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Austria

Rock Bed Thermal Energy Storage for Medium-Temperature Applications

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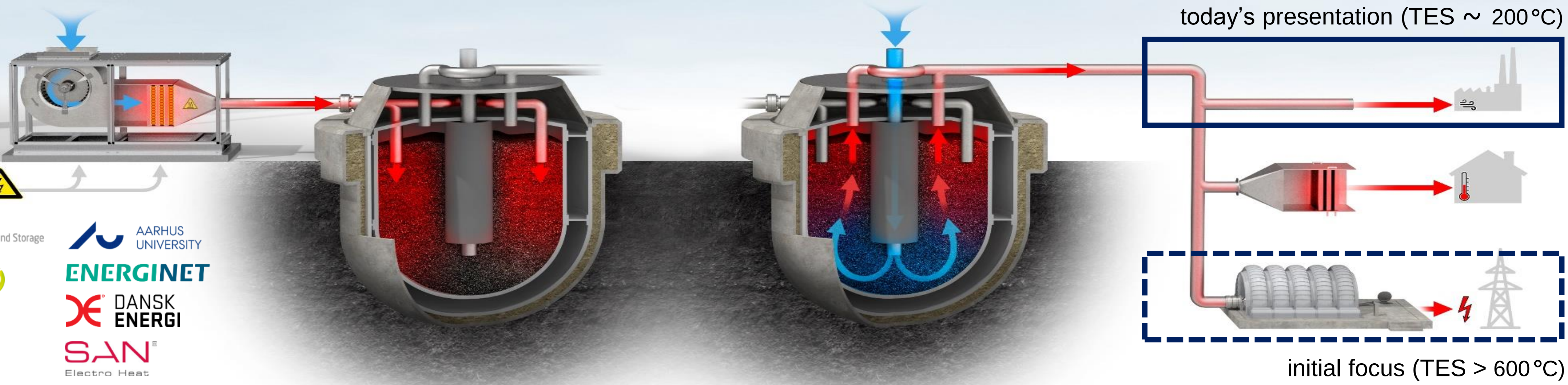
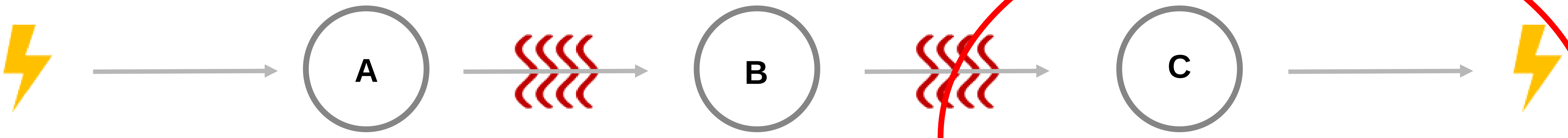


DTU Energy Department of Energy Conversion and Storage
AARHUS UNIVERSITY
seas-nve
ENERGINET
ROCKWOOL
DANSK ENERGI
EUDP Energiteknologisk udvikling og demonstration
SAN Electro Heat

Initial focus: Power-to-Heat-to-Power *

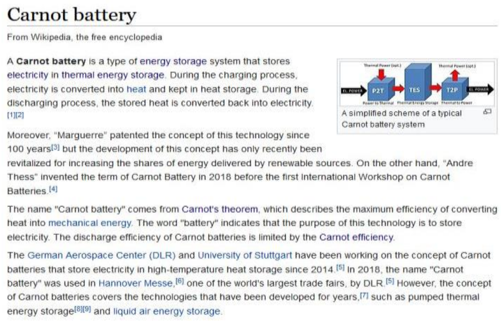
* classified as *Carnot Battery*

IEA Task 36



CONVERSION	STORAGE	CONVERSION
Resistive heating	Thermal Storage	Water-steam cycle

More about Carnot Batteries?



Carnot battery

From Wikipedia, the free encyclopedia

A **Carnot battery** is a type of energy storage system that stores electricity in thermal energy storage. During the charging process, electricity is converted into heat and kept in heat storage. During the discharging process, the stored heat is converted back into electricity.[1][2]

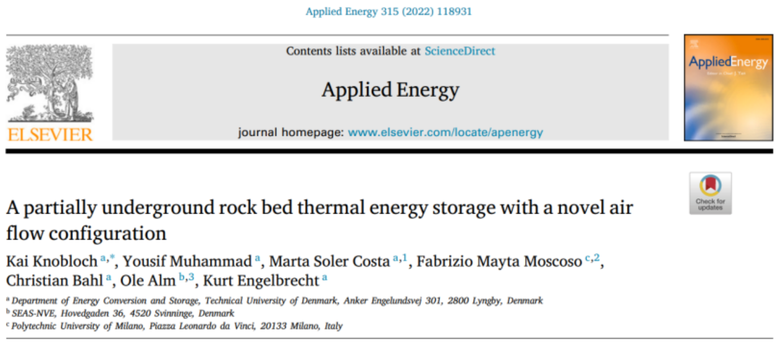
A simplified scheme of a typical Carnot battery system

Moreover, "Marguerre" patented the concept of this technology since 100 years[3] but the development of this concept has only recently been revitalized for increasing the shares of energy delivered by renewable sources. On the other hand, "Andre Thess" invented the term of Carnot Battery in 2018 before the first International Workshop on Carnot Batteries.[4]

The name "Carnot battery" comes from Carnot's theorem, which describes the maximum efficiency of converting heat into mechanical energy. The word "battery" indicates that the purpose of this technology is to store electricity. The discharge efficiency of Carnot batteries is limited by the Carnot efficiency.

The German Aerospace Center (DLR) and University of Stuttgart have been working on the concept of Carnot batteries that store electricity in high-temperature heat storage since 2014.[5] In 2018, the name "Carnot battery" was used in Hannover Messe,[6] one of the world's largest trade fairs, by DLR.[5] However, the concept of Carnot batteries covers the technologies that have been developed for years,[7] such as pumped thermal energy storage[8][9] and liquid air energy storage.

More about our high-temperature rock bed?



