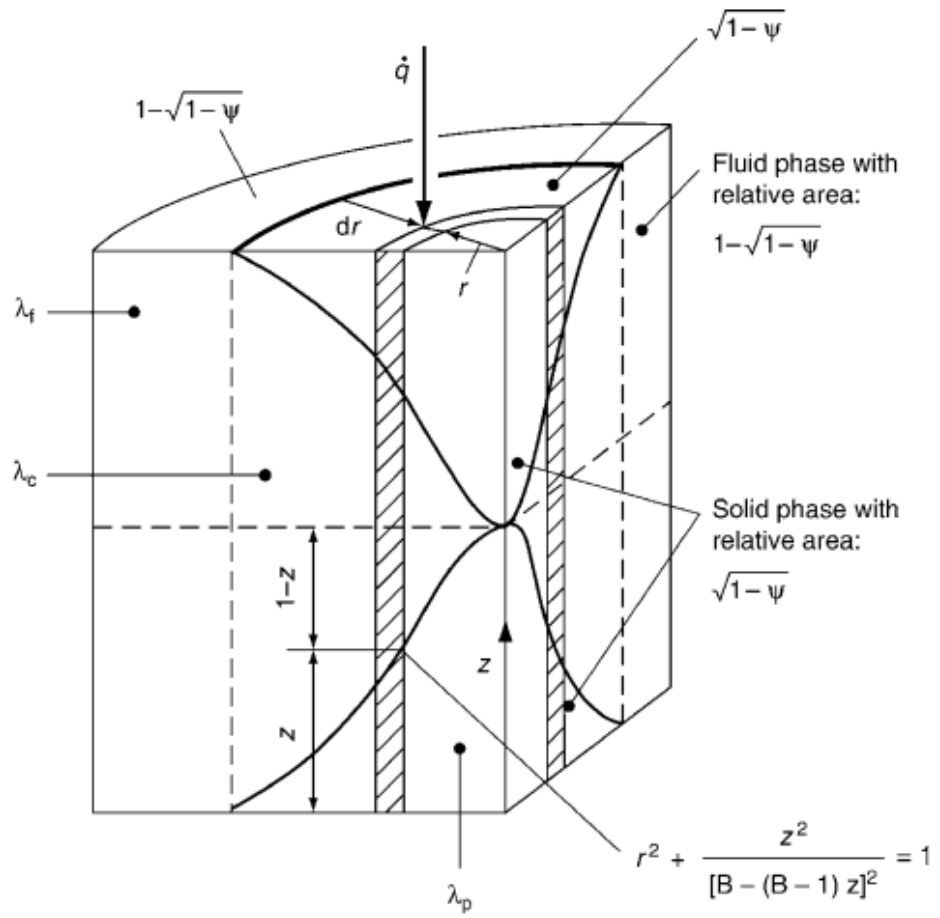



# Conclusion of research

- 1. New analytical calculation formula for the effective thermal conductivity coefficient for porous media with open pores has been proposed, which can be applied to the solar absorbers. The proposed formula includes dislocation vector that allows to calculate different porous structures with the same porosity value.
- 2. The proposed criterion dependence for the calculation of the Nusselt number includes the calculation of the lengths of the hydrodynamic and aerodynamic layers. The constants for the proposed dependencies for modern types of solar receiver absorbers are obtained. Validation of the results on a numerical model showed high reliability of the obtained results.

# Heat Transfer to Mechanically Agitated Beds with Latent Sink

## *VDI Heat Atlas 2010:*




Unit cell of the model of Zehner/Bauer/Schlünder.

According to Fig. 3, the reduced thermal conductivity of the bed can be calculated to

$$k_{bed} = 1 - \sqrt{1-\psi} + \sqrt{1-\psi}\ \ k_c, \qquad (5a)$$

with

$$k_c = \frac{2}{N}\left(\frac{B}{N^2}\frac{k_p - 1}{k_p}\ln\frac{k_p}{B} - \frac{B+1}{2} - \frac{B-1}{N}\right), \qquad (5b)$$

and

$$N = 1 - (B/k_p), k_c = \lambda_c/\lambda_f. \qquad (5c, d)$$

Here, $\lambda_c$ is the thermal conductivity of the core of the unit cell [5]. The deformation parameter $B$ is derived for spherical particles by putting the porosity of the unit cell equal to the porosity of the packed bed. This leads approximately to

$$B = 1.25\left(\frac{1-\psi}{\psi}\right)^{10/9}. \qquad (5e)$$

Heat transfer kinetics can, again, be expressed in the form

$$\alpha_{WS} = \dot{q}_0/(\vartheta_W - \vartheta_0), \qquad (16)$$

$$\alpha_{bed} = \dot{q}_0/(\vartheta_0 - \vartheta_{bed}). \qquad (17)$$

The contact heat transfer coefficient $\alpha_{WS}$ does not change in principle and can be calculated according to Sect. 4.1 for pure vapor atmosphere. On contrary, the consumption of heat by evaporation in the interior of the bed (the latent heat sink) has a significant influence on the penetration coefficient, which is in this case obtained to

$$\alpha_{bed} = \frac{2}{\sqrt{\pi}}\frac{\sqrt{(\rho\lambda c)_{bed,dry}}}{\sqrt{t_R}}\frac{1}{\operatorname{erf}\zeta} = \frac{\alpha_{bed,dry}}{\operatorname{erf}\zeta}. \qquad (18)$$

# PRACTICAL SOLUTIONS IN DLR

**Part 3 of „Heat and mass transfer in high temperature solar technology for cement production”**

Cheilytko Andrii, DLR 26.11.2024 | New Delhy, Indian Institute of Technology Delhi

# Where are we?

Müller, Amelie und Harpprecht, Carina und Sacchi, Romain und Maes, Ben und van Sluisveld, Mariesse und Daioglou, Vassilis und Savija, Branko und Steubing, Bernhard (**2024**) *Decarbonizing the cement industry: Findings from coupling prospective life cycle assessment of clinker with integrated assessment model scenarios.* Journal of Cleaner Production. Elsevier. doi: 10.1016/j.jclepro.2024.141884.

