



ASME ES 2025

19th International Conference on
Energy Sustainability

Conference: July 8–10, 2025

**The Westin Westminster
Westminster, Colorado, USA**



Solar Absorptance and Thermal Emittance of Particle Heat Carriers in a Solar Driven Biomass Process

J.P. Rincon Duarte^{1,4}, M. Josse¹, C. Lorreyte¹, M. Kirschmeier¹,
J. Pernpeintner², F. Sutter³, M. Roeb¹, C. Sattler^{1,4}

¹German Aerospace Center (DLR), Institute of Future Fuels, Cologne - Germany

²German Aerospace Center (DLR), Institute of Solar Research, Cologne - Germany

³German Aerospace Center (DLR), Institute of Solar Research, Almería - Spain

⁴RWTH University, Chair for Solar Fuel Production - Faculty of Mechanical Engineering, Aachen - Germany

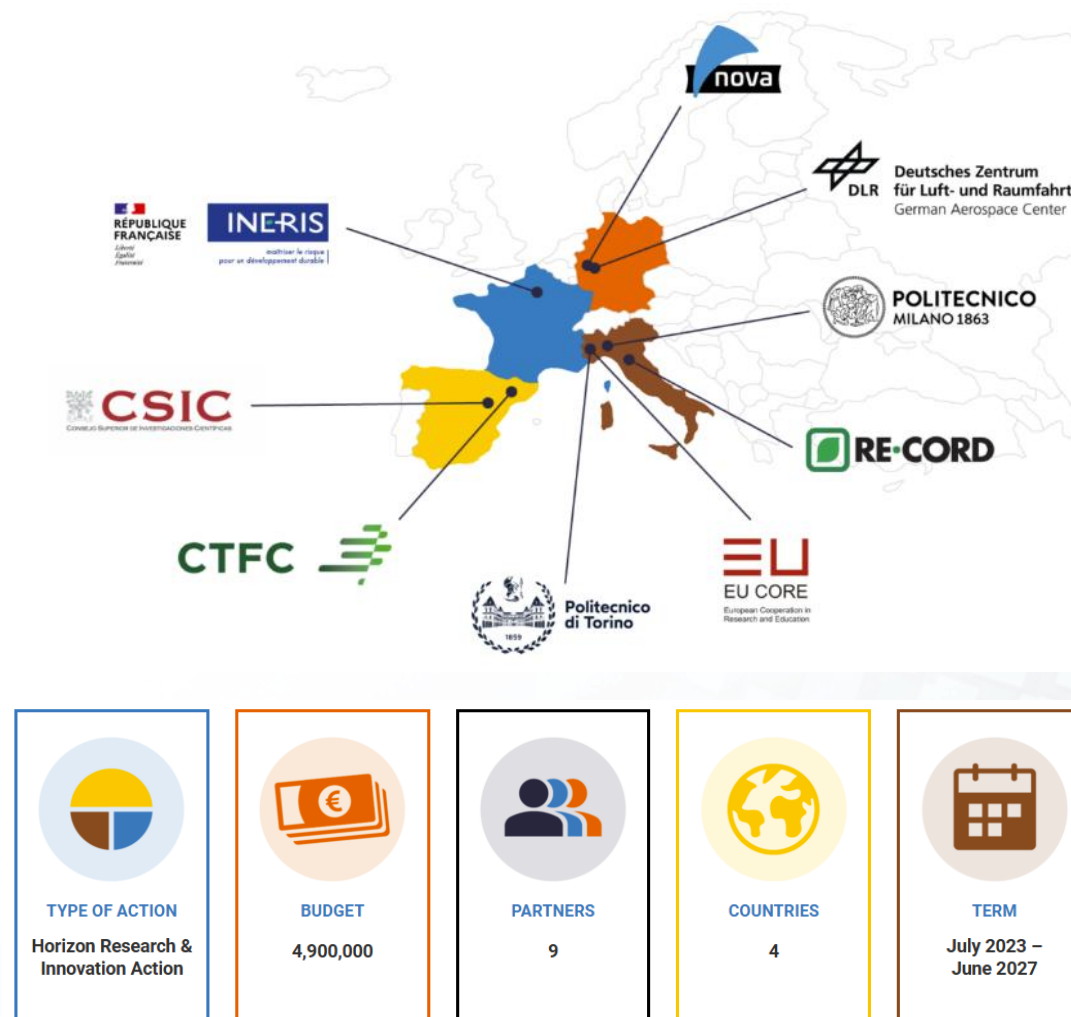
The content of this presentation is part of the following ASME publication: Rincon Duarte, JP, Josse, M, Lorreyte, C, Kirschmeier, M, Pernpeintner, J, Sutter, F, Roeb, M, & Sattler, C. "Solar Absorptance and Thermal Emittance of Particle Heat Carriers in a Solar Driven Biomass Process." *Proceedings of the ASME 2025 19th International Conference on Energy Sustainability collocated with the ASME 2025 Heat Transfer Summer Conference. ASME 2025 19th International Conference on Energy Sustainability*. Westminster, Colorado, USA. July 8–10, 2025. V001T06A001. ASME. <https://doi.org/10.1115/ES2025-156580>; permission for reproduction in Zenodo has been granted by Copyright ASME.



Agenda

- Introduction: The PYSOLO project
- Research questions
- Methods
- Results - Solar absorptance and thermal emittance of PHCs
- Results - Suitability of PHCs for the PYSOLO process (solar point of view)
- Conclusions and Outlook

