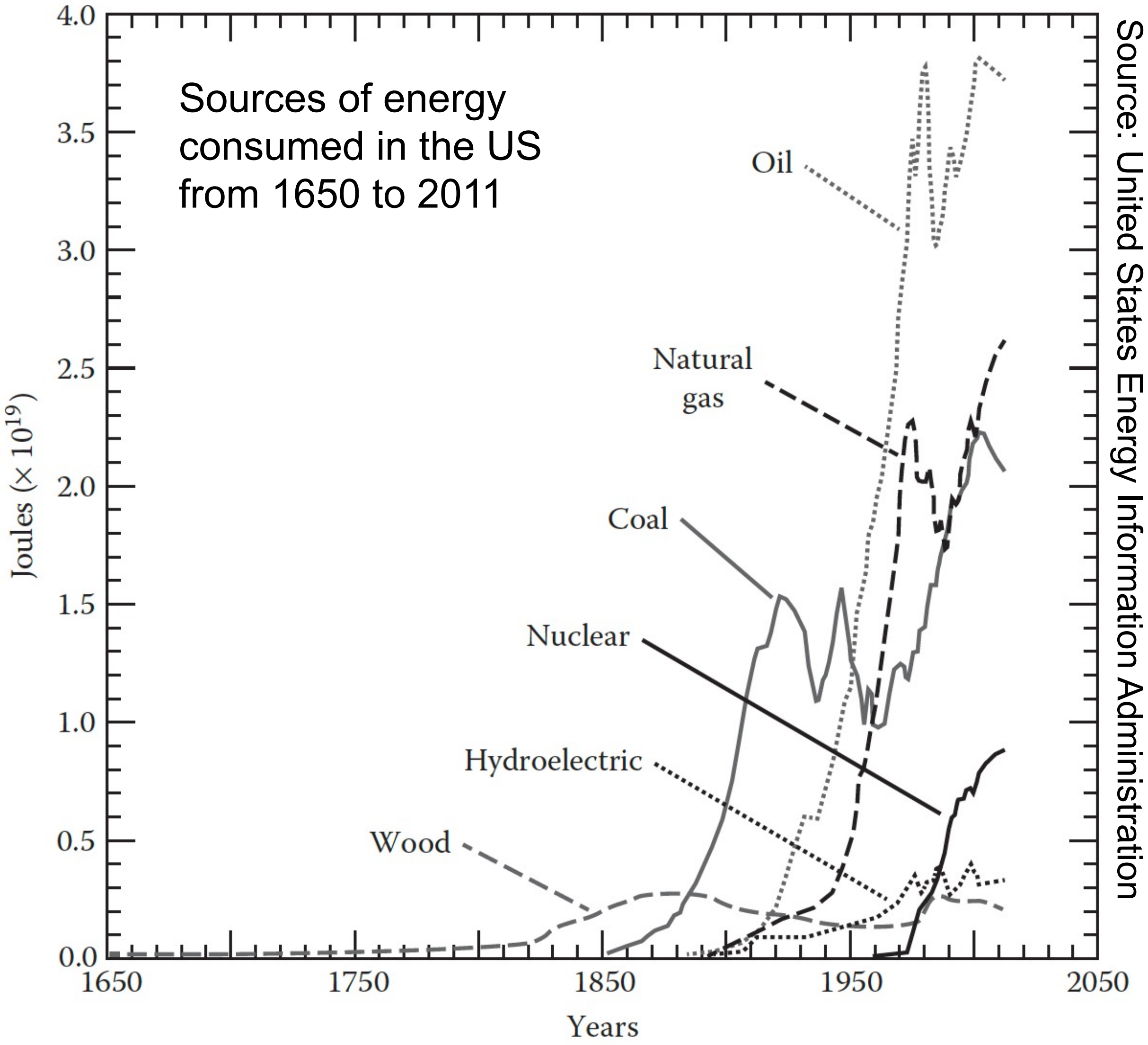
Geothermal Resource Development

Introduction

Fuel use through history

- Industrial activity and economic growth require access, control, and maintainence of fuel sources
- Example: 85% of the energy used in the US comes from wood, coal, oil and natural gas, which are not renewable resources
- Coal, oil, natural gas reserves take millions of years to form
- The rate of extraction far exceeds the rate of formation



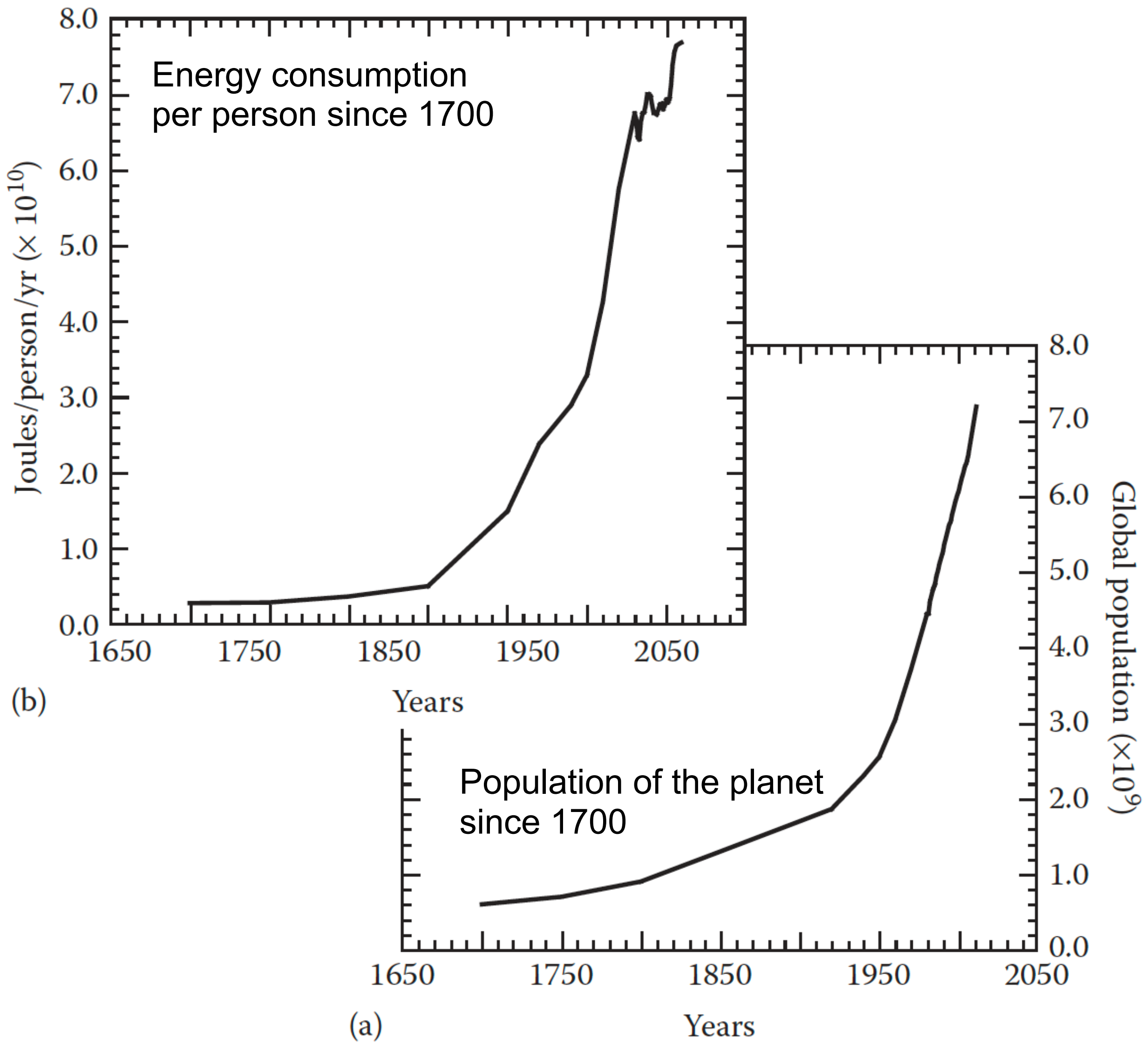
Source: United States Energy Information Administration

Population growth and per capita energy use

- Global population has increased by 5x between 1850 (1.3 billion) and 2010 (6.9 billion)
- Global population is projected to increase by 57% between 2000 and 2050
- Energy use per capita has increased by more than 15x between 1850 and 2010

Take home points:

- Global population is increasing
- EACH person uses more energy now than in 1850