**Overview of scenario results from IMAGE as input to LCA model**

| | SSP2-Base (3.5°C) | SSP2-2.6 (2°C) | SSP2-1.9 (1.5°C) |
|---|---|---|---|
| **Foreground system** | | | |
| Process regionalization | 26 IMAGE regions | 26 IMAGE regions | 26 IMAGE regions |
| Kiln technology mix | No CCS kilns | Mainly MEA CCS + DS CCS | Mainly MEA CCS + Oxy CCS |
| Fuel switch | Fuel shares stay largely similar | Higher uptake of modern biomass, large regional variations | Higher uptake of natural gas next to modern biomass, large regional variations |
| Clinker-to-cement ratio | 71% CTC (global average) by 2060 | 67% CTC (global average) by 2060 | 65% CTC (global average) by 2060 |
| Thermal energy efficiency[a] | Up to -13% by 2060, depend. on technology and region | Up to -21% by 2060, depend. on technology and region | Up to -21% by 2060, depend. on technology and region |
| Electric energy efficiency[b] | Up to -21% by 2060, depend. on technology | Up to -21% by 2060, depend. on technology | Up to -21% by 2060, depend. on technology |
| **Background system** | | | |
| Futurization of background system - electricity, steel, fuels, transport, CCS and non-$CO_2$ emission | IMAGE SSP2-Base | IMAGE SSP2-2.6 | IMAGE SSP2-1.9 |

**Fig. 3.** Scenario results from IMAGE used in this study and their implications in the different scenarios. [a] Thermal energy efficiency from IMAGE undergoes corrections documented in Figs. A5–6, [b] electric energy efficiency is taken directly from IMAGE model documentation; see Table A9.

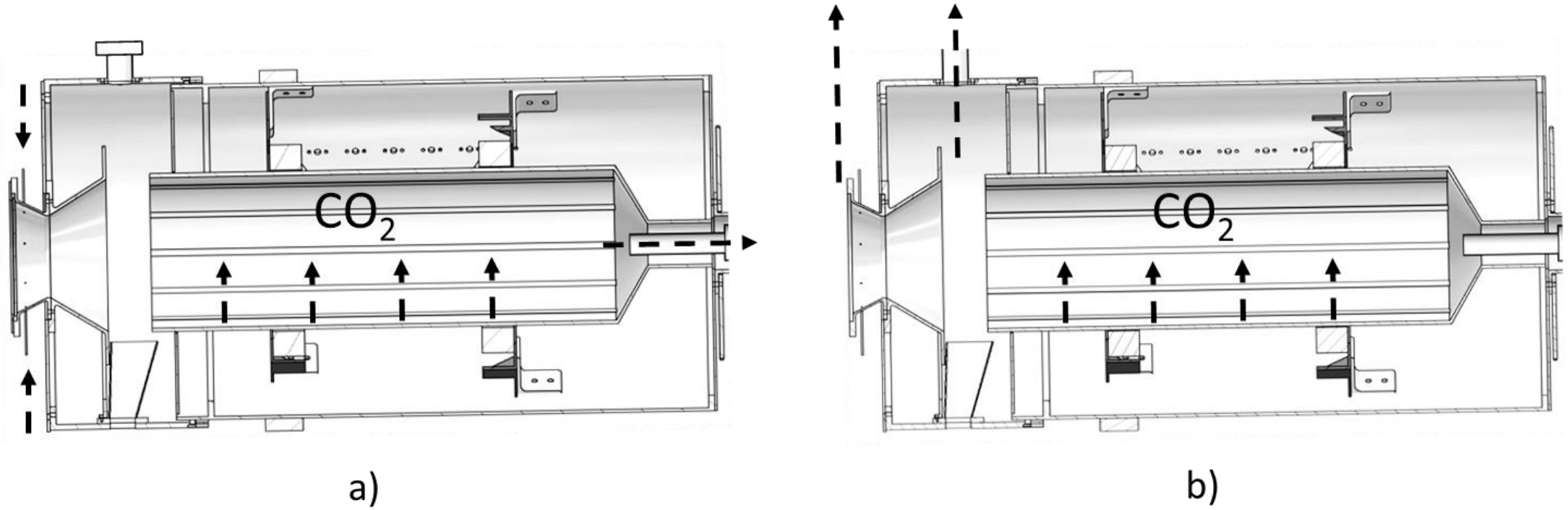
## 5. Conclusion

This study has presented a prospective life cycle assessment (pLCA) for the global clinker production until 2060 for a 3.5°C-baseline, 2°C- and 1.5°C-compatible scenario, using scenarios from the IMAGE integrated assessment model. A deep futurization of the supply chains in the life cycle inventory database ecoinvent v3.9.1 is achieved by combining scenarios for foreground clinker production with consistent scenarios for other major background sectors.

