Hydrothermal Spallation Drilling - a novel drilling technology for deep geothermal heat mining

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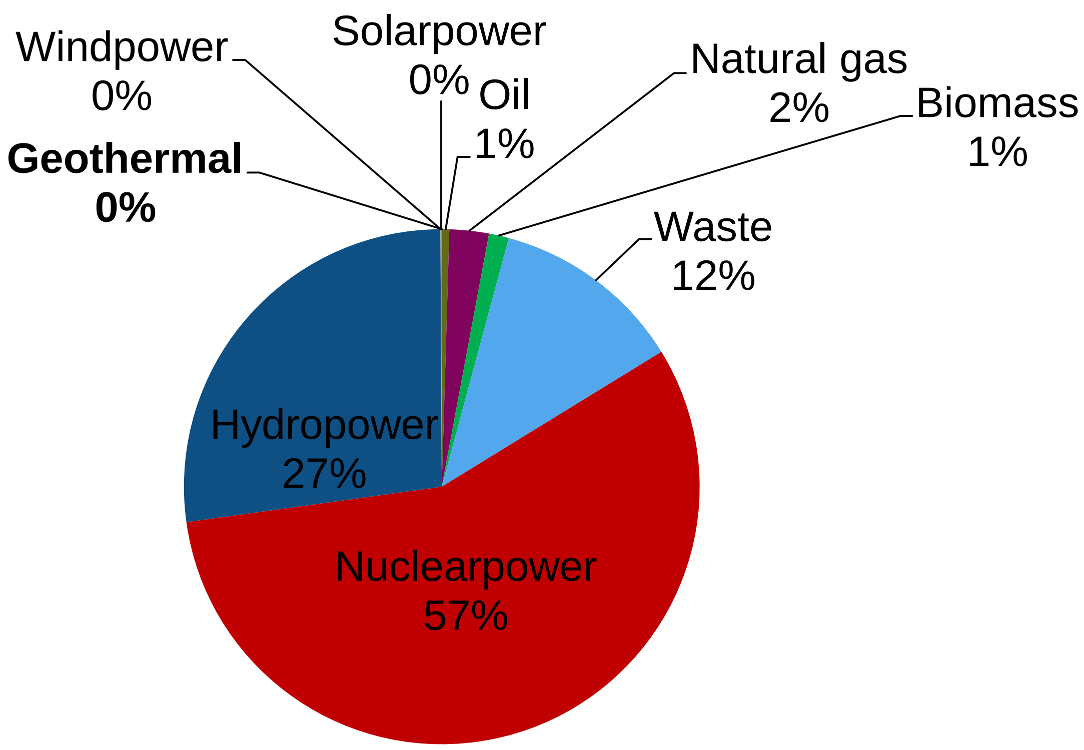
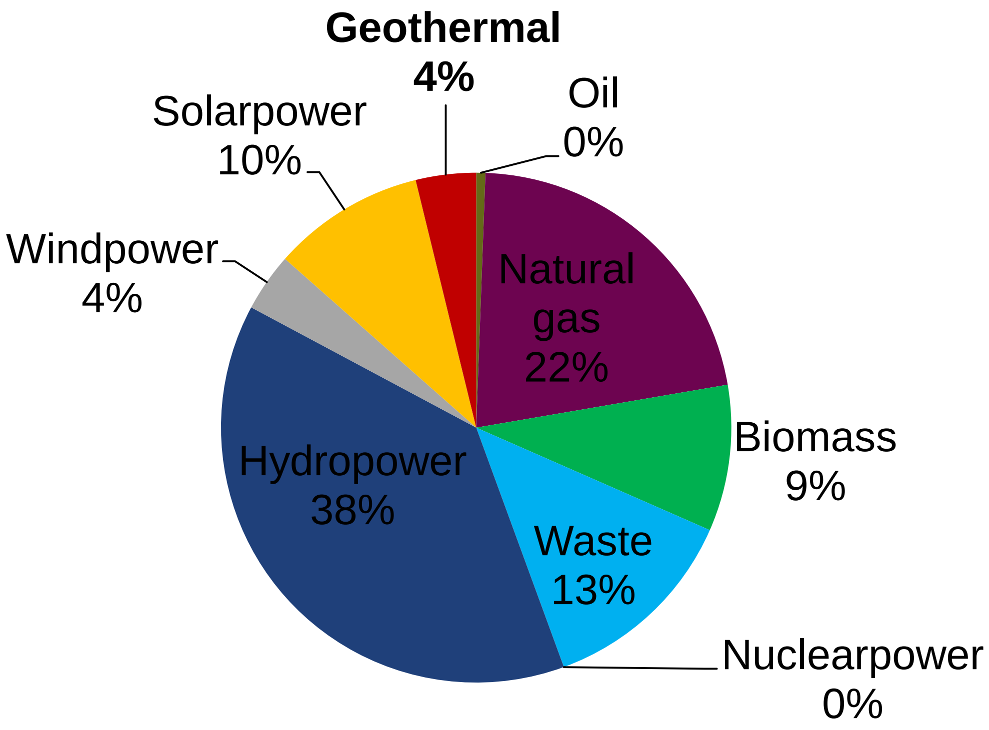
Swiss electricity supply by energy carriers

Today 2010



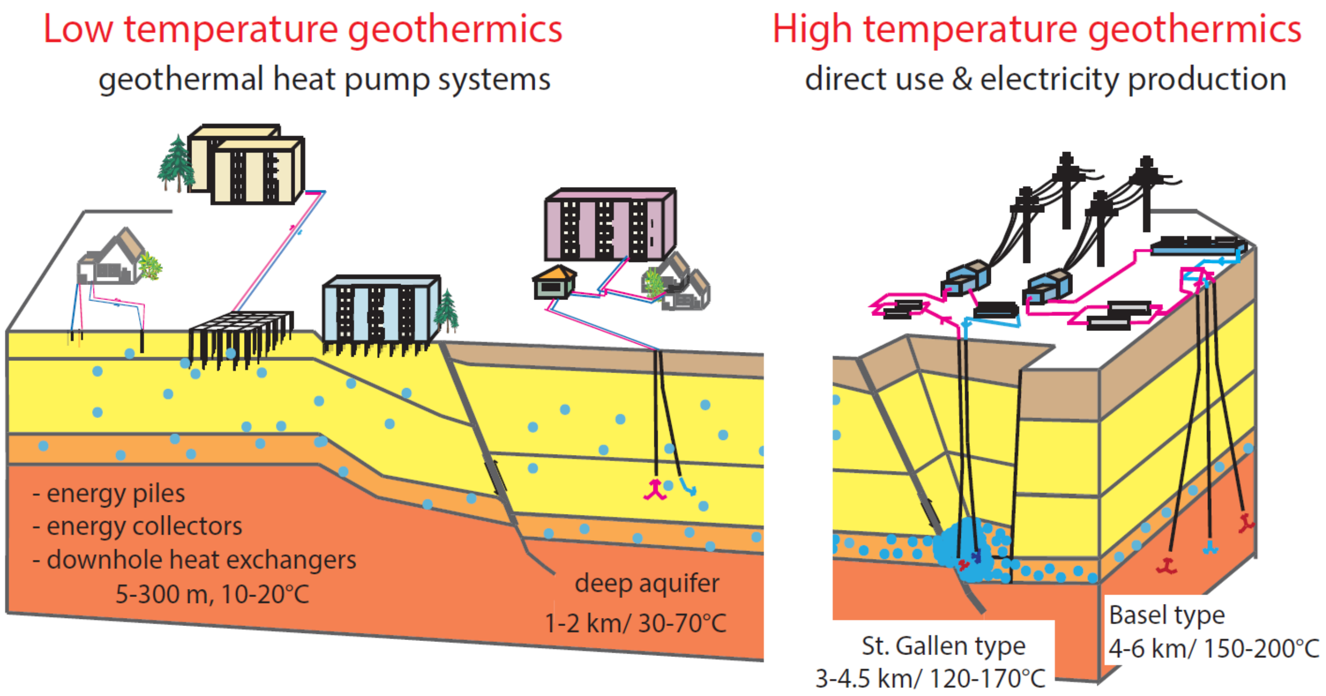
Swiss energy strategy 2050



Data from: BFE – Swiss Energy Strategy 2050, Scenario C&E

Common geothermal Systems

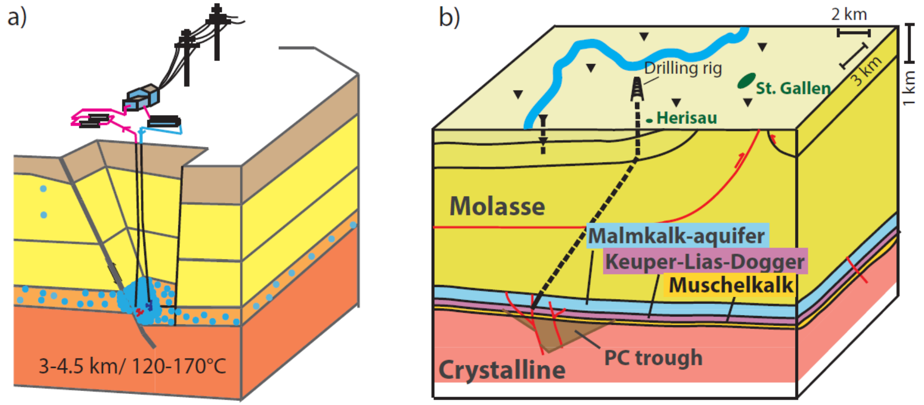
- Geothermal power:
  - Heat from the subsurface
  - Low temperature
    - Energy piles, collectors
    - Depth: 5 m – 2 km
    - Temperature: 10-70°C
    - Only heat use
  - High temperature
    - Hydrothermal, Petrothermal
    - Depth: 2 km – 7 km
    - Temperature: 120-250°C
    - Heat use and direct electricity production