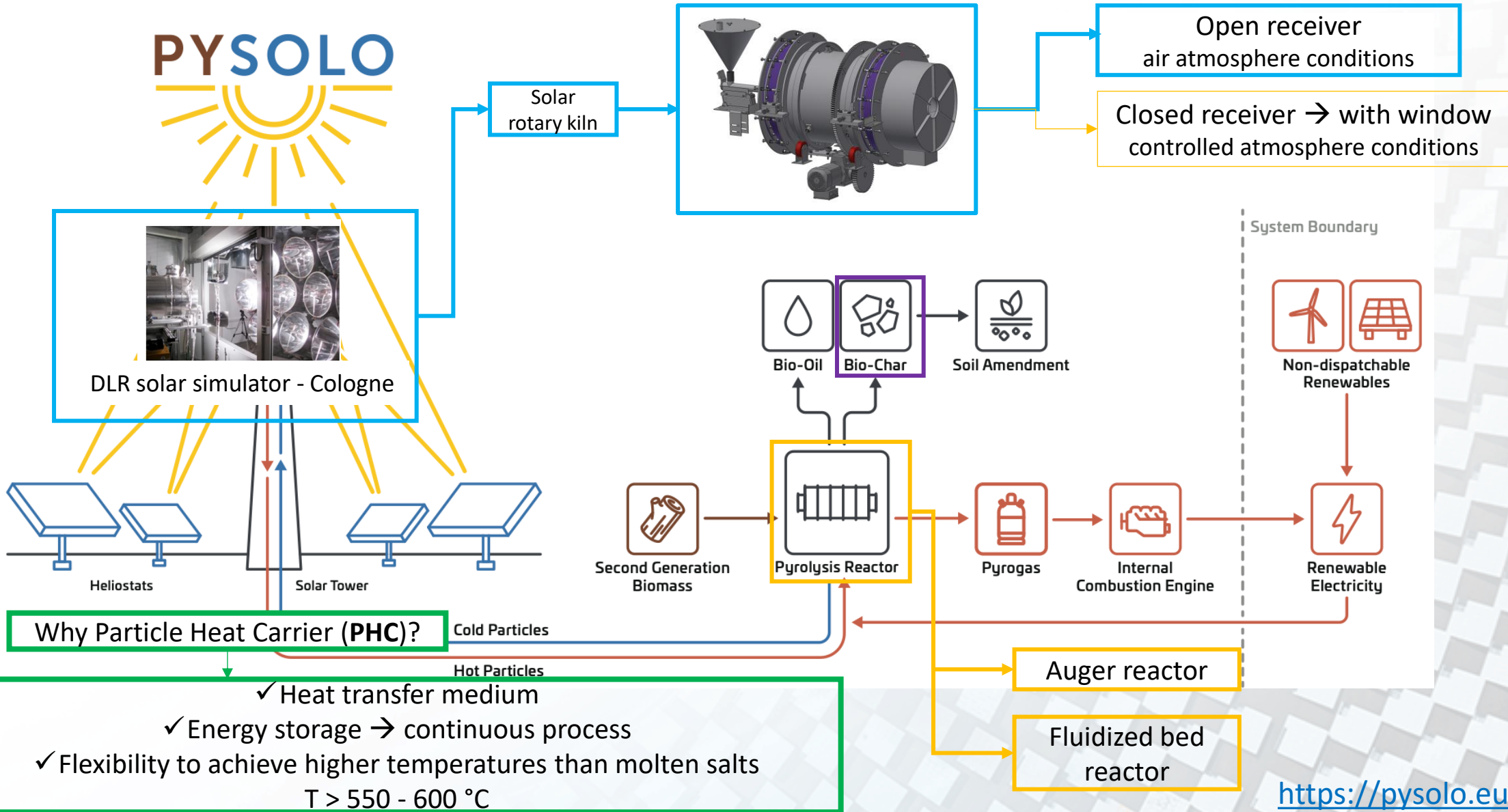
Introduction – PYrolysis of biomass by concentrated SOLar pOwer



<https://pysolo.eu/>



Introduction – PYrolysis of biomass by concentrated SOLar pOwer





Introduction – Biomass feedstock and PHCs in PYSOLO

Mapping of solar and biomass resource in Italy, Spain and Greece

- ✓ **Pine wood chips chosen as biomass feedstock**



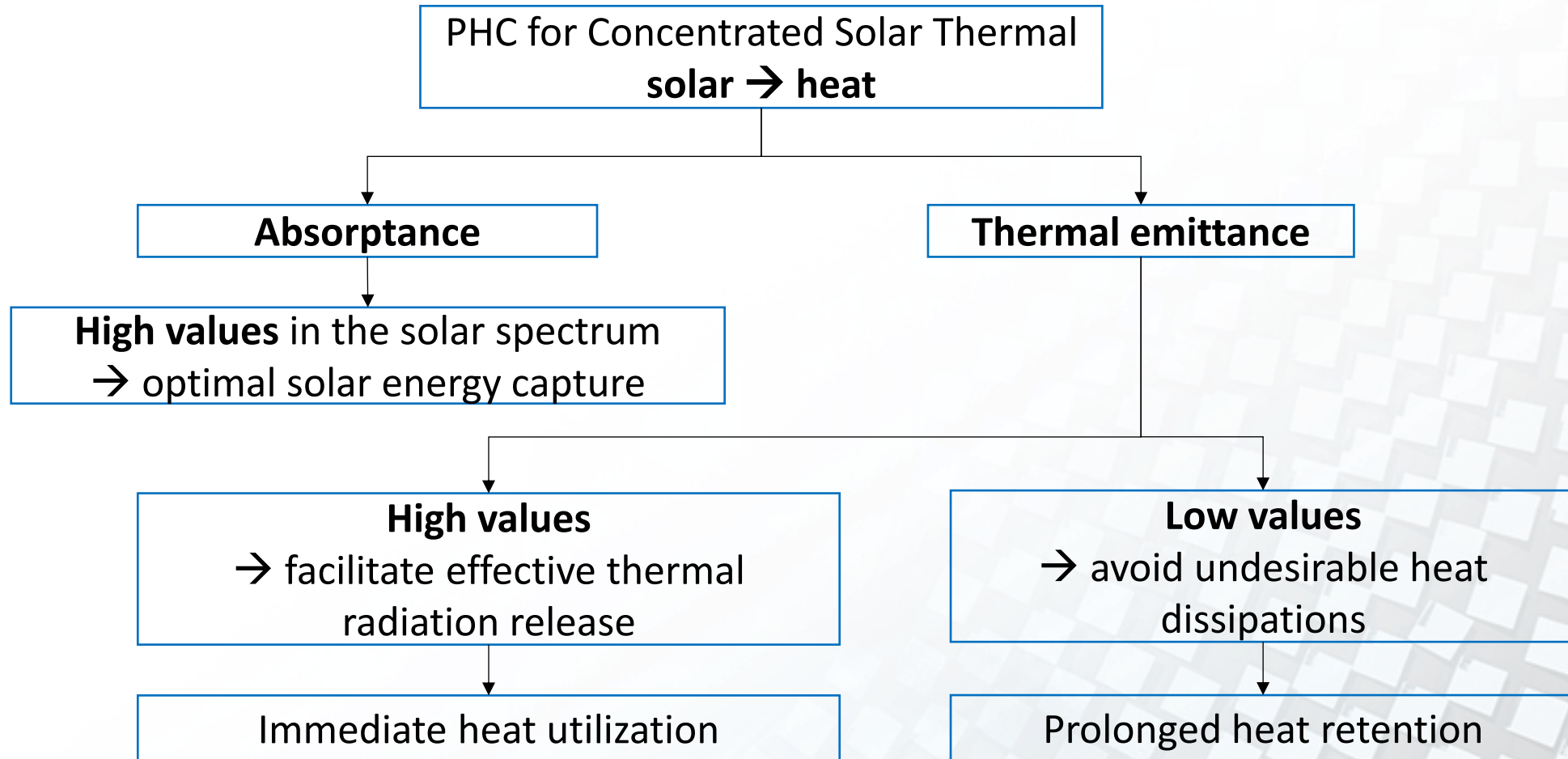
Evaluation of the suitability of several materials as PHC for the process → aluminum oxide, bauxite, calcium oxide, calcined flint clay, magnesium oxide, quartz, sand, silicon carbide and steel