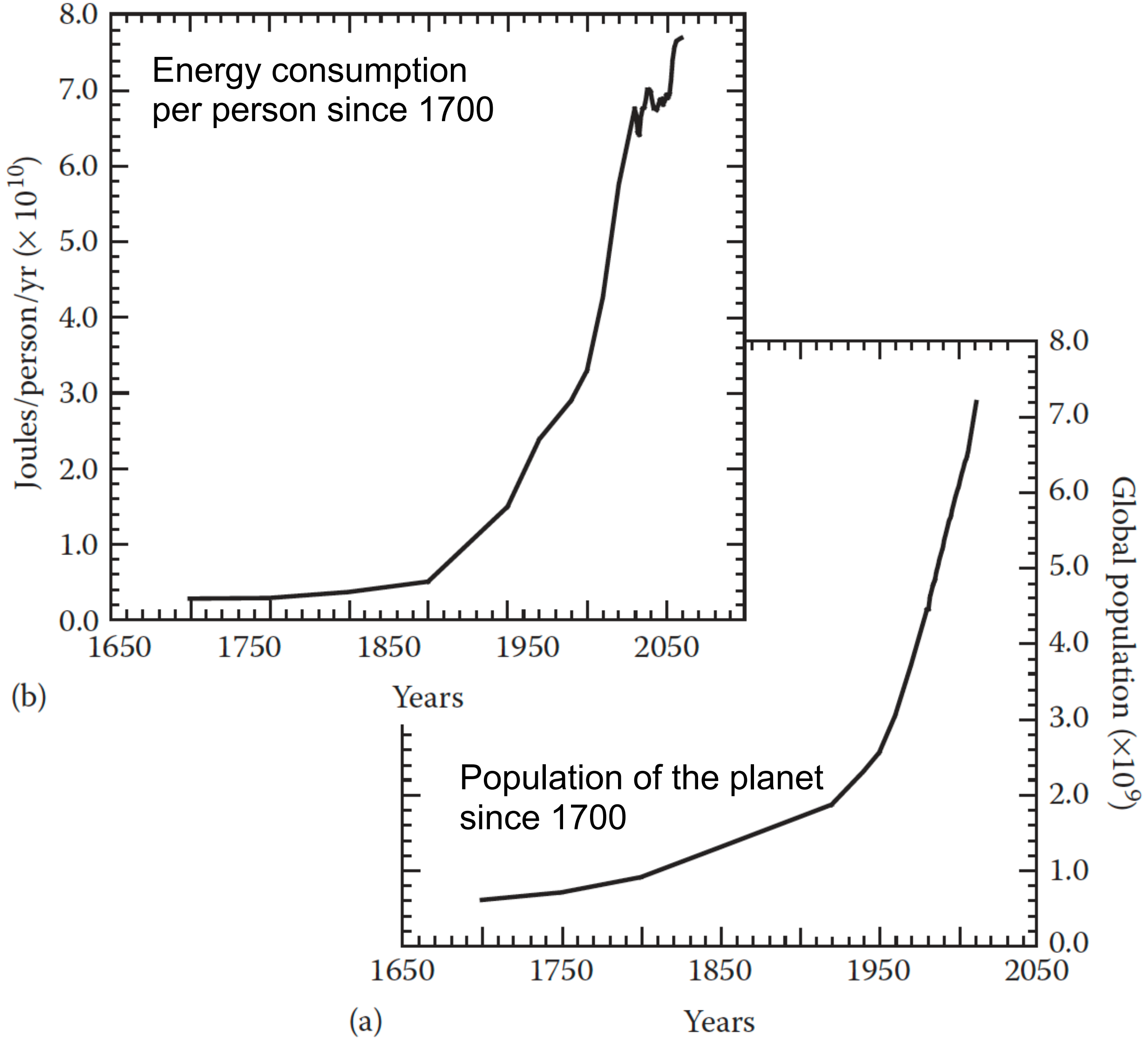
Source: Glassley, W. E., *Geothermal Energy*

Population growth and per capita energy use

Loss of access to energy has societal, economic, industrial, and political implications.

Examples:

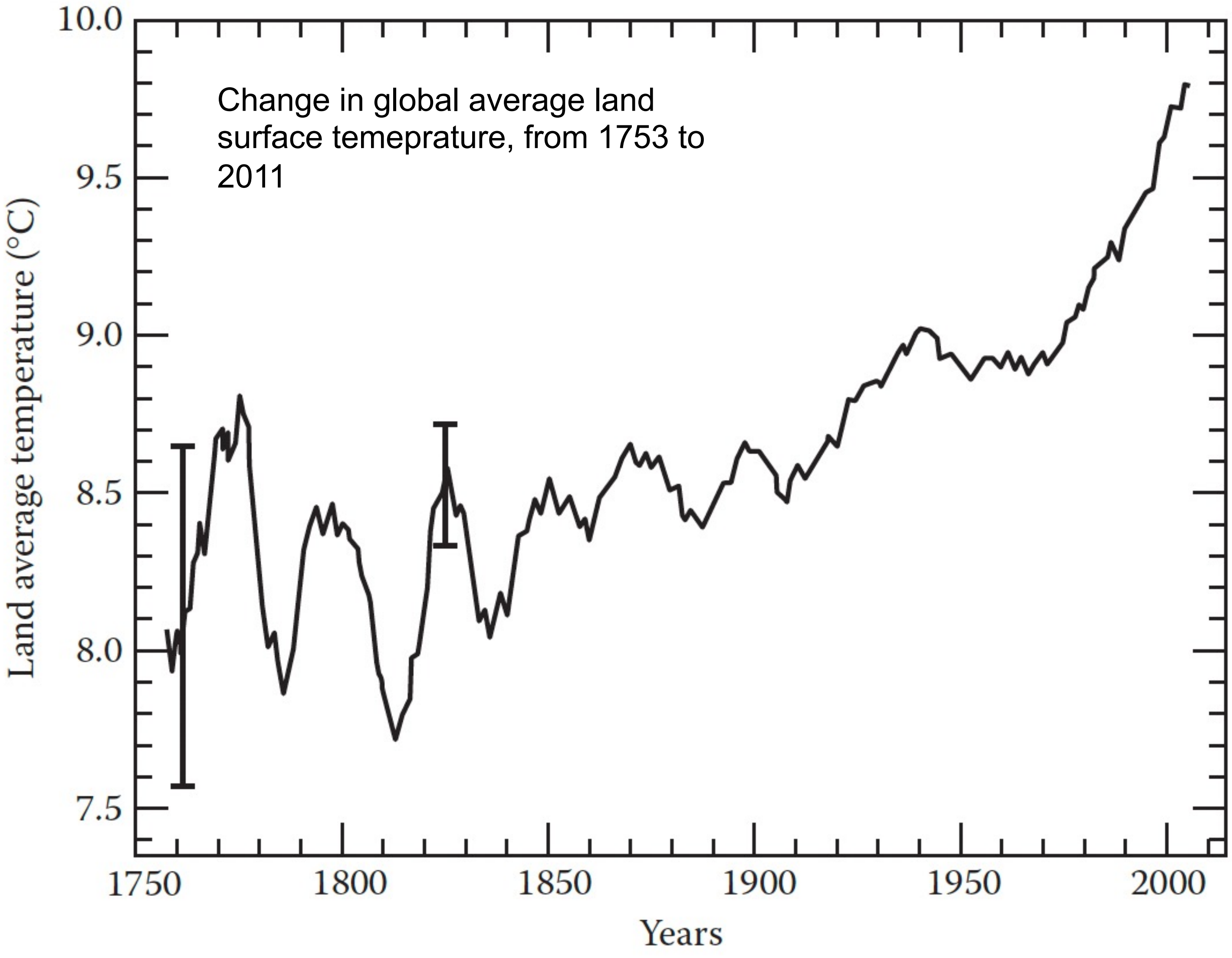
- 1973 oil crisis
- 1979 oil crisis
- 2007/2008 oil shock
- 2022 energy crisis



Source: Glassley, W. E., *Geothermal Energy*

Greenhouse gas emissions

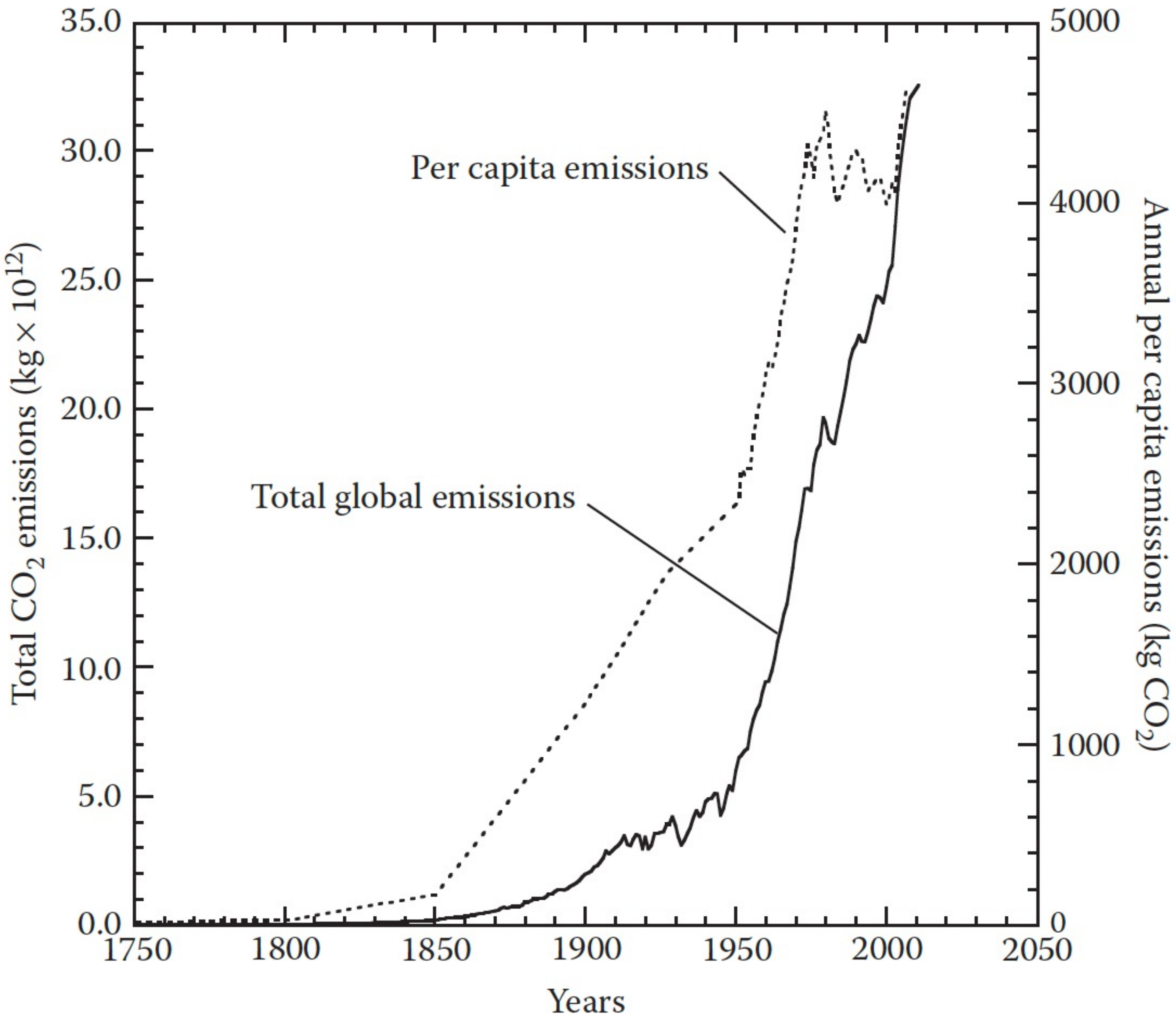
- Carbon-based fuels increase greenhouse gas (CO_2, CH_4) concentration in the atmosphere
- Greenhouse gases reduce the transmissivity of the atmosphere to thermal energy: the atmosphere traps heat
- Surface temperature increases