**Our life-cycle-based results show that a net-zero clinker production may not be achieved by 2060 with the production-oriented transition pathways considered in this study.** Using pLCA, any

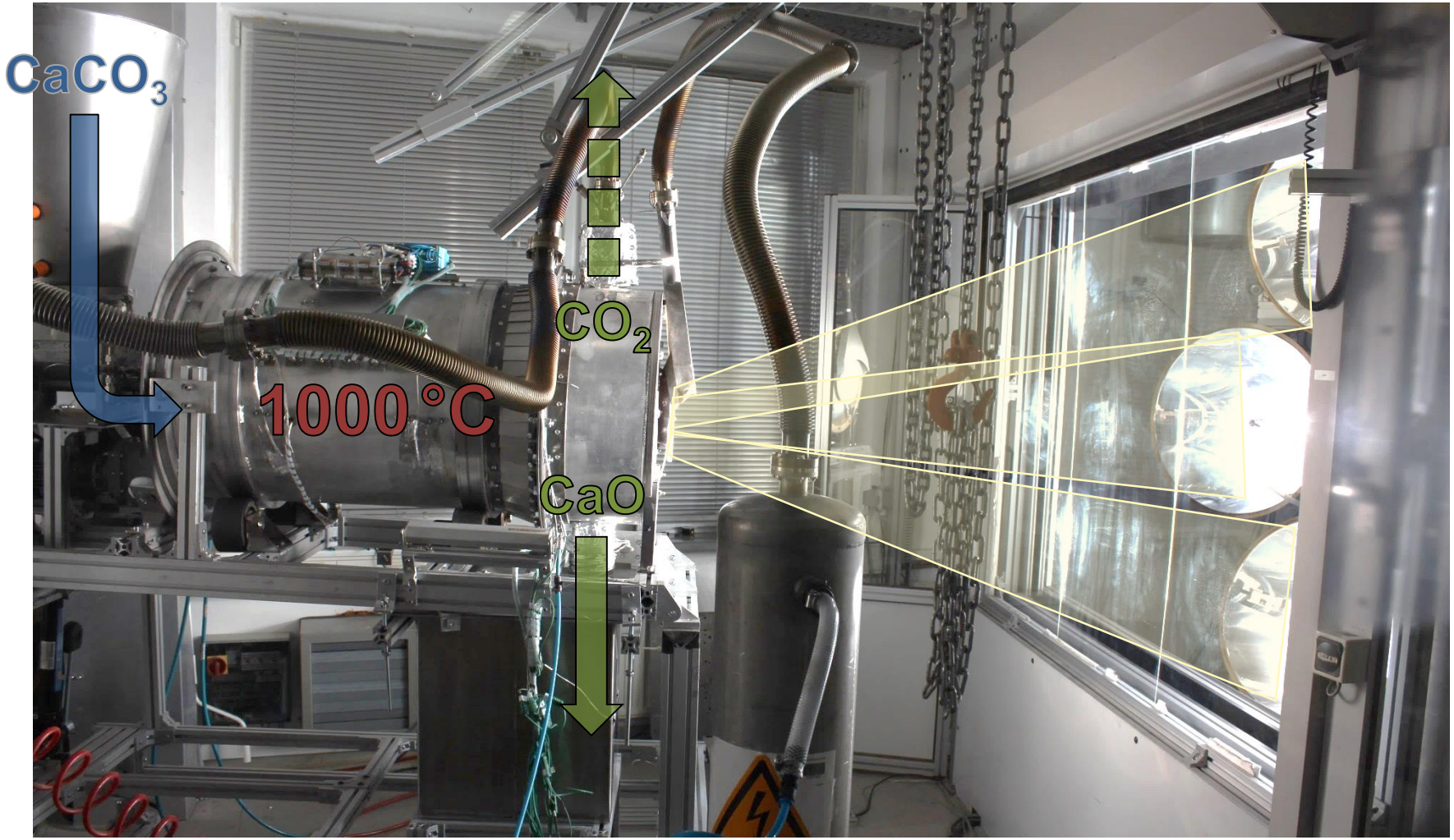
CCS - Carbon capture and storage
IMAGE - Integrated Model to Assess the Global Environment
CTC Clinker-to-cement

# Visualisation of (a) the closed configuration where purge gas flow can be injected at the window and suction can be applied at the back and (b) the open configuration where suction can be applied before and behind the aperture



