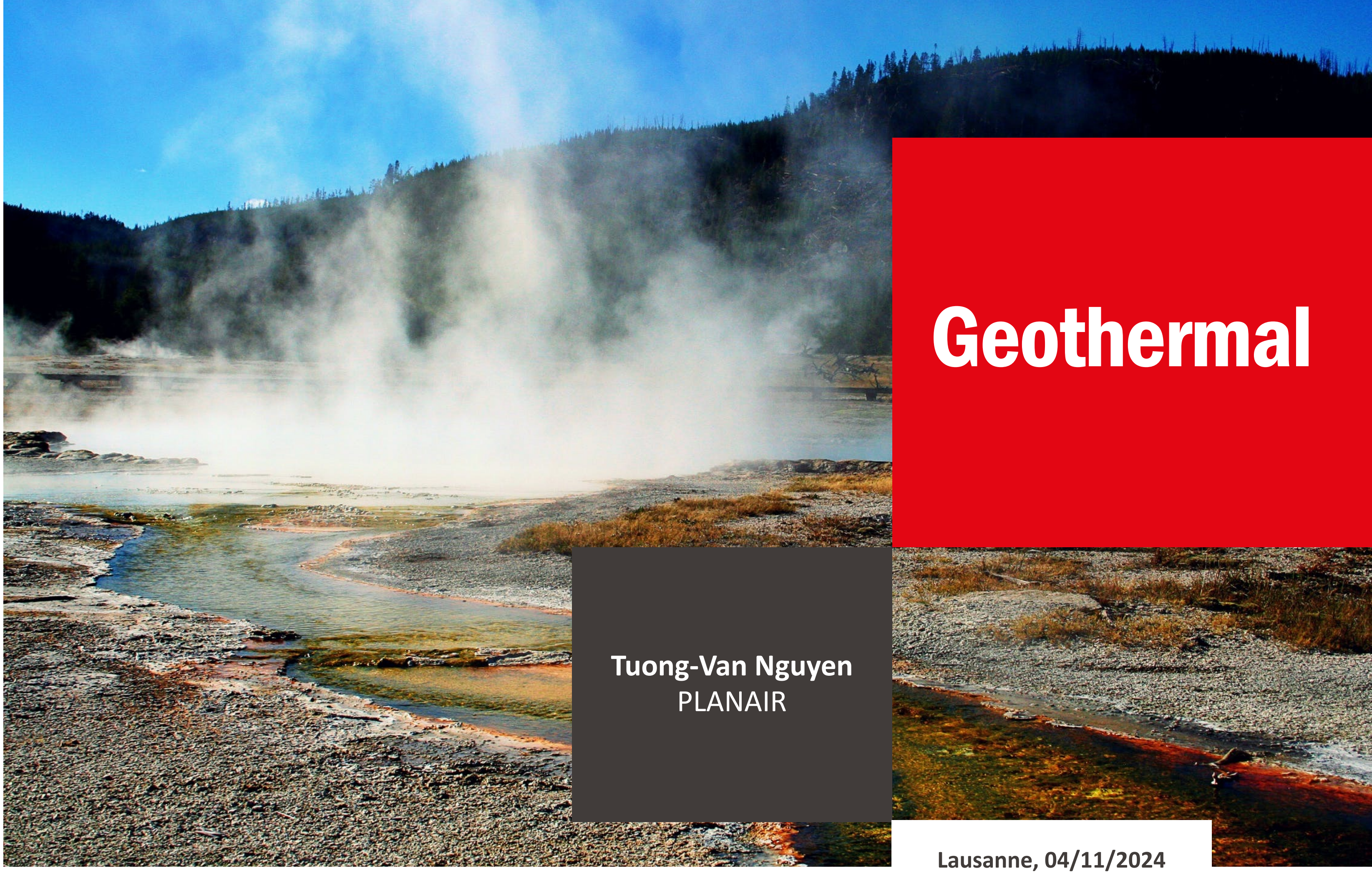
EPFL



Geothermal

Tuong-Van Nguyen
PLANAIR

Lausanne, 04/11/2024

École polytechnique fédérale de Lausanne

Goals

- ***Justify*** the main advantages and drawbacks of this energy resource
- ***Select*** the most suitable application based on the depth and temperature
- ***Estimate*** the efficiencies of a geothermal power plant and heat pump

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Introduction

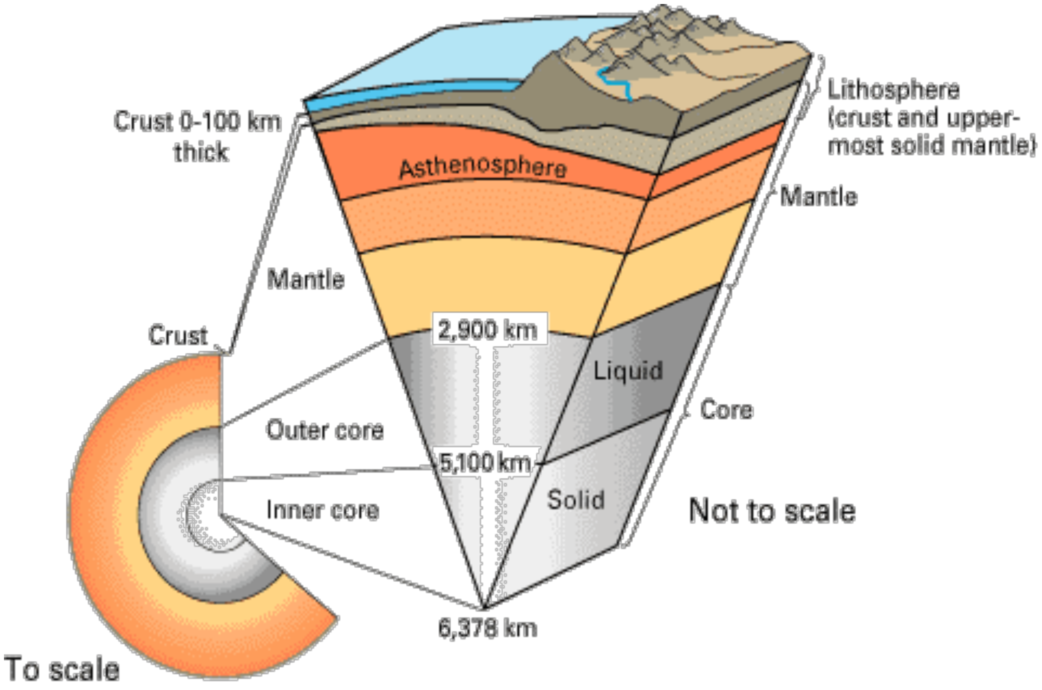
The “**underground**” resource

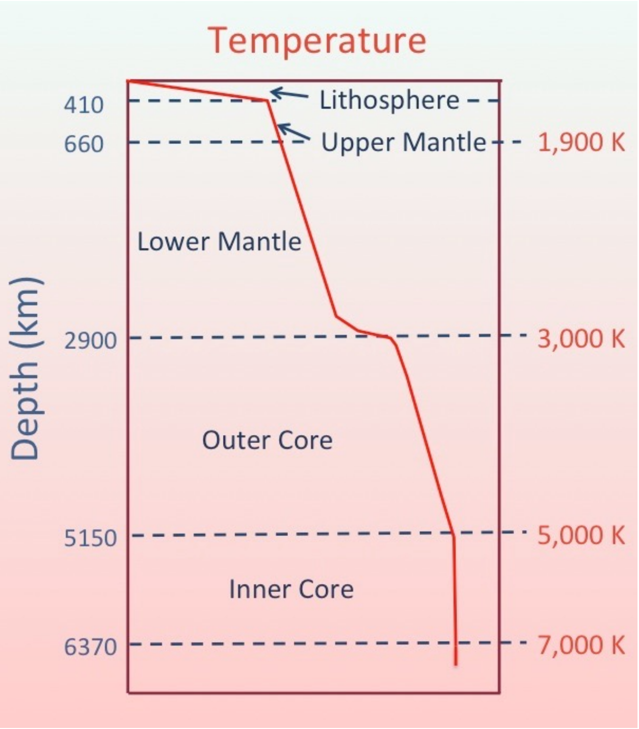
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Introduction

What is geothermal energy?

- **Heat** from the original formation of the planet and from radioactive decay





Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Introduction

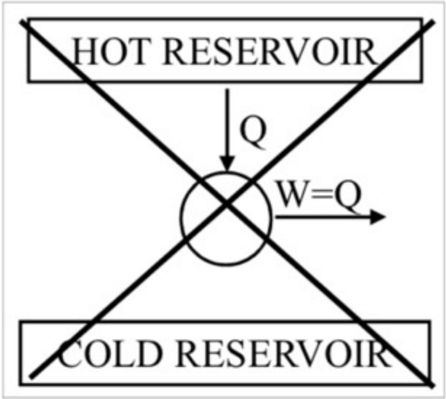
Recall: Carnot factor θ

- **Not all heat** can be converted into **electricity**

- $\theta = (1 - \frac{T_0}{T_Q})$

High T_Q
= high value of heat

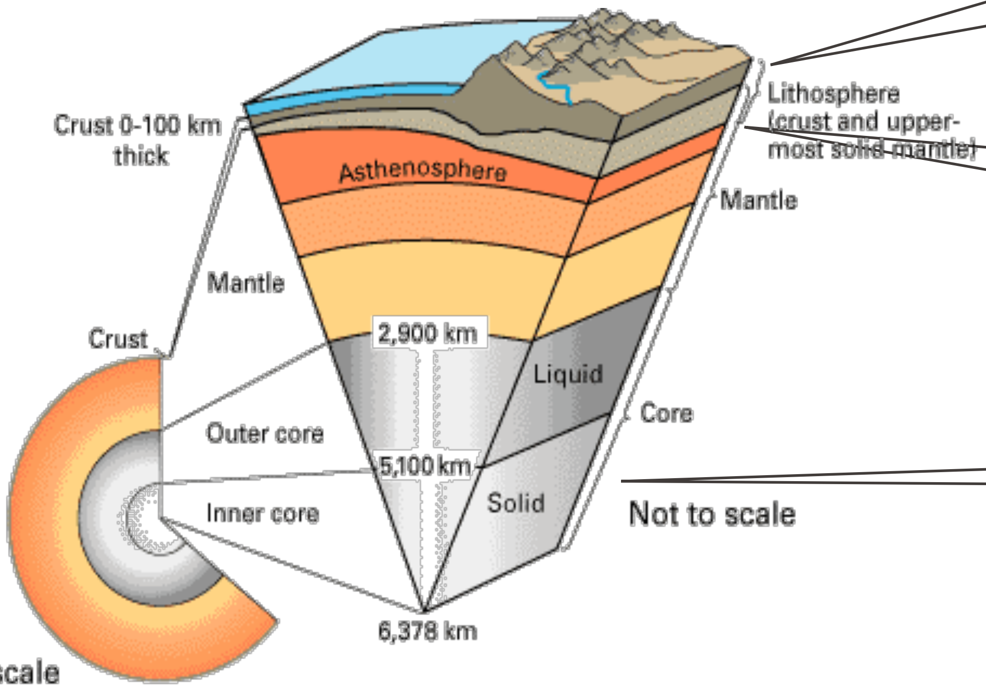
Carnot factor = **"value of heat"**



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Introduction

"Value" of heat



3 km

$$\theta = 1 - \frac{298}{423} = 30\%$$

10 km

$$\theta = 48\%$$

$$\theta = 96\%$$

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Introduction

History

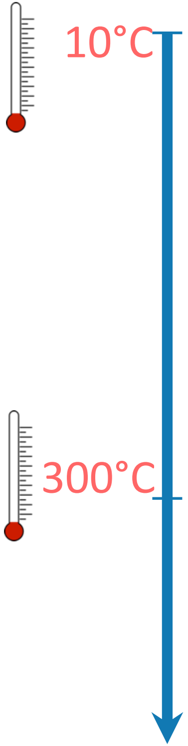
- First geothermal power station: **Larderello** (1911)

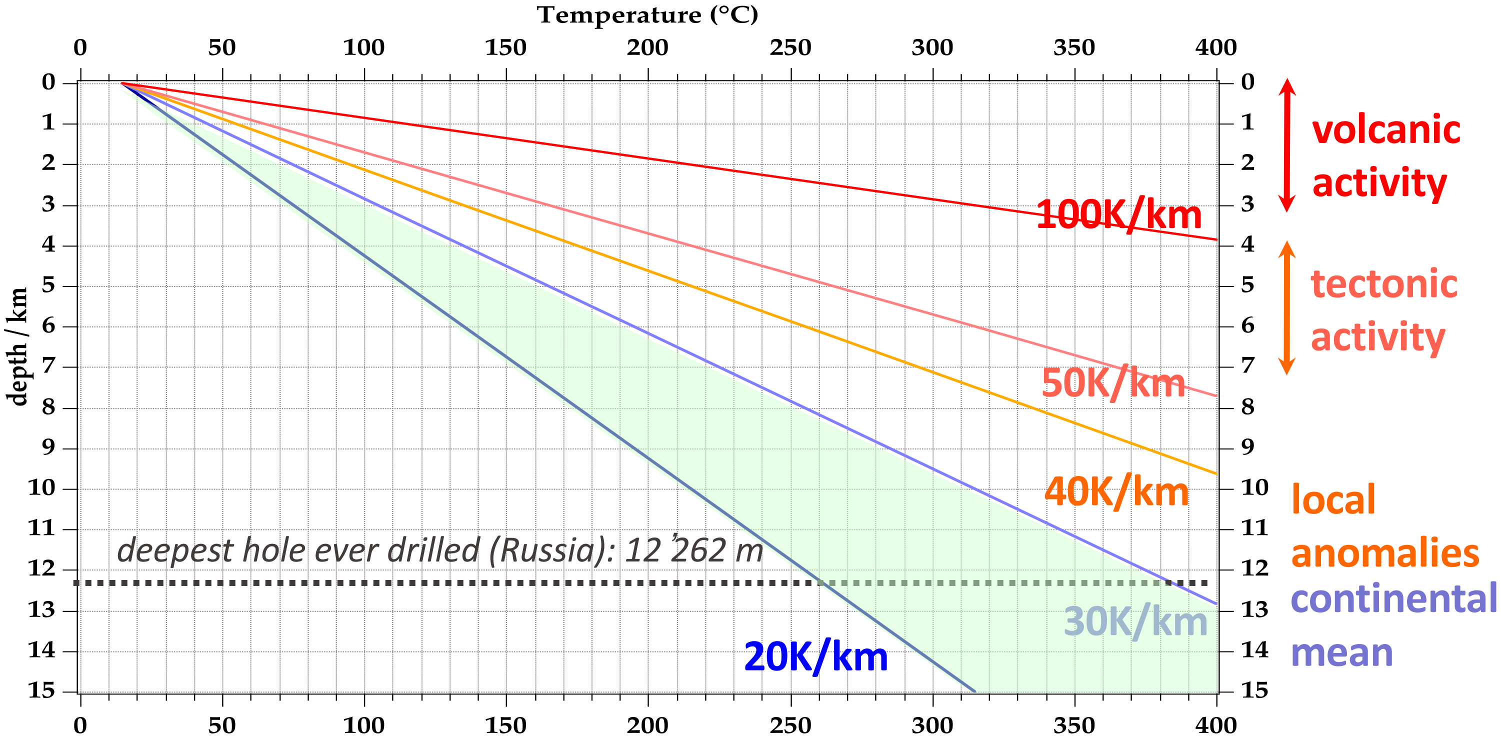
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Introduction

Geothermal gradient

- Rate of temperature increase with depth [K/m] (30 K/km in **CH**)





Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

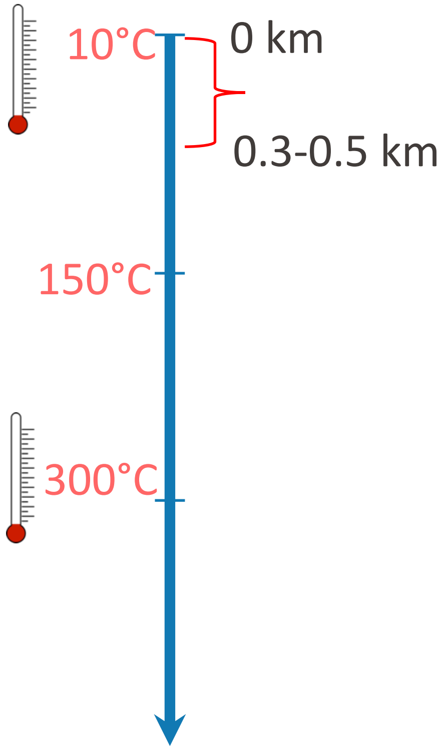
Demands and applications

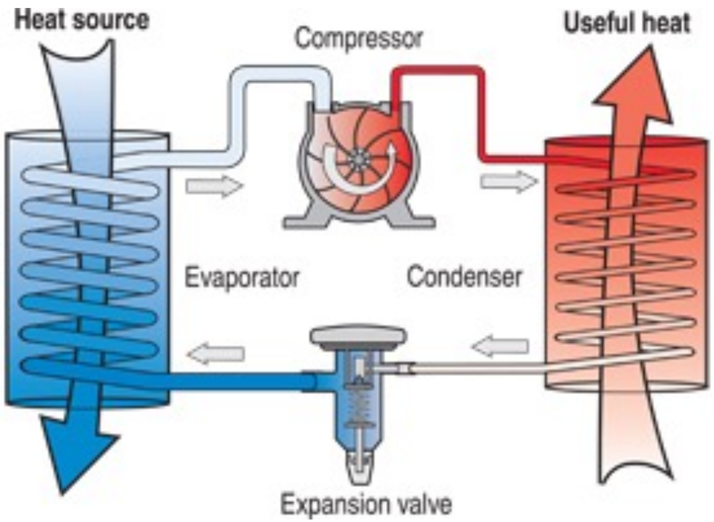
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Demands and applications

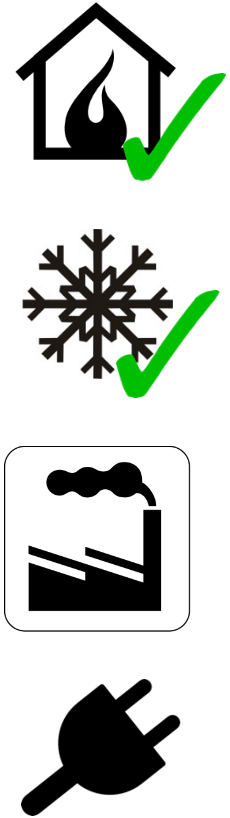
Ground source heat pumps

- Direct **heating**/**cooling – stable ground temperature**





End-uses

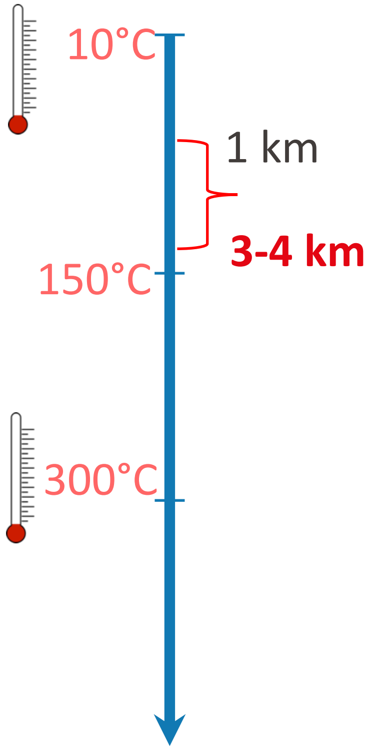


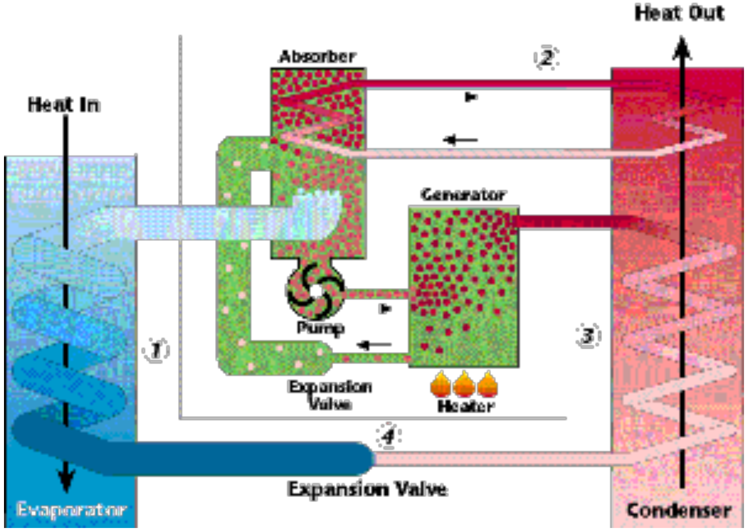
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Demands and applications

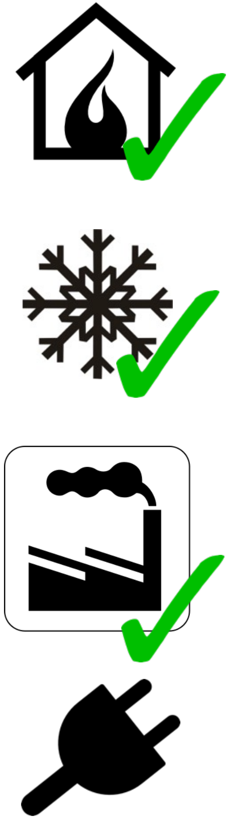
Direct use

- District **heating**/**cooling,** **residential/industry use**





End-uses

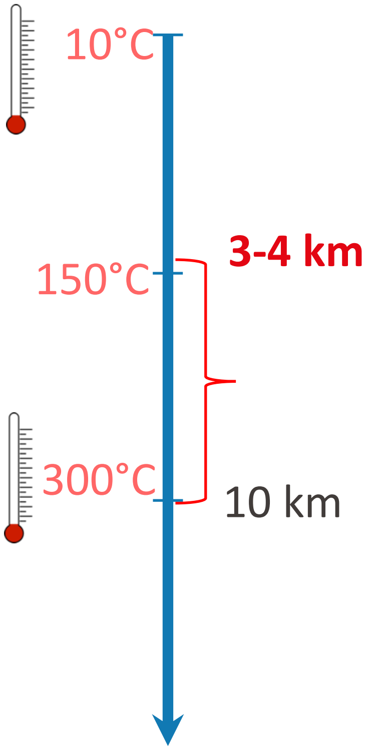


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

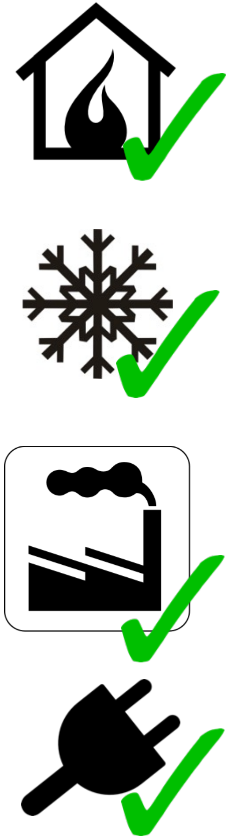
Demands and applications

Electricity production

- **Power plants** and cogeneration



End-uses



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

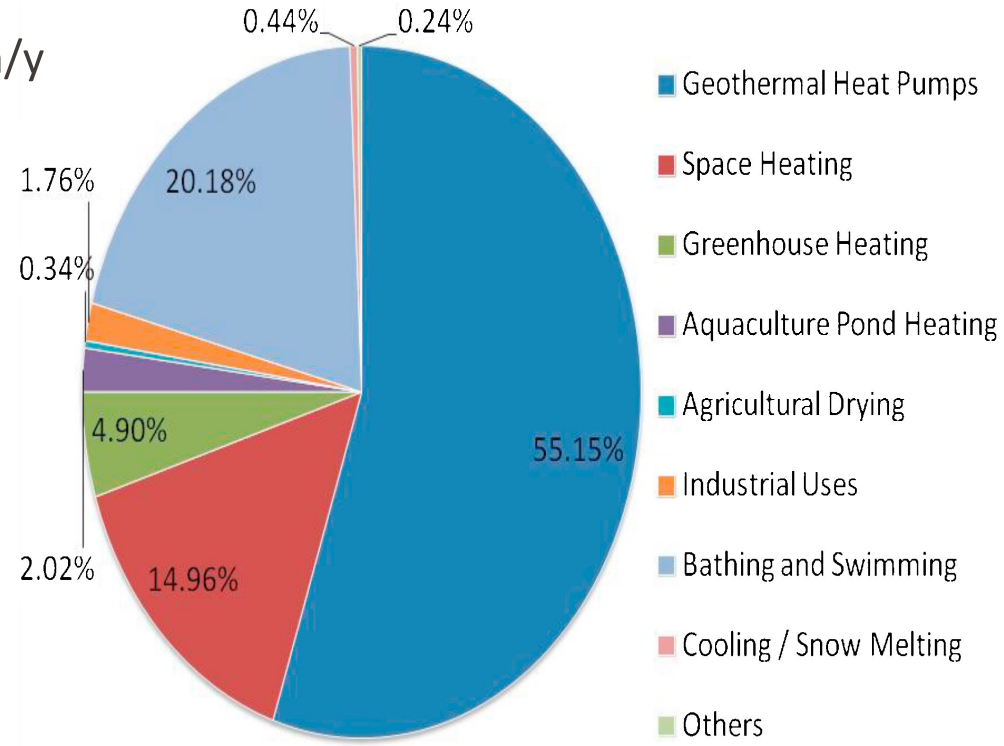
Demands and applications

Status in the world

- Primary energy: 158’700 TWh/y
- Final energy: 109’100 TWh/y

⇢ **0.2%**

- Electricity: 73.5 TWh_e/y
- Heat: 164.6 TWh_{th}/y

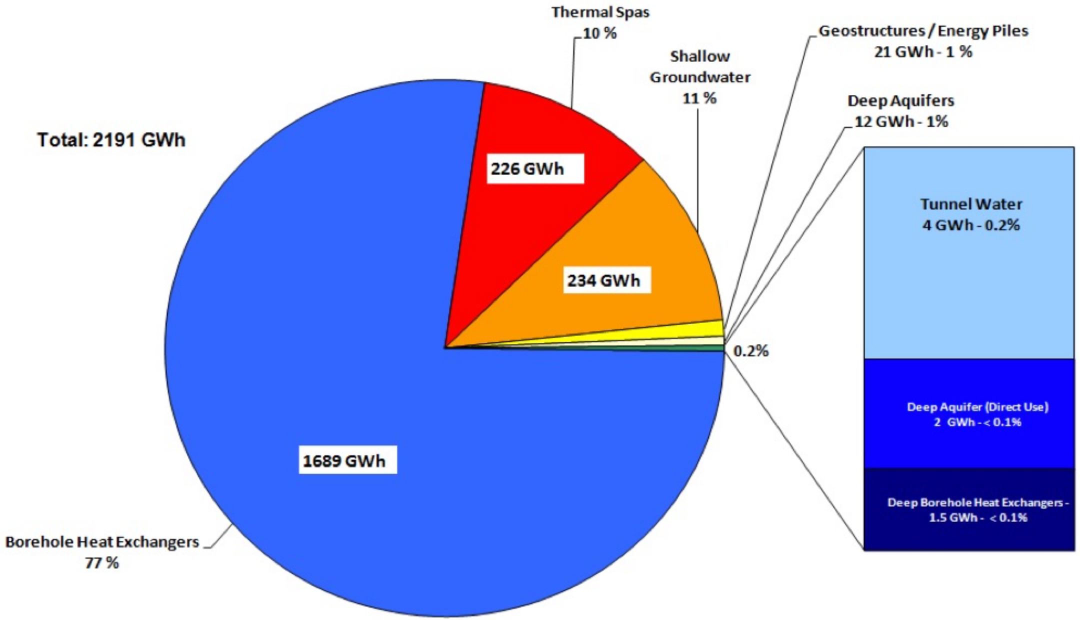


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Demands and applications
Status in Switzerland

- Heat: 2.5 TWh_{th}/y

⇢ 1% of Swiss final energy use



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Reserves and resources

Formation

Properties

Reserves and resources

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Reserves and resources

Hydrothermal

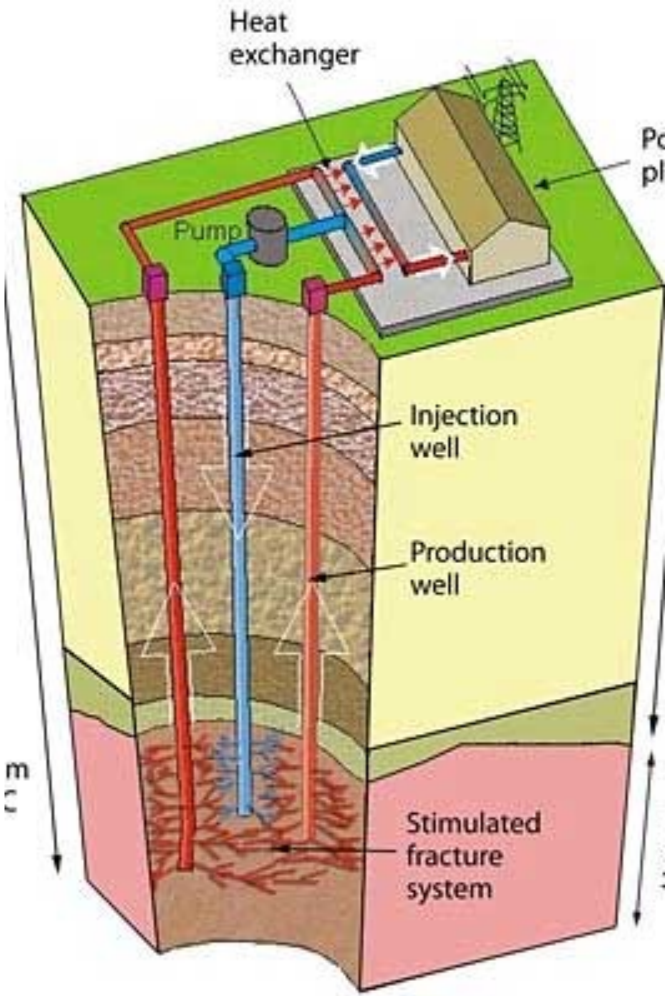
- **High-temperature** (water/steam at 100-400°C), "hot springs" or "heated water resources"
- *Naturally occurring* – with the high temperatures of the rocks, water/steam is heated
- *Volcanic settings* (ex: Indonesia) or hot wet rocks (fractured granite)

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Reserves and resources

Hot dry rock

- **Hot dry rocks** = geological formations abnormally hot, but *without water*
- **High temperature, low permeability** injection necessary
- *Not naturally occurring* water flows
- *Injection and extraction of water* through drilled wells, joined to form a circulating loop through the reservoir



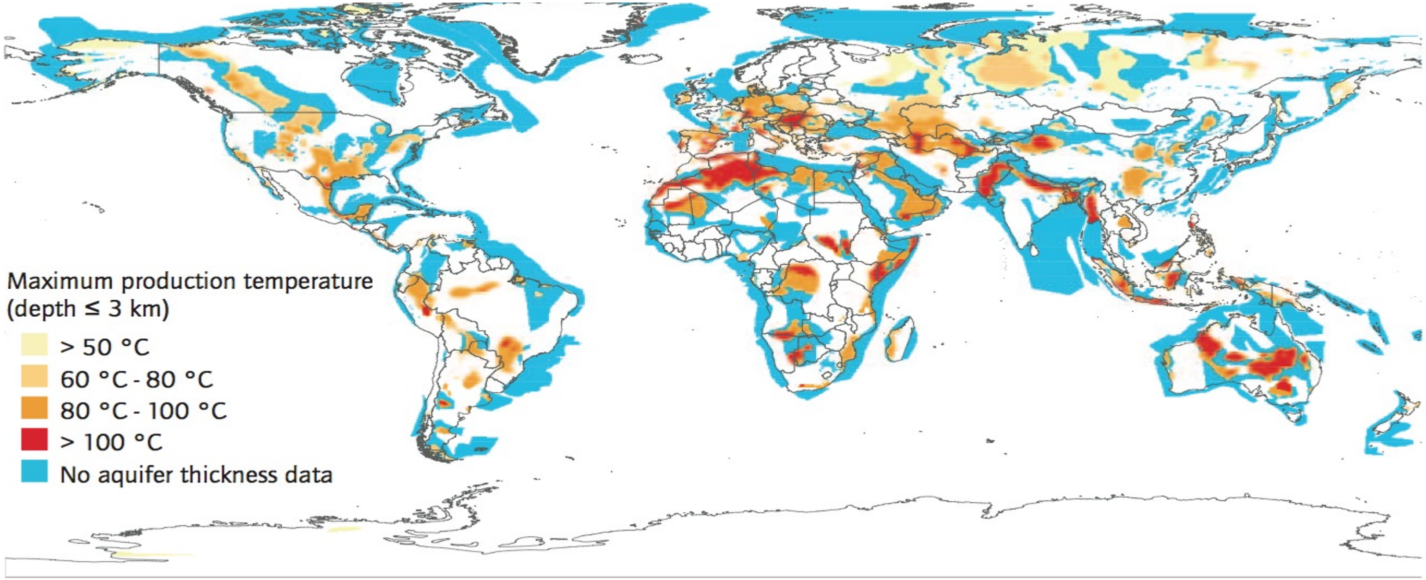
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Reserves and resources

Deep aquifers

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

- Deep aquifers **widely available – temperature gradient**
- Reservoirs within the Earth (subsurface reservoirs) with hot fluids
- Temperatures of 20°C-70°C

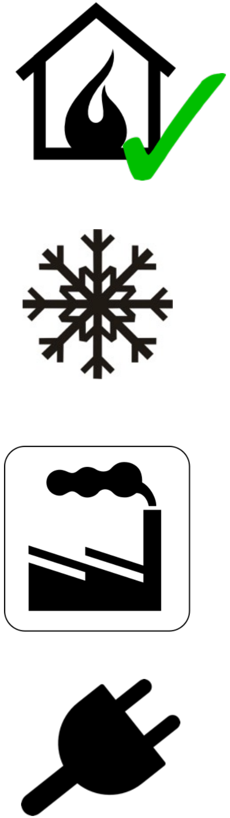


Conversion

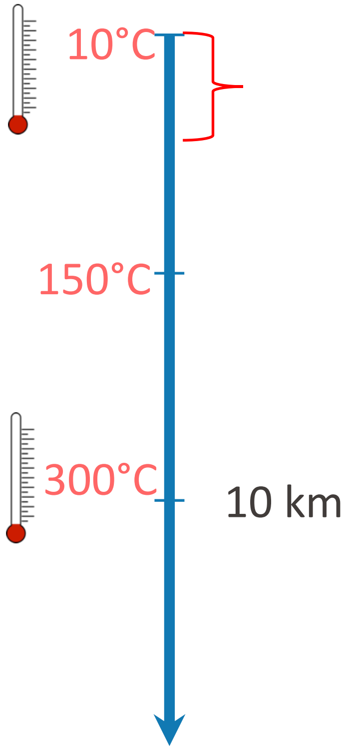
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Heat production

End-uses



- **Heat pumps and direct heat exchange**

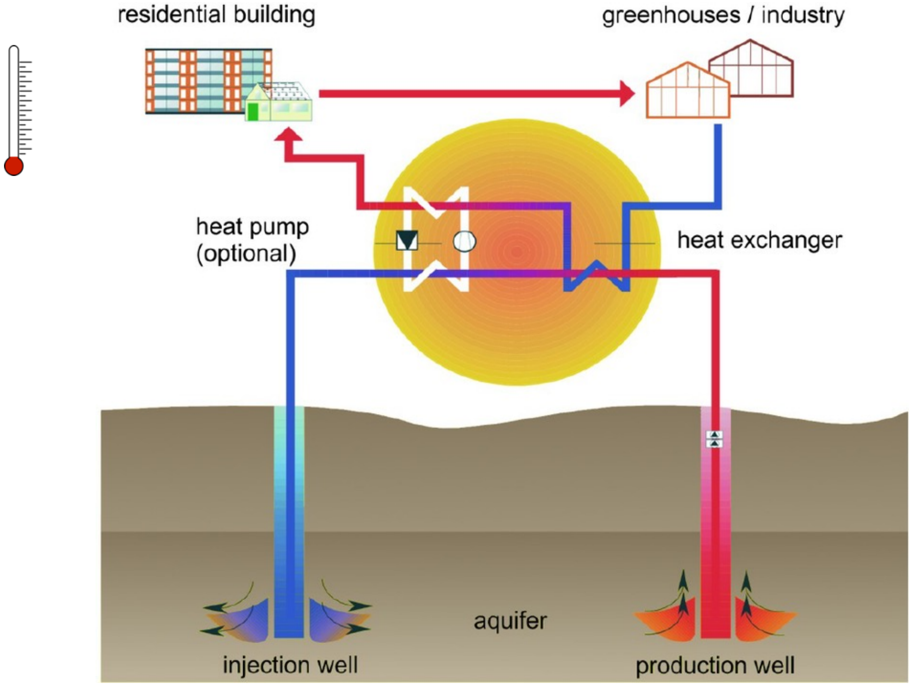


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Heat production

- Most common use of geothermal energy nowadays
- Heat pumps and direct heat exchange

$$Q = m\, c_{p,\text{water}} \left(T_{\text{extraction}} - T_{\text{injection}}\right)$$



End-uses

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

GROUP QUESTION (2 ppl., 10 mins)

A typical Swiss family living in an old building needs, per year, 4’000 kWh electricity and 18’000 kWh heat. The heating takes place at **35°C** and the outdoor conditions are **7°C** on average. Hot geothermal water is available at **14°C and can be rejected at 10°C.**

- *Based on the heat pump size calculated before, how much water (in kg/s) should be processed? (cp of water : 4.16 kJ/kg K)*

- *If we want to avoid the use of a heat pump and directly process geothermal water to heat up the house, at which depth should it be done at **minimum (m)**?*
- *What is the maximum amount of electricity (kW) that can be produced from geothermal water at 14°C using a perfect (Carnot) heat engine? (tip : calculate the exergy!)*

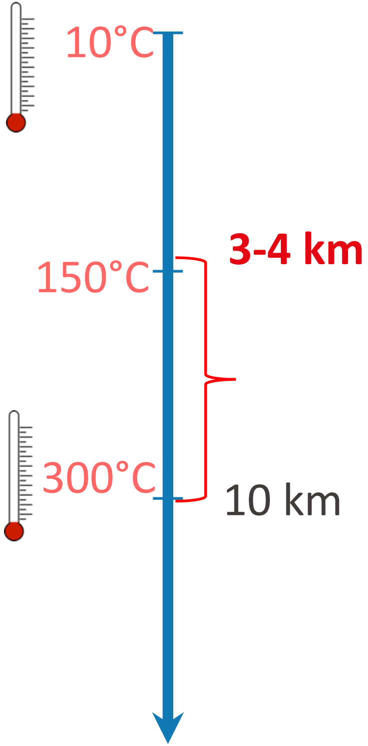
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Electricity production

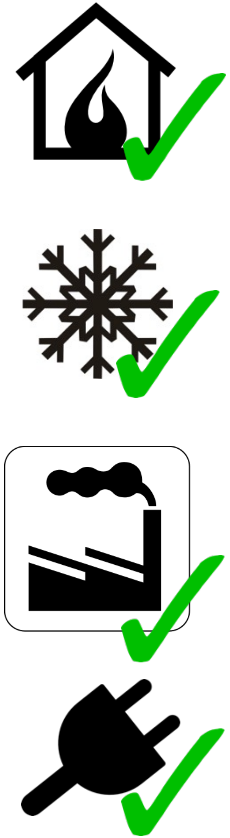
- **Power plants** and cogeneration

$$Q = m\,c_{p,\text{water}}\left(T_{\text{extraction}} - T_{\text{injection}}\right)$$

$$W \leq \boldsymbol{\theta}\,Q$$



End-uses



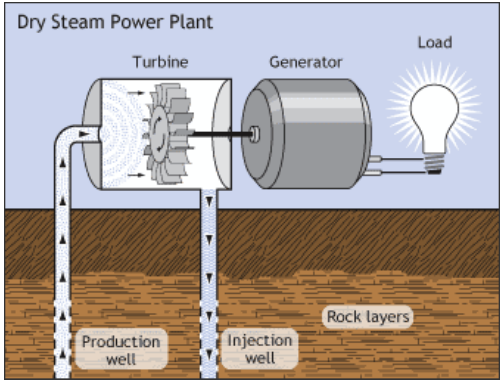
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

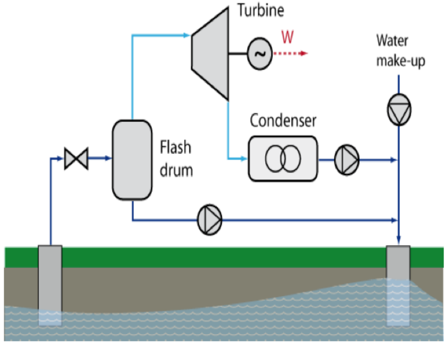
EPFL

Electricity production

Types of geothermal power plants

- Dry-steam power plants (dry steam : only vapor)
- Flash steam power plants (mixture of steam and liquid water)
- Binary cycles (ORC/Kalina) – similar to Rankine cycles with other fluids than water



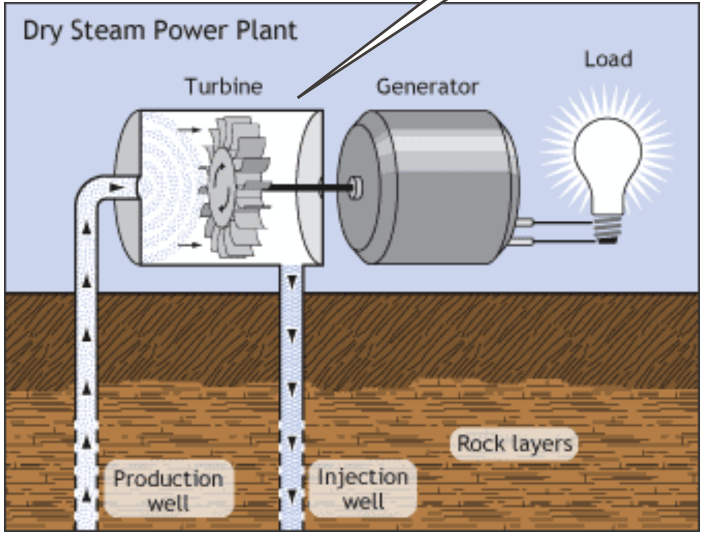


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Electricity production
Dry-steam power plants

Direct use of geothermal steam

- **27% of worldwide capacity**



- The Geysers (California)

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

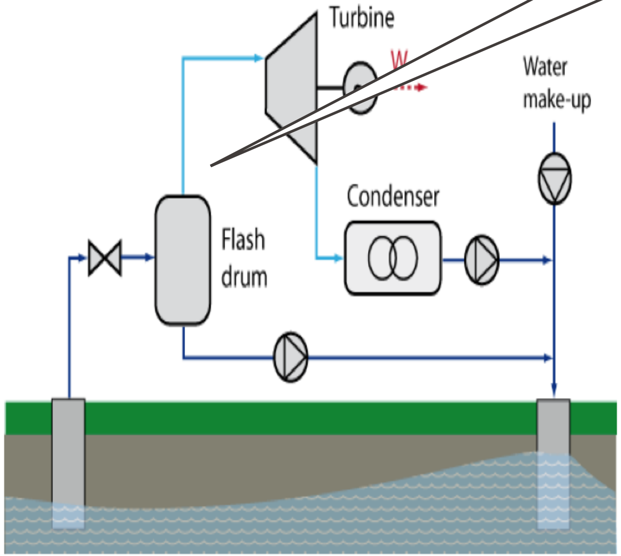
EPFL

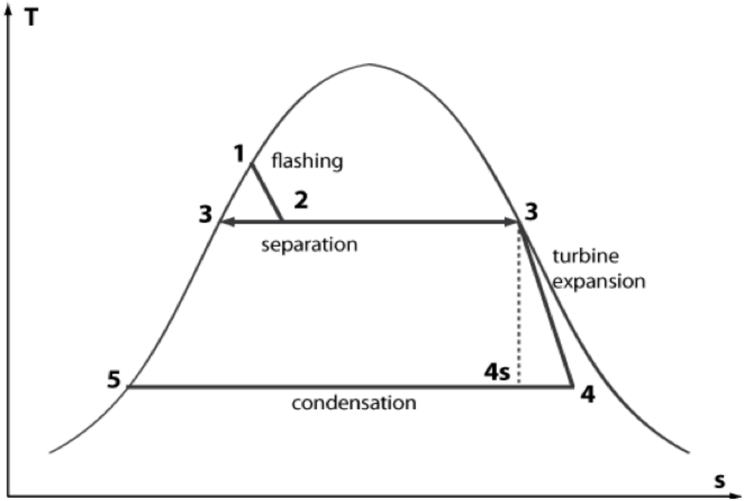
Electricity production

Flash steam power plants

- **Most common type (60% installed capacity)**

Pressure losses - Separation of liquid/vapour

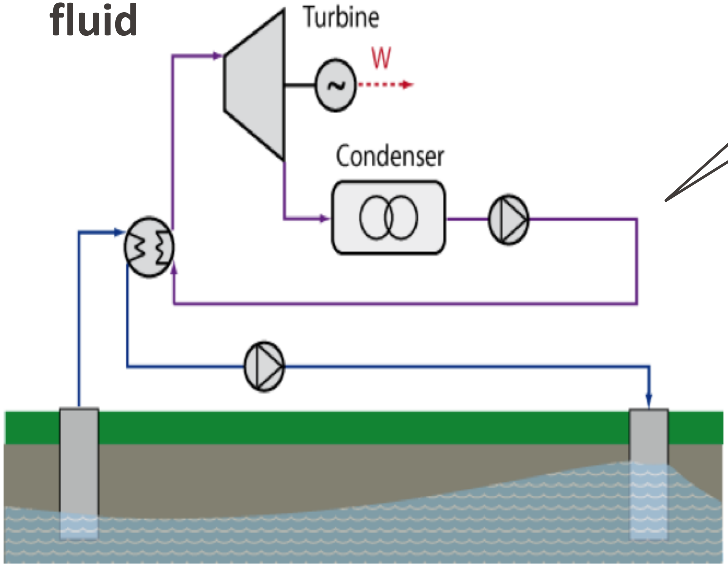




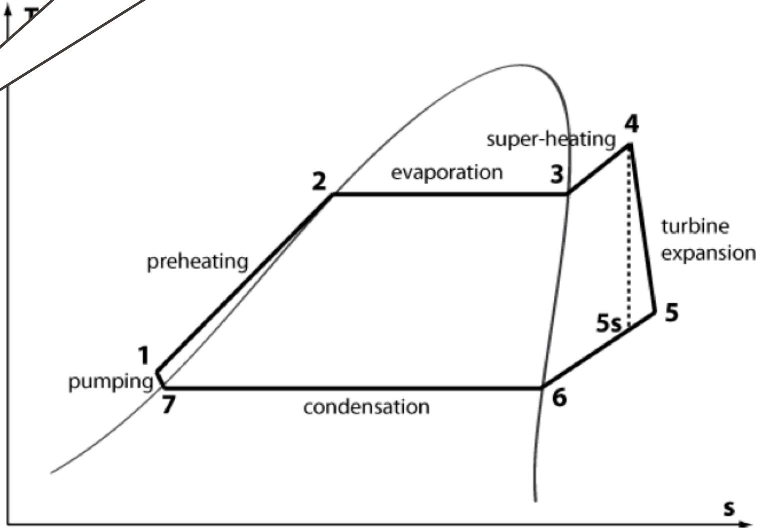
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Electricity production
Binary power plants

- Small-scale
- Low temperature of geothermal fluid



Use of a secondary fluid

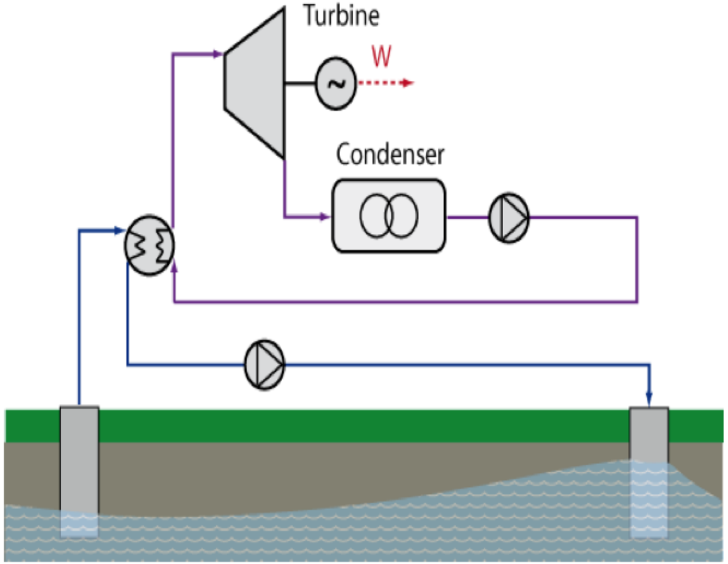


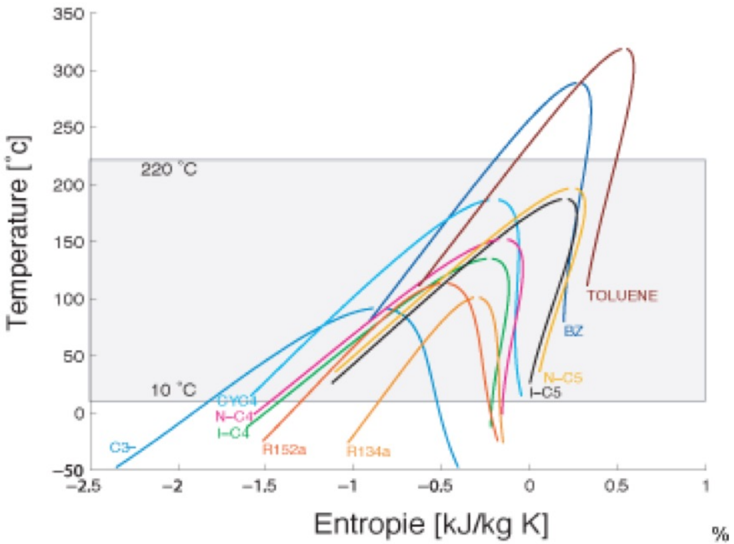
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Electricity production

Binary power plants

- Selection of secondary fluid challenging: thermodynamic properties, safety,

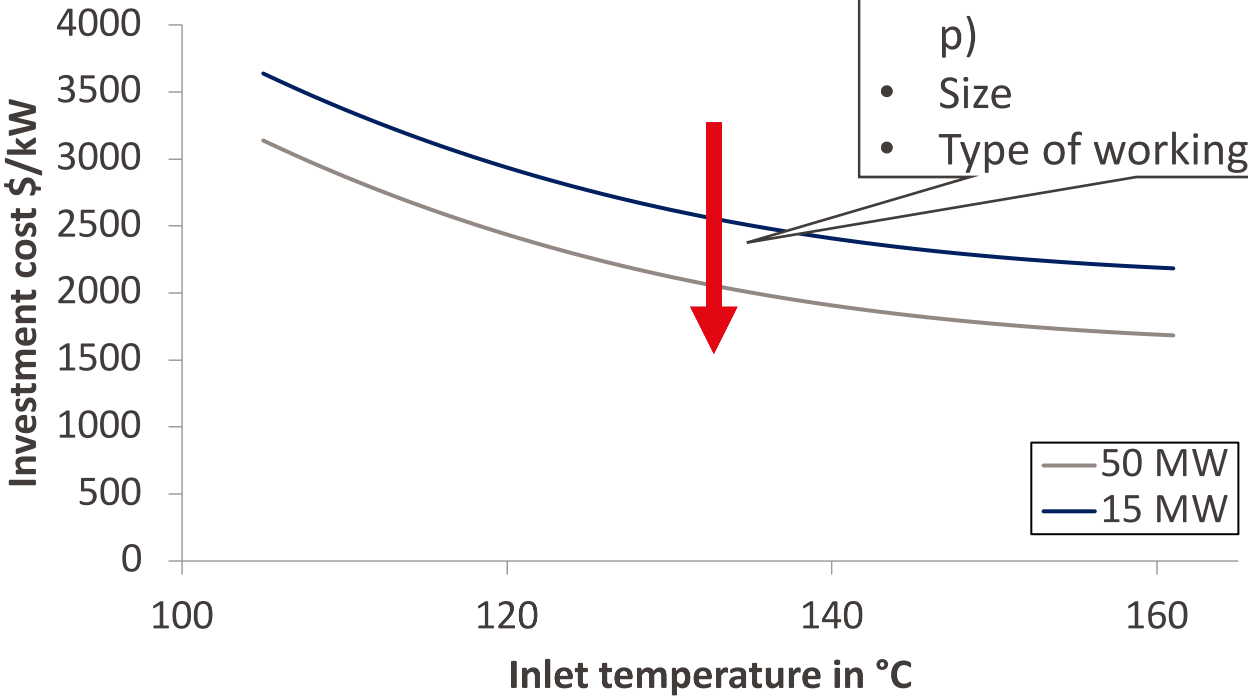




Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Electricity production

Capital costs of geothermal power plants

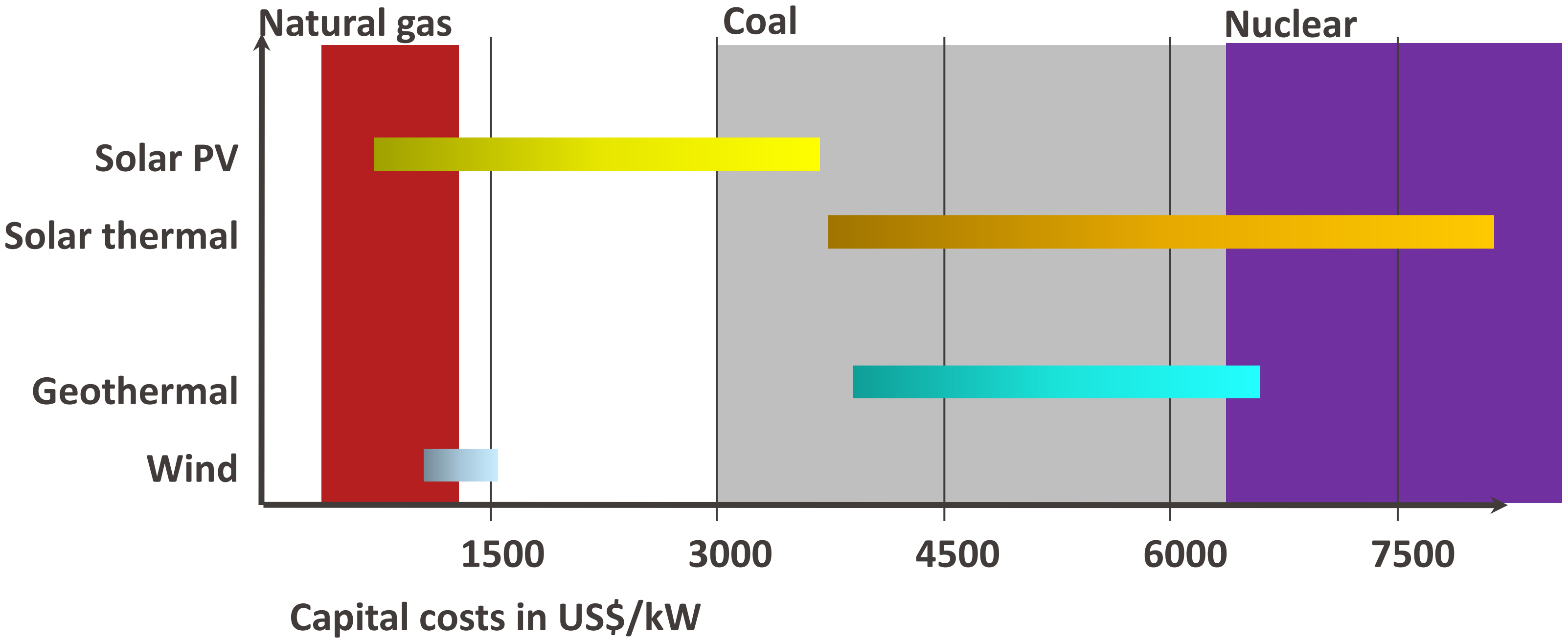


- Temperatures (T_{ext}, T_{in})
- Turbine inlet conditions (T, p)
- Size
- Type of working fluid

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Electricity production

Capital costs of geothermal power plants

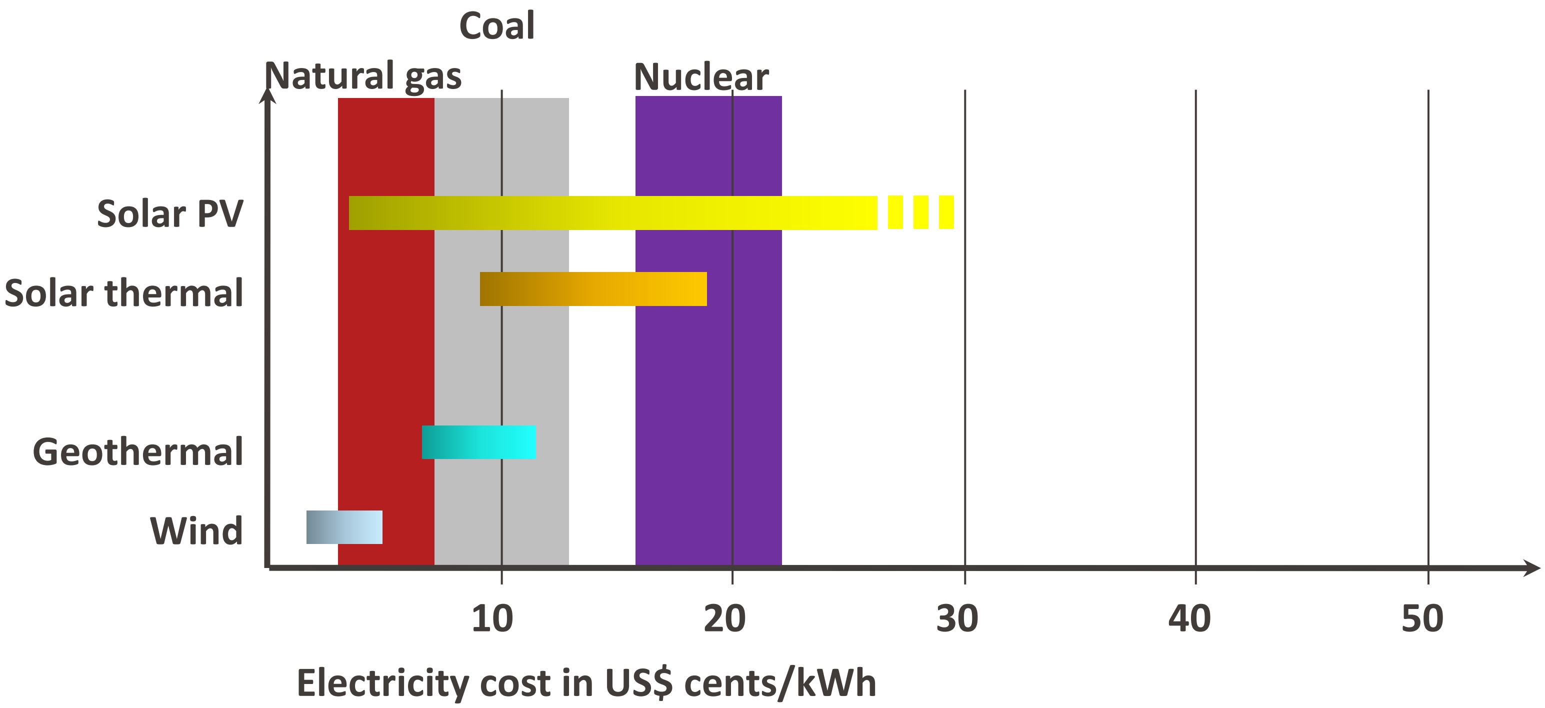


Reference: Lazard levelised cost of energy (2022), URL : https://www.lazard.com/media/451905/lazards-levelized-cost-of-energy-version-150-vf.pdf

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Electricity production

Cost of production of electricity (LCOE)



Reference: Lazard levelised cost of energy (2022), URL : https://www.lazard.com/media/451905/lazards-levelized-cost-of-energy-version-150-vf.pdf

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

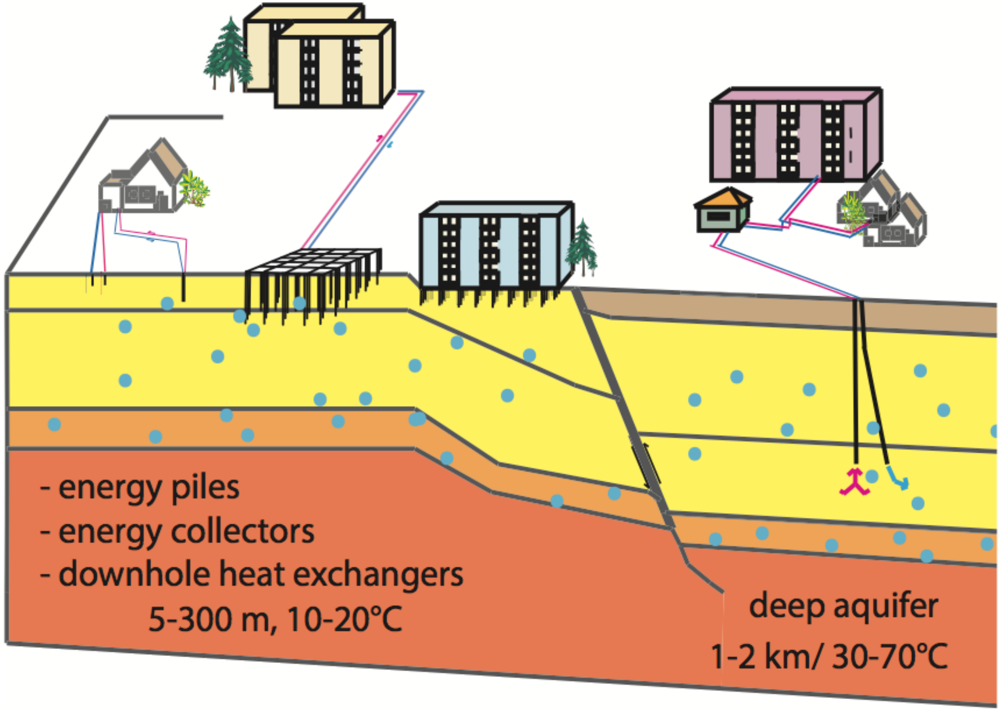
What's next for geothermal?

Role in the Energy System

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

What's next?
Potential worldwide

- **Technical potential**
  - 12,500 TWh_e/y
  - 289,000 TWh_{th}/y
- **IEA (2050)**
  - 1400 TWh_e/y (3.5%)
  - 1610 TWh_{th}/y (3.9%)

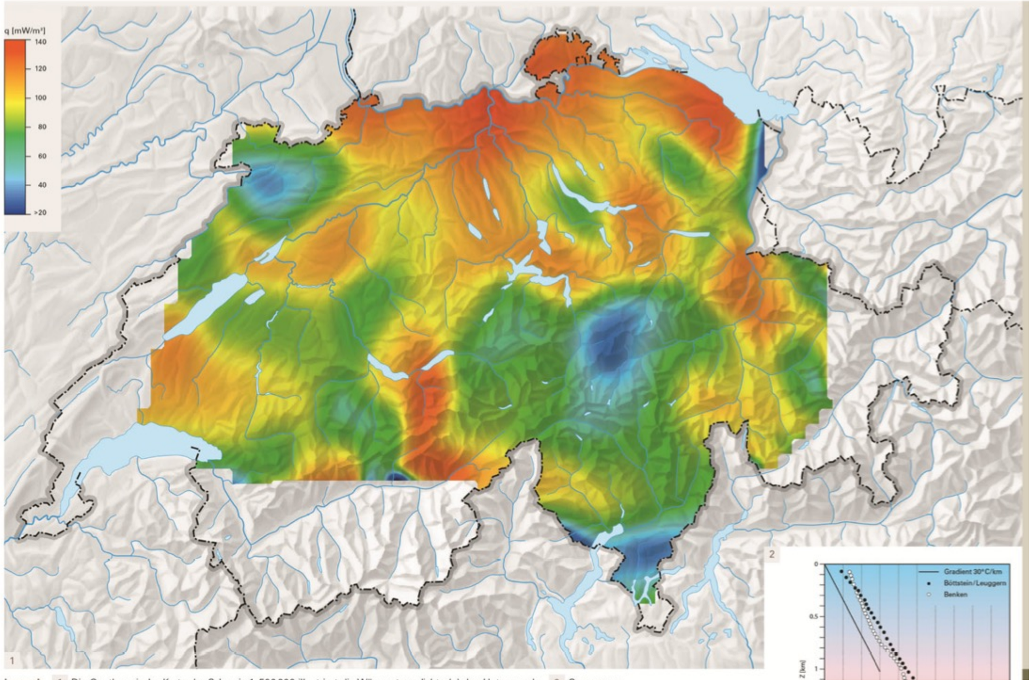


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

What's next?

Potential in Switzerland

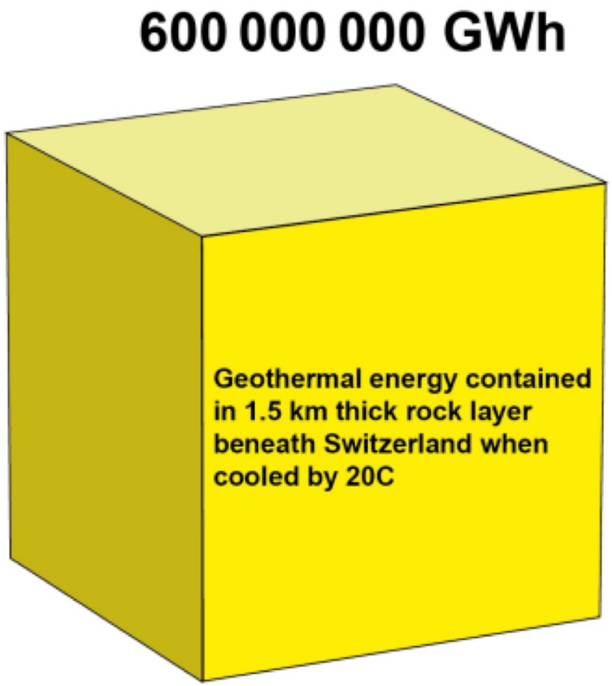
- **SFOE (2050)**
  - 4-5 TWh_e/y (7-8%)
  - District heating



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

What's next?

Potential in Switzerland



60 000 GWh

Swiss annual electric energy consumption

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Take-home message

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Take-home message

- **Geothermal energy applications**
  - Heat has different "values"
  - Not only electricity! Ground Source Heat Pumps and direct use of heat
  - Baseload: non-seasonal resource

- **Resources**
  - Location-specific to ubiquitous resources
  - Huge potential but technical difficulties

- **Geothermal power plants**
  - Low first-law efficiencies, good second-law efficiencies

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Important formulas and concepts

- Geothermal gradient in CH (30 K/km)
- Carnot factor $\boldsymbol{\theta} = (1 - \frac{T_0}{T_Q})$
- Heat extraction $Q =$ $m\, c_{p,\text{water}} \left(T_{\text{extraction}} - T_{\text{injection}}\right)$

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch