Geothermal project risk mitigation

Geothermal 2023
Aberdeen SPE

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Geothermal project risks

Subsurface uncertainties

Flow rate lower than expected (reservoir)
Flow rate degrades over time
Temperature lower than expected (reservoir)
Temperature degrades too quickly
Pressure lower/higher than expected
Pressure is changing during the operation in an unexpected way
Fluid chemistry/physical properties are different from expected
Fluid chemistry/physical properties change
Target formation is missing in the well
Target formation has no fluid
Geological stratigraphy is different than expected
Excessive scaling in the geothermal loop
Excessive corrosion in the geothermal loop
Particle production
Hydraulic connectivity between wells is suboptimal
Re-injection of the fluid is more difficult than expected
Degradation of the reservoir

Technical issues

Mud losses leading to severe technical issues
Wrong density of mud leading to damage to well/reservoir
Not able to lower the casing string
Trajectory issues (deviation from target)
Drilling is more complicated/more expensive than anticipated
Technical failure during drilling
Rig issues
Issues in transporting/handling radioactive sources for diagraphy
Technical failure of the equipment
Well casing collapse

Internal deficiencies

Low financing for work leading to low safety standards
Design of well leads to reduced flow rate
Best practices not applied (data aquisition modelling, decision making, design of
Unsuitable contracts (roles and responsibility not clearly defined) leading to sub
Human error leading to failure during drilling / work
Wrong choice of stimulation fluids or techniques damaging the reservoir/well
Organization is not experienced / financially robust enough for the challenge
Demand analysis and forecast are inaccurate

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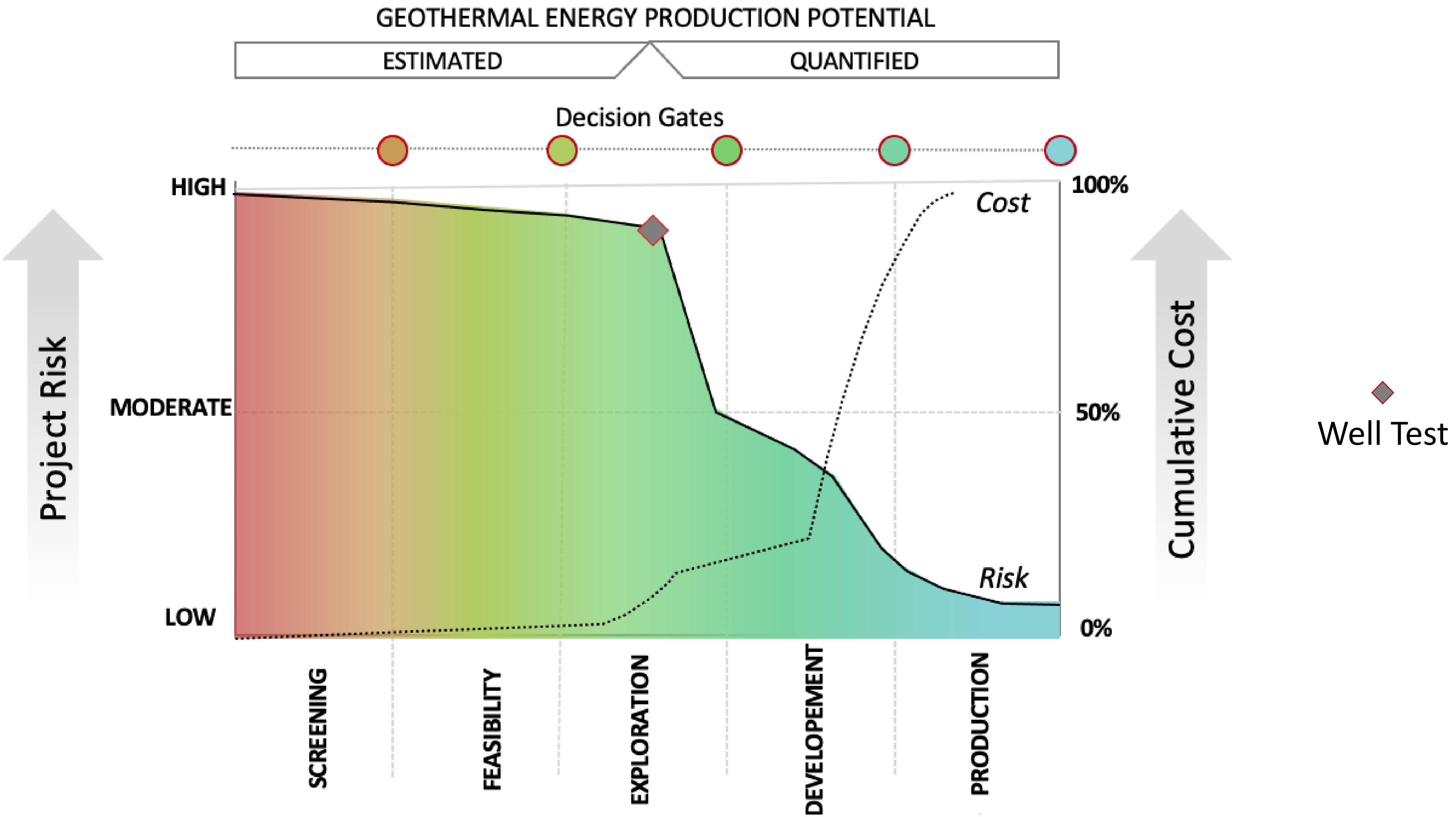
Source: GEORISK [818232 - GEORISK]

Geothermal projects risk profile



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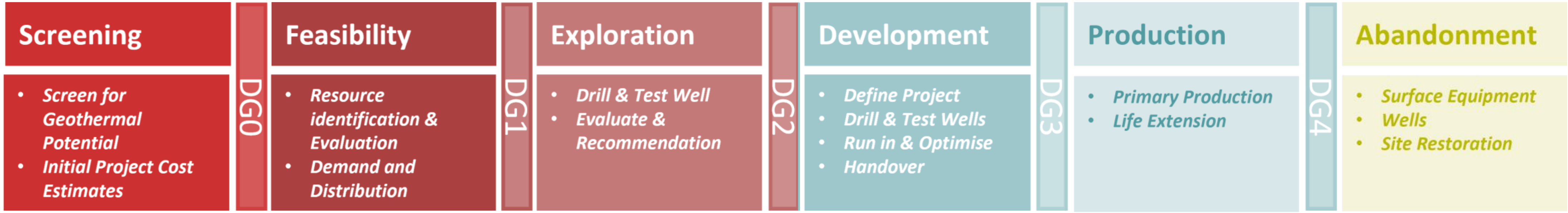
Modlified from: Gehringer, M. and Loksha, V., 2021. Geothermal Handbook: Planning and Financing Power Generation. Washington DC: Energy Sector Management Assistance Program (ESMAP).

