Geothermics and Geothermal Energy
Introduction

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The Relevance of Geothermal Energy

Forms of Energy

All other forms of energy (electrical, mechanical, chemical, ...) can be completely converted to thermal energy, but not vice versa.

Thermal energy is the least valuable form of energy.

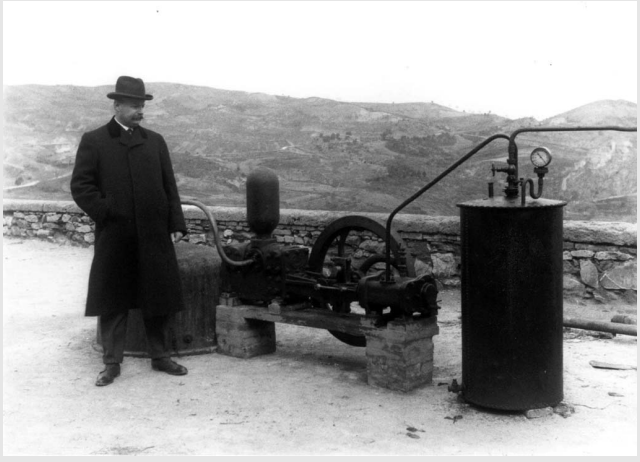
Main Problem of Geothermal Energy

Enormous amount of energy in total, but most of Earth is not warm enough in the accessible depth range.

Production of electricity requires advanced technologies (Organic Rankine Cycle or Kalina Cycle) at large parts of Earth.

History of Geothermal Energy Production

Larderello 1904 – First Geothermal Electricity



Source: Unione Geotermica Italiana

History of Geothermal Energy Production

The First Boreholes for Geothermal Heating

1926 Kalmath Falls, Oregon, USA

1928 Reykjavik, Iceland

The Biggest Geothermal Power Plant

1960 "The Geysers", California, USA: 750 MW_{el} (today)

Geothermal Energy Without Thermal Water ("Hot Dry Rock")

1978 Los Alamos, New Mexico, USA: 180°C, 4 MW_{th}

2008 Soultz-sous-Forêts, France: 5000 m, 175°C (rock 200°C), 13 MW_{th}, 1.5 MW_{el}

Types of Geothermal Systems

Classification According to Depth

Shallow: depth $< 400\,\text{m}$

- Not very expensive.
- Temperature is neither sufficient for producing electricity nor for direct heating; heating requires heat pumps.

Deep: depth $> 400\,\text{m}$

Classification According to the Type of Heat Exchange

Closed systems: closed fluid cycle in a heat exchanger

- Quite safe if some basic rules are obeyed.
- Achieved temperature is significantly lower than the reservoir temperature.
- Down to depths of about 3000 m.

Open systems: exchange of water with the reservoir

Types of Geothermal Systems

Classification of Deep Open Geothermal Systems

Hydrothermal systems: Use natural hydrothermal water; rare on Earth, but almost all geothermal power plants actually working are of this type.

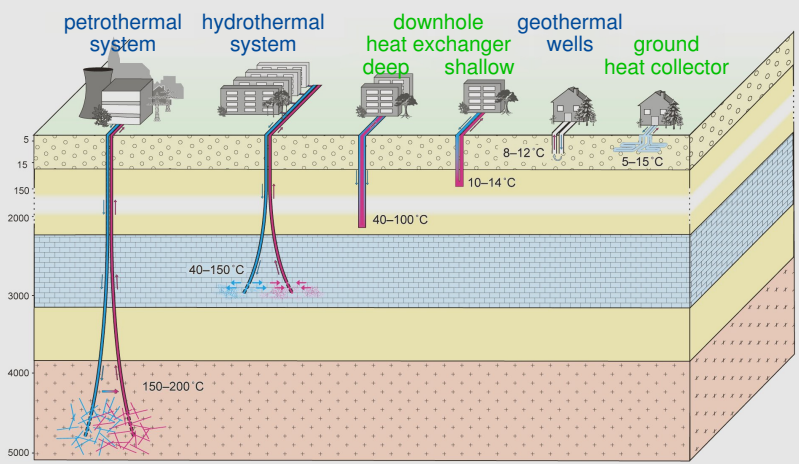
Petrothermal systems: Extract energy from rock without a high water content; formerly called "Hot Dry Rock"; abundant on Earth, but still a great challenge.

High-enthalpy resources: $T > 200°C$; production of electricity with steam possible; confined to specific geological conditions (plate boundaries, volcanic areas) and very rare on Earth.

Low-enthalpy resources: $T < 200°C$; production of electricity economically reasonable only with advanced techniques (Organic Rankine Cycle or Kalina Cycle).

Types of Geothermal Systems

Examples of Geothermal Systems



Source: Ingolstädter Kommunalbetriebe (modified)

The Three Mechanisms of Heat Transport

Radiation

- Does not require a medium.
- Only significant at very high temperatures.

Conduction

- Driven by spatial differences in temperature.
- Takes place in solids, fluids and gases.

Advection

- Heat is carried by a moving (flowing) medium.
- Called convection if flow of material arises from buoyancy due to thermal expansion.

The Three Mechanisms of Heat Transport

Predominant Mechanisms of Heat Transport

Type	Rock	Rock $\rightarrow$ Device	Device
hydrothermal	advection (driven + natural)	advection	advection
petrothermal	advection (driven)	advection	advection
closed	conduction (+ advection)	conduction	advection

Types of Geothermal Systems

Fields of Application

Hydrothermal systems: electricity and / or heating

Petrothermal systems: electricity

Closed systems: heating

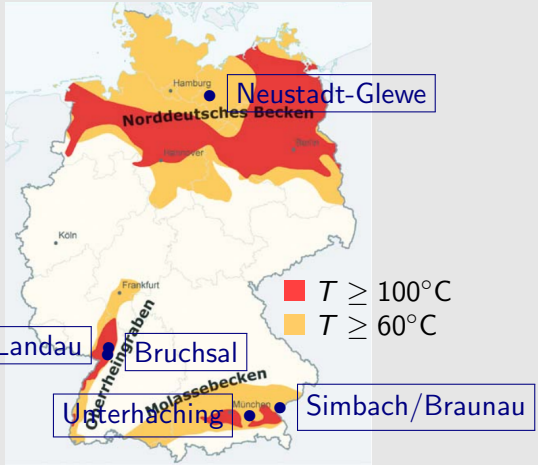
Main Problems

Hydrothermal systems: limited number of locations worldwide

Petrothermal systems: Driving water through the rock requires specific technologies (hydraulic fracturing) and consumes much energy.

Closed systems: Heat transport by conduction causes a temperature drop from the rock to the device.

Hydrothermal Potential and the First Power Plants in Germany



Source: Bundesverband Geothermie, Nutzungsmöglichkeiten der tiefen Geothermie in Deutschland (modified)