Lithium from Deep Geothermal Fluids

Chances and Challenges of a Domestic Production

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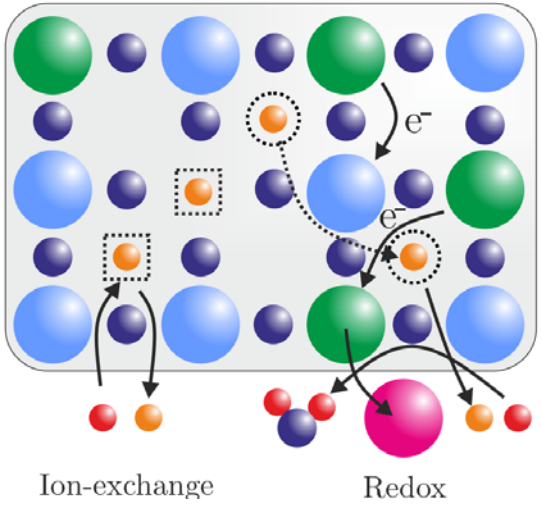
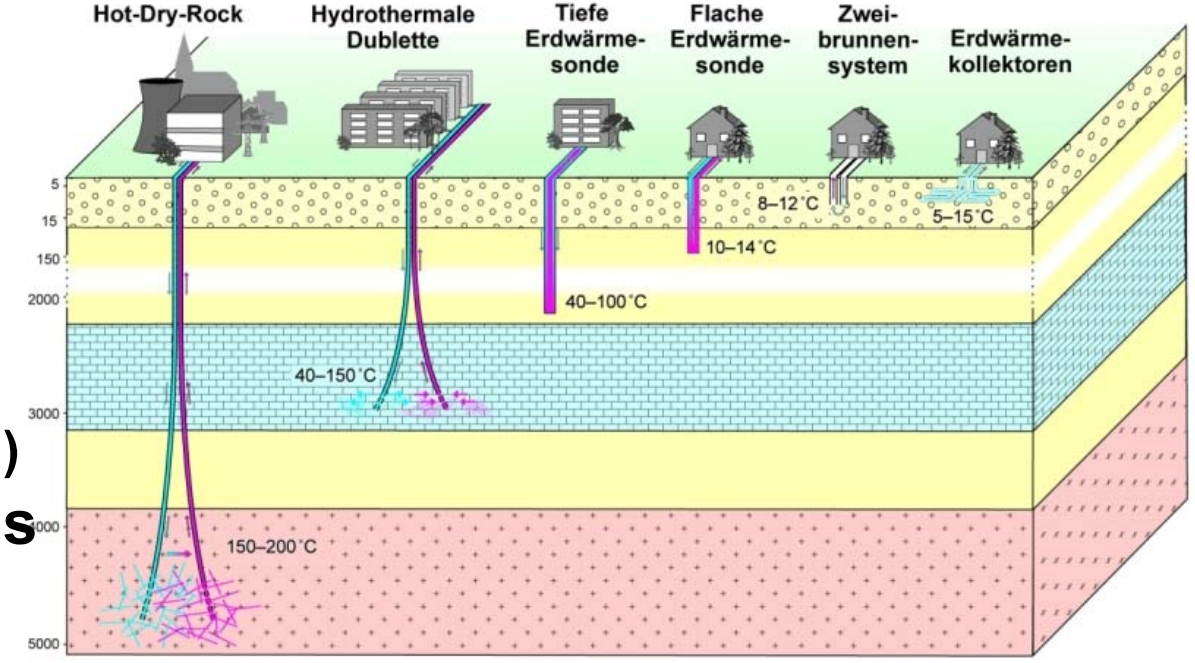


Geothermal energy use
Central Europe

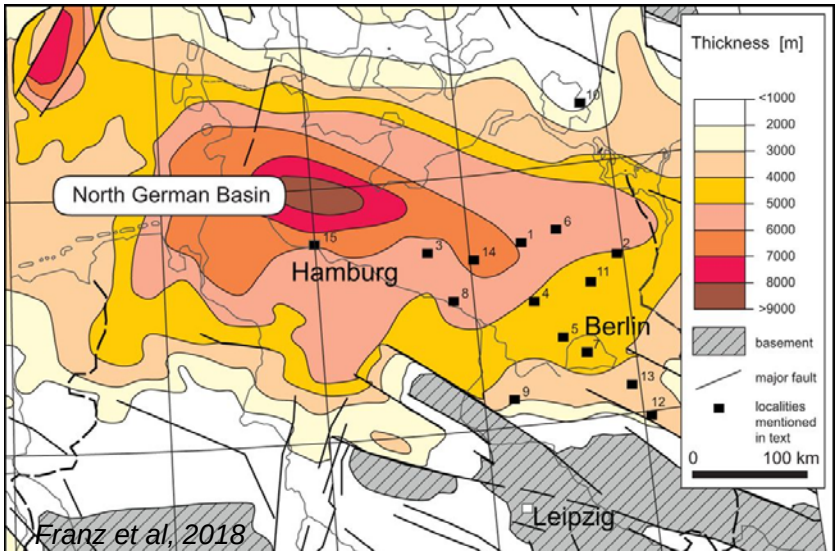
- Shallow geothermal use
  - In Germany <400m depth (≤20°)
  - Mostly closed system
  - Heat pumps (Buildings)
- **Hydrothermal systems**
  - **Open doublets in aquifers**
  - **In URG reaching 4000m depth**
  - **District heating/electricity (<200°C)**
- **Enhanced Geothermal Systems**
  - **Open doublets**
  - **Underlying crystalline basement**
  - **Electricity production (>130°C)**