De-risking and maturing geothermal projects

Tailored made project development model, designed to de-risk and mature geothermal district heating projects.



- Defines the roles, responsibilities, tasks and deliverables for each geothermal project phase
- Defines the decision gate criteria (DG) that must be met in order to mature the project
- Helps maximise the project profitability by avoiding mistakes commonly made in the geothermal industry

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Drill and test an exploration well?

Step 1. Screening Study

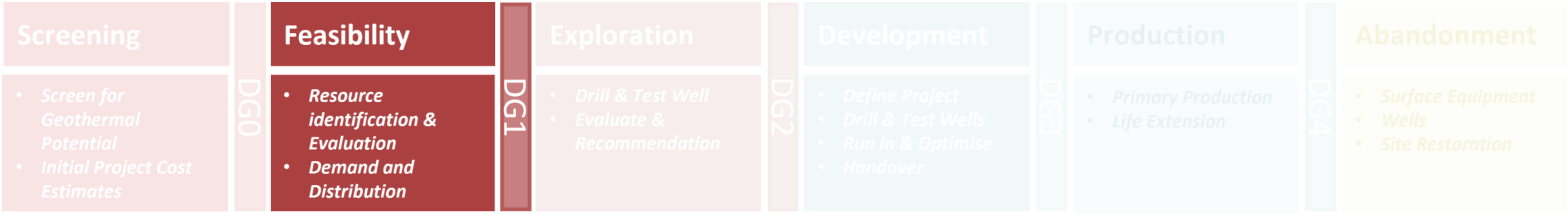
- Provides an initial assessment of the use of geothermal energy for district heating based on estimates of the geothermal energy production, heat demand, development concepts and project economics.
- Projects are scored and ranked in order to identify the viability of each project to mature to a Feasibility Study

Screening		Feasibility		Exploration		Development		Production		Abandonment
• *Screen for Geothermal Potential* • *Initial Project Cost Estimates*	DG0	• *Resource identification & Evaluation* • *Demand and Distribution*	DG1	• *Drill & Test Well* • *Evaluate & Recommendation*	DG2	• *Define Project* • *Drill & Test Wells* • *Run in & Optimise* • *Handover*	DG3	• *Primary Production* • *Life Extension*	DG4	• *Surface Equipment* • *Wells* • *Site Restoration*

Drill and test an exploration well?

Step 2. Feasibility Study

- Identify, evaluate and quantify the opportunities for the production and commercial use of geothermal energy for district heating.
- The results are used to support a decision to mature the project to the Exploration Phase and the drilling and testing of an exploration well



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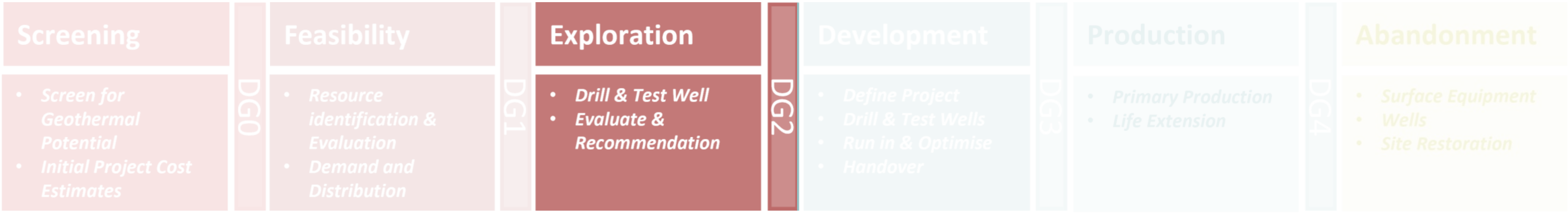
Develop a geothermal project?

Step 3. Exploration Study

- Drill and test an exploration well to obtain subsurface data to quantify the geothermal energy production, minimize uncertainty and reduce risk.
- The results of the Exploration Study are used to support a decision to mature the project to the Development Phase and provide the subsurface design basis for the geothermal production and injection wells



Development of the geothermal wells and plant

Step 4. Development

- Select the final development concept, drill the production and injection wells, build the geothermal plant, tie-in with the district heating network.
- The results of the Development Phase are a commissioned geothermal wellfield and production plant. The geothermal wells and plant are handed over to Production along with a set of operating and maintenance instructions.

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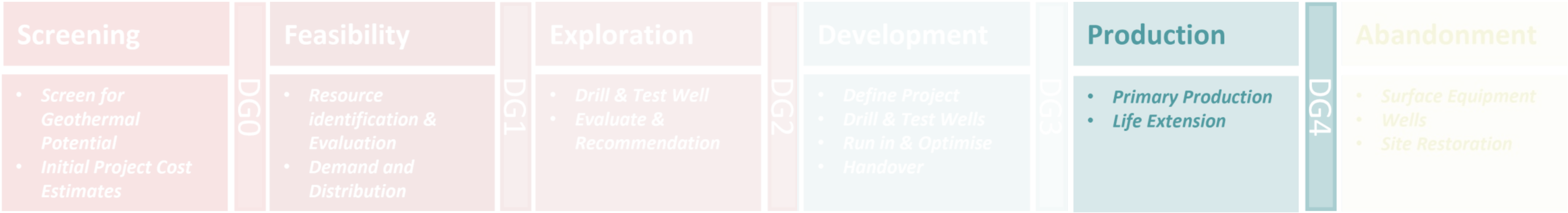
Operation of the geothermal wellfield and plant

Step 5. Production

- Operate and manage the production of geothermal energy for the delivery of thermal energy to the district heating network.
- The operational experienced gained during the Production Phase are used to optimize production and evaluate opportunities to extend the life of the project beyond the designed lifetime.