- ✓ **Five PHCs were preselected**



*The use of biochar as PHC is considered in the PYSOLO project, but it has not been included in this study due to the considerations for the samples preparation of this study → use of an open solar receiver

Introduction – Importance of absorptance and thermal emittance. Which values are the best?



Based on 2024, Kyu Bum Han et al.



Research questions - PHCs in PYSOLO

Previous studies have determined these properties for fresh- and oxidized samples (in air) of bauxite, SiC and sand **



but



There is insufficient data on:

- olivine and MgO
- PHCs when exposed to pyrolysis conditions

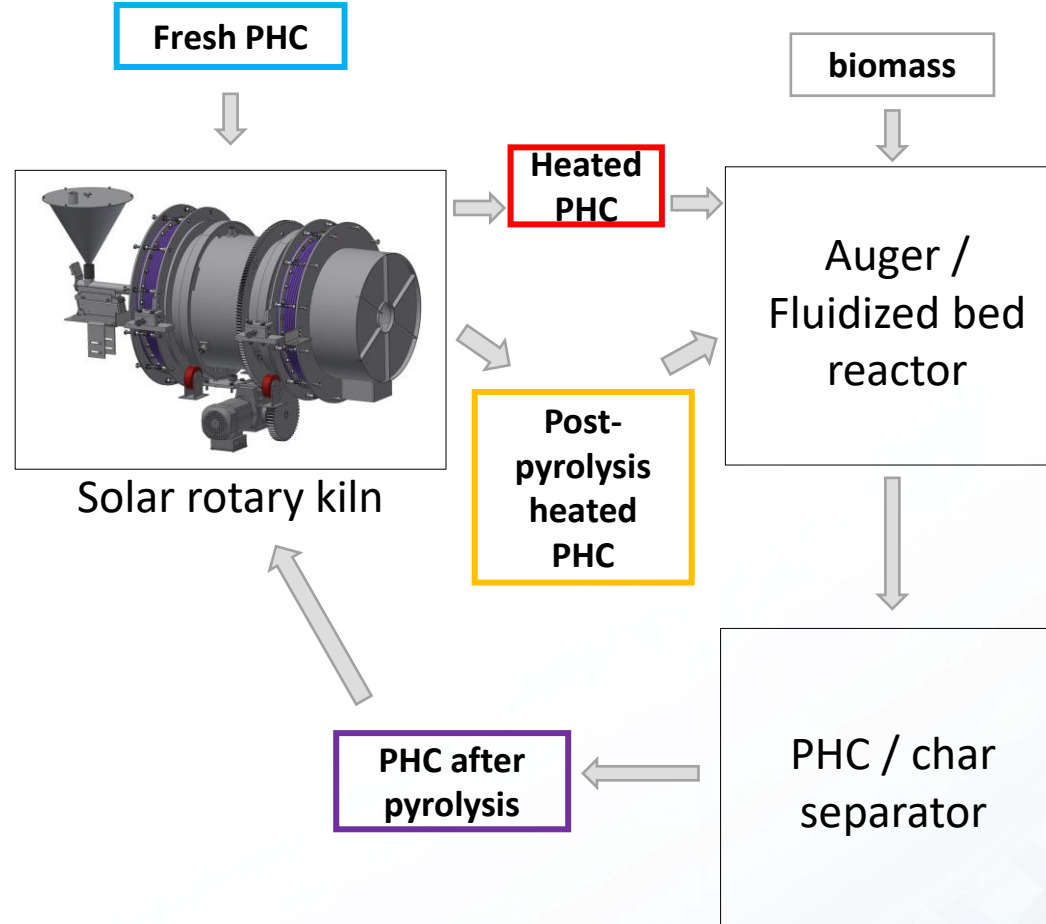
- How do the solar absorptance and the thermal emittance of PHCs change during the **different stages** of the PYSOLO process?
- From the solar point of view, which PHC is the most suitable for the PYSOLO process?

**2020, Chen et al.; 2021, Chen et al.; 2020, Díaz-Heras et al.; 2019, Palacios et al.; 2025, Sutter et al.; 2025, Schröder et al.; 2022 Chen et al.; 2023 Chen et al.

