

How Much Gets Through? Energy per Level and a Caterpillar's Matter Budget

Learning target: I can graph energy at each trophic level, calculate the fraction passed from one level to the next, and account for every gram of matter an animal eats.

Data and graphing

About 45 min

Individual

MS-LS2-3 · practice

MS-LS1-7 · supports

data analysis

independent practice

Standards connections

MS-LS2-3 (practice): Calculating transfer fractions and balancing a matter budget gives students the quantitative reasons behind the model they build for this PE: energy shrinks at every level because most of it leaves as heat, while the matter that leaves an animal is still in the ecosystem.

MS-LS1-7 (supports): Part B relies on the earlier idea that food is broken down inside an organism, releasing energy and carbon dioxide; students use that idea to account for matter without writing any chemical reactions.

Purpose: practice · **Time:** about 45 minutes · **Format:** individual

Answers with reasoning

Part A: Energy stored at each trophic level

Ecologists estimate how much energy each trophic level stores in new living material over a year, in kilojoules per square meter per year ($\text{kJ}/\text{m}^2/\text{yr}$). The table gives teaching estimates for a shallow pond and a nearby grassland. First-stage consumers eat producers; second-stage consumers eat first-stage consumers; third-stage consumers eat second-stage consumers.

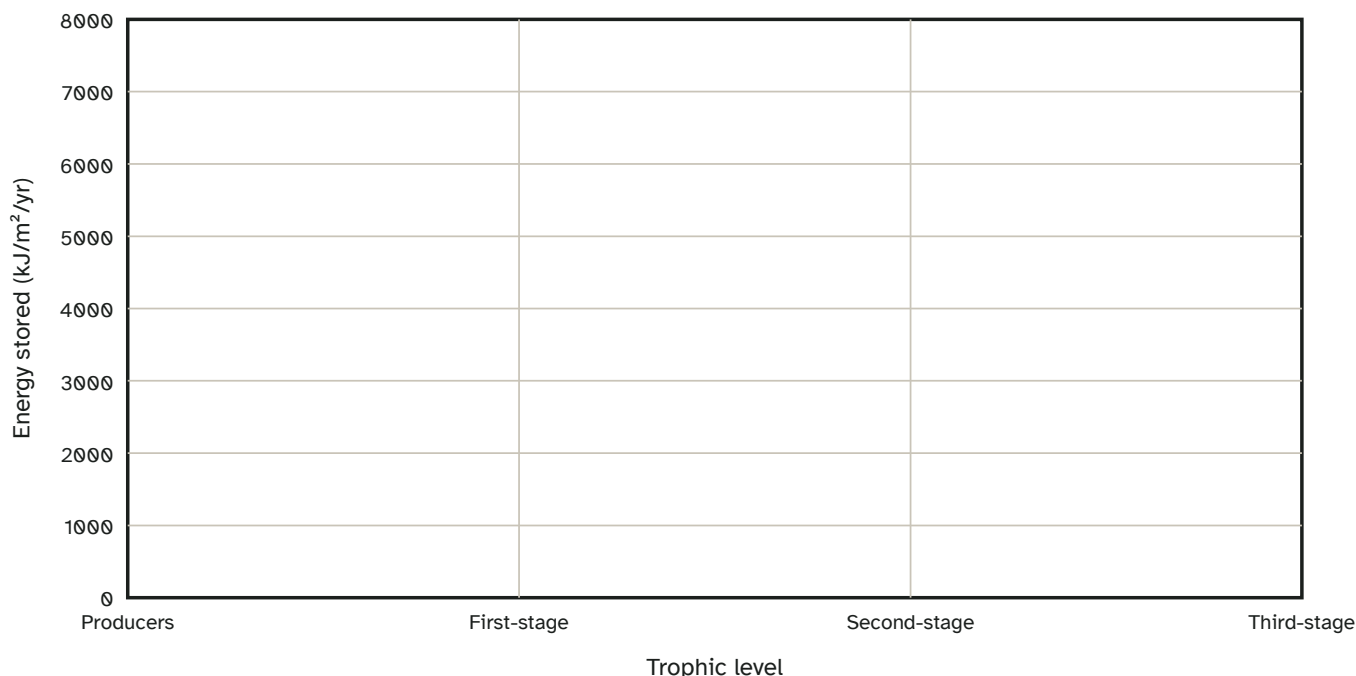
Energy stored in new growth per year at four trophic levels (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Trophic level	Pond ($\text{kJ}/\text{m}^2/\text{yr}$)	Grassland ($\text{kJ}/\text{m}^2/\text{yr}$)
Producers	8000	6000
First-stage consumers	900	480
Second-stage consumers	90	60
Third-stage consumers	7	5

Simulated data for teaching. Values are in the realistic range for temperate ponds and grasslands but were not measured at a real site.

