



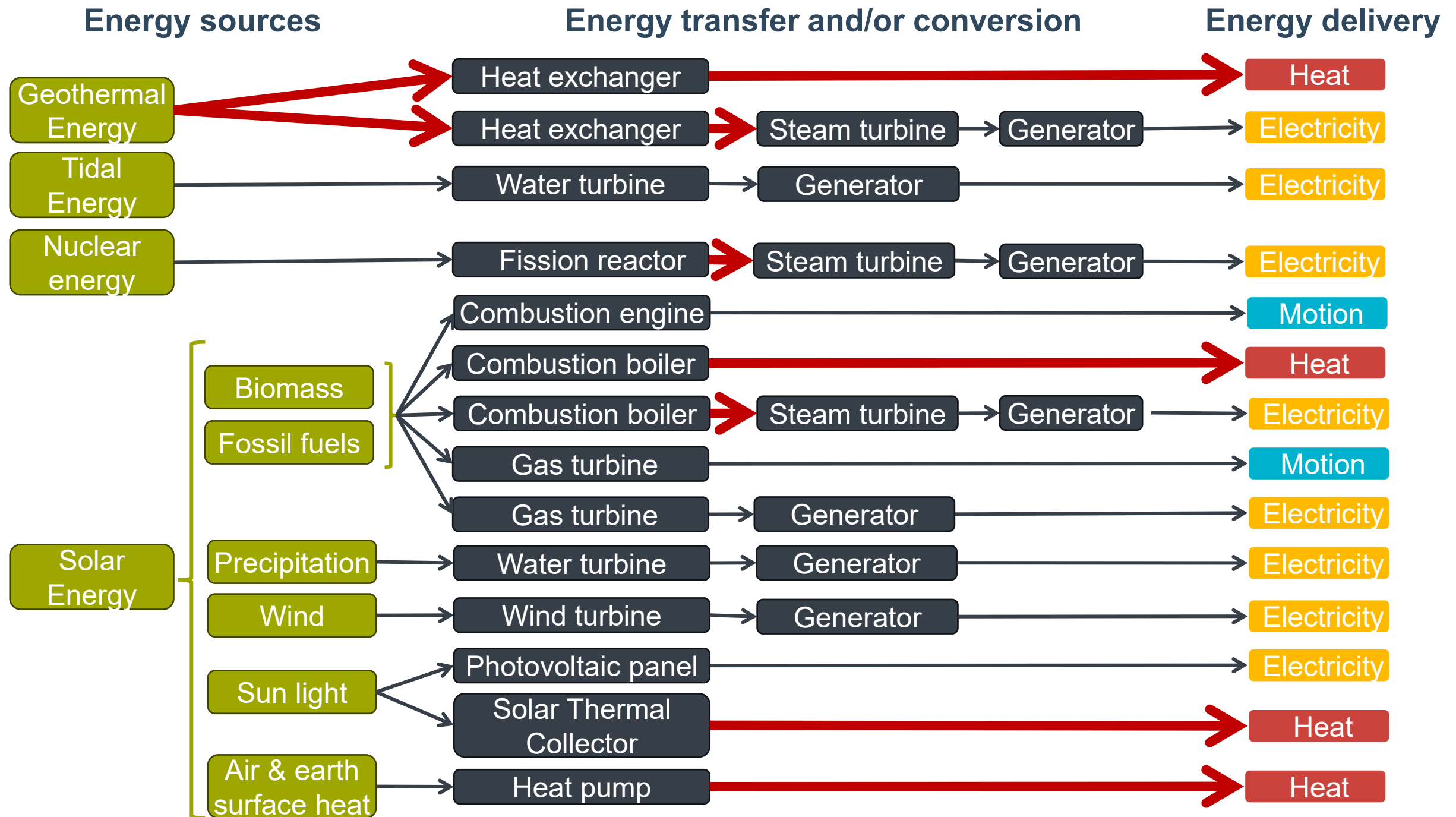
Heat Delivery

Renewable Energy Integration in the Energy System

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Research Group Energy in Transition

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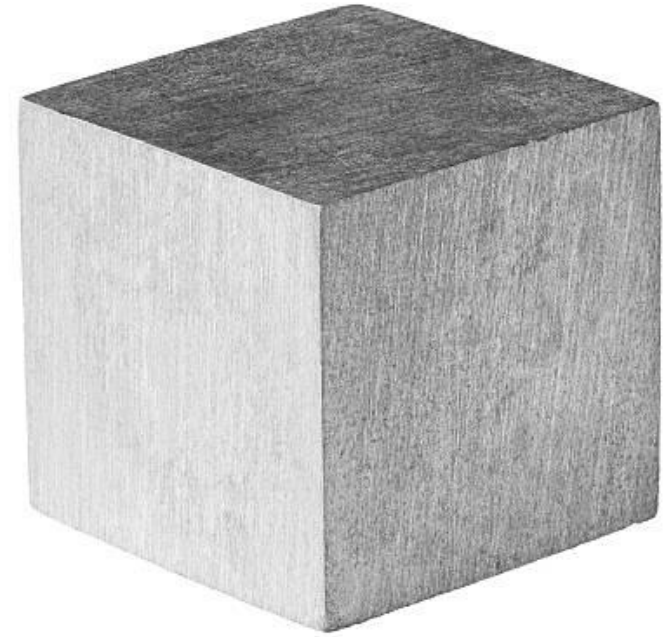
Thermal energy

$$E_{thermal} = Q = m \cdot c_p \cdot \Delta T$$

$$m = mass [kg]$$

$$c_p = specific\ heat \left[\frac{J}{kg \cdot K} \right]$$

$$\Delta T = difference\ of\ temperature [K]$$



Temperature

Kelvin [K]	Celsius [°C]	Fahrenheit [°F]
0	-273,15	-460
273,15	0	32
373,15	100	212

- $^{\circ}\text{C} = (^{\circ}\text{F} - 32) * 5 / 9$
- $^{\circ}\text{F} = (^{\circ}\text{C} * 1.8) + 32$
- $\text{K} = ^{\circ}\text{C} + 273.15$
- $^{\circ}\text{C} = \text{K} - 273.15$

Specific heat

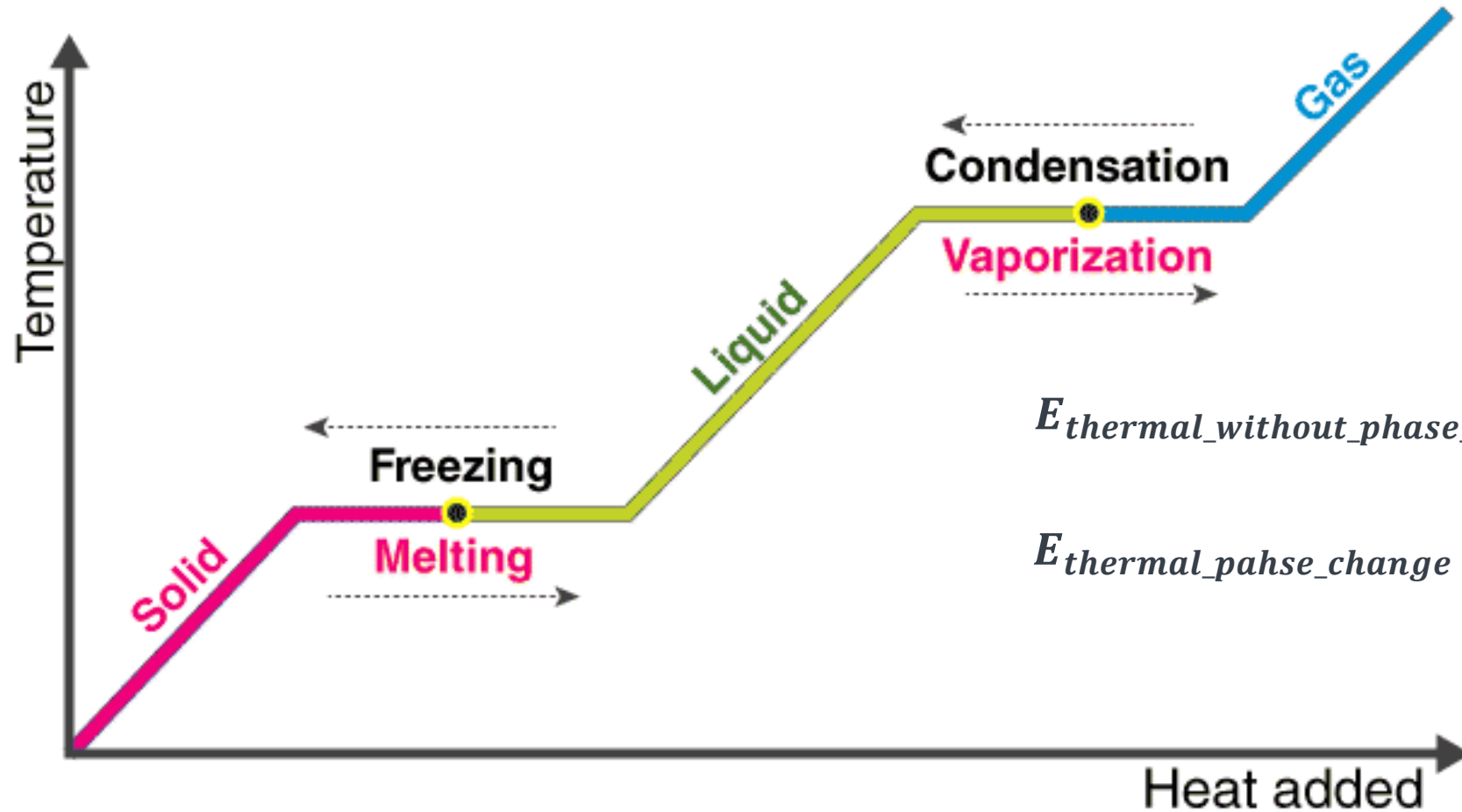
Specific heat is the amount of thermal energy required to raise the temperature of one unit of mass of a substance by one degree Celsius (or Kelvin).

C_p [J/kgK]

Material	C_p [J/kgK]
Air	1012
Glas	840
Granite	790
Water	4180

By 25°C and atmospheric pressure.