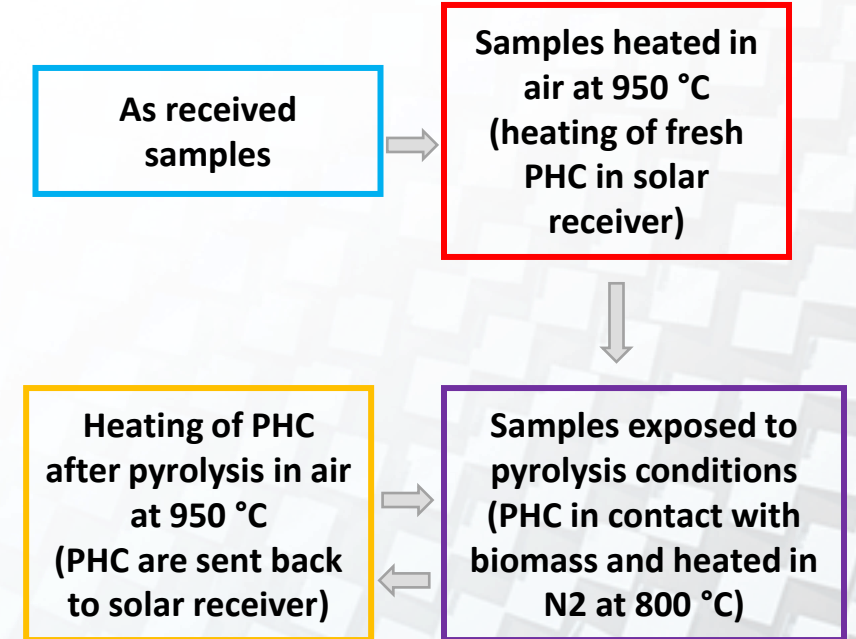


Methods – Sample preparation

Different stages of PHCs in the PYSOLO process considering an open receiver

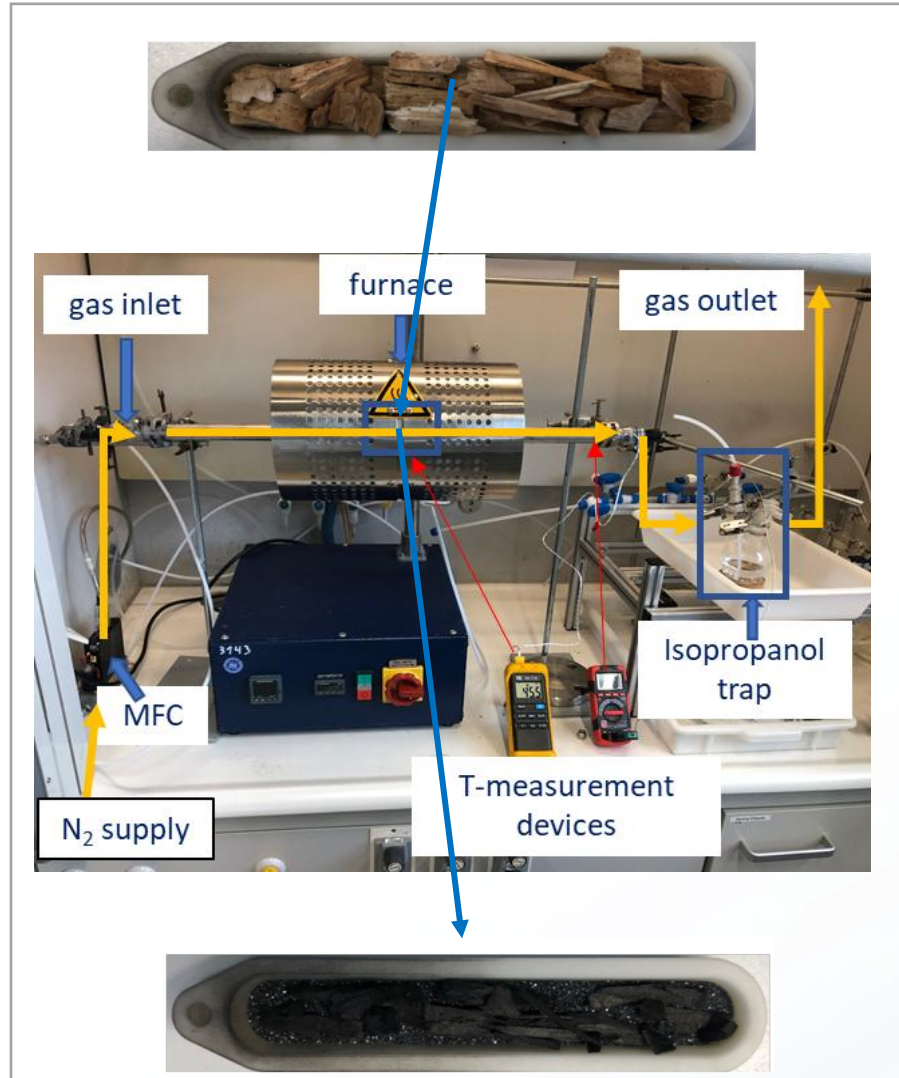


Preparation of samples





Methods – Sample preparation: PHC during pyrolysis



Material characteristics:

- Mean particle size of PHC samples 250 – 300 μm
- Pine wood chips with an average size of 8 mm

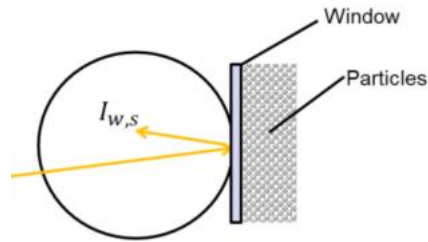
Devices:

- Tubular furnace operated in controlled atmosphere conditions $\rightarrow$ N_2 used as inert gas
- Mass Flow Controller to set gas flow
- Temperature readers to measure temperature in position of the sample holder and gas outlet
- Isopropanol bottle for cleaning gas

Methods – Reflectance measurements of particles with spectrometer and spectrophotometer

Measurements were performed **at room temperature** following the **SolarPACES guidelines** for measuring reflectance, absorptance and emittance of particles [2022, Sutter et al.]

Reflectance of particle sample (R_s) is measured in a spectrometer/spectrophotometer → crucible and window are needed to hold PHC sample



Estimation of solar absorptance

$$A_s = 1 - R_s$$

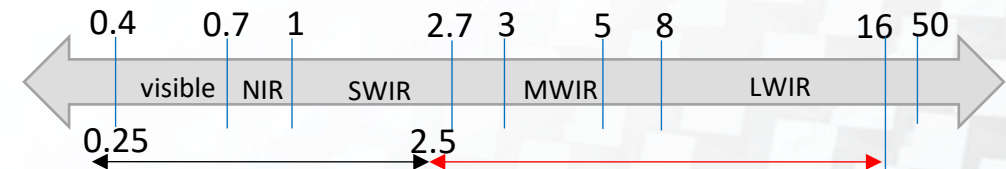
Blackbody spectral emittance at temperature of interest (M_{bb})

Estimation of thermal emittance (E_s)

*Assuming emittance = absorptance

Measuring devices

wavelength / μm



Perkin-Lambda 950 Spectrophotometer

Estimation of solar absorptance

DLR-Cologne

Fourier Transform Spectrometer FTIR Perkin Elmer

Estimation of thermal emittance

DLR-Almería

NIR: Near infrared, SWIR; short wave; MWIR: medium wave infrared; LWIR: low wave infrared

Methods – Estimation of solar absorptance and thermal emittance of PHC

Based on 2022, Sutter et al.

