High Temperature Energy Storage in a Rock Bed

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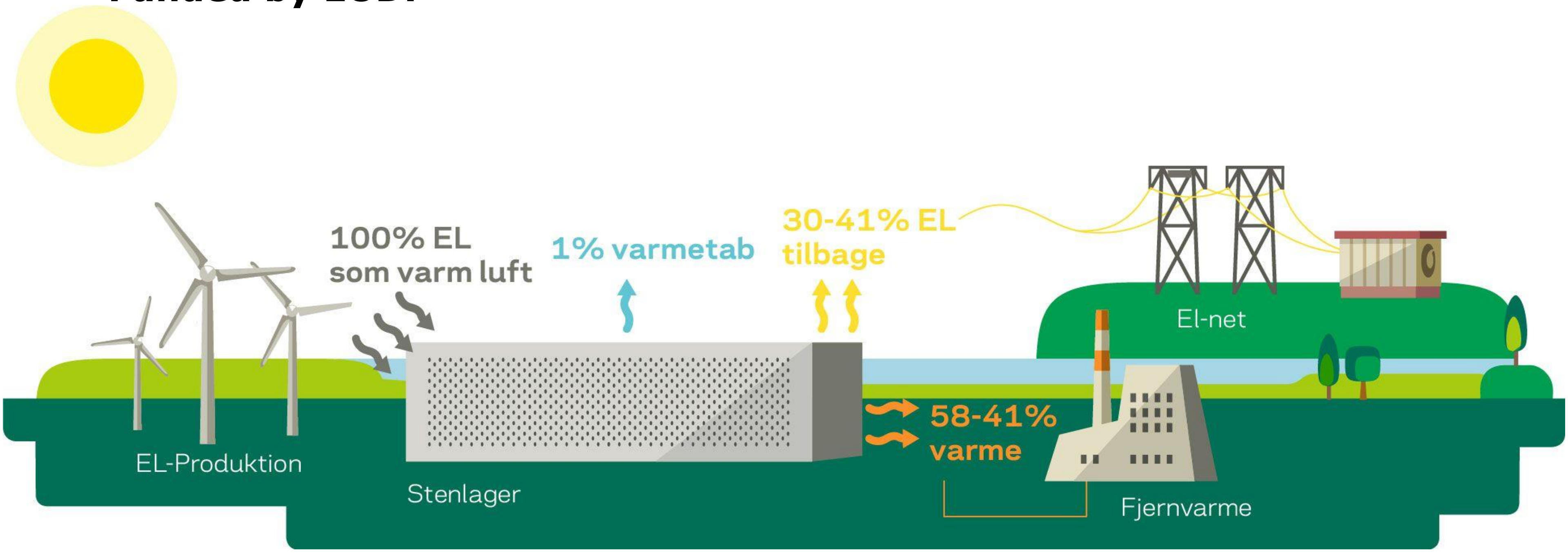
Project Description (HT TES project)

- **Heat** is stored at **high temperature (600 ^{0}C)**.
- The heat is used to produce **high pressure steam** to expand in a **turbine**.
- **Funded by EUDP**



Source: SEAS-NVE

Project Challenges and Research Areas

- Choose suitable rock material
- Design of the rock bed
- System testing
- Model rock bed operation, both thermal and economic aspects

Brief summary of thermal rock storage

- Low cost electricity is stored as heat in a rock bed then used to produce electricity or district heating when prices are high

- Due to the reduced efficiency associated with thermal conversion to electricity, the technology relies on relatively high electricity price fluctations

- The main advantages are low cost and easy scalability

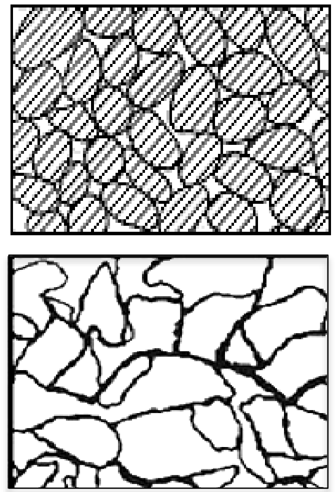
- Storage period is a few days up to several weeks, depending on the insulation and thermal losses

Rocks…the very basics

Rock texture

'Monomineralic' rocks

(>90% one mineral)



Quartzite (Hardeberga, Sweden)

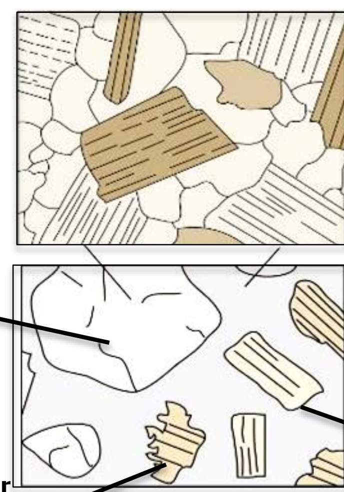
Magnadense (Kiruna, Sweden)

Dunite (Norway)

Ansite (Norway)

'Polymineralic' rocks:

(several minerals)



Granite (Bornholm)

Norite/Gabbro (Telnes, Norway)

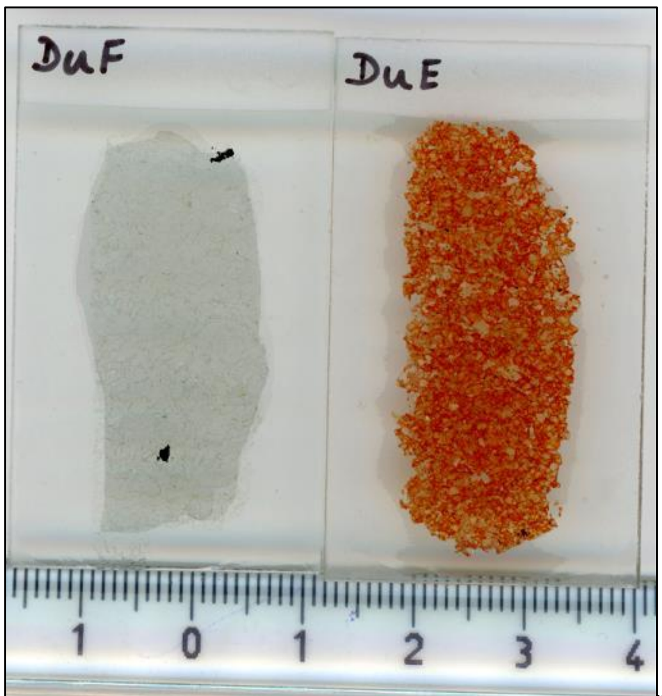
Diabas (Finland, Sweden)

Basalt (Germany/Austria)

