Transfer of energy and matter

C4.2 · SL and HL

A leaf returns its atoms, but not its original sunlight

Follow carbon and usable energy separately

Full shared C4.2: open systems, nutrition, feeding, decomposition, respiration, production and energy pyramids, carbon budgets and atmospheric carbon dioxide.

Prerequisites: photosynthesis, respiration, organic molecules, percentages and graph scales. The topic has no additional Higher-Level-only content.

Examples are invented unless explicitly identified as published research or NOAA measurements. Match boundaries, units and periods.

Classify the system by what can cross its boundary

System	Exchange and example
Open	Matter and energy cross; a pond receives sunlight, rain and leaf litter and exports heat/water/material
Closed	Energy crosses but matter does not; an ideally sealed transparent vessel can receive light and lose heat
Isolated	Neither matter nor energy crosses; a different idealization
Boundary	An organism, pond and catchment enclose different stores and transfers

Count an internal transfer once, inside the boundary

1. **Invented pond.** External carbon inputs 120 kg/year; outputs 95 kg/year; all external transfers included.
2. **Balance.** Storage change = inputs − outputs = $120 - 95 = 25$ kg/year gained.
3. **Internal arrow.** Algal carbon eaten by grazers moves between stores already inside the pond. It is not another external input.

A dark habitat still needs an identifiable energy input

Darkness alone does not establish chemosynthesis

Sunlight sustains most ecosystems through photosynthesis. A dark cave can receive wood, leaves or animal waste made from externally captured energy.

Deep communities can receive sinking organic material or depend on local chemical-energy-based production.

Trace the actual supply; an open ecosystem can import organic matter as well as mineral substances.

