A Strategy for the Optimization of Geothermal Resource Development

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E.ON, Iceland Drilling Company and Ross DK Partnership

E.ON

- District heating system design, construction and operation

Iceland Drilling Company

- Geothermal well drilling

Ross DK

- Reservoir and well management

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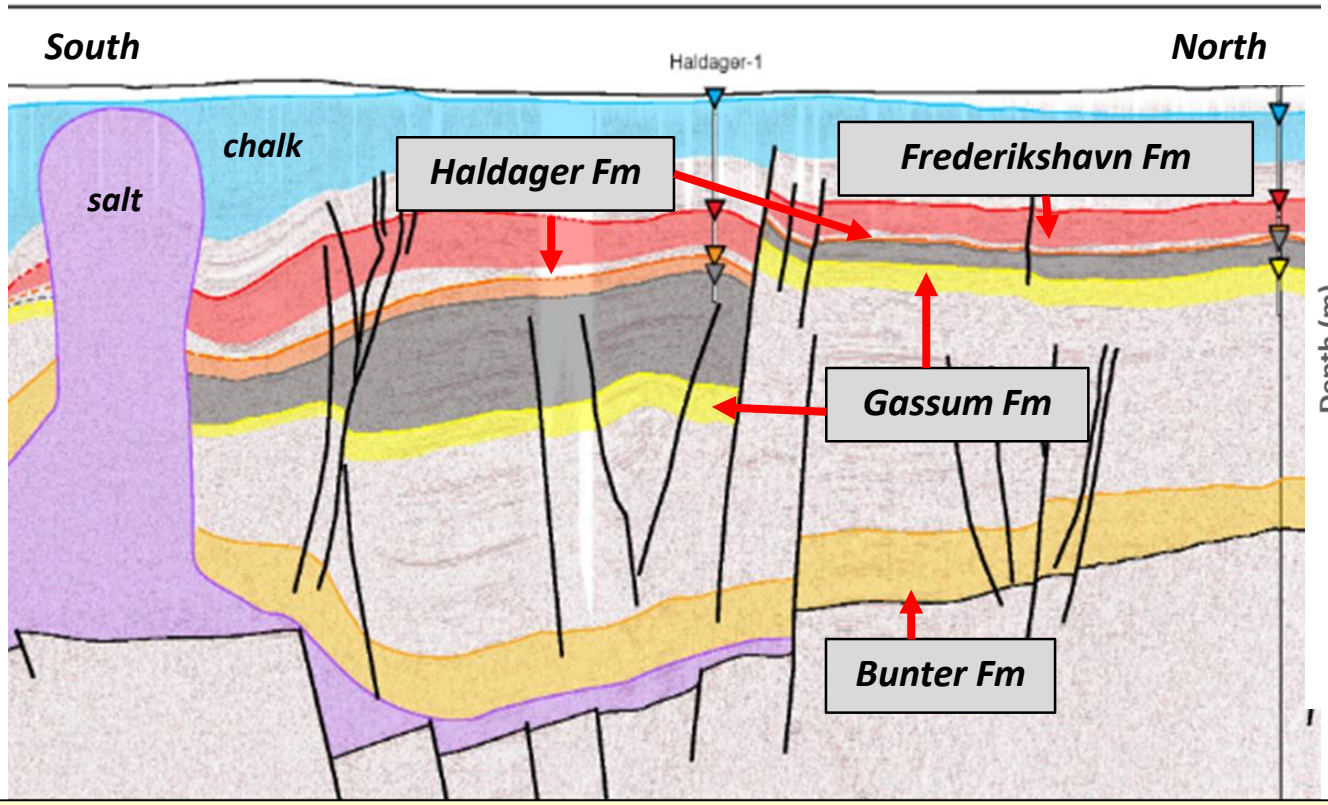
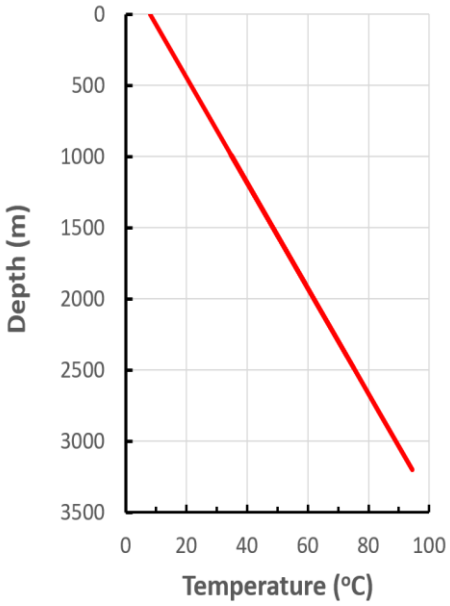
Geothermal reservoirs in northern Denmark





BIG QUESTION:
Which reservoir to develop for the production of geothermal energy?