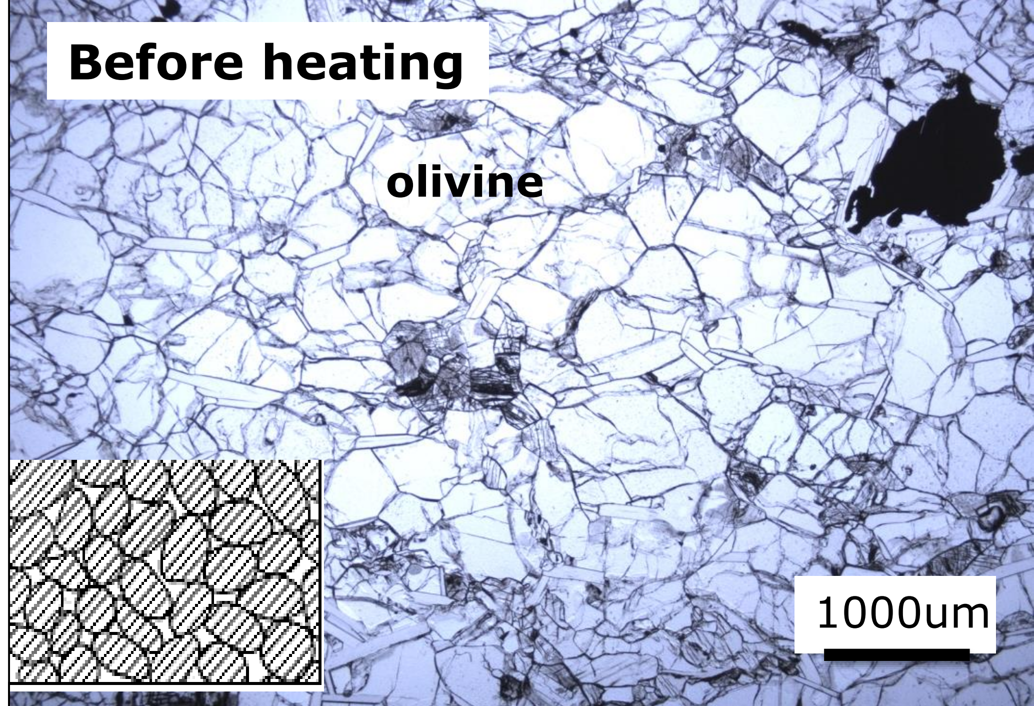
Hyperite (Norway)

