



Insulation concepts and materials for an innovative ultra-high temperature latent heat energy store

Stephan Lang

University of Stuttgart (Germany)

Institute for Building Energetics,
Thermotechnology and Energy Storage (IGTE)

What is ultra-high temperature?

- It depends on the technology...

What is ultra-high temperature?

Maximum temperature for „high-temperature“ Thermal Energy Stores so far $\approx 1\ 000\ ^\circ\text{C}$

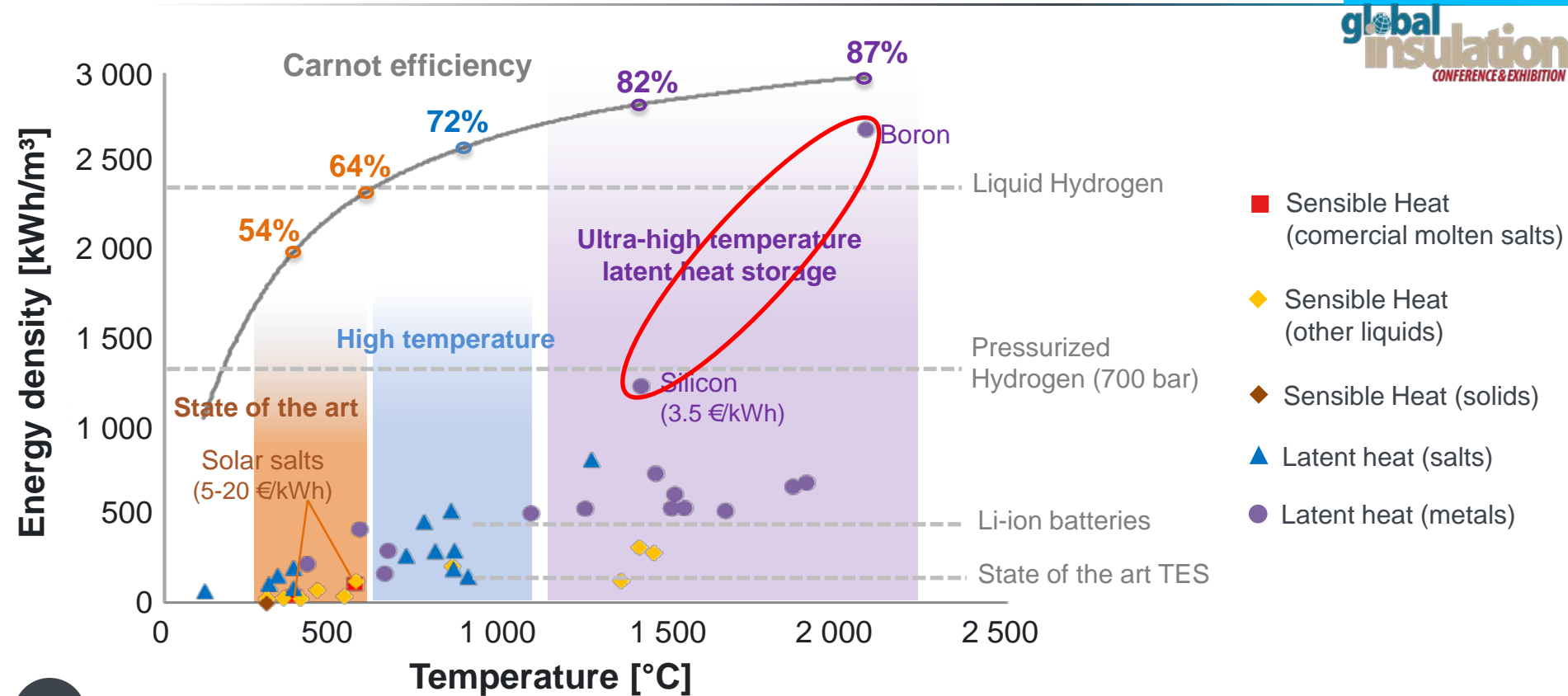
Ultra-high temperature Thermal Energy Store:

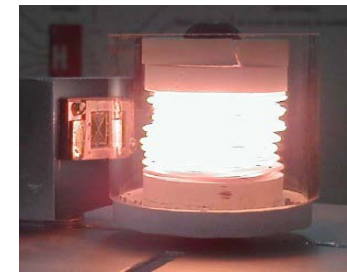
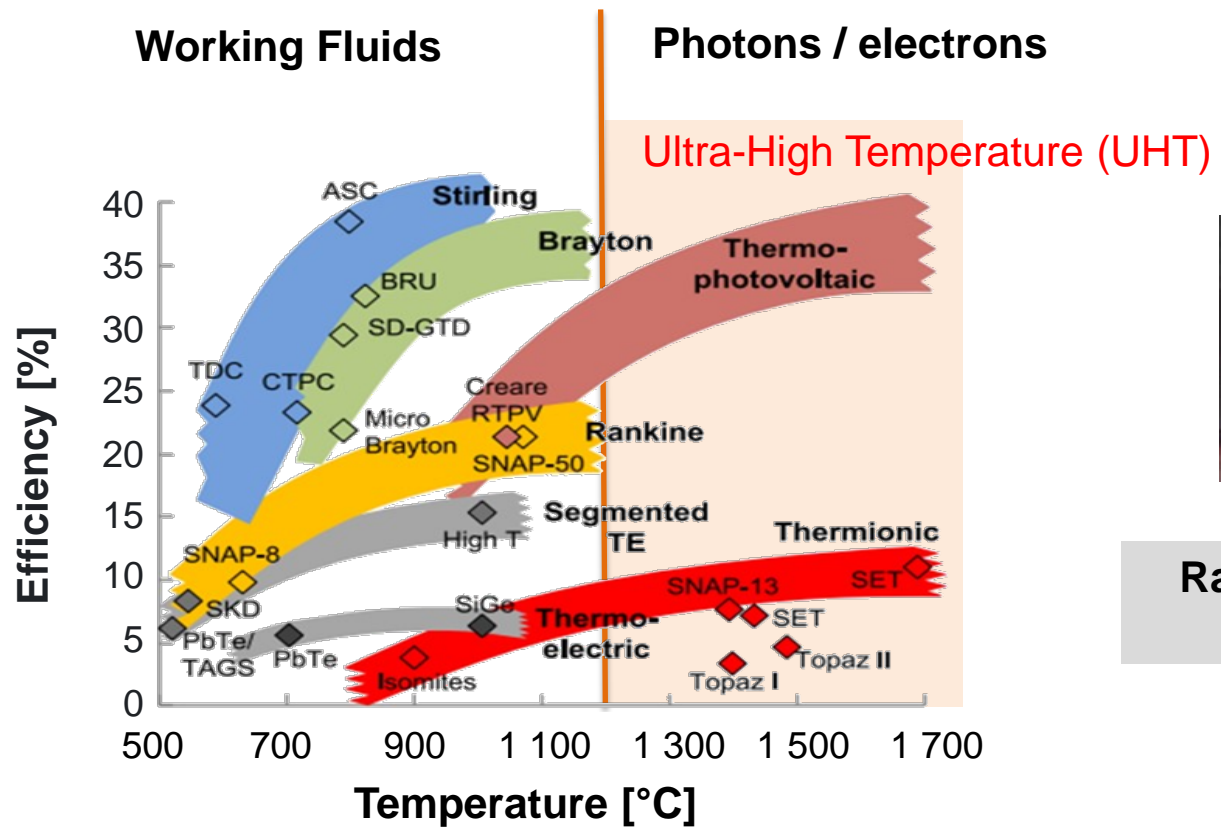
$> 1\ 200\ ^\circ\text{C}$

Maximum temperature for the planned Thermal Energy Store:

$2\ 000\ ^\circ\text{C}$

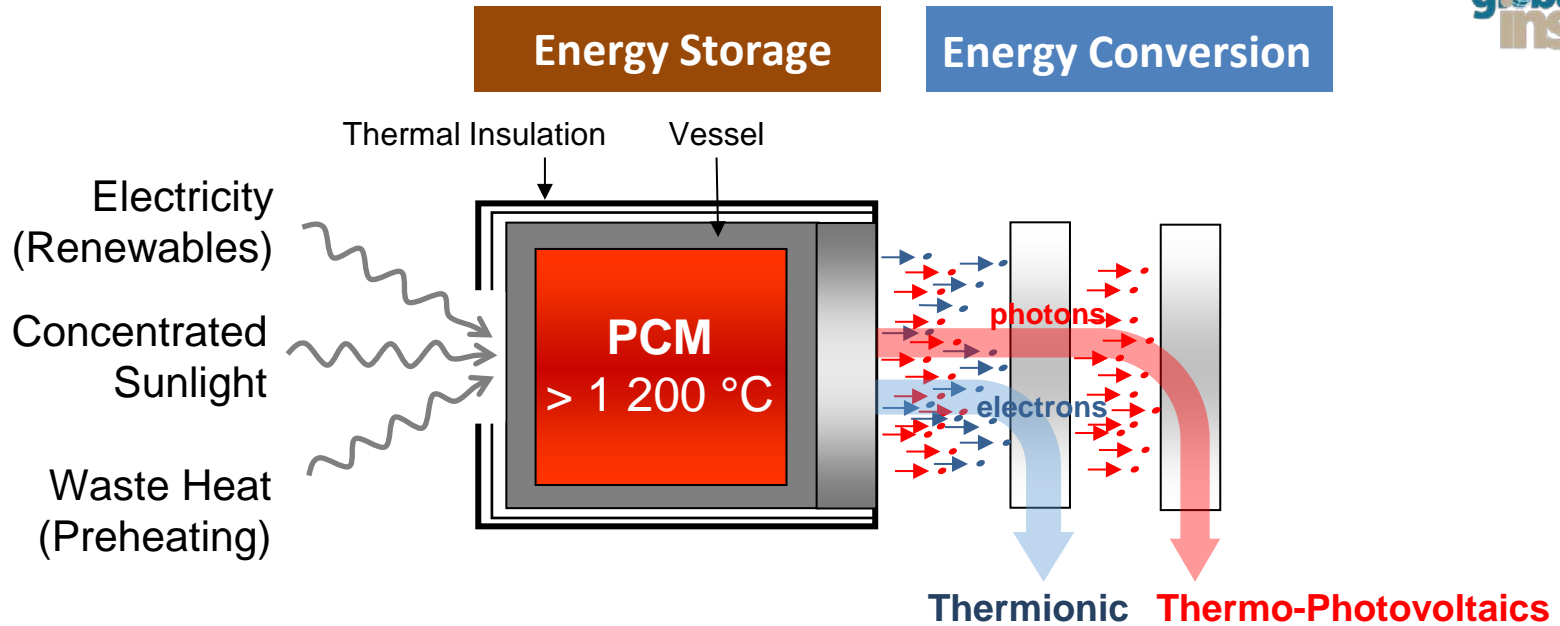
Why ultra-high temperature?





Radiative-based solid state converters

Source: A. Datas, A. Martí, *Thermophotovoltaic energy in space applications: Review and future potential*, Solar Energy Materials and Solar Cells, Volume 161, March 2017, Pages 285-296



> 1 000 kWh_{th}/m³
(> 10 times than salts)
(> 2 times than best Li-Ion cells)

> 50 kW_e/m²
(> 200 times than solar PV)

Source: A. Datas (modified by the speaker)

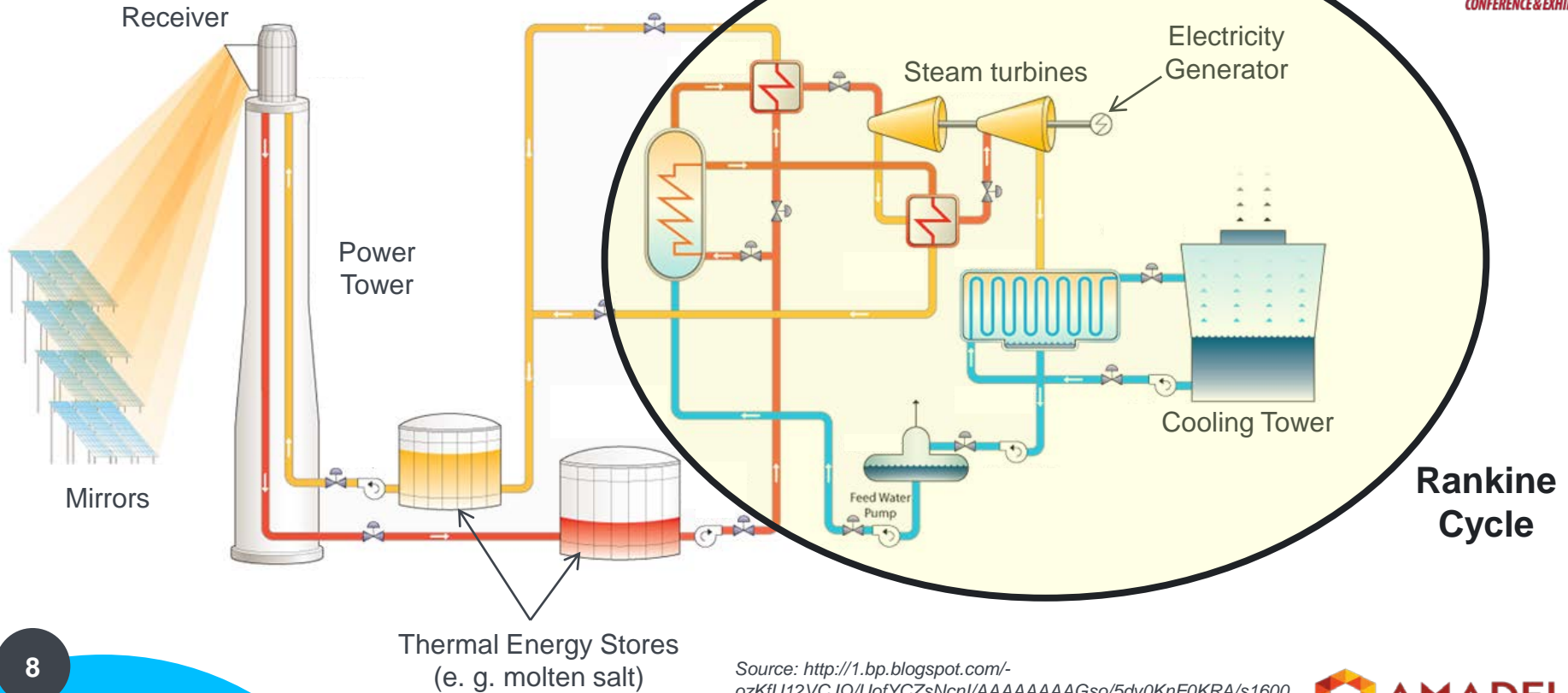
What is it good for?

Solar Power Tower:



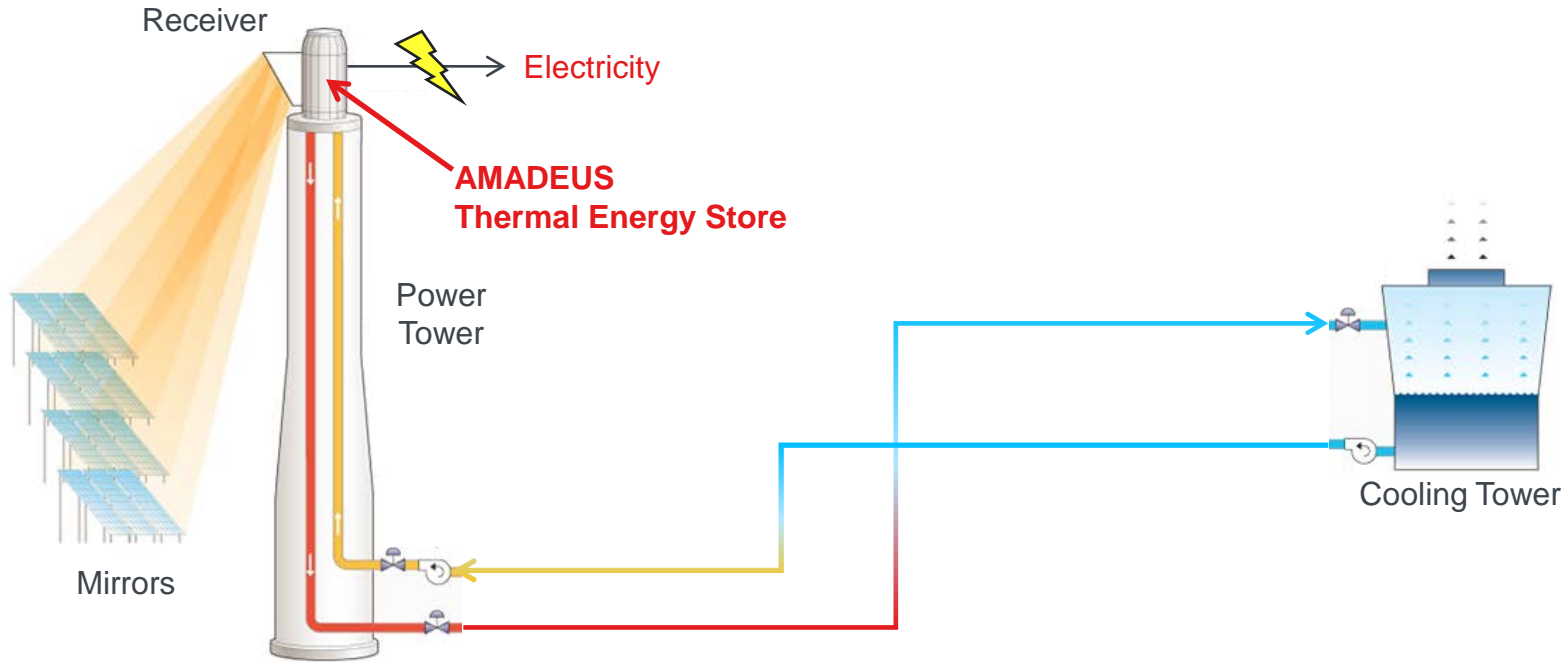
What is it good for?