Cross-section from GEUS Geotermi WebGIS-portal http://data.geus.dk/geoterm/

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Optimization of geothermal resource development

Objectives

- Maximize geothermal energy production
- Minimize risk and cost

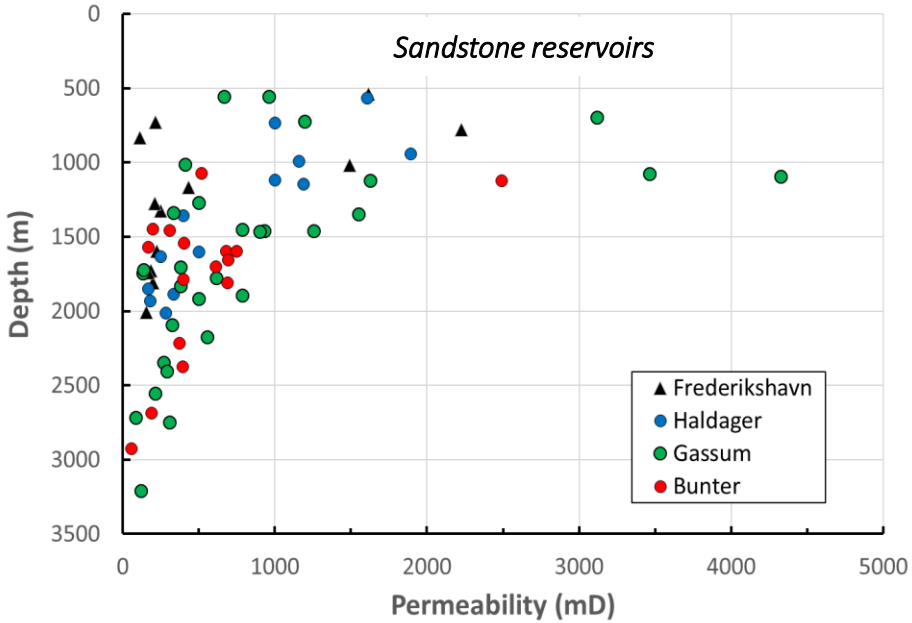
Create business case models for each geothermal reservoir

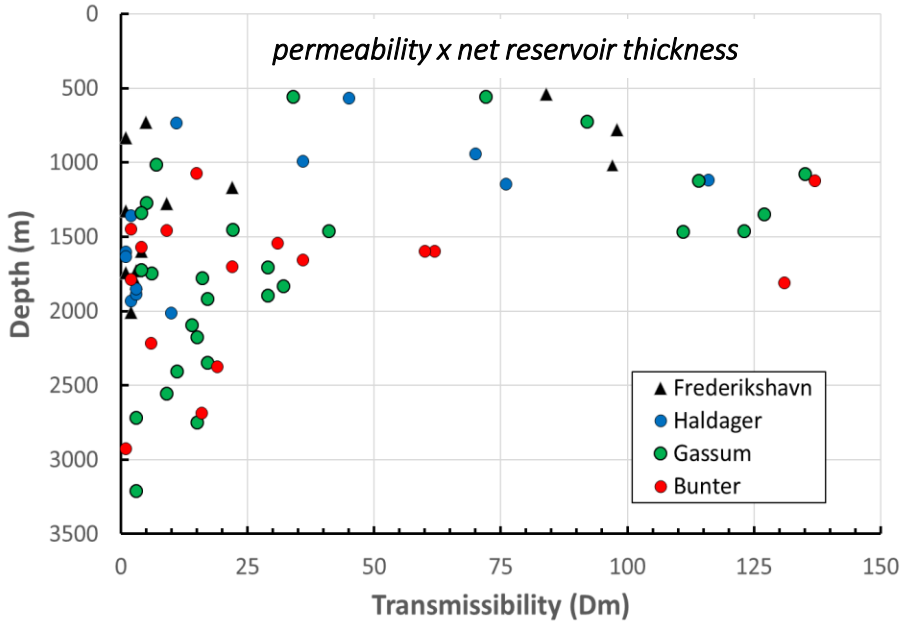
- Estimates of geothermal power production
- Heat demand
- Drilling and well completion costs
- Facilities cost
- Operations and maintenance costs
- Abandonment cost

