

Two Furnaces, One Surface: Where Earth's Energy Comes From

Learning target: I can use evidence from a passage to explain that Earth's systems run on two energy sources, how each one's energy travels, and why one of them matters far more at the surface.

Reading with evidence

About 40 min

Individual

MS-ESS2-1 · practice

MS-ESS2-6 · supports

reading

writing

Standards connections

MS-ESS2-1 (practice, the flow-of-energy half of the PE): The passage traces the energy from Earth's interior that drives mantle convection and compares it with solar energy. Students gather the evidence they will need to label the energy flow in their models; the sheet builds toward the PE without producing a model.

MS-ESS2-6 (supports): Paragraphs on unequal solar heating and sinking polar water give background for the ocean and air circulation patterns in this Grade 6 PE of the California sequence. This chapter touches that PE only as background.

Purpose: build · **Time:** about 40 minutes · **Format:** individual

Answers with reasoning

Two Furnaces, One Surface

[1] Stand on a beach in the afternoon and two furnaces are working on you at once. One is obvious: the sun, warming your shoulders and the sand. The other is hidden under your feet. About 6,400 kilometers below the beach is the center of Earth, and at that depth the temperature is roughly 5,000 °C or more. Almost everything that moves on Earth, from mantle rock to ocean currents to a seagull, is moved by one of them.

[2] The inner furnace has two fuel supplies. The first is leftover heat. When Earth formed about 4.5 billion years ago, countless collisions and the sinking of heavy iron toward the center released an enormous amount of energy, and a planet this large loses that energy very slowly. The second supply is radioactive decay: tiny amounts of elements such as uranium, thorium and potassium inside the rock break down over time, and each breakdown releases a little energy. This energy leaves the core by conduction into the rock touching it, and then the mantle carries it upward as rock that is warmer and less dense creeps up while cooler, denser rock sinks. The creep is slow, only a few centimeters per year, but it has not stopped for billions of years.

[3] The outer furnace sends its energy a very different way. There is almost no matter between the sun and Earth, so nothing can conduct and nothing can convect across that gap. Instead the sun's energy travels as light, including kinds of light our eyes cannot see, such as infrared. That is radiation. Most of what Earth absorbs is soaked up by the ground and the sea, not by the air itself; the surface then warms the air resting on it by conduction, and that warm, less dense air begins to rise.

[4] How do the two furnaces compare? Averaged over the whole planet, day and night, sunlight delivers about 340 watts to every square meter at the top of the atmosphere. The heat leaking up from Earth's interior averages about 0.09 watts per square meter. A hundred-watt light bulb's worth of solar energy falls on a patch of ground smaller than a desk, while the interior's contribution to that same patch is less than the glow of a tiny indicator light. For the ocean, the air and living things, the sun is the furnace that counts.

[5] Then why does the inner furnace matter at all? Because its energy arrives from below, and because it is attached to rock. Solar energy warms only the top of things; it cannot reach down and stir the mantle. The interior's energy, small as it is per square meter, is what keeps mantle rock circulating, and that circulation drags the plates of the crust along, lifts mountains, and feeds volcanoes. A geyser is the two furnaces meeting: groundwater that fell as rain (the sun's doing) sinks into cracks, touches rock heated from below (the interior's doing), boils, and bursts back out.

[6] The sun's energy does not land evenly. Earth is a sphere, so sunlight strikes the tropics almost head-on and the polar regions at a slant, spread over more ground. Air and ocean water warmed in the tropics are less dense; near the poles the surface loses energy, and when sea ice forms it leaves its salt behind, so the water left over is both colder and saltier, and therefore denser. Gravity pulls that dense water down to the sea floor, and the gap it leaves is filled by water sliding in from warmer regions. Giant, slow loops in the ocean and the air are the result, and they carry energy from the tropics toward the poles.