Source: Rohde et al. (2013) *Geoinformatics & Geostatistics: An Overview*

Greenhouse gas emissions

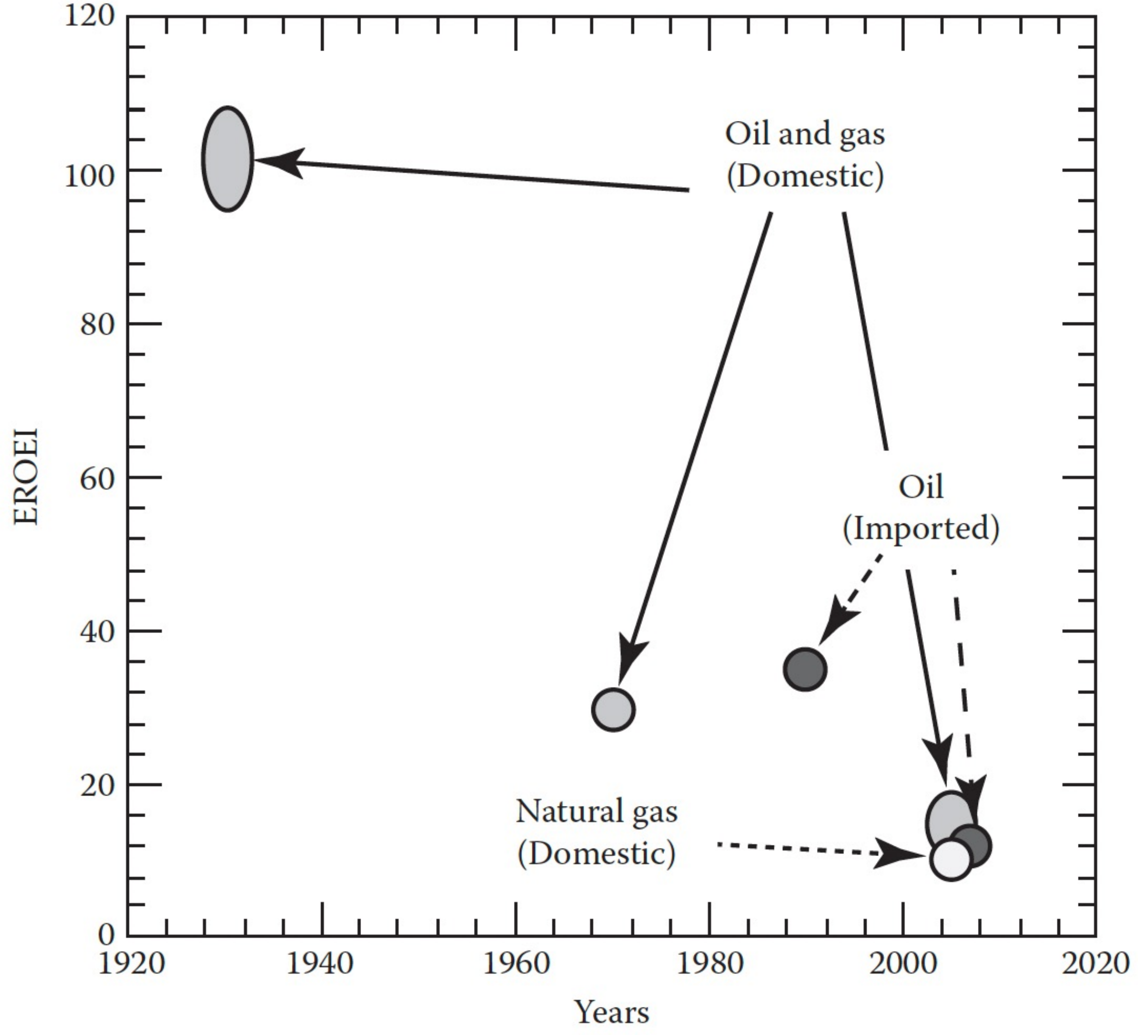
- Total global CO_2 emissions from burning fossil fuels increased by 16x between 1750 and 2011
- Per capita CO_2 emissions increased almost 30x between 1750 and 2011



Source: Glassley, W. E., *Geothermal Energy*

EROEI: Energy Returned On Energy Invested

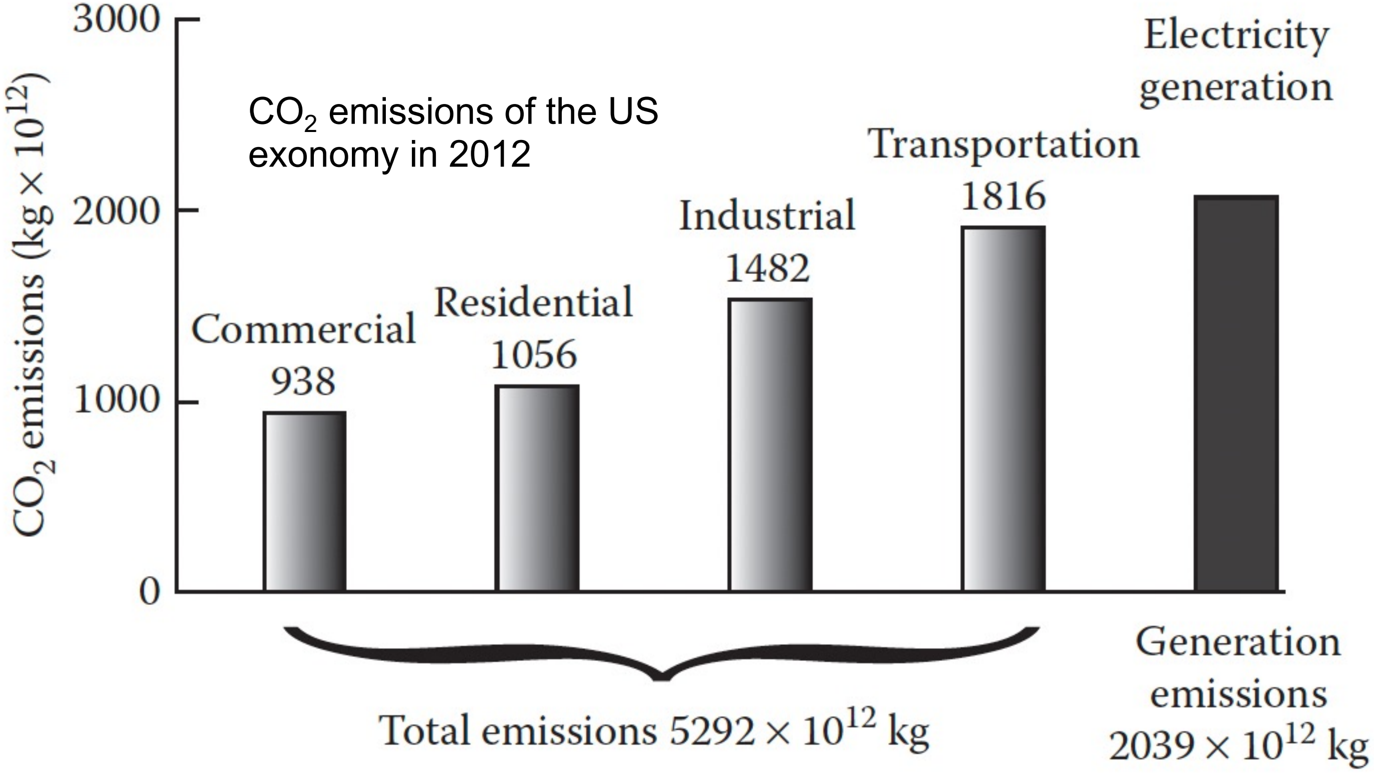
- You need to use energy to produce energy
- EROEI: $\frac{\text{Energy obtained from an energy source}}{\text{Energy expended in exploiting an energy source}}$
- EROEI is difficult to quantify and to normalise across all energy resources globally:
  - **Example of oil production:** Energy invested in exploiting the resource includes initial resource exploration, drilling wells, pumping oil, transporting oil to a refinery, processing oil at refinery, transporting fuel to distribution stations, environmental maintenance, cleanup of site post-production or in case of spill, marketing
- EROEI drops as fuel becomes more difficult to access



Source: Glassley, W. E., *Geothermal Energy*

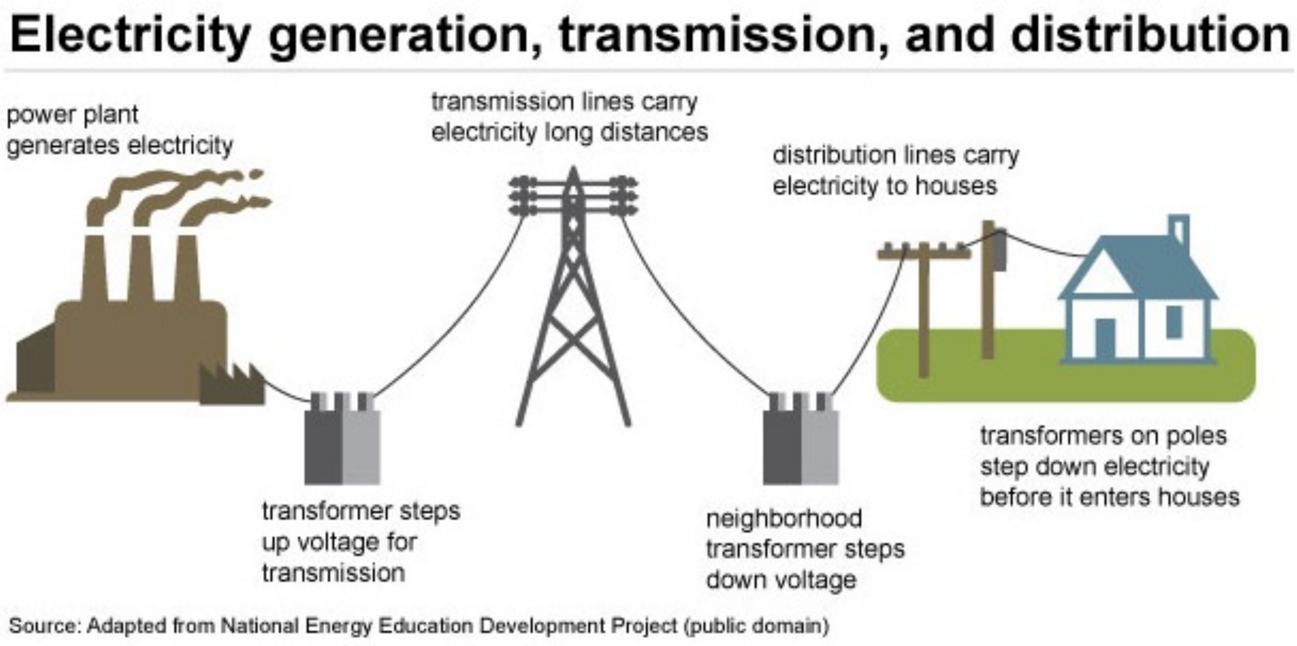
What do we use energy for?