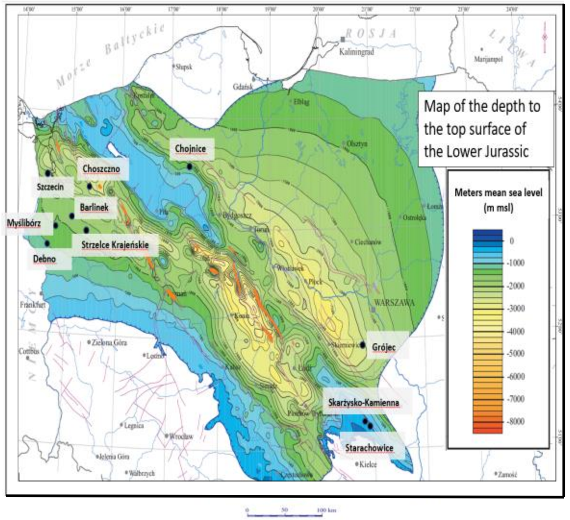


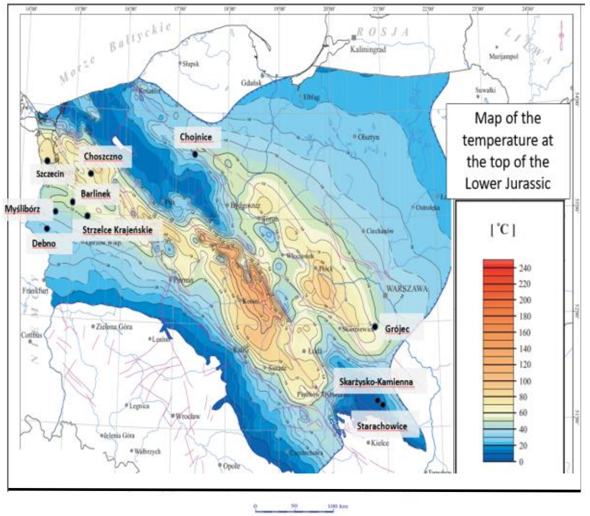
Screening study example: Poland

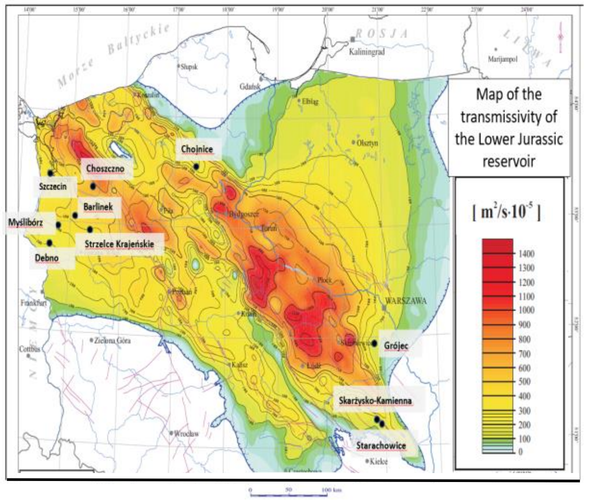
Provide an initial assessment of the use of geothermal energy for district heating based on estimates of:

- Geothermal energy production
- Heat demand
- Development concepts
- Project economics

Identify projects to mature to the Feasibility Phase







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Business case development

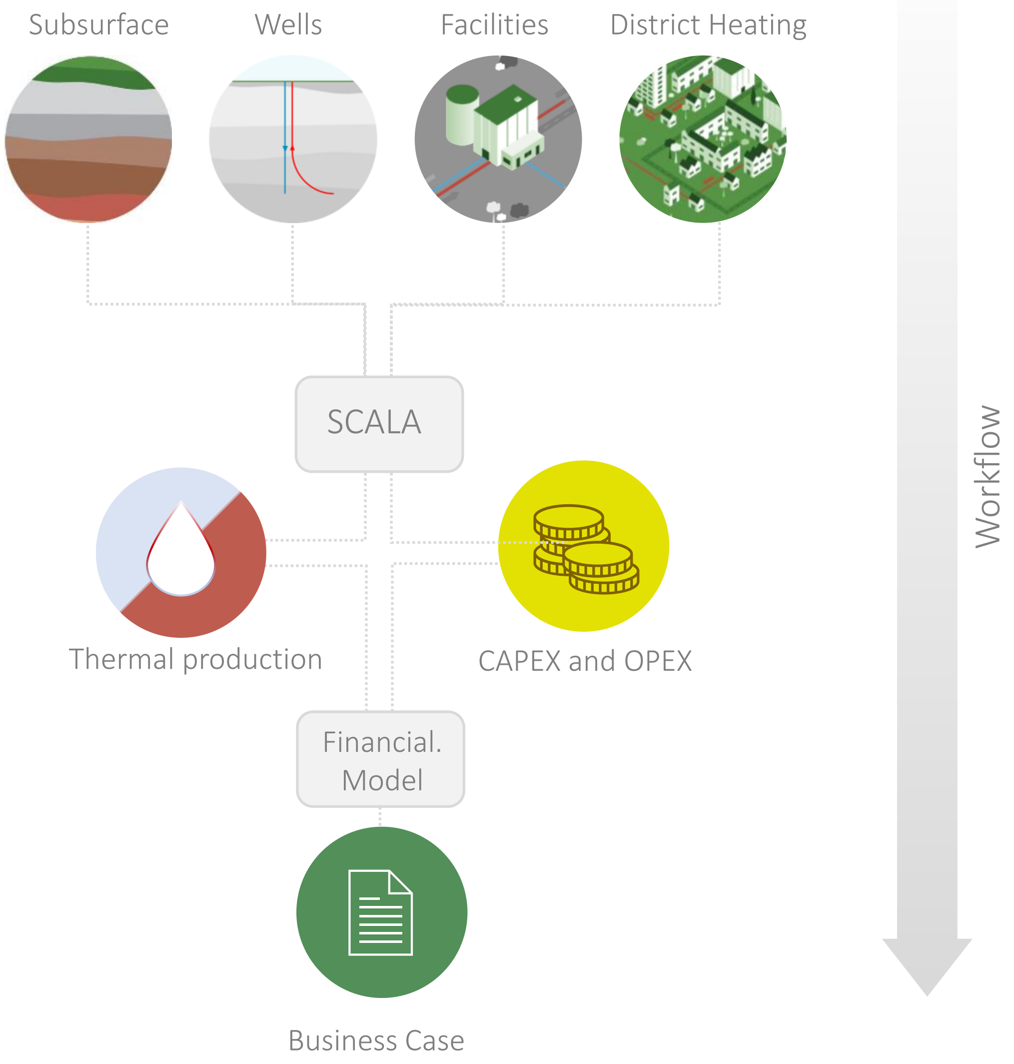
Business Cases
- 3 to 6 scenarios for each of the 10 selected locations resulting in 34 business cases

Scenarios variation
- Production temperature, flow rate and reservoir depth uncertainties
- Production capacity constraints

