ETH zürich

Geothermal energy for baseload electricity production in Switzerland

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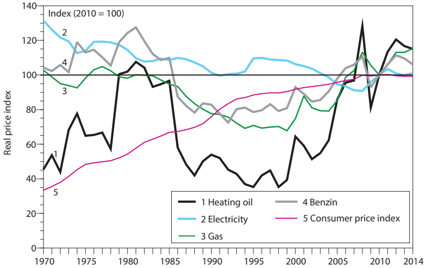
Outline

1. Motivation for the development of geothermal energy
2. Origin of geothermal energy
3. Access geothermal resources (drilling)
4. Mine the resource (hydrothermal and petrothermal systems)
5. Exploit the resource (dry steam, flash, binary cycles)
6. Advantages of geothermal energy
7. Drawbacks of geothermal energy
8. Potential of geothermal energy in Switzerland
9. Summary

Motivation (1/3)

There is a need to find alternatives to fossil fuels and nuclear power for different reasons:

- global warming (reduce CO_2 and other greenhouse gases emissions)
- fossil resources depletion & rising costs of oil and gas



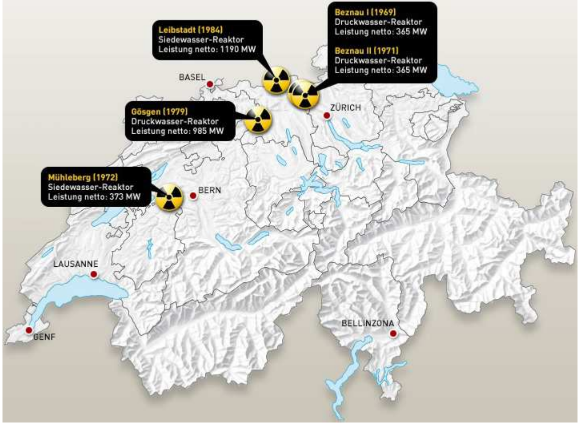
Motivation (2/3)

There is a need to find alternatives to fossil fuels and nuclear power for different reasons:

- Kyoto protocol (2005) places stringent restrictions on the CO_2 emission $\rightarrow$ disadvantages coal and promotes nuclear, wind, solar and geothermal
- Fukushima accident (2011) and decision of the Swiss Federal Council to phase-out the nuclear power plants (without strict deadlines besides for Mühleberg [1])

Motivation (3/3)

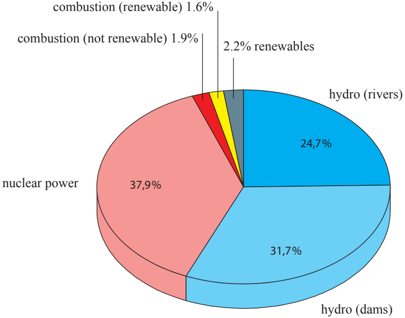
Switzerland has 5 nuclear power plants and an installed capacity of 3278 MW_e.



Motivation (3/3)

Switzerland has 5 nuclear power plants and an installed capacity of 3278 MW$_e$.

In 2014, nuclear power contributed to $\sim 40\%$ of the Swiss electricity production



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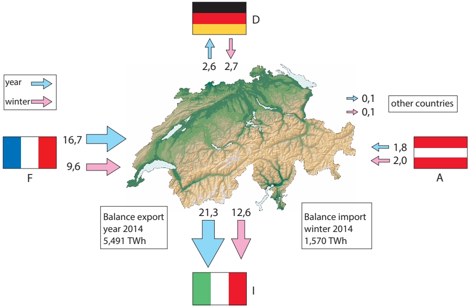
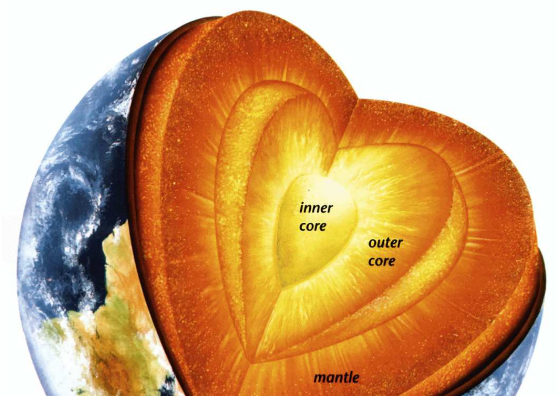