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A partially underground rock bed thermal energy storage with a novel air flow configuration

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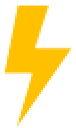
[1] or https://doi.org/10.1016/j.apenergy.2022.118931

New focus: Power-to-Heat- …

EU28, 2020: More than 74% of the final energy demand for process heat accounts to temperatures above 200 °C. [2]



A

B

CONVERSION

Resistive heating
(or heat pump)

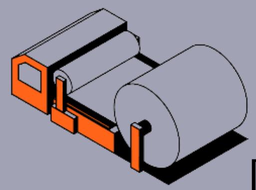
STORAGE

Thermal Storage

Energy-intensive industries
such as

[3]

[4]

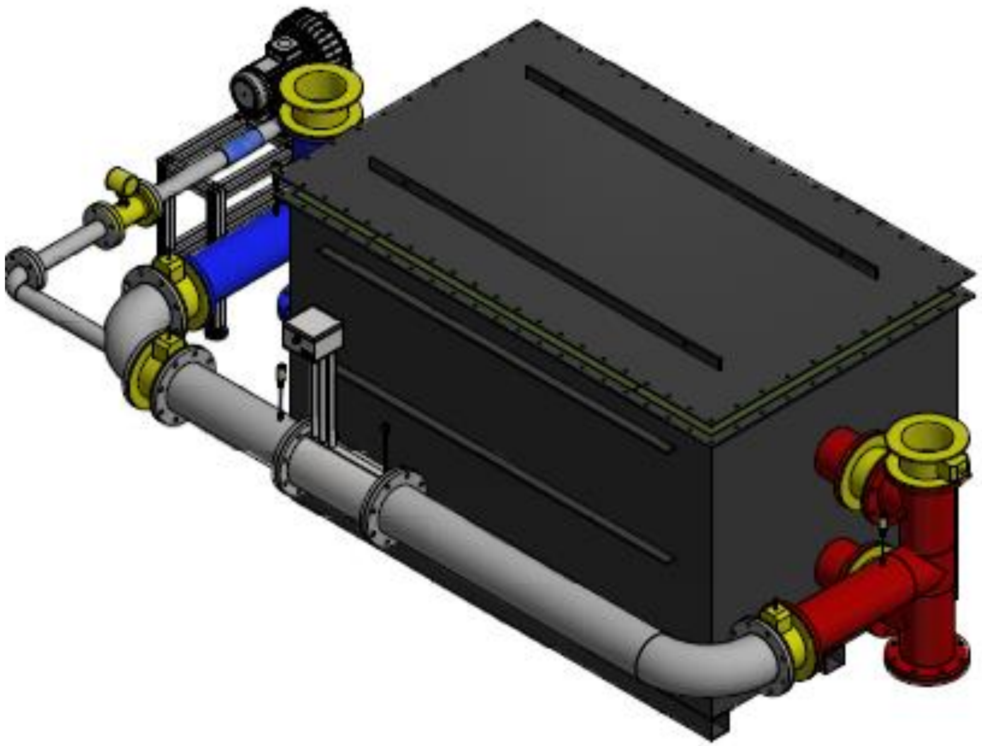


[5]

…

Rock Bed 1.0 and 2.0 at DTU Energy

Shoebox [5]



Droplet [1]

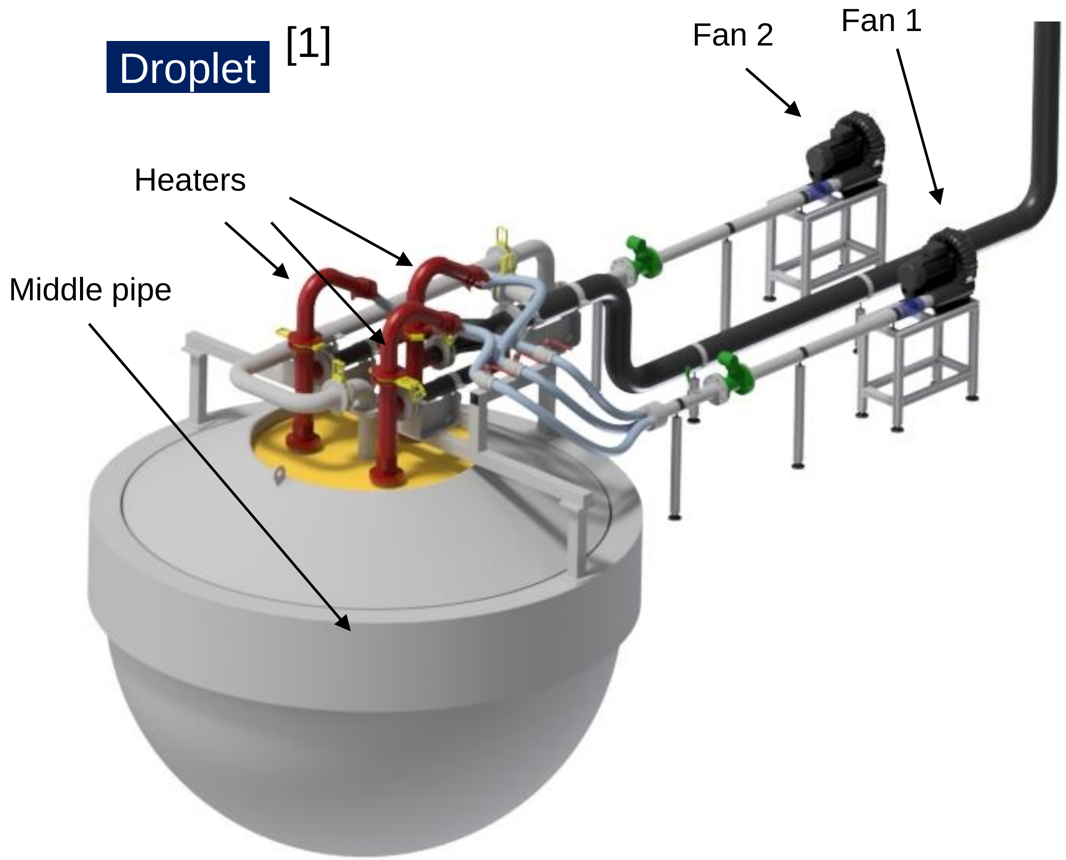
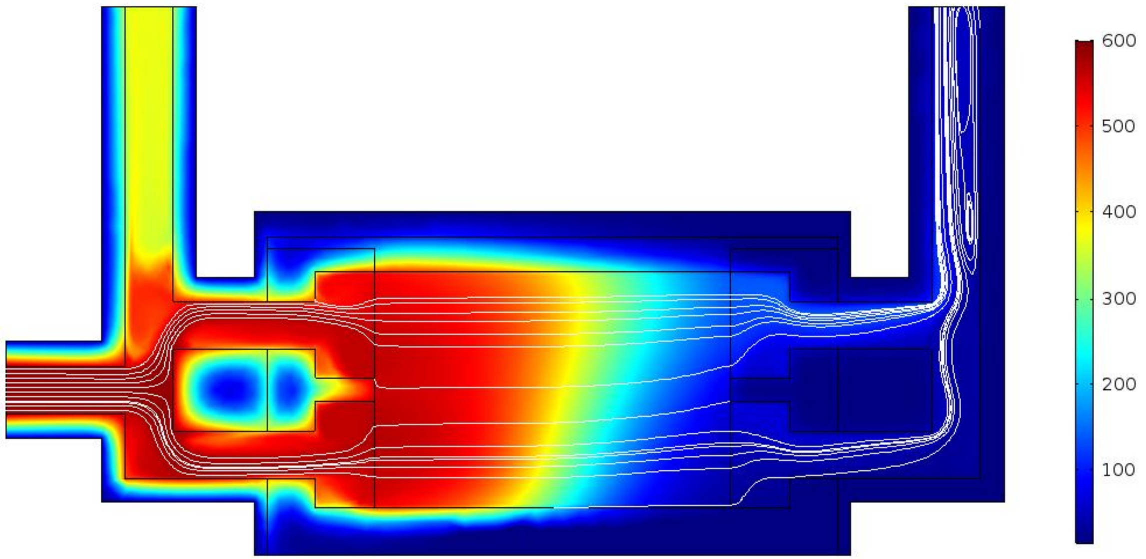


Figure 1 Rock bed concepts developed at DTU Energy [1] [5].