Delivery temperature
- Use of heat pumps with delivery temperature up to 85°C

Standardised production configurations
- Standard production plant and wells configuration

Collaboration
- Business cases developed in cooperation with local utility companies



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Screening study results: opportunities ranking

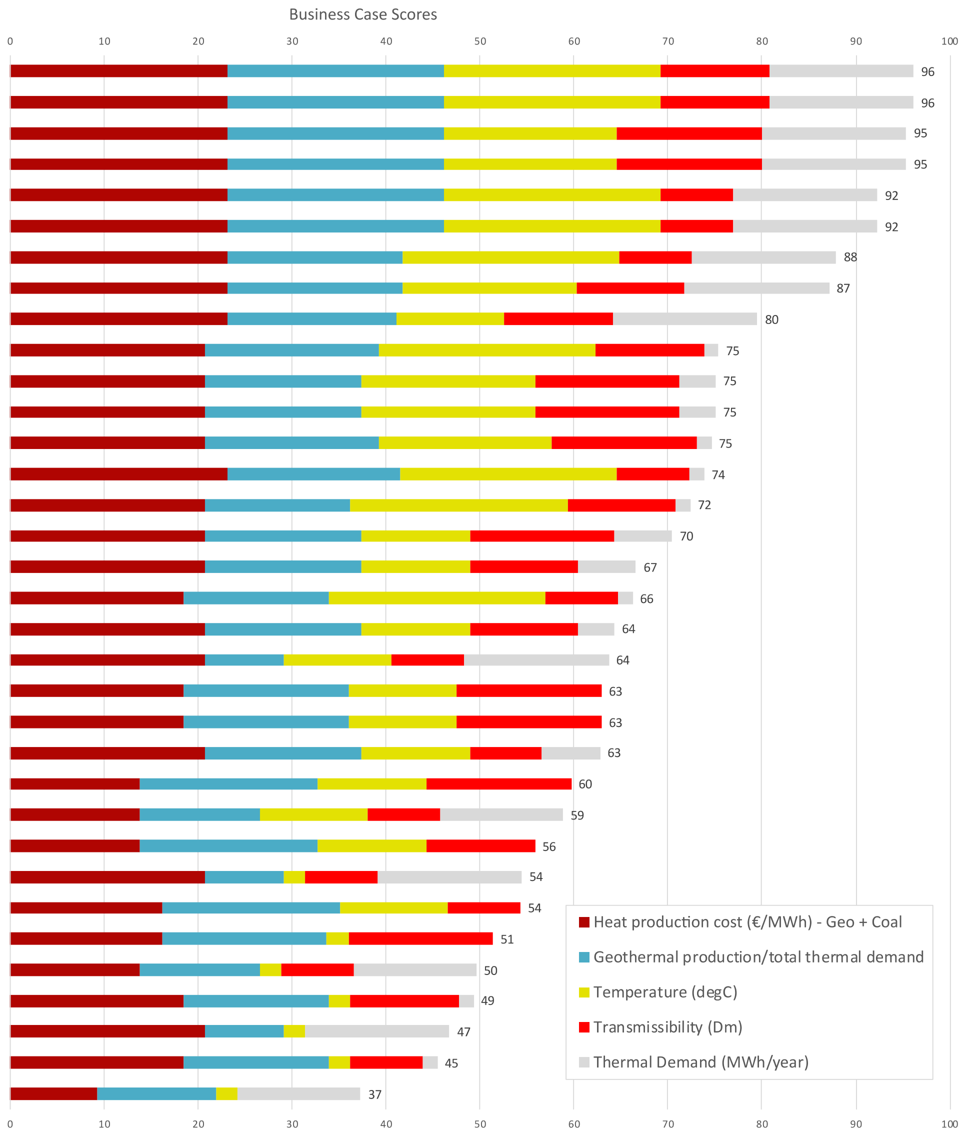
Heat production cost (€/GJ)

Geothermal production/total thermal demand ratio

Temperature (°C)

Transmissibility (Dm)

Thermal Demand (MWh/year)



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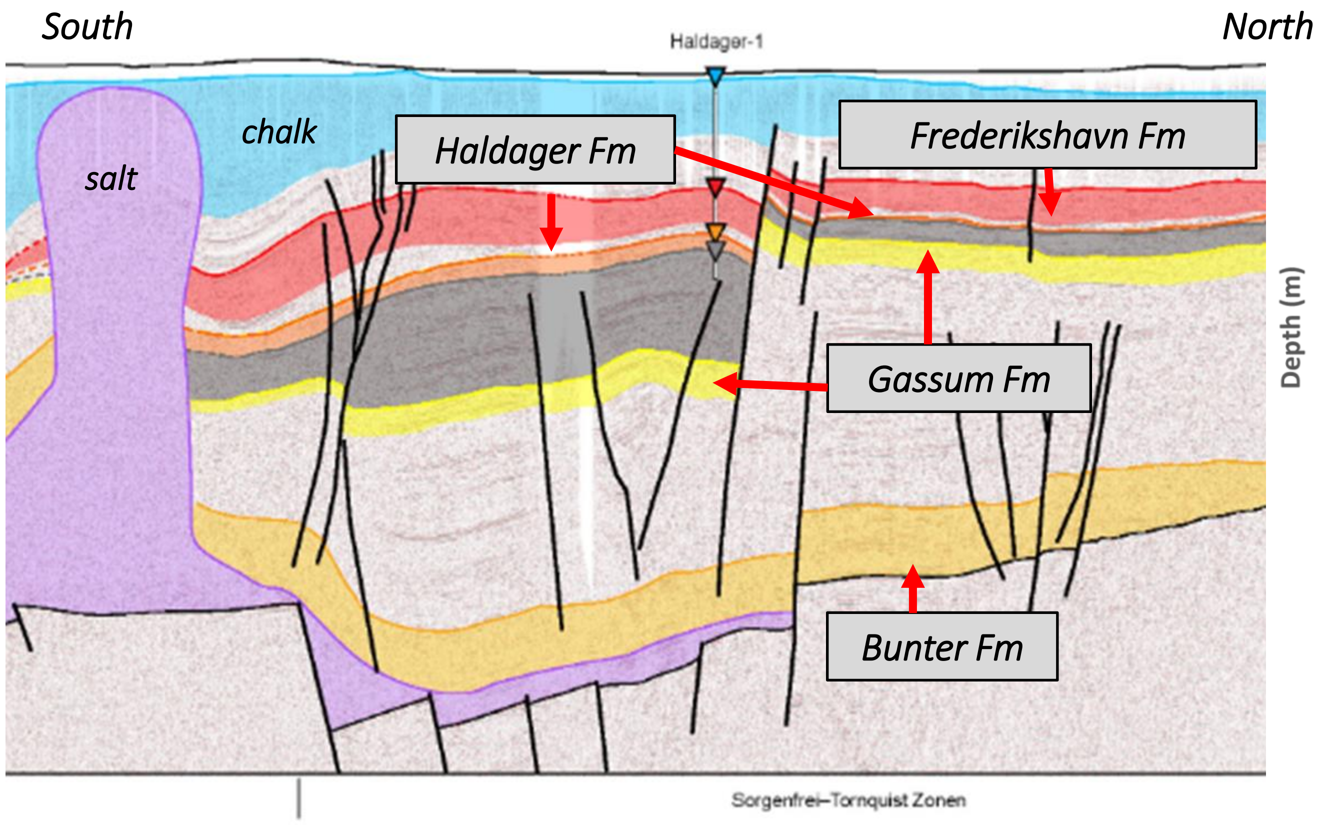
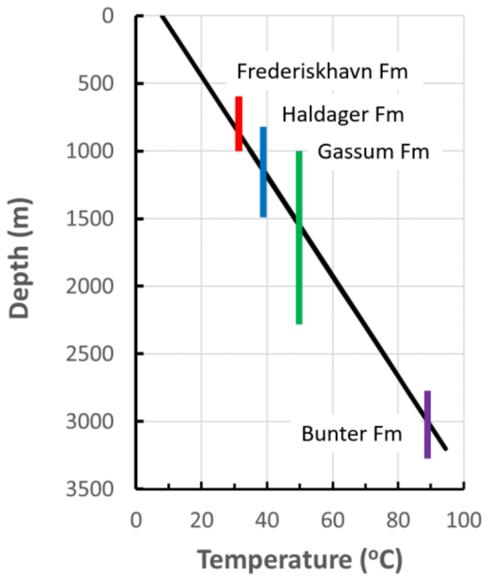
Feasibility study example: Jutland, Denmark