Measurements and procedure to estimate solar absorptance of particle sample

Measurements using spectrophotometer device

1. zero line of the device (I_z)
2. window transmittance using the standard white reference (τ_w)
3. window reflectance with black cover (I_w)
4. base line with the standard grey reference ($I_{\#1}$)
5. window + standard grey reference ($I_{w,\#1}$)
6. PHC in crucible + window ($I_{w,s}$)

Certified near-normal hemispherical spectral of reference coupon → SRS-05-020



Calculation of reflectance of window and window+PHC

$$\rho_w = \frac{I_w - I_z \tau_w^2}{I_{\#1}} R_{\#1}$$

$$\rho_{w,s} = \frac{I_{w,s}}{I_{\#1}} R_{\#1}$$

Calculation of reflectance and absorptance of particle sample

$$R_s = \frac{\rho_{w,s} - \rho_w}{\tau_w^2 + \rho_w (\rho_{w,s} - \rho_w)} \quad R_{s,h} = \frac{\int_{320 \text{ nm}}^{2500 \text{ nm}} R_s(\lambda) \cdot G_b(\lambda) d\lambda}{\int_{320 \text{ nm}}^{2500 \text{ nm}} G_b(\lambda) d\lambda}$$

$$A_s = 1 - R_s$$

Measurements and procedure to estimate thermal emittance of particle sample

Measurements using spectrometer device

1. zero line of the device (I_z)
2. base line with gold reference ($I_{\#1}$)
3. base line with grey reference ($I_{\#2}$)
4. window reflectance with black cover (I_w)
5. window transmittance using the gold reference (τ_w)
6. window + gold reference ($I_{w,\#1}$)
7. window + standard grey reference ($I_{w,\#2}$)
8. PHC in crucible + window ($I_{w,s}$)



$R_s(\lambda)$

$$M_{bb} = \frac{2\pi hc}{\lambda^5 \left[e^{\left(\frac{hc}{\lambda kT} \right)} - 1 \right]}$$

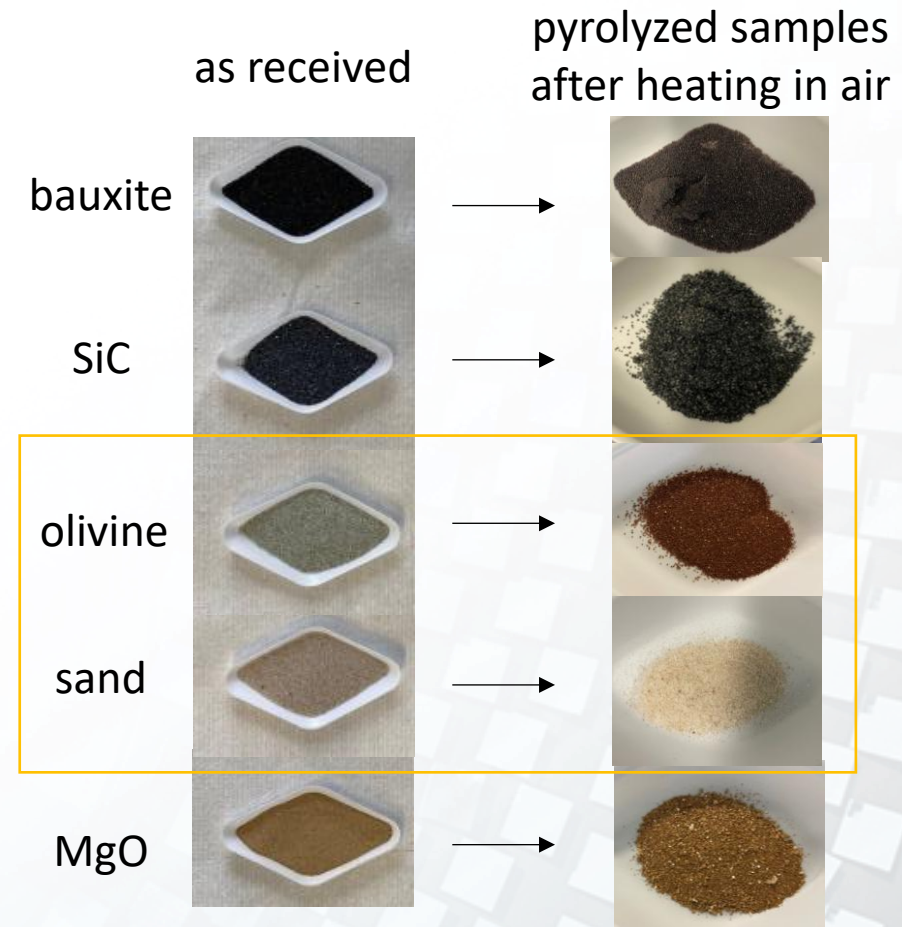
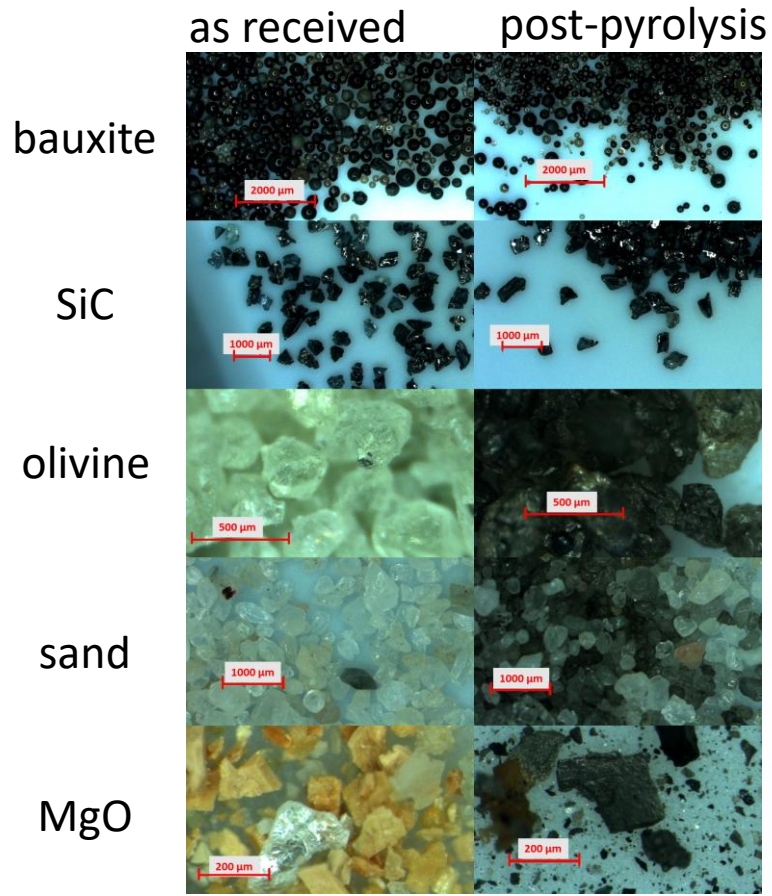
$$E_s = \frac{\int_{2.5 \mu\text{m}}^{16 \mu\text{m}} [1 - R_s(\lambda)] M_{bb}(\lambda, T) d\lambda}{\int_{2.5 \mu\text{m}}^{16 \mu\text{m}} M_{bb}(\lambda, T) d\lambda}$$