Mühleberg will go off-grid by December 20, 2019 subtracting its 373 MW_e from the grid

$\rightarrow$ how to sustain a stable electrical grid? EU or self production

Origin of geothermal energy (1/1)

1. Formation of the earth, gravitational collapse of dust / gas and latent heat of formation of the solid core.
2. Decay of radioactive elements in minerals (about 50% of the total surface heat flux) [2]



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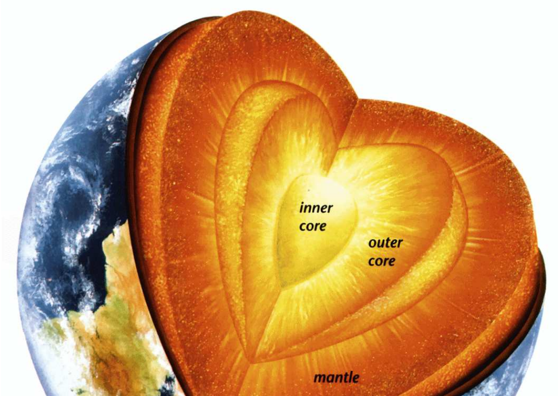

about 99 wt. % of the earth is hotter than 1000 °C → resource is in principle infinite

Access geothermal resources (1/11)

Geothermal energy is located in the underground in the form of hot water reservoirs and hot dry rocks. Accessing the resource requires drilling

Access geothermal resources (2/11)

Drill rig ITAG 23, e.g. St-Gallen:

- Iron structure which supports the **top drive**, **drill pipes** and **bottom hole assembly** is called the derrick (45 m & 590 t hook load capacity)

Access geothermal resources (3/11)

- **top-drive** ($\sim$ 750 kW & torque 75 kN m) rotates the drill string ($\sim$ 40-70 rpm), moves up and down the derrick and is driven hydraulically

Access geothermal resources (4/11)

- **drill pipe** usually 31 foot long (∼ 9 m), different grades, diameter (2” to 6 5/8”). Using a top drive, joints are pre-assembled by 3 (triple stand) and stored vertically in the pipe rack next to the **top drive**.

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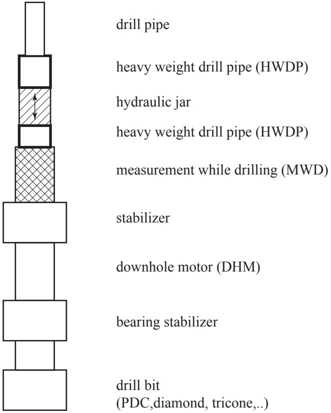
Access geothermal resources (5/11)

Bottom hole assembly (e.g. Blanc-Mesnil):

- heavy weight drill pipe (HWDP),
- hydraulic jar,
- measurement while drilling (MWD),
- stabilizer,
- mud motor,
- drill bit,



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Access geothermal resources (5/11)

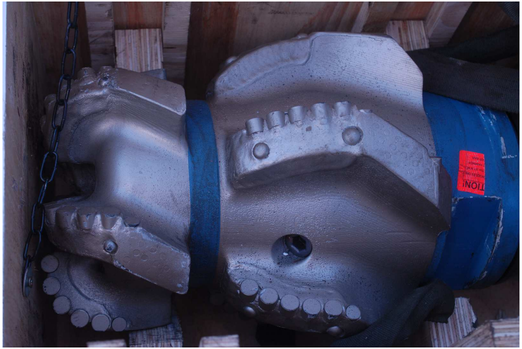
Bottom hole assembly:

- **drill bit**, tricone steel tooth (e.g. Blanc-Mesnil) or with tungsten carbide inserts, soft to very hard formations, low penetration rate 2-4 m/h, economical

Access geothermal resources (5/11)

Bottom hole assembly:

- **drill bit**, polycrystalline diamond compact (PDC), soft formations (e.g. sediments, shale), high penetration rate 6-10 m/h, expensive



Access geothermal resources (5/11)

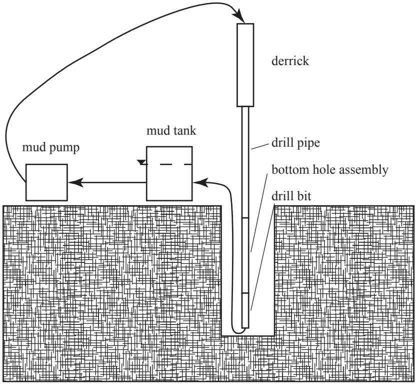
Bottom hole assembly:

- **drill bit**, coring bit (e.g. GUL), soft to very hard formations, medium penetration rate 4-6 m/h, to satisfy geologists.