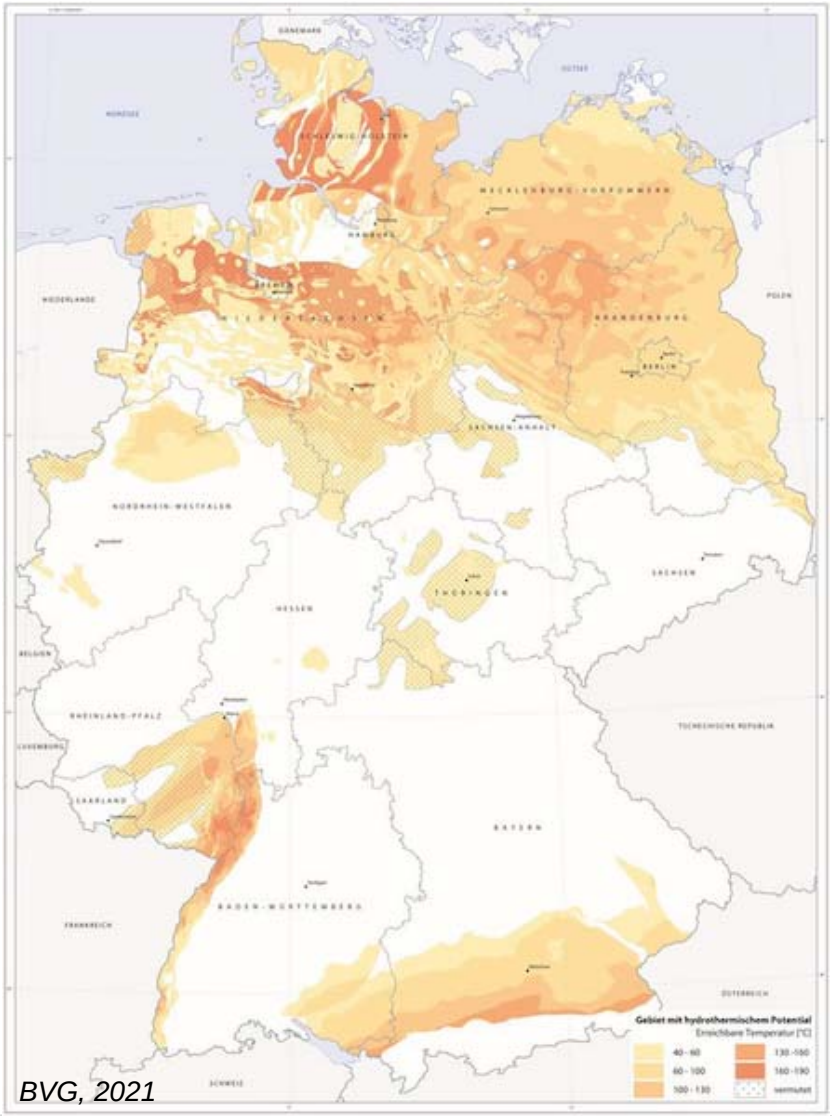
Ref: LfU Bayern

Deep Geothermal
Germany

- Three major geothermal regions
  - Molasse Basin
  - Upper Rhine Graben
  - North German Basin



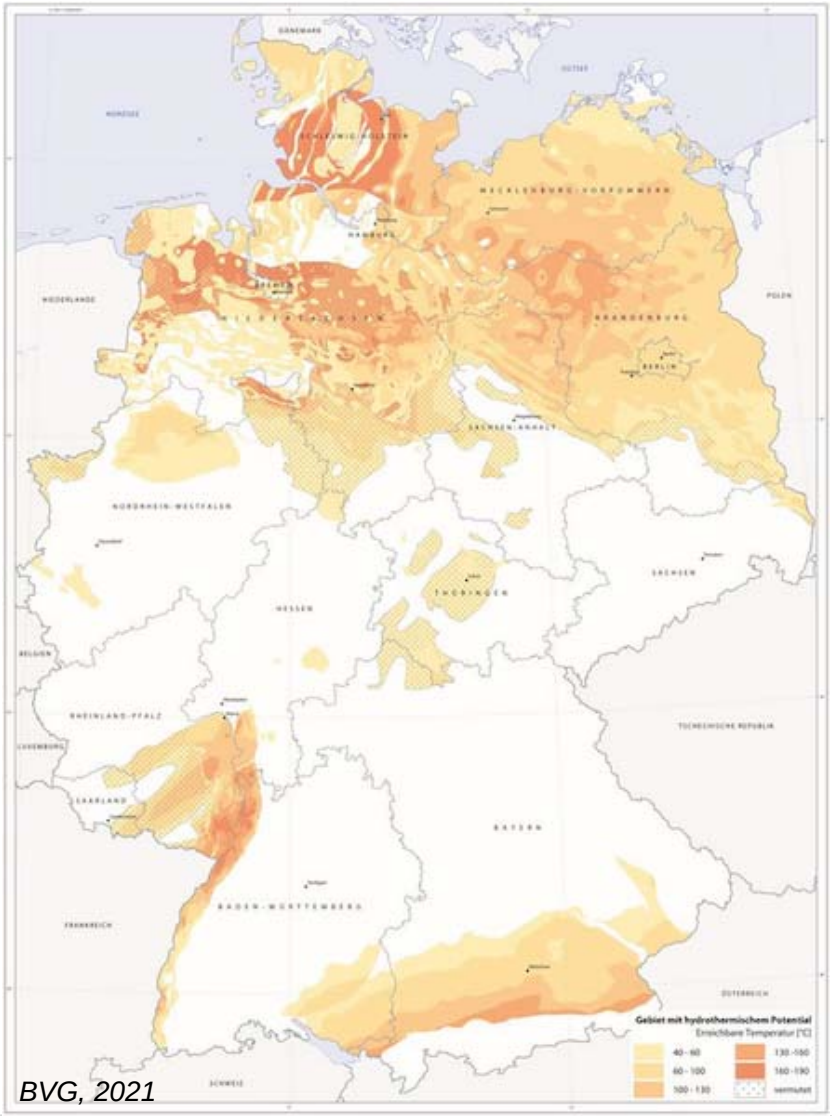
Franz et al, 2018


BVG, 2021

Deep Geothermal
Germany

- Three major geothermal regions
  - Molasse Basin
  - Upper Rhine Graben
  - North German Basin

- 42 plants in operation
  - 30 heating, 2 electricity, 10 combined
- Installed capacity
  - 417 MW_{th}
  - 46 MW_{el}



BVG, 2021

Research on geothermal lithium

The German-Chilean *Brine-Mine* Project

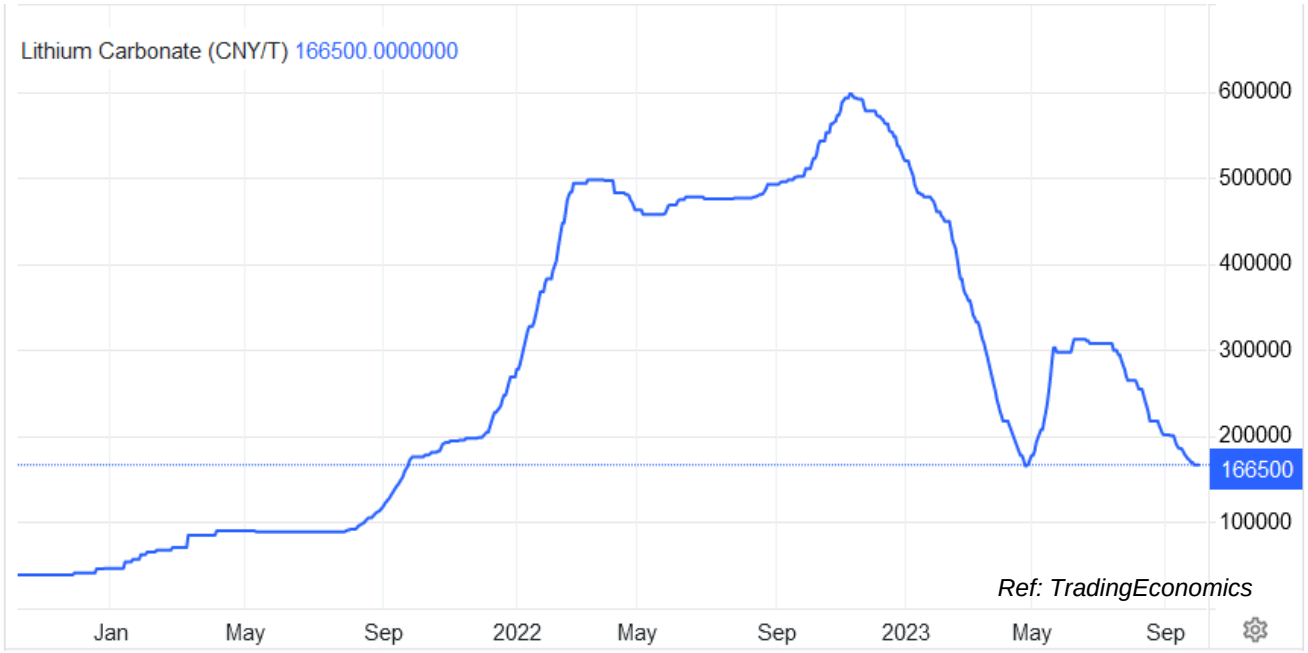
- Lithium Market
  - Resources and reserves
- Exploration
  - Finding geothermal lithium
- Extraction strategies
  - Fluid pre-treatment / concentration demonstrator
- Germany's lithium situation
  - Potentials
- Resource long-term assessment