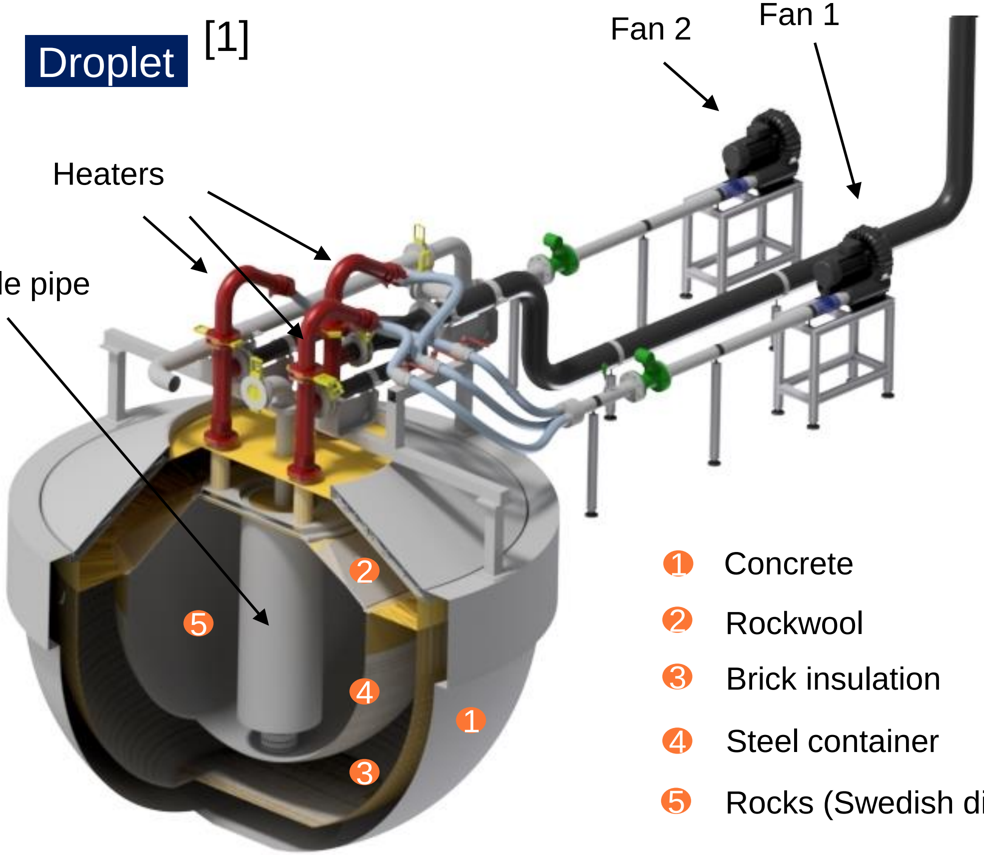
Rock Bed 1.0 and 2.0 at DTU Energy

Shoebox [5]



Temperature and air flow streamline after 6 h charge with *Re* = 12 and *NTU* = 56 [5].

Droplet [1]

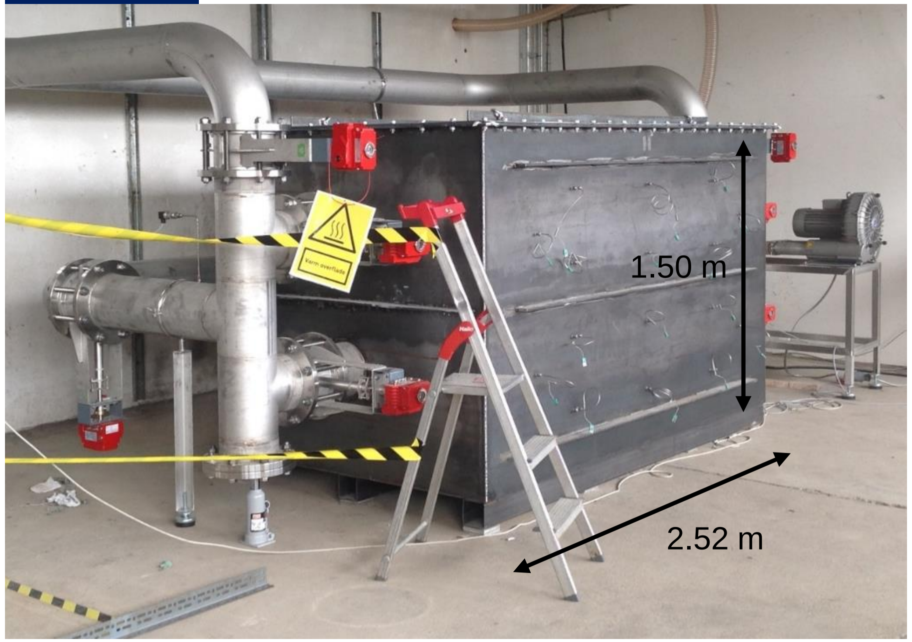


- two different rock sizes (8-11 mm and 16-22 mm)
- piping and heaters mounted on top of the storage
- middle pipe for flow reversal

Figure 1 Rock bed concepts developed at DTU Energy [1] [5].

Thermal energy storage (TES) pilot plants built at DTU Energy

Shoebox [5]



V_{pb} = 1.5 m^3

P_{ch} = 30 kW$_{el}$

T_{ch} = 600 °C

C_{th} = 450 kWh$_{th}$ (ΔT = 600 °C)

η_{RT} < 68.5 % (with one layer)

Droplet [1]