Energy stored per year at each trophic level in the pond



- For each step, calculate the percent of energy passed from the lower level to the next: (energy in upper level ÷ energy in lower level) × 100. Fill in all six cells and show one full calculation below the table.

Answer: Pond: $900 \div 8,000 \times 100 = 11.3\%$; $90 \div 900 \times 100 = 10.0\%$; $7 \div 90 \times 100 = 7.8\%$. Grassland: $480 \div 6,000 \times 100 = 8.0\%$; $60 \div 480 \times 100 = 12.5\%$; $5 \div 60 \times 100 = 8.3\%$.

Why: Each percent is upper divided by lower times 100. The six values were chosen to scatter around 10 percent so that students see the figure as an average, not a law.

Also acceptable: Accept 11.25 for the first pond value if not rounded; accept 7.7 or 7.8 and 8.3 or 8.33 depending on rounding.

- Find the average of your six percentages. Compare it with the textbook's 10 percent model in one sentence.

Answer: $(11.3 + 10.0 + 7.8 + 8.0 + 12.5 + 8.3) \div 6 = 57.9 \div 6 = 9.65\%$, about 9.6 to 9.7% depending on rounding. The average is close to the textbook's 10 percent, but the individual steps range from about 8 to 12.5 percent.

Why: The average lands near 10 percent by design; the spread is the point of the comparison.

Also acceptable: Accept 9.6 to 9.7 percent.

3. Describe the shape of your bar graph. Why are the last two bars almost impossible to see on this scale, and what does that tell you about how much energy reaches the top of a food chain?

Answer: The bars drop steeply: the first bar reaches 8,000, the second is about one ninth as tall, and the third and fourth (90 and 7) would be barely a pencil line above the baseline. On a scale built to fit the producers, the upper levels are tiny, which shows that only a minute fraction of the energy captured by producers is stored at the top of the chain.

Why: The scale problem is itself the lesson: the shrinking is so extreme that a single linear scale cannot show both ends.

Also acceptable: A student who suggests a different scale or a log scale is reasoning well.

- Describes a steep drop
- Explains the invisible bars by the scale
- Concludes that very little energy reaches the top

4. What percent of the pond's producer energy ends up stored in third-stage consumers? Show the calculation. Then explain in one sentence why a heron that eats bass needs a lot of pond.

Answer: $7 \div 8,000 \times 100 = 0.0875\%$, which is less than one tenth of one percent. Because such a tiny share of the producers' energy is stored at the third level, a heron must hunt over a large area of pond to gather enough bass and bluegill to live.

Why: Three transfer steps of roughly 10 percent each leave about 0.1 percent; this pond is a little below that.

Also acceptable: Accept 0.09% or 'about 0.1%'.

5. A different pond's bass population stores 20 kJ/m²/yr, and bass are third-stage consumers there. Using the 10 percent model exactly, how much energy would that pond's producers need to store each year? Show each step.

Answer: Bass (third-stage) 20 kJ/m²/yr → second-stage must store $20 \times 10 = 200$ → first-stage must store $200 \times 10 = 2,000$ → producers must store $2,000 \times 10 = 20,000$ kJ/m²/yr.

Why: Working backward through three levels multiplies by 10 three times ($\times 1,000$).

Also acceptable: Accept $20 \times 1,000 = 20,000$ kJ/m²/yr with the levels named.

6. A student claims, 'Every level always passes on exactly 10 percent.' Does the data support that claim? Write a claim the data **does** support, using your numbers.

Answer: No. The steps range from 7.8 percent to 12.5 percent, so no level passes on exactly 10 percent. A supported claim: 'In both ecosystems, each level stores only about 8 to 13 percent as much energy as the level below it, roughly one tenth on average.'

Why: The data refute 'exactly' and 'always' while supporting the pattern. The chapter's accuracy notes flag the textbook's 'only 10 percent' as an average.

Also acceptable: Accept 'always much less than the level below, close to one tenth.'

- Rejects the exact claim with numbers
- Writes a claim that states a range or an average
- Claim fits all six values

Part B: Where does 100 grams of leaf go?

Researchers raised a group of caterpillars in a screened cage on oak branches and tracked the dry mass of everything that went in and came out over one summer. Dry mass means the mass after all the water has

been removed, so the numbers compare only the solid material. The table shows what happened to 100 grams of leaf that the caterpillars ate.