Geothermal lithium
A productive research topic

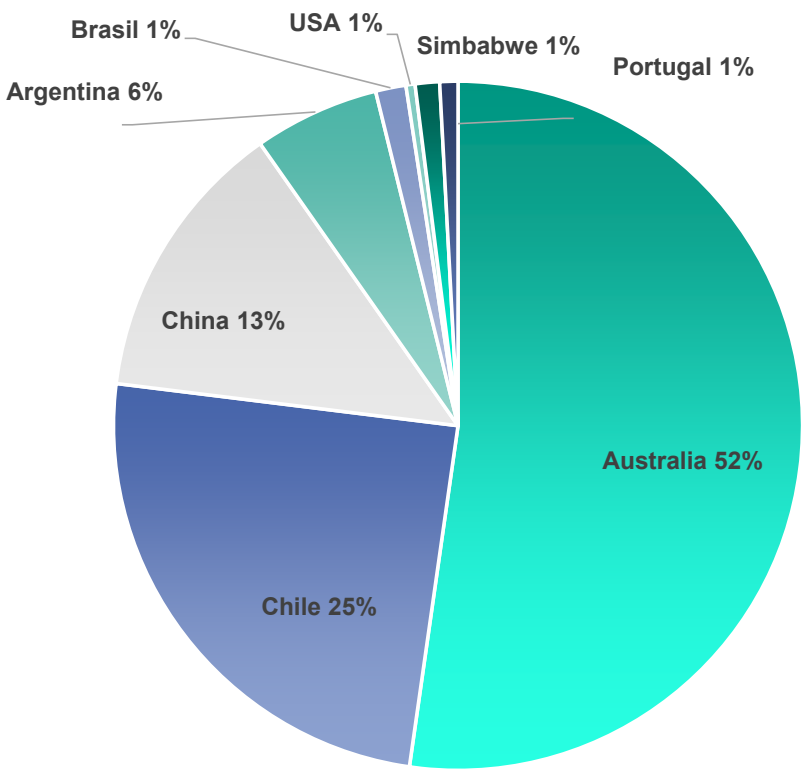
- Scientific publication
  - 9x high-ranked peer-reviewed paper since 2021
- Communication to stakeholders
  - >500 articles in press (print and online) in 2023 alone
  - Frequent expert guests in TV and radio
  - Consulting to authorities and policymakers
  - Communication to the public (e.g. action groups)
- Teaching
  - 2x PhD theses (final stages)
  - 2x Master theses
  - 2x Bachelor theses
  - 4x Project studies

Lithium world market

- The EU groups Li among the most critical raw materials
  - High economic importance
  - High supply risk
- Highly volatile market
  - 600% rally 2022/2023
  - Strong loss in beginning of 2023
  - Rise is expected again with ending of China‘s economic crisis