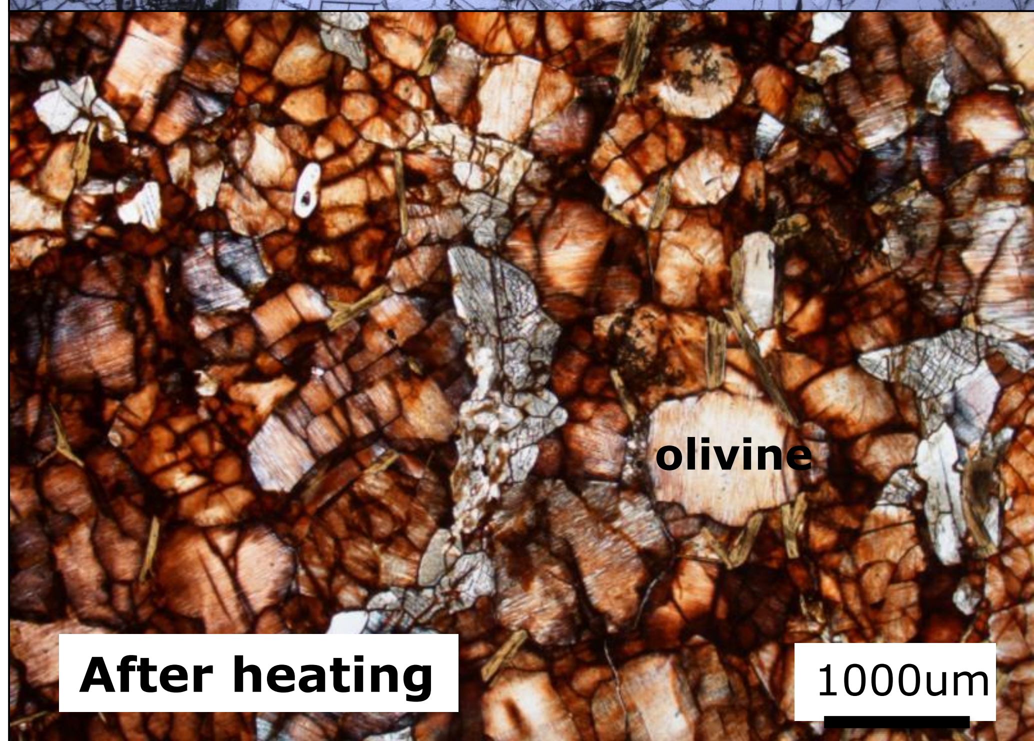
Dunite

before after



Microscopic texture



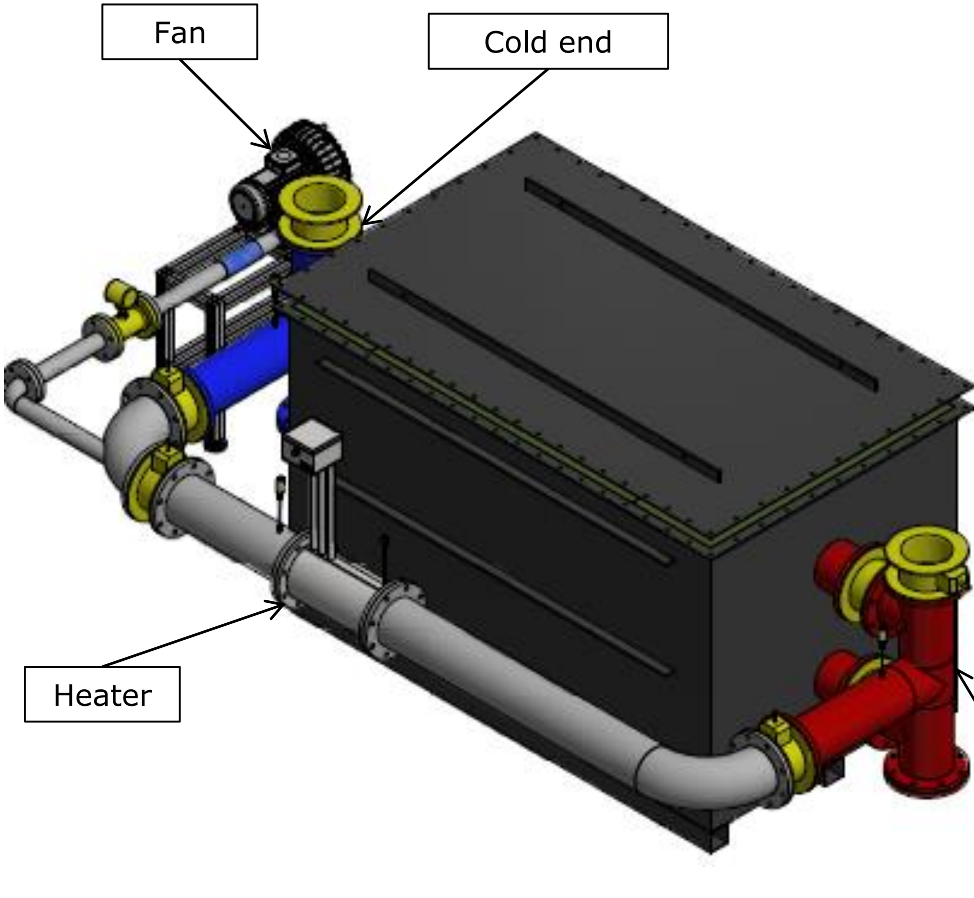


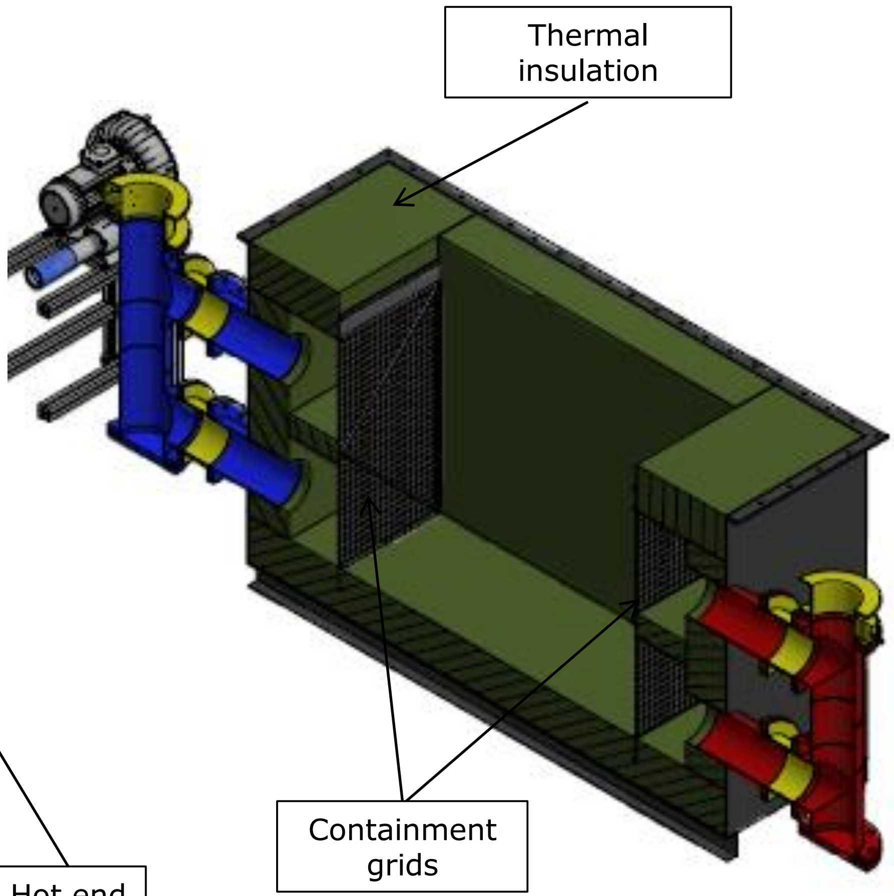
Rock selection for first experiments

- We chose Swedish diabase as the first rock material
  - Cheap and available day-to-day in Denmark
  - Available in different sizes
  - Able to withstand cycling to 600 C
  - First rocks tested were sieved between 20 mm and 40 mm

- We are looking at different rock types and sizes for future experiments

Experimental setup "shoebox"





Experimental setup “shoebox”

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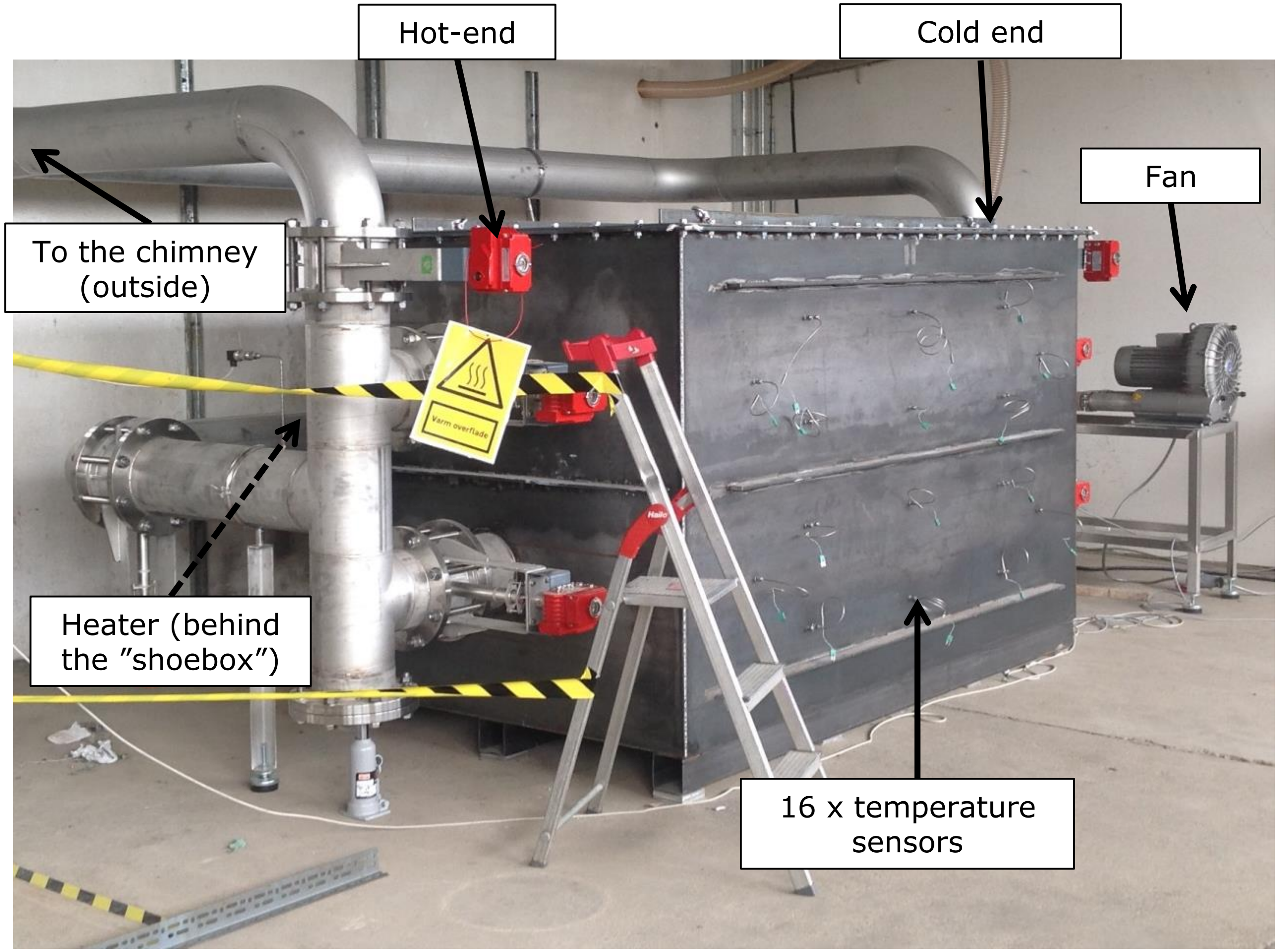
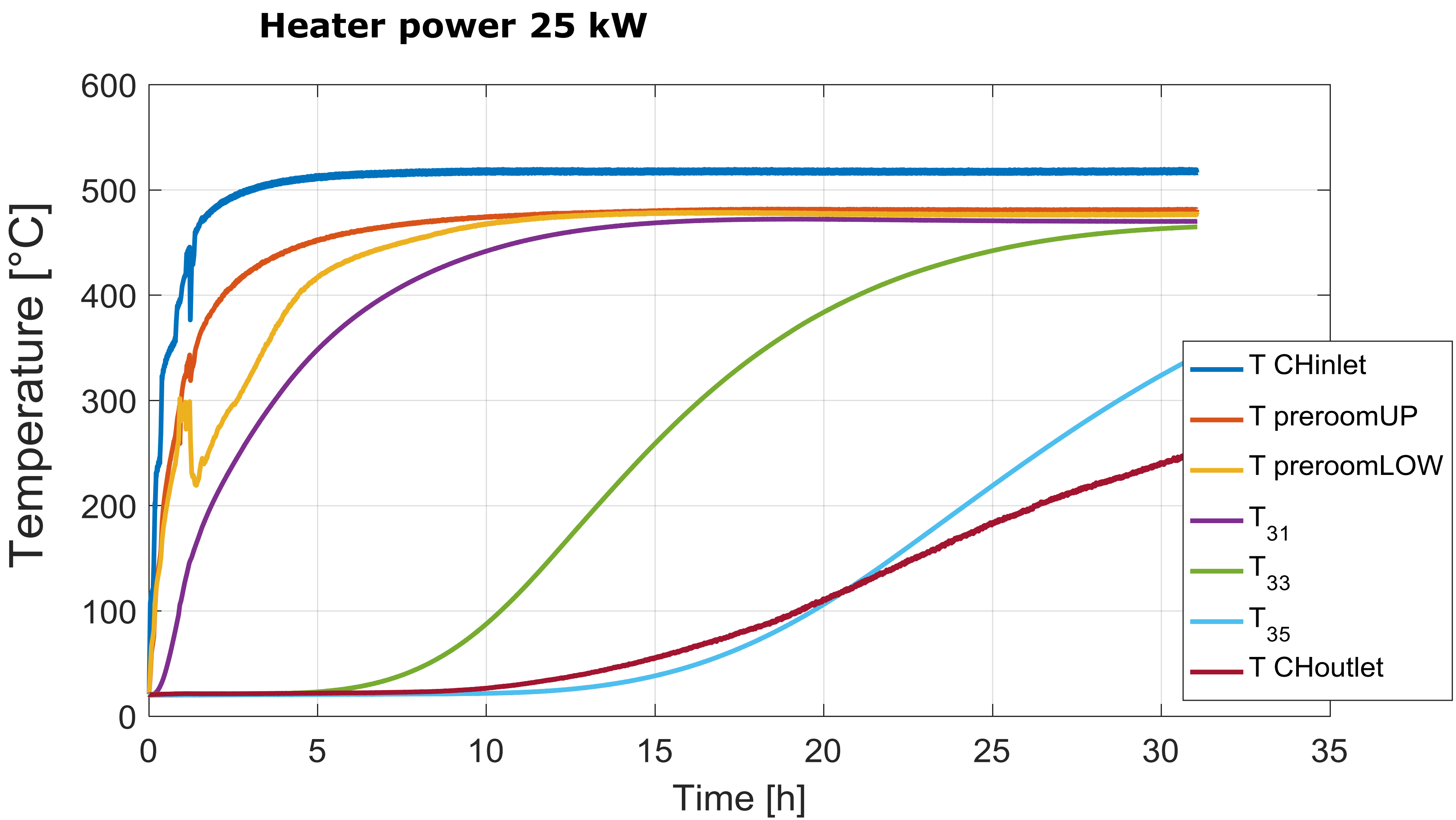