Solar Power Tower Process, state of the art:



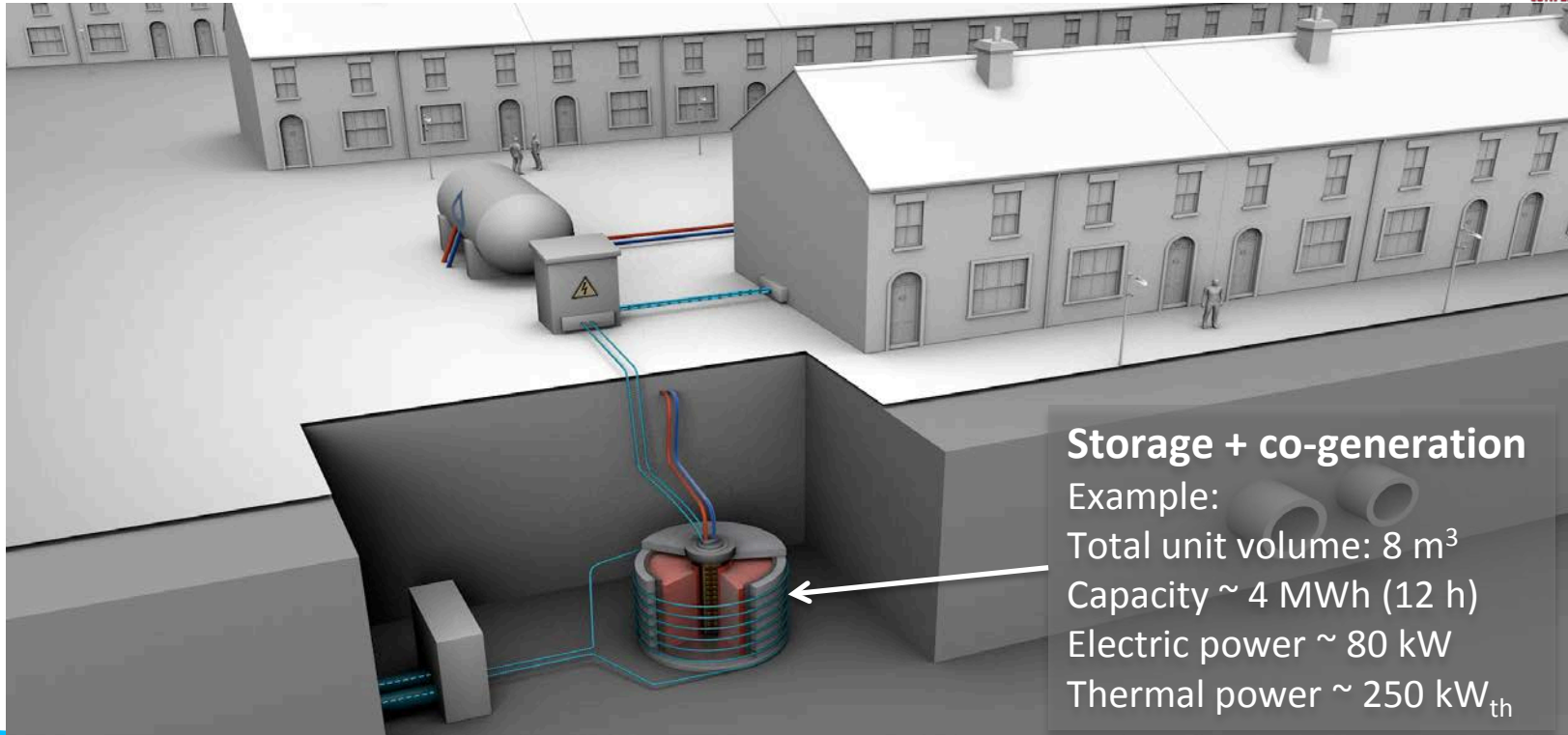
What is it good for?

Solar Power Tower Process, the AMADEUS way:



What is it good for?

Domestic use of surplus renewable electricity production:



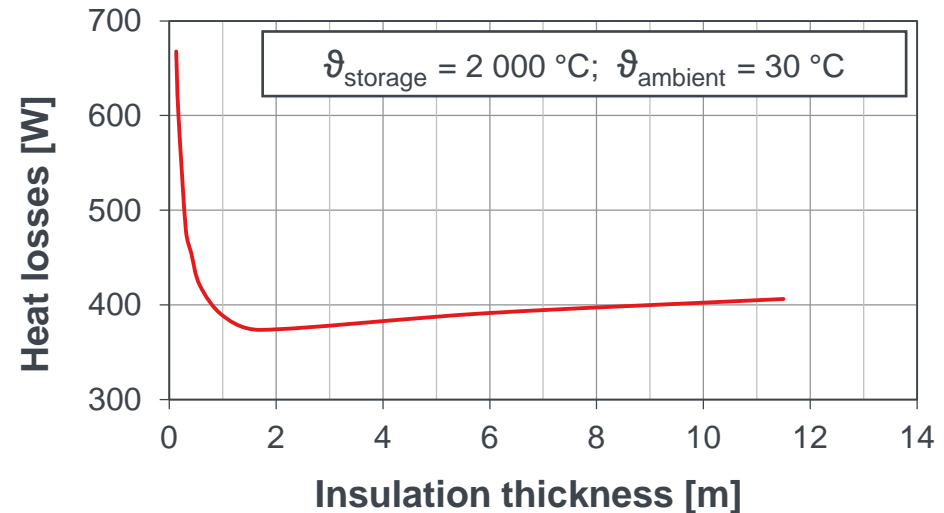
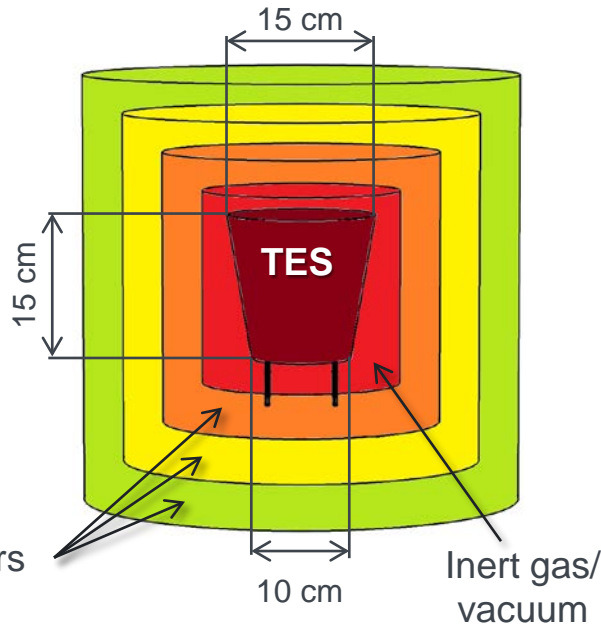
Insulation concept

Motivation for a high insulation performance

- Decreasing energy losses
- Increasing storage time
 - hours, or maybe days...?