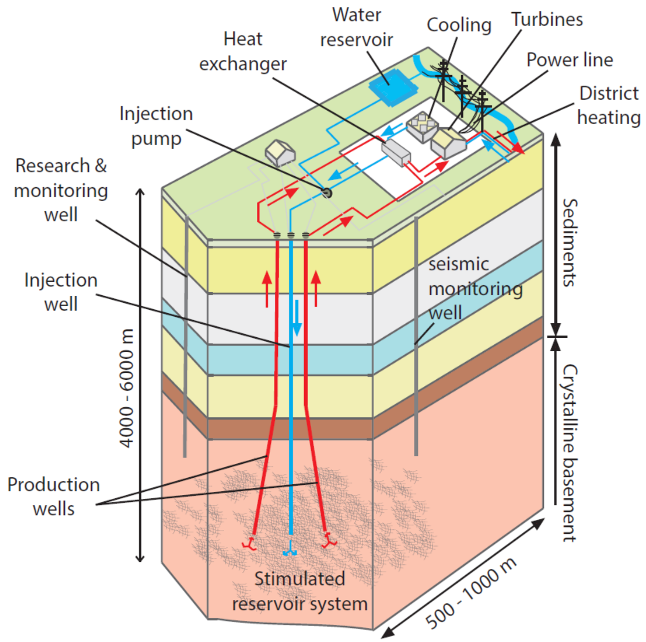


Types of deep geothermal systems

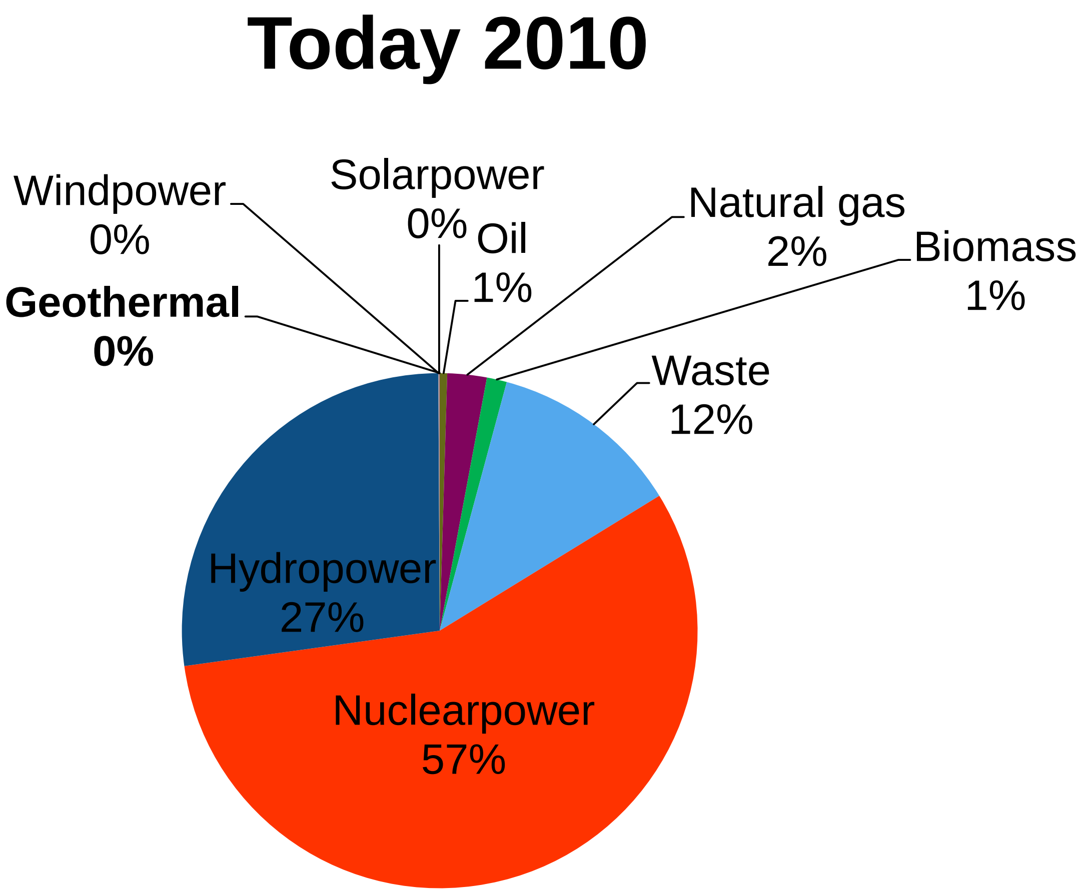
- **Hydrothermal systems**
  - Natural Aquifers
  - Exploitation of hot water
  - Re-injected of used water

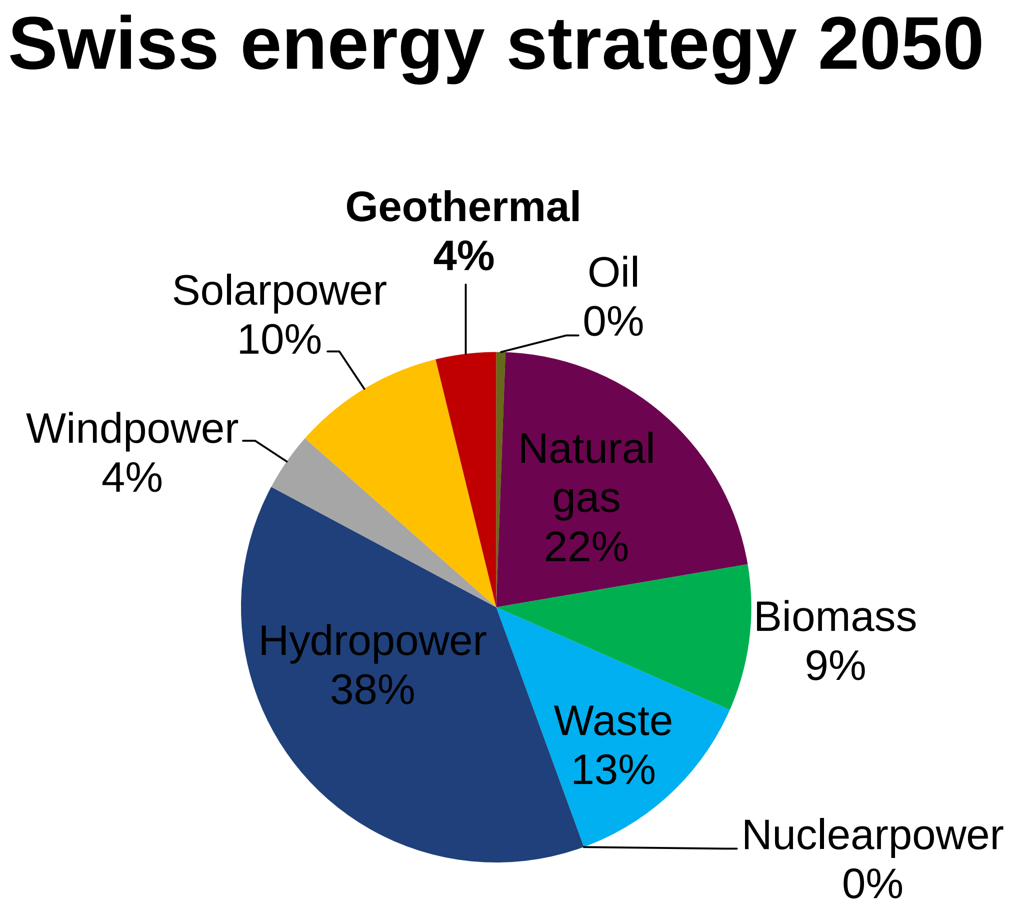
- **Petrothermal systems**
  - EGS (engineered geothermal system)
  - Extract heat from a stimulated reservoir
  - Injection of cold water from the surface
  - Water heats up in the reservoir
  - Hydraulic fracturing required