$T = 950 \text{ }^\circ\text{C}$





Results – Appearance of PHCs during different process stages

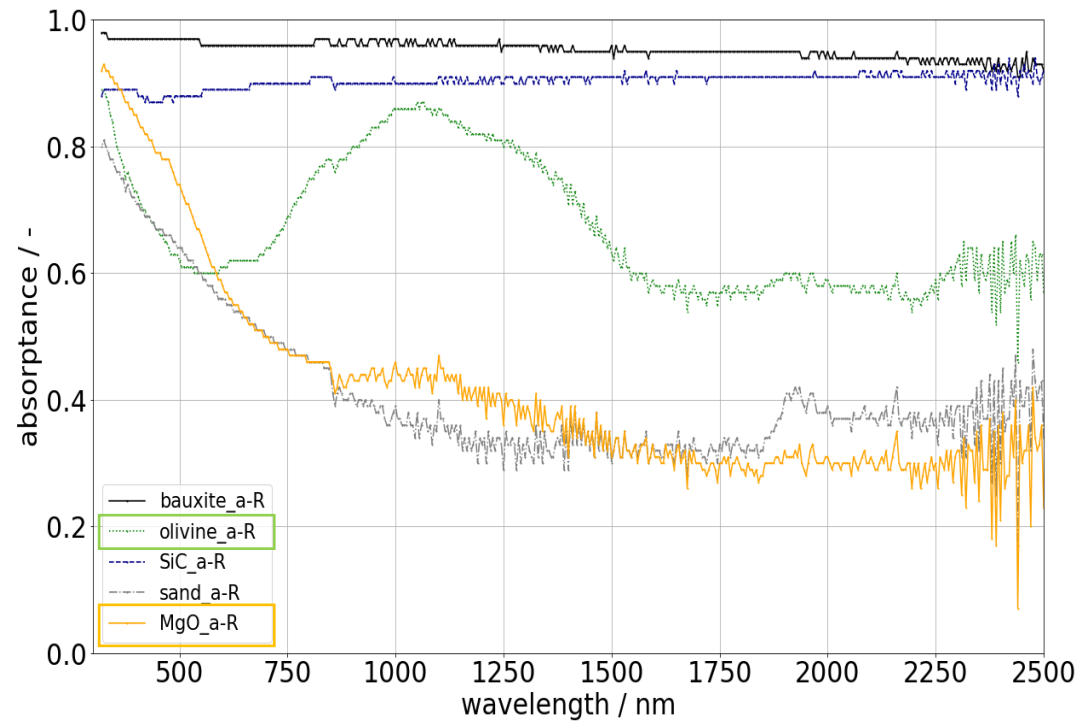


- Olivine, sand and MgO became evidently darker due to their contact with the pyrolysis products (char, tar, oil)
- The dark color gained after pyrolysis is lost when samples are heated in air again
- Exposure to heating in air caused notable changes for olivine and sand