Motivation for a very efficient insulation (low thermal conductivity)

- Decreasing total volume of device
- Heat losses ~ surface of heat transfer



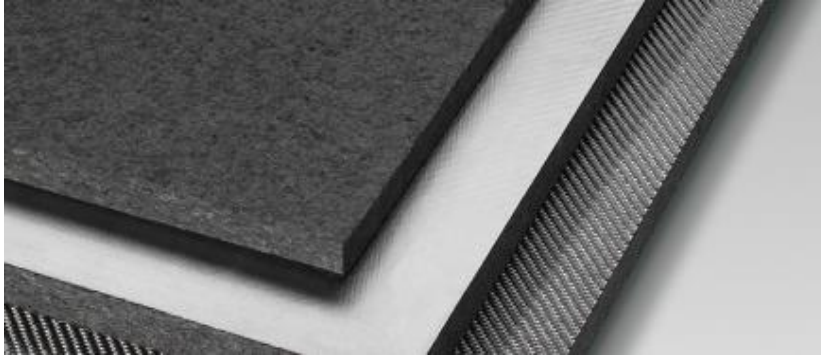
Screening for insulation materials

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- Main criteria:
 - Temperature stability (permanent)
 - Costs
 - Thermal conductivity

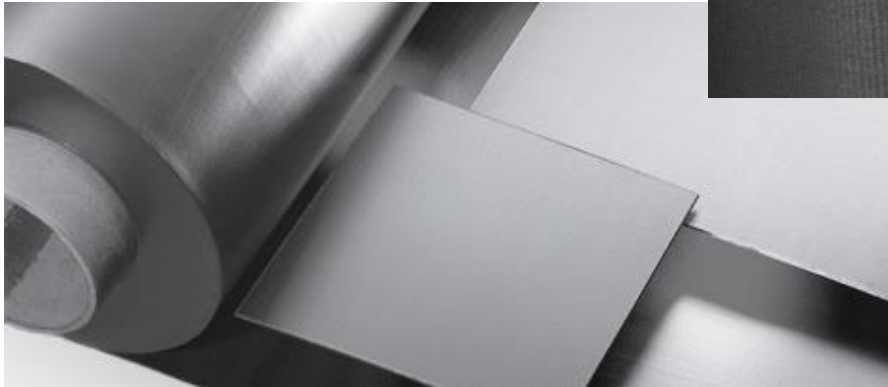
Graphite insulation materials ($\leq 2\,000\text{ °C}$)



Rigid fiber boards



Flexible fiber mats



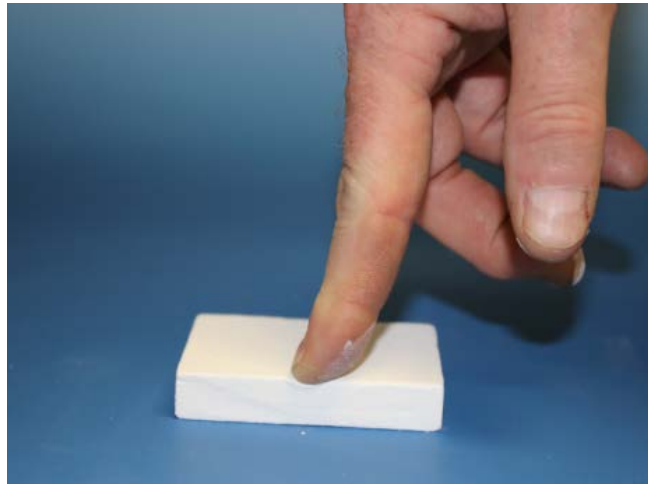
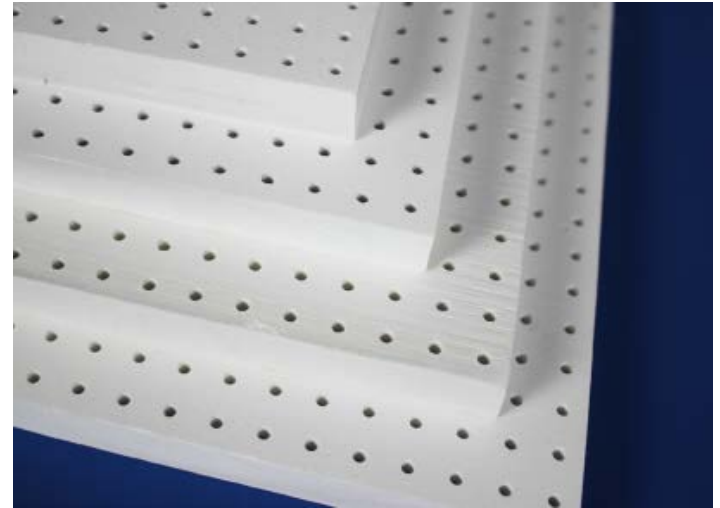
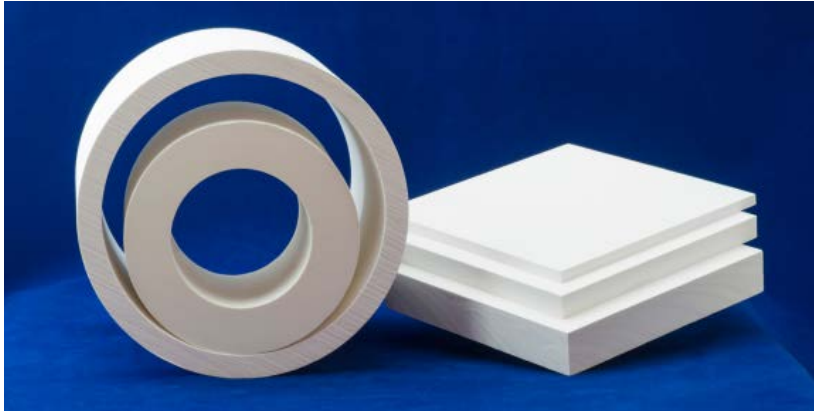
Reflexing foils/ heat shields

Sources:

https://www.sglgroup.com/cms/international/infokorb/Downloadcenter/products/cfrc-felt/technical-data-sheets/felt/index.html?__locale=en

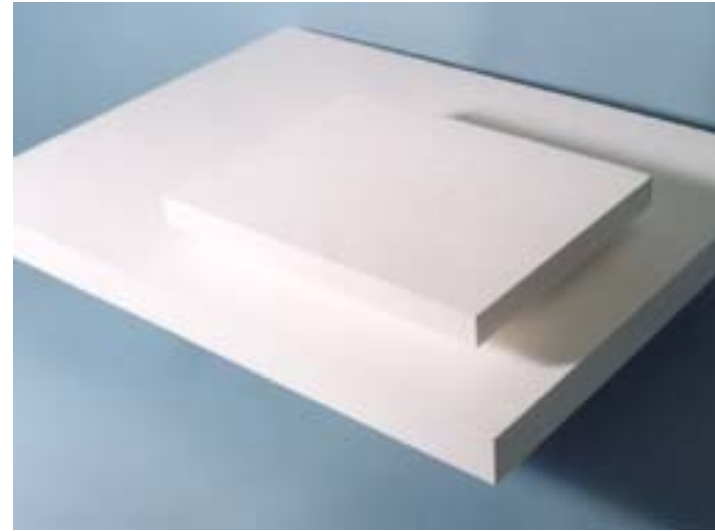
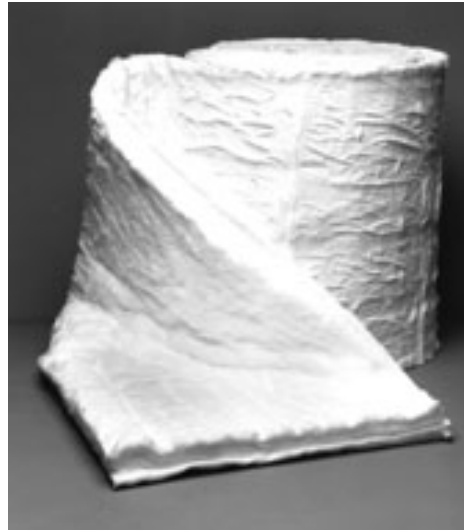
https://www.sglgroup.com/cms/de/Infokorb/Download-Center/Produkte/Expandierter-Graphit/Technische-Datenblaetter/Expandierter-Graphit/index.html?__locale=de

Zirconia fiber boards ($\leq 2\,000\text{ °C}$)



Source: <https://zircarzirconia.com/products/>

Alumina fiber materials ($\leq 1\ 800\ ^\circ\text{C}$)



Sources:

<http://www.zircarceramics.com/pages/rigidmaterials/aluminaproducts.htm>

<http://www.zircarceramics.com/pages/flexible/specs/almat.htm>

<https://zircarzirconia.com/products/type-buster-blanket/>

Microporous materials ($\leq 1\ 000\ ^\circ\text{C}$)