Estimate the cost of geothermal energy from each reservoir

Variation in reservoir flow properties with depth

Deep wells in Denmark





Reservoir flow properties decrease markedly with depth

Data Source: GEUS Geotermi WebGIS-portal http://data.geus.dk/geoterm/

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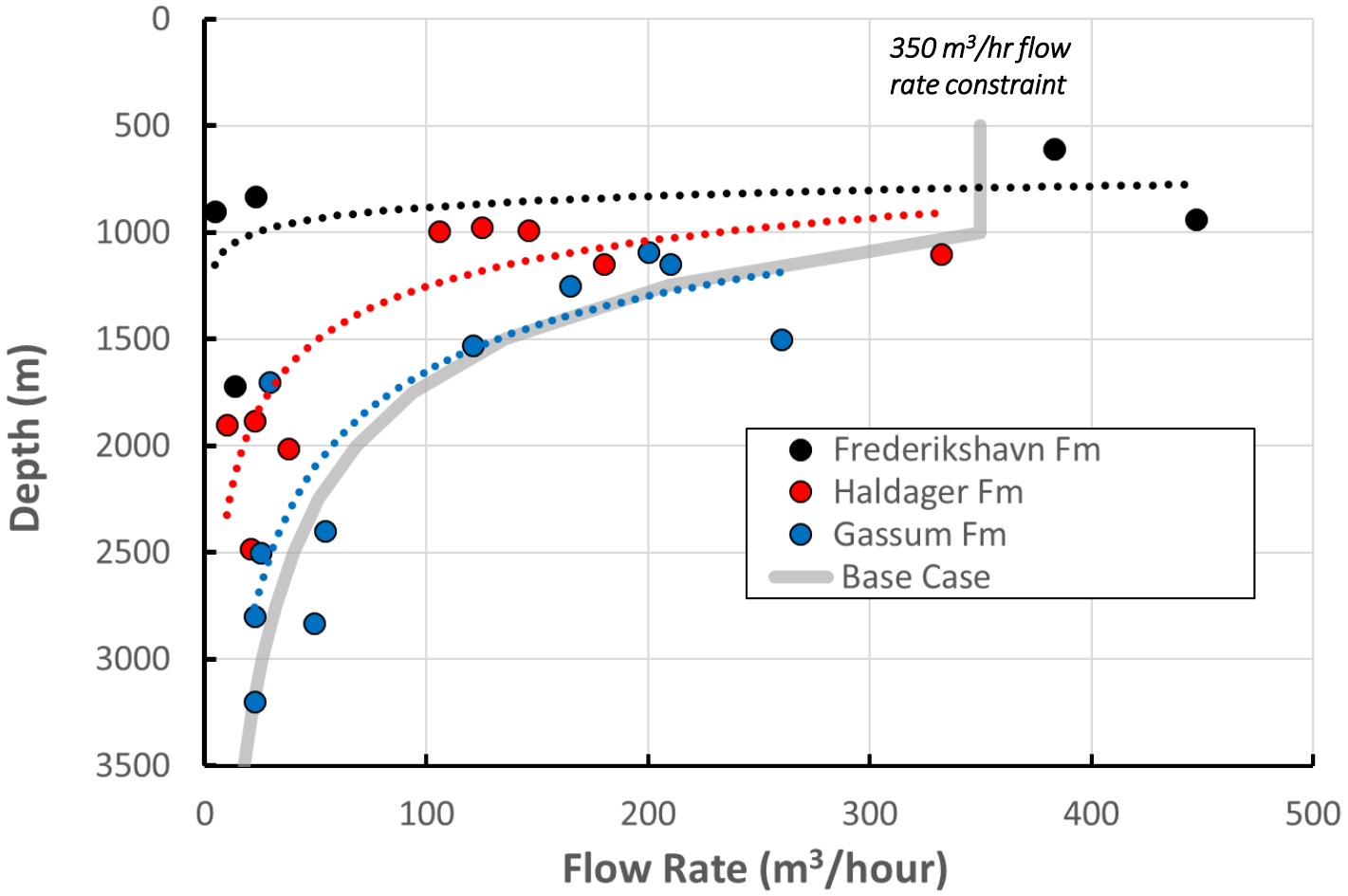
Flow rate estimates for wells in northern Denmark