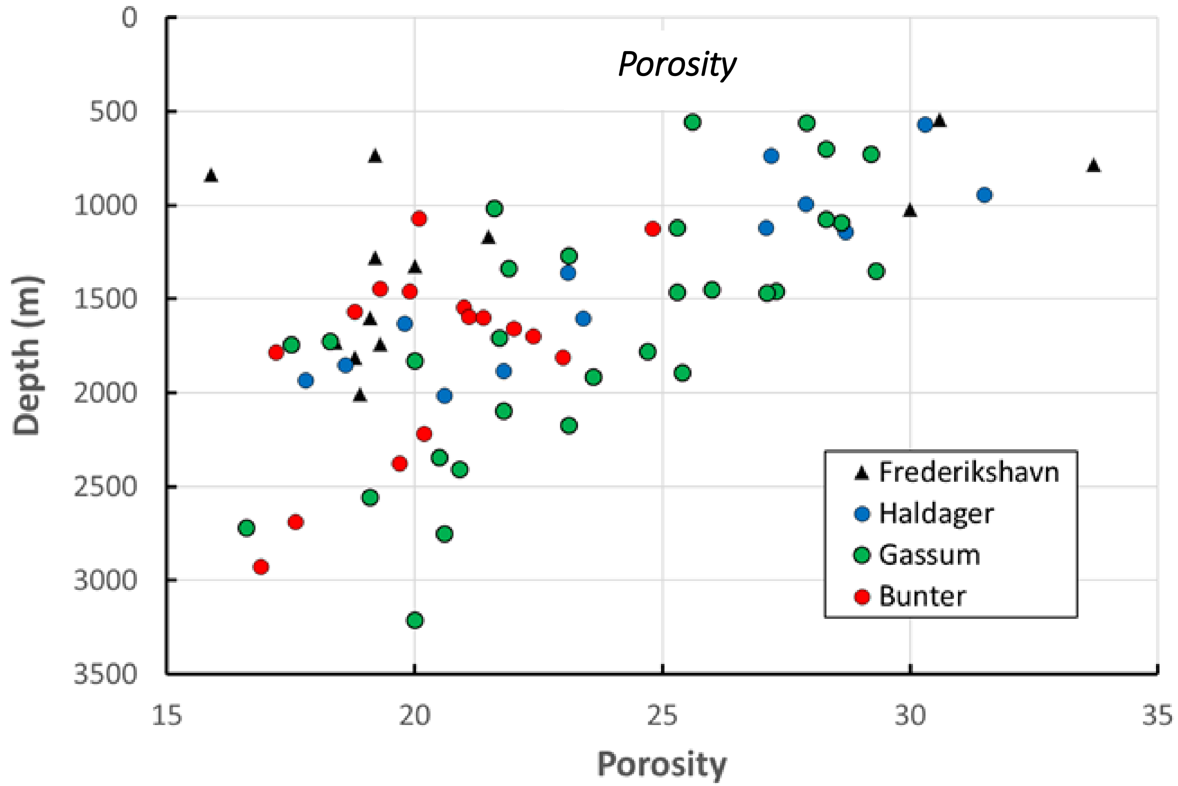


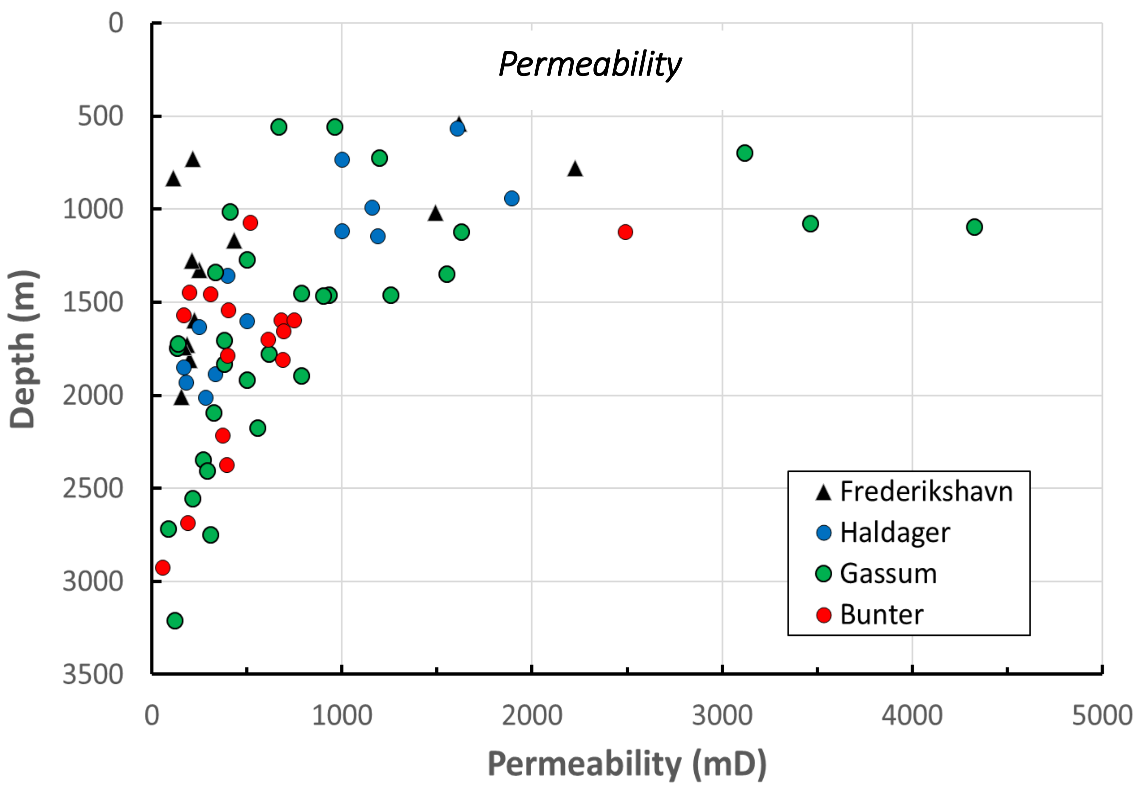


Cross-section from GEUS Geotermi WebGIS-portal http://data.geus.dk/geoterm/

Reservoir flow properties versus depth

Deep wells in Denmark





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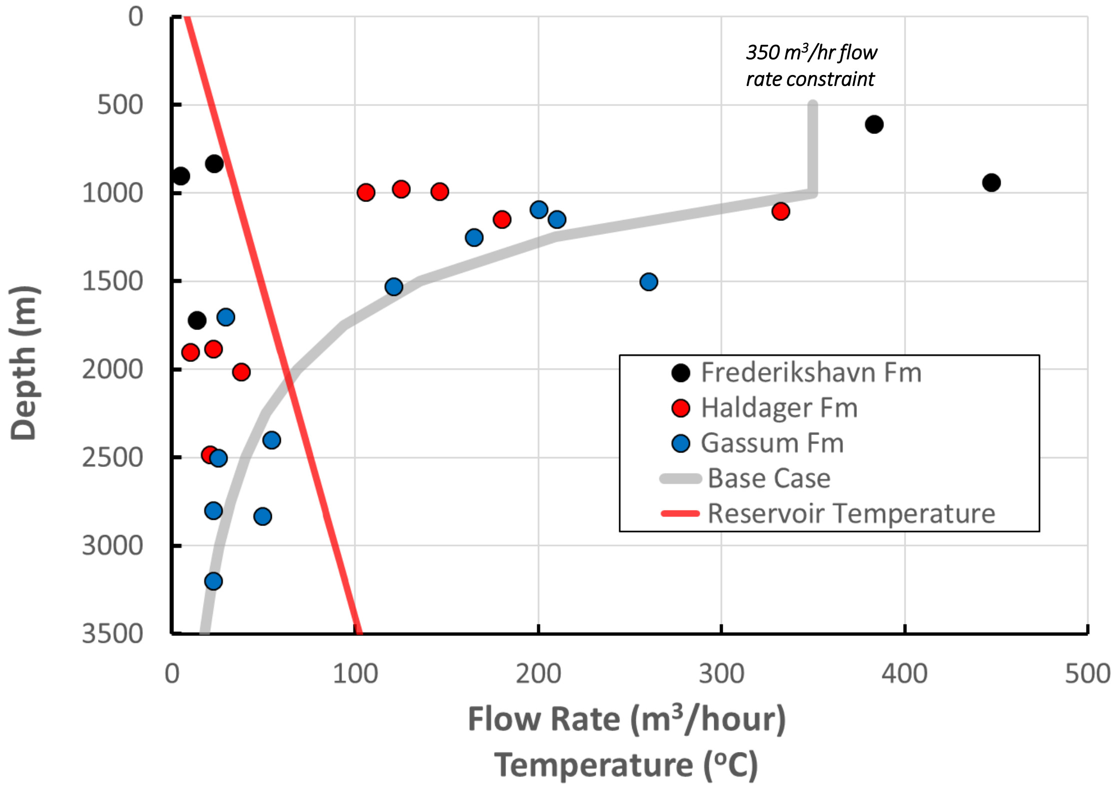
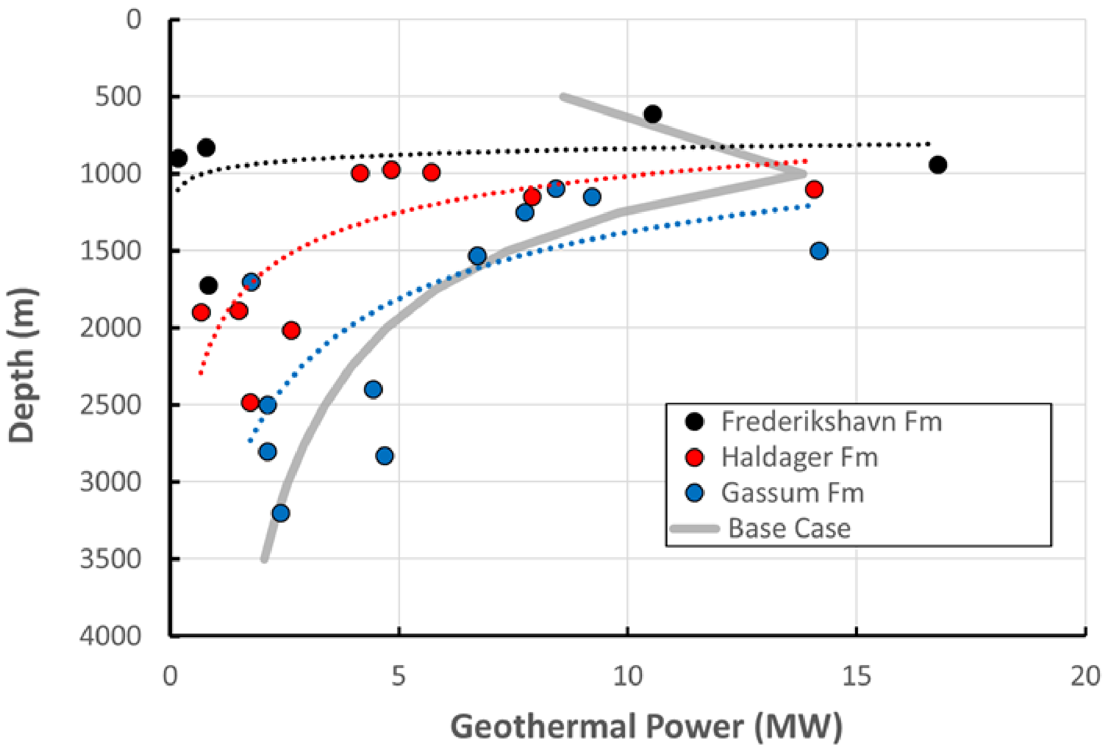
Geothermal power versus depth





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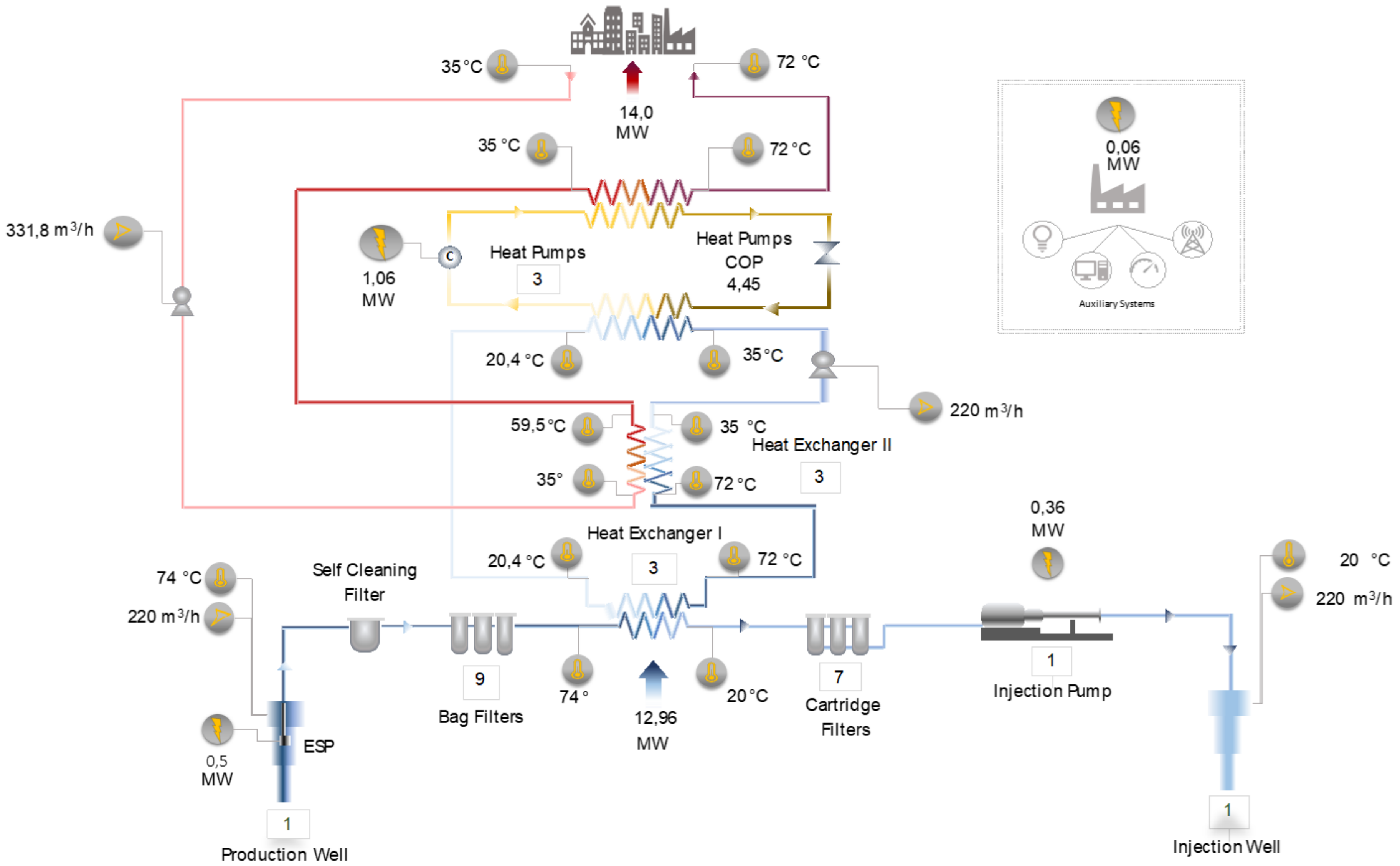
Development concept and geothermal plant design