247 cycles, approx. 3500 h

V_{pb} = 3.2 m^3

P_{ch} = 45 kW$_{el}$

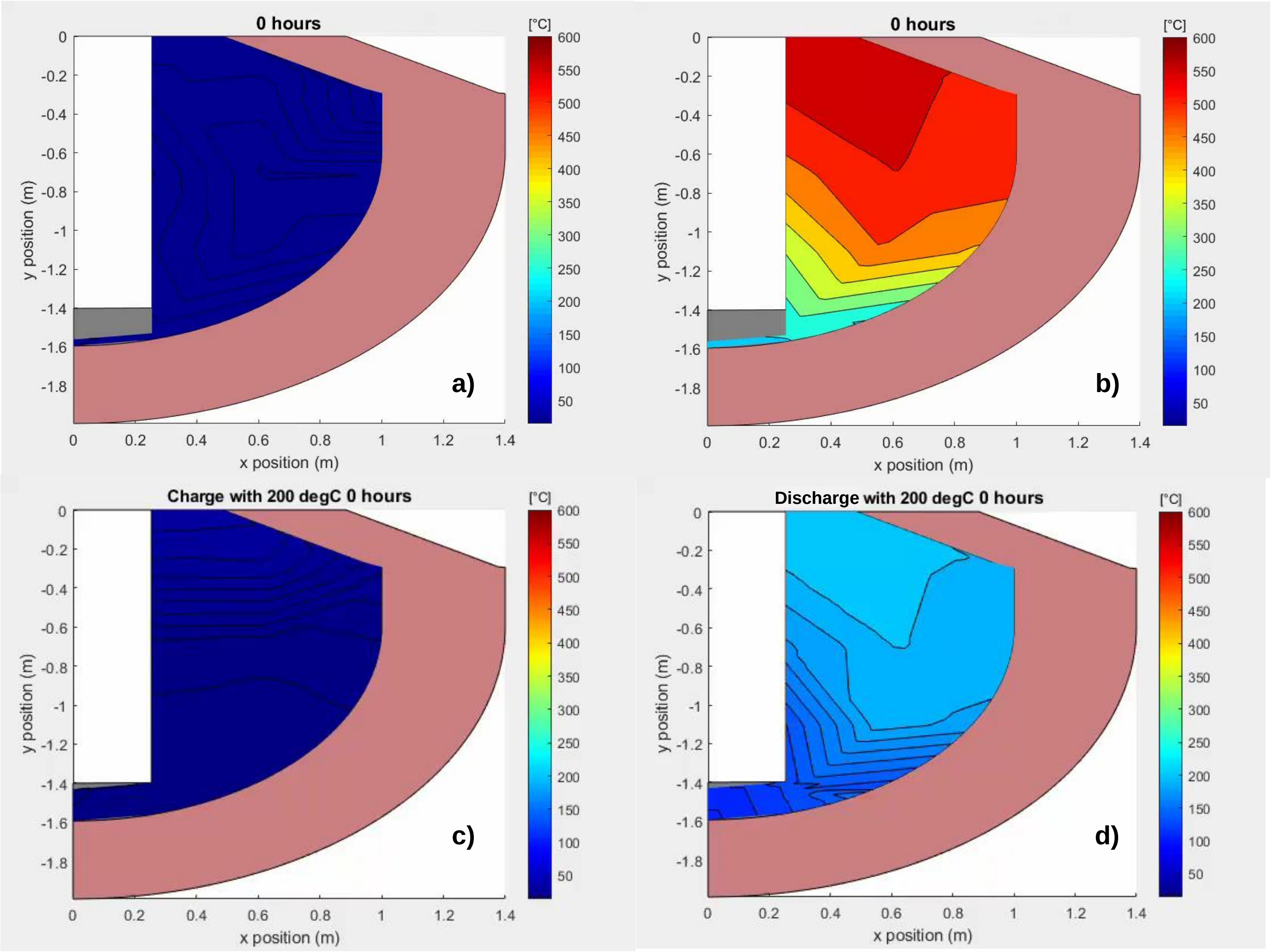
T_{ch} < 675 °C

C_{th} = 1000 kWh$_{th}$ (ΔT = 600 °C)

η_{RT} < 80.7 %

Video: Reconstructed temperature profiles

Figure 3 Reconstructed temperature during
a) 600 ℃/200 m^3/h charge,
b) followed by a 200 m^3/h discharge.
c) 200 ℃/200 m^3/h charge,
d) followed by a 200 m^3/h discharge.