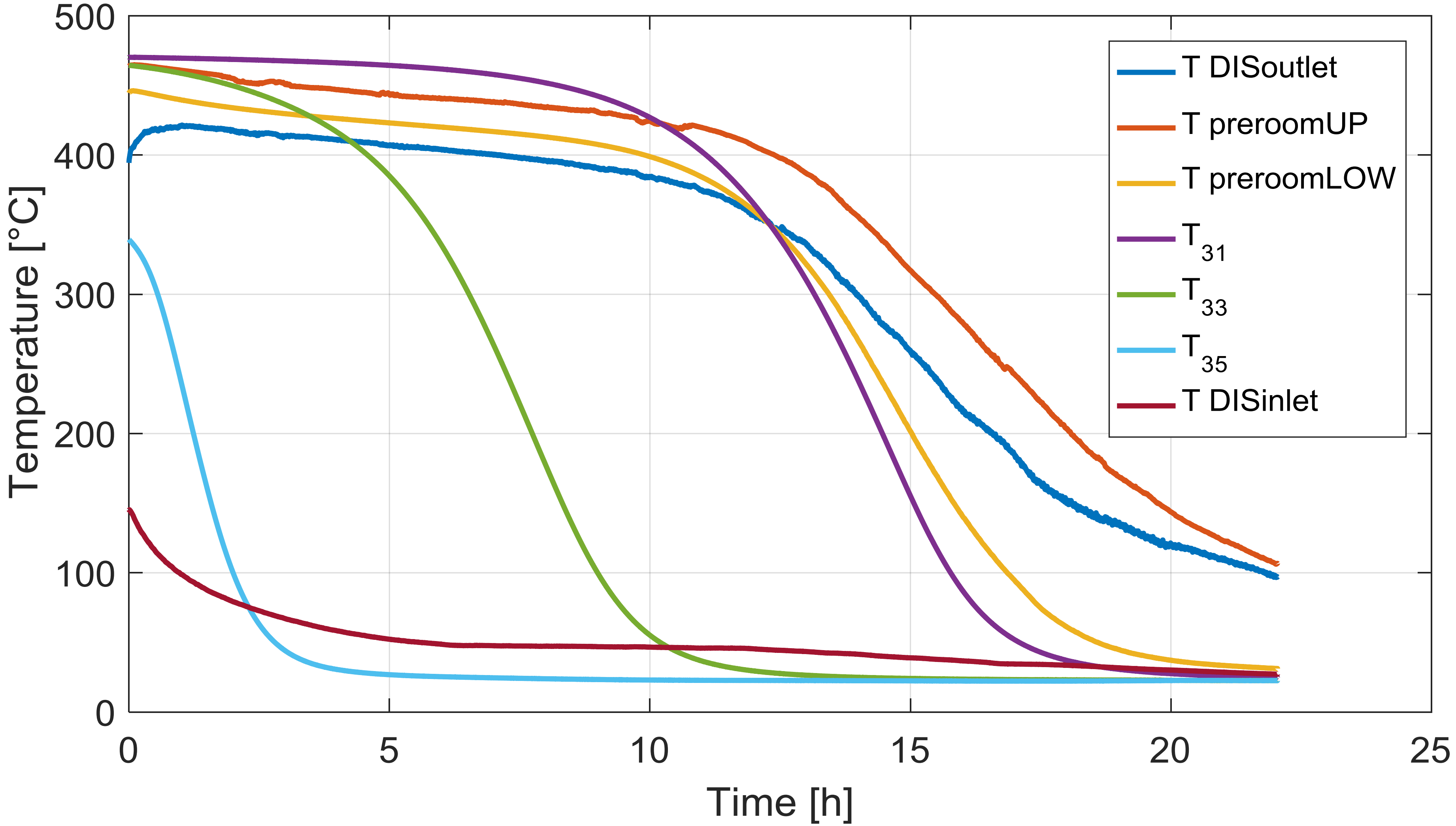
Size = 1.5 m^3 of rocks ~ 450 kWh_{th} ΔT=600C