Flow rates decrease with depth by greater than a factor of 10

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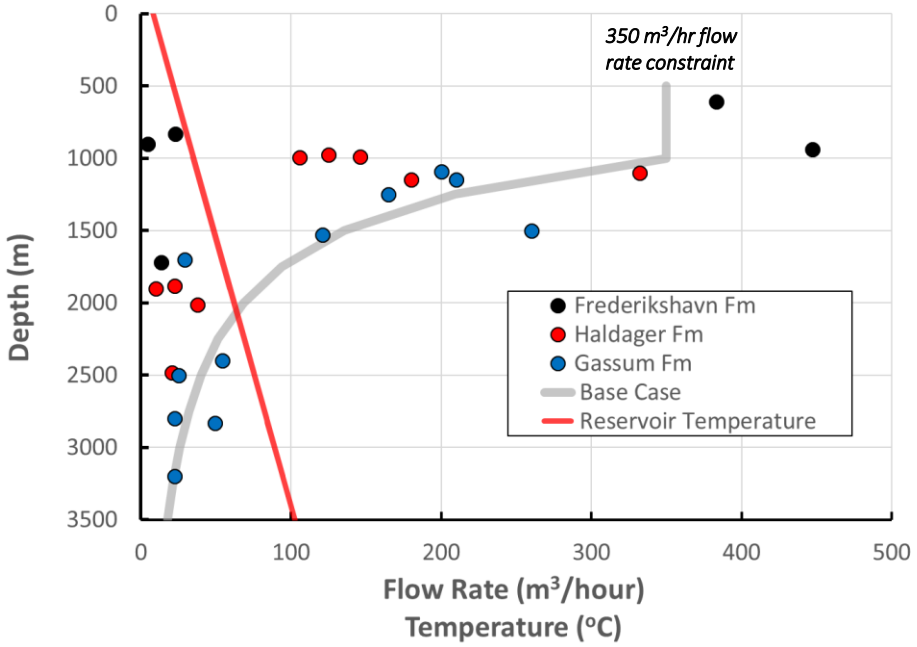
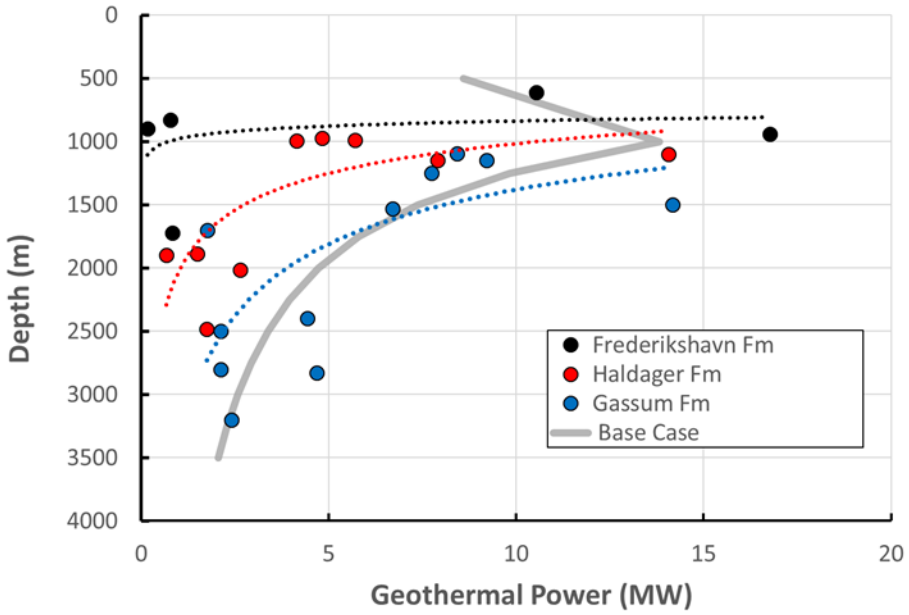
Flow rate, temperature and geothermal power

Flow Rate x Temperature x Water Heat Capacity = Geothermal Power





- Flow rates decrease with depth by > 10X
- Temperatures increase with depth by 2.7X

Shallow wells

- produce more geothermal power than deep wells
- less risky to drill and operate than deep wells
- less expensive to drill and operate than deep wells

