HEMISPHERICAL UNDERGROUND BOREHOLE HEAT EXCHANGER FIELD AS A SOURCE OF GEOTHERMAL ENERGY

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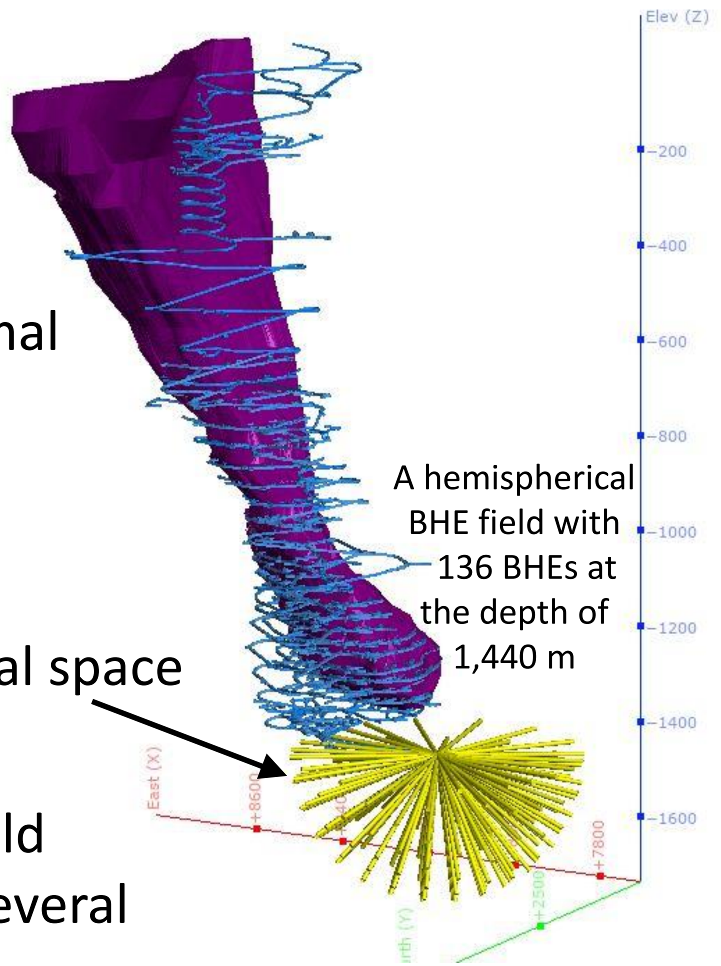
WHY A HEMISPHERICAL UNDERGROUND BOREHOLE HEAT EXCHANGER (BHE) FIELD?

- Significant benefits in heating energy production can be gained by going from the cold ground surface to the warmer deep ground
- The soon-to-be decommissioned Pyhäsalmi Zn/Cu mine in central Finland offers access to the warmer deep ground where the geothermal resources are significantly higher than at the shallow ground
- Mine tunnels and underground spaces do not offer much possibility to construct conventional BHE fields with vertical boreholes
- However, a large BHE field can be constructed by drilling from a central space out into a hemispherical volume
- We wanted to see if it is possible to construct a hemispherical BHE field that is large enough to provide heating power of at least 1 MW and several hundreds of GWh of heating energy using open loop coaxial BHEs



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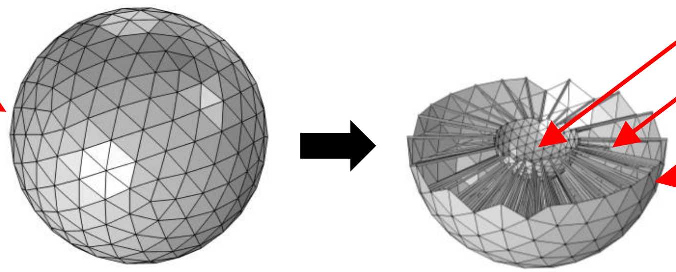
THE BHE FIELD GEOMETRY AND NUMERICAL MODEL

- The most optimal geometry for a hemispherical BHE field is such in which each of the BHEs extract heat from an equally large volume of rock (i.e. the BHEs are equispaced)
- Such a geometry can be created with the help of a geodesic sphere (which is a sphere made from triangles that have approximately equally long edges)