Temperature in the outlet pipe

lower flow rate would make the outlet temperature nearly constant

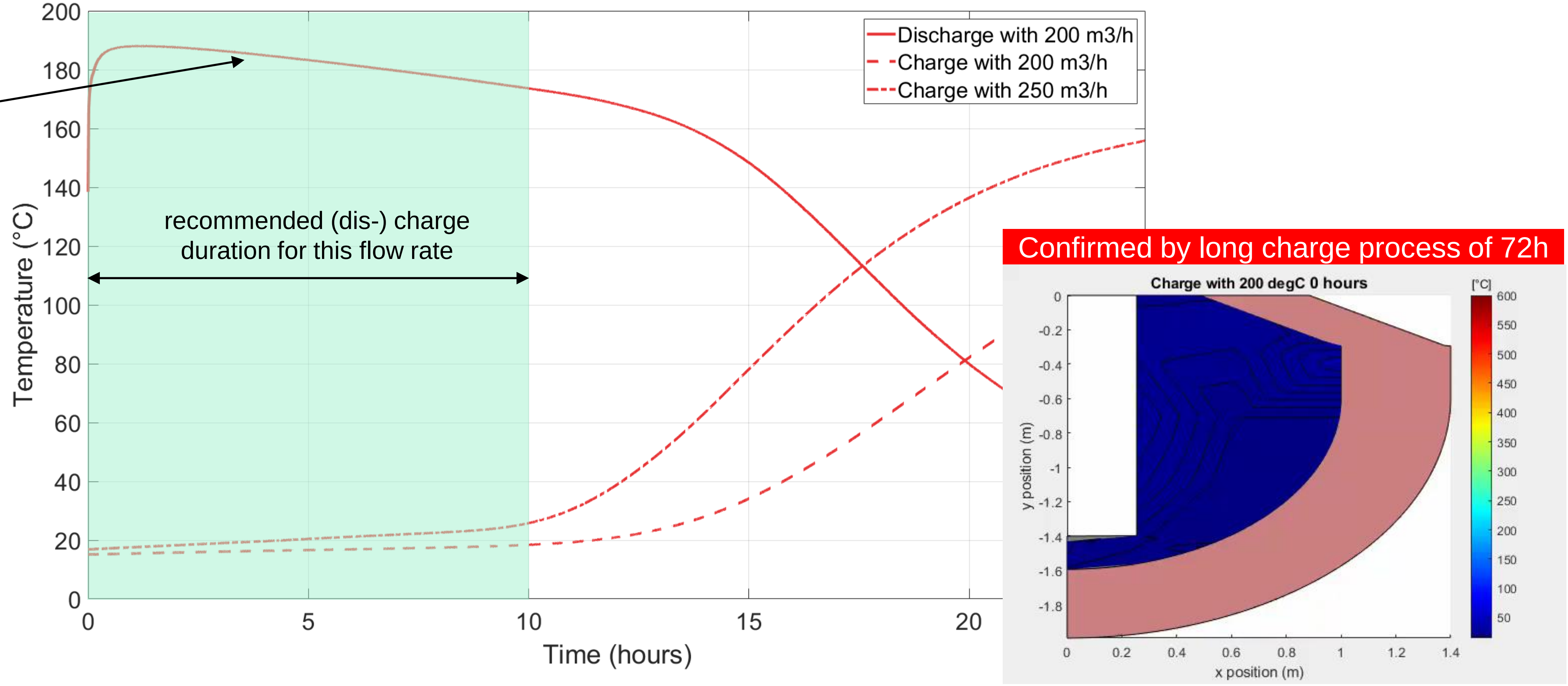


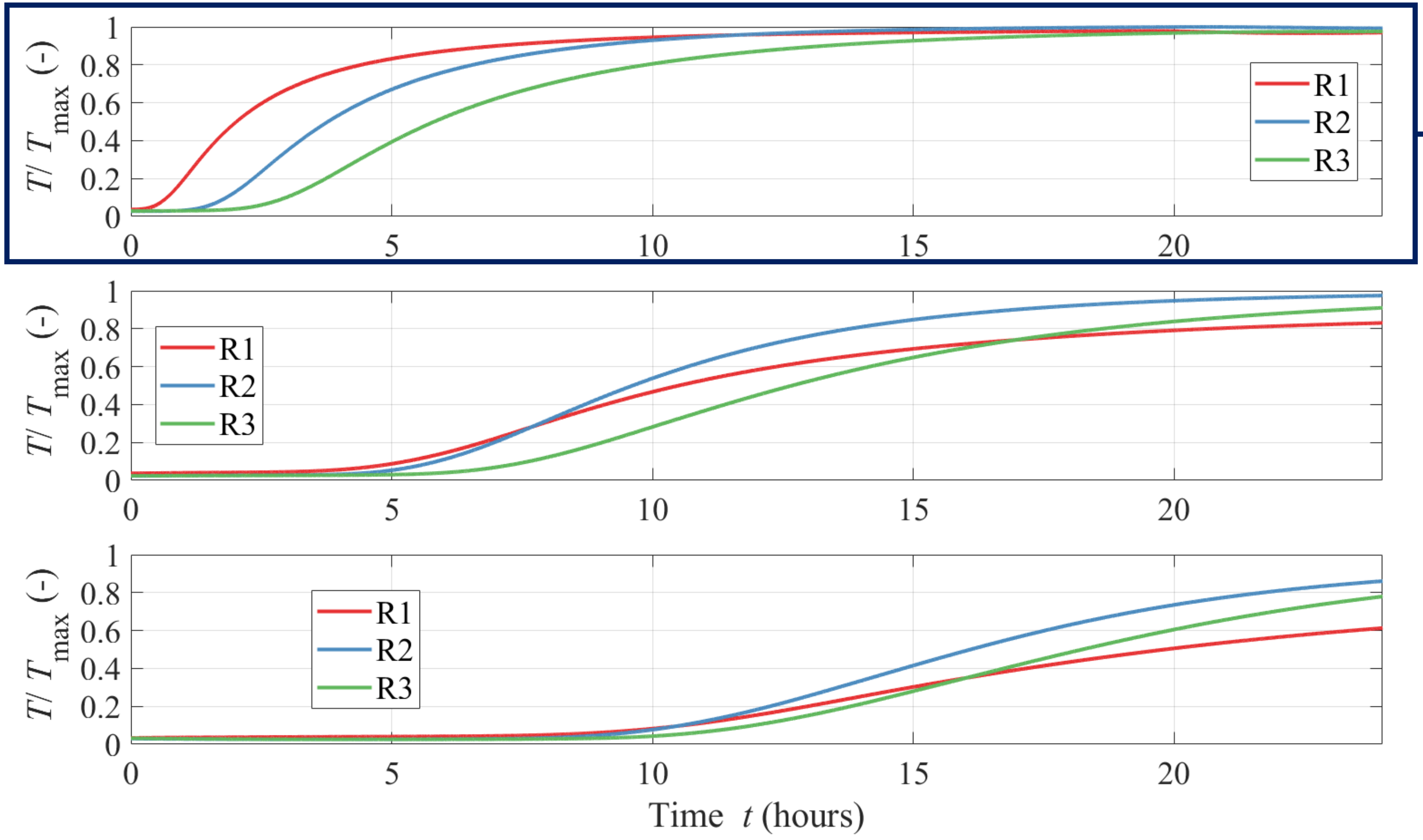
Figure 4 Temperature in outlet pipe as a function of time for 200 °C experiments.

Rock bed temperature distribution

a)

b)

c)