[7] Both furnaces end the same way. Energy that reaches the surface eventually leaves Earth as infrared radiation into space. The planet is neither warming up nor cooling down much from year to year because, over a year, what goes out roughly balances what comes in. What happens in between, during the energy's stay, is the weather, the ocean currents, the growth of forests and the slow rearranging of continents. Earth's systems are not powered by energy that is stored forever; they are powered by energy that is passing through.

Questions: cite the passage

1. According to paragraph 2, what are the two fuel supplies of Earth's inner furnace? Name both and give the paragraph number.

Answer: Leftover heat from Earth's formation (collisions and iron sinking to the center) and energy released by radioactive decay of elements such as uranium, thorium and potassium (paragraph 2).

Why: Both supplies are named explicitly in paragraph 2. This is also the accurate correction to the textbook's suggestion that pressure makes the core hot.

Also acceptable: Accept 'heat from when Earth formed' and 'radioactive elements breaking down.'

- Leftover heat from formation
- Radioactive decay
- Paragraph number given

2. Paragraph 2 describes energy leaving the core and then moving up through the mantle. Name the two transfer methods in the order they happen and quote the words that tell you rock is moving.

Answer: First conduction ('leaves the core by conduction into the rock touching it'), then convection ('rock that is warmer and less dense creeps up while cooler, denser rock sinks'). The quoted words about rock moving: 'creeps up' and 'sinks,' or 'the creep is slow, only a few centimeters per year.'

Why: The order (conduction at the core contact, then convection in the mantle) is the same sequence students met in W2 q6.

Also acceptable: Accept a close paraphrase of the creeping sentence if marked as evidence.

- Conduction then convection, in that order
- A quotation showing rock moving

3. Why can the sun's energy not reach Earth by conduction or convection? Use evidence from paragraph 3.

Answer: Conduction and convection both need matter, and there is 'almost no matter between the sun and Earth,' so 'nothing can conduct and nothing can convect across that gap.' The energy has to travel as light (radiation) instead.

Why: The evidence is a direct statement in paragraph 3.

Also acceptable: Accept 'space is empty, and those two methods need stuff to move through.'

- States that conduction and convection need matter
- Cites the near-empty space between sun and Earth

4. Use the two numbers in paragraph 4 to calculate roughly how many times more energy the sun delivers to an average square meter than Earth's interior does. Show the division and round to the nearest hundred.

Answer: $340 \text{ W/m}^2 \div 0.09 \text{ W/m}^2 \approx 3,778$, which rounds to about 3,800. The sun delivers roughly 3,800 times more energy per square meter than the interior.

Why: Division of the two averages; the units cancel, leaving a pure ratio. Accept 3,700 to 3,900 depending on rounding of 0.09.

Also acceptable: A student who rounds 0.09 to 0.1 gets $340 \div 0.1 = 3,400$; accept it if the rounding is stated, and show the student that rounding the divisor up lowers the result, so 3,800 is closer. Do not accept 'about 4,000' without the division shown.

5. Paragraph 3 says most absorbed sunlight is 'soaked up by the ground and the sea, not by the air itself.' Explain what this means for how air near the surface gets warm, and name the transfer method involved.

Answer: Sunlight mostly passes through the air and is absorbed by the ground and water. The air near the surface is warmed mainly because it is touching the warm ground, which is conduction. Only after the lowest air is warmed does it become less dense and rise (convection).

Why: This corrects the common idea that sunlight heats the air directly. Students should name conduction at the ground-to-air contact.

Also acceptable: Accept an answer that adds the later rise as convection.

- Surface absorbs the sunlight
- Air warms by touching the surface (conduction)

6. Paragraph 5 argues that the inner furnace matters even though it delivers far less energy. Give the two reasons the paragraph offers, in your own words, and explain how the geyser example shows both furnaces at work.

Answer: Reason 1: the interior's energy arrives from below, where sunlight cannot reach, so only it can stir the mantle. Reason 2: it is attached to rock, so when it moves rock it also drags plates, lifts mountains and feeds volcanoes. The geyser shows both: the water came from rain, which the sun's energy lifted into the air by evaporation, and the heat that boils that water comes from rock warmed from below by the interior.