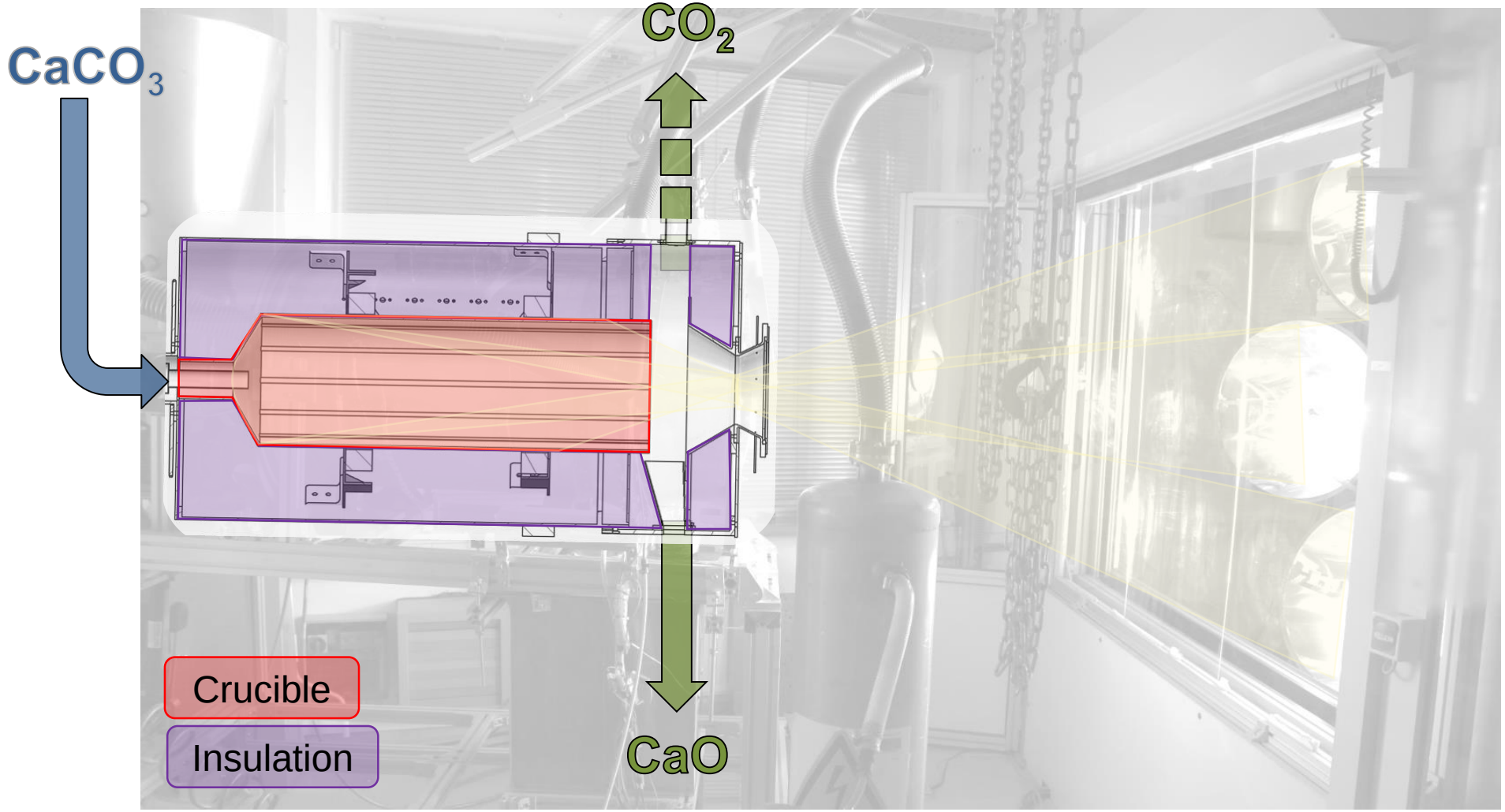

Source: Gkiokchan Moumin, Stefania Tescari et al. Solar treatment of cohesive particles in a directly irradiated rotary kiln. https://doi.org/10.1016/j.solener.2019.01.093.

# Principle of solar rotary kiln for calcination
## Example: limestone




Pasabeyoglu, Pelin und Moumin, Gkiokchan und de Oliveira, Lamark und Roeb, Martin und Akata, Burcu (2023) *Solarization of the zeolite production: Calcination of kaolin as proof-of-concept.* Journal of Cleaner Production, 414 (137611).