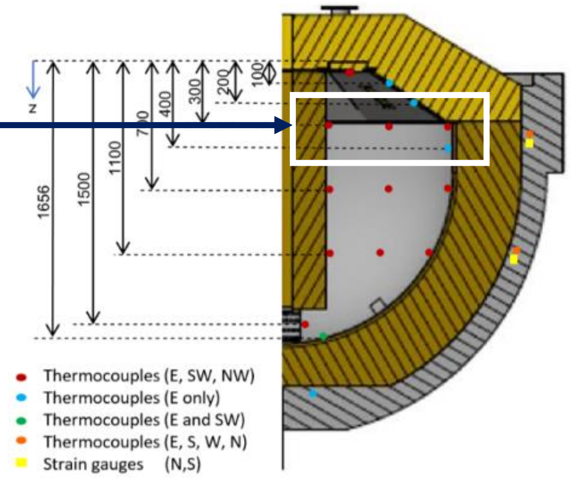
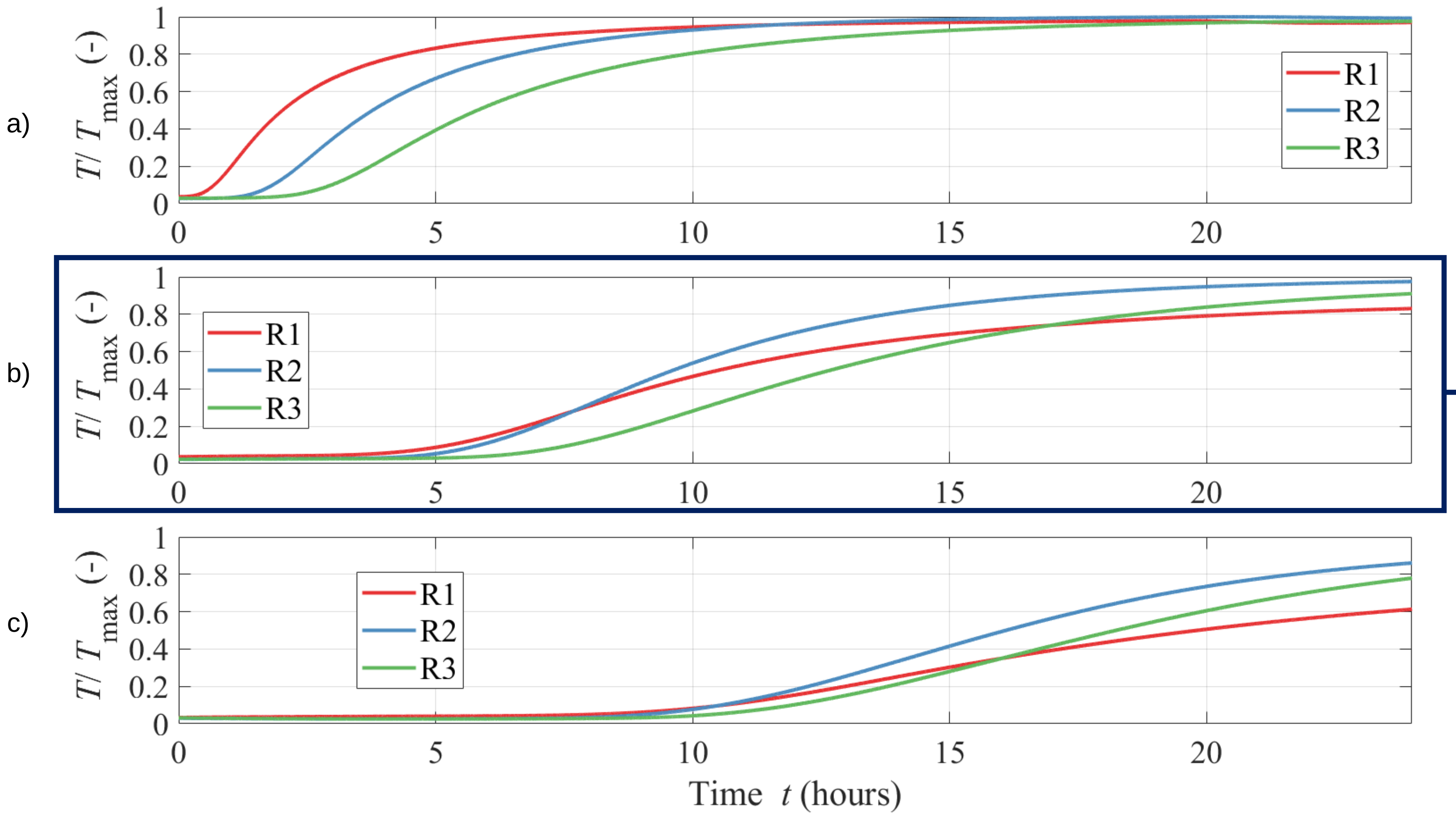
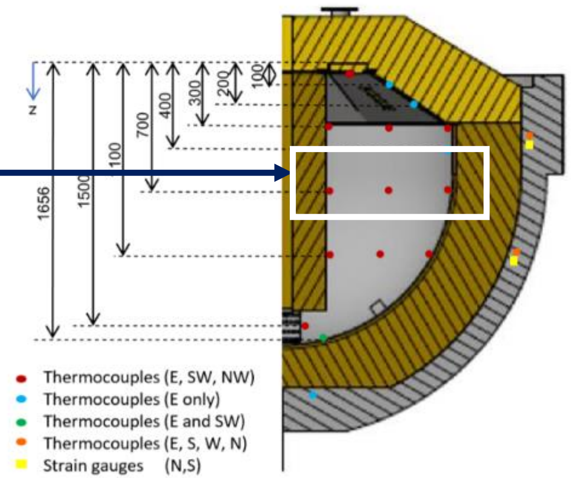


Figure 5 Dimensionless temperature as a function of time for all three radial positions (R1,R2,R3) and three axial positions at depths of a) z= 300 mm b) z = 700mm c) z = 1100 mm) in NW orientation during 600 °C (solid) and 200 °C (dashed), both with 200 m^3/h.

Rock bed temperature distribution





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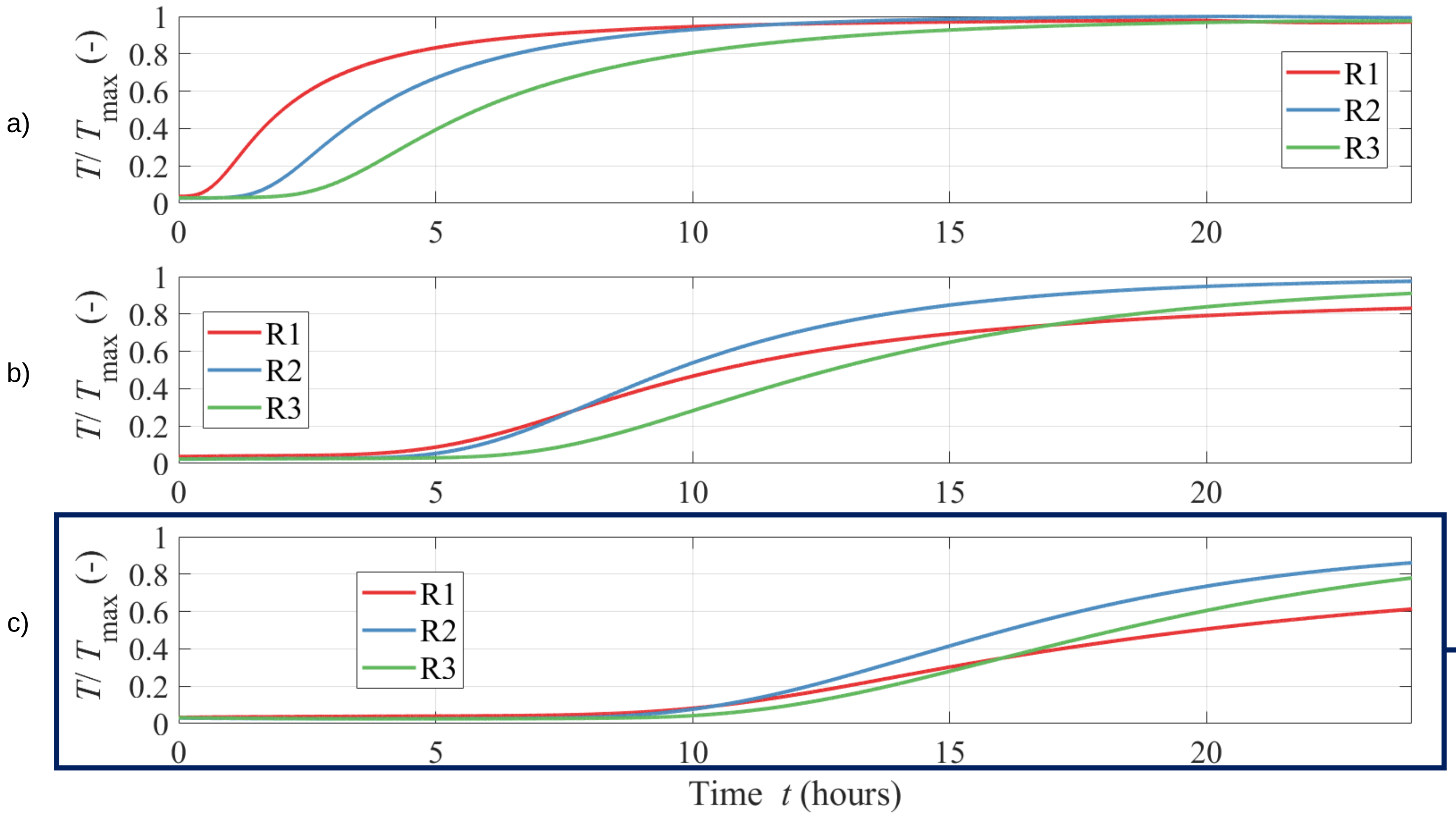
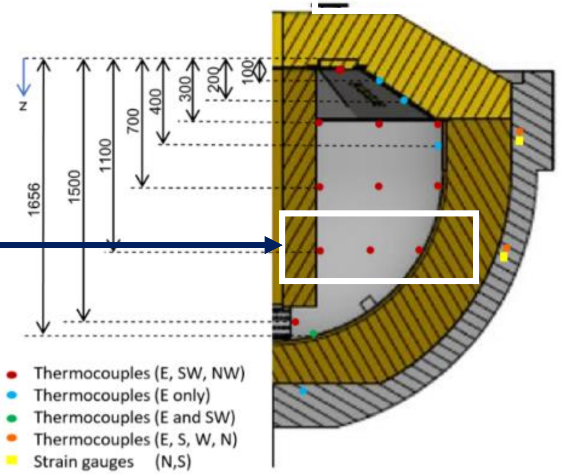
Rock bed temperature distribution