Thermal energy



$$E_{thermal_without_phase_change} = Q = m \cdot c_p \cdot \Delta T$$

$$E_{thermal_pahse_change} = Q = m \cdot L_f$$

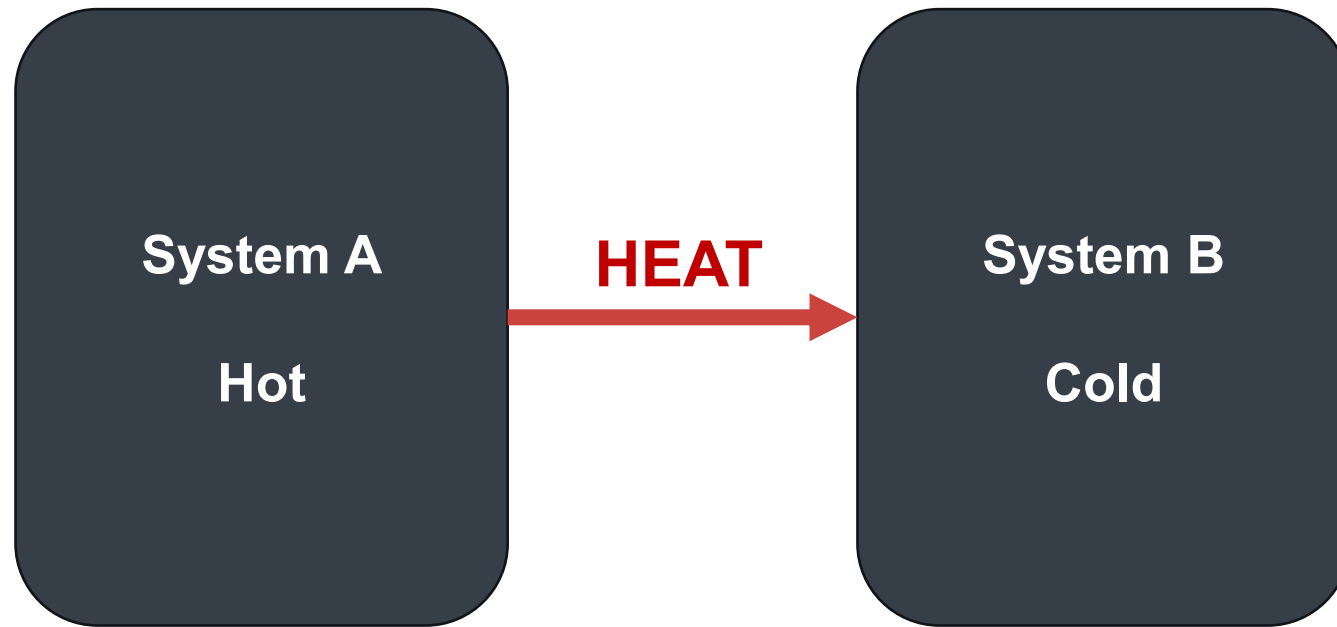
Latent heat

$$L_f \left[\frac{J}{kg} \right]$$

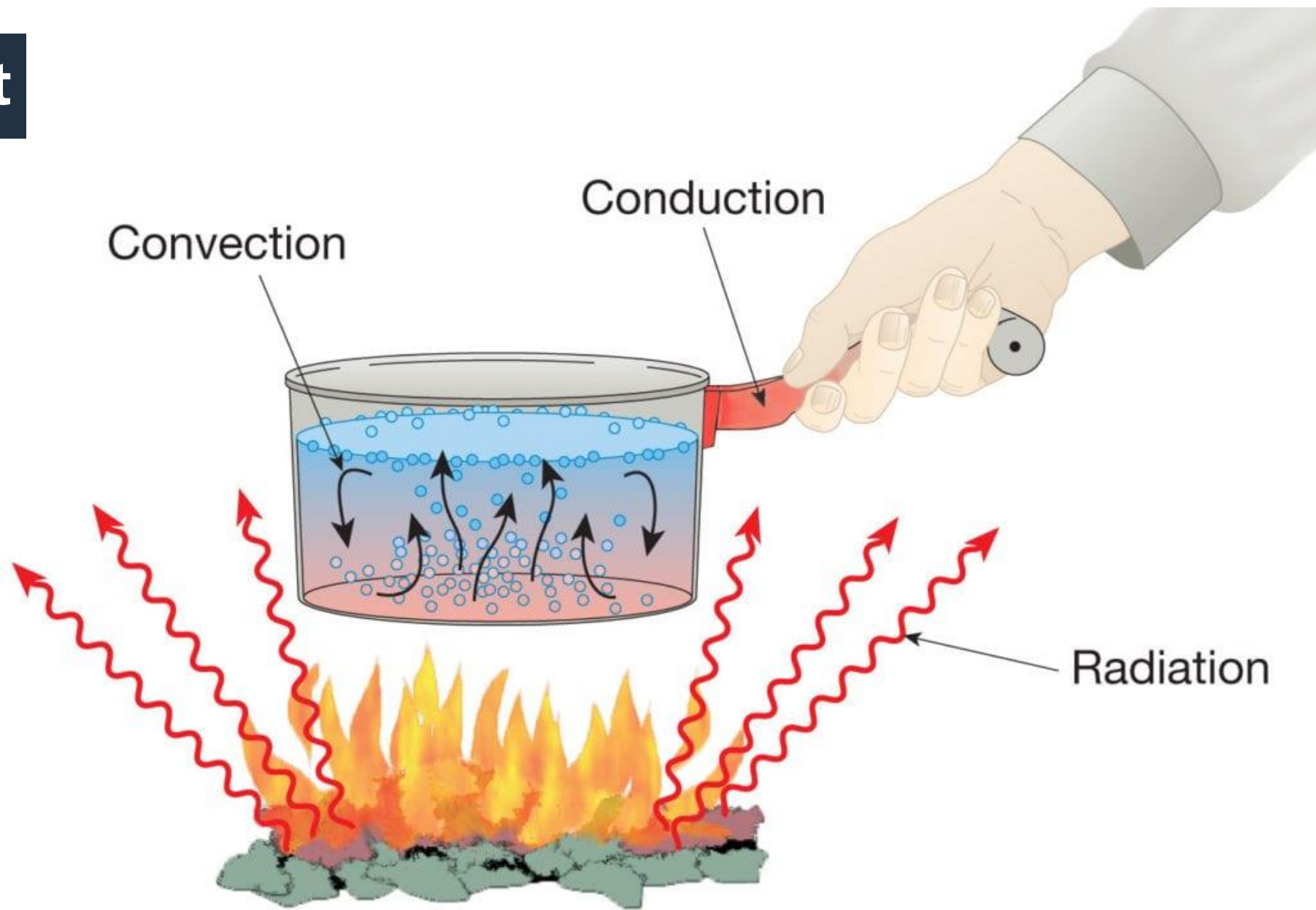
Material	Latent heat fusion [J/kg]	Verdampingswarmte [J/kg]
Water	334,000	2,249,000

$$E_{thermal_pahse_change} = Q = m \cdot L_f$$

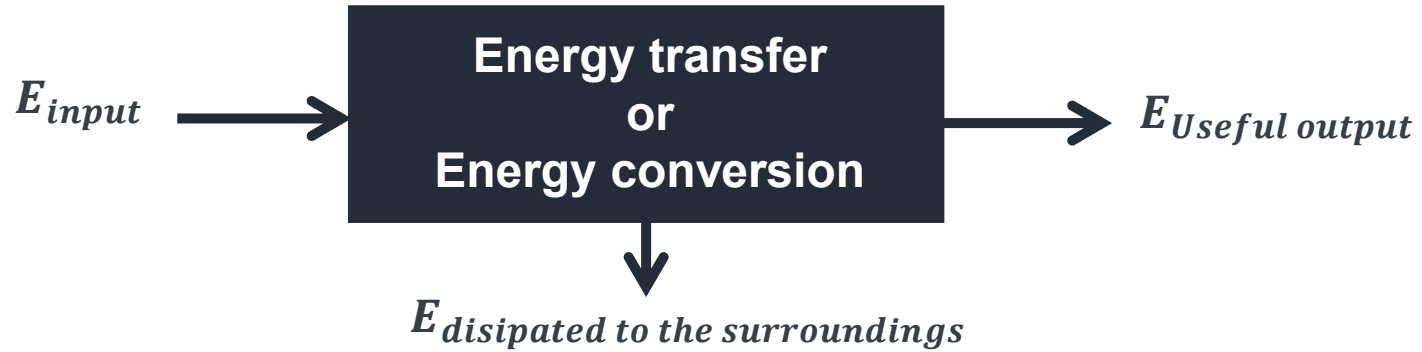
Heat



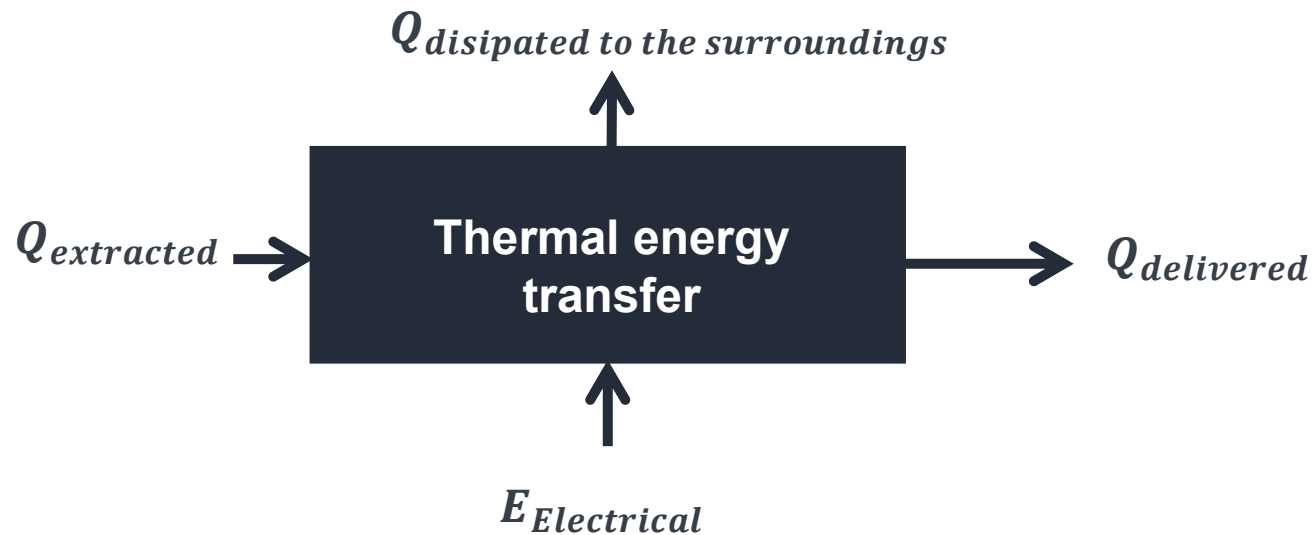
Heat



Efficiency vs coefficient of performance (COP)



$$\eta = \text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}}$$

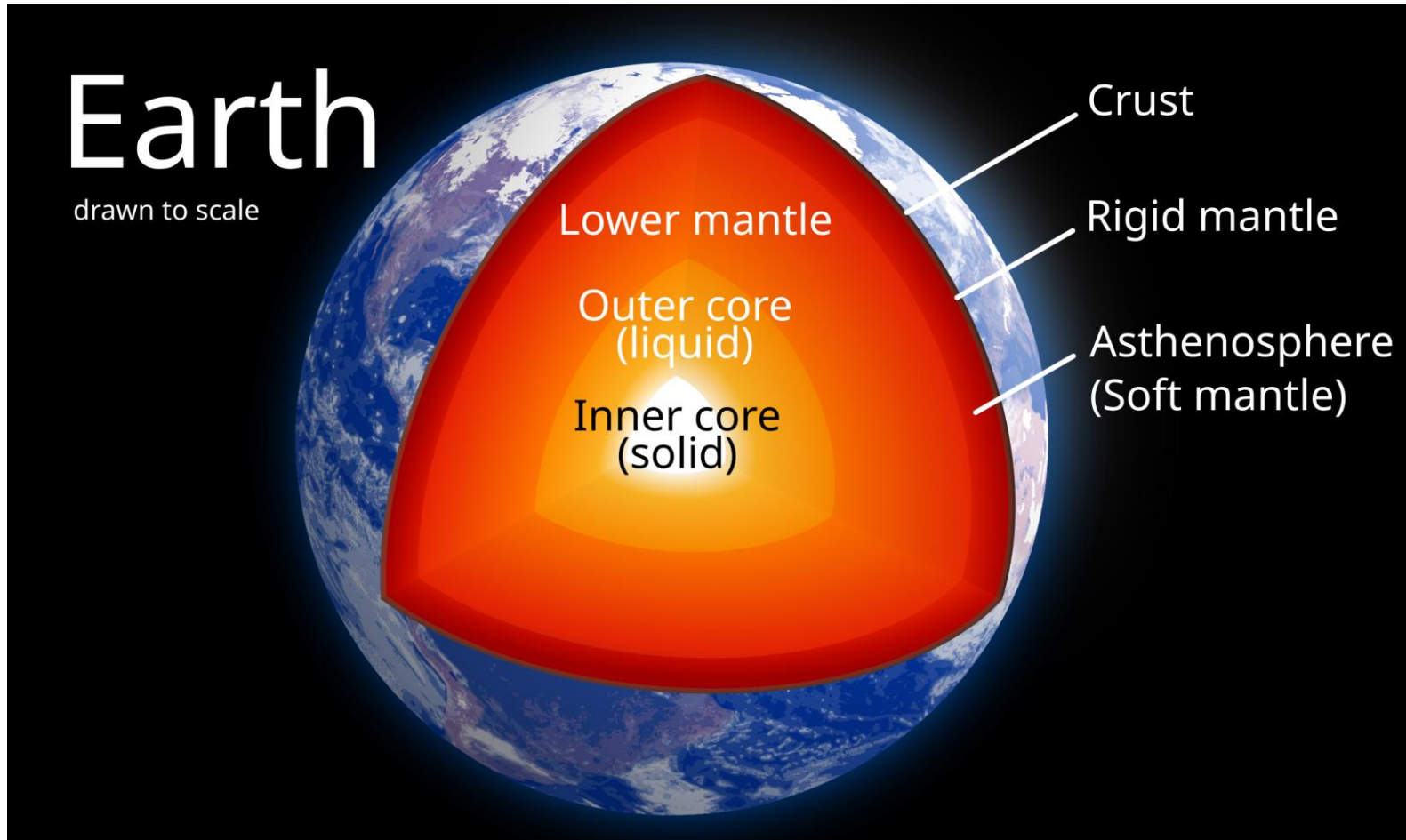


$$COP = \frac{Q_{Delivered}}{E_{electrical}}$$

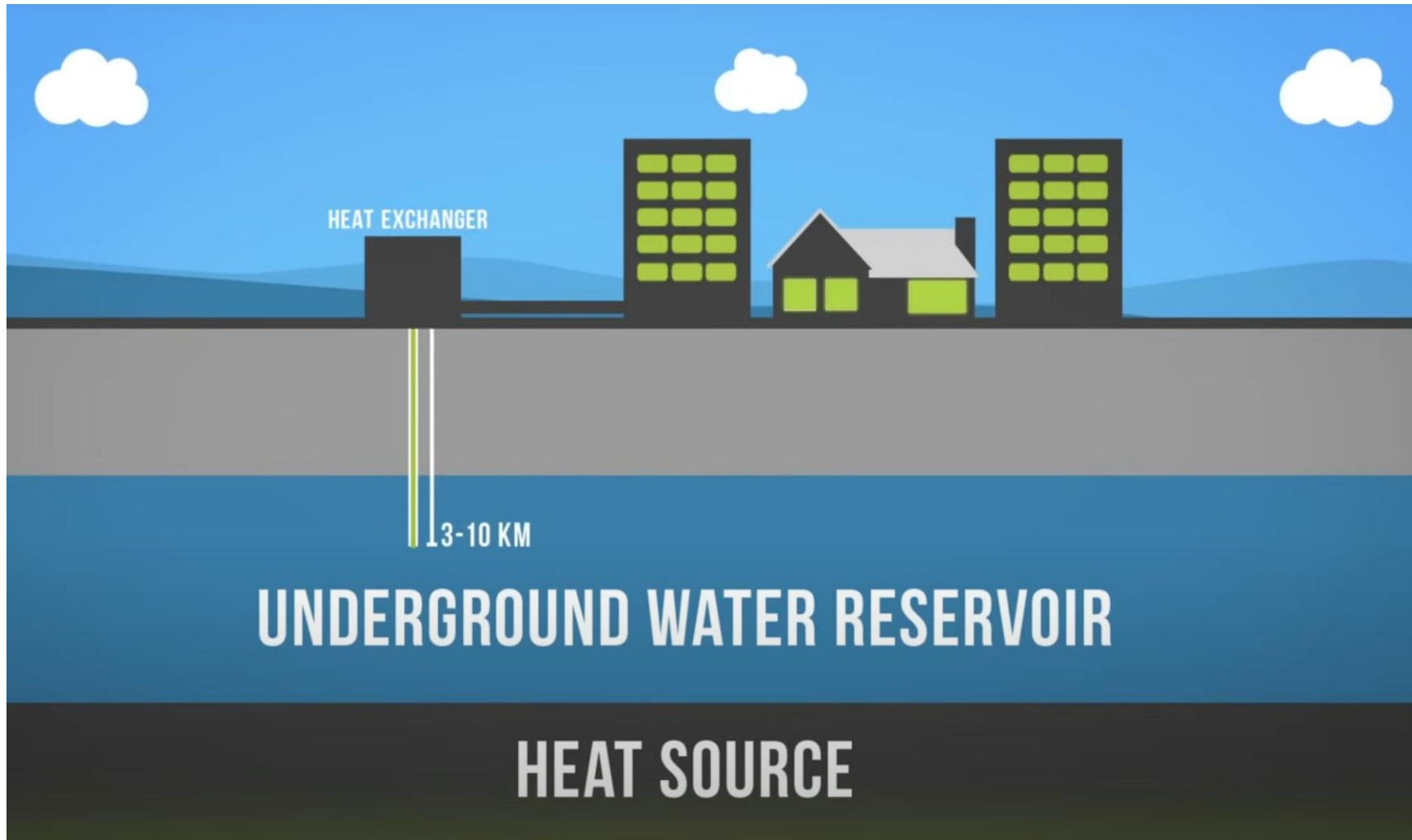
$Q_{delivered}$ = delivered thermal energy [J]

$E_{electrical}$ = used electrical energy [J]