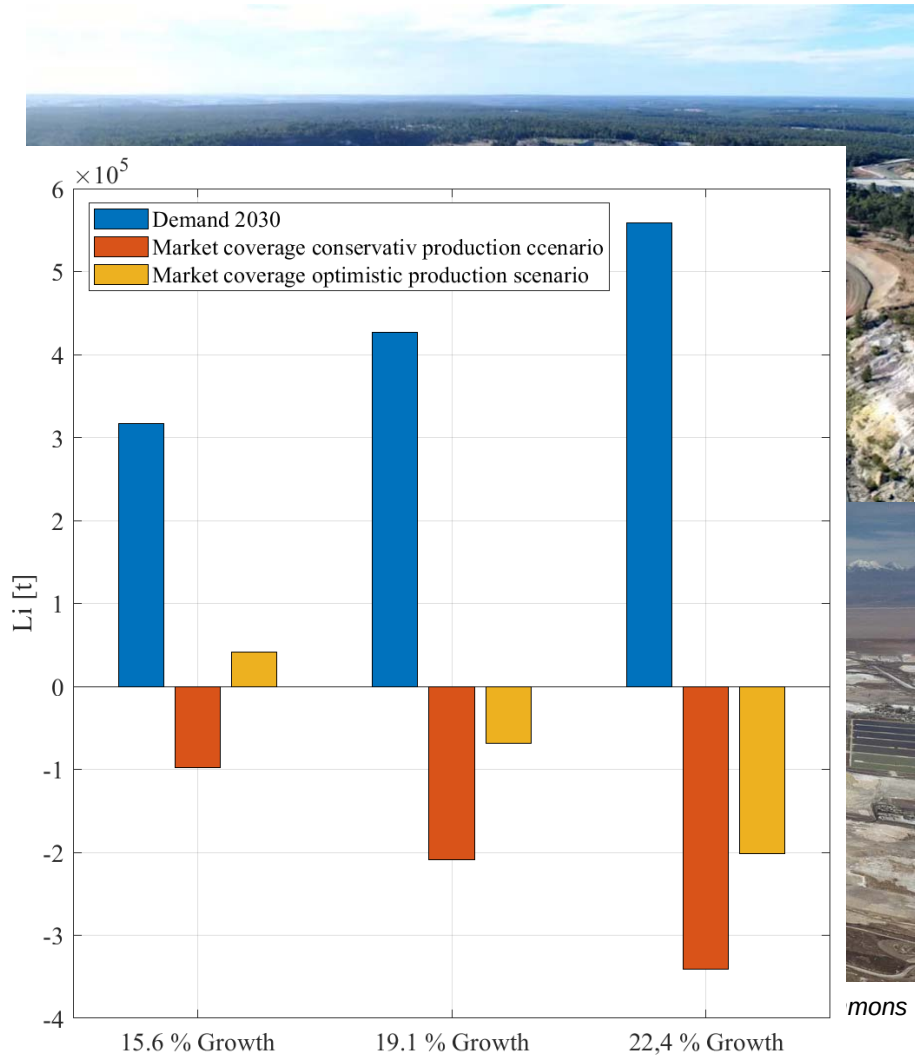


Lithium world market



2021 worldwide total: 105.250 t

Ref: Schmidt et al. 2022



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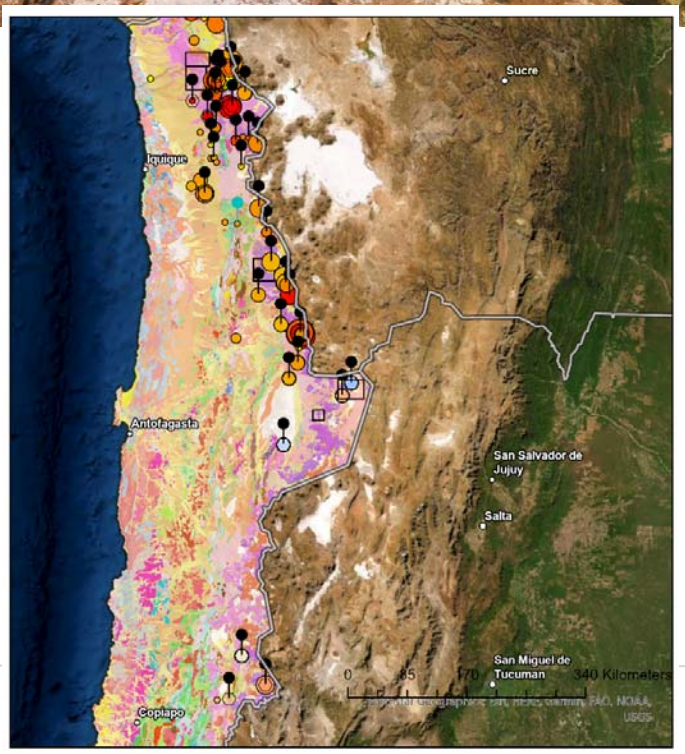
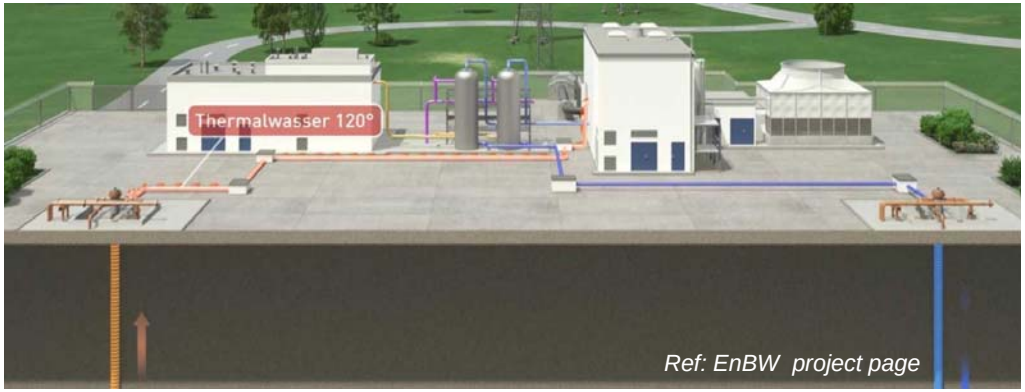
Finding geothermal Lithium
Case study: Chile

- Large scale hydro-geochemical sampling campaign
- Identification of potential target elements
- Assessment of the resources
  - Origin
  - Recharge
  - Size/volume and sustainability of the reservoir

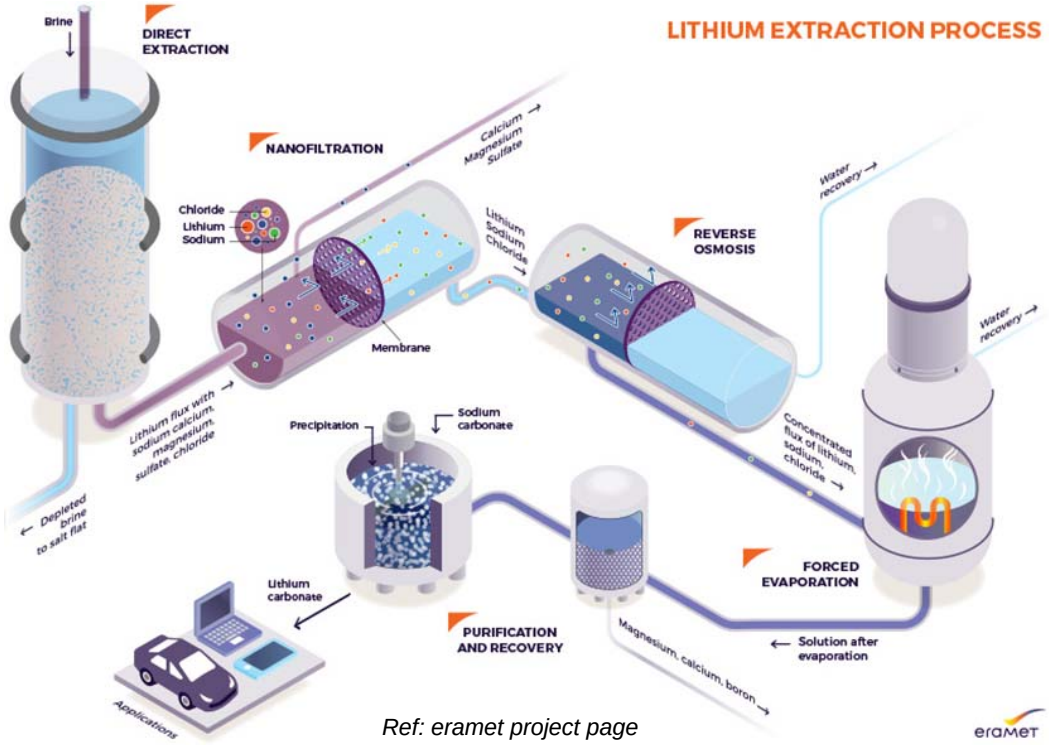


Combined energy & raw material production

- Two-stage extraction process:
- Concentration stage (on-site)
  - Selective Li extraction
  - Nanofiltration for purification/concentration
  - Reverse osmosis for water recycling
- Refining stage (refinery)
  - Battery quality lithium



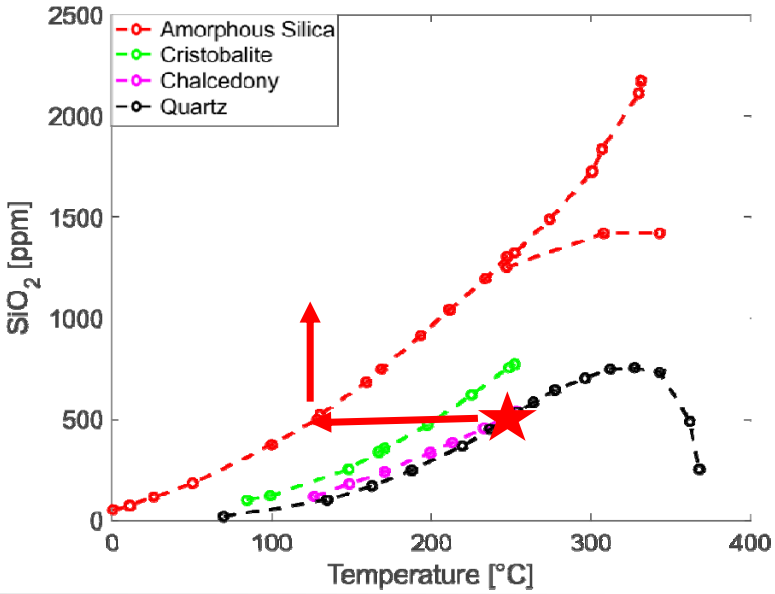
Ref: EnBW project page



Ref: eramet project page

Fluid pre-treatment
Silica scaling

- Silica (amorphous SiO_2) scaling is one of the major challenges in geothermal energy production
- Raw material coproduction increases scaling risk