Max. charging rate = 25 kW

Experimental result - charging



Experimental result - discharging



Experiment status

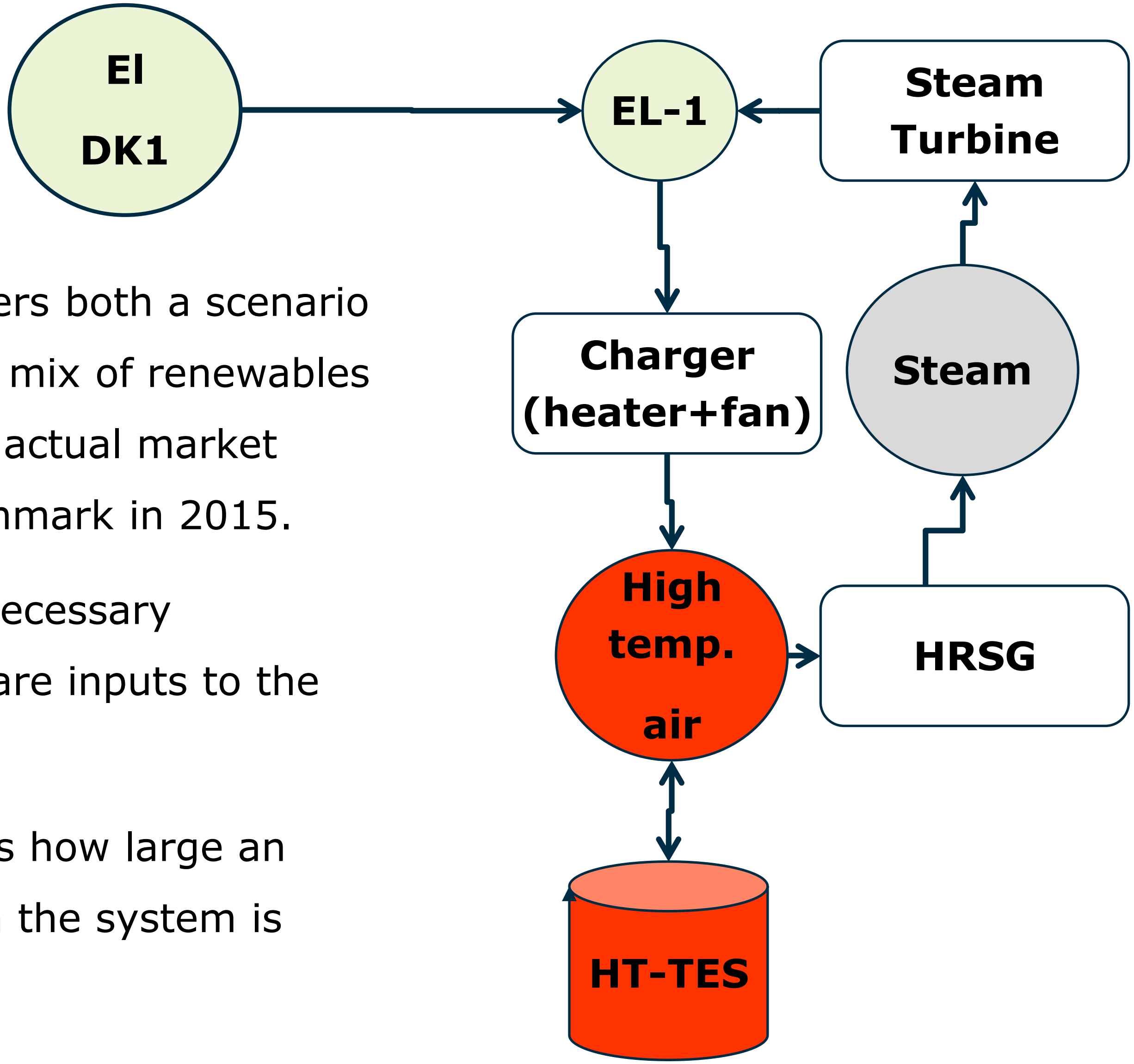
- Initial testing indicated that heat losses were a problem and more insulation has been added.
- Our first heater is broken and we are waiting on its replacement
- Next step is to fully test the 20-40 mm Swedish diabase
- Future tests will investigate the effects of varying the rock size

Modelling efforts in the project

- Inside the project we have both economic models of the Danish electricity market and the cost of the thermal storage and a numerical model of thermal interactions in the rock bed.

- A goal of the project is to couple the two models to give accurate performance predictions and a prediction for how a company might invest is such a storage based on realistic market conditions

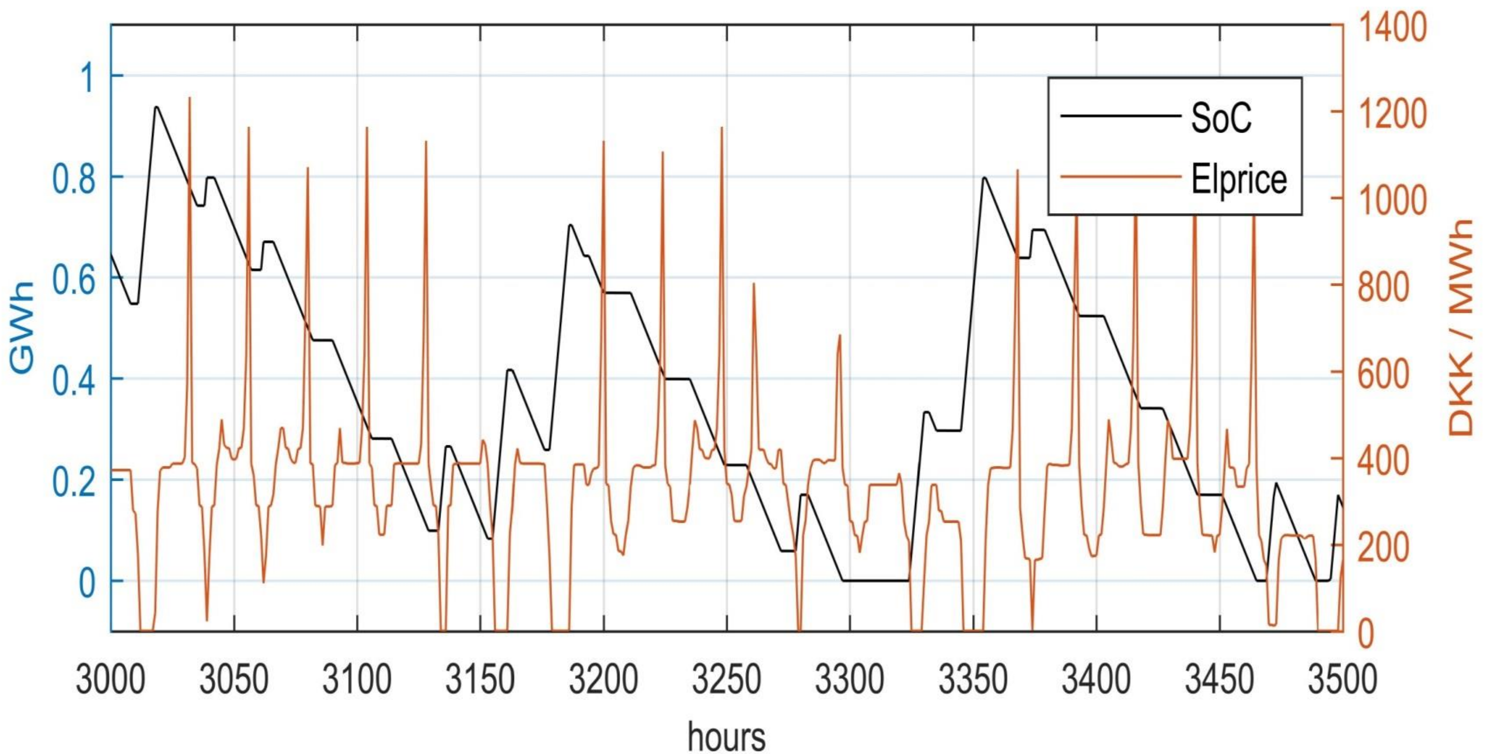
Economic model: electricity storage



- Model considers both a scenario with a higher mix of renewables for 2035 and actual market prices for Denmark in 2015.
- Prices of all necessary components are inputs to the model
- Main output is how large an investment in the system is optimal