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Business case models

CAPEX

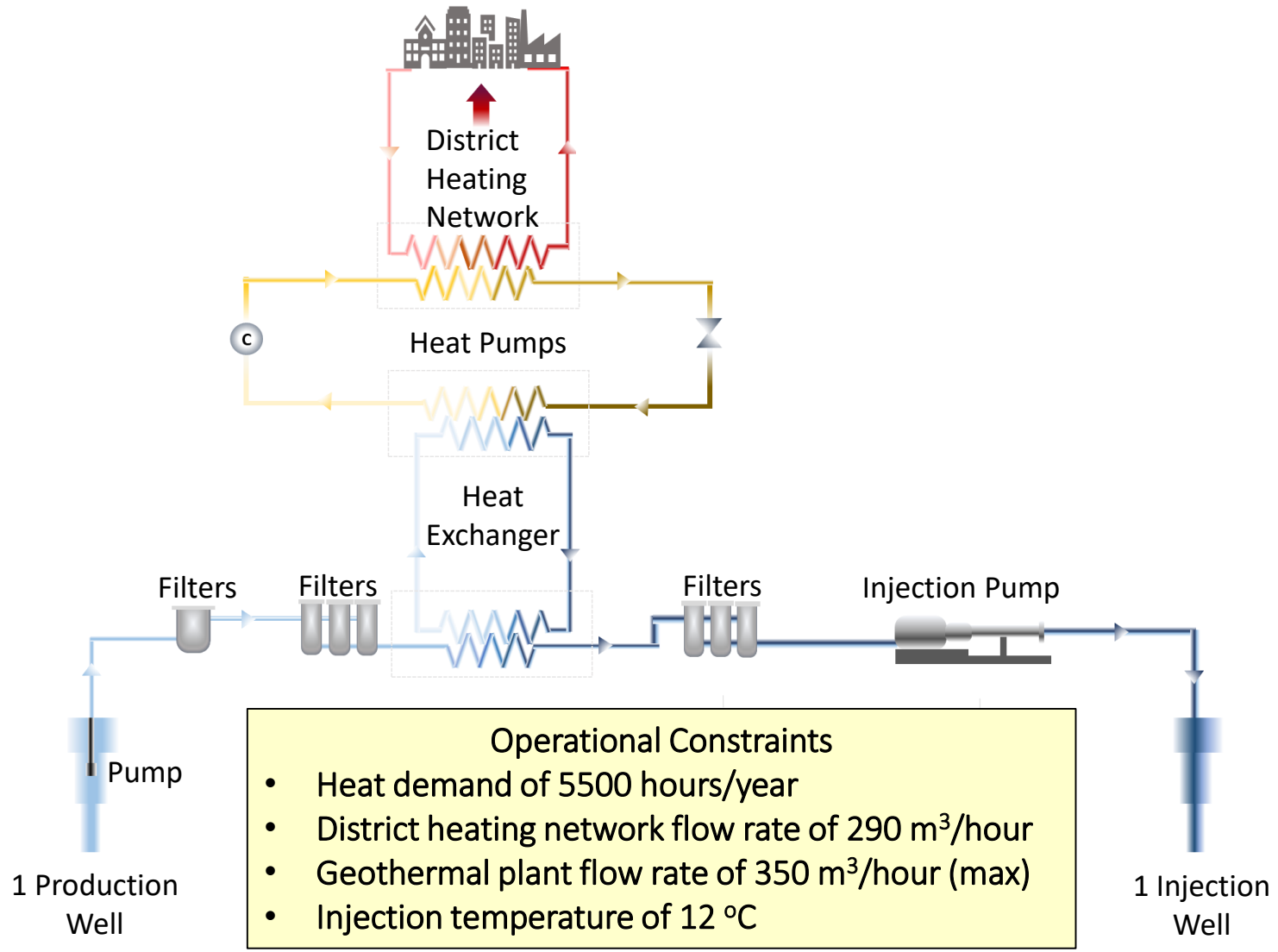
- Production and injection pumps
- Filters
- Heat exchanger
- Heat pump
- Installation, piping, electrical and buildings
- Well design and drilling (doublet)

OPEX

- Operations
- Maintenance
- Well workovers
- Electricity
- Consumables

Abandonment

Facilities model



Operational Constraints

- Heat demand of 5500 hours/year
- District heating network flow rate of 290 m^3/hour
- Geothermal plant flow rate of 350 m^3/hour (max)
- Injection temperature of 12 ^oC