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Rock bed temperature distribution

a)
b)
c)

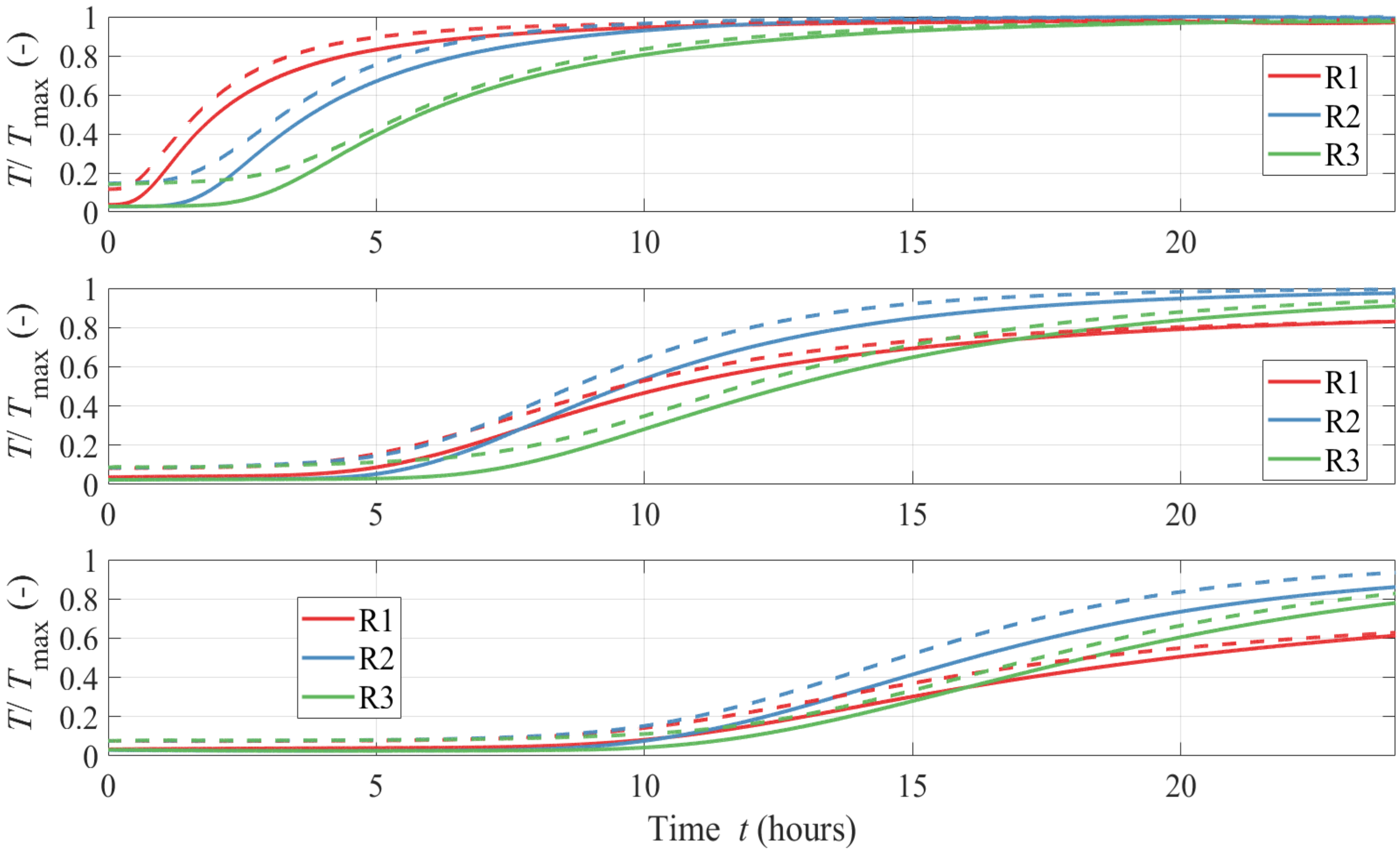


Figure 5 Dimensionless temperature as a function of time for all three radial positions (R1,R2,R3) and three axial positions at depths of a) z= 300 mm b) z = 700mm c) z = 1100 mm) in NW orientation during 600 °C (solid) and 200 °C (dashed), both with 200 m^3/h.

- same general behaviour (R1-R3)
- faster energy storage
- difference between heater and highest rock bed temperature is smaller