Why: Both reasons are in paragraph 5; the geyser sentence explicitly tags each step with its furnace.

Also acceptable: Accept 'sunlight only warms the top' for reason 1.

- Energy from below cannot be replaced by sunlight
- Energy is tied to moving rock
- Geyser: rain (sun) plus hot rock (interior)

7. Paragraph 6 gives two reasons polar surface water becomes denser. State both, then explain what gravity does once the water is denser.

Answer: The polar surface water loses energy and gets colder, and when sea ice forms it leaves its salt behind, so the remaining water is saltier. Both changes make the water denser. Gravity then pulls the denser water down to the sea floor, and water from warmer regions slides in to fill the gap, which starts the loop.

Why: The salinity reason is the accurate addition to the textbook's temperature-only picture; the passage states both.

Also acceptable: Accept 'it sinks' for gravity's role if the student says the water is denser.

- Colder
- Saltier because of sea-ice formation
- Gravity pulls the denser water down

8. The passage ends: Earth's systems 'are powered by energy that is passing through.' Using evidence from at least two paragraphs, explain what the author means, and describe where the energy finally goes.

Answer: Model response: The author means that Earth does not run on a stored supply of energy that stays here; energy enters (as sunlight, paragraphs 3 and 4, and as heat leaking from the interior, paragraph 2), does work while it is here (moves rock, stirs the ocean and air, grows forests, paragraph 7), and then leaves. Paragraph 7 says the energy finally leaves Earth as infrared radiation into space, and that over a year what goes out roughly balances what comes in, which is why the planet's temperature stays about the same.

Why: Full credit requires the in-and-out idea, evidence from two paragraphs, and the exit as infrared radiation to space.

Also acceptable: A student who notes that the balance is only approximate and that a long-term imbalance would change Earth's temperature is reasoning beyond the passage in a valid way.

- Energy enters and leaves rather than being stored
- Evidence from at least two paragraphs with numbers
- States that energy leaves as infrared radiation into space

Teacher notes

The passage is about 700 words. Its numbers are real reference values: the global average solar input at the top of the atmosphere is about 340 W/m² (one quarter of the solar constant of about 1,361 W/m²), the average geothermal heat flow is about 0.09 W/m², the center of Earth is estimated at roughly 5,000 to

6,000 °C, mantle flow and plate motion are a few centimeters per year, and Earth formed about 4.5 billion years ago. Two deliberate corrections to the textbook appear here: the interior's heat comes from formation and radioactive decay (not from pressure), and polar water sinks because it is colder and saltier, not colder alone. The passage keeps the lesson's two-source picture; tidal energy from the Moon is a real third, much smaller source and can be mentioned to students who ask whether there are only two. For the extension: $100 \text{ W} \div 340 \text{ W/m}^2 \approx 0.29 \text{ m}^2$, smaller than a 0.4 m^2 desk, so the claim is fair; noon sunlight on a clear day is much stronger (up to about $1,000 \text{ W/m}^2$ at the ground) because 340 is an average over night, slanted sunlight and the whole globe.

Scaffold offered to students: Two-column notes before the questions

Draw a line down a sheet of scrap paper. Label the left column 'Inner furnace' and the right column 'Sun.' As you read the second time, write every fact about where that furnace's energy comes from, how it travels, how much there is, and what it moves, each with the paragraph number. Most questions can be answered by reading down one column; q6 and q8 use both.

Extension: Check the bulb comparison

Paragraph 4 says a hundred-watt bulb's worth of sunlight falls on a patch 'smaller than a desk.' Using 340 watts per square meter, calculate the area that receives 100 watts, and decide whether the claim is fair for a school desk (about $0.4 \text{ square meters}$). Then explain why the real sunlight hitting the beach at noon is much stronger than 340 watts per square meter even though the passage's average number is correct.