Geothermal Energy



Geothermal Energy

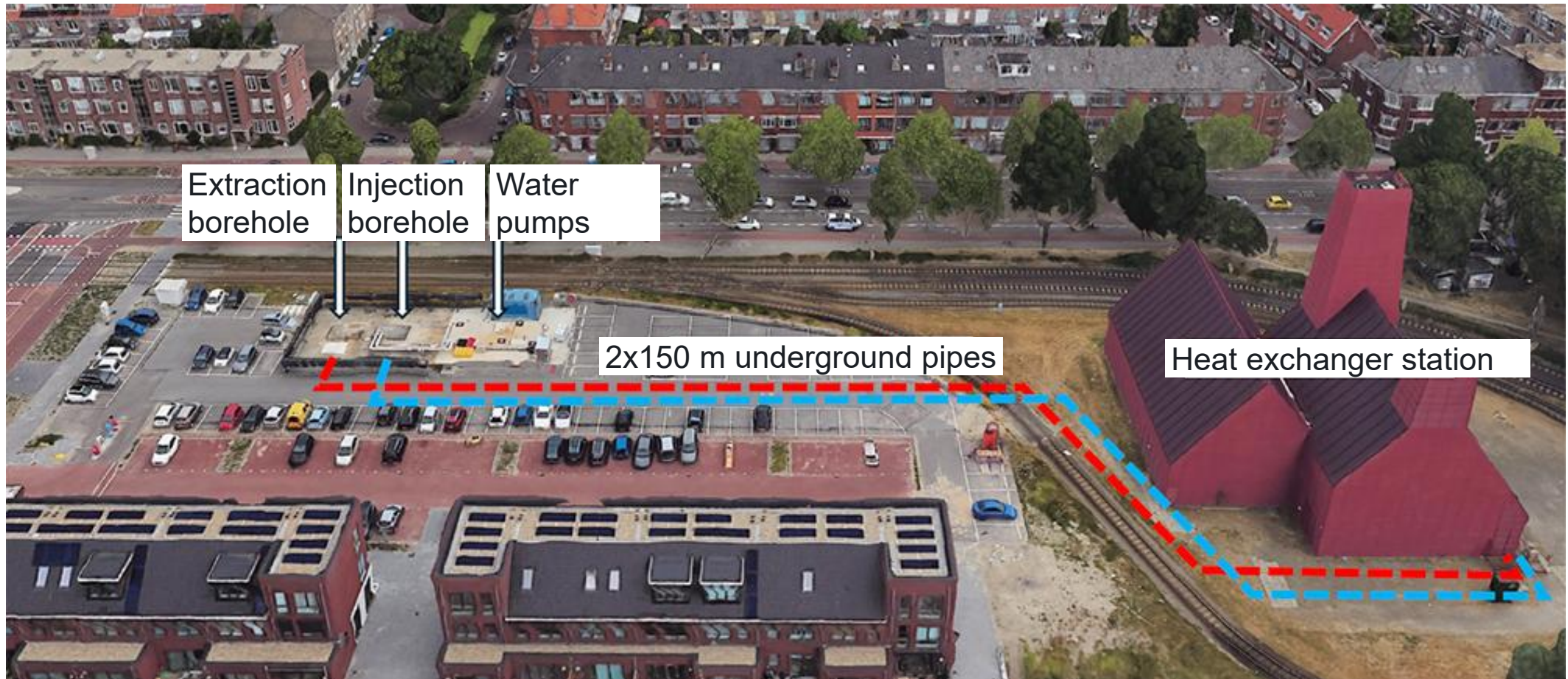


Geothermal Energy

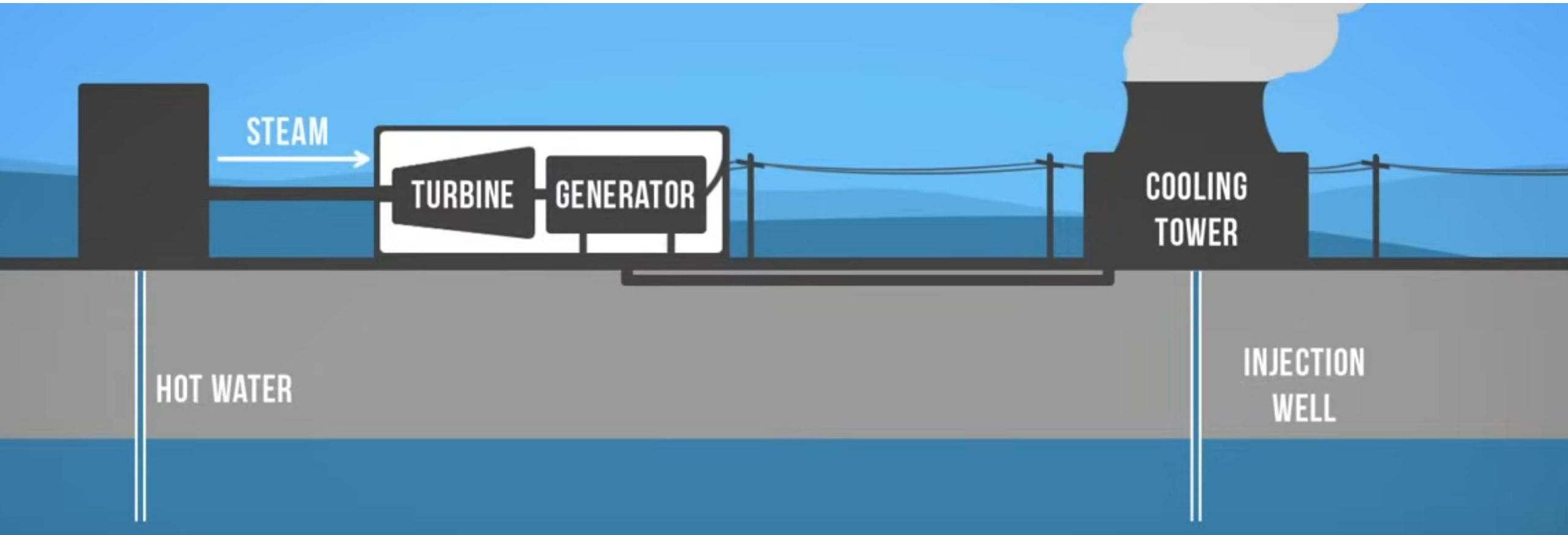
Geothermal
Energy

Heat exchanger

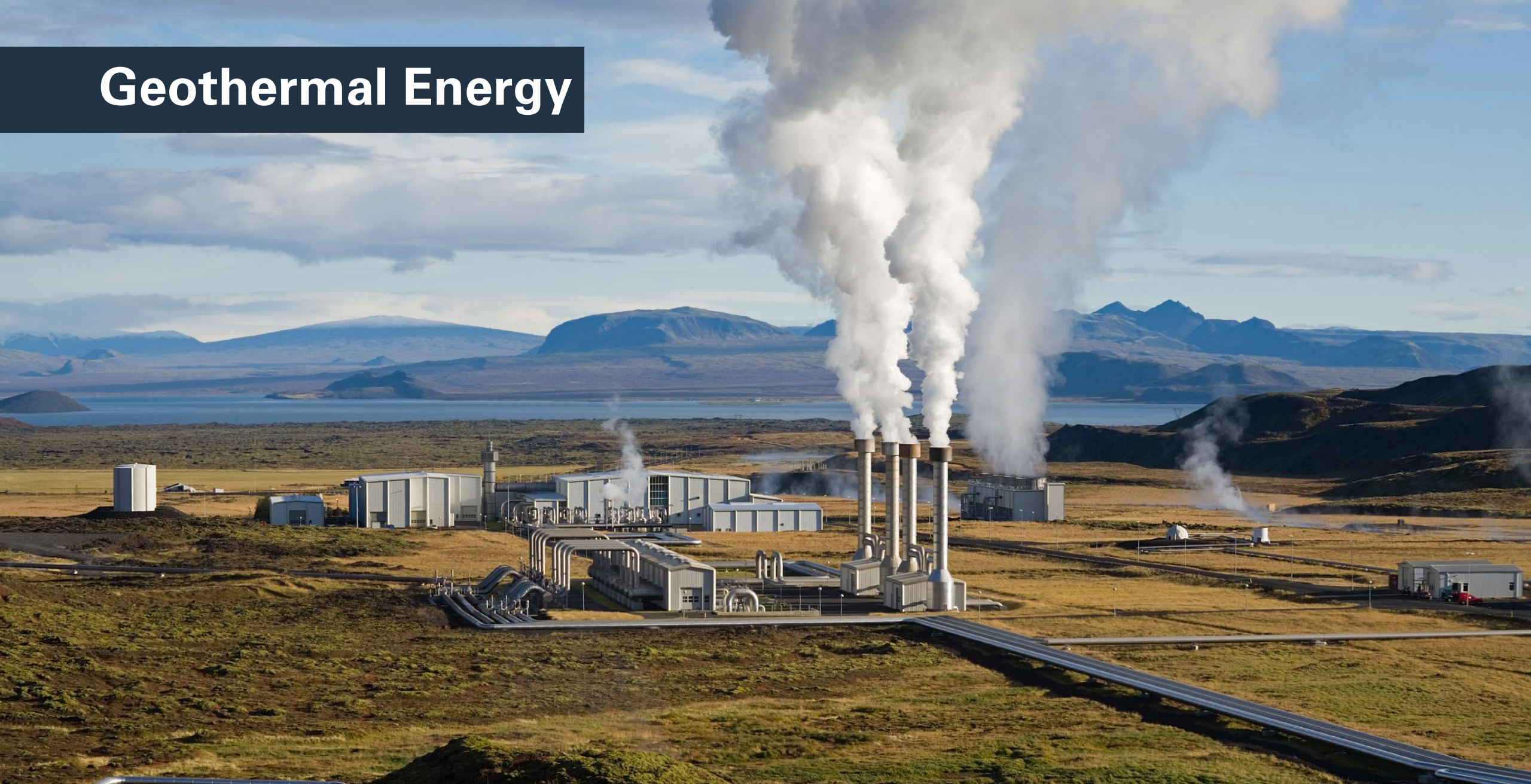
Heat



Geothermal Energy



Geothermal Energy



[Nesjavellir Geothermal Power Station](#) in Iceland

Geothermal energy advantages vs disadvantages

1. Renewable
2. High COP (up to 20)
3. Reliable (base-load energy)
4. Small land footprint
5. Low operating costs

1. High initial investment
2. Location-specific.
3. Resource depletion risk
4. Induced seismicity
5. Possible gas emissions