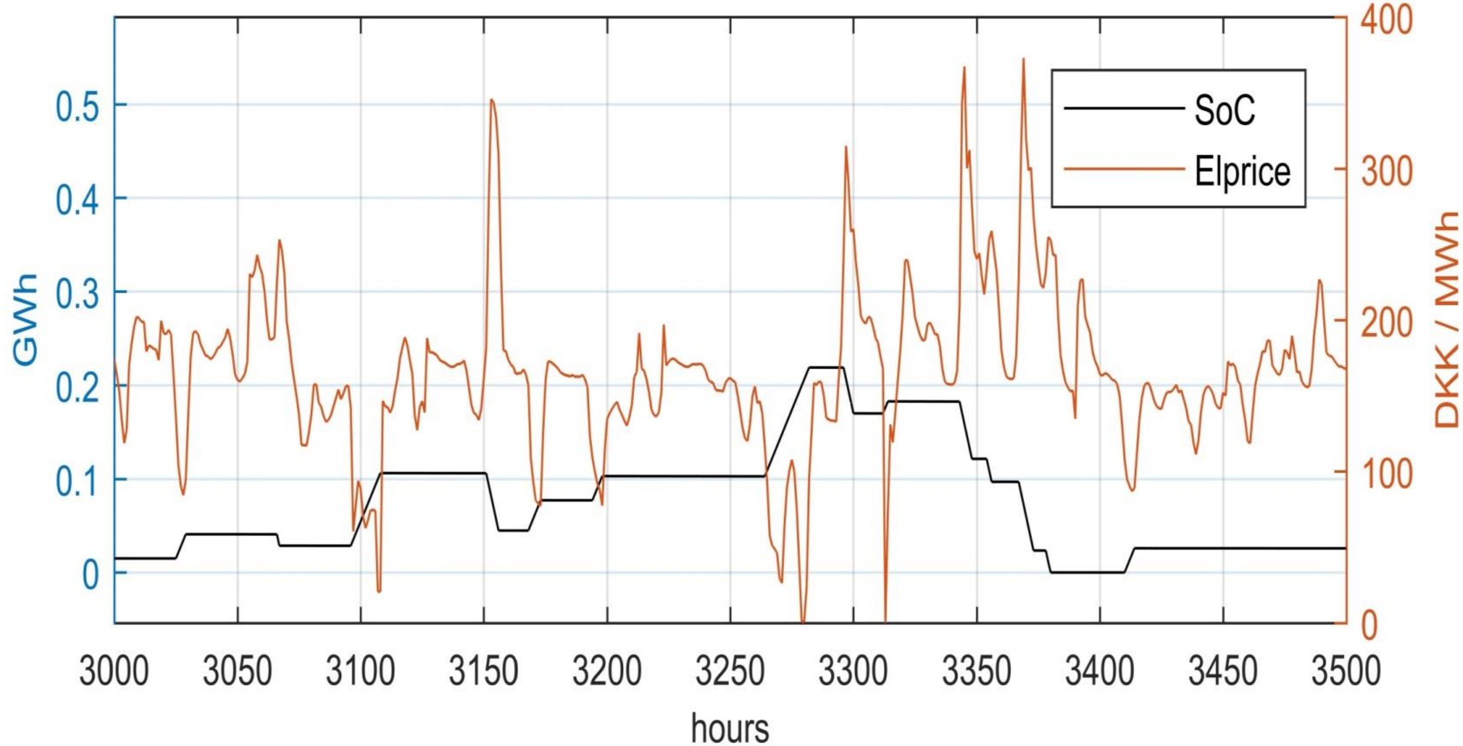
Case 1: electricity storage 2035 prices

Unit	CAPEX [DKK/MW]	OPEX [DKK/MW/y]	Yearly investment Cost [MDKK]	Invested capacity
Charger	625,000	6250	2.9 MDKK	55.6 MW_el
Discharger	4,580,000	180,000	2.8 MDKK	5.5 MW_el / 12 MW_th
Storage	2,620	0	0.2 MDKK	1000 MWh_th
Revenue			7.76 MDKK	



Case 2: electricity storage DK1 2015 prices

Unit	CAPEX [DKK/MW]	OPEX [DKK/MW/y]	Yearly investment Cost [MDKK]	Invested capacity
Charger	625,000	6250	0.34 MDKK	6.5 MW_el
Discharger				5.5 MW_el / 12 MW_th
Storage	2,620	0	0.10 MDKK	540 MWh_th
Revenue			0.75 MDKK	

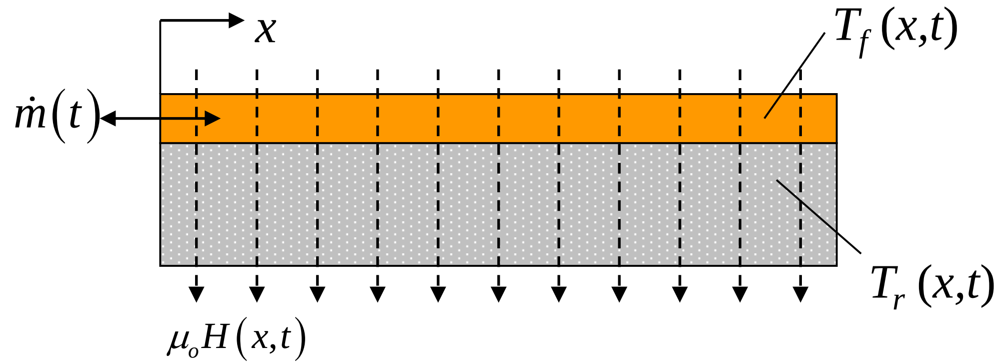


Governing Equations of a 1D Numerical Rock Bed Model

Fluid:

$$\underbrace{\dot m(t)\, c_f(T_f)\frac{\partial}{\partial x}\left[T_f\right]}_{\text{enthalpy flow}} + \underbrace{\frac{Nu(Re_f, Pr_f)\, k_f(T_f)}{d_h} a_s A_c (T_f - T_r)}_{\text{heat transfer to regenerator material}} + \underbrace{\rho_f c_f(T_f) A_c \varepsilon \frac{\partial}{\partial t}\left[T_f\right]}_{\text{capacity of entrained fluid}}$$

$$\underbrace{- k_{disp} A_c \frac{\partial^2 T_f}{\partial x^2}}_{\text{axial dispersion}} = \underbrace{\left|\frac{\partial p}{\partial x}\frac{\dot m(t)}{\rho_f}\right|}_{\text{viscous dissipation}}$$