# Cut view of solar calciner





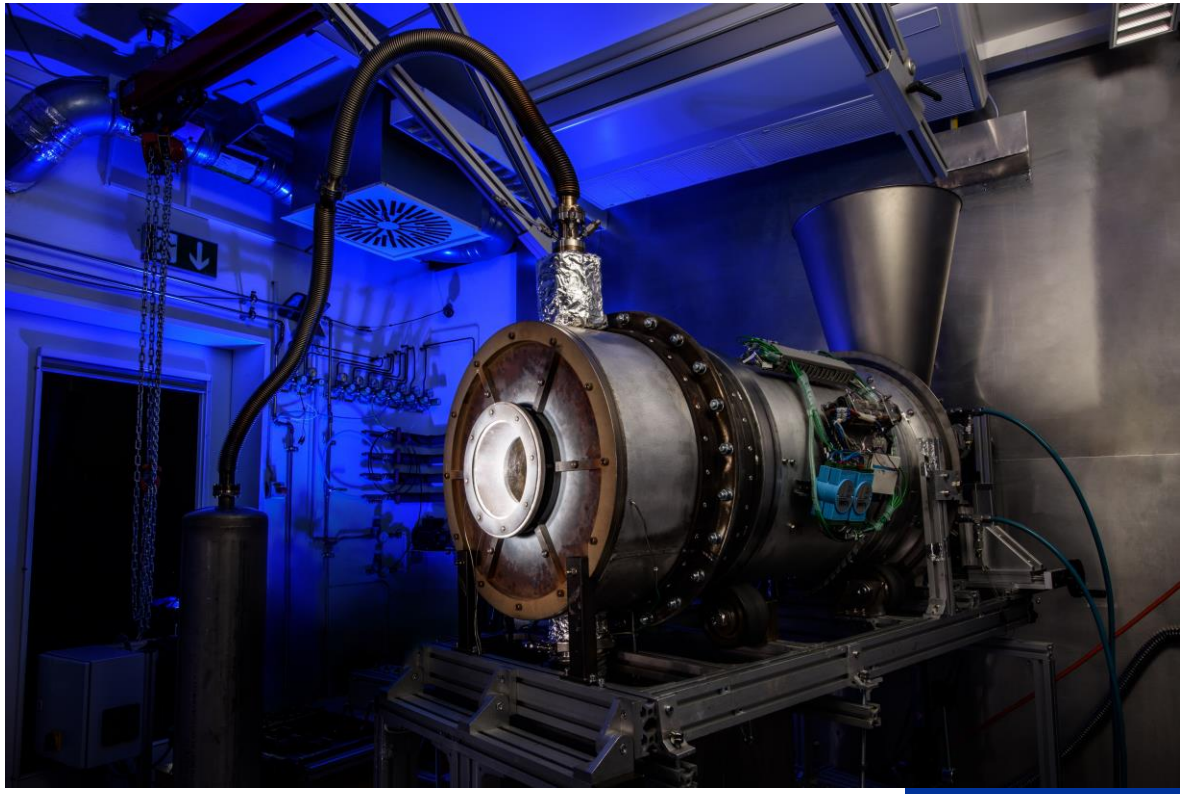



Source: Institute for Future Fuels | Solar-Chemical Process Development | Linder Höhe | 51147 Cologne

# Overview of research on the rotary kiln
## Completed

### Calcination of cement raw meal

- Industrial meal from the cement manufacturer
- 17 runs with calcination rates up to >95 %
- Treated continuous mass flow from 4-12 kg/h
- Heat input through radiation up to 14 kW
- Investigation of mixing and heat input



Openly accessible publications:

Solar treatment of cohesive particles in a directly irradiated rotary kiln (2019)

Impact of bed motion on the wall-to-bed heat transfer for powders in a rotary kiln and effect of built-ins (2021)



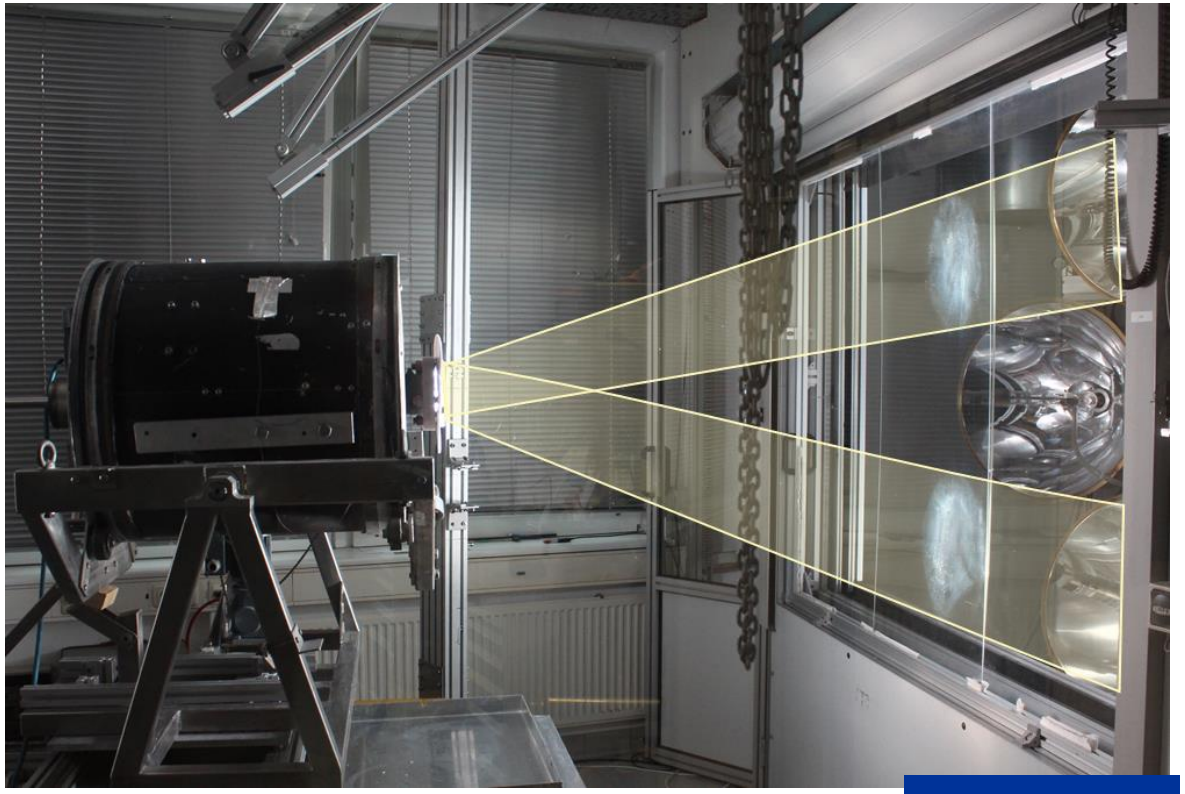


Source: Institute for Future Fuels | Solar-Chemical Process Development | Linder Höhe | 51147 Cologne

# Overview of research on the rotary kiln
## Completed

### Calcination of kaolin and halloysite

- Raw materials from Turkey for the synthesis of zeolites (nanofilters)
- 20 runs in the temperature range 600-1000 °C
- Batch operation with 1 kg of material at a time
- Heat input through radiation up to 6 kW