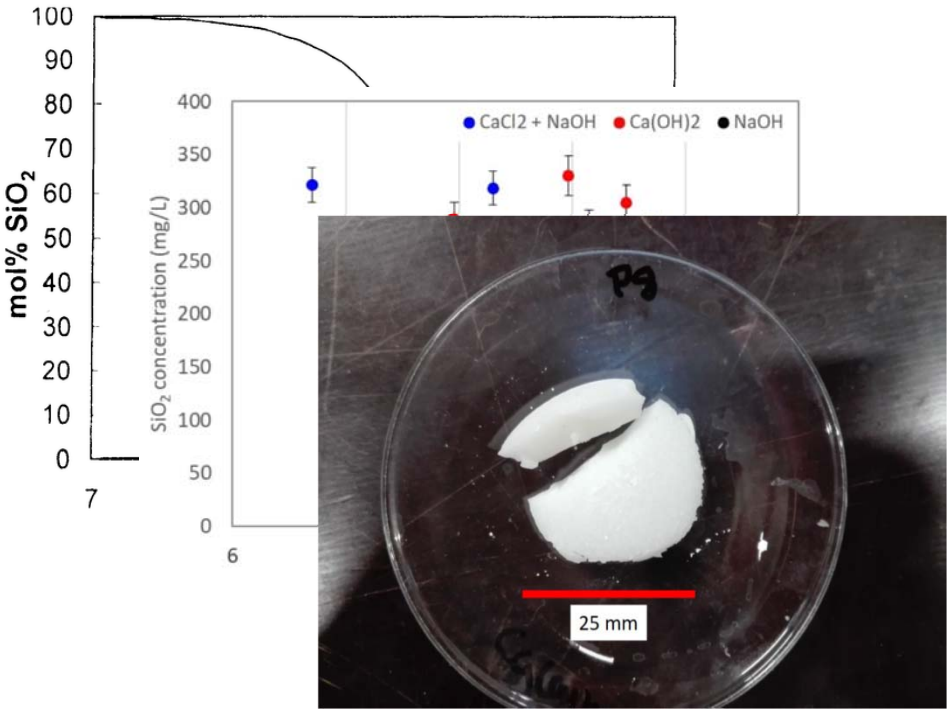
Ref: Wateronline.com

Ref: Augustinus et al. 2018

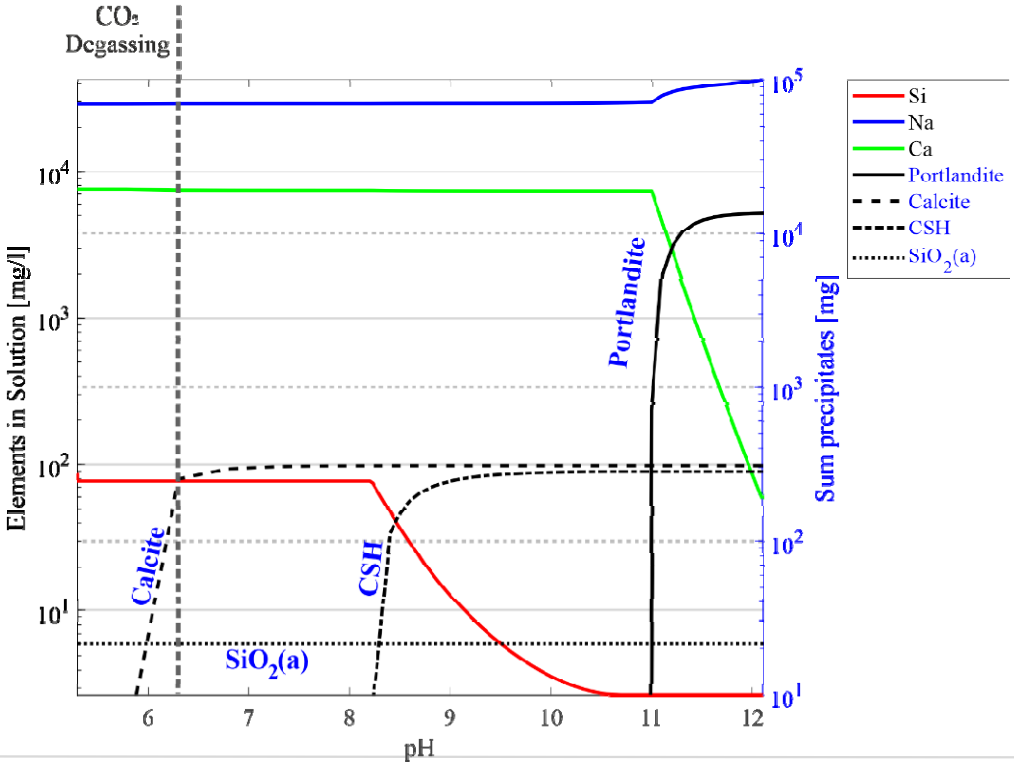
Fluid pre-treatment
Controlled silica precipitation