Nuclear Energy

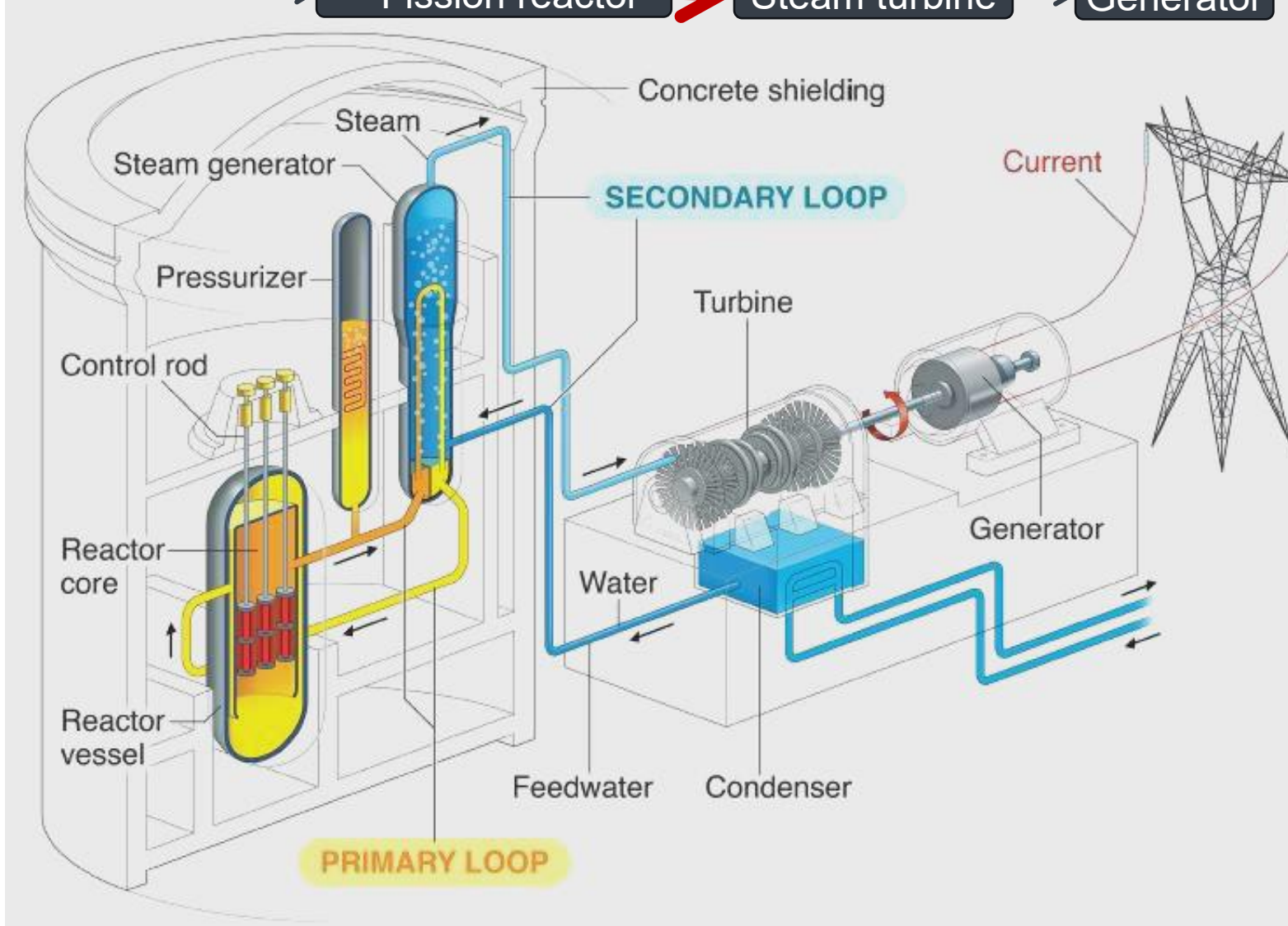
Nuclear
energy

Fission reactor

Steam turbine

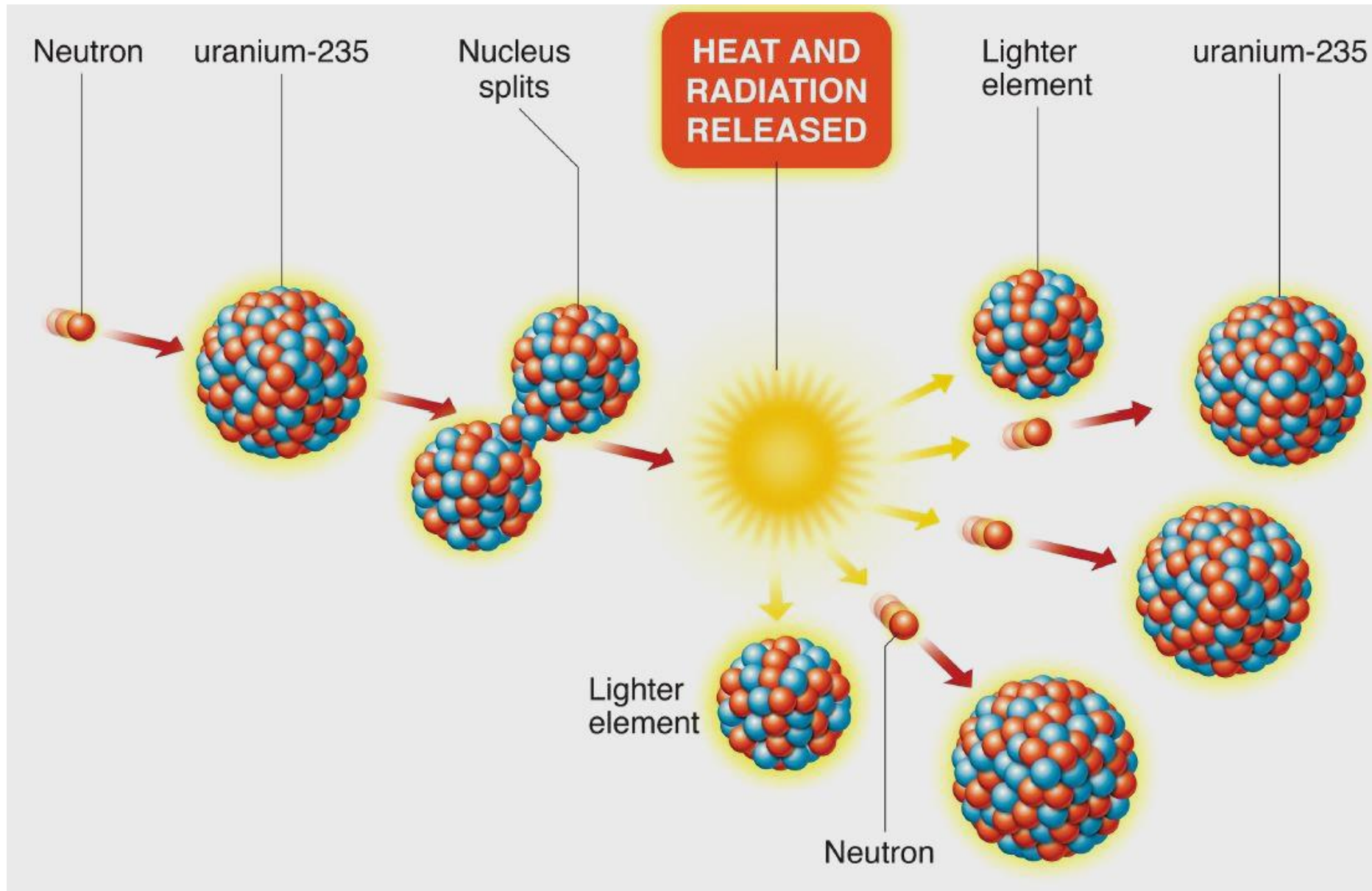
Generator

Electricity

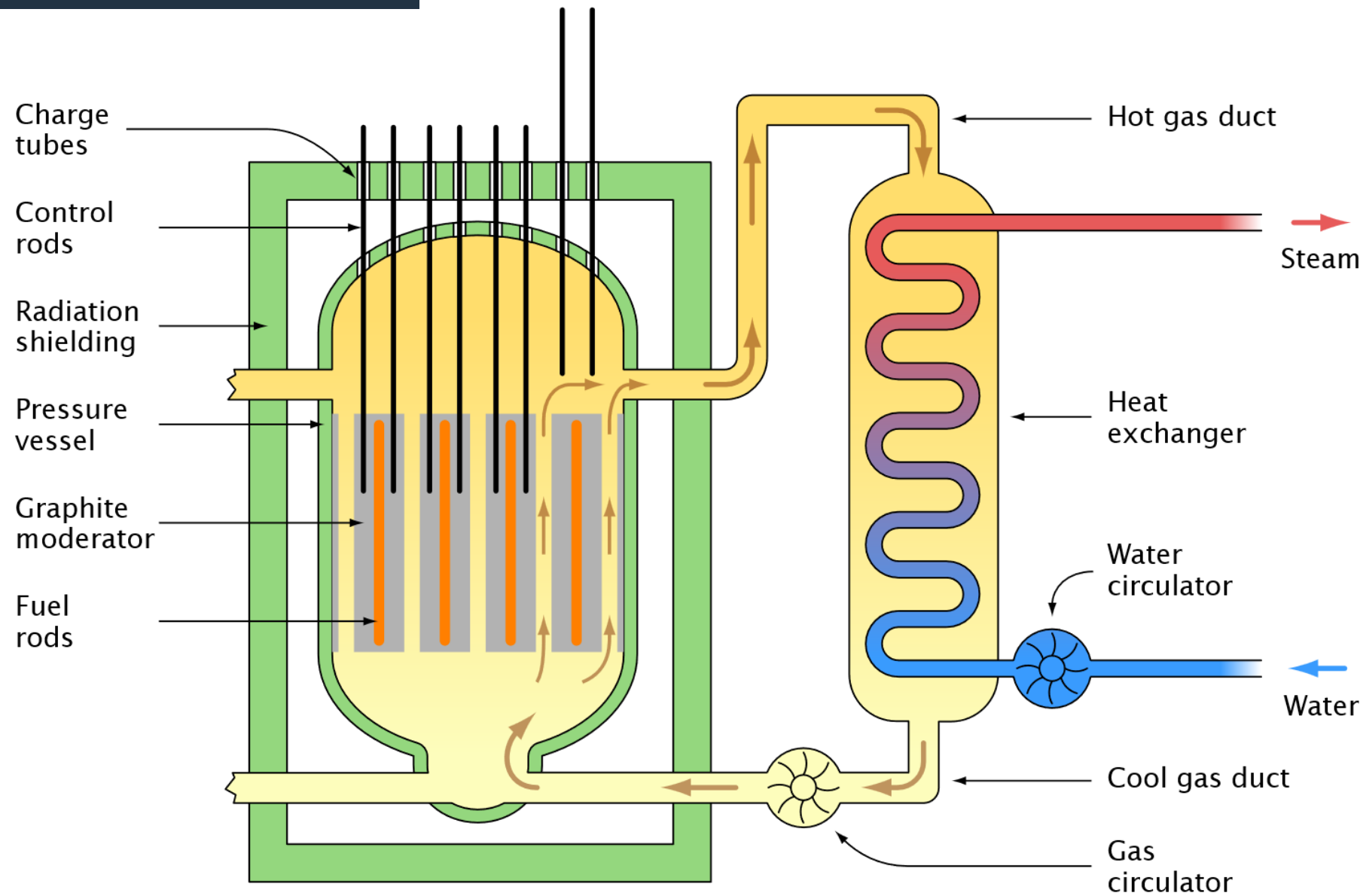


<https://www.enec.gov.ae/discover/how-nuclear-energy-works/how-does-a-nuclear-energy-plant-generate-electricity/>

Nuclear Energy



Fission reactor



https://chem.libretexts.org/Courses/Furman_University/CHM_101%3A_Chemistry_and_Global_Awareness_%28Gordon%29/07%3A_Nuclear_Energy/7.04%3A_Generating_Electricity_by_Using_Fission

Nuclear Power Plant



[Taishan Nuclear Power Plant, Units 1 & 2, Guangdong, China](#)

Nuclear energy advantages vs disadvantages

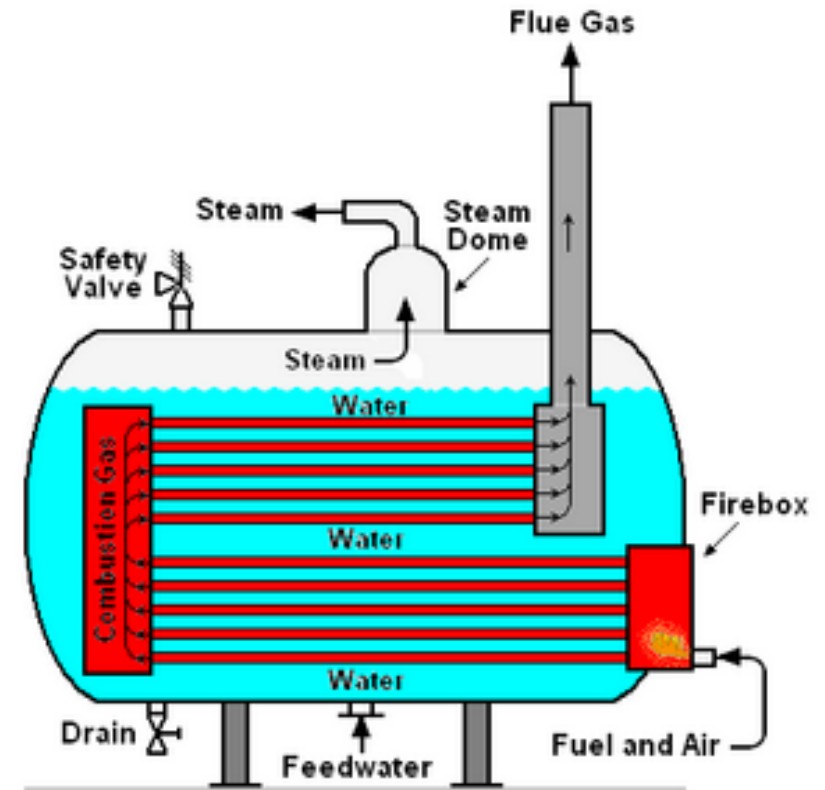
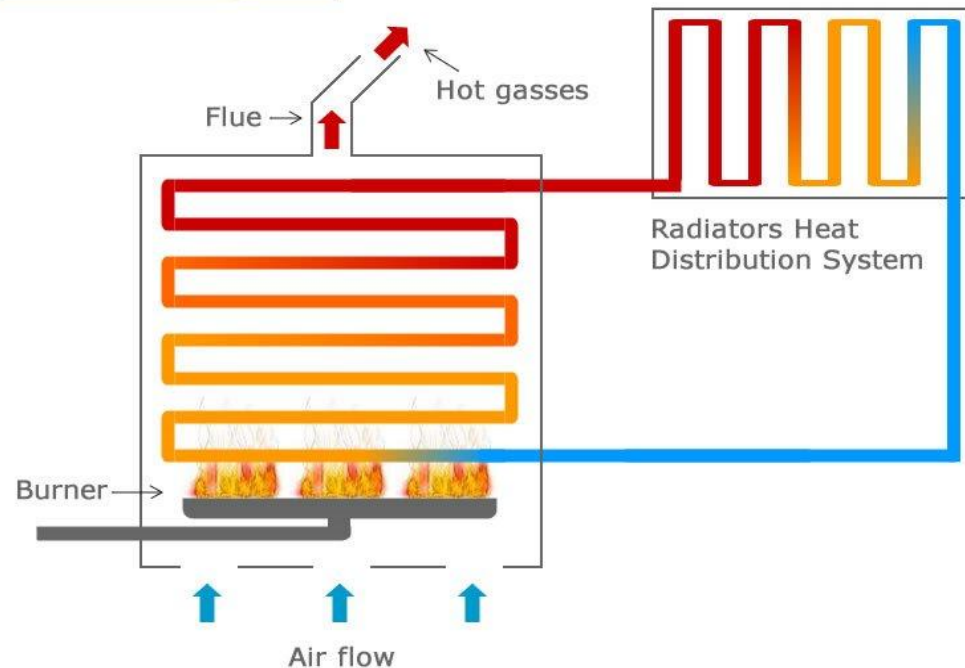
1. Very low CO₂ gas emissions
2. High energy density
3. Reliable, continuous power
4. Stable electricity supply
5. Low fuel costs

1. Limited fuel resources
2. Radioactive waste
3. Risk of severe accidents
4. Very high construction costs
5. Long decommissioning process
6. Public perception and political resistance

Combustion boiler



A non condensing boiler



Fuels combustion boiler residential hot water

1. Natural gas (most common in many countries)
2. Fuel oil
3. LPG (propane/butane).
4. Biomass (wood, pellets, wood chips)