Video: CFD modeling

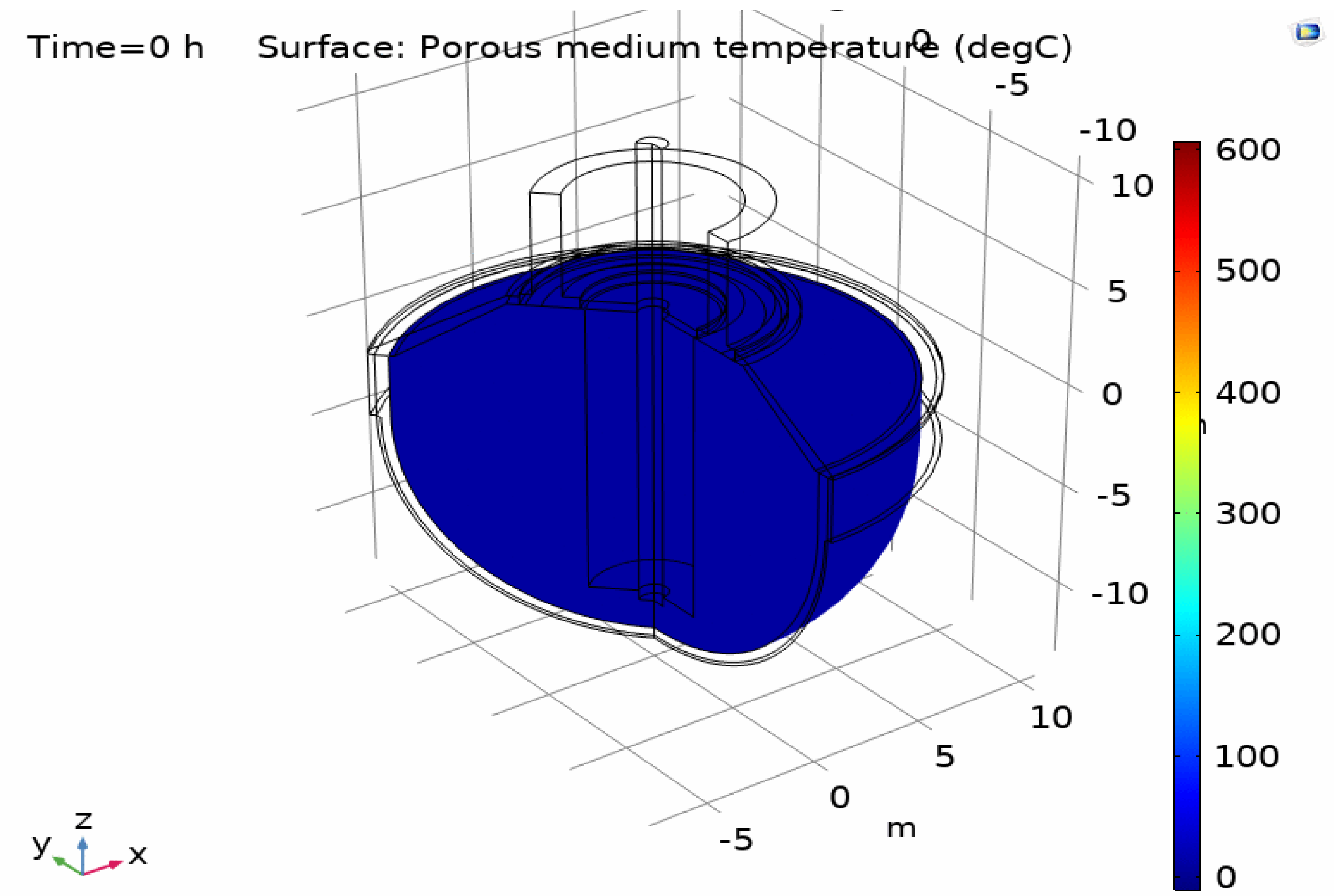
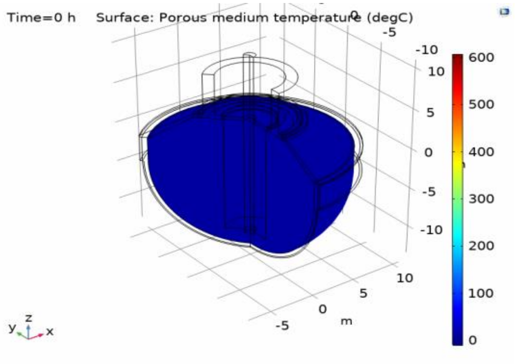


Figure 6 Animation of the charge and discharge process of an upscaled rock bed based on CFD modeling.

Outlook

- Thermal energy storage is a promising way to incorporate renewable energy sources with intermittent power output into the electricity grid and industrial processes

- Rock beds represent a **thermally efficient, cost-effective** and **readily available** thermal storage for temperatures above 200 °C
    - Operated the pilot plant for over 2 years and 3500 operating hours with no failures to date



- Successful validation of our CFD models, development of dynamic model for system integration

- DTU Energy is investigating the supply of process heat, potentially in combination with electricity, and is happy to support industries during their decarbonization

Thank you.

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References

[1] Knobloch, K., Muhammad, Y., Costa, M. S., Moscoso, F. M., Bahl, C., Alm, O., & Engelbrecht, K. (2022). A partially underground rock bed thermal energy storage with a novel air flow configuration. *Applied Energy*, *315*, [118931]. https://doi.org/10.1016/j.apenergy.2022.118931

[2] Fleiter, T.; *Steinbach*, *J*.; *Ragwitz*, *M*. et al. (*2016*): Mapping and analyses for the current and future (*2020* - *2030*) heating/cooling fuel deployment; WP 3+4 European Commission under contract N°ENER/C2/2014-641.

[3] Illustoon, can be found here

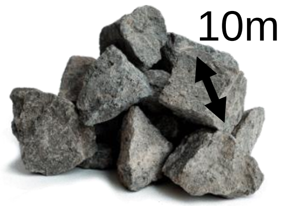
[4] KindPNG, can be found here

[5] Schneider, can be found here

[6] Marongiu, F., Soprani, S., & Engelbrecht, K. (2019). Modeling of high temperature thermal energy storage in rock beds – Experimental comparison and parametric study. *Applied Thermal Engineering*, *163*, [114355]. https://doi.org/10.1016/j.applthermaleng.2019.114355

Back up: Construction of the Rock Bed 2.0

Back up: Rock selection



stratification ↓

pressure drop ↓

Nr	Petrologic classification	Origin	High temp.	Average c_p raw [J/(K*g)]	Average c_p after heating [J/(K*g)]	Density [g/cm^3]	Average c_p after heating times Density [J/(K*m^3)]
~~1~~	~~Magnetite~~	~~Sweden~~	~~Yes~~	~~0.93~~	~~0.82~~	~~4.68 ± 0.23~~	~~3.8~~
~~2~~	~~Dunite~~	~~Norway~~	~~No~~	~~n/a~~	~~n/a~~	~~2.74 ± 0.10~~	~~n/a~~
~~3~~	~~Ilmenit-norite/Gabbro~~	~~Sweden~~	~~Yes~~	~~0.90~~	~~0.82~~	~~2.82 ± 0.28~~	~~2.2~~
5	Anorthosite	Norway	Yes	1.08	0.95	2.71 ± 0.09	2.6
→ 6	Diabase	Sweden, Finland	Yes	1.13	0.96	2.75 ± 0.09	2.6
7	Basalt	Germany, Austria	Yes	1.08	0.85	3.09 ± 0.39	2.6
~~8~~	~~Quartzite~~	~~Sweden~~	~~No~~	~~n/a~~	~~n/a~~	~~2.66 ± 0.07~~	~~n/a~~
~~9~~	~~Granite~~	~~Denmark~~	~~No~~	~~1.18~~	~~n/a~~	~~n/a~~	~~n/a~~