- Lab experiments

$SiO(OH)_3^{1-} + xOH^- + Ca^{2+} \rightarrow CaSiO_{3-x}(OH)_{2x}.yH_2O$



- Design calculation for demonstrator
  - Thermodynamic modelling

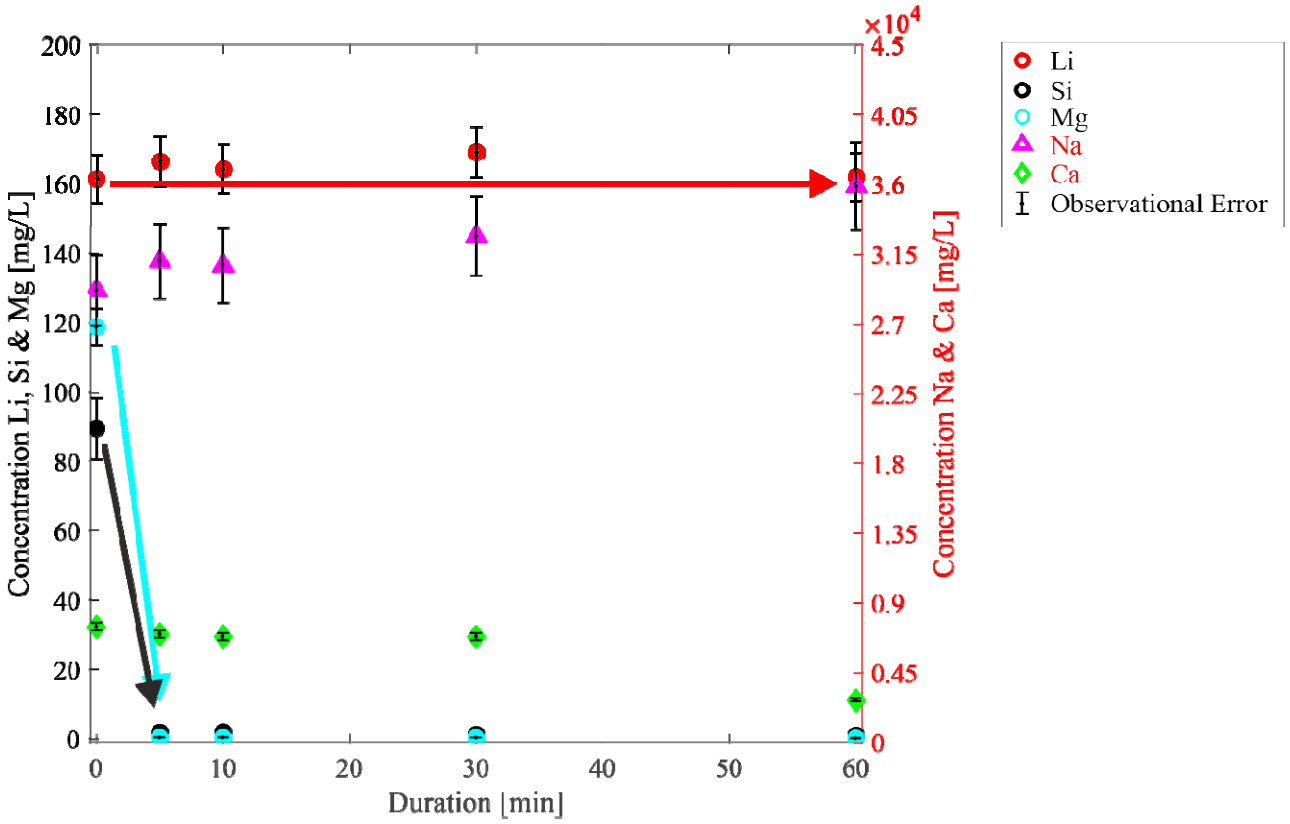


Fluid pre-treatment
Controlled silica precipitation

- Commissioning and field operations in the Insheim geothermal power plant

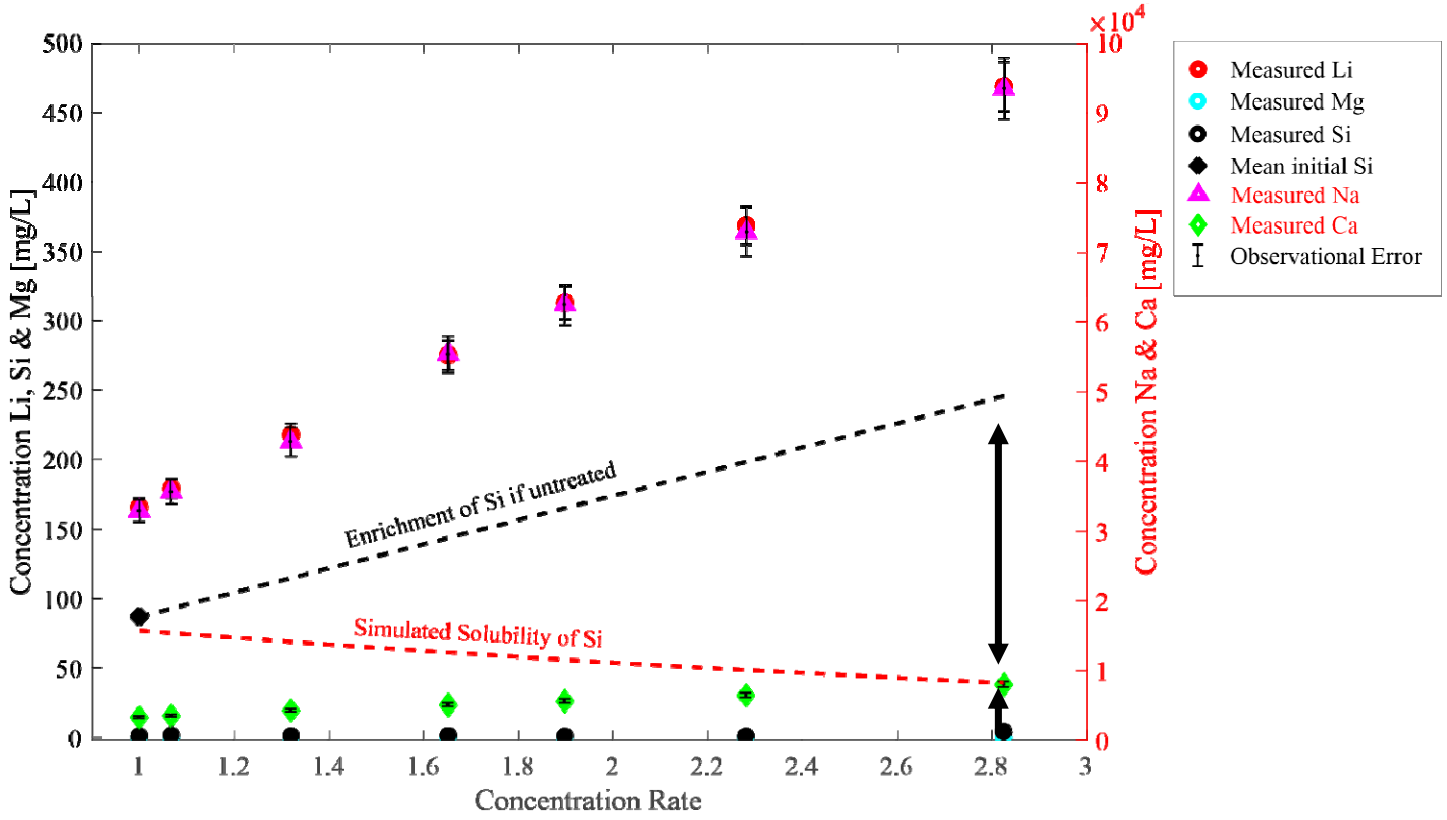
Fluid pre-treatment
Controlled silica precipitation

- Successful onsite demonstration
  - Fast and effective removal of SiO_2 (and Mg)
  - 98% reduction in less than 5 minutes
  - Lithium concentration stays unaffected



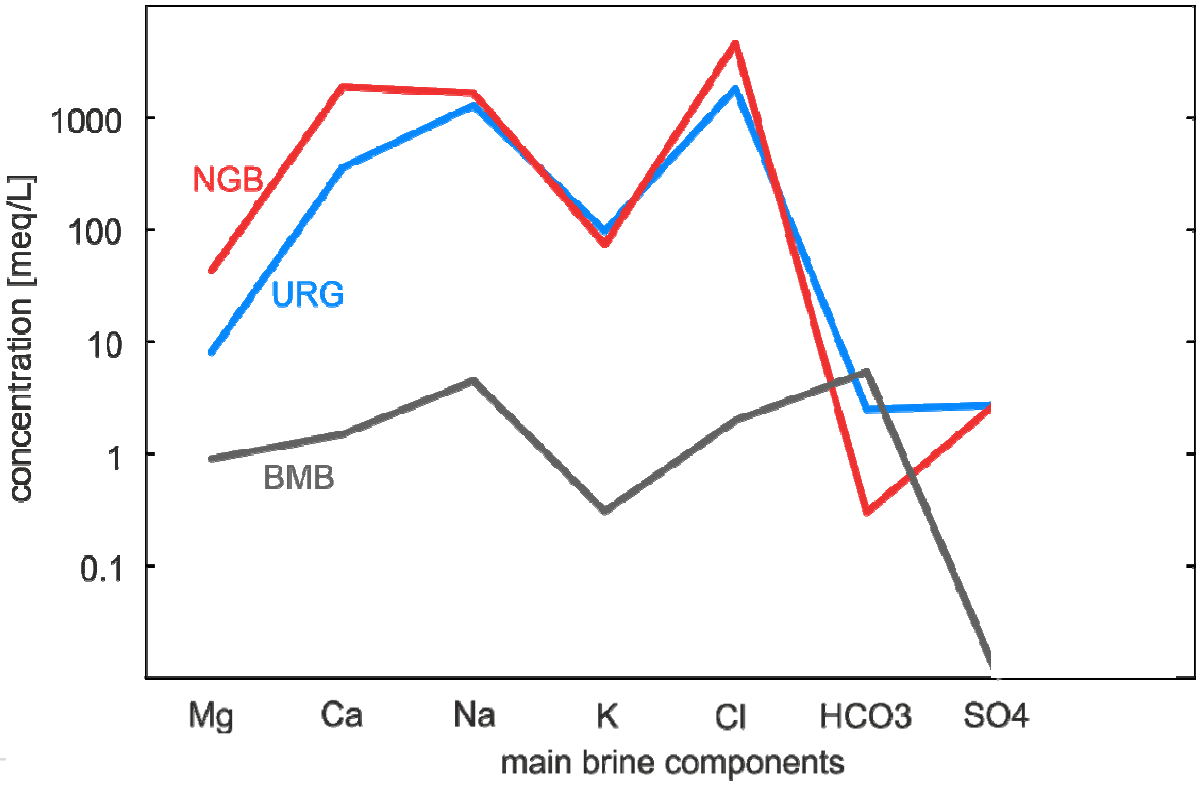
Fluid concentration
Membrane distillation