Fumed silica board

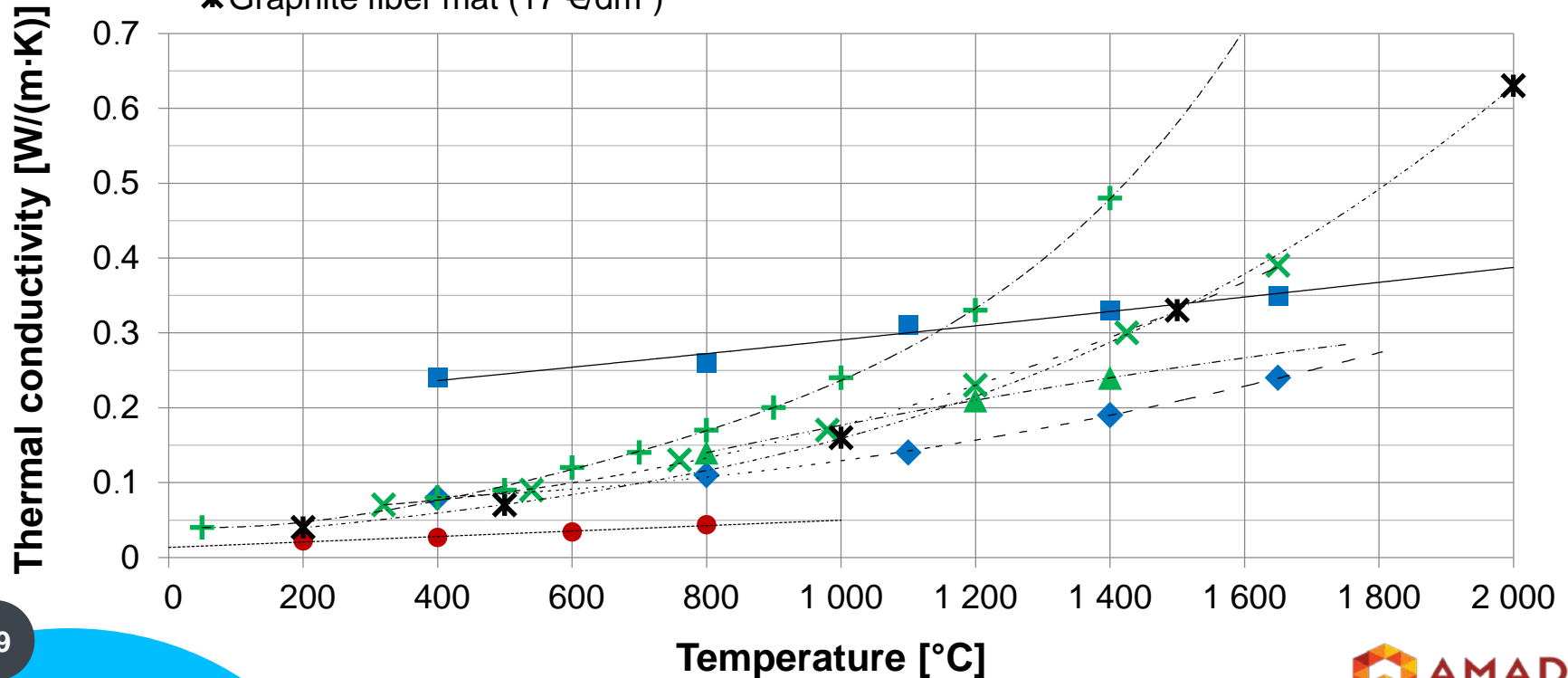


Aerogel embedded fiber mat

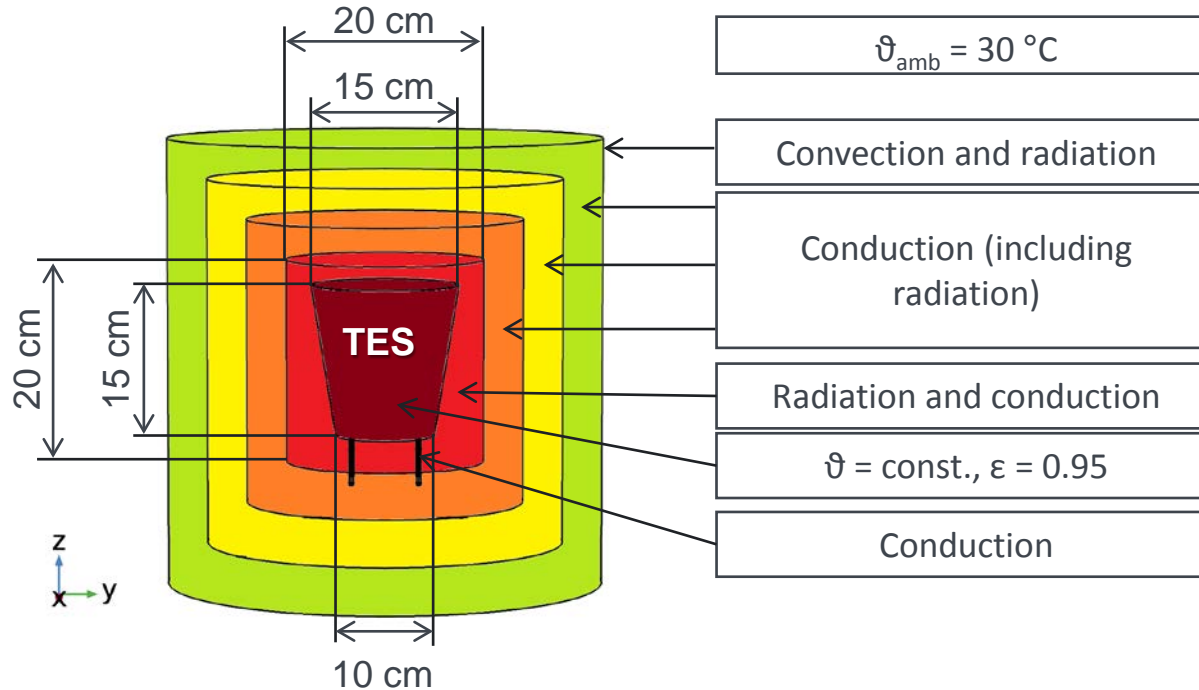
Sources: <http://www.morganthermalceramics.com/media/2631/wds-ultra-data-sheet-english-mi.pdf>
https://www.aerogel.com/_resources/common/userfiles/file/Data%20Sheets/Spaceloft-European-Datasheet-DE.pdf

Thermal conductivities in air/ nitrogen (manufacturer data)

- Zirconia fiber board 1 (585 €/dm³)
- ▲ Alumina fiber board (65 €/dm³)
- + Alumina fiber mat 2 (9 €/dm³)
- ✱ Graphite fiber mat (17 €/dm³)
- ◆ Zirconia fiber board 2 (263 €/dm³)
- ✕ Alumina fiber mat 1 (7 €/dm³)
- Fumed silica board (2.5 €/dm³)