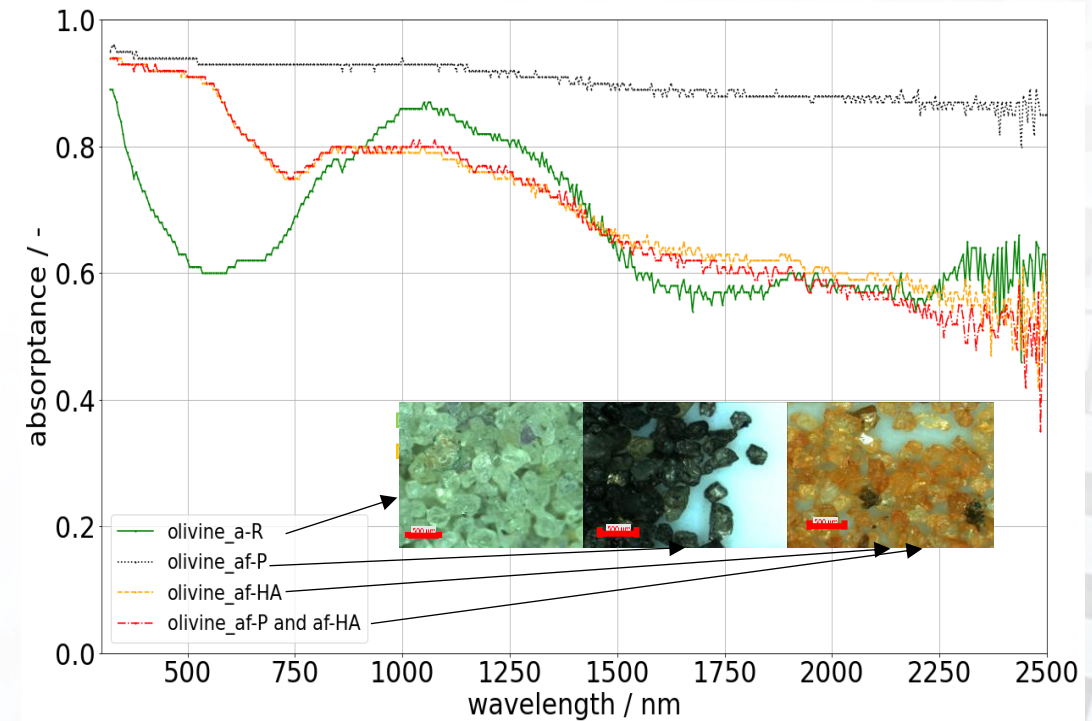


Results – Solar absorptance of PHCs

As received materials



Olivine samples



- For the fresh samples: the darker materials (bauxite and SiC) showed the highest absorptance, followed by olivine, MgO and sand
- For the olivine samples:
 - The change in color due to pyrolysis increases the optical properties of the fresh samples
 - The heating of samples in air also affects the solar absorptance



Results – Solar absorptance of PHCs

PHC	As received	↓ After heating in air at 950 °C	↓ After pyrolysis at 800 °C	↓ After pyrolysis and after heating in air at 950 °C
SiC	0.90	0.96	0.90	0.96
bauxite	0.96	0.97	0.96	0.93
olivine	0.70	0.80	0.93	0.81
MgO	0.53	0.53	0.89	0.54
sand	0.49	0.46	0.88	0.43

Increase of more than 3 points compared to fresh sample

Decrease of more than 3 points compared to fresh sample

- Heating of samples in air is very beneficial to improve the absorptance of SiC and olivine, but not for bauxite and sand
- Exposure to pyrolysis conditions increased the absorptance of olivine, MgO and sand
- Heating of pyrolyzed samples in air results in absorptance values similar to those of heating fresh material

Results – Thermal emittance of PHCs

PHC	As received	↓ After heating in air at 950°C	↓ After pyrolysis at 800°C
SiC	0.90	0.92	0.90
bauxite	0.91	0.88	0.89
olivine	0.85	0.74	0.89
MgO	0.63	0.53	0.92
sand	0.77	0.72	0.84

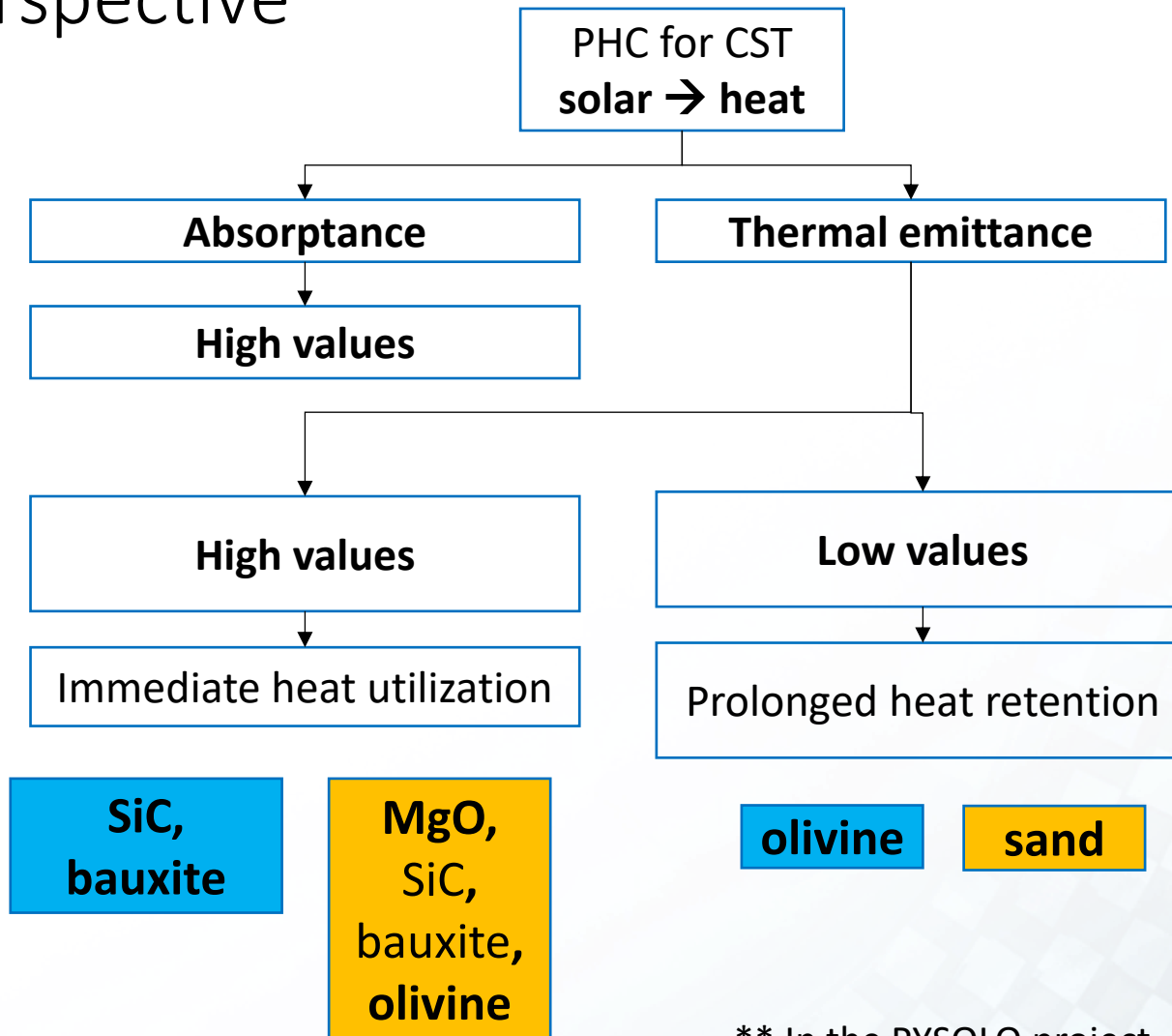
Increase of more than
3 points compared to
fresh sample