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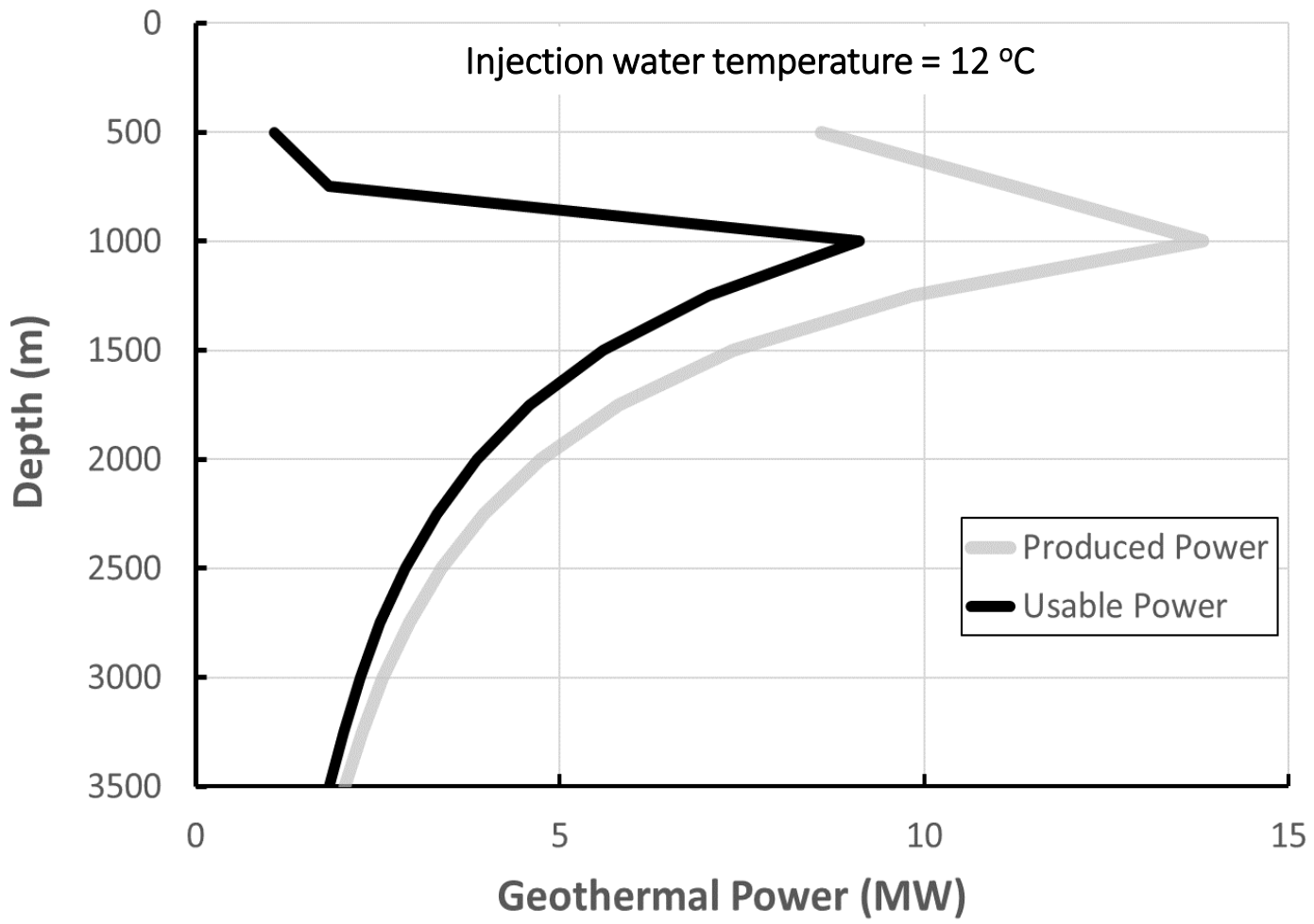
Produced and usable geothermal power