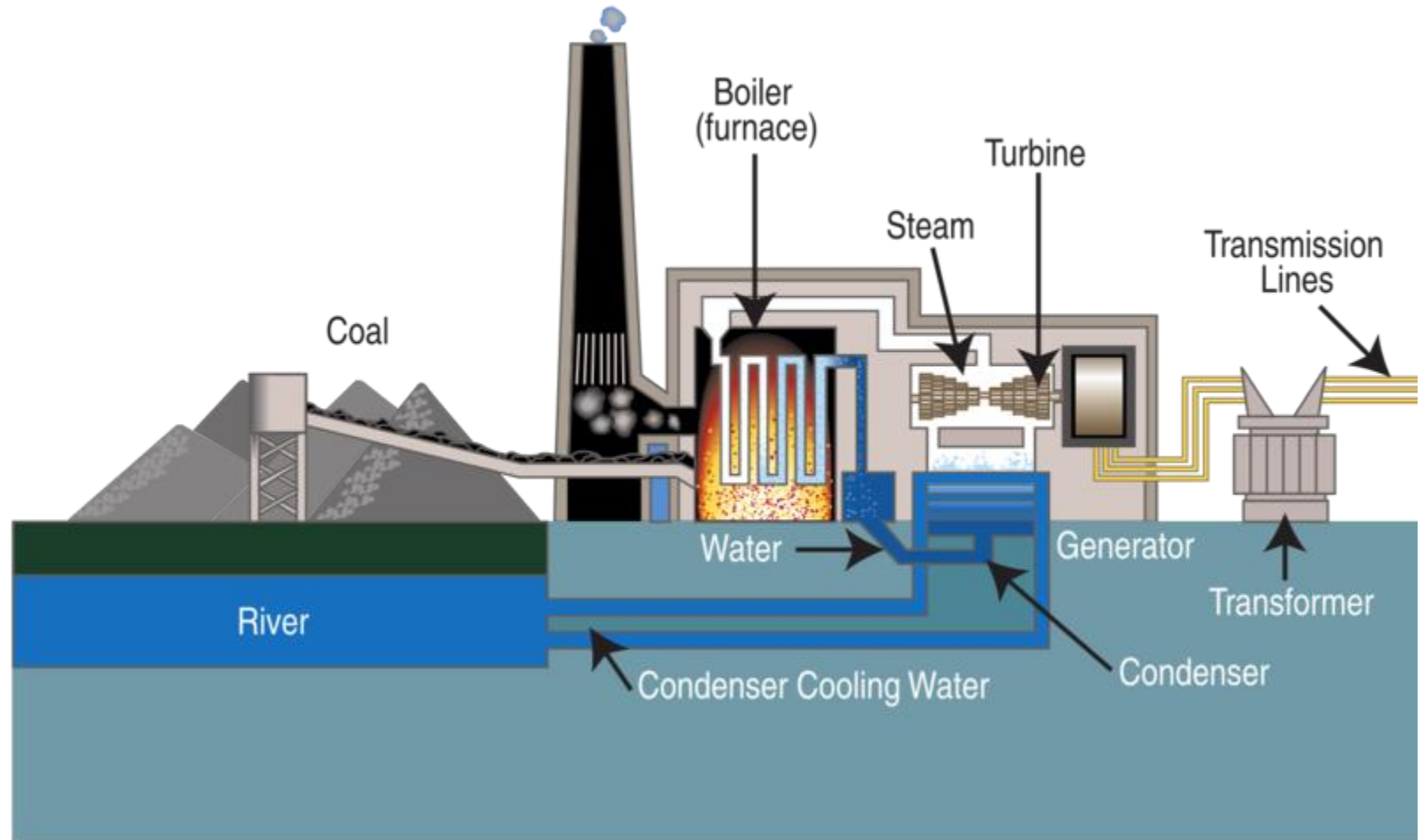
Gas, Fuel oil, LPG



Biomass

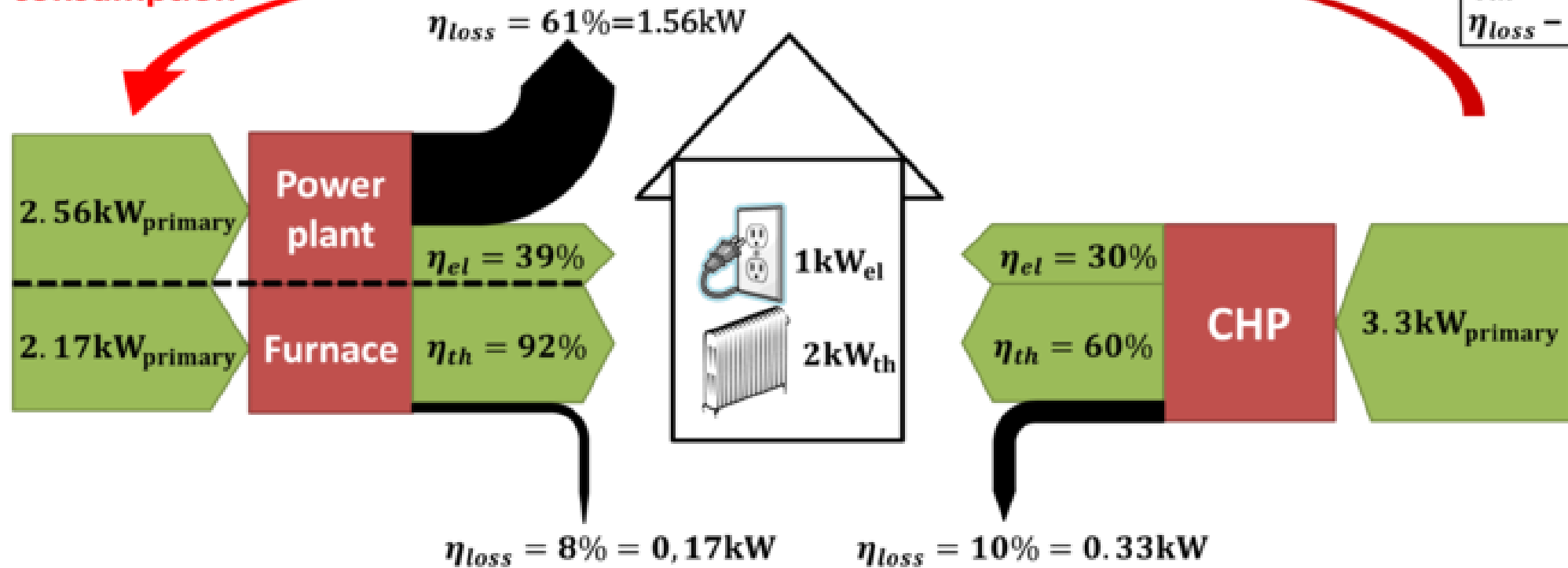
Fuels combustion industrial boiler steam

1. Coal (historically dominant)
2. Natural gas
3. Oil (heavy fuel oil or diesel)
4. Biomass



Cogeneration

+43% primary energy consumption

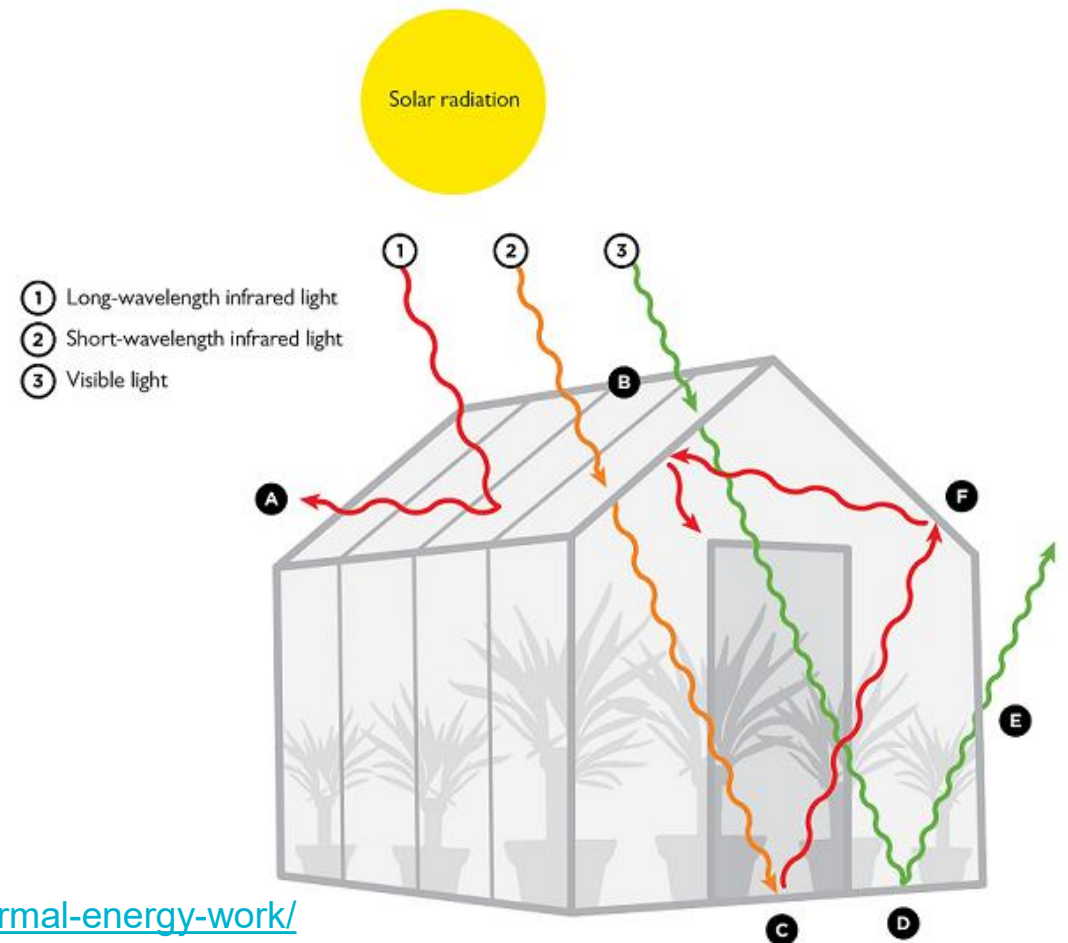
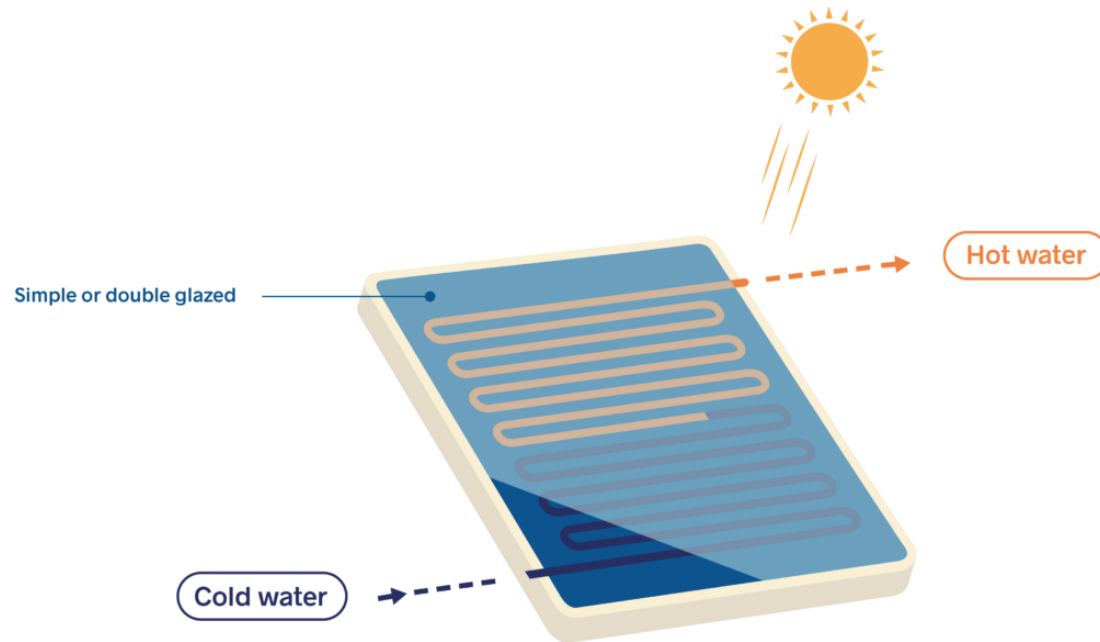
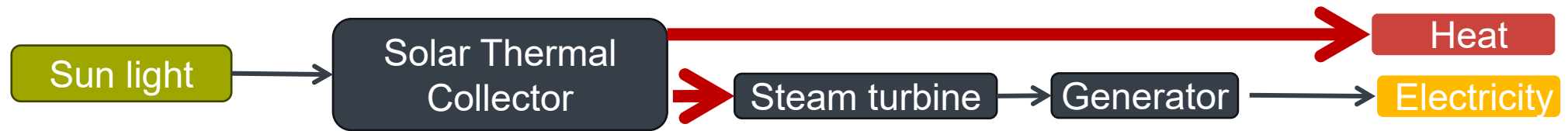


