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Geothermal energy solutions - digging deeper

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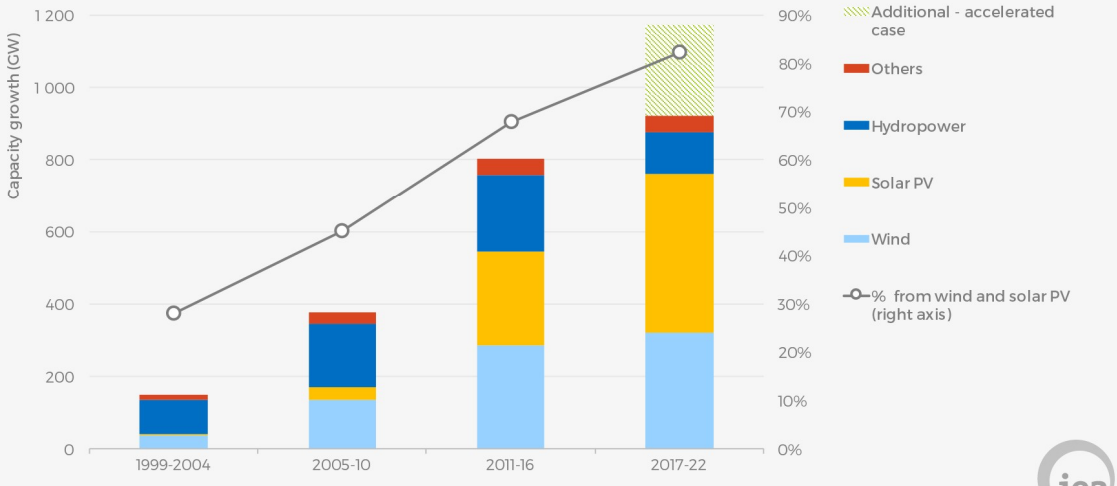
Renewable electricity capacity growth by technology

Renewables 2017



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Capacity factor

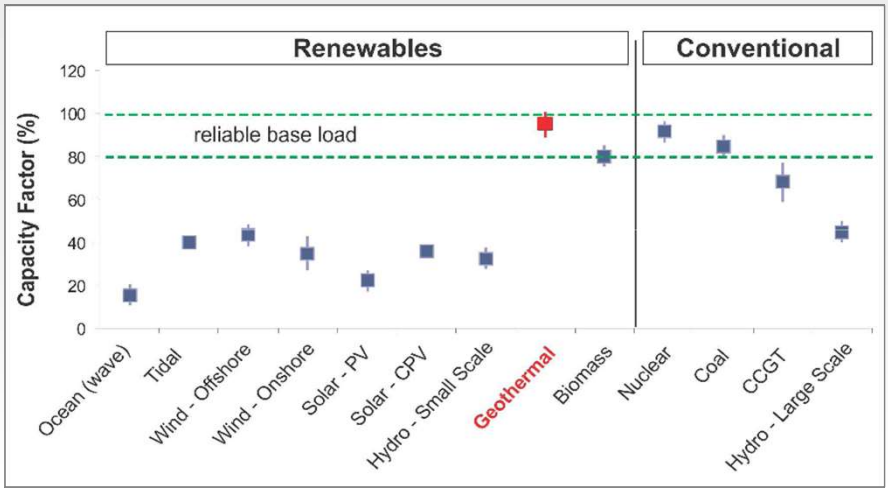
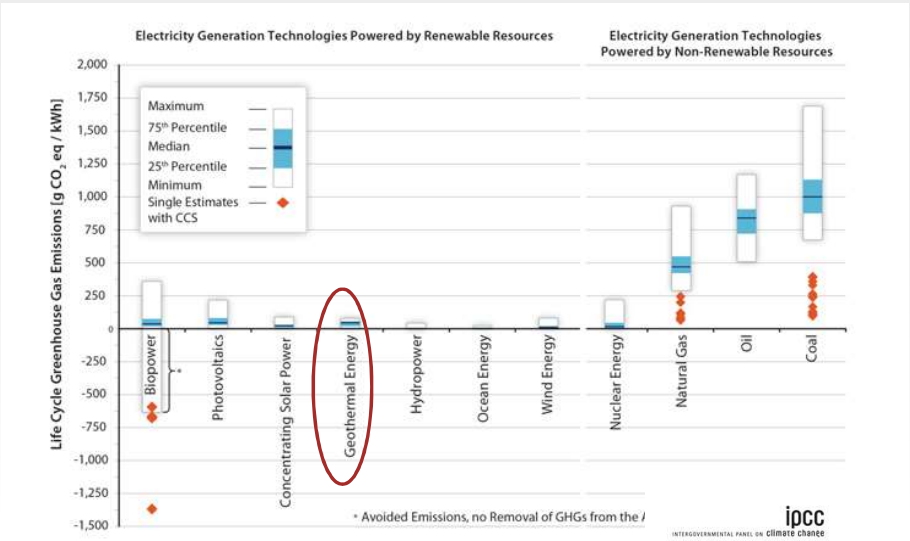


Image source: Emerging Energy Research (2009)

3

Life-cycle analysis - IPCC



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Land use km^2/TWh

The energy transition is a transition in land use

[McDonald et al., PLoS ONE, 2009]

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Geothermal energy

- Thermal energy in the earth
- The thermal energy in the crust (<1% of earth's volume) corresponds to 9 million times annual energy production
- Temperature increases on average 25-30ºC per km depth on the continents (large regional differences)

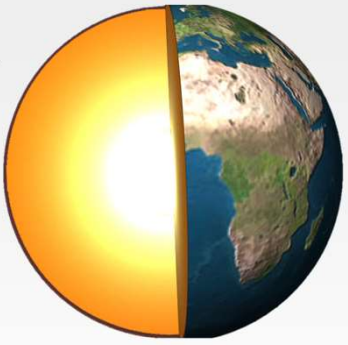

Image source: livescience.com

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Hydrothermal system

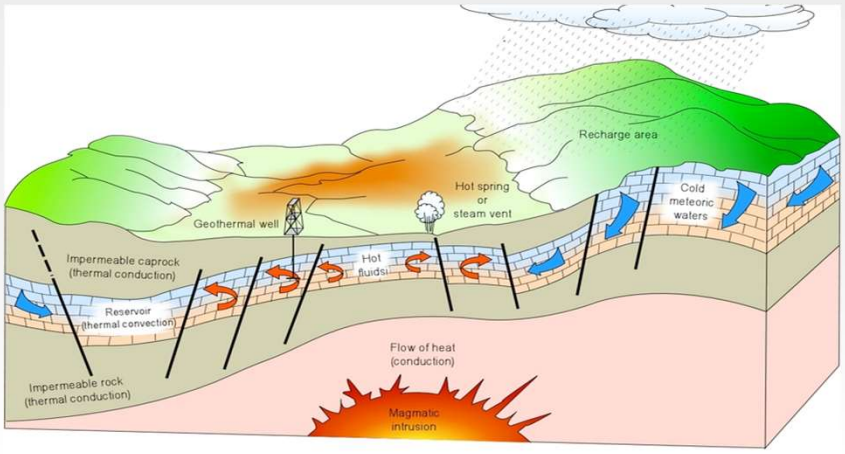

Image source: IGA, 2004

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Geothermal heat and power

- Mature technology for heat and power – Commercial power production in Larderello for more than 100 years

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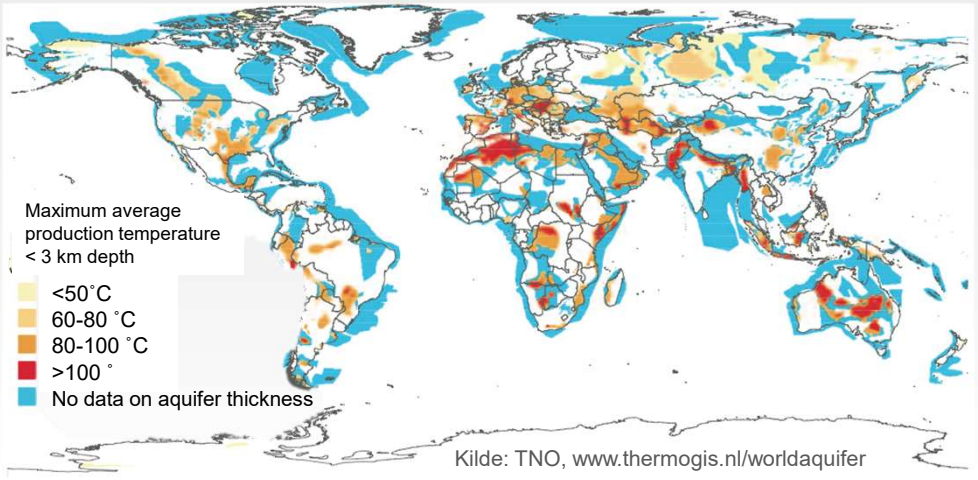
Hydrothermal resources



Kilde: TNO, www.thermogis.nl/worldaquifer

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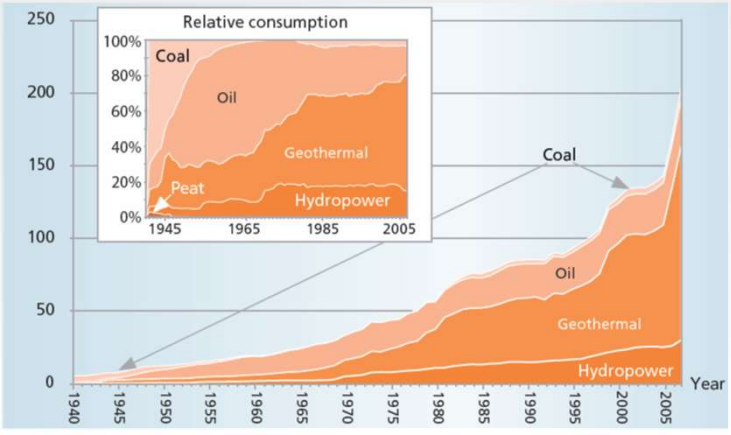
Icelands primary energy consumption 1940-2007



Source: Orkustofnun Energy Statistics

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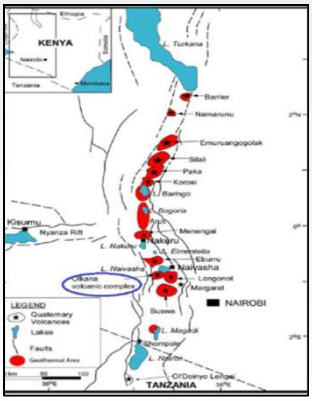
Recent developments - Kenya

Currently geothermal accounts for 28% of grid capacity.



Location of geothermal fields and prospects
Along the axial region of Kenyan rift [Mangi, 2017]

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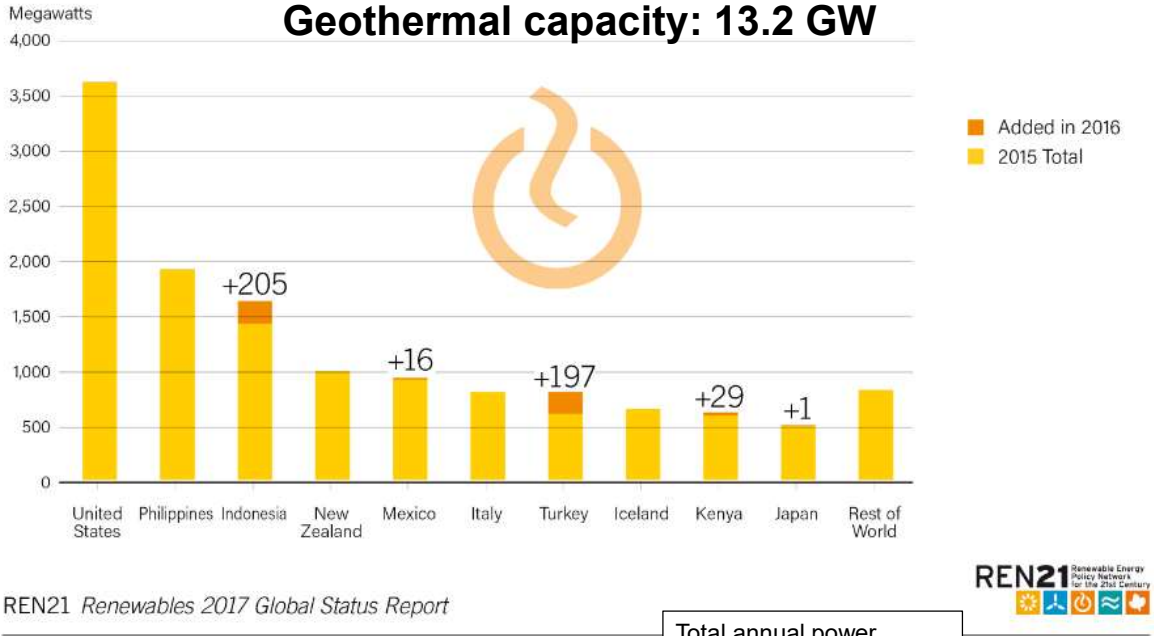

Total annual power Production 2015: 75 TWh

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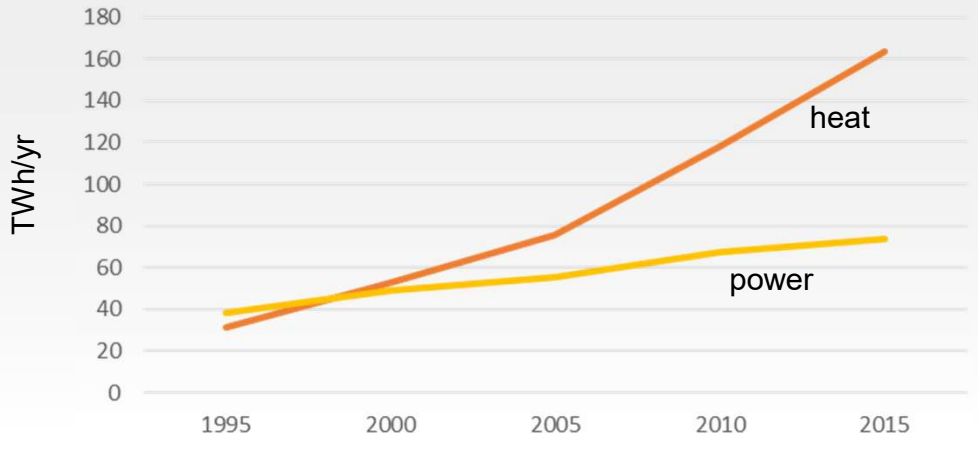
Geothermal energy production (shallow and deep)



Source: Bertani (WGC, 2015)

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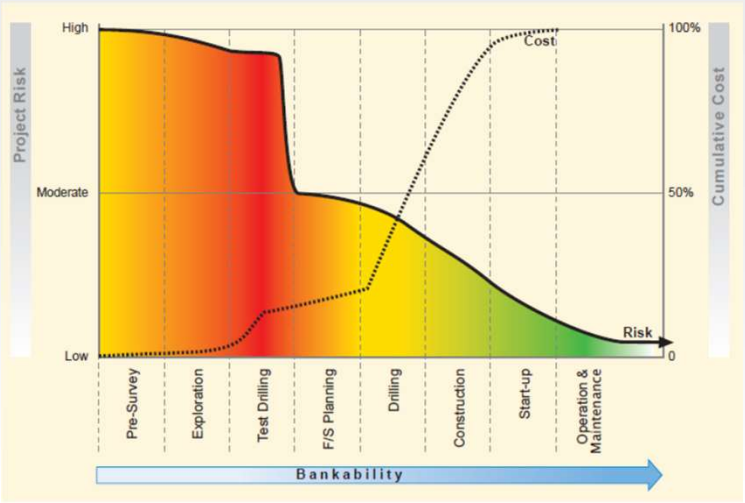
Risk and cost during different stages of geothermal development



Source: ESMAP Technical report 002/2012

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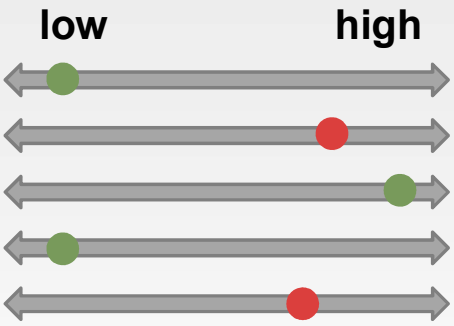
Short summary



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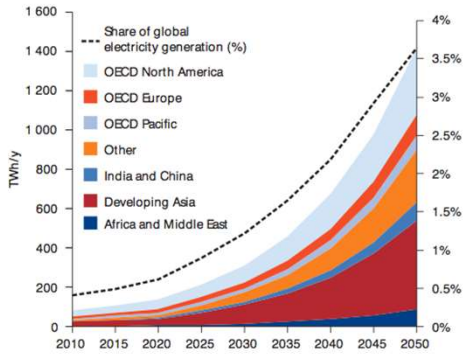
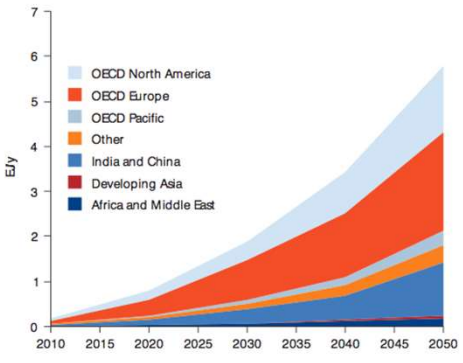
Potential

IEA Roadmap vision of geothermal power production by region



IEA Roadmap vision of direct use of geothermal heat by region, excluding geothermal heat pumps



- More than half of the projected increase from EGS resources
- Substantially more research, development and demonstration needed

Source: IEA Technology Roadmap: Geothermal heat and power, 2011

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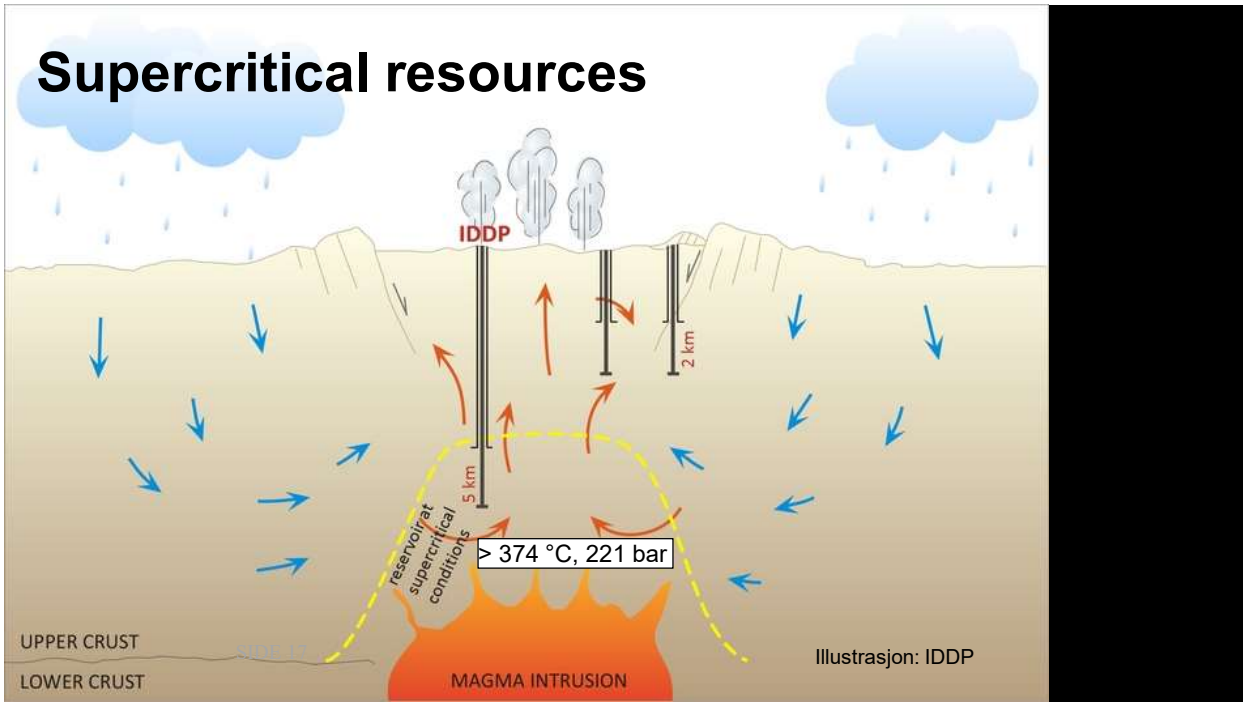

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SiGS project (2019-2023)

Research example 1 (UiB-MI, ÍSOR, Landsvirkjun, Equinor)

Objective: Testing of the hypotheses of **enhanced fluid convection due to thermal deformation of fractures in superheated and supercritical systems**.

Advance understanding of superheated and supercritical geothermal systems:

- Develop conceptual and numerical model of the **coupled thermal, hydraulic and mechanical processes in the deep roots of a supercritical system** and determine the significant processes for heat transfer
- Develop numerical model to investigate **formation response to drilling fluids in superheated geothermal systems**

Data

- Hellisheidi (superheated conditions)
- Krafla (2.1 km depth, 450ºC steam)
- IDDP-2 Reykjanes (4.7 km depth, 535ºC est. bottomhole, supercritical cond.; thermal stimulation performed; flow test April 2019)

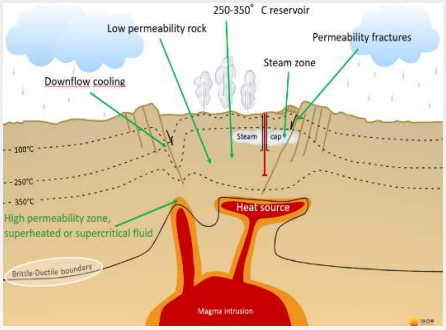

Image source: ÍSOR

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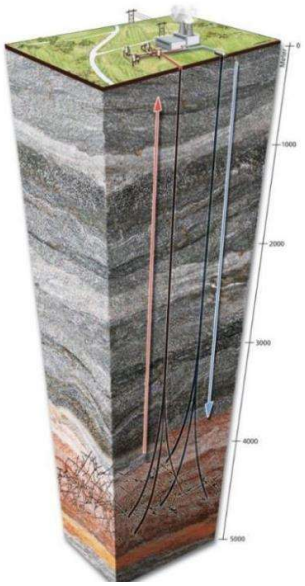
EGS («Enhanced Geothermal Systems»)

Enhancement of high-temperature geothermal reservoirs with low water content and/or permeabilty through hydraulic stimulation.



Europe

- Power plants
  - Insheim, Germany
  - Landau, Germany
  - Soultz-sous-Forêts, France
- Heat plants
  - Rittershoffen

Approx. 10 plants under development in Europe.

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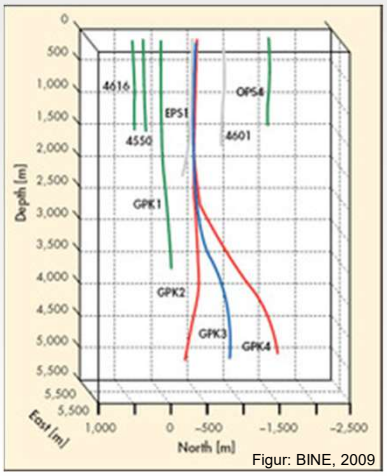
Enhanced Geothermal System – Soultz, France



Figur: BINE, 2009

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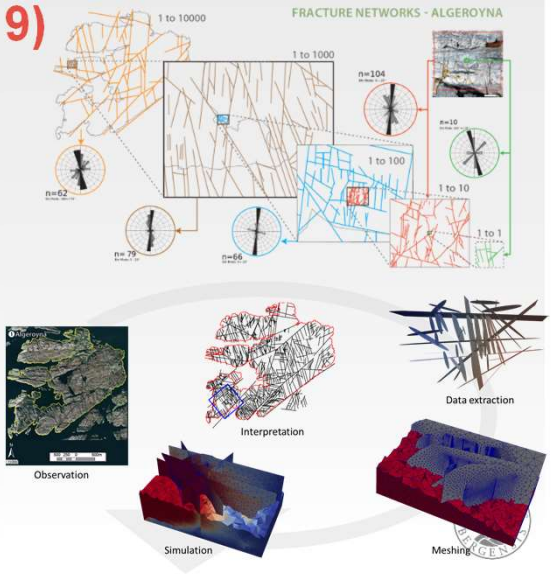
ANIGMA project (2015-2019)

Research example 2 (UiB-GEO, UiB-MI)

Objective: Develop a fully integrated approach to the *characterization, modelling and simulation* of fractured geothermal basement reservoirs.

Improved understanding of geothermal reservoirs by:

1. Allowing geologists and mathematicians to work on realistic data simultaneously
2. By-product: Domain-specific research to facilitate communication
   - Improved geological description of fractured rocks
   - New simulation methods for energy production in these environments



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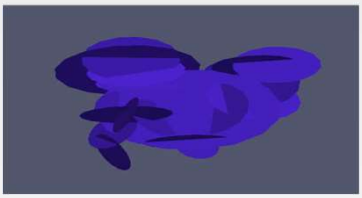
ERiS project (2017-2021)

Research example 3 (UiB-MI, NORSAR, ÍSOR, INGV, Equinor, HS Orka, Imperial College)

Objective: complement the expertise of the geothermal energy sector in exploitation of unconventional geothermal resources by developing **new numerical models and data interpretation workflows that can identify governing mechanisms and forecast reservoir response to stimulation**

Advance the geothermal energy research field by developing

- Improved numerical models for slip along faults accounting for dynamic friction.
- Improved numerical models for assessing thermal stimulation of fractured geothermal reservoirs.
- New monitoring data interpretation workflows integrated with numerical modelling for identification and characterization of active fracture clusters based on case studies.
- A new framework for data-driven numerical modelling of geothermal reservoir stimulation.



Hydraulic stimulation of fractured geothermal reservoir [Ucar, Berre, Keilegavlen, *Geophys.Res. Let.*, 2017]

Thermal stimulation [Stefansson, Berre, Keilegavlen, Paluszny. *Unpublished*, 2019]

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Next step: Simulation of injection at the Reykjanes geothermal field.

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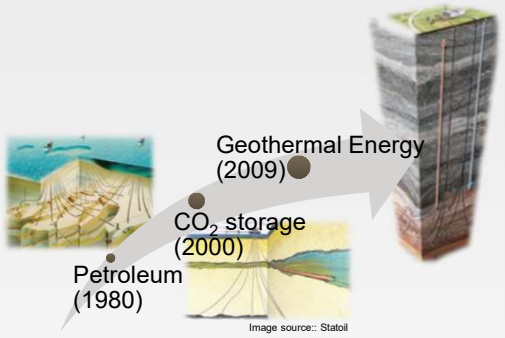
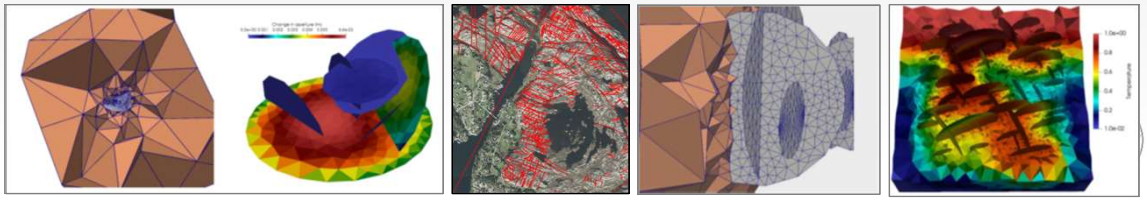
Geothermal energy research – University of Bergen

De-risking and efficient and sustainable production of geothermal resources (hydrothermal, EGS, supercritical)

- Efficient methods for geological and geophysical characterization
- Reservoir characterization, modeling and simulation for optimal development solutions and production
- Effective reservoir stimulation to ensure commercial flow rates without negative environmental impact





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