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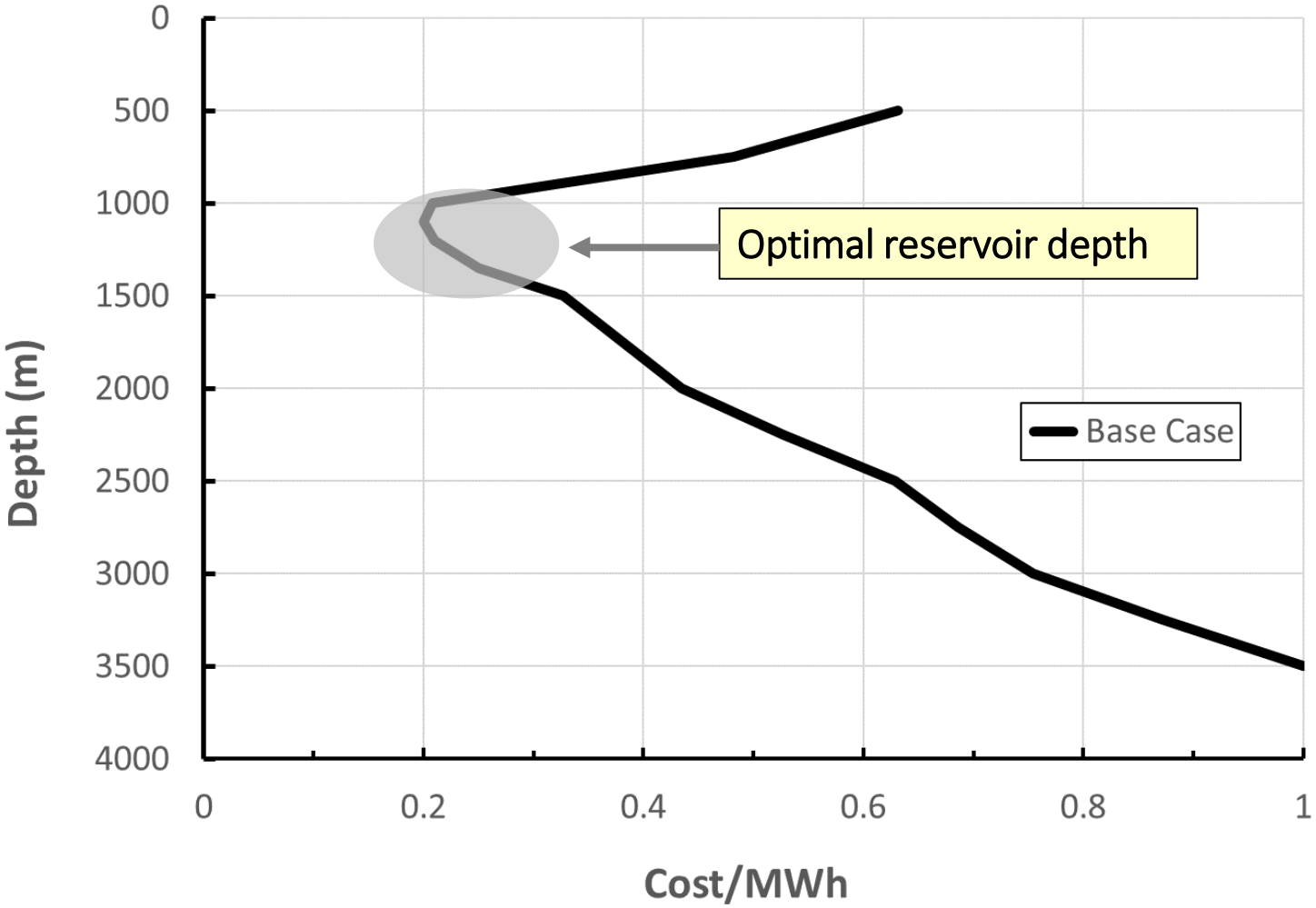
Cost of geothermal energy



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Other factors that affect cost

- Salinity
  - Well materials and flow assurance
- Geochemistry
  - Potential contaminants such as Pb
- Well design
  - Stimulated or deviated wells
- Geothermal power production profiles
  - flow rates and temperature change over time

Summary

- Strategy for the optimization of geothermal resource development based upon:
  - Estimates of geothermal power production from each target reservoir
  - Heat demand
  - Business case models for each target reservoir
  - Estimates of the cost of geothermal energy production from each reservoir

- Subsurface data and business case models for sandstone reservoirs in northern Denmark show that, for this case, the optimal geothermal energy production is from shallow reservoirs with high flow productivity and relatively low temperatures.

Shallow, low temperature reservoirs may be the best targets for maximizing geothermal energy production while minimizing risk and cost