A geodesic sphere made from 500 triangular faces

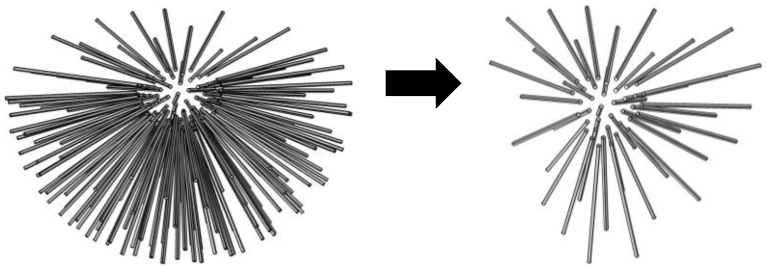


Underground space from which 136 boreholes are drilled from

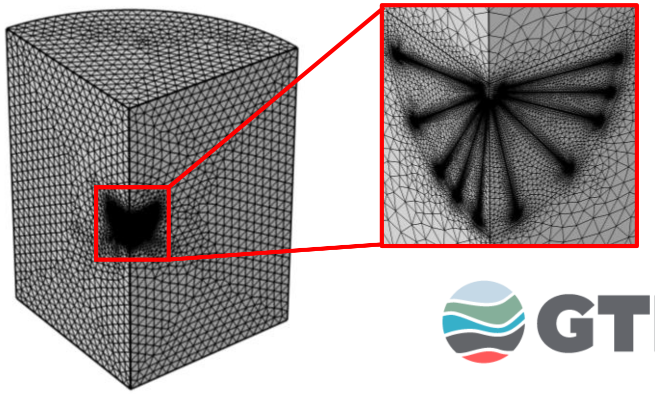
Lower hemisphere (z ≤ 0) of the geodesic sphere

- COMSOL Multiphysics® v5.5 was used to simulate the operation of the BHE fields
- Finite element models with quarter symmetry were created

Full 3D model with 136 BHEs



Model that takes symmetry into account (39 BHEs)



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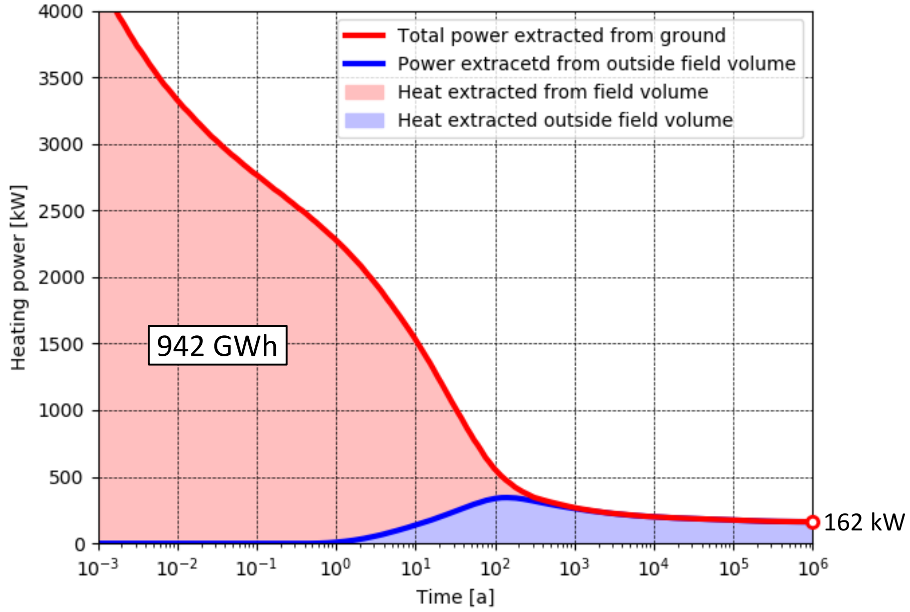
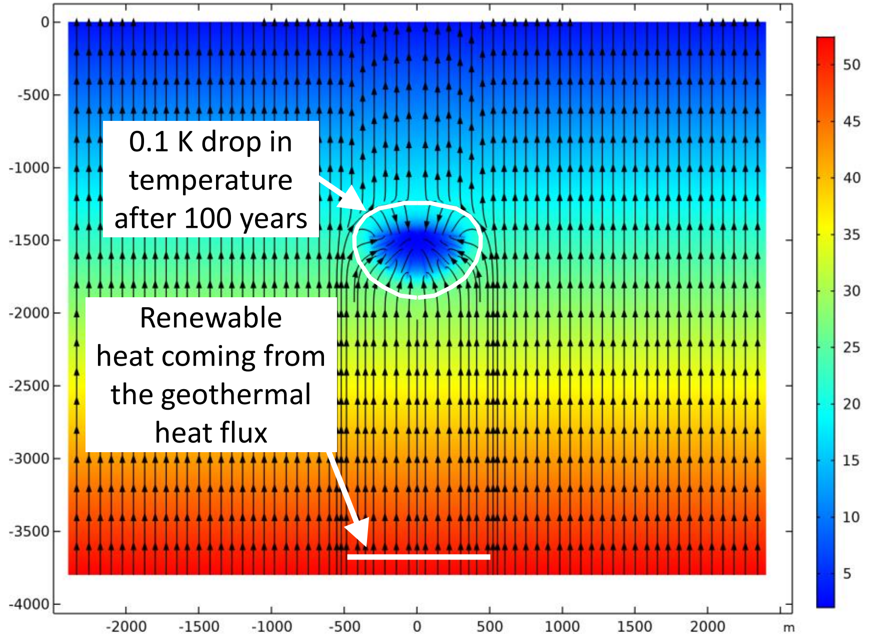
EXTRACTING THERMAL ENERGY STORED IN THE BEDROCK

- A hemispherical BHE field that has the radius of *r* (i.e. the length of BHEs is *r*) and where a 2 °C fluid is circulated has access to a thermal energy storage of the size of

$$E = \rho \cdot C_p \cdot \frac{1}{2} \cdot \frac{4}{3} \pi \, r^3 \cdot (T - 2\,°\mathrm{C})$$

- The BHE density (the number of BHEs per volume) determines how much of the storage can be extracted using the BHE field
- A simulation reveals that a hemispherical BHE field with 136 BHEs having the length of 300 m can extract 86 % (942 GWh) of the heat storage of 1,099 GWh
- Once the BHE field has extracted all the stored heat that it can access, a new steady state is reached with a sustainable heating power of 162 kW coming from the geothermal heat flux





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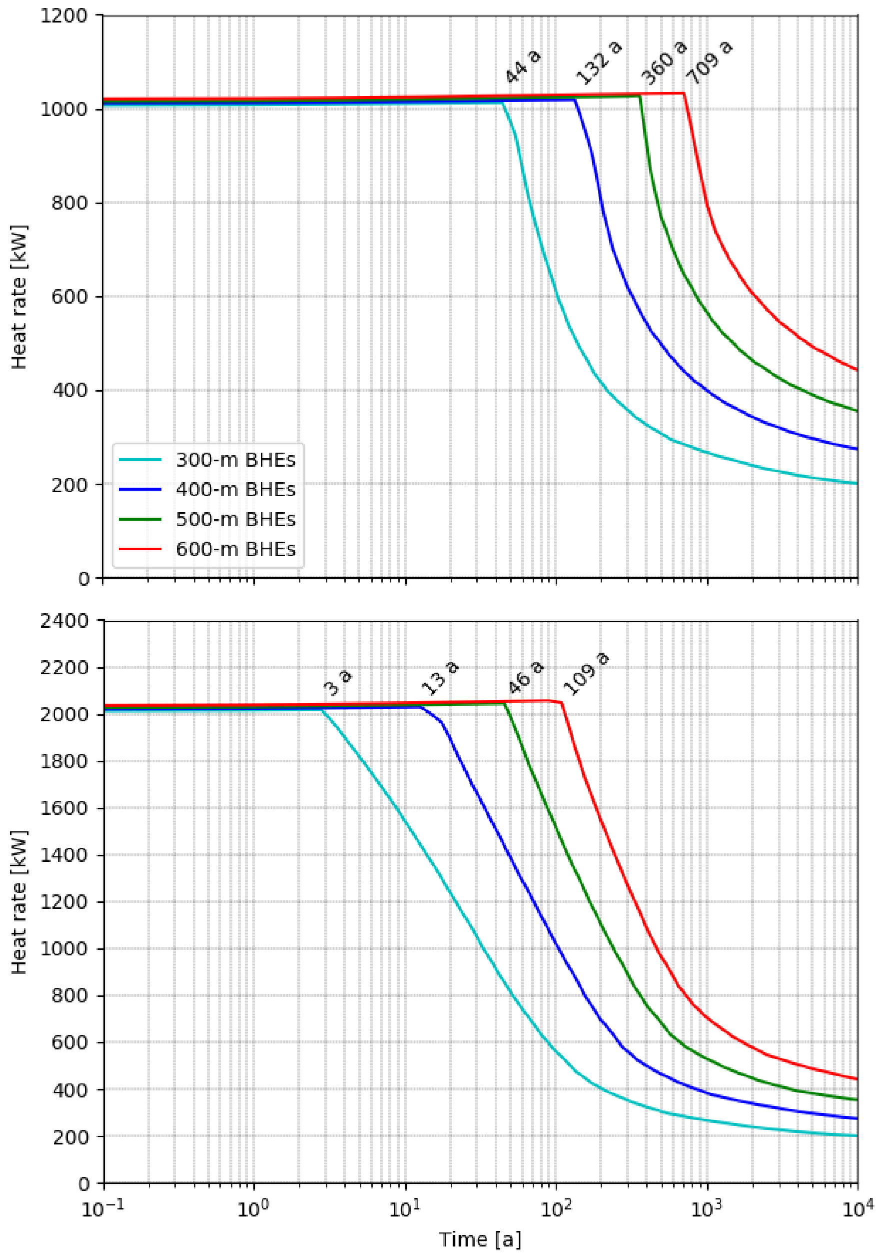
INFLUENCE OF THE HEATING POWER

- The heat stored in the bedrock can be extracted either fast or slow
- Simulations indicate that BHE fields with 136 BHEs can sustain the heating power of 1 MW for at least 44 years (before the fluid temperature in the BHE field drops below 2 °C)
- Simulations show that extracting heat using the heating power of 2 MW will deplete the BHE field significantly faster and to sustain this level of heating power for a significant period of time will require increasing the volume of the field (e.g. from a field of 300-m BHEs to a field of 500-m BHEs)



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