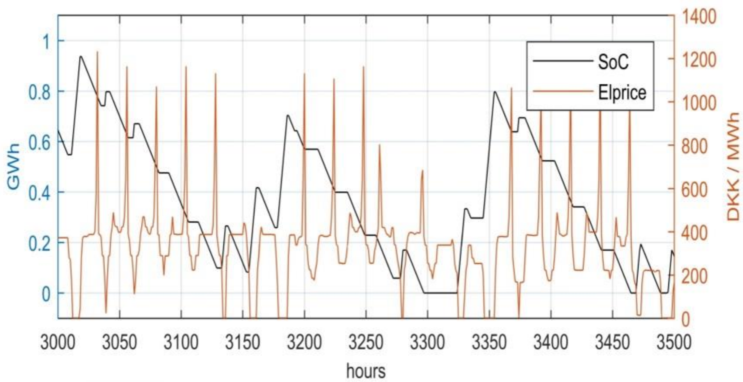


Regenerator:

$$\frac{Nu(Re_f, Pr_f)\, k_f(T_f)}{d_h} a_s A_c (T_f - T_r) \ldots$$

heat transfer from fluid; [illegible]; axial conduction; [illegible]

Coupling economic model to 1D model



- Bed size
- Charge and discharge characteristics
- Heater power

1D model inputs

- Rock type
- Bed geometry
- Air flow rate etc

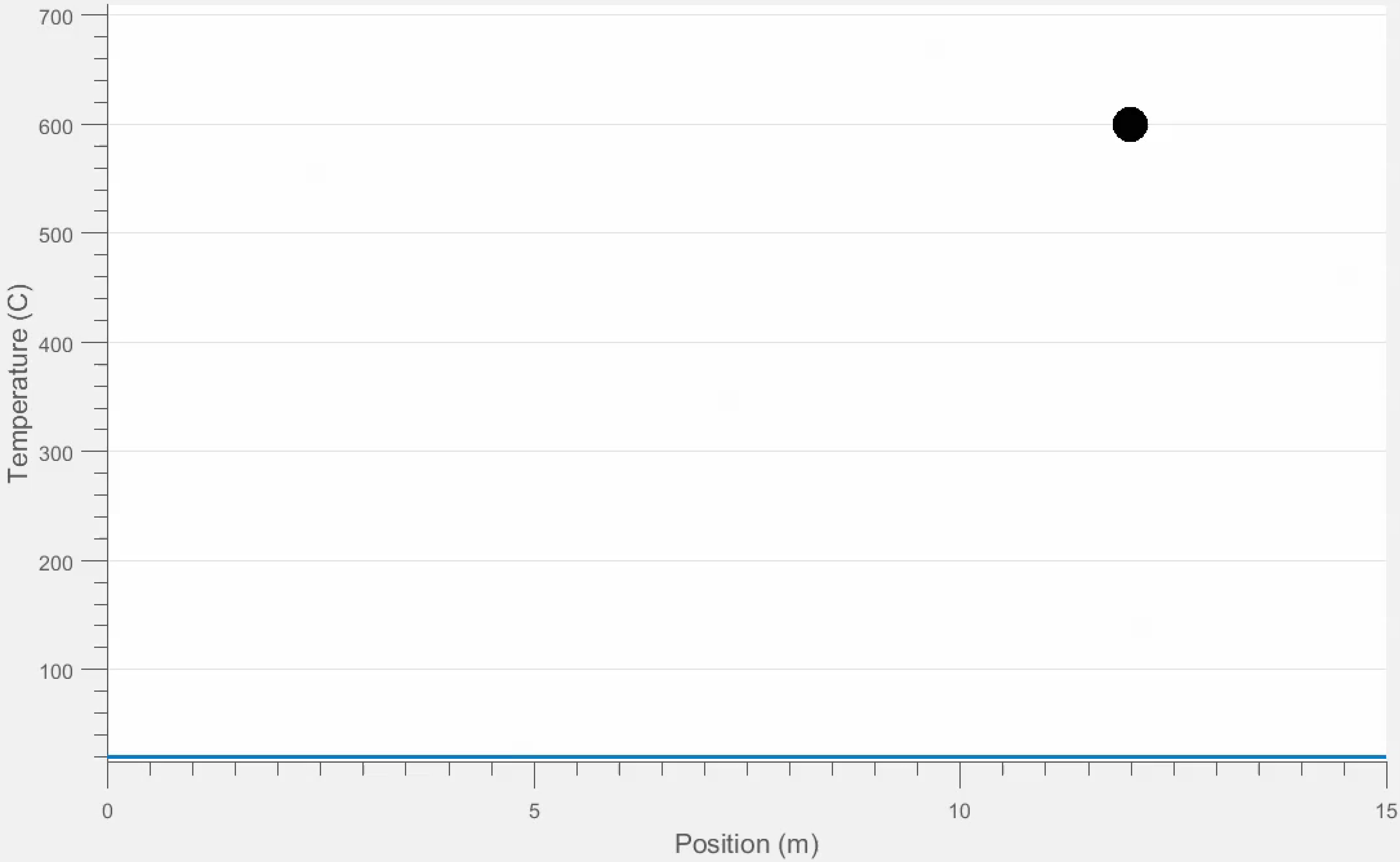
Run 1D model over an entire year

Some model constraints

- Minimum temperature for steam productin is 530 C
- Charge inlet temperature is 600 C
- Maximum outlet temperature is 300 C
- We use the return temperature from the heat recovery steam generator as the inlet discharge temperature (100 C)
- Initial rock bed temperature is 20 C