Openly accessible publication:

Solarization of the zeolite production: Calcination of kaolin as proof-of-concept (2023)





Source: Institute for Future Fuels | Solar-Chemical Process Development | Linder Höhe | 51147 Cologne

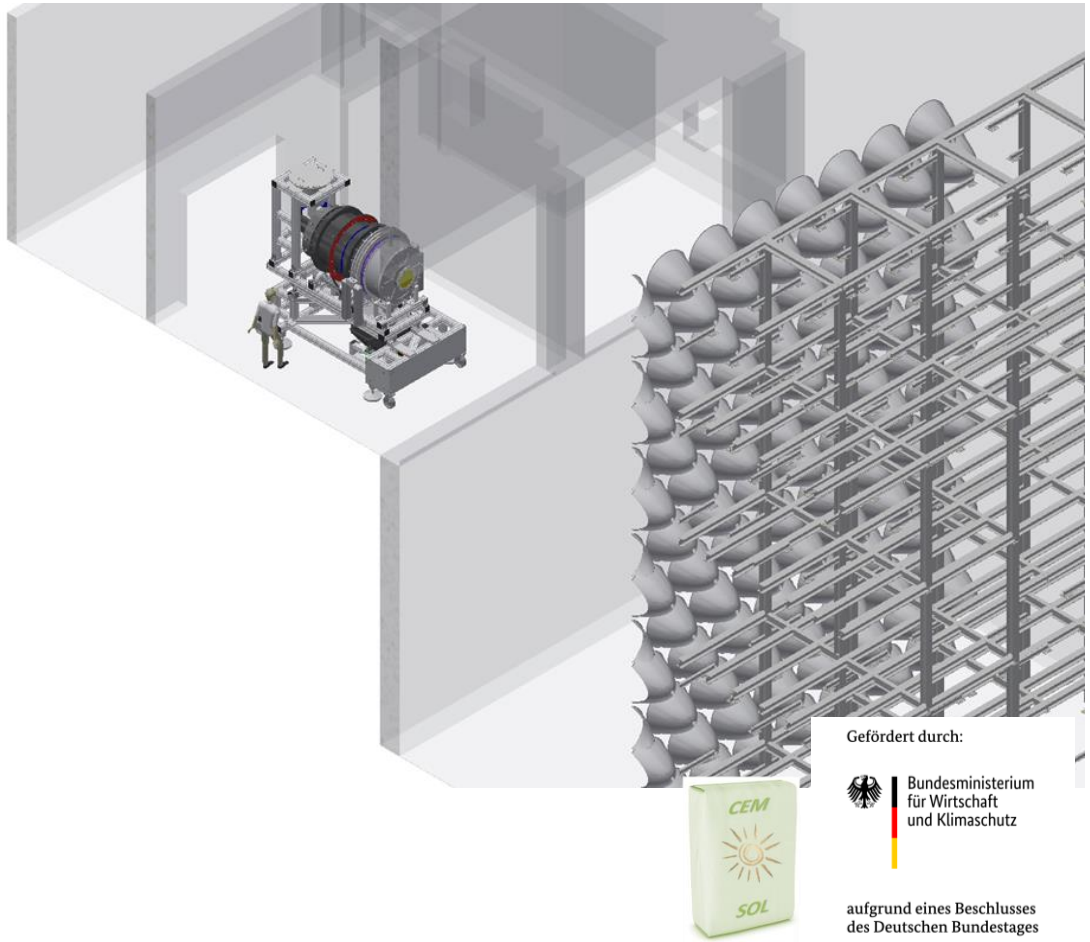
# Overview of research on the rotary kiln
## Ongoing

### Calcination of limestone

- The aim is to feed quicklime into the cement process
- Continuous operation with 40-95 kg/h
- Heat input through radiation 50-100 kW
- As pure as possible separation of the $CO_2$
- Trials planned for early 2025

Further information:

BMWK project CemSol (2021-2025)