Combustion boiler advantages vs disadvantages

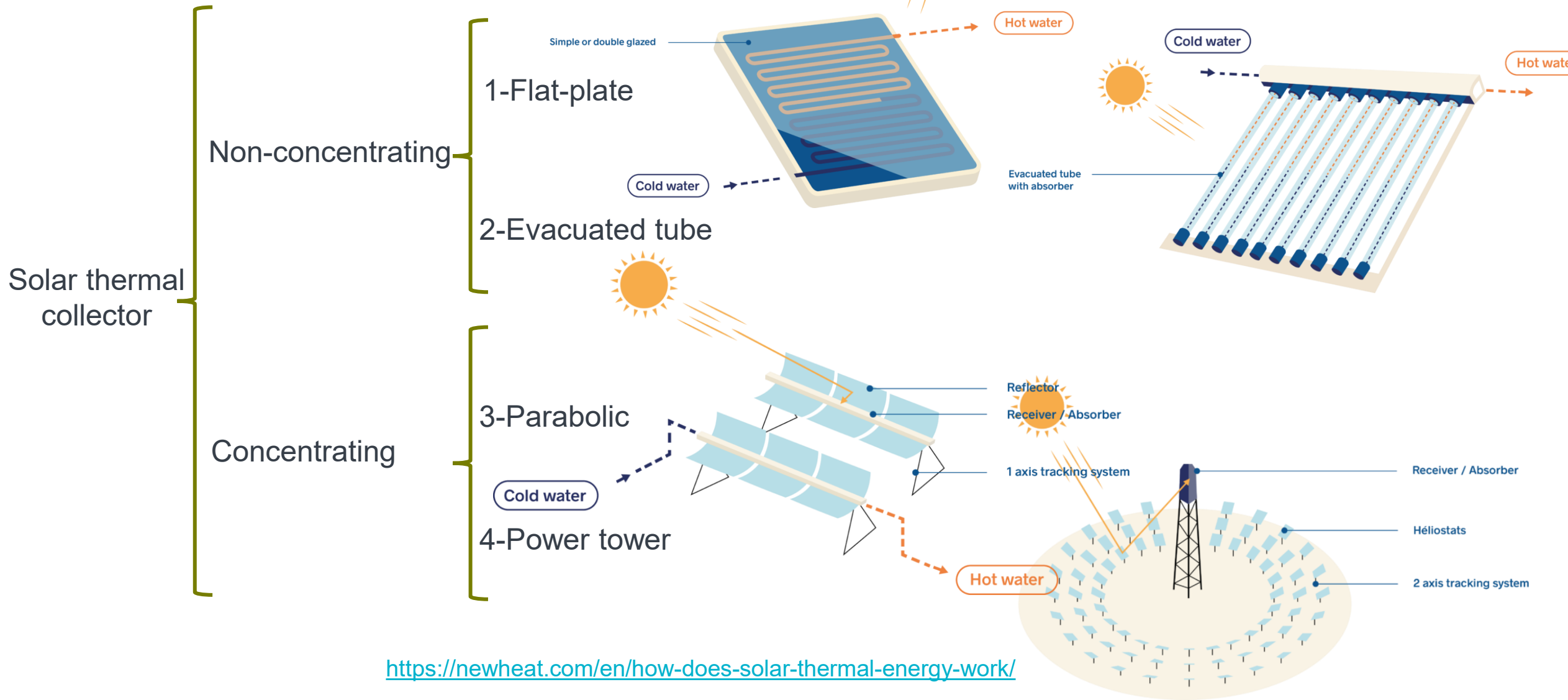
1. High heat output and reliability
2. Mature and well-known technology
3. Fuel flexibility
4. Fast response and controllability
5. High temperature capability

1. High CO₂ emissions
2. Air pollution
3. Lower efficiency compared with heat
4. Dependence on fuel supply
5. Maintenance and safety

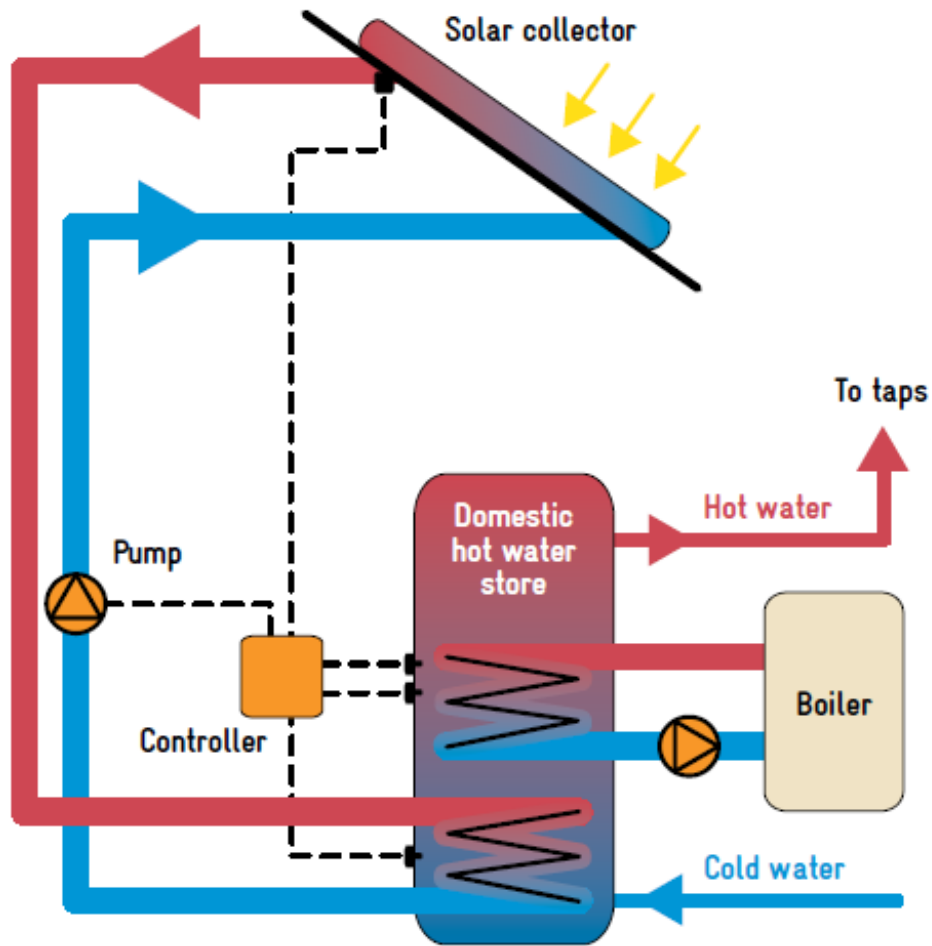
Solar thermal collector



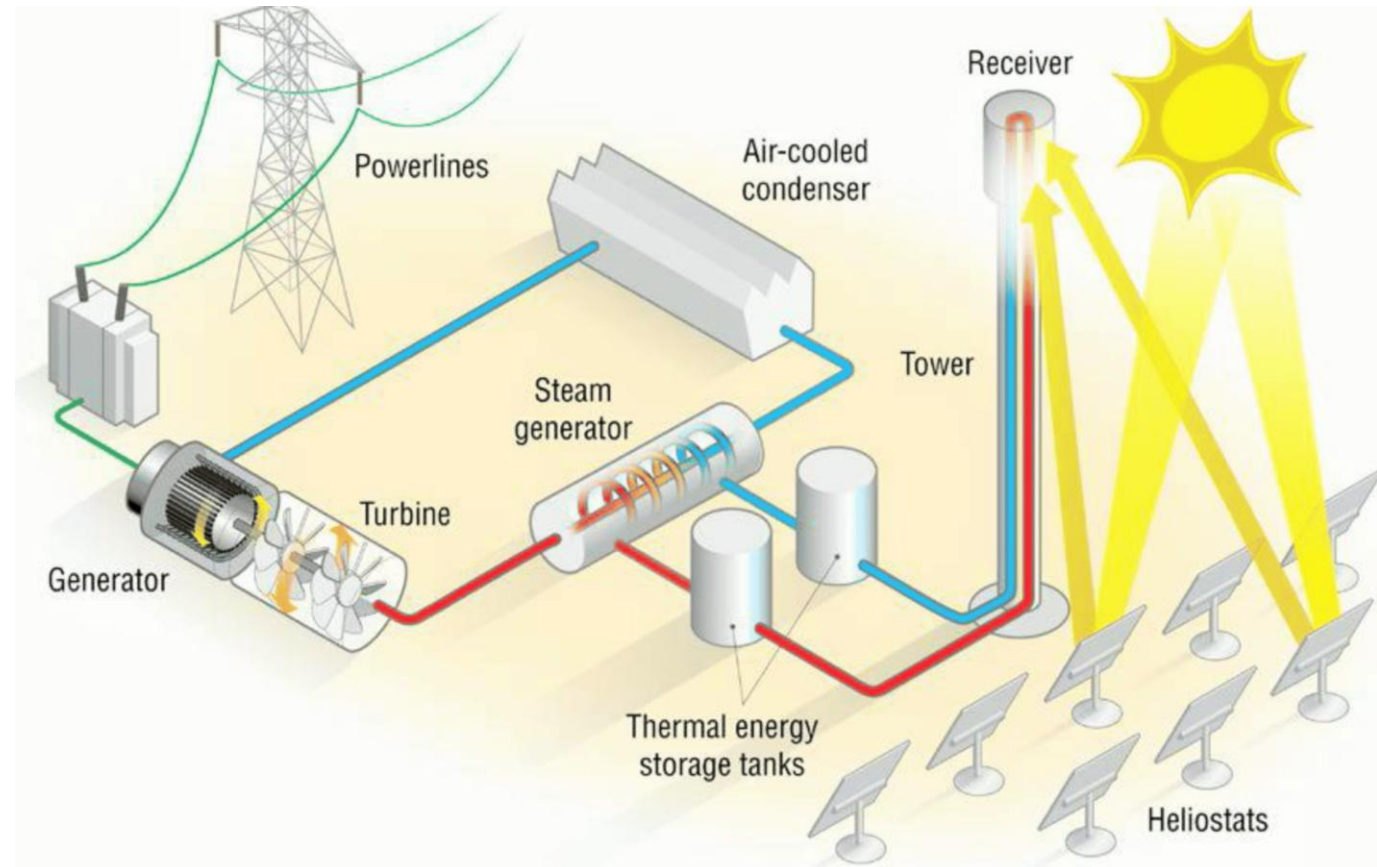
Solar thermal collector



Solar thermal collector system



<https://etl.energysecurity.gov.uk/products/solar-thermal-systems-collectors/solar-thermal-collectors-1>