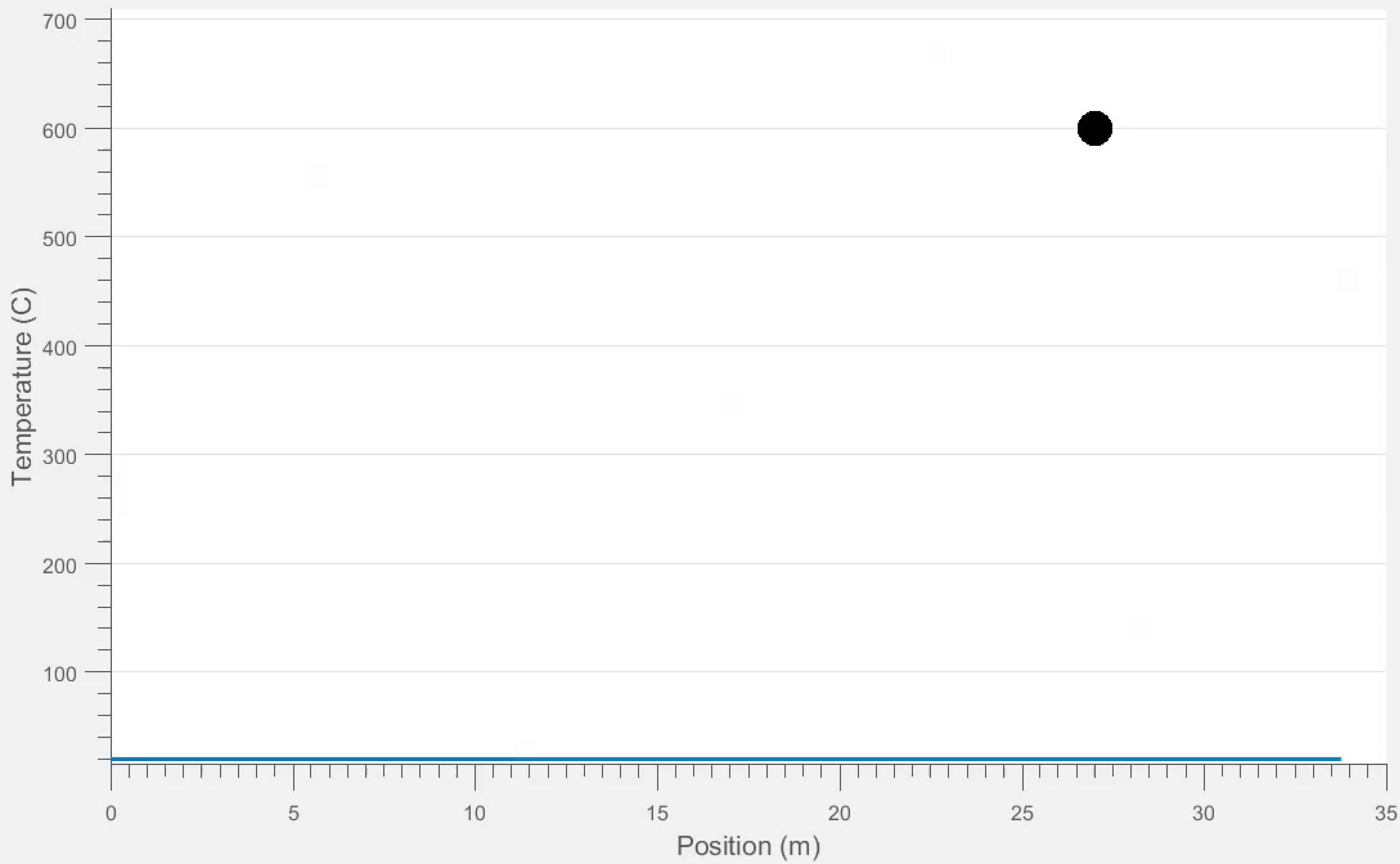
Full year rock bed operation for 2035

- Economic model calls for a bed that is approximately 3,400 m3 in volume. First we model a 15 x 15 x 15 m^3 rock bed

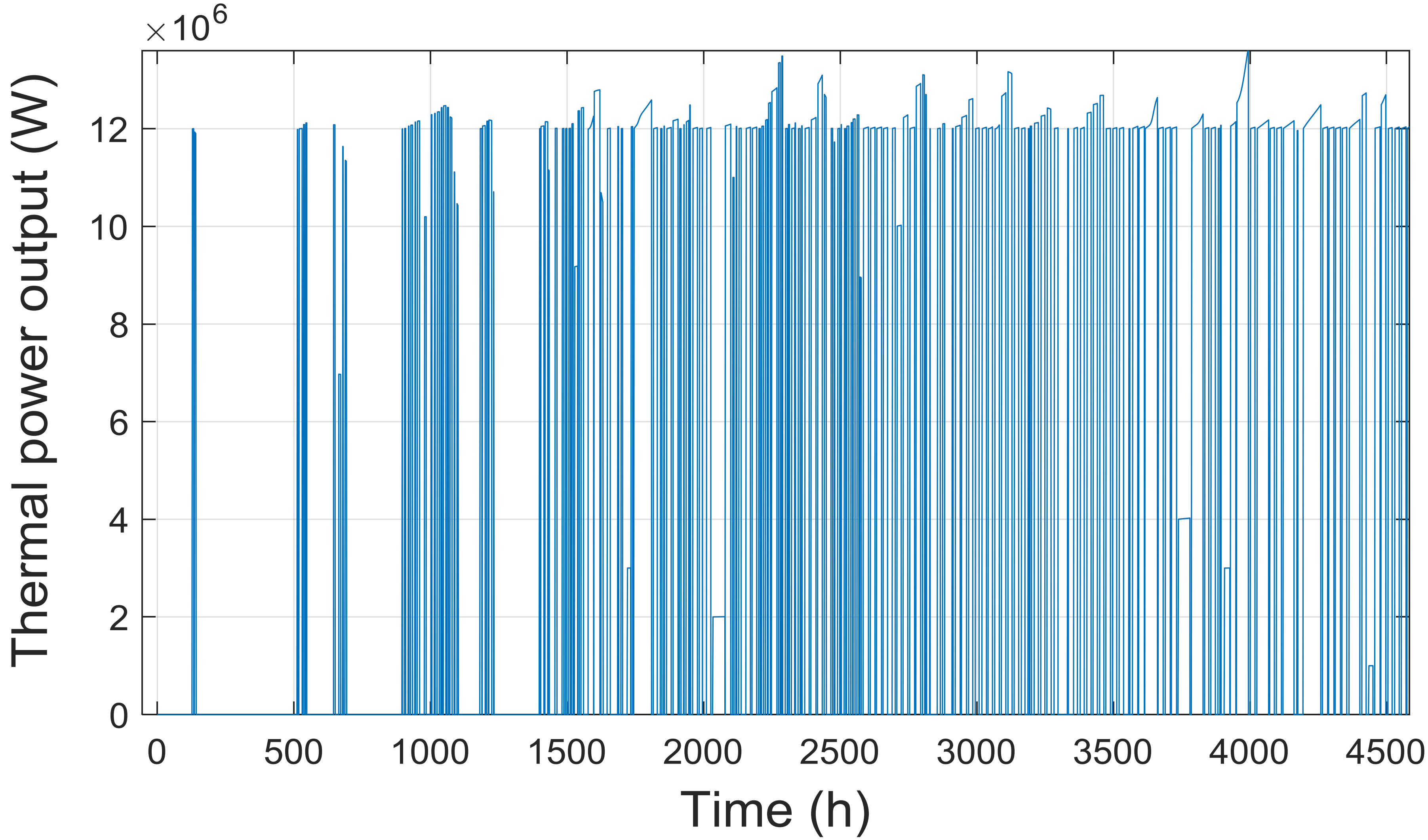


Full year rock bed operation for 2035

- "Skinny" bed 10 x 10 x 33.75 m



Predicted power supplied to power cycle

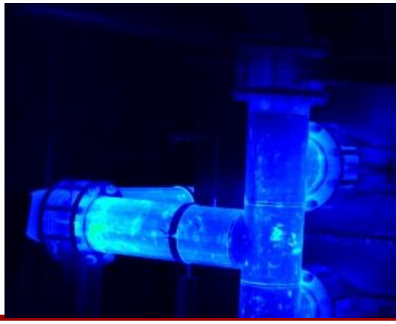


Preliminary model conclusions

- Sometimes the temperature in the bed is too low to produce steam, although the economic model expects a power production
  - May need a minimum charge energy constraint in the economic model
- System optimization based on rock bed dimensions and rock size is necessary
- We have demonstrated modelling a full year of operation using a detailed 1D numerical model of the rock bed
  - System optimization of such a rock storage will be performed in the near future
- Pressure drop can become a major issue for long beds or small rock sizes
- Reducing rock size from 20 mm to 16 mm gives approximately 2% more power production over the full year
- Reducing the length of the bed to 8.4 m while increasing cross sectional area gives a reduction in power production of 5.5% over the full year

Conclusions

- At DTU we have a functional 1.5 m^3 rock bed storage that can operate at temperatures up to 600 C
  - Capable of quickly testing different rock types and sizes and system configurations
- Economic modelling shows that for 2015 prices, the system needs to use an existing steam turbine to be economical
  - Using a 2035 scenario with higher renewable mix it can make sense to invest in a new turbine dedicated to a rock storage unit
- We have demonstrated modelling a full year of operation using a detailed 1D numerical model of the rock bed
  - System optimization of such a rock storage will be performed in the near future



THANK YOU FOR YOUR ATTENTION