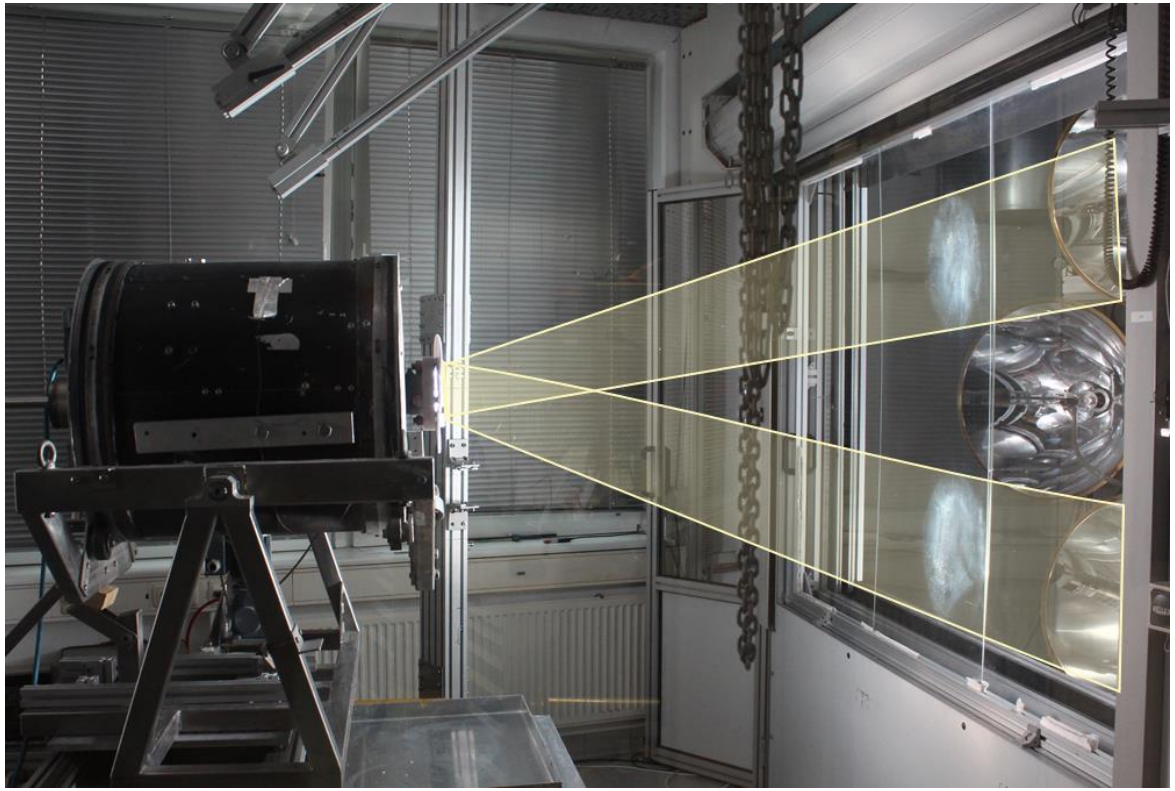


Source: Institute for Future Fuels | Solar-Chemical Process Development | Linder Höhe | 51147 Cologne

# Overview of research on the rotary kiln
## Ongoing

### Calcination of kaolin

- Raw materials from Turkey for addition to cement as SCM
- Tests in the temperature range 600-1000 °C
- Batch operation with 1 kg of material at a time
- Heat input through radiation <10 kW



Source: Institute for Future Fuels | Solar-Chemical Process Development | Linder Höhe | 5114

# Overview of research on the rotary kiln

In addition, studies and work in the field of

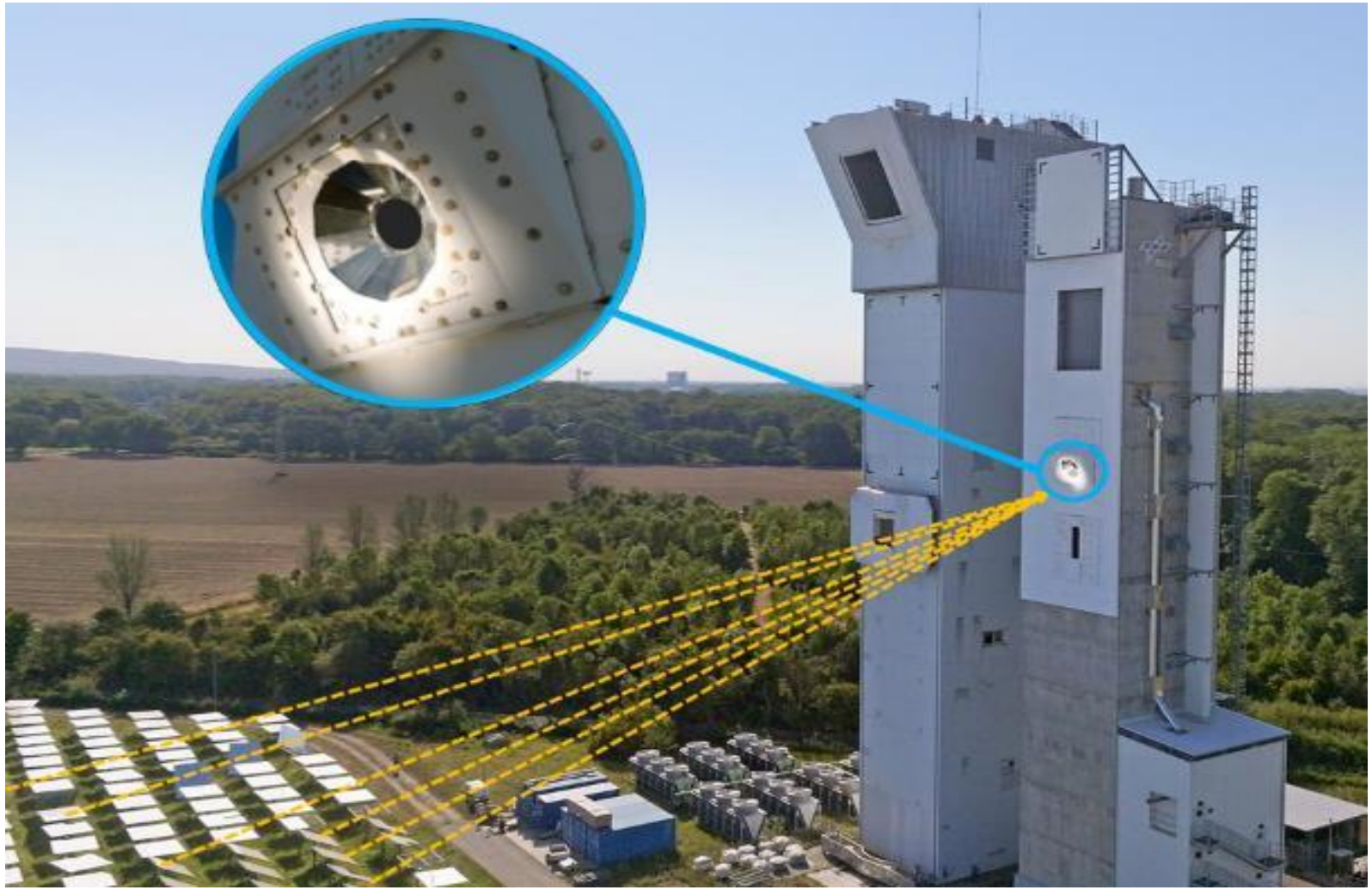
- Thermal treatment of dolomite
- Calcination and firing of magnesium carbonate
- Pyrolysis of biomass
- Reduction and oxidation of metal oxide particles