Swiss electricity supply by primary energy carriers



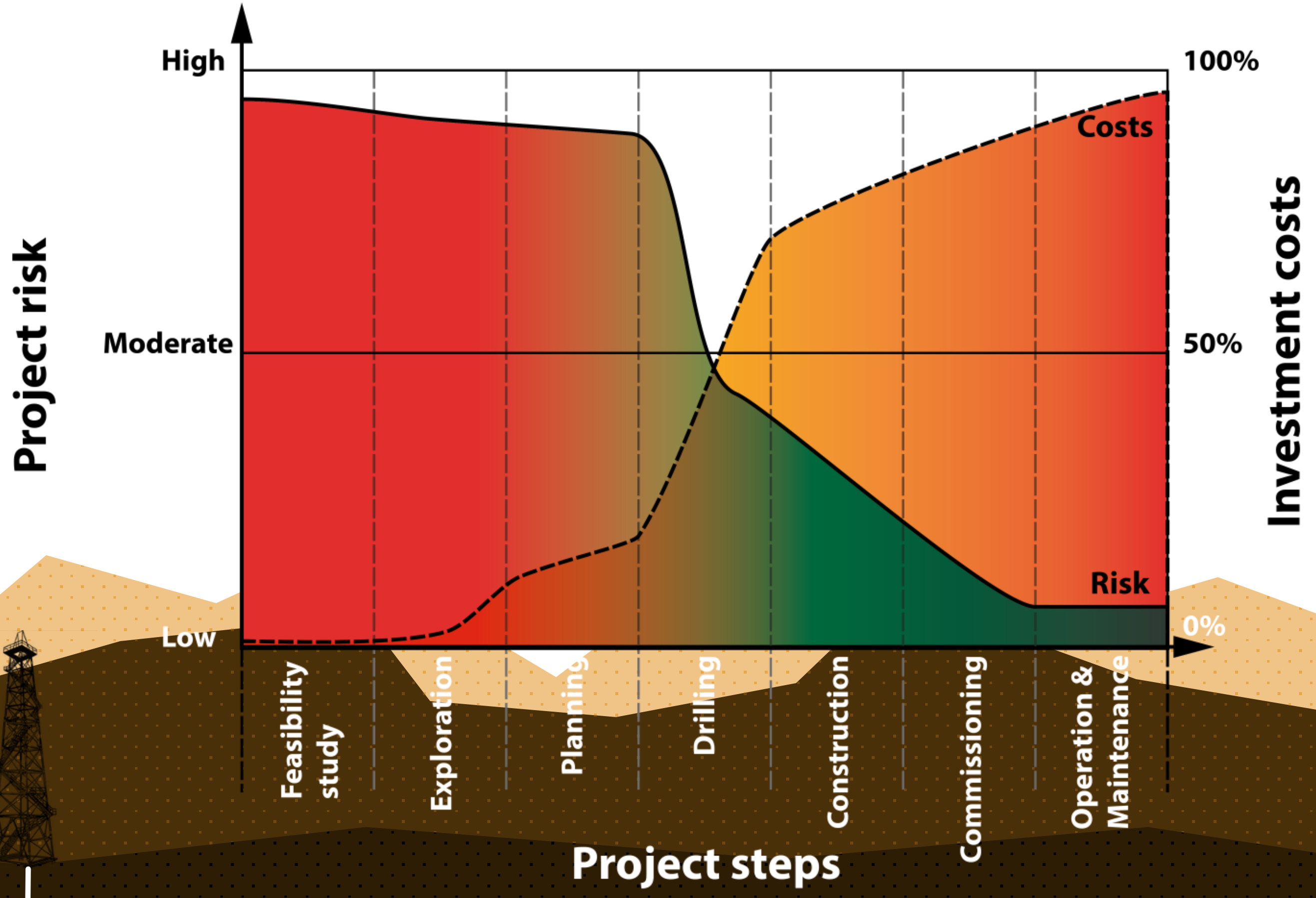


Data from: BFE – Swiss Energy Strategy 2050, Scenario C&E

Actual deep geothermal electricity production:

in percentage of the total electricity production

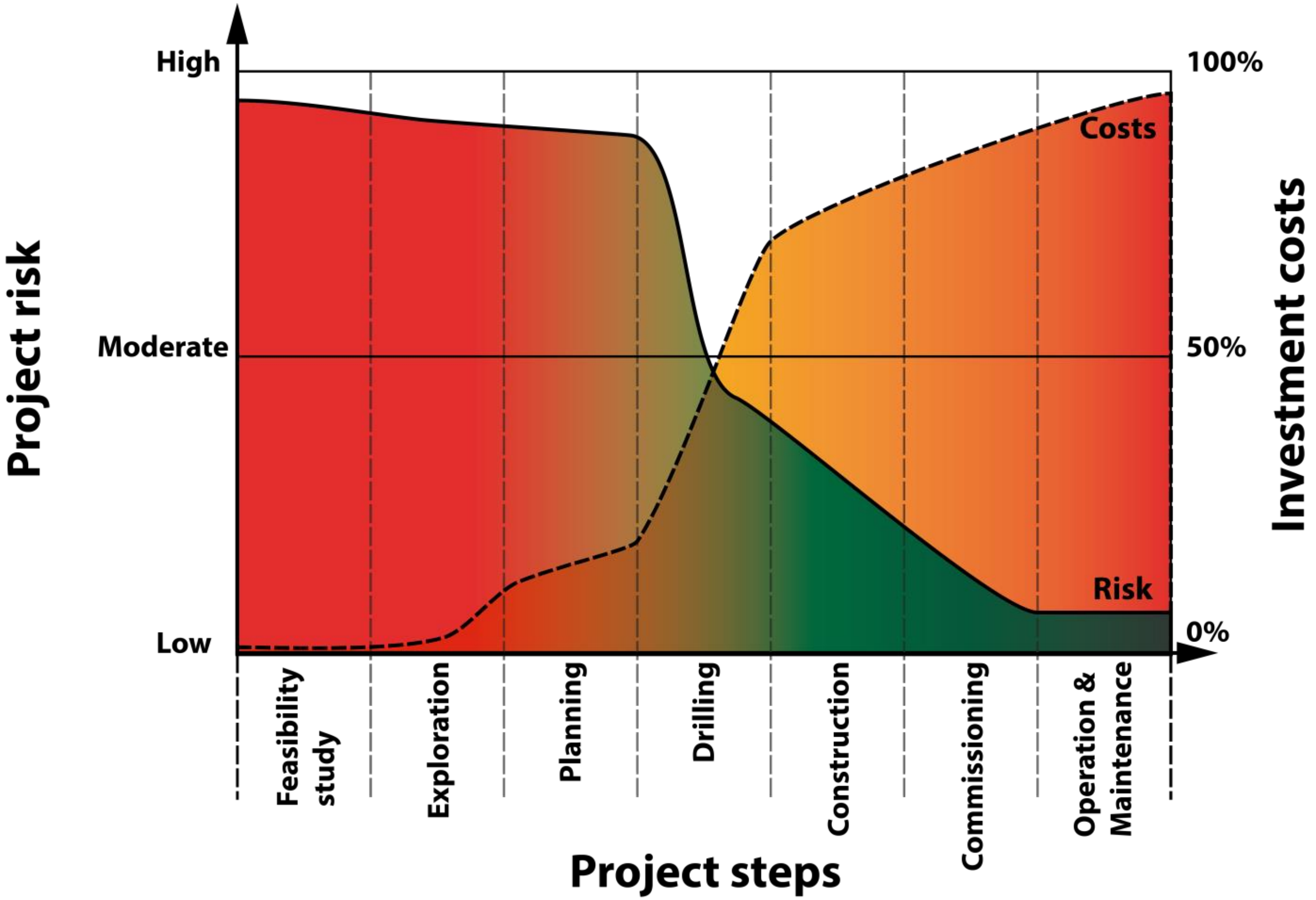
- Switzerland: 0.00% [1]
- Germany: 0.02% [2]
- EU: 0.20% [3]



adapted from ESMAP Geothermal Handbook Planning and Fnancing Power Generation

[1] TA Swiss Energy from the Earth – Deep Geothermal as a Resource for the Future?
[2] German Federal Ministry for Economic Affairs and Energy – Erneuerbare Energien im Jahr 2014
[3] European Commission - 2014 JRC Geothermal Energy Status Report