- Successful brine concentration
  - Factor ~3
- Strongly reduced Si concentration
  - Only ~4mg/L
  - Far off saturation (@60mg/L)



Geothermal lithium in Germany
Potential sites

- Different brine types in our three German systems
  - Highly saline fluids in the NGB (250 g/L) and URG (100 G/L)
  - Low mineralization in BMB (1g/L)
- Li enriched brines only in URG and NGB



Geothermal lithium in Germany
Strategic importance

- Planned domestic battery cell production
  - Initially: 55 GWh ~ 7.000 t/a Li
  - Finally: 215 GWh ~ 28.000 t/a Li
  - Up to 30% of global market (2021)
- Requirement for raw material import
  - Long-term contracts on world market strongly limits access to resources for new players
- Relevance of a domestic geothermal resources
  - Economically
  - Geo-strategically
  - Environmental impact

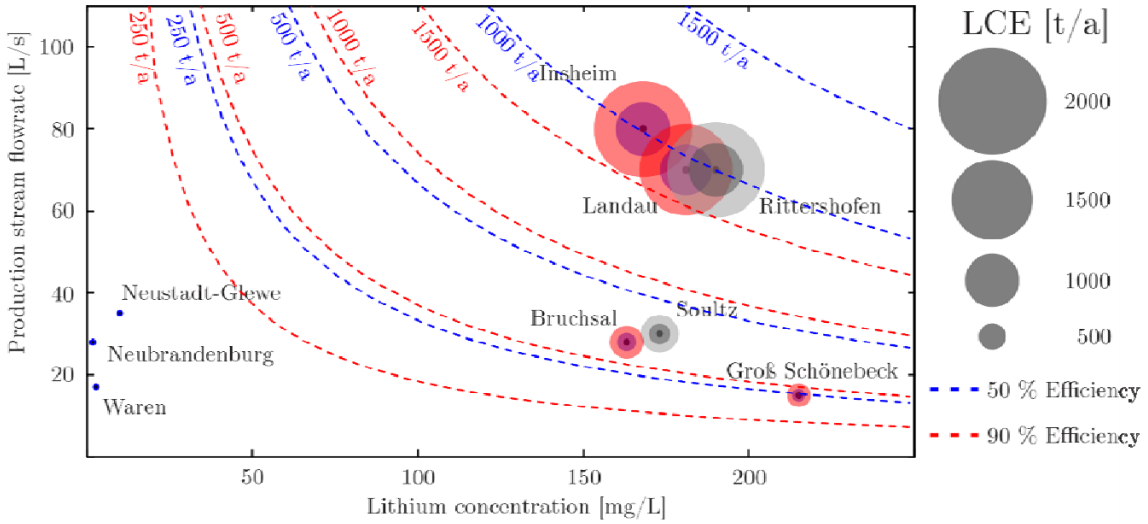
Geothermal lithium in Germany
Current potentials

- $m = Amount\ Lithium\ (LCE)\ [\frac{t}{a}]$
- $Q = Flowrate\ \left[\frac{l}{s}\right]$
- $A = Availability$:
  Assumption 90 % (329 days)
- $c = Concentration\ Lithium\ \left[\frac{mg}{l}\right]$
- $q_Q = Processable\ substream$:
  Assumption 100 %
- $\varepsilon = Extraction\ efficiency$:
  Assumption 50 – 90 %

Circulated brine per year

$$m = \overbrace{Q \cdot A}^{} \cdot c \cdot q_Q \cdot \varepsilon$$

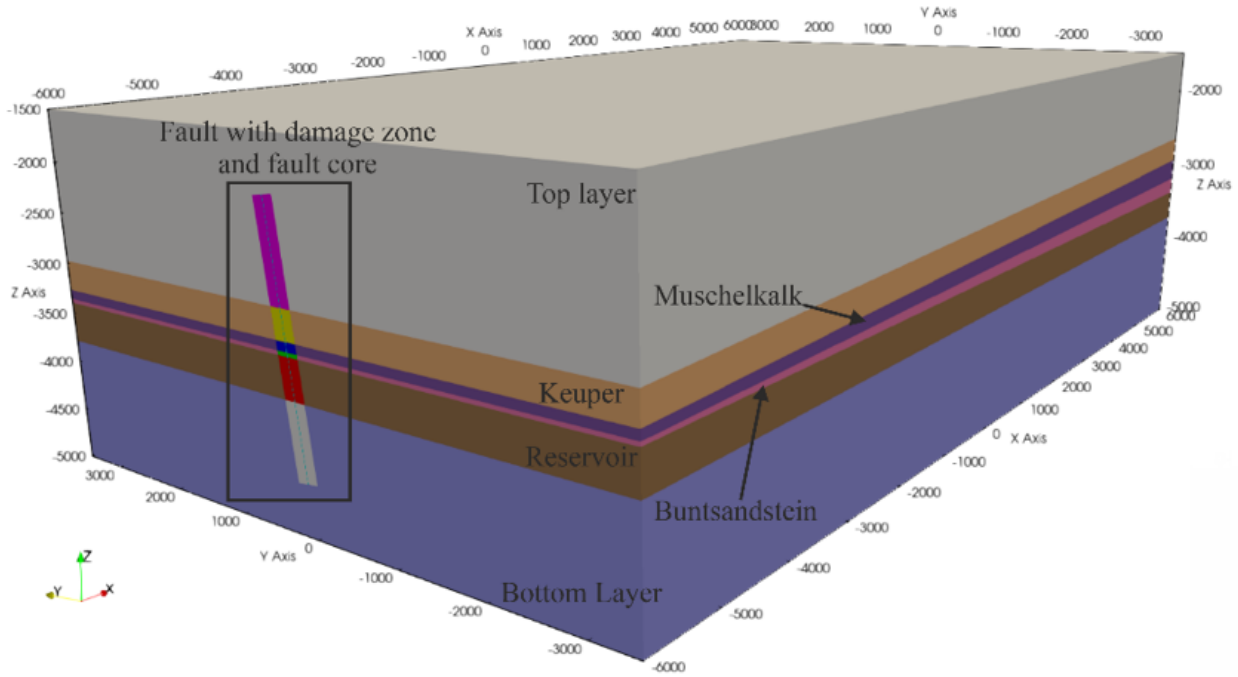
Total available Lithium amount

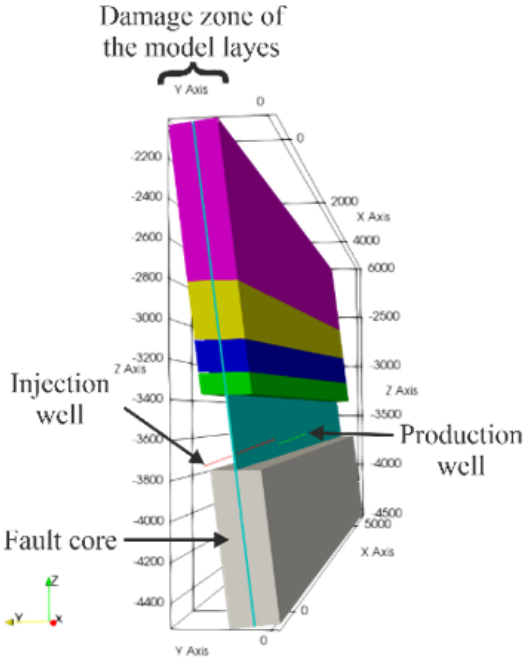


- Potential of geothermal lithium from currently existing plants:
  - 2 – 12 % German market (prognosis 2025)
  - Ca. 50.000 – 90.000 electric vehicles per annum
- Upscaling: More access to the reservoirs is required
  - Increase number of boreholes
  - Faster development of geothermal