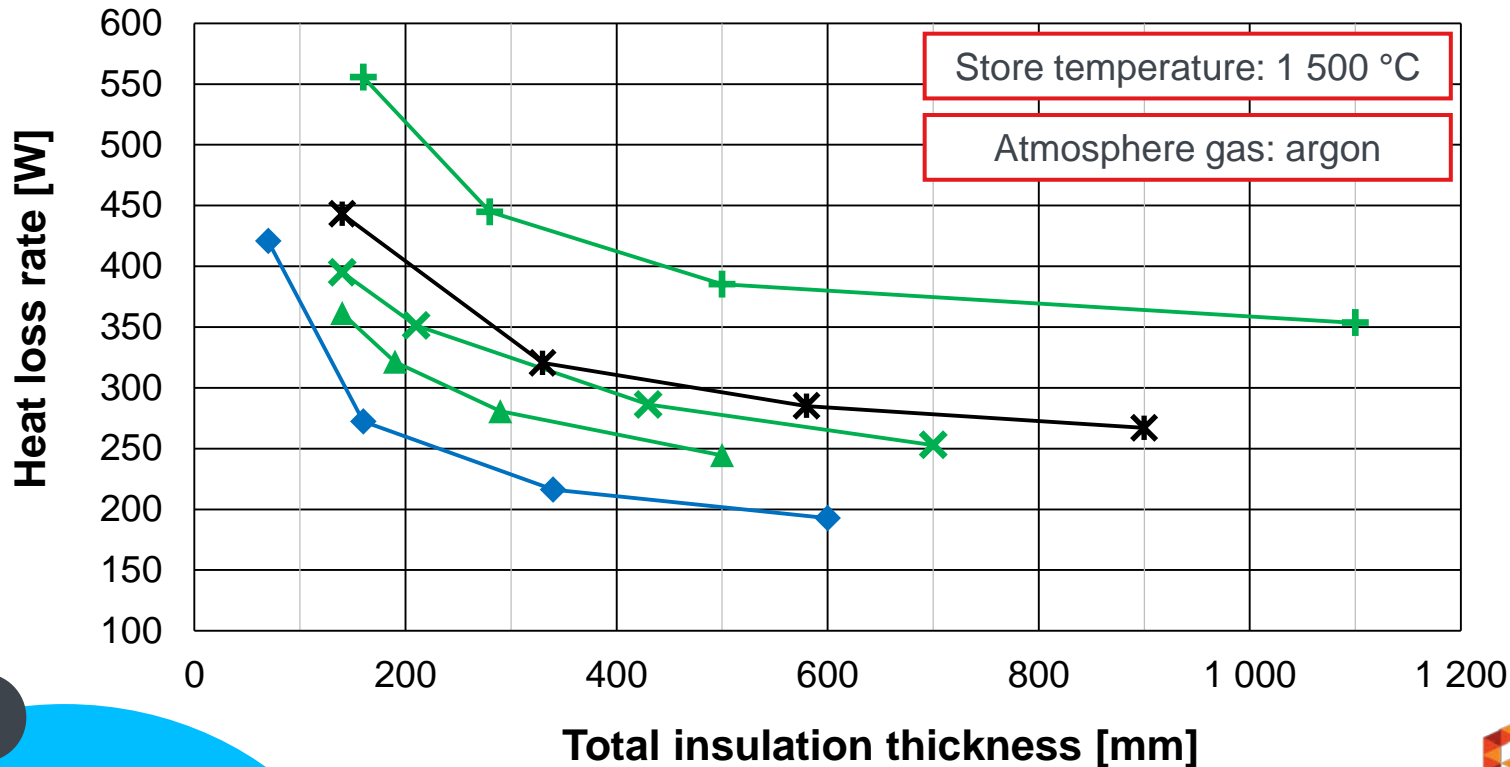
Preliminary thermal simulations – Model



- Simulation software: COMSOL Multiphysics
- Outside insulation layer: fumed silica board

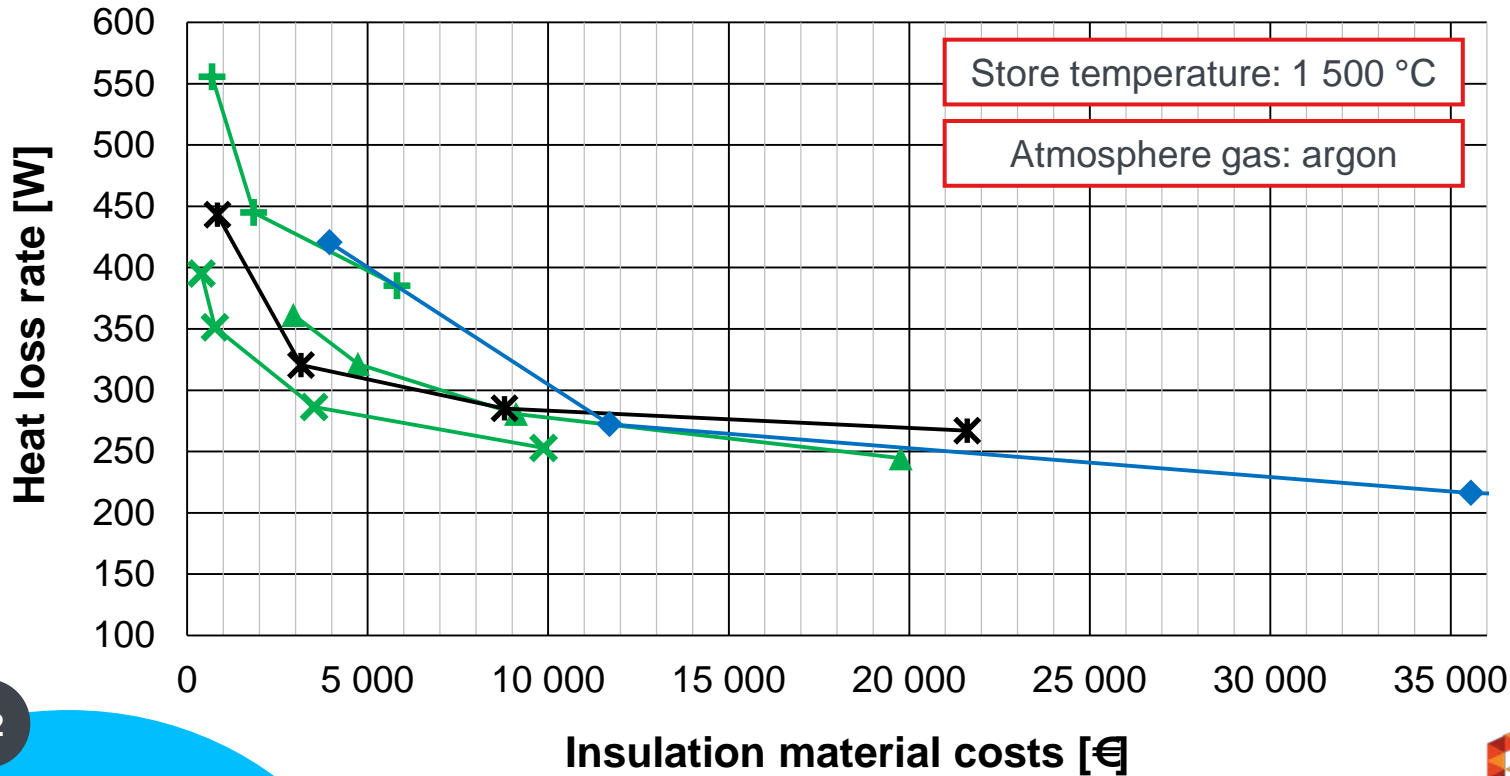
Preliminary thermal simulations – Results

- ✕ Alumina fiber mat 1
- ✕ Alumina fiber mat 2
- ▲ Alumina fiber board
- ✱ Graphite fiber mat
- ◆ Zirconia fiber board 2



Preliminary thermal simulations – Results

- ✕ Alumina fiber mat 1
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- ▲ Alumina fiber board
- ✱ Graphite fiber mat
- ◆ Zirconia fiber board 2

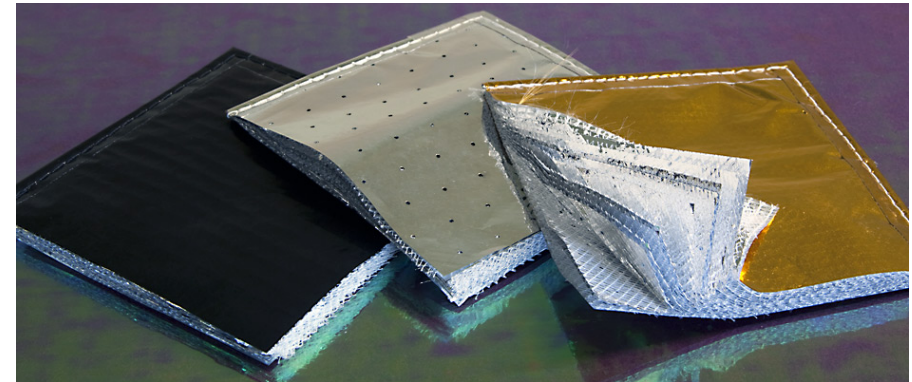


Choice of insulation materials for prototype

- Main criteria:
 - Temperature stability (permanent)
 - Costs
 - Thermal conductivity

- Screening showed: comparably lower cost materials with very low thermal conductivity only available up to 1 000 °C
 - Multi-layer solution
 - **Graphite fiber materials (1 000 °C – 2 000 °C; 17 €/dm³)**
 - **Fumed silica board (up to 1 000 °C; 2.5 €/dm³)**

Heat shields/ multi-foil instead of insulation materials?