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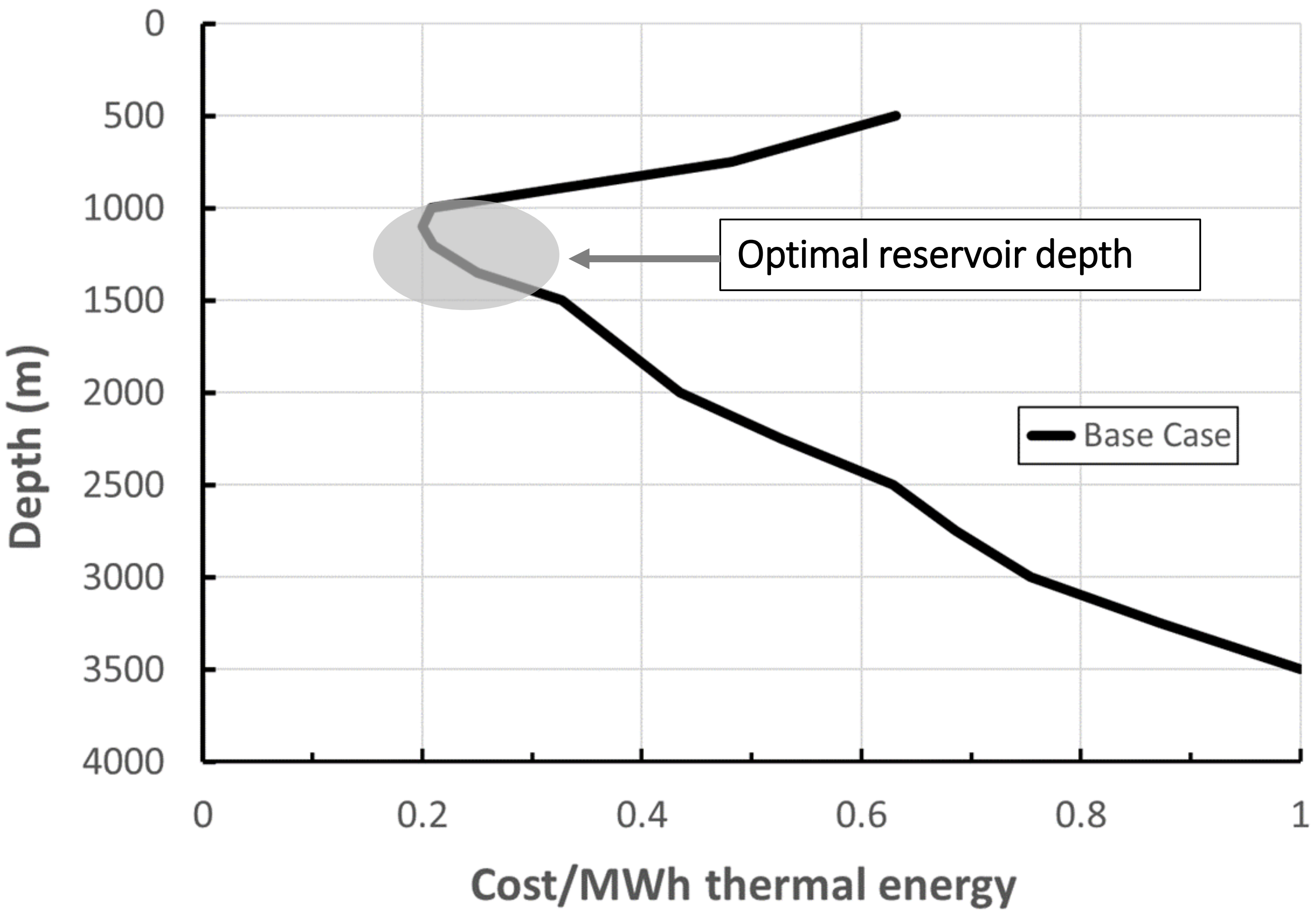
Heat price versus depth



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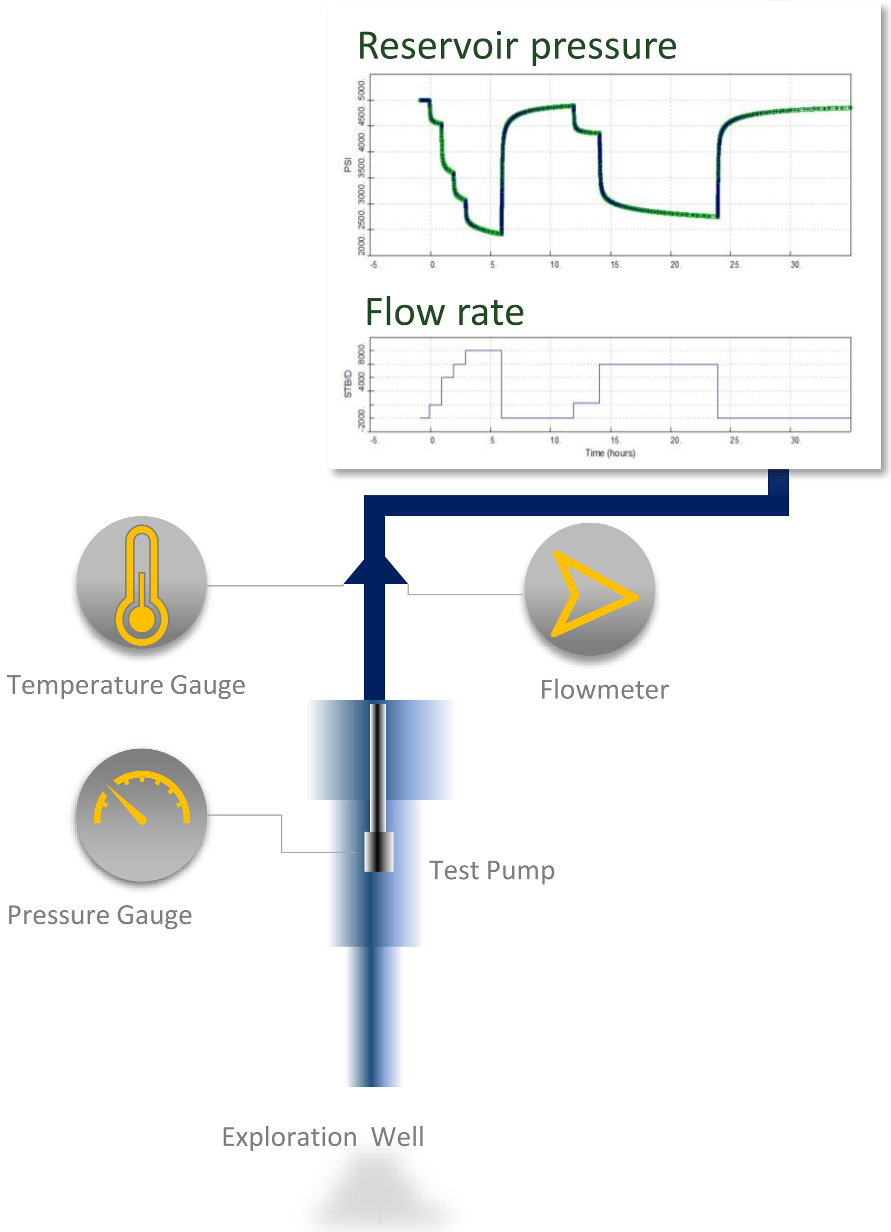
Exploration Phase: Well test

1. Produce from a geothermal well and measure flow rates, temperature and pressure

2. Analyze well test data to quantify:
    - Reservoir flow properties
    - Reservoir temperatures
    - Well performance
    - Size (volume) of the reservoir
    - Presence of and distance to flow barriers in the reservoirs

3. Results used to:
    - quantify the geothermal power production
    - update reservoir and business case models
    - to support a decision to mature the project to the Development Phase
    - provide the subsurface design basis for the geothermal production and injection wells



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Summary

Phased management approach to de-risk and mature geothermal district heating projects

- Defines the roles, responsibilities, tasks and deliverables for each project phase
- Defines the decision gate criteria (DG) that must be met in order to mature the project

Business case models

- Developd and refined throughout the project life time

A properly designed well test is the single best tool to minimize subsurface uncertainty and reduce risk