Access geothermal resources (6/11)

Mud (e.g. water & additives, non-Newtonian, shear-thinning):

- **circulation loop**: mud tank → mud pump → derrick → drill pipe → BHA → drill bit → back to the mud tank.
- the mud tank level is constantly monitored to spot circulation loss or incoming fluid in the well (“kick”)
- stabilize the well, prevent infiltration, cool and lubricate the bit, transport the cuttings



Access geothermal resources (7/11)

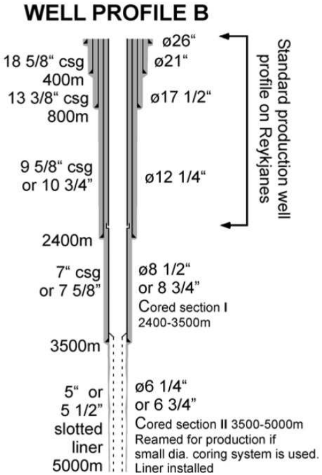
Mud (e.g. water & additives):

- triplex **mud pump** ($\sim$ 17 t, 750 kW, 140 SPM and 40 L/s to 160 bar. Typically, 2 or 3 mud pumps are used in parallel.

Access geothermal resources (8/11)

Casing and cementing:

- different casing sections (conductor, surface, intermediate and production) have different purpose (stabilize the well, prevent fresh water contamination and produce the reservoir)



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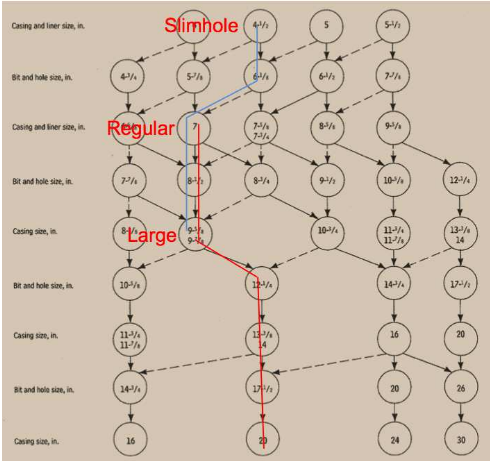
- **casing**: K-55 grade (two green lines) and **casing collar**
- **casing shoe** with check valve → guide the casing and float

Access geothermal resources (9/11)

Casing and cementing (e.g. casing program):

- regular diameter wells have a 9 5/8" production casing
- large diameter wells take about the same time to drill but cost $\sim 30\%$ more and are less stable
- large diameter wells are preferred for projects with down-hole pumps



Access geothermal resources (10/11)

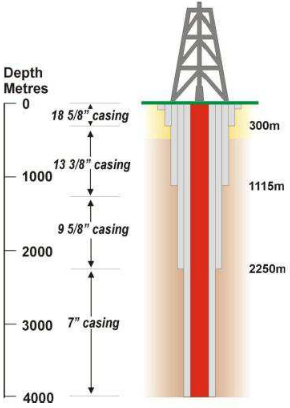
Casing and cementing:

- cementing is a time consuming (i.e. expensive) and critical operation
- once the casing is completely installed and secured, logs are run to make sure cement is dried
- finally the well is completed and the production can start start

Access geothermal resources (11/11)

Summary

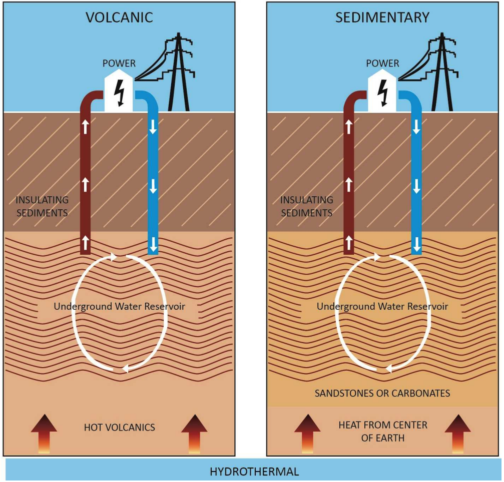
- for a rate of penetration (ROP) in the range of 5 to 10 m/h only 15% of the rig time is used for drilling and the remaining 85% is spent for: cementing, tripping, fishing, logging, coring etc.
- drilling is complex and mostly developed by oil & gas companies (i.e. for sediments)
- it remains very expensive for geothermal projects which target hot dry rock reservoirs (EGS) → **alternative drilling technique**



Mine the resource (1/4)

Hydrothermal systems

- circulation possible in the aquifer (e.g. Paris, Munich, Lardarello (IT), Iceland)
- stimulation only needed if productivity index (L/(s MPa)) is too low (Paris, Iceland).
- most of geothermal systems worldwide



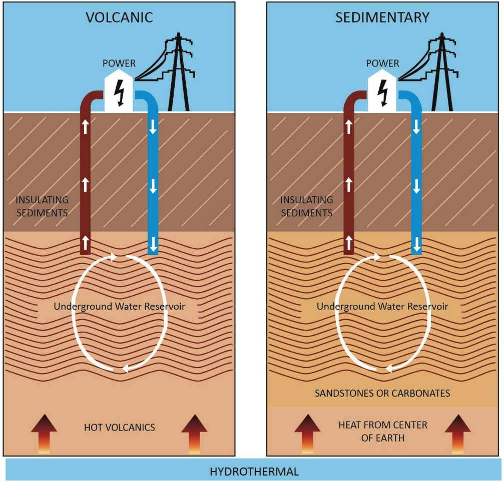
Mine the resource (2/4)

Hydrothermal systems - advantages

- heat exchanger is free
- resources in volcanic area have usually high enthalpy

Hydrothermal systems - disadvantages

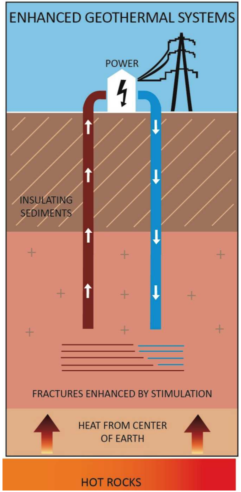
- location dependent
- sometimes difficult to identify the resource



Mine the resource (3/4)

Petrothermal systems (EGS)

- doublet needed (two wells)
- artificial underground heat exchanger
- stimulation is important and critical to obtain the right reservoir parameters (swept area and productivity)



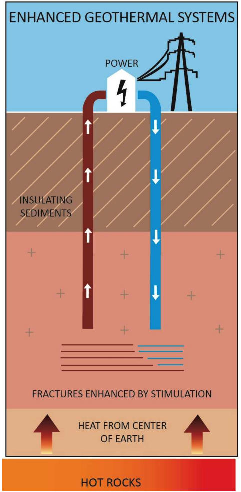
Mine the resource (4/4)

Petrothermal systems - advantages

- independent of geographic location, i.e. available everywhere
- less exploration risks

Petrothermal systems - disadvantages

- expensive wells (i.e. deep) in the crystalline basement are required (∼€ 15 M for 5 km well)
- stimulation is arbitrary



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Petrothermal prototype (research) systems built and circulated to date:

	Wells	Well sep. [m]	Duration [days]	Q_{prod} [l/s]	Res. Imp.[(1)] [MPa/l/s]	Loss [$\%Q_{inj}$]
Target				>40	<0.2	<10%
Fenton Hill, New Mexico (1972-1996):						
upper 2-well system (2.8 km):	GT2a-EE1	200	282	5.5	1.7	10%
deep 2-well system (4.2 km):	EE3a-EE2a	~200	112	5.7	4.0	16%
Rosemanowes, Cornwall UK (1978-1991):						
3-well system (2.2 km): 1988	RH12-11/15	120/135	300	2.3/14.0	4.1/0.7	25%
Hijiori, Japan (1985-2002):						
upper 4-well system (1.8 km):	SKG2-HDR1/2/3	40/50/55	90	12.8	0.4-0.7	23%
deep 3-well system (2.2 km):	HDR1-HDR2/3	90/130	300	5.8	1.4/2.1	64%
Soultz, France (1987-present):						
upper system (3.5 km):	GPK1-GPK2	450	120	25	0.2	0%
deep 3-well (5.0 km) 2005	GPK3-GPK2/4	600	~150	12/3	0.6/1.9	0%
deep 2-well (5.0 km) 2008	GPK3-GPK2[(2)]	600	~60	25[(3)]	~0.55	0%
Habanero-Cooper Basin (2003-2014)						
2-well system (4.2 km): 2009	Hab1-Hab3	560	60	15	0.7[(3)]	0%

(1) pressure difference across reservoir / production flow rate
(2) with downhole pump
(3) surface impedance

Exploit the resource (1/6)

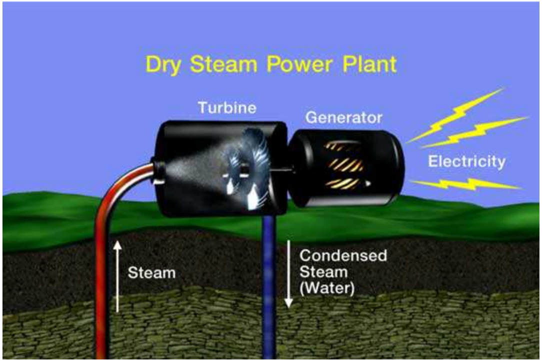
Dry steam power plant

- artesian (i.e. pump not needed to produce the well)
- direct use of the resource (ideal case)
- higher temperature results in a better Carnot efficiency (e.g. T_p=270 °C & T_i=50 °C, $\eta \leq 40.5\%$)
- e.g. Lardarello (IT), Geysers (CA, USA)

Exploit the resource (2/6)

Dry steam well in Lardarello (IT)

- T_p up to 150-270 °C
- well is produced by choking the flow at the wellhead
- pressure of the production fluid fed to the plant is usually 0.2-2 MPa
- 221 wells are producing 800 MW_e, about 25% of Tuscany electricity demand
- standardized 20 MW_e power units



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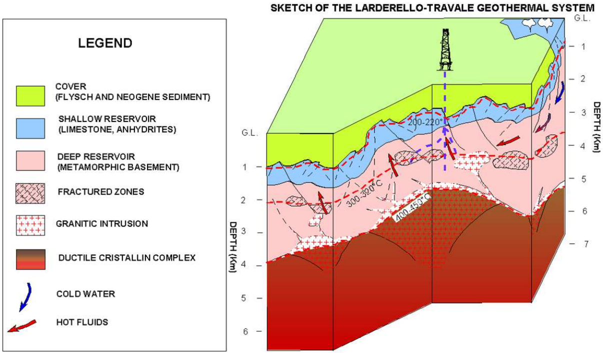
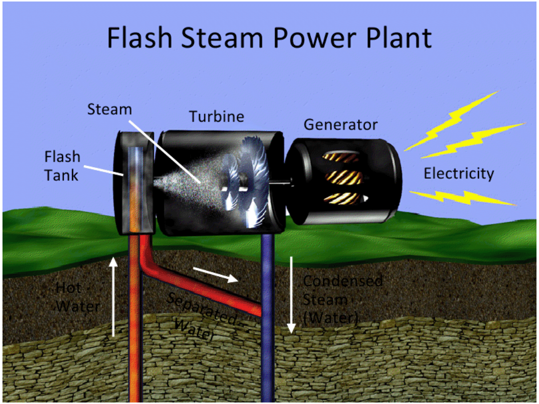


Exploit the resource (3/6)

Flash steam power plant

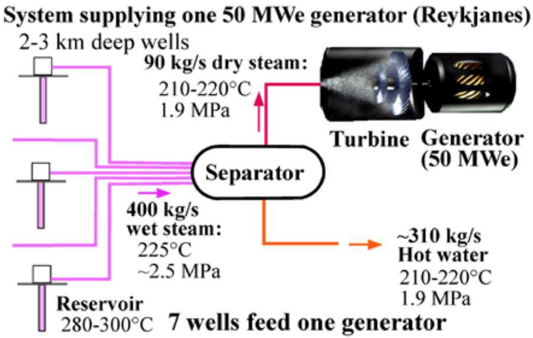
- flash and double flash units (depending on the brine temperature $180 \leq T_p \leq 250\,°\mathrm{C}$)
- e.g. El Salvador, $T_p = 250\,°\mathrm{C}$ two 30 MW_e single flash units and one 35 MW_e double flash unit [3].



Exploit the resource (4/6)

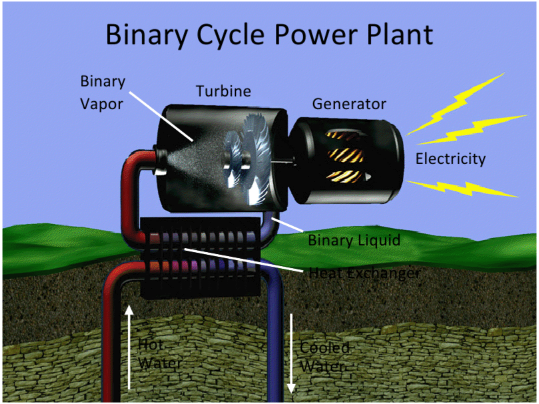
Flash steam power plant in Iceland

- $T_p = 225\,°\mathrm{C}$
- shallow wells but large geothermal gradient gradient (over 200 °C/km at some places in Iceland)
- 7 wells feed one generator
- outlet turbine steam pressure kept at 0.01 MPa with a flow of 1700 kg/s of sea-water at 8 °C pumped through the tubes of the condenser



Exploit the resource (5/6)

- binary cycles (ORC and Kalina) $100 \leq T_p \leq 180\,^{\circ}\mathrm{C}$
- low enthalpy resource
- downhole pump (submersible) usually needed
- e.g. Landau (DE) and Soultz-sous-forêt (European research project)
- $T_i = 50\,^{\circ}\mathrm{C}$, $0.13 \leq \eta \leq 0.28$



Exploit the resource (6/6)

ORC unit in Landau (DE)

- single doublet (depth 3000 m)
- $T_p \approx$ 160 °C, $\dot{V}_p = 50 - 80$ L/s
- co-generation ORC plant ($\sim$ 3 MW$_e$ and heat for about 300 houses)

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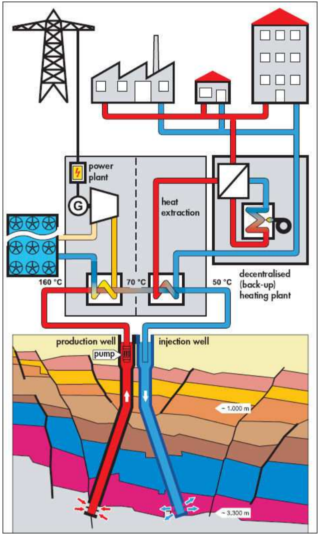
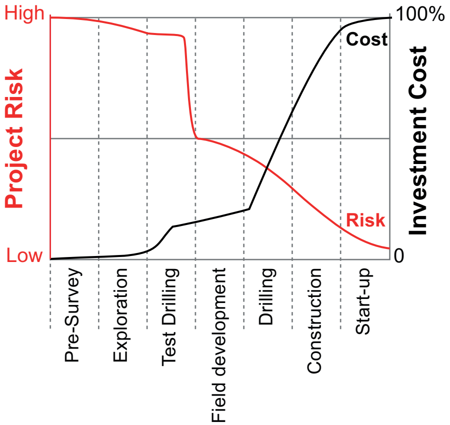


Advantages of geothermal energy (1/1)

- low surface footprint (e.g. heating district in Reykjavik, IS, 130 °C, 330 L/s)
- baseload energy source
- co-generation (electricity + heat)
- high feed-in tariff and risk guarantee (50%) financed from the network surcharge fund (CH)

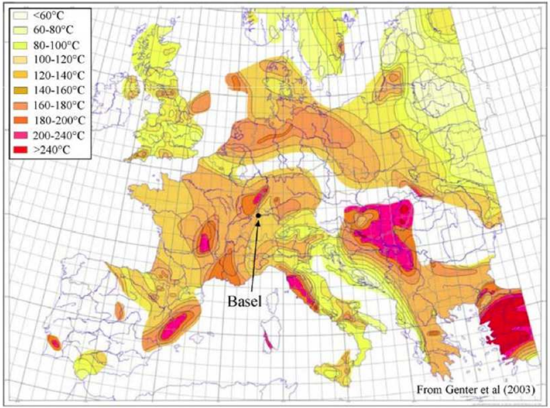
Drawbacks of geothermal energy (1/1)

- renewable time scale of geothermal is much larger than for solar and wind
- thermodynamic mismatch: heat is transformed to mechanical and then to electricity…
- large investment costs at high risk
- global solution (EGS) is still at its infancy
- $MW_e/M€$ investment is unfavorable compared to other renewables



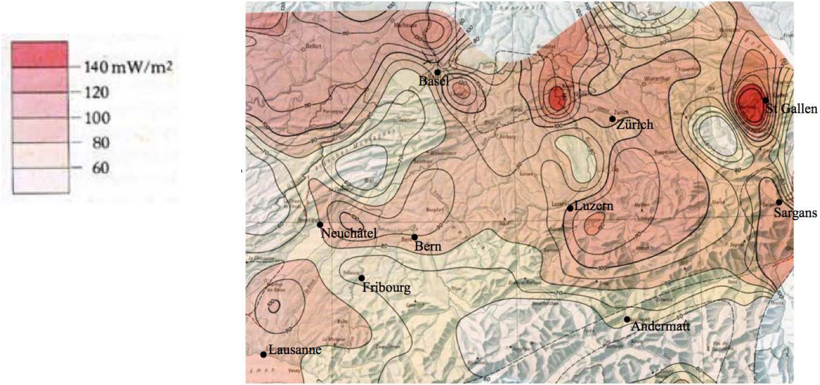
Potential of geothermal energy in Switzerland (1/3)

temperature map in Europe extrapolated to 5 km



Potential of geothermal energy in Switzerland (2/3)

Surface heat flux in CH. None of the power plant will be able to operate for a period longer than 20 years and new wells will have to be drilled.



Potential of geothermal energy in Switzerland (3/3)

Geothermal systems in Switzerland and ongoing projects

1. 1993: Riehen (BS) doublet produces 2.5 MW_{th} for a local heating district system. The pump delivers 20 L/s of water at 68 °C. The water is injected at 25 °C back in the aquifer. Less successful in GE and ZH.

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5. 2020: Lavey-les-bains (VD) 110 °C, 40 L/s, ORC power plant 250 kW_e ongoing...

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- with the moderate geothermal gradient (31-35 °C/km) and surface heat flux exceeding (100 mW/m^2) over large areas, EGS systems in Switzerland will be possible as soon as the construction of the downhole heat exchanger is controlled.
- therefore, it is likely that geothermal energy will contribute to the swiss electricity production by 2050!

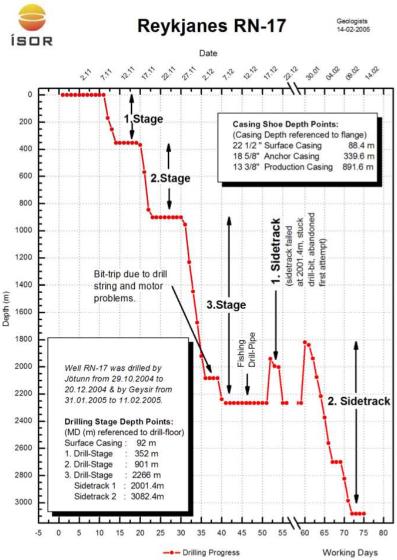
Summary (2/2)

Thank you for your attention!

Any question?

Backups

Drilling progress chart (Iceland)



References

[1] "SWI swissinfo.ch." http://www.swissinfo.ch/eng/nuclear-power-station-_muehleberg-sets-definitive-decommissioning-date/41997110. Published: 2016-03-02, Accessed: 2016-04-10.

[2] E. Keith, "Geothermal energy." ETH lecture, 2015.

[3] R. Bertani, "Geothermal power generation in the world 2005–2010 update report," *Geothermics*, vol. 41, pp. 1–29, 2012.