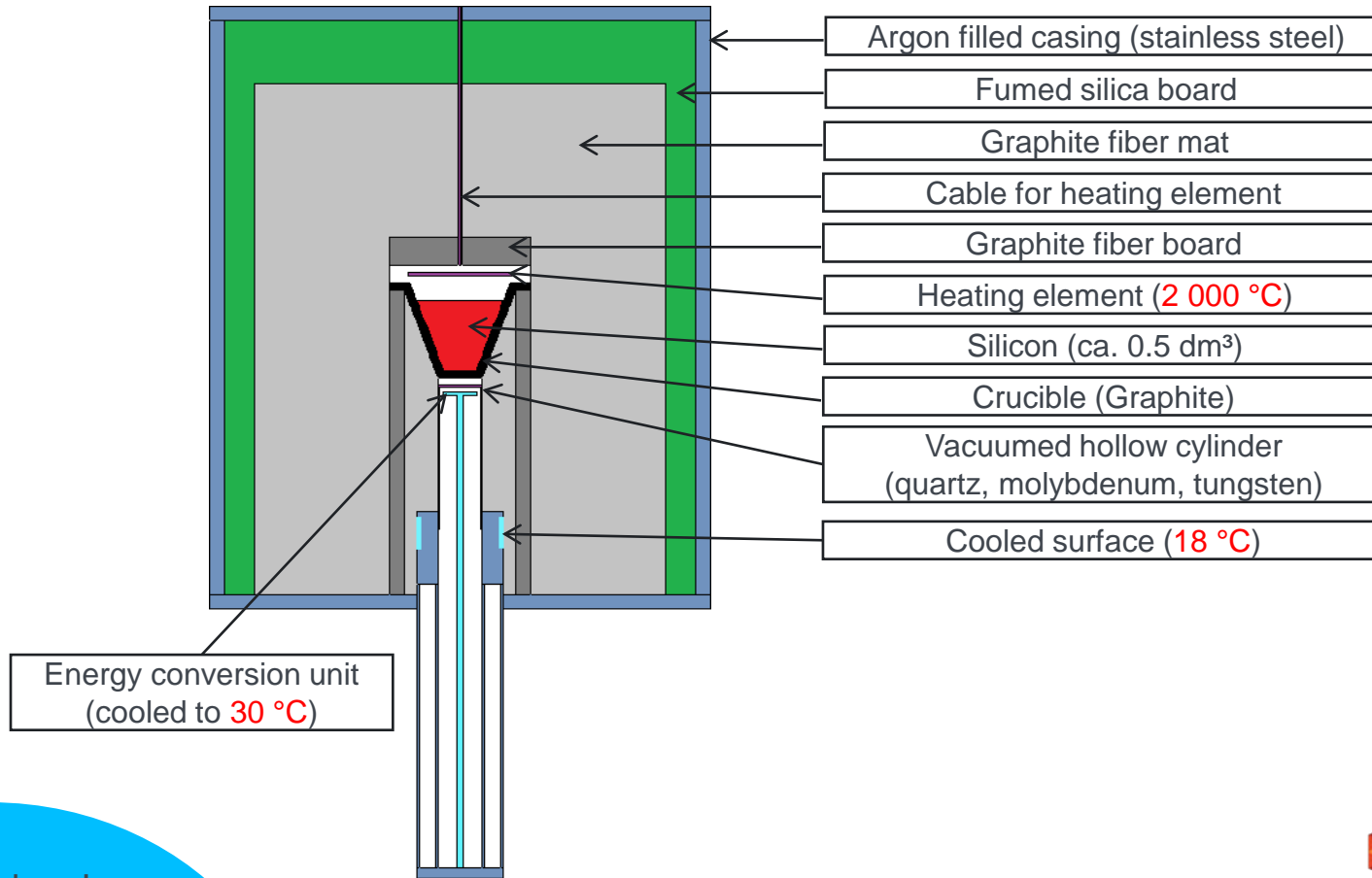


Source: <http://bronaerotech.com/wp-content/uploads/2011/04/space.jpg>

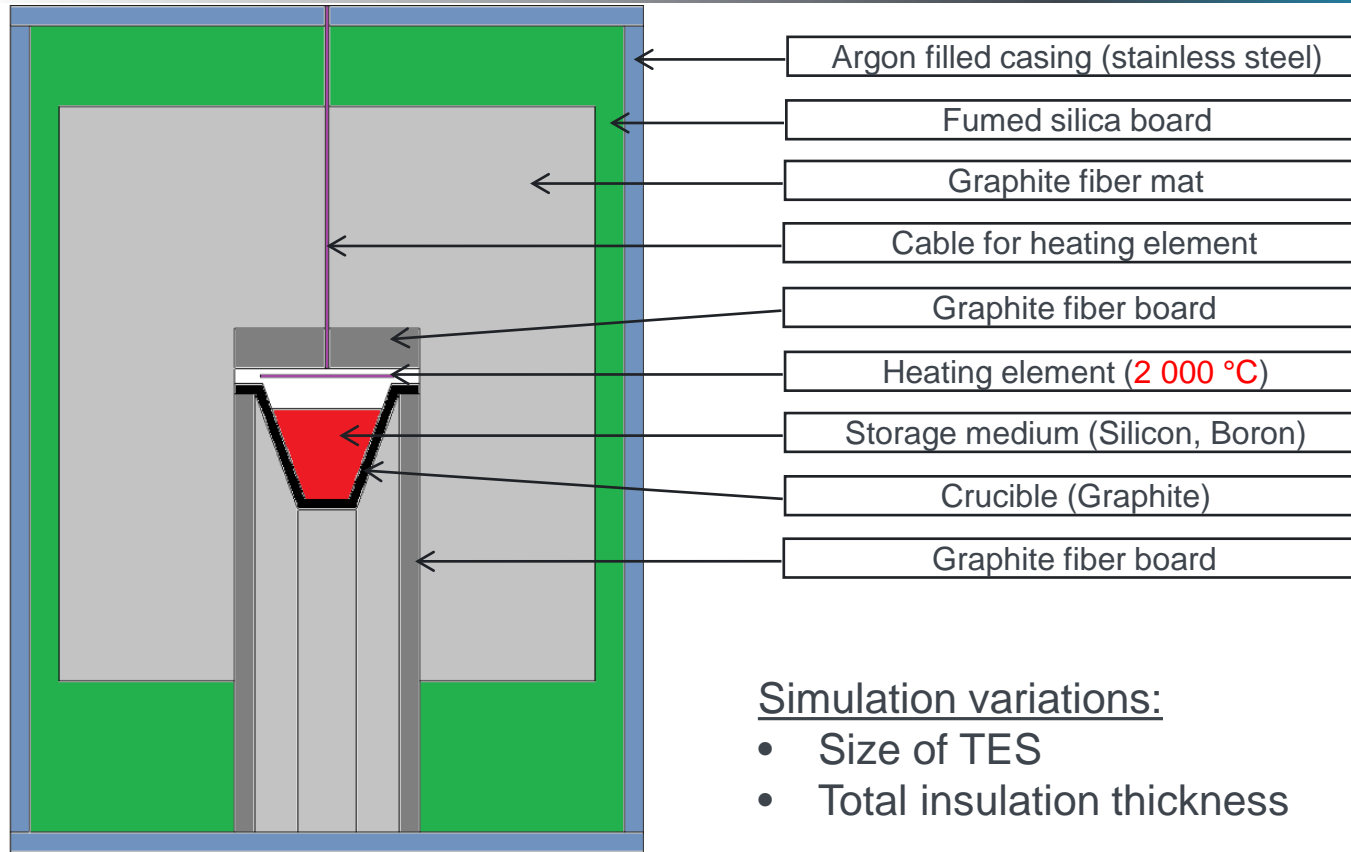
- Calculations on heat shield insulation were carried out
- Insulation materials turned out to be more cost-efficient than heat shield insulation

Source: Waitz, R.; Wübben, P. Journal „elektrowärme international“, Vol 3/2010

Prototype insulation concept (proof of concept)



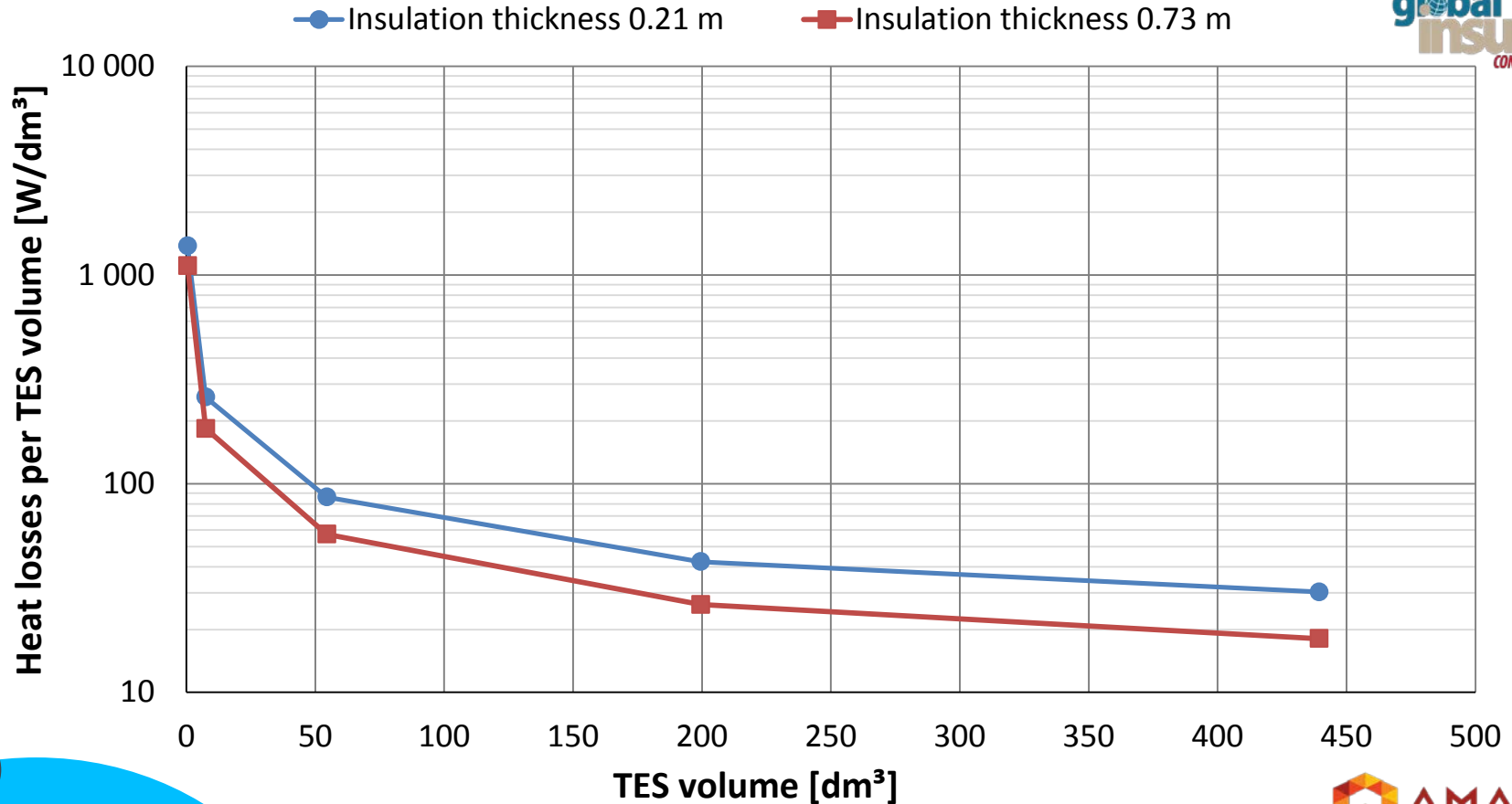
Real case insulation concept, charging phase