Geothermal lithium in Germany
Resource longterm assessment

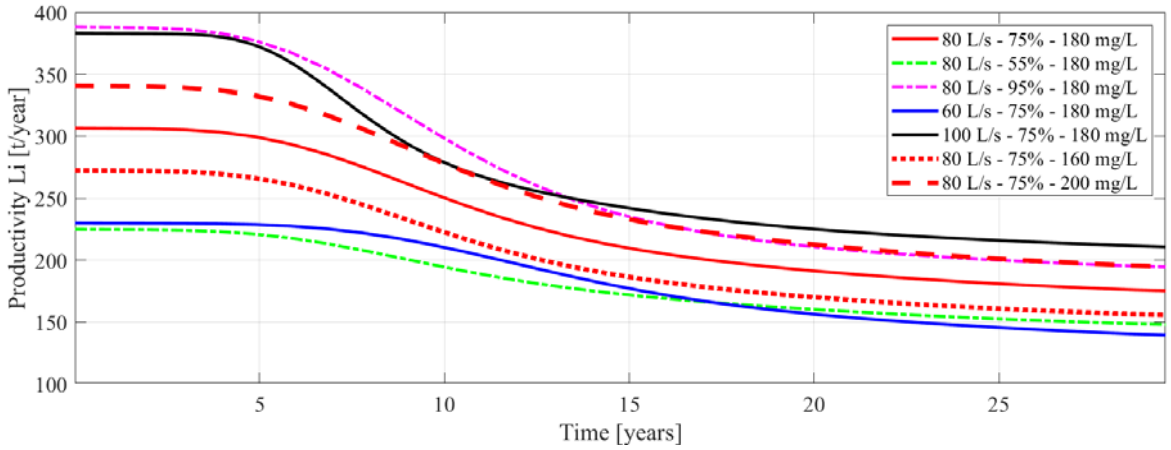
- Assessment of lithium depletion of the fluid over time due to extraction
- Conventional hard rock mining concepts are not viable
- Coupled reactive thermo-hydraulic-chemical transport models are needed

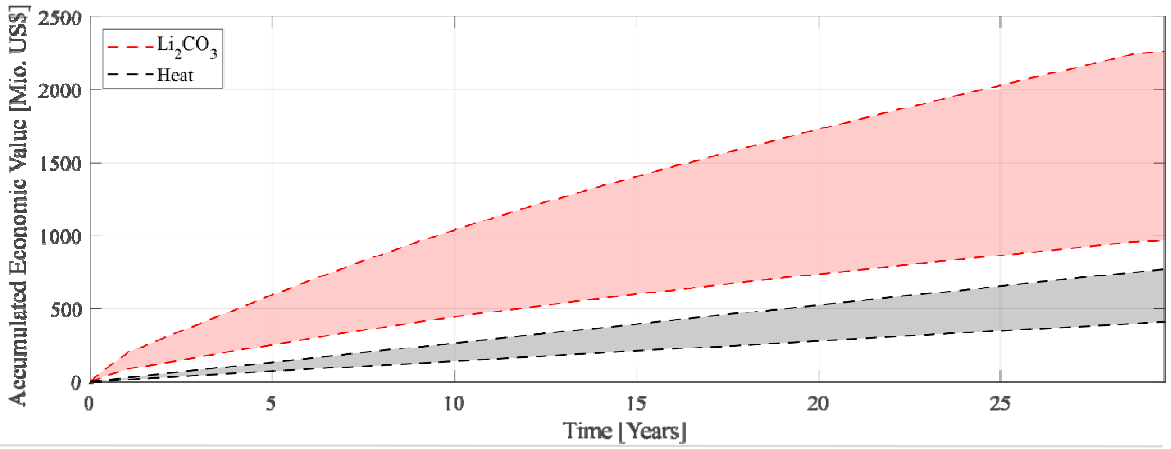




Geothermal lithium in Germany
Resource longterm assessment

- Model ensemble parameters:
  - Extraction Efficiency: 55 – 75 %
  - Flowrate 60 – 100 L/s
  - Li Concentration: 160 – 200 mg/L
- Ensemble lithium productivity decline ranges from 30 – 50% (30a)
- Based on today's prices geothermal lithium extraction seems to be more viable than heat (excluding OpEx/ CapEx)





Conclusions

- Geothermal brines have high potentials as a domestic lithium resource
- Currently installed geothermal infrastructure could provide up to 12% of the forecasted German demand of 2025
  - Increase of production only by larger number of boreholes
  - Mutual roll-out boost for both technologies (geothermal & raw material production)
- Feasible extraction approaches exist
  - Process upscaling and power plant integration is still challenging
- Hydrochemical challenges exist (scaling)
  - Fluid pre-treatment processes have been developed and demonstrated
- Longterm behavior of reservoirs never tested
  - Modelling results are rather promising
  - Lithium origin and recharge is under investigation
- To Do
  - Determination of the catchment area

Selection of Publications

- *Spitzmüller, L.; Goldberg, V.; Held, S.; Grimmer, J.C.; Winter, D.; Genovese, M.; Koschikowski, J.; Kohl, T. (2021):* Selective silica removal in geothermal fluids: Implications for applications for geothermal power plant operation and mineral extraction. Geothermics, 95, 102141.
- *Goldberg, V.; Nitschke, F.; Kluge, T. (2022):* Herausforderungen und Chancen für die Lithiumgewinnung aus geothermalen Systemen in Deutschland – Teil 2: Potenziale und Produktionsszenarien in Deutschland. Grundwasser, 27, 261–275.
- *Goldberg, V.; Kluge, T.; Nitschke, F. (2022):* Herausforderungen und Chancen für die Lithiumgewinnung aus geothermalen Systemen in Deutschland – Teil 1: Literaturvergleich bestehender Extraktionstechnologien. Grundwasser, 27, 239–259.
- *Goldberg, V.; Winter, D.; Nitschke, F.; Held, S.; Groß, F.; Pfeiffle, D.; Uhde, J.; Morata, D; Koschikowski, J.; Kohl, T. (2023)*: Development of a silica treatment for metal extraction processes in operating geothermal plants. Accepted for Desalination.
- *Goldberg, V.; Dashti, A.; Egert, R.; Benny, B.; Kohl, T.; Nitschke, F. (2023):* Challenges and Opportunities for Lithium Extraction from Geothermal Systems in Germany. Part 3: The Return of the Extraction Brine. Under revision for Energies.