If you have any questions, please do not hesitate to contact me:

Dr.-Ing. **Gkiokchan Moumin** | Team Leader Carbon Management for Commodities
Phone +49 (0)2203 601-2353 | Fax +49 (0)2203 601-4170 | gkiokchan.moumin@dlr.de
DLR.de - Future Fuels

**German Aerospace Center** (DLR)
Institute for Future Fuels | Solar-Chemical Process Development | Linder Höhe | 51147 Cologne

# Secondary concentrator

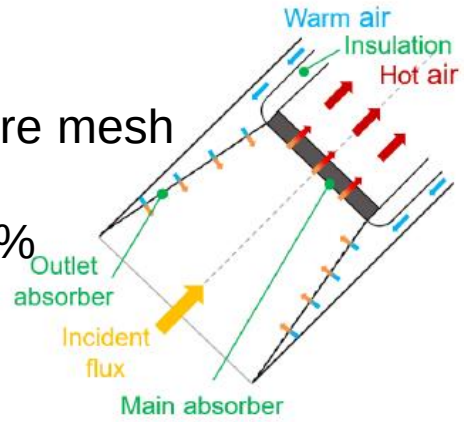


Source: DLR Stelleangebote

# Open Volumetric Air Receiver: Previous Design

**Volumetric Conical Receiver (VoCoRec):**

- Conical design – hexagonal cross-section
- Ambient air is heated by flowing through a metallic wire mesh
- T air = 800 C
- Calculated air return ratio ranges between 88 and 90%



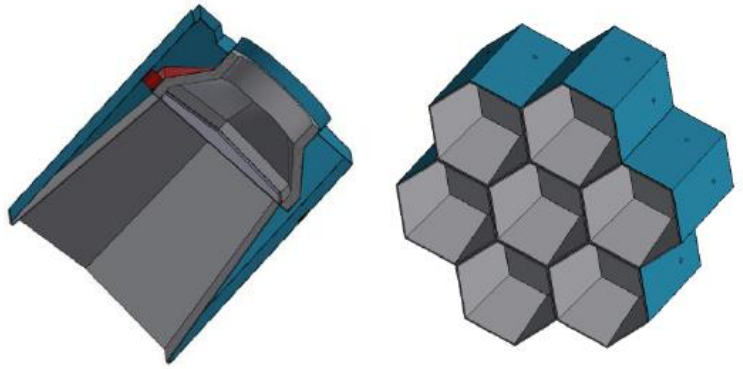
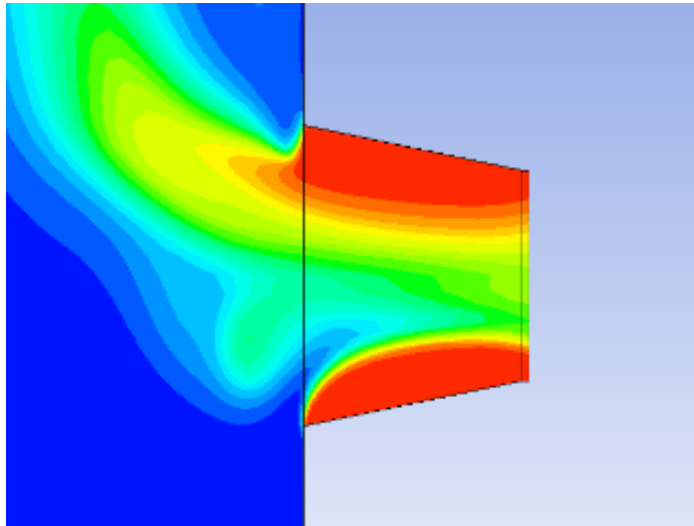



Illustration of VoCoRec

## Currently Research:
## attaining a higher Air Return Ratio (ARR) with an alternative configuration

**Alternative Design:**

- Conical design – Square cross-section
- The inner section of the receiver is to be investigated using flow analysis
- T air ➔ 900 C



# Impressum

Thema: Heat and mass transfer in high temperature solar open volumetric receivers for cement production

Datum: 26.11.2024

Autor: Andrii Cheilytko: anrii.cheilytko@dlr.de

Institut: Institute for Solar Research, DLR

Bildcredits: Cheilytko A. Heat and mass transfer in high temperature solar open volumetric receivers for cement production. Work Shop. Department of Civil Engineering Indian Institute of Technology Delhi, New Delhi (26.11.2024)

For the first part, source is: Prof. Dr.-Ing. Robert Pitz-Paal. Institutspraesentation komprimiert: Solar research at the German Aerospace Center. 2023