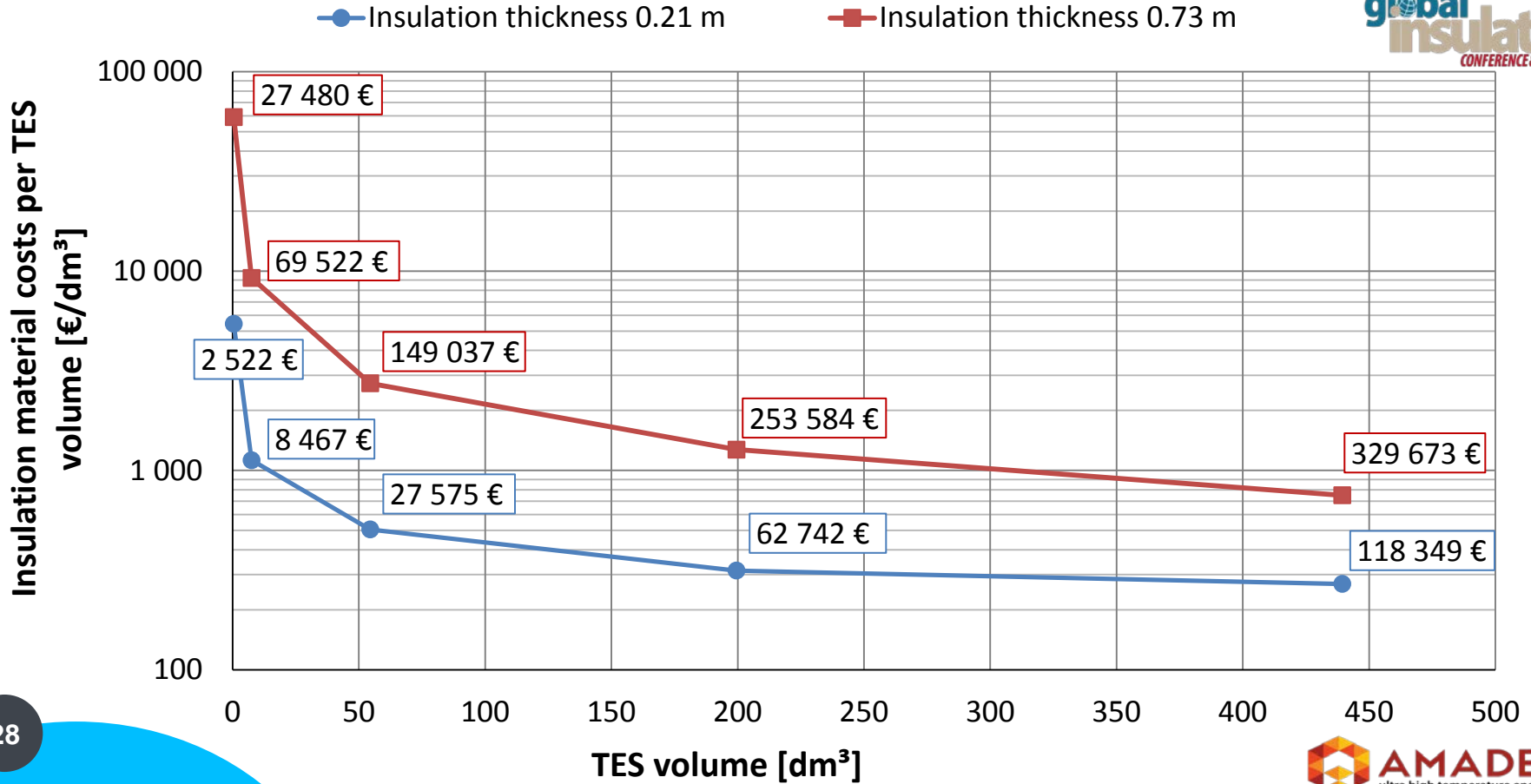
Simulation variations:

- Size of TES
- Total insulation thickness

Simulation study of different TES sizes, charging phase



Simulation study of different TES sizes, charging phase



Summary & Conclusions

- AMADEUS concept brings big chances for renewable energies
 - yet in the proof-of-concept state
- Insulation is a critical part of the concept
 - high cost reduction potential
 - lower cost ultra-high temperature insulation materials to be found or developed

Research project the presented work is part of

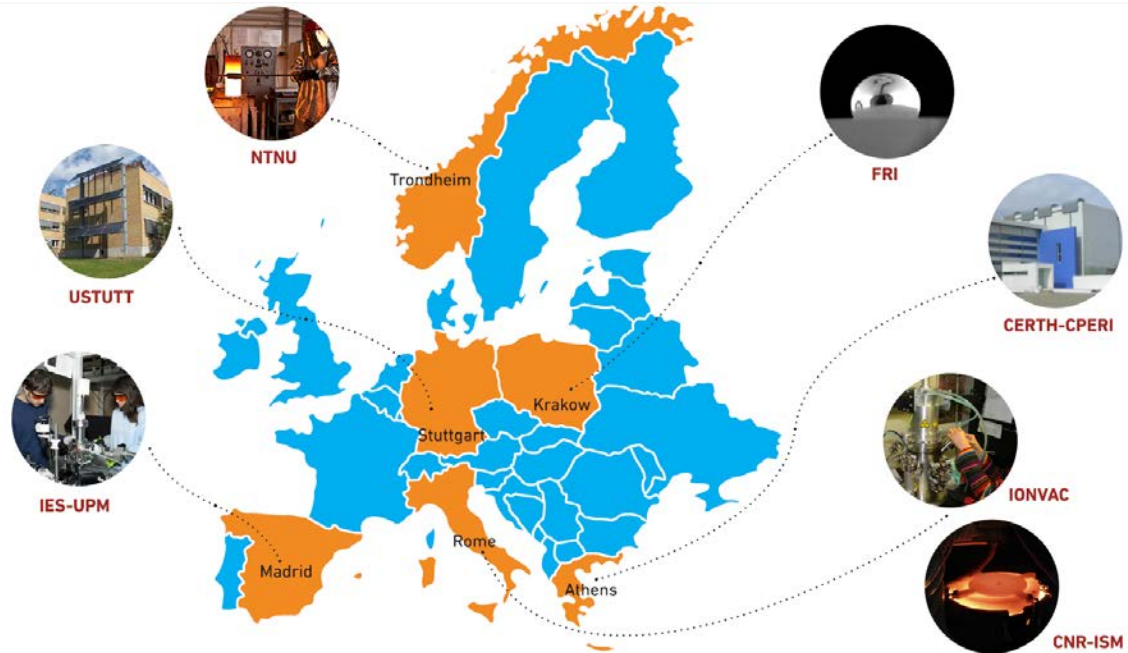
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www.amadeus-project.eu





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(IGTE)

Thank you!



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