Matter budget for 100 g (dry mass) of oak leaf eaten by caterpillars (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

What happened to the leaf matter	Dry mass (g)
Passed through and left as droppings	60
Released to the air as carbon dioxide and water during cellular respiration	25
Built into new caterpillar body	15

Simulated data for teaching. The split between droppings, respiration and growth is realistic for leaf-eating insects.

7. Convert each row of the matter budget into a percent of the 100 g eaten.

Answer: Droppings: $60 \div 100 \times 100 = 60\%$. Respiration: $25 \div 100 \times 100 = 25\%$. New body: $15 \div 100 \times 100 = 15\%$.

Why: With a 100 g total, each mass is its own percent.

Also acceptable: None.

8. Add the three masses. How many grams are unaccounted for? What does that total tell you about whether any matter was destroyed?

Answer: $60 \text{ g} + 25 \text{ g} + 15 \text{ g} = 100 \text{ g}$. $100 \text{ g} - 100 \text{ g} = 0 \text{ g}$ unaccounted for. Every gram of leaf that went in can be found again, so no matter was destroyed; it only moved to droppings, to the air, or into caterpillar bodies.

Why: The closed budget is the evidence for conservation of matter in a feeding step.

Also acceptable: Accept 'nothing is missing' with the sum shown.

9. Suppose birds eat all 15 g of caterpillar and build the same share (15 percent) into their own bodies. How many grams of bird body come from the original 100 g of leaf? Show the calculation.

Answer: $15 \text{ g} \times 0.15 = 2.25 \text{ g}$ of bird body from the original 100 g of leaf (about 2 percent).

Why: Applying the same 15 percent share to the 15 g that became caterpillar gives the second-step result; this mirrors the energy pyramid with matter.

Also acceptable: Accept 2.3 g if rounded, with the multiplication shown.

10. Use both parts of this sheet. Energy and matter **both** shrink from one level to the next. Explain where the missing energy goes and where the missing matter goes, and then explain why only one of them is truly gone from the ecosystem.

Answer: Missing energy: at each level most of the food's energy is used by the organisms to live and is released as heat into the surroundings (the respiration share), and some stays in droppings and uneaten remains, where decomposers use it and also release heat. Missing matter: the 85 g that did not become caterpillar body went into droppings (60 g) and into carbon dioxide and water in the air (25 g). The matter is still in the ecosystem: decomposers break down the droppings and release nutrients, and producers take the carbon dioxide back in, so the atoms can be used again. The energy that left as heat cannot be gathered up by producers, so it is truly gone from the living system; that is why ecosystems need a constant supply of sunlight but not of new atoms.

Why: This is the synthesis of the chapter: both quantities decrease up the pyramid, but matter cycles and energy flows out as heat.

Also acceptable: Accept 'matter is recycled, energy is not' if each half is backed by a number from the sheet.

- Energy leaves mainly as heat (and some in wastes and remains)
- Matter leaves as droppings and carbon dioxide and water
- States that the matter is reused by decomposers and producers
- States that heat cannot be reused, so only energy is gone

Teacher notes

Both datasets are simulated. The Part A values scatter around 10 percent on purpose (7.8 to 12.5 percent) so that q6 can reject 'exactly 10 percent'; real measured efficiencies range even more widely. The pond's top bars cannot be drawn on a linear 0-8,000 scale; let students discover that and discuss scale choice. In Part B, dry mass is used so that water drunk or lost does not confuse the budget; the respiration row represents carbon dioxide and water vapor leaving the body, and the budget is an accounting of mass, not a chemical equation, which keeps the sheet inside the MS-LS2-3 assessment boundary. Common errors: dividing the lower level by the upper in q1 (giving values near 10 instead of 0.1), and forgetting to multiply three times in q5. The extension's number pyramid (grass, grasshoppers, lizards, hawks) is also invented and is upright; the oak-and-caterpillars example is where a number pyramid inverts.

Scaffold offered to students: Percent in two steps

To find the percent passed on, divide the upper level by the lower level first, then multiply by 100.

Example with made-up numbers: $50 \div 400 = 0.125$; $0.125 \times 100 = 12.5$ percent. Write the division on one line and the multiplication on the next so you can check each step. In q5 you are working backward, so multiply by 10 for each level you go down instead of dividing.

Extension: Numbers versus energy

In a 100-hectare grassland valley (one square kilometer), suppose there are about 2,000,000 grass plants, 200,000 grasshoppers, 400 lizards and 4 hawks. Make a second bar chart of these counts, then compare it with the energy pattern. Next, imagine one oak tree holding 20,000 caterpillars. Explain why a pyramid of numbers can be upside down at the bottom while a pyramid of stored energy never is, and what the caterpillar budget in Part B tells you about why.