Decrease of more than
3 points compared to
fresh sample

The estimated thermal emittance at 950 °C:

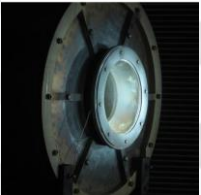
- Decreased for the heated samples in air of bauxite, olivine, MgO and sand
- Increased for the pyrolyzed samples of olivine, MgO and sand

Results – Best PHCs for the PYSOLO process from the solar perspective



Best candidate(s)
open solar receiver

Best candidate(s)
closed solar receiver



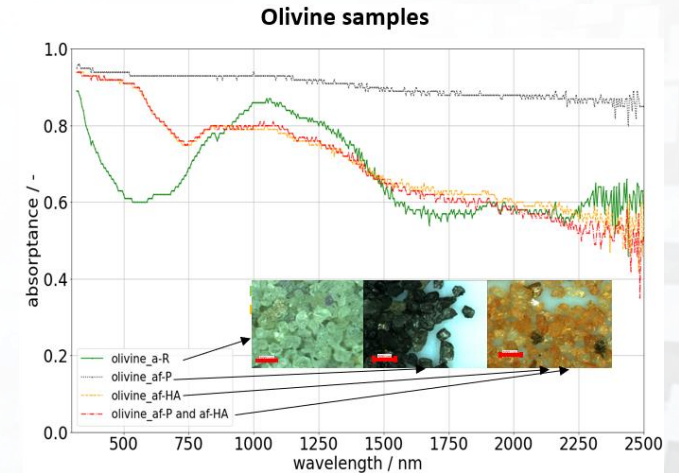
* PHCs retain the dark color
gained during pyrolysis

** In the PYSOLO project, additional environmental, technical and economical aspects are considered for the final PHC selection (upcoming publication)



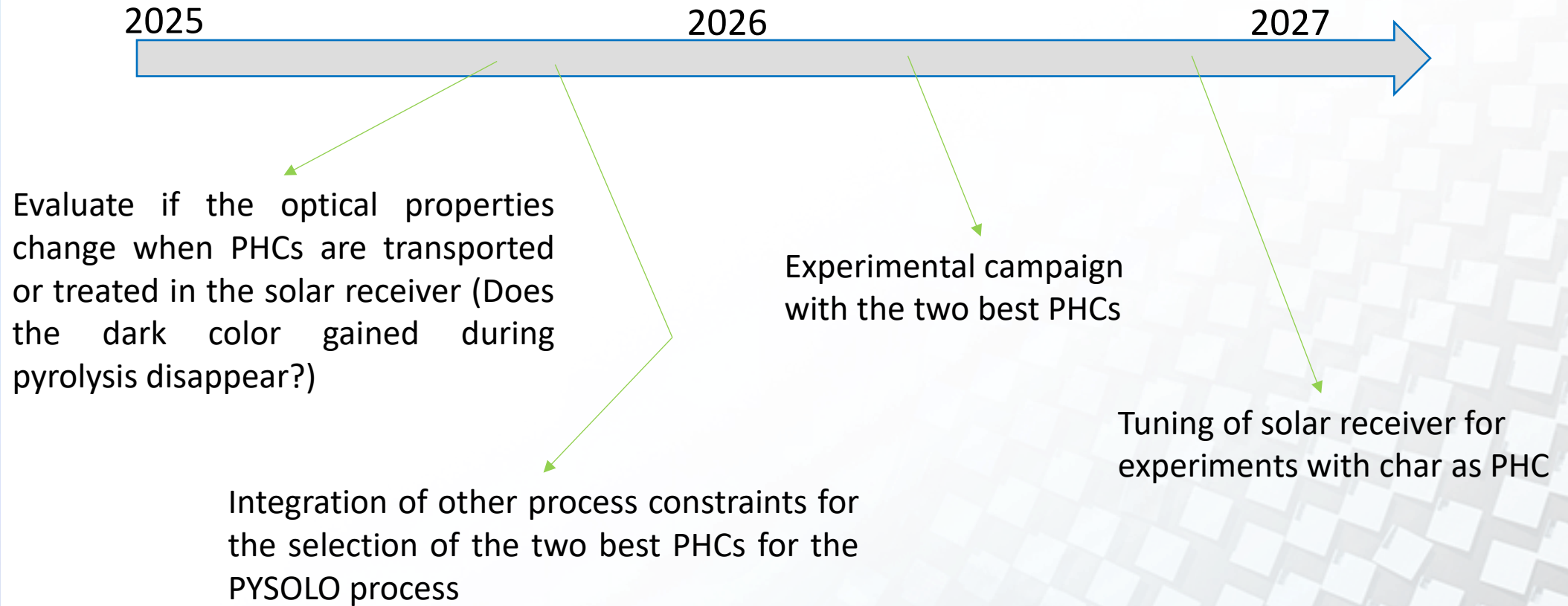
Conclusions

- The absorptance and emittance of olivine, sand and MgO are significantly affected by the process conditions
- The gain in absorptance and emittance due to the pyrolysis stage is lost if PHCs are oxidized in air, which is the case for an open solar receiver
- For all conditions tested, SiC and bauxite showed high absorptance and emittance → suitability for open receiver with immediate heat utilization
- For an open solar receiver, olivine is also an interesting PHC offering prolonged heat retention than SiC and bauxite





Outlook





Thanks for your attention! Questions?

Juan.RinconDuarte@dlr.de

DLR - Institute of Future Fuels

Department of Solar Chemical Process Development

This study is funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them. The **PYSOLO** project receives funding from the Horizon Europe Framework Programme under **grant agreement number 101118270**.



Materials

Composition/ Diameter	Bauxite	MgO	Olivine	SiC	Sand
SiO ₂	23.5	5	42		99.5
Al ₂ O ₃	76	1	0.4		0.13
Fe ₂ O ₃	3	4	7	0.2	
MgO		83	50		
CaO		5			
Cr ₂ O ₃			0.3		
NiO			0.3		
SiC				99	
C free				0.5	
Mean Particle Diameter / μm	250	250	250	300	250