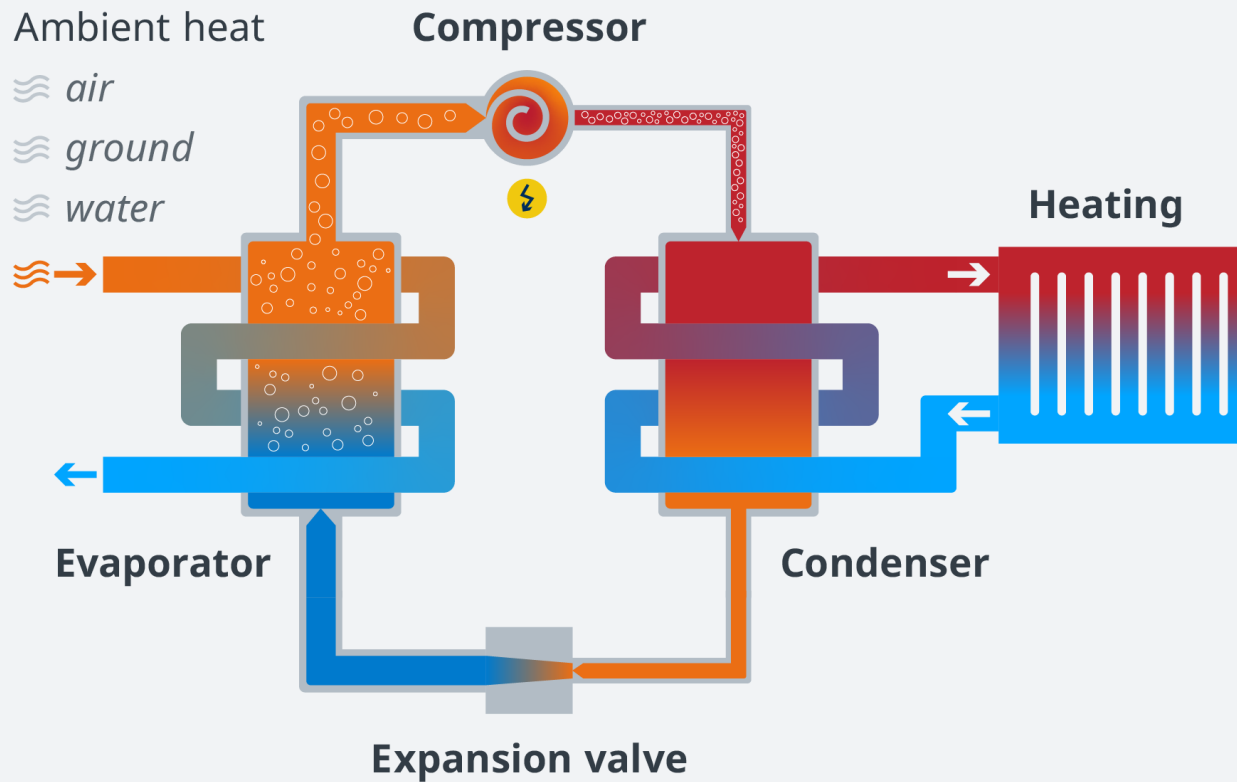
<https://solarcc.com/thermal-solar-power-plant-explained/>

Solar thermal collector advantages vs disadvantages

1. Renewable and very low operational CO₂ emissions.
2. Free fuel and low operating costs
3. High efficiency (up to 70%)
4. Suitable for different temperature levels
5. Thermal energy storage is relatively easy

1. Intermittent energy
2. Lower output in winter
3. Roof area needed for residential use or large land area for CSP
4. Complexity of installation for large CSP systems

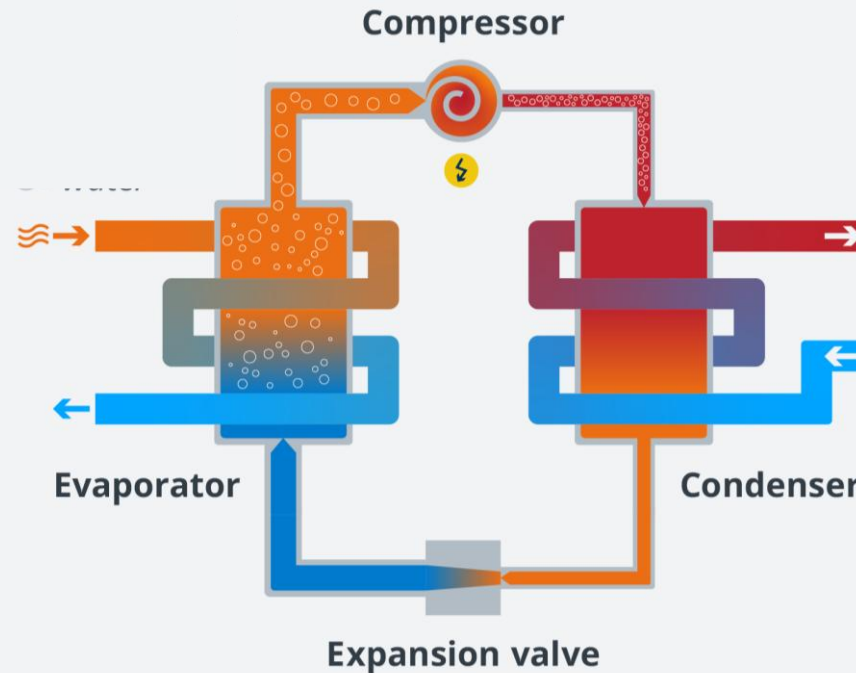
Heat pump



Heat pump coefficients of performance (COP)

Heat source

- Air
- Ground
- Water



Heat sink

- Floor heating
- Convactor
- Radiator

Heat sink →	Floor heating (~35 °C)	Convactor / fan-coil (~45 °C)	Radiator (~55 °C)
Heat source ↓			
Air source [-5 °C,15°C]	2.1–4.6	1.7–4.0	1.4–3.5
Ground source [8°C,12°C]	3.9–5.7	3.3–5.1	3.0–5.4

Heat pump advantages vs disadvantages

1. High COP, especially if difference of temperature between source and sink is small
2. Low direct CO₂ emissions
3. Ability to use renewable heat sources
4. Multi-functionality (heating, cooling, domestic hot water)

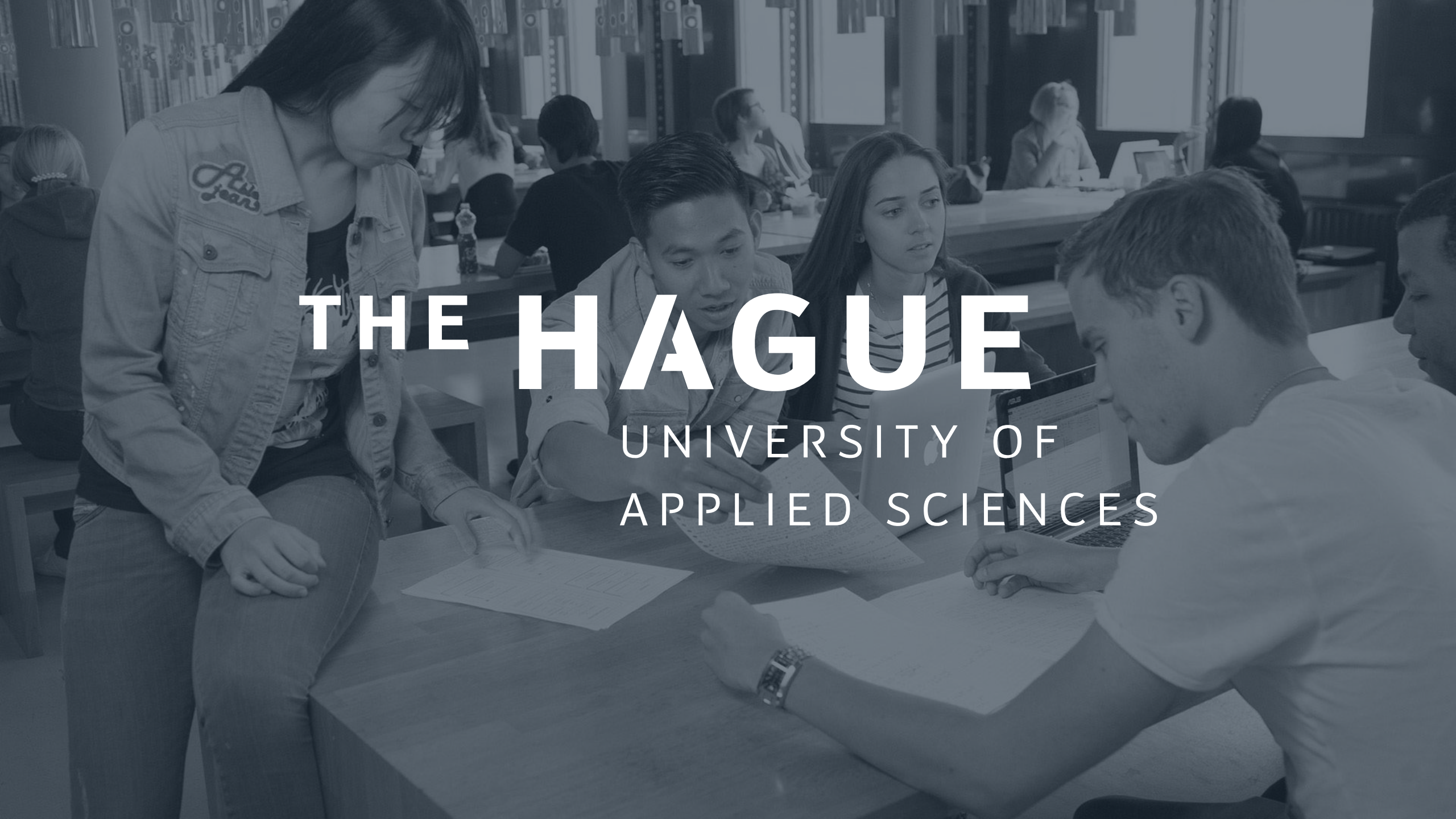
1. Initial investment
2. Performance depends on temperature difference.
3. Reduced efficiency in existing high-temperature systems
4. Electricity dependence
5. Installation constraints
6. Refrigerant environmental impact

References

[Energy Education](#) Calgary University

Books

Ouwehand, J., Trynke, P., Post, E., Taal, A. (2012) Toegespaste Energietechniek, Sdu, Den Haag.
Ouwehand, J., Trynke, P., Gilijamse, W., Geus, J. de (2017) Duurzame energietechniek, Boom, Amsterdam.

A grayscale photograph of a modern classroom or study hall. In the foreground, a group of four students are gathered around a table, looking at papers and a laptop. A young woman on the left is leaning over the table, pointing at a document. Next to her, a young man is also looking at the papers. Behind him, another young woman is looking towards the right. In the foreground on the right, a young man is sitting at the table, looking at a laptop. The background shows other students sitting at long tables, some working on laptops. The room has large windows and a bright, airy feel.

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