- Total CO_2 emissions in the US in 2012: 5292×10^{12} kg
- >50% of CO_2 emissions result from generation of electricity for:
  - Commercial
  - Residential
  - Industrial
  - Transportation sectors
- Electricity generation accounts for >50% of all greenhouse gas production



Source: Glassley, W. E., *Geothermal Energy*

Supplying electricity to the power grid



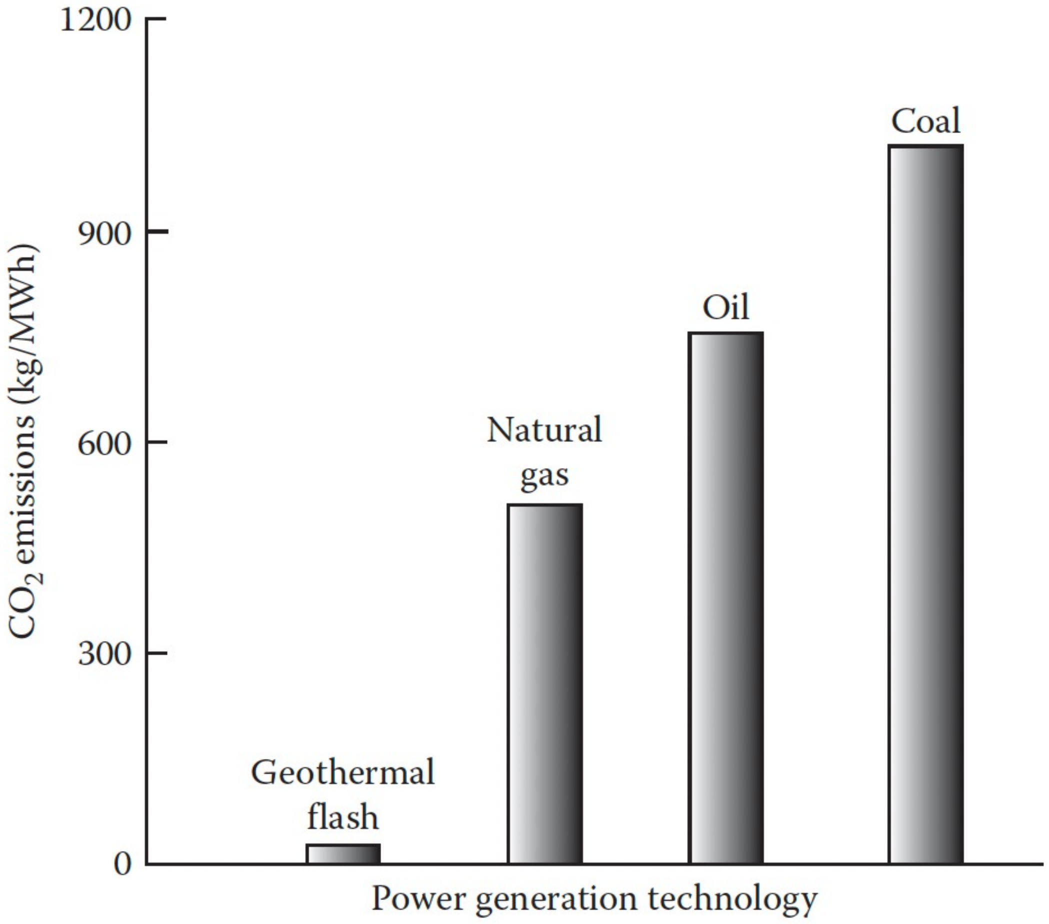
- Electrical grid links power generators and power users
  - A system of distribution and transmission lines
- Commonly segmented into regions supplied and administered by operators and regulators

Supplying electricity to the power grid

- **Base load:** Minimum amount of power a supplier must make available to customers
  - Quantity is informed by the historical record
- **Peak load:** Load placed on grid by immediate conditions experienced at the moment, in excess of the baseload
  - Affected by extremes in weather, local emergencies
  - Peaking capacity is the capacity to meet this temporary increase in load (also informed by historical records)
  - The capacity of the grid is generally designed to exceed the peak load estimate by a few percent
- **Load following:** Ability to respond to changes in demand for power
  - Ability to increase power output on a timescale of minutes to tens of minutes
  - Power distributors must have generating plants capable of relatively rapid changes in power output **or** can buy power at short notice from suppliers

How do we reduce our reliance on fossil fuels

- Reduce demand for electricity
- Replace fossil fuel-based electricity generation with renewable energy sources
- Replace liquid fossil-fuels with other forms of portable energy sources



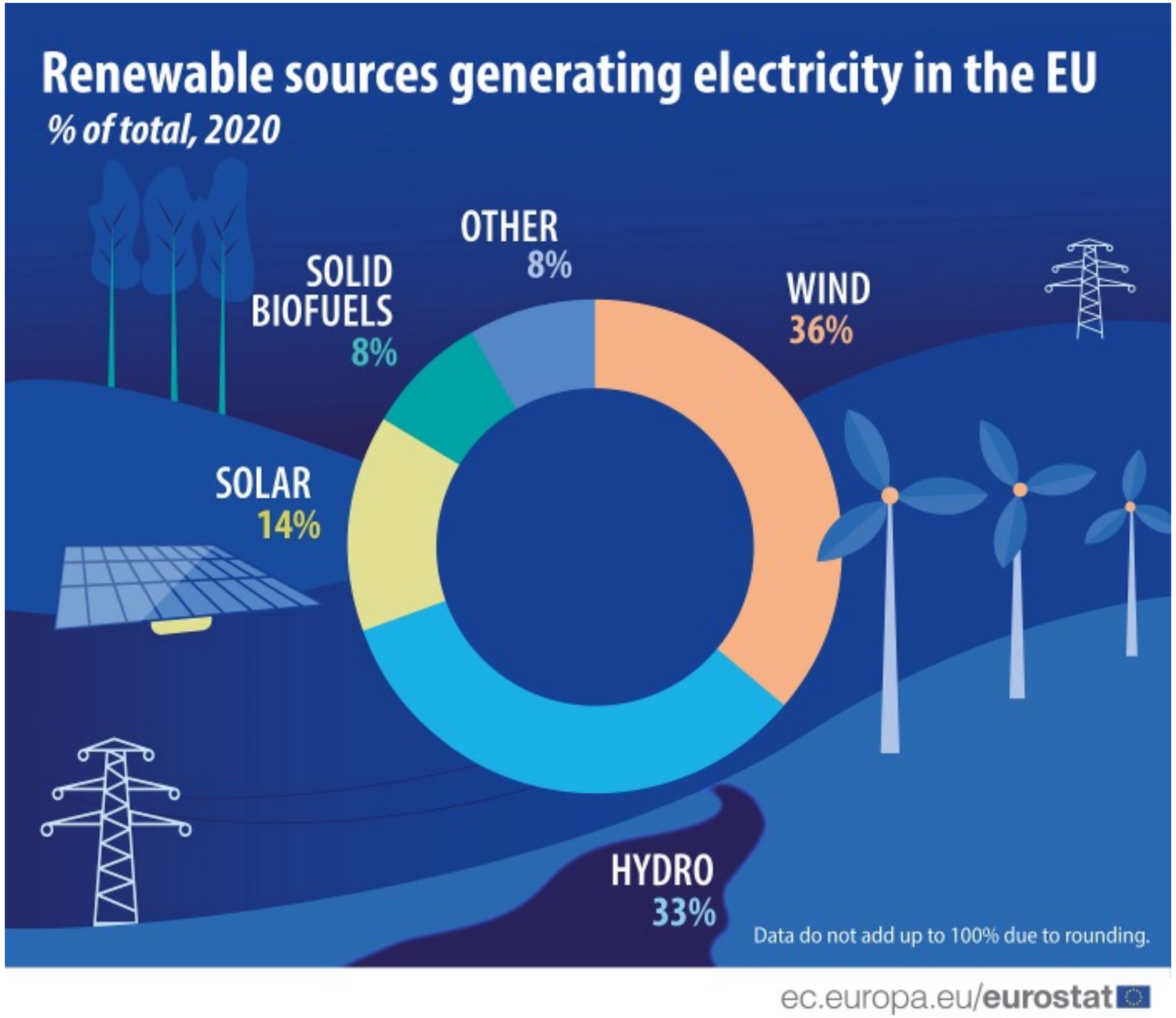
Source: Glassley, W. E., *Geothermal Energy*

Replacing fossil fuels

To replace fossil fuels, new fuel sources need to meet certain criteria:

- Sufficiently abundant to meet a significant percentage of the market demand
- Obtained at a cost competitive with existing energy sources
- Reduce or eliminate greenhouse gas emissions
- Renewable: is it self-replenishing?

In 2020, renewable energy generated about 37% of all electricty in the EU



Replacing fossil fuels

Solar and wind energy are intermittent:

- Their output does not remain constant due to diurnal and seasonal variations

Geothermal energy is not intermittent:

- Can be used as a baseload power source and, with management, can be dispatchable

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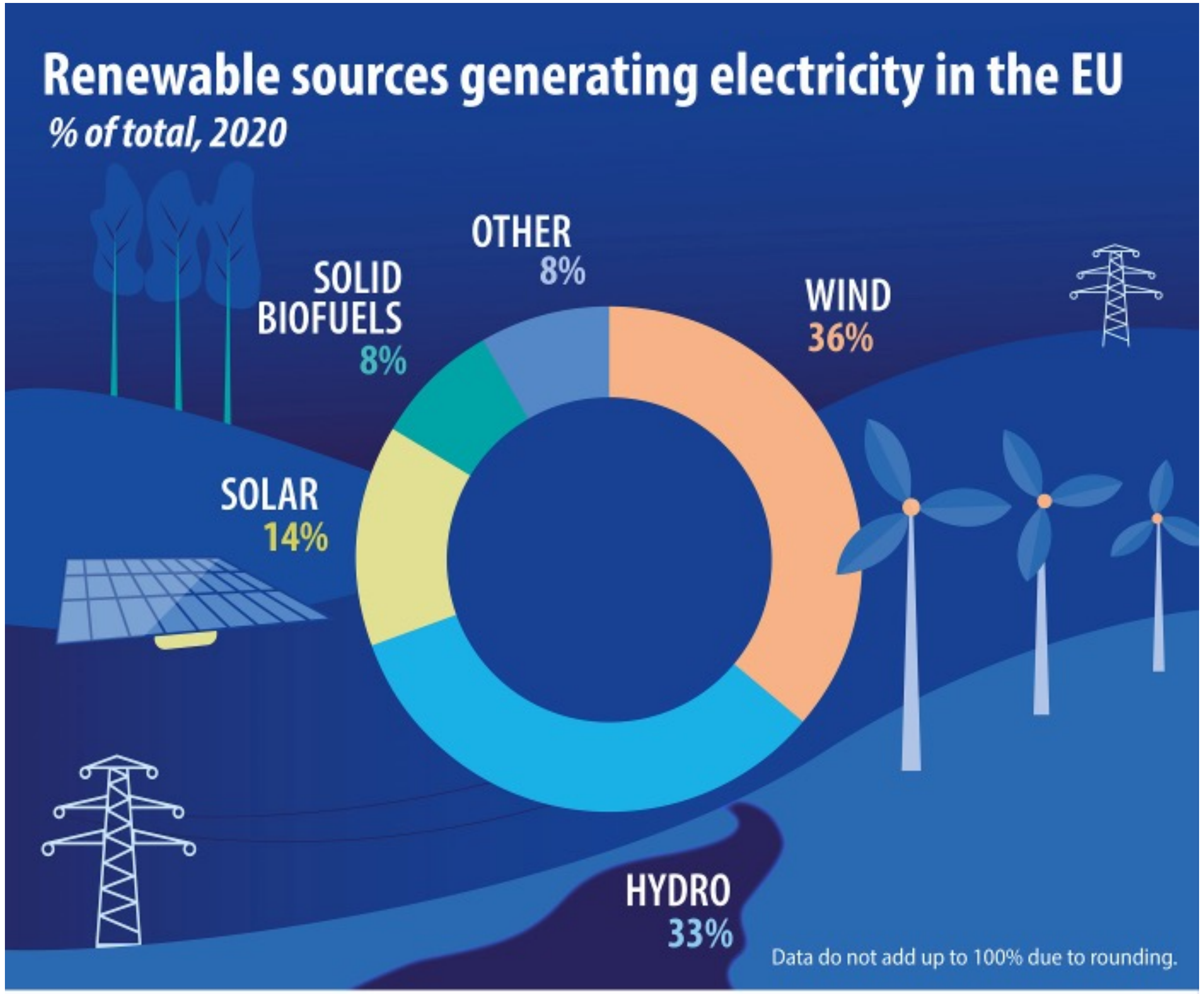
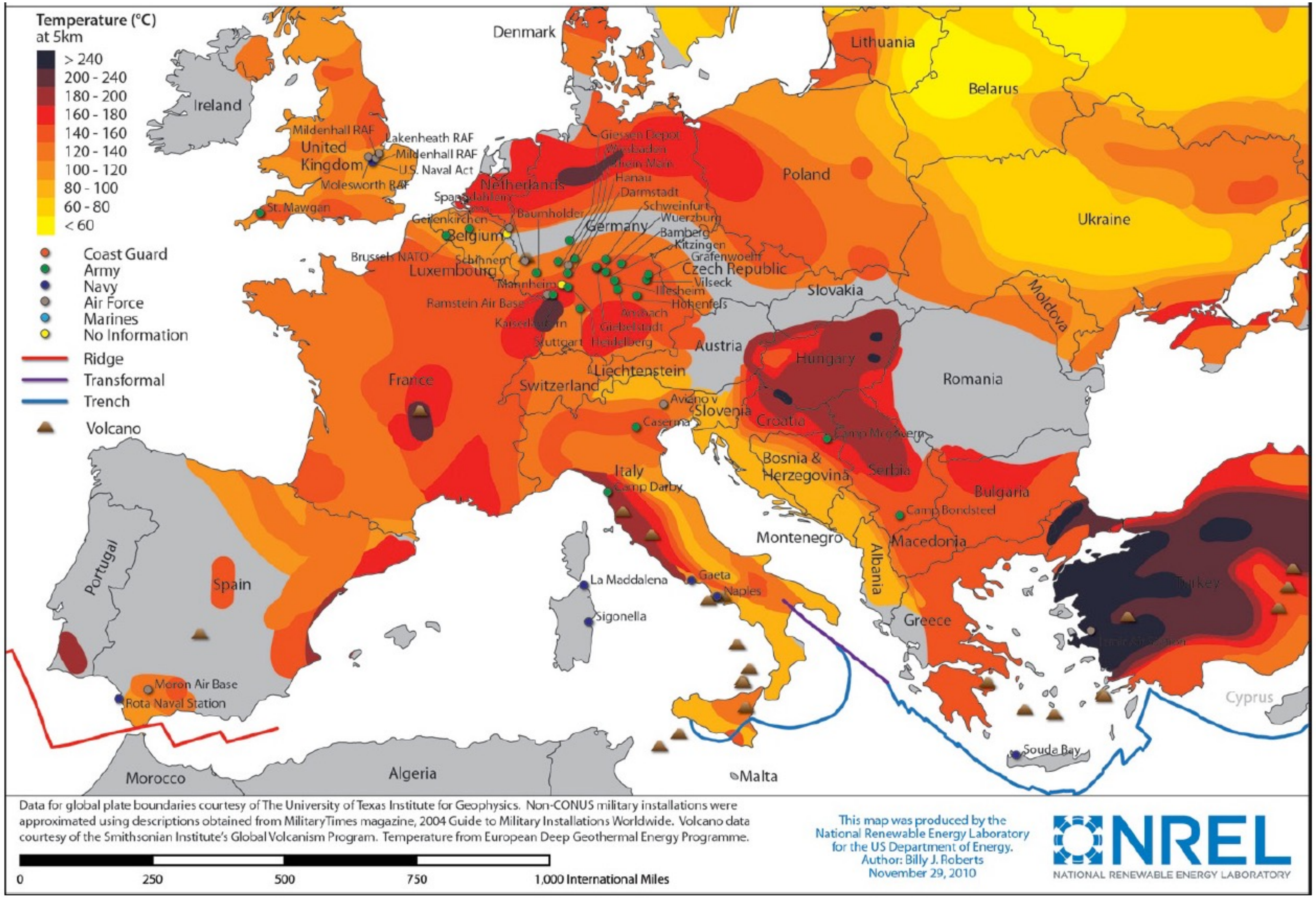


ec.europa.eu/eurostat

What is geothermal energy?

- Heat constantly radiates from the Earth's surface into space
- 1% of the total energy that radiates into space is heat that comes from the Earth's interior



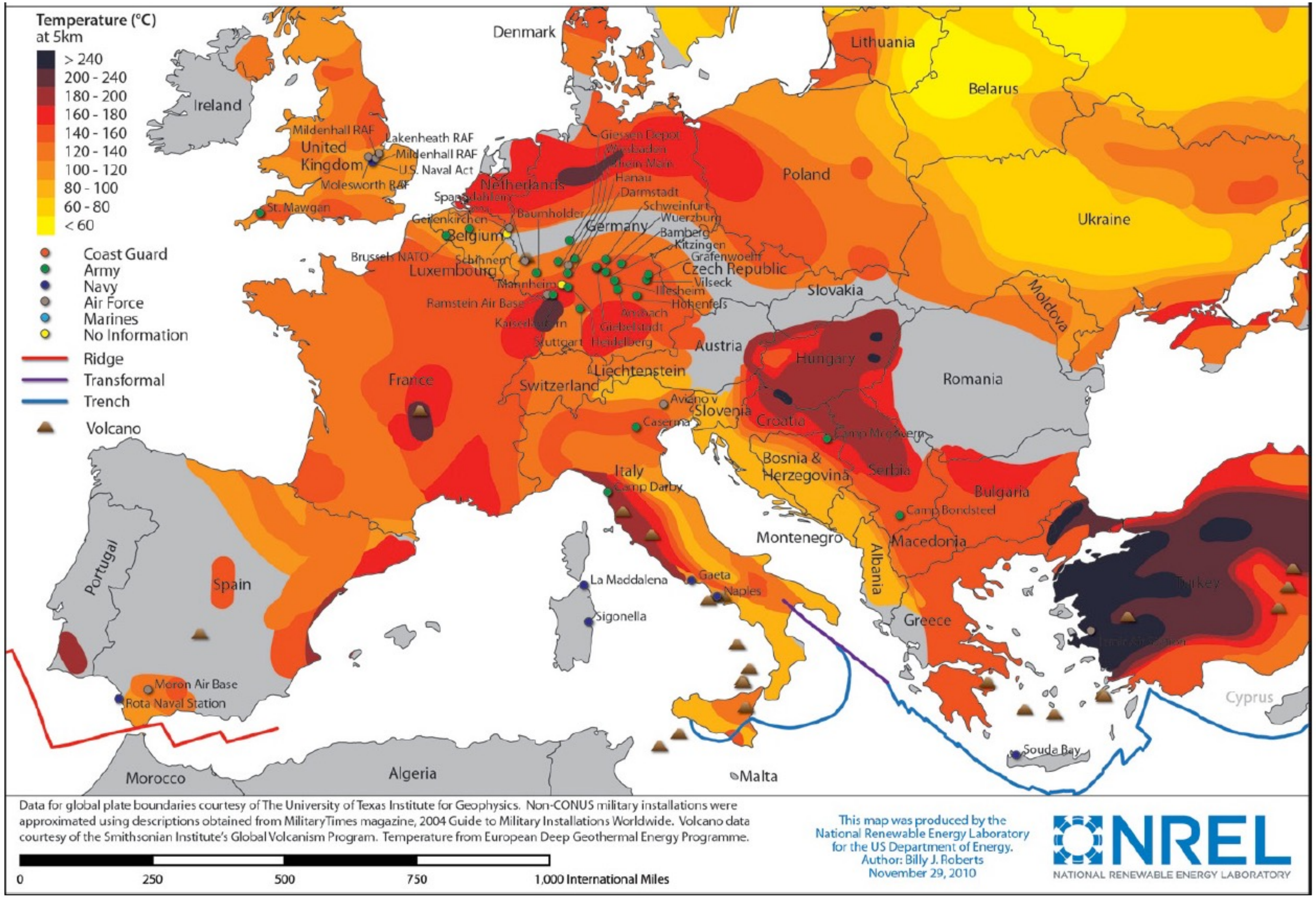
What is geothermal energy?

Geothermal energy:

Remnant heat from the formation of the planet 4.5 billion years ago

+

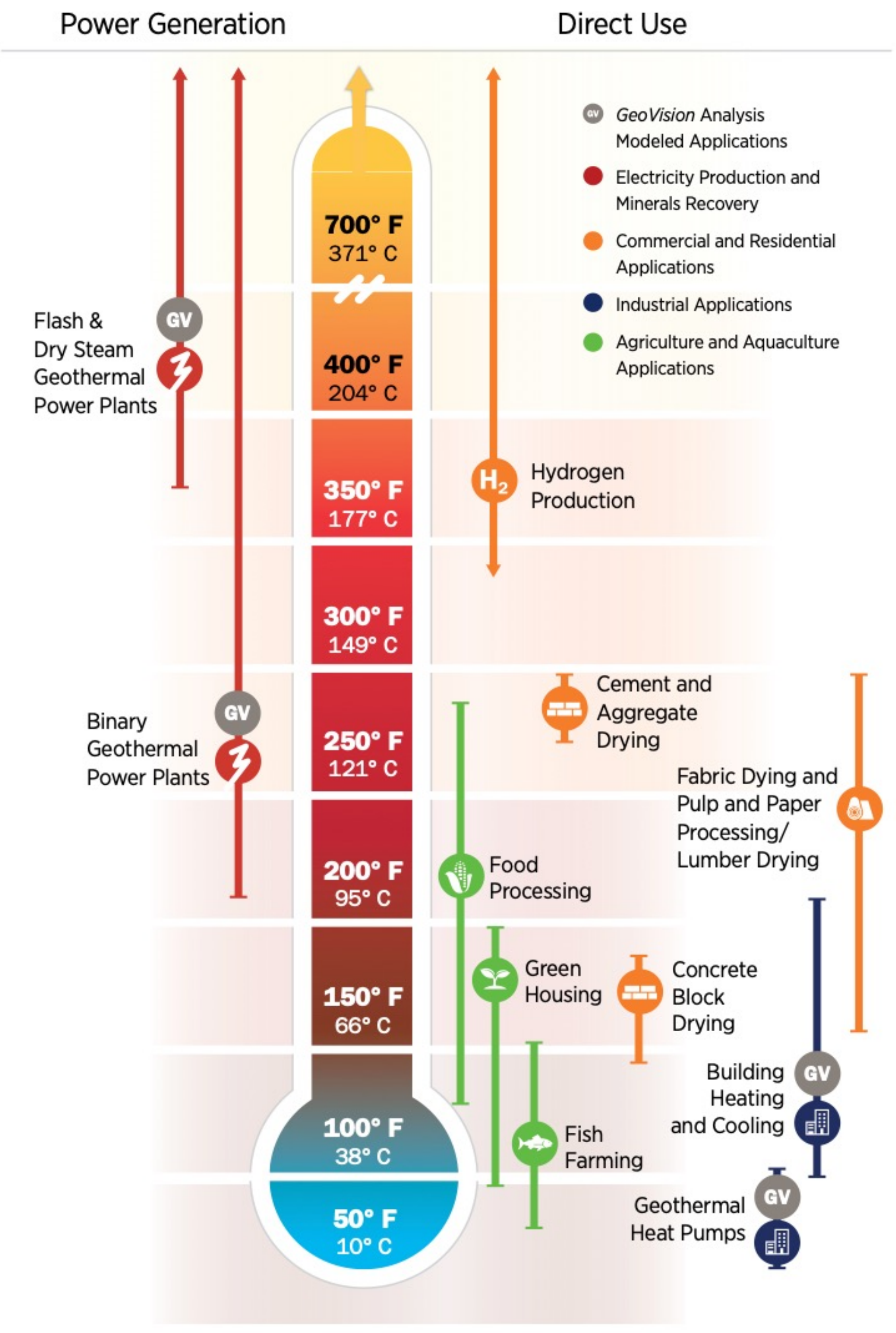
Radioactive decay of naturally occurring radioactive species



Role of geothermal energy

- Direct heat use:
  - Moderate heat flow
  - Direct heating and cooling of buildings can reduce the electrical demand on heating, ventilation, air conditioning, and cooling (HVAC)
  - Other uses: food processing, drying materials, aquaculture, agricultural activities, greenhouses, paper manufacturing…

- Electricity generation
  - High heat flow
  - Depends on geological context: only 30% of the geographical area of the US can support electricity generation
  - New technologies being developed to increase geographical extent of electricity generation



Source: US Department of Energy, *U.S. GeoVision report, Chapter 2, p. 14*

Global heat production in 2010: Electricity

Courtesy of C. Dezayes, 2021

In 2010:

25 countries

10.7 GWe

Predicted 2015:

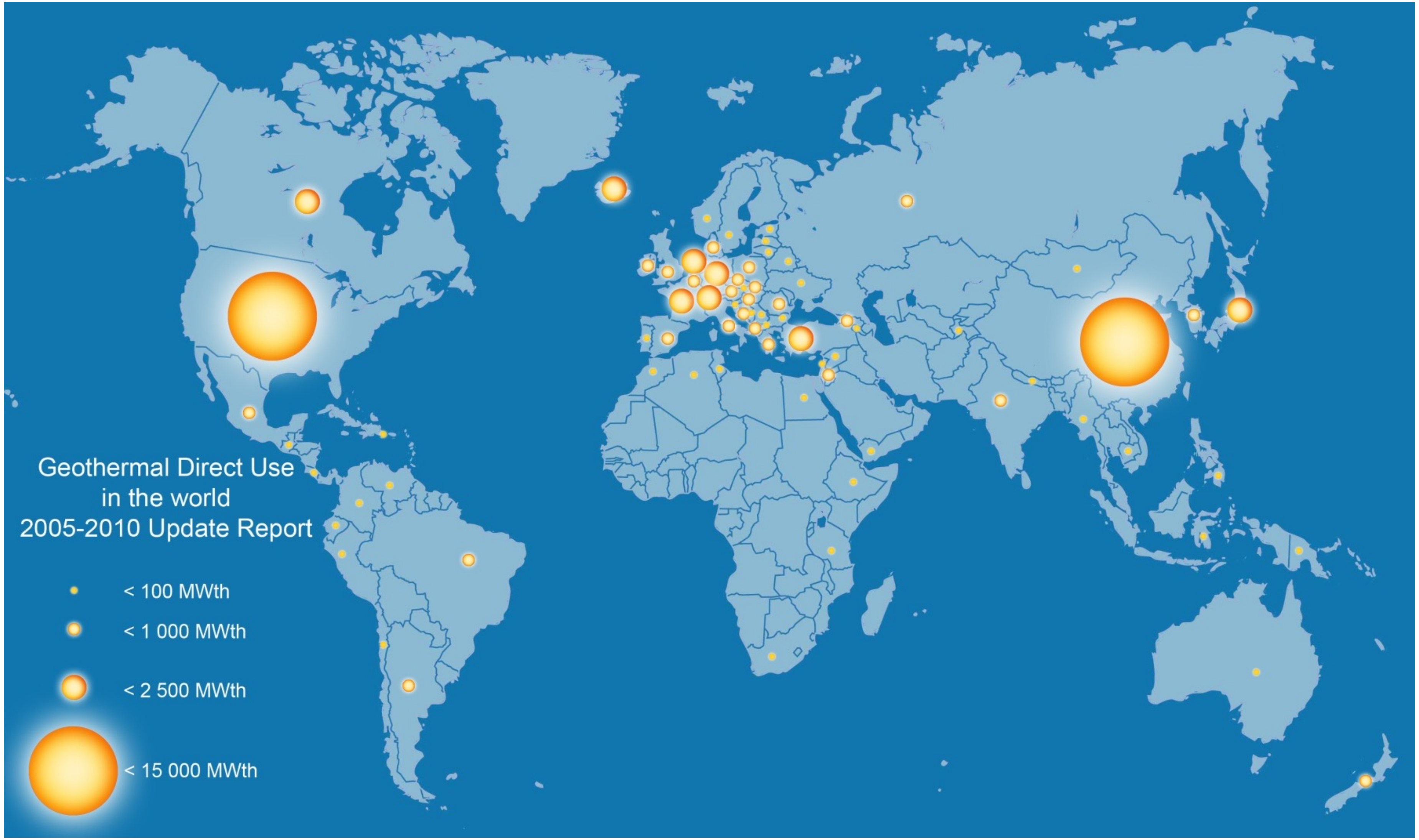
18.5 GWe

Predicted 2050:

70 GWe

(Bertani, 2010)

Global heat production in 2010: Heat



Courtesy of C. Dezayes, 2021

In 2010:

78 countries

43 GWth

Uses:

Greenhouses

Aquaculture

Residential heating

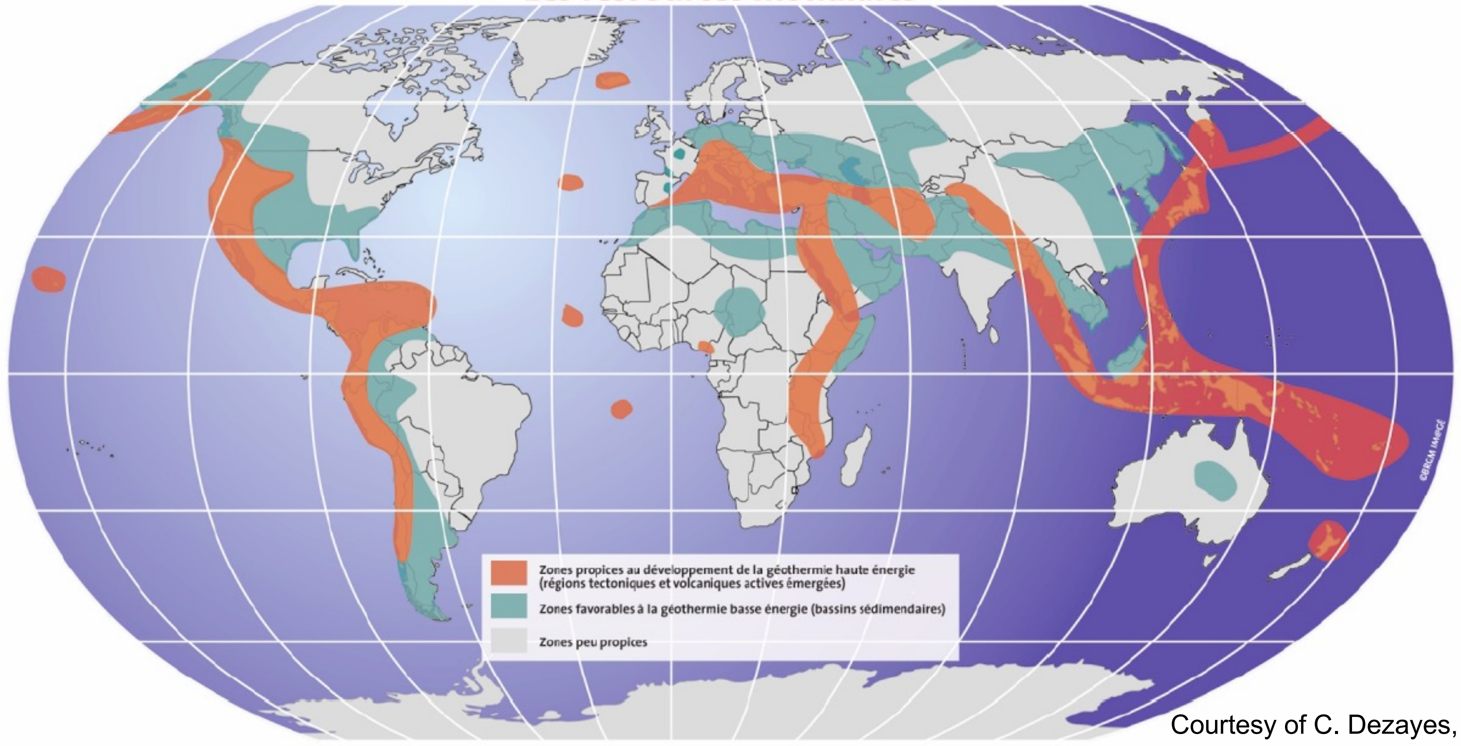
District heating

Global geothermal potential

The International Energy Agency (IEA 2005) estimates that global geothermal capacity is equivalent to 4.5 million MW.

Global energy production from all resources was 14.7 million MW in 2005.

Geothermal can contribute a quater of all global power production.



Courtesy of C. Dezayes, 2021

Low temperature resources
Heat production

High temperature resources
Electricity production

Course description

Part I: The Basics

Week 1 (September 11): Introduction / Heat production in the Earth

Week 2 (September 18): Thermodynamics recap

Week 3 (September 25): Subsurface fluid flow

Week 4 (October 2): Geochemistry – **Assignment 1 due**

Part II: Exploration to production

Week 5 (October 9): Exploration methods: Geochemistry

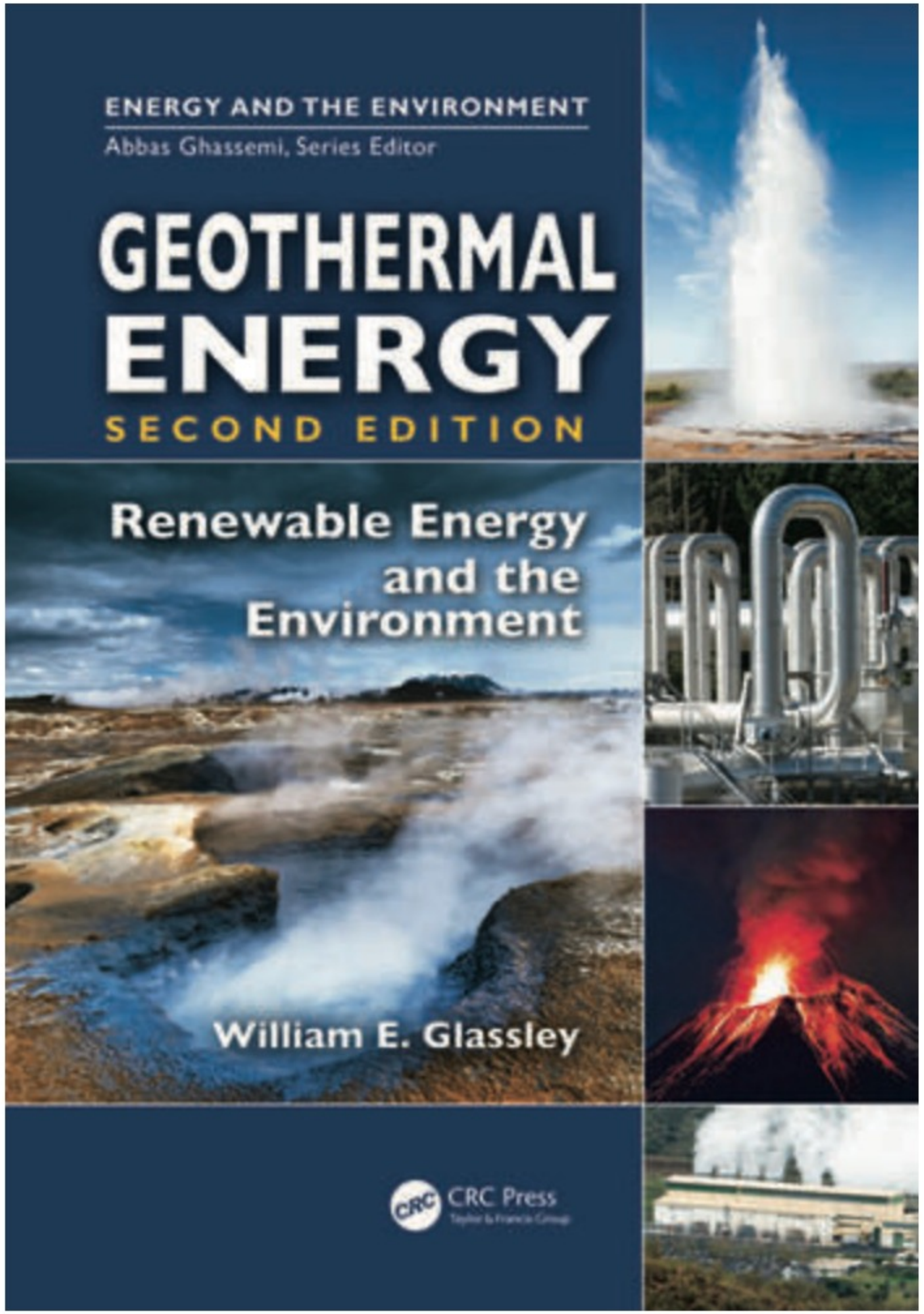
Week 6 (October 16): Exploration methods: Geophysics – **Assignment 2 due**

Mid-term break (October 23)

Week 7 (October 30): Resource assessment / Drilling

Week 8 (November 6): Generating power using geothermal – **Assignment 3 due**

*Lectures subject to some change, based on course progress.



Course description

Part III: Specific geothermal types and associated environmental, societal, and economic impacts

