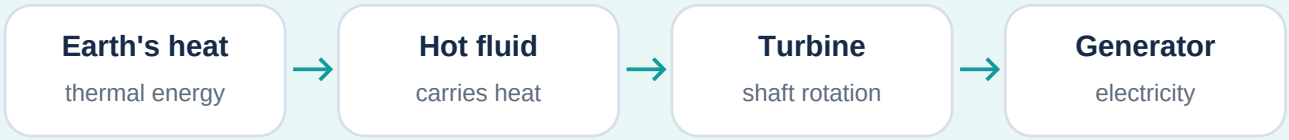
Geothermal energy: heat from Earth

Earth's internal heat can supply electricity or useful heat without burning a fuel. In a power plant, a turbine drives a generator; underground heat is the original energy source.

FROM UNDERGROUND HEAT TO ELECTRICITY



Wells bring hot water or steam toward the surface. Steam, or vapor from a separate working fluid, turns the turbine. Heat transfer and mechanical motion come before electrical output.

1. DRY STEAM AND FLASH STEAM

Dry-steam plants send steam from a geothermal reservoir to a turbine. Flash-steam plants bring up hot water under high pressure. Lowering its pressure causes some water to vaporize; this steam drives the turbine. The energy comes from underground heat, not from burning the water.

2. BINARY CYCLE: KEEP THE TWO FLUIDS SEPARATE

Extension: geothermal water passes through a heat exchanger and heats a second fluid with a lower boiling point. That fluid vaporizes and drives the turbine, then condenses for reuse. The geothermal water does not pass through the turbine. A heat exchanger transfers heat without mixing the fluids.

3. RETURN FLUIDS, BUT ALSO MANAGE THE HEAT

After use, geothermal water and condensed steam can be reinjected. This can support reservoir pressure and reduce surface discharge. Reinjection returns fluid; it does not instantly replace all the heat extracted. Long-term operation requires management of flow, pressure and the resource itself.

Dry steam, flash steam and binary cycles: US EIA, Geothermal Power Plants.
Energy conversion and heat exchange: US DOE, Geothermal Electricity Generation.
Reservoir management: US DOE, Geothermal FAQs.

Scope: College Board AP Environmental Science CED, Topic 6.10, p. 130.

Accessible heat is the limiting factor

Heat exists beneath every location, but not every location offers an economical electricity resource. Distinguish deep, high-temperature generation from shallow-ground heat exchange.

1. SUITABLE GEOLOGY AND COSTLY ACCESS

Conventional hydrothermal plants need accessible hot fluid and pathways through rock. Strong resources often occur near tectonic plate boundaries, where heat is closer to the surface. Hot springs and geysers are clues, not proof of a viable plant. Exploration and drilling can be expensive before electricity is produced.

2. RENEWABLE, BUT A LOCAL RESERVOIR HAS LIMITS

Earth continuously supplies internal heat, including heat from natural radioactive decay. A useful reservoir can still lose pressure or output if it is poorly managed. Extension: enhanced geothermal systems improve fluid pathways in hot rock, expanding access while adding engineering and monitoring requirements.

3. GROUND-SOURCE HEAT PUMPS ARE DIFFERENT

Extension: a heat pump uses electricity to move heat between a building and the relatively stable shallow ground. It does not generate electricity from deep steam.

WINTER: HEAT MOVES INTO THE BUILDING

Ground → heat pump → building

SUMMER: HEAT MOVES OUT OF THE BUILDING

Building → heat pump → ground

4. IDENTIFY THE USEFUL OUTPUT

A power plant produces electricity. Direct-use geothermal heating supplies heat. A ground-source heat pump heats or cools a building; it consumes electricity to transfer heat.

Resource geography and exploration: US EIA, Where Geothermal Energy Is Found.
Renewability, access and engineered systems: US DOE, Geothermal FAQs.
Seasonal heat exchange: US EIA, Geothermal Heat Pumps.

Scope: College Board AP Environmental Science CED, Topic 6.10, p. 130.

Steady supply, site-specific tradeoffs

Geothermal generation can operate without waiting for sunshine or wind. Its benefits do not remove the need to manage gases, water, drilling impacts and underground conditions.

1. BENEFIT: STEADY POWER WITHOUT BURNING FUEL

Geothermal power normally needs no fuel combustion to supply its heat. Suitable plants can provide continuous power and complement variable solar and wind output. Maintenance and reservoir conditions still limit performance. Low operating emissions do not mean construction and drilling have no environmental cost.

2. HYDROGEN SULFIDE: A CORE AIR-QUALITY CONCERN

Some geothermal fluids contain hydrogen sulfide (H_2S), which can be released as gas. Gas-treatment systems such as scrubbers reduce releases. Some plants also emit CO_2 from underground fluids. Closed binary systems keep geothermal fluid contained and can greatly limit direct releases; plant design matters.

3. WATER, BRINES AND WASTE MANAGEMENT

Water demand varies with the resource, cooling method and system design. Geothermal fluids can contain dissolved minerals, and some plants produce mineral-rich solids or sludge. Manage fluids and wastes appropriately rather than releasing them untreated. Reinjection can reduce discharge and support the reservoir, but water use still needs assessment.

4. UNDERGROUND CHANGES NEED MONITORING

Extension: injecting or withdrawing fluids can alter underground pressure and stress and may induce seismicity. Assess local geology, monitor seismic activity and manage operations accordingly. A suitable project combines usable heat, feasible drilling costs and controls matched to its particular environmental risks.

Gas emissions, scrubbers and reinjection: US EIA, Geothermal and the Environment.
Continuous operation and mineral-rich wastes: US DOE, Geothermal FAQs.
Water use and induced seismicity: US DOE, Environmental Analysis.

Scope: College Board AP Environmental Science CED, Topic 6.10, p. 130.