Boost the development of geothermal power



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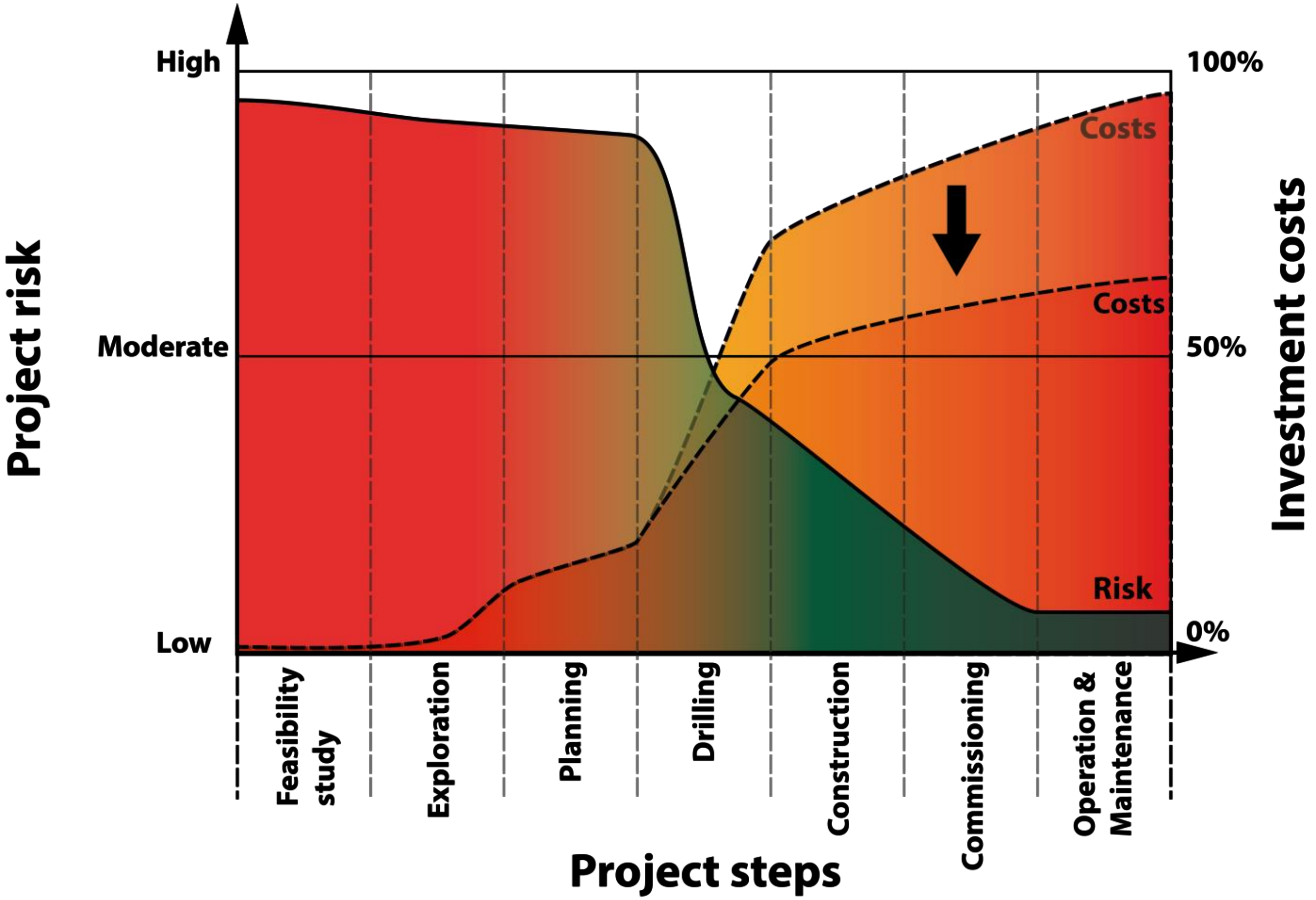

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- **Engineer drilling solutions**
  - Reduction of the drilling costs
  - Shift costs to low risk steps

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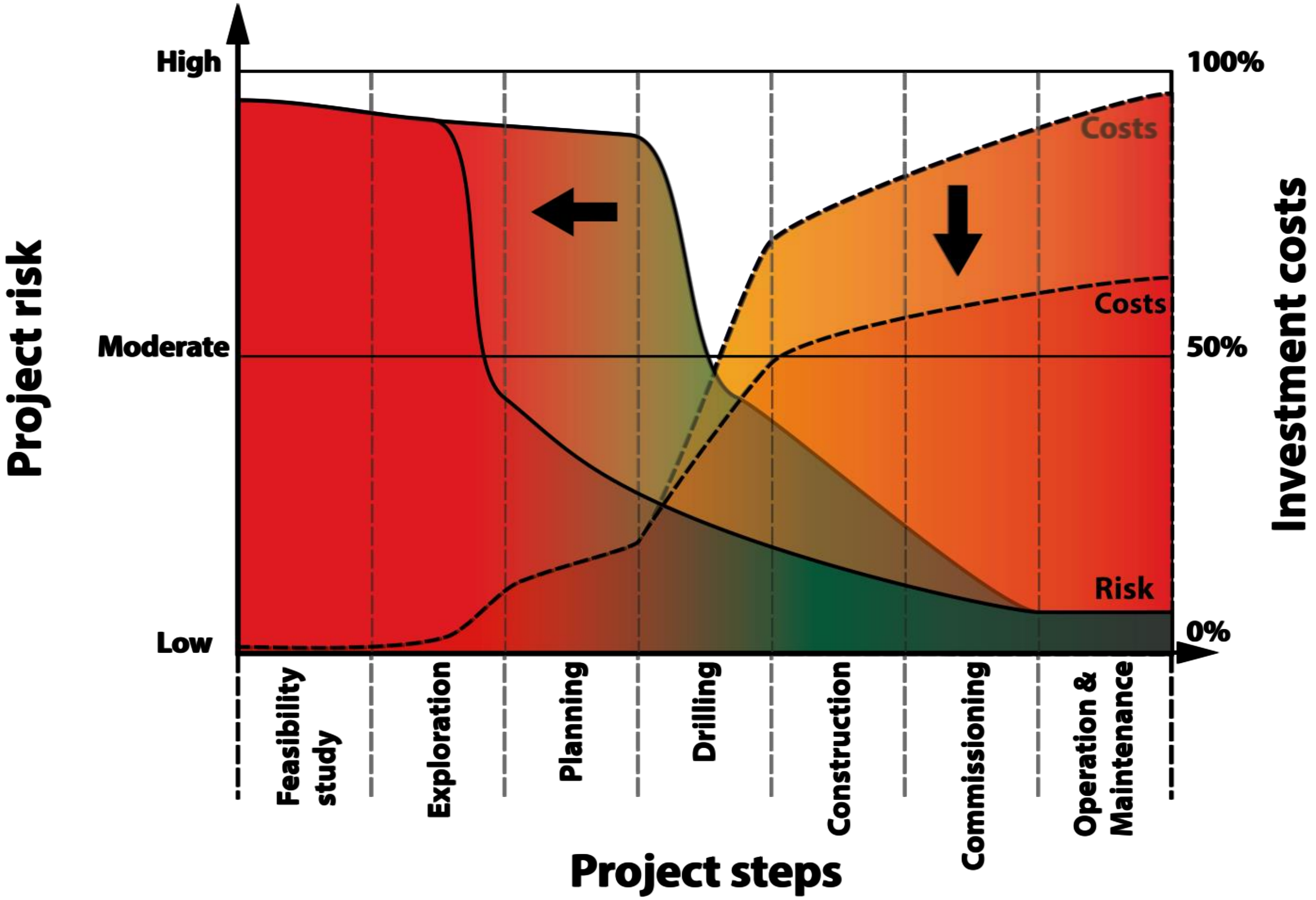
Boost the development of geothermal power



adapted from ESMAP Geothermal Handbook Planning and Financing Power Generation

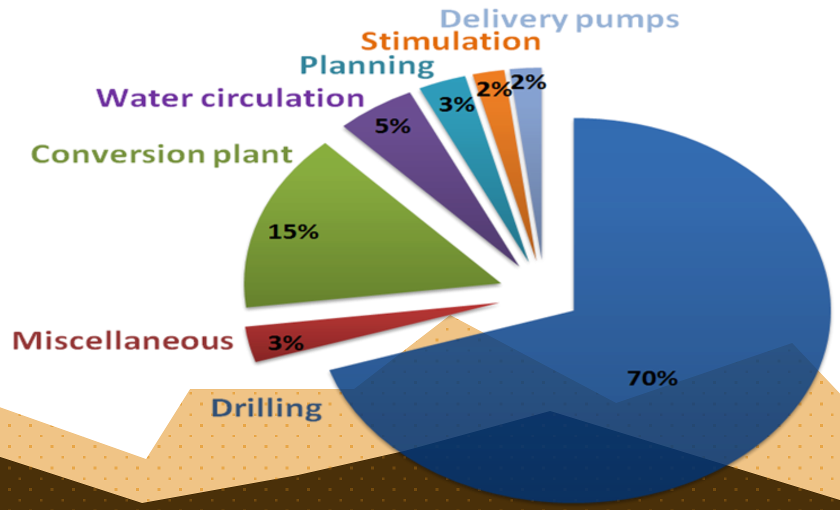
- **Engineer drilling solutions**
  - Reduction of the drilling costs
  - Shift costs to low risk steps

- **Enhance geological knowledge**
  - Increase knowledge about the subsurface
  - Shift risk to low cost steps

→ **Enhance the development of geothermal power**

How can we reduce the costs for hard rock drilling operations?

- **Example: Deep geothermal power plant**



⇨ **The drilling costs account for up to 70% of the total costs**

- **Improvement of the actual technology**
- **Alternative drilling technologies**
  - Laser assisted rotary drilling
  - Electro pulse drilling
  - **Flame-jet drilling**

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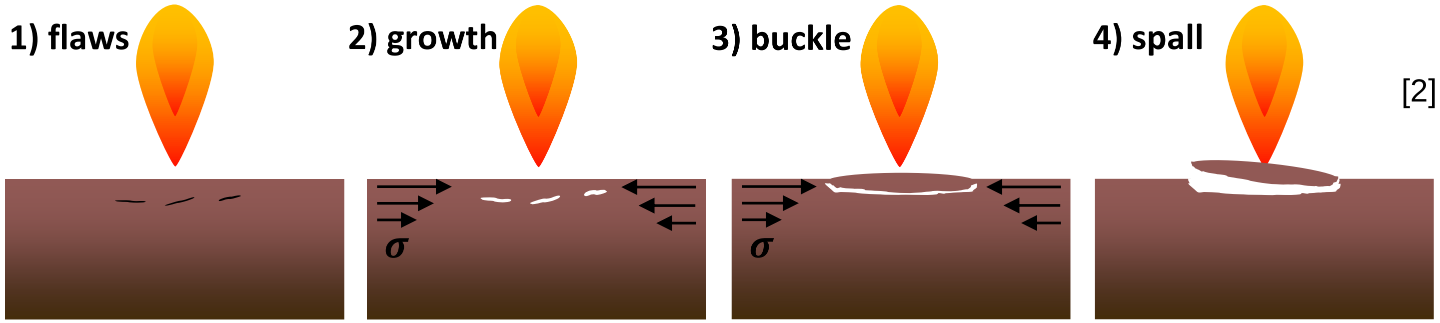
Spallation Process, the basis of flame-jet drilling

+ In application
+ No contact with the rock
+ Reduced drill bit wear and trip time
+ High penetration rates (16m/h[1])
+ Spallability ~ (Drillability)$^{-1}$

→ **Reduction of drilling costs**

– Difficulties to flush the cuttings in a low density environment (e.g. air)
– Bad performance in soft rocks
– Controlling of drilling direction



[2]

[1] J. A. Browning, W. B. Horton, and H. L. Hartman – Recent advances in flame jet working of minerals. In Proceeding Annual Symposium on Rock Mechanics
[2] M. A. Kant, P. Rudolf von Rohr – Minimal Required Boundary Conditions for the Thermal Spallation Process, Int. Journ. of Rock Mech. and Mining Science, 2016

Simulating the downhole conditions of a deep well

- **Water-based drilling fluid**
  - Transport of cuttings
  - Borehole stability
  - Cooling and lubrication
- High pressure
- Aqueous environment

Challenges:

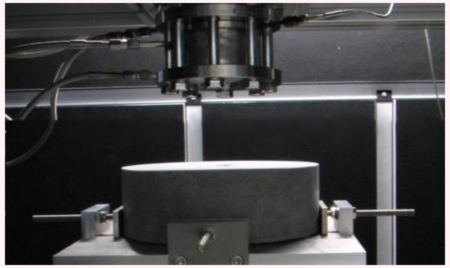
1. Ignition
2. Stable and effective combustion
3. Heat transfer to the rock
4. Optimal operating conditions
5. Rock fracturing mechanism

- **Our approach → Flames in water**
  - 20 years of experience !

Experiments in the laboratory at ambient conditions

Research facilities

Experimental setups

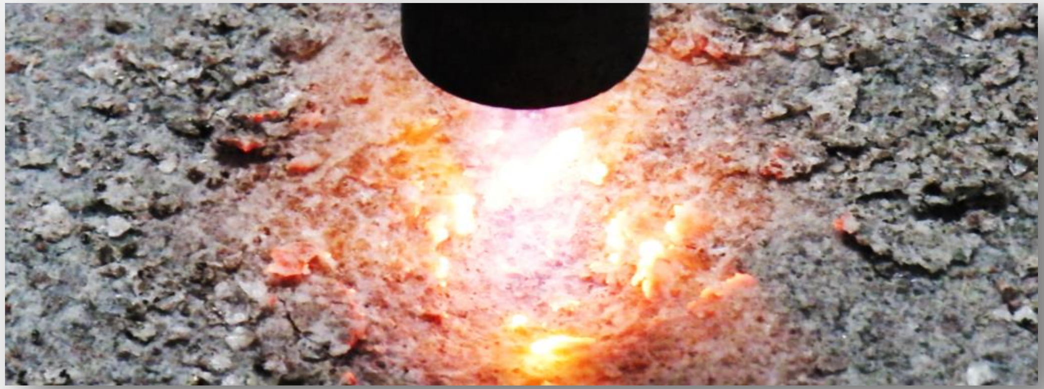
Ambient environment		Simulated downhole conditions	
L-ASDP	**S-ASDP-DRY**	**WCHB-4**	**S-ASDP-WET**
			
1 bar, 1400 °C 100 kW	1 bar, 2500 °C 30 kW	500 bar, 2000 °C 120 kW	1 bar, 2500 °C 30 kW
▪ Combustion process ▪ Heat transfer ▪ Penetration rate ▪ Parametric studies and optimization	▪ Operating conditions ▪ Rock fracturing mechanism ▪ Spallability of rocks	▪ Heat flux measurements ▪ Burner design ▪ Process optimization ▪ Drilling head design ▪ Feasibility & application	▪ Efficient nozzle design ▪ Drilling under realistic conditions ▪ Testing of hybrid systems

Scientific topics on the research of spallation drilling

Flame Operating Conditions

Hybrid-Drilling

Direction Controlling



Ignition and operation of flames in water

Safety Considerations

Nozzle-Design

Transport of the fluids

Spallability Rock Properties

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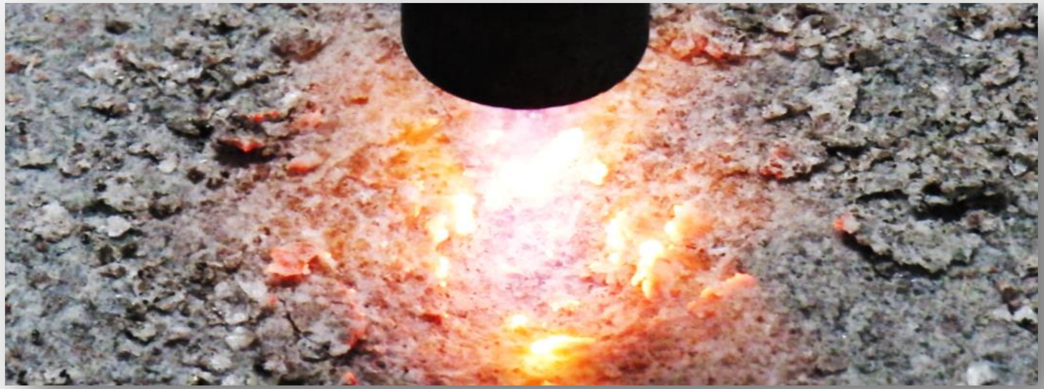

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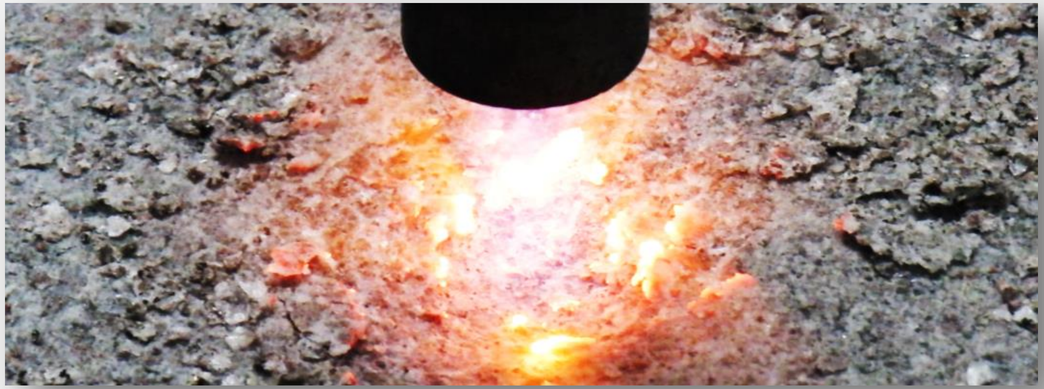

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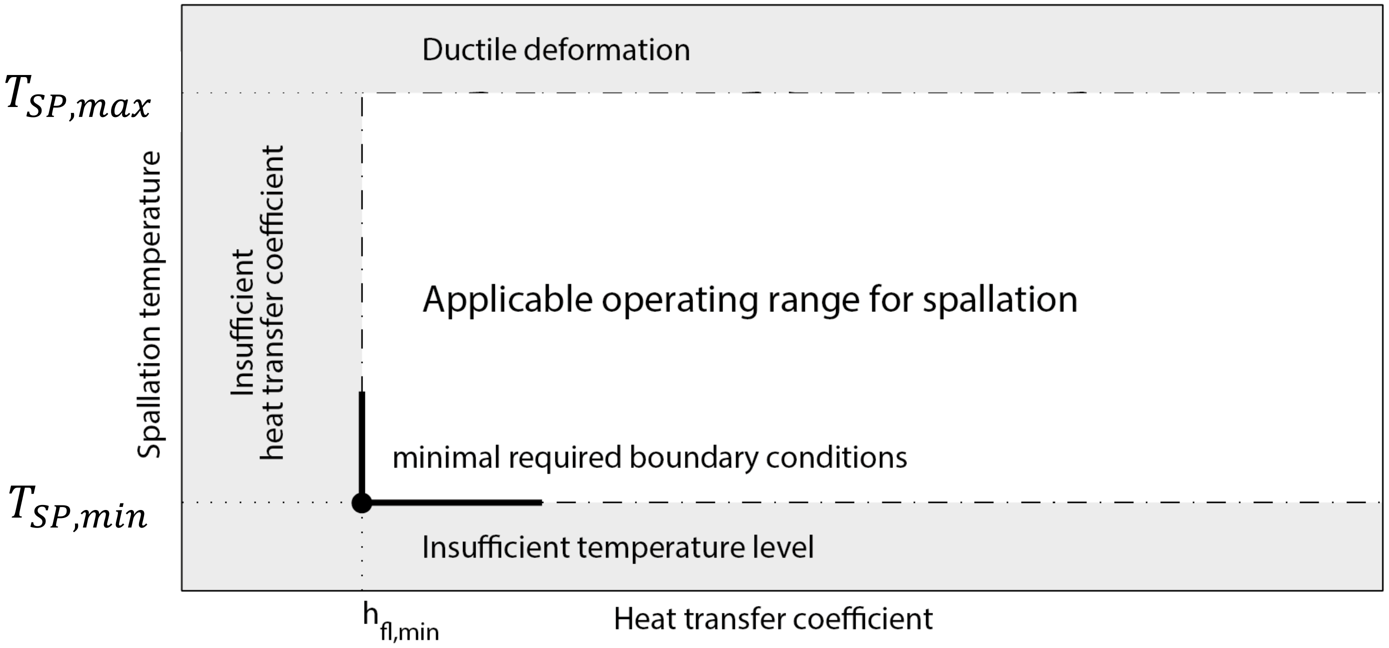
Spallability Rock Properties

Operating range of the flame-jet drilling process

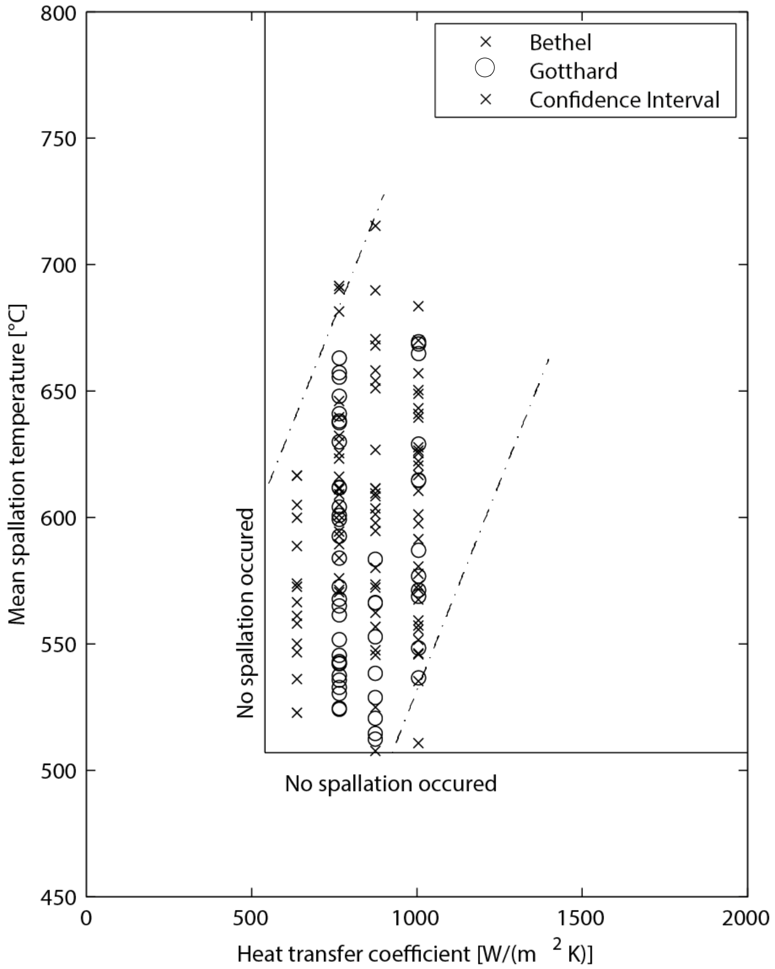
- Limits the applicable operating conditions
- Ductile deformation or melting
  - Property of the rock
  - Approx. 1000°C
- Insufficient temperature level
  - No cracking
- Insufficient heat transfer
  - Global cracking
- Minimal operating conditions
  - Experimental investigation required



M. A. Kant, P. Rudolf von Rohr – Minimal Required Boundary Conditions for the Thermal Spallation Process, Int. Journ. of Rock Mech. and Mining Science, 2016

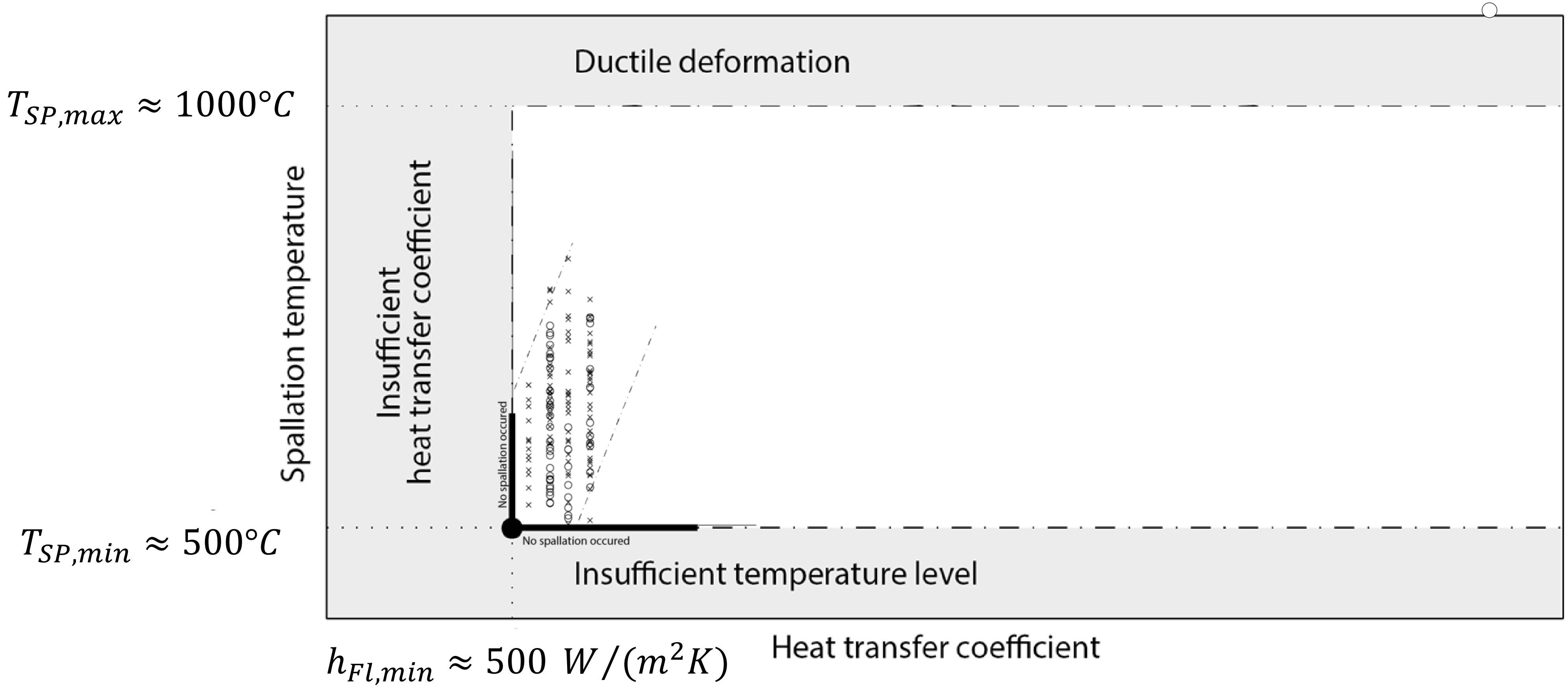
Determination of the minimal required boundary conditions

- Experiments at ambient conditions
- Rock samples
  - Gotthard Granite, Switzerland
  - Bethel Granite, USA
- Increase of the distance until no spallation occurred
- Surface temperature
  - 2 high-speed pyrometer (1000Hz)
  - Emissivity calibration required
- Heat transfer coefficient
  - Commercially available heat flux sensor
  - Or Inverse Techniques [1]



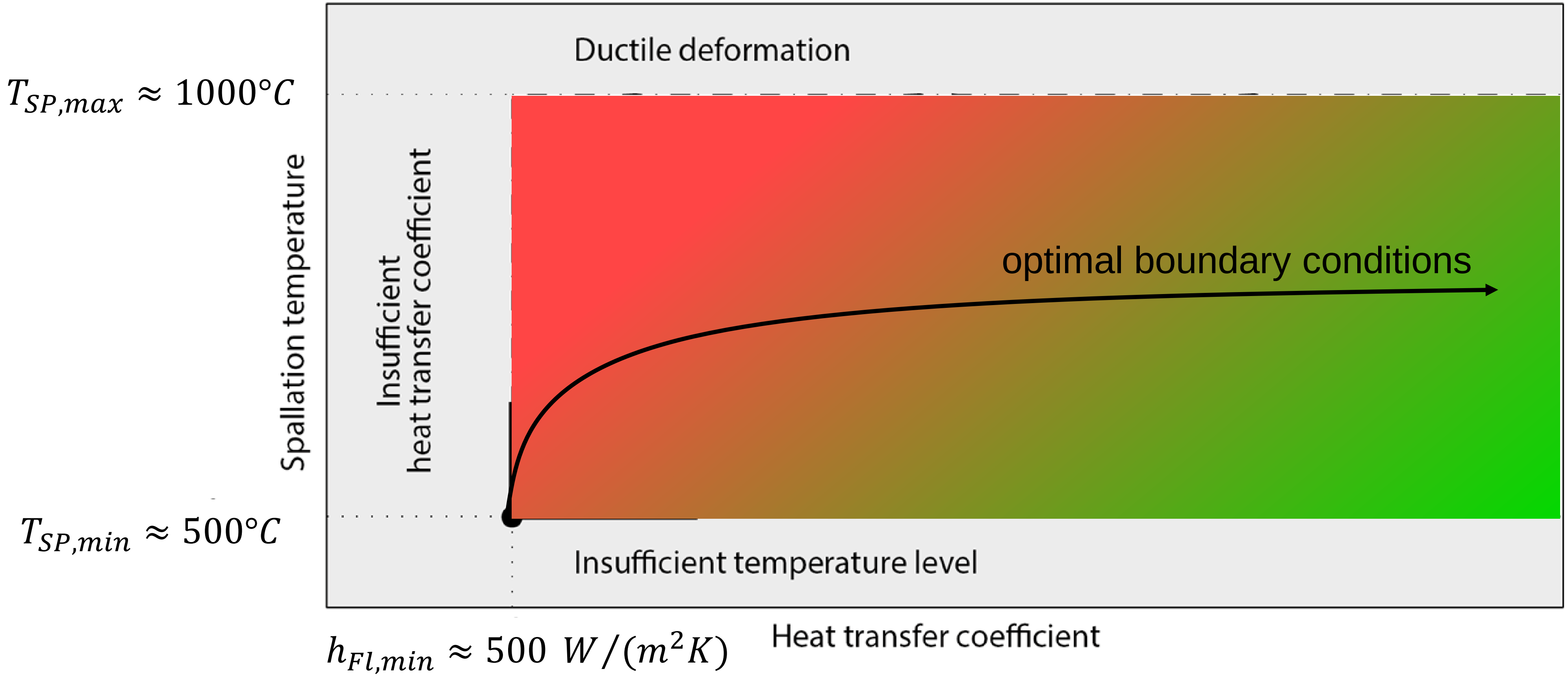
M. A. Kant, P. Rudolf von Rohr – Minimal Required Boundary Conditions for the Thermal Spallation Process, Int. Journ. of Rock Mech. and Mining Science, 2016
[1] M. A. Kant, P. Rudolf von Rohr - Determination of surface heat flux distributions by using surface temperature measurements and applying inverse techniques, Int. Journal of Heat and Mass Transfer, accepted, in press, 2016

Determination of the minimal required boundary conditions



M. A. Kant, P. Rudolf von Rohr – Minimal Required Boundary Conditions for the Thermal Spallation Process, Int. Journ. of Rock Mech. and Mining Science, 2016

Optimal boundary conditions



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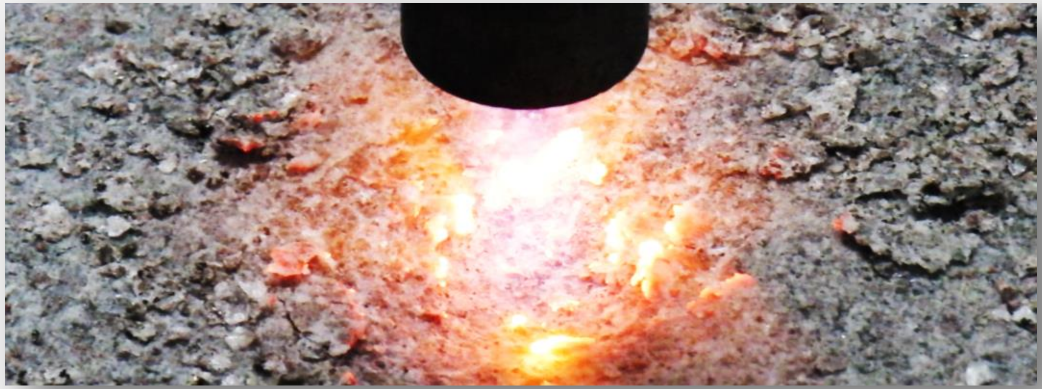
Scientific topics on the research of spallation drilling

Flame Operating Conditions

Hybrid-Drilling

Direction Controlling



Ignition and operation of flames in water

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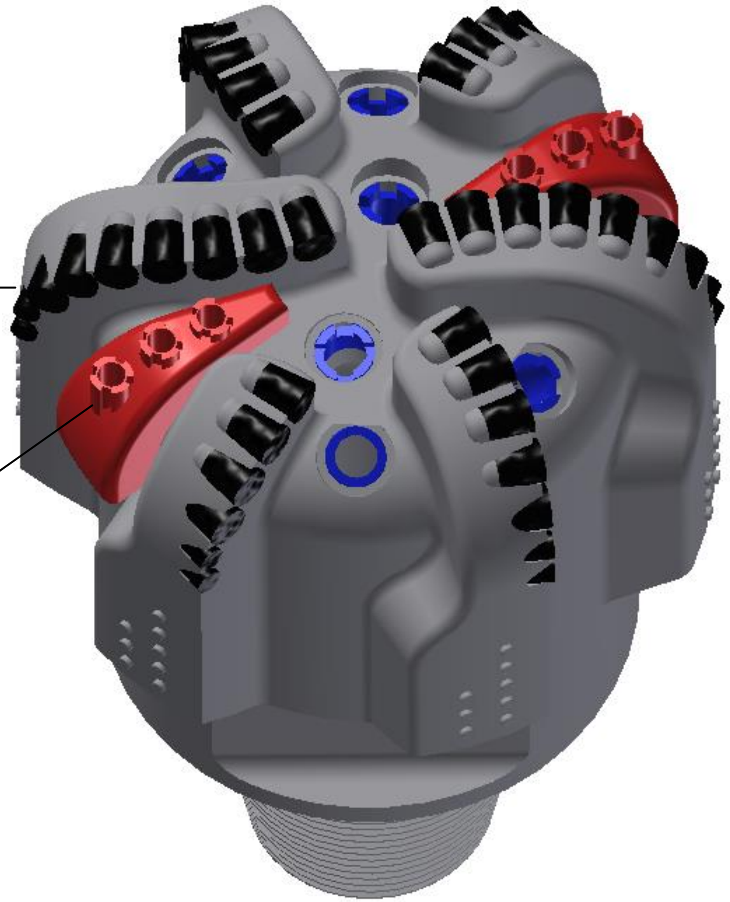
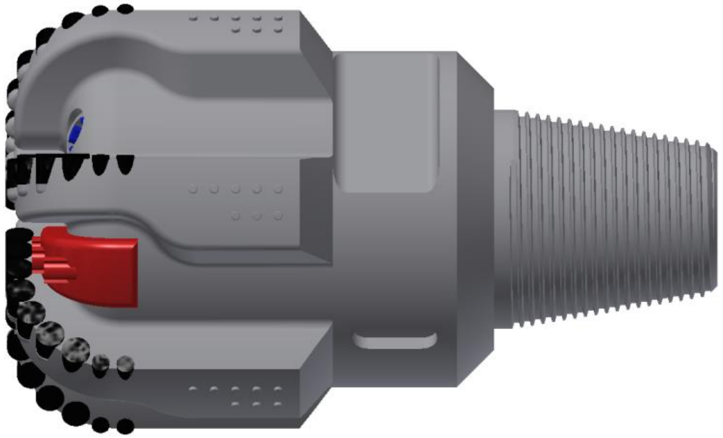
Hybrid Drilling:
Combining conventional and spallation drilling

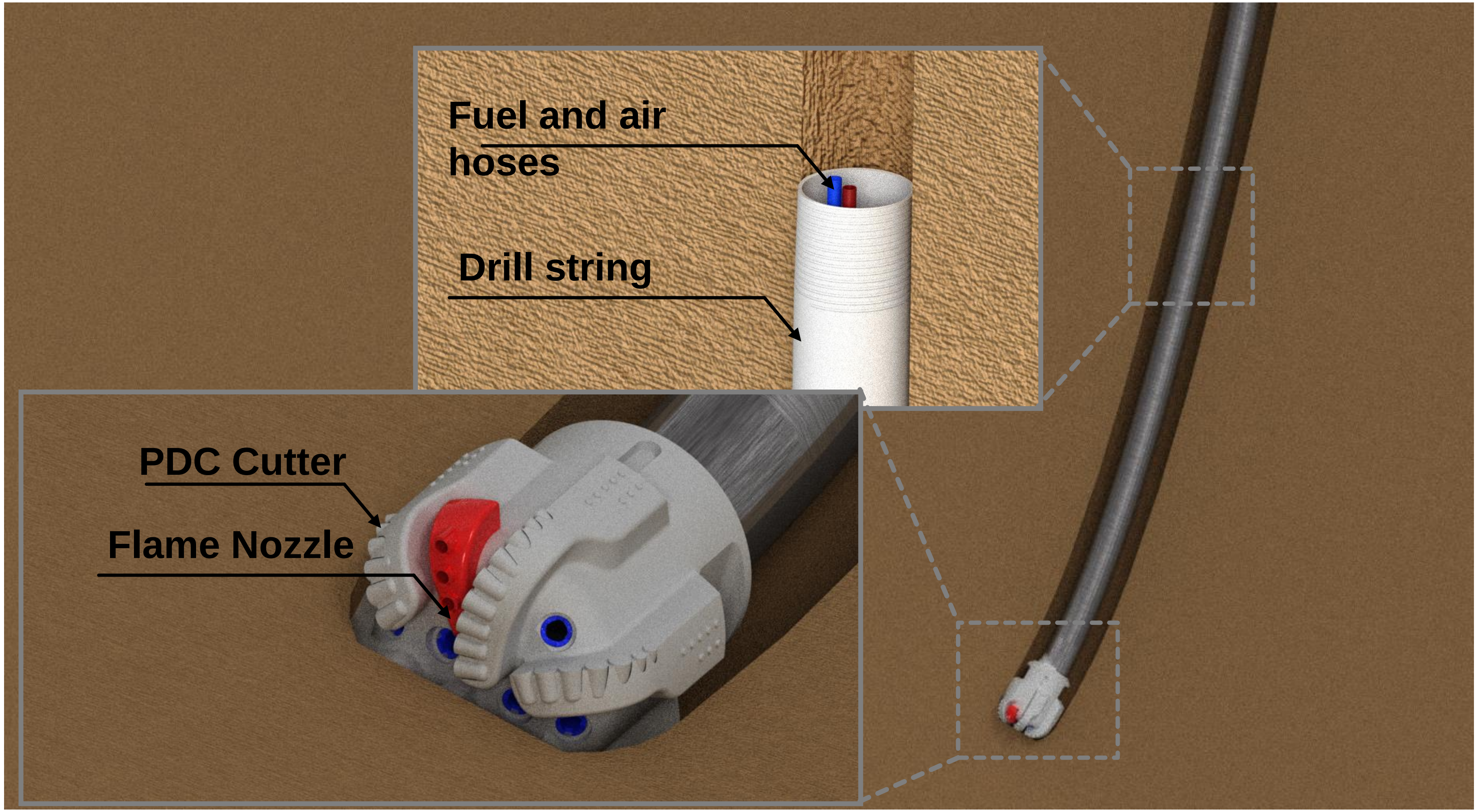




Features of Hybrid Spallation Drilling

- Synergy of conventional and spallation technology
- Significant reduction of WOB and torque
- Enhances the applicability of PDC cutters for hard rock drilling
- Smoothens rock strength for drilling in alternating geological formations
- Reduction of drilling vibrations due to smoother drilling
  - Less wear rate, reduced tripping times

Possible implementation of a hybrid drill head

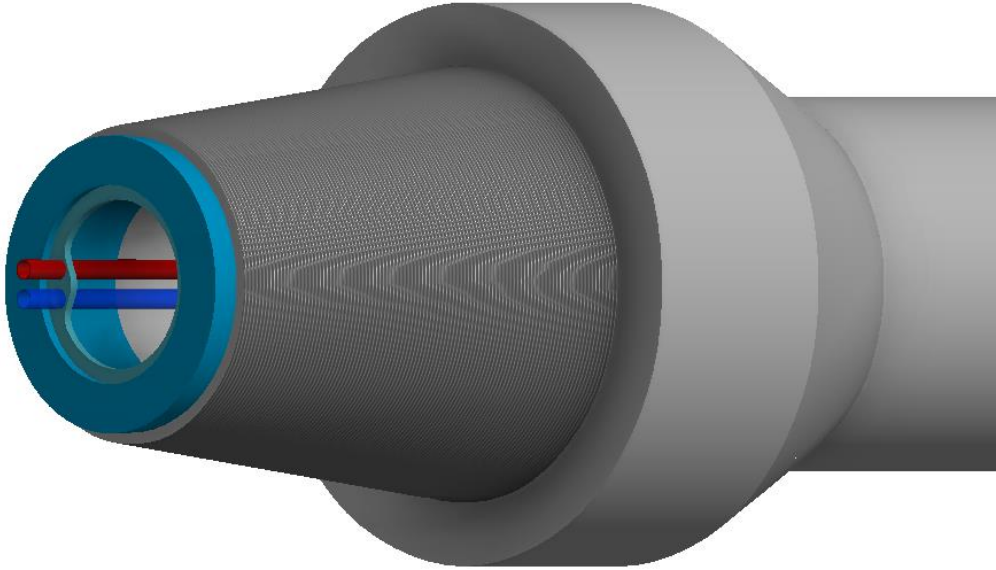


Implementation Challenges:

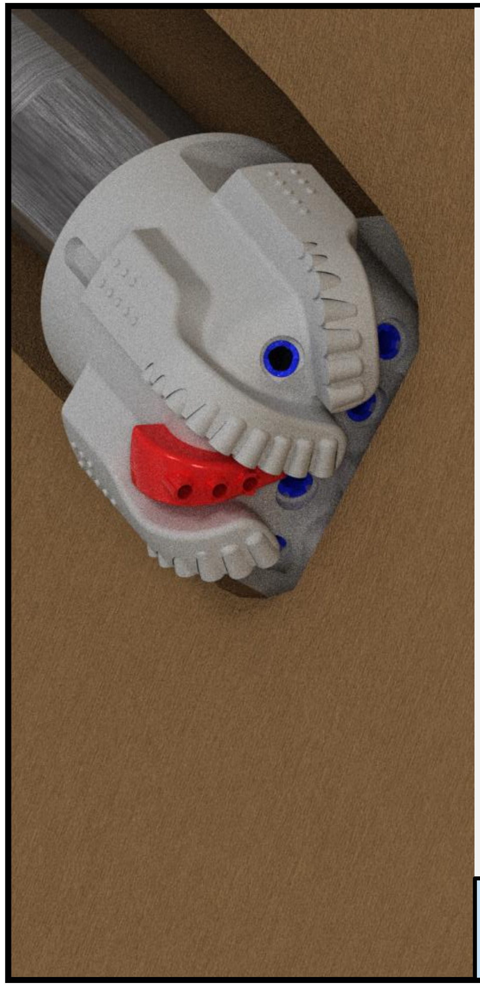
- Drill string configuration
  - Coiled tube drilling
  - Conventional drill string with integrated piping

- Safe and stable ignition
  - Re-ignition
  - Flame monitoring
  - Permanent Ignition

- Safety aspects



Roadmap – Hybrid Drilling



Step 1

Preliminary Design of the Hybrid Head:
- Required flame properties
- Flame treatment zone
- Ignition

Step 2

30m Drilling Tests in Grimsel:
- Stand-alone spallation
- Water-flushing
- High drilling velocities

Step 3

Hybrid drill head
- Manufacturing
- Testing
- Drill string

Step 4

Field test

2016 → **2017**

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Thank you for your attention !