Week 9 (November 13): Direct-use / Enhanced Geothermal Systems

Week 10 (November 20): Enhanced Geothermal Systems – **Assignment 4 due**

Week 11 (Novemer 27): Societal impacts / Environmental impacts

Week 12 (December 4): Economics of geothermal systems – **Assignment 5 due**

Week 13 (December 11): Oral exam preparation

Week 14 (December 18): Oral exam

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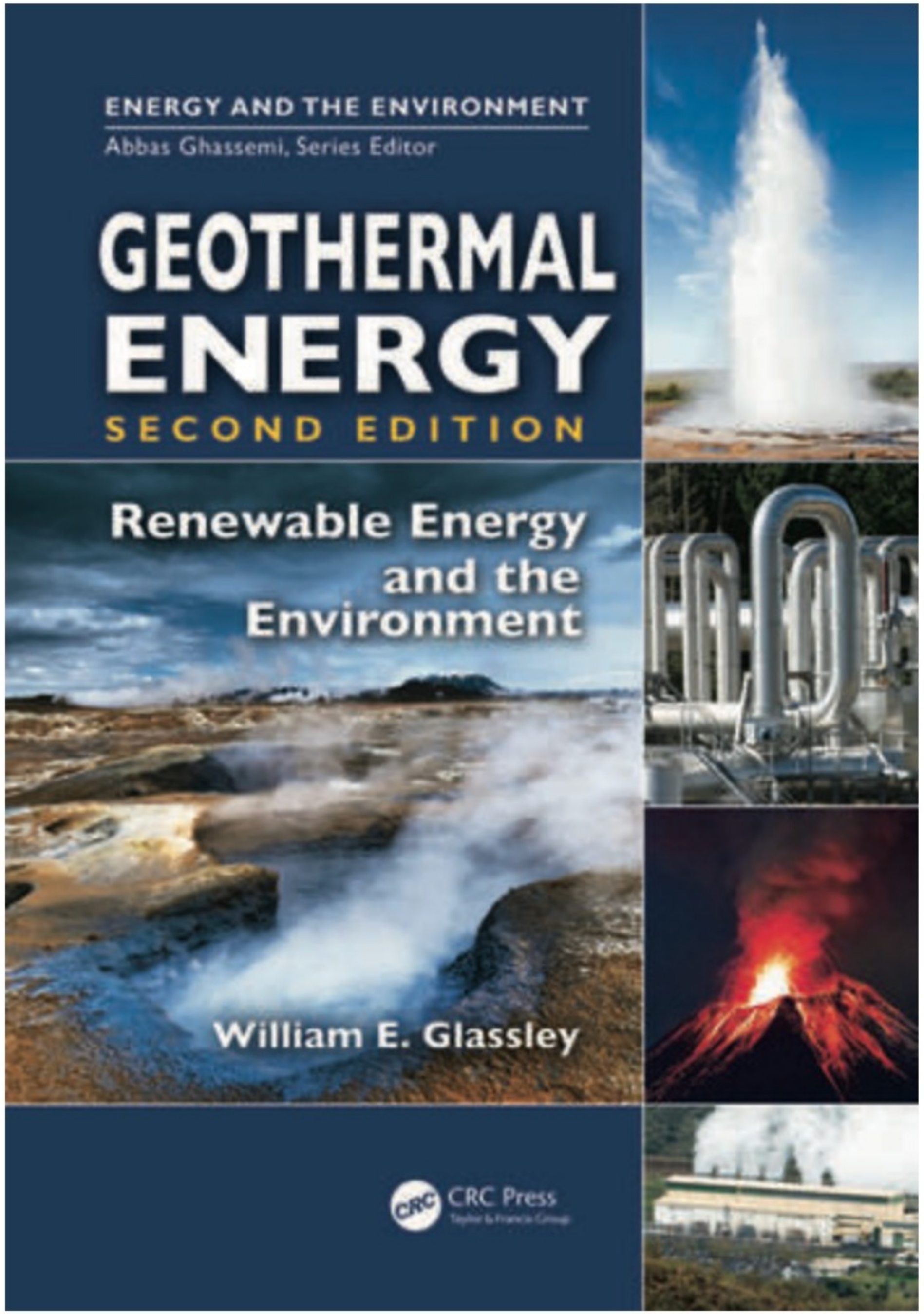

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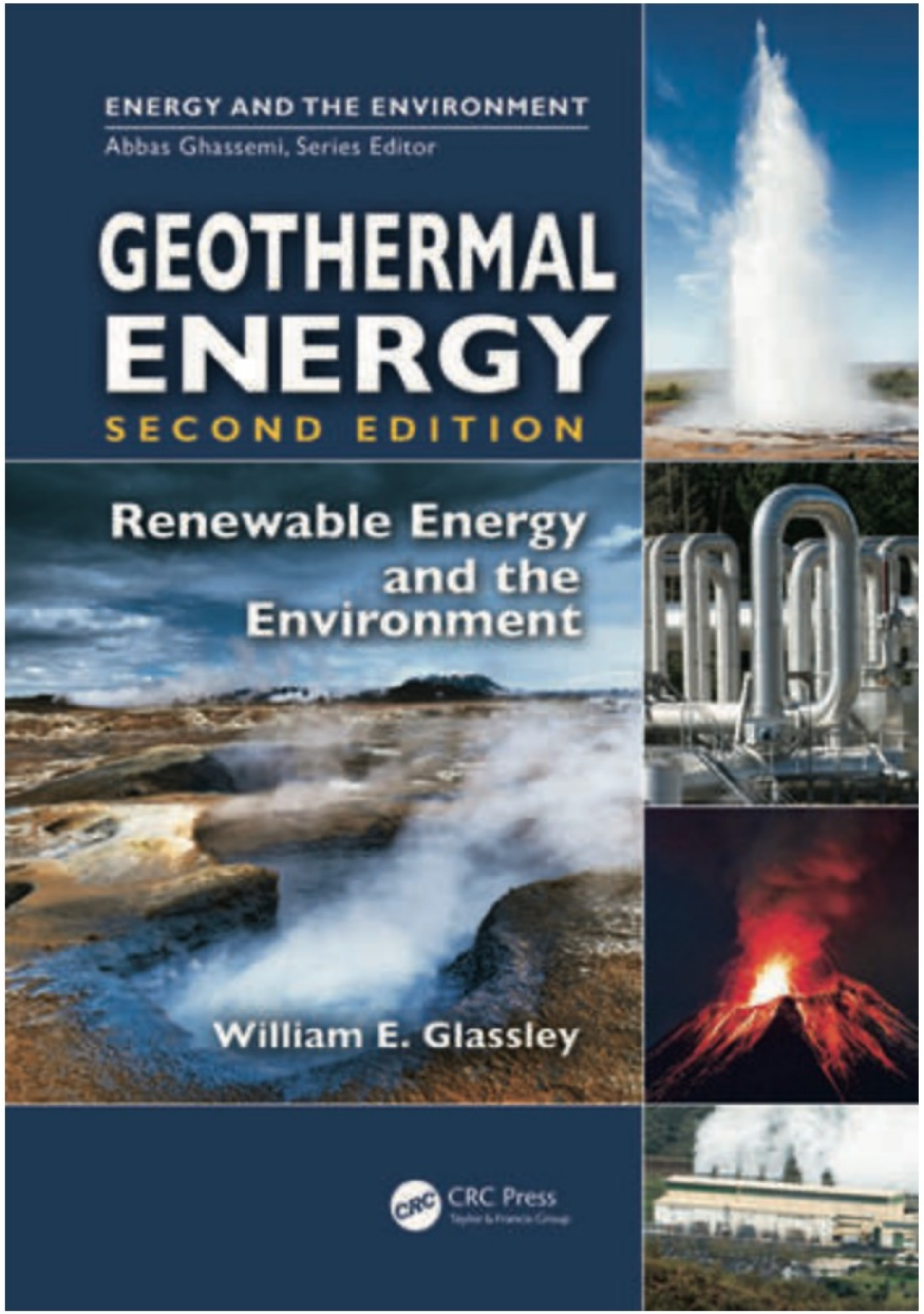

Course administrative details

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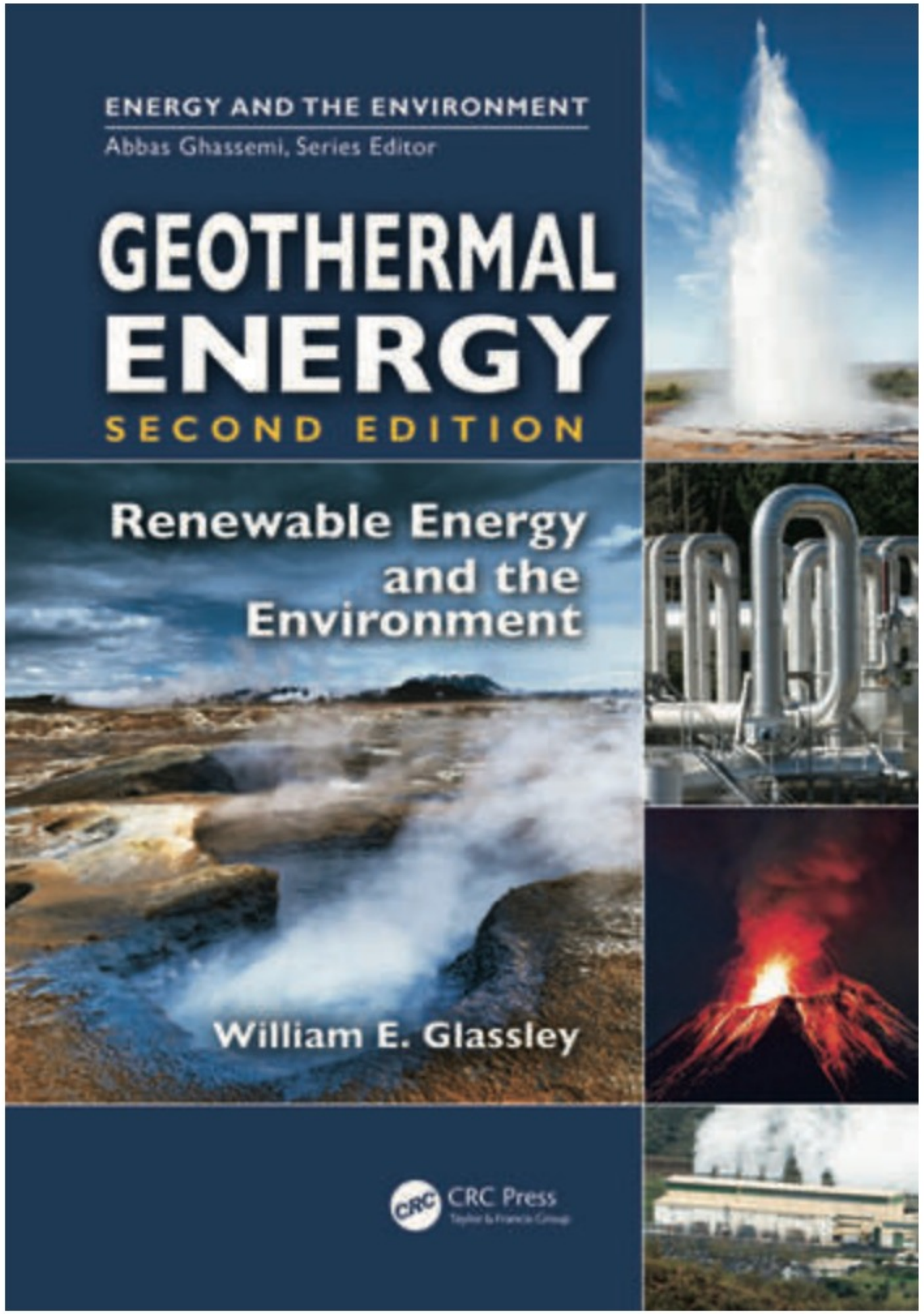
GC D0 393

3 credits

2 hours lecture, 1 hour exercises per week

90h workload



Course assessment

50% Bi-weekly assignments

- To be handed in individually

50% Oral exam

- Poster exam, done in pairs or groups of 3, depending on class size
- 3 hours preparation
- 3 hours for presentations: 10 minute presentations per group, plus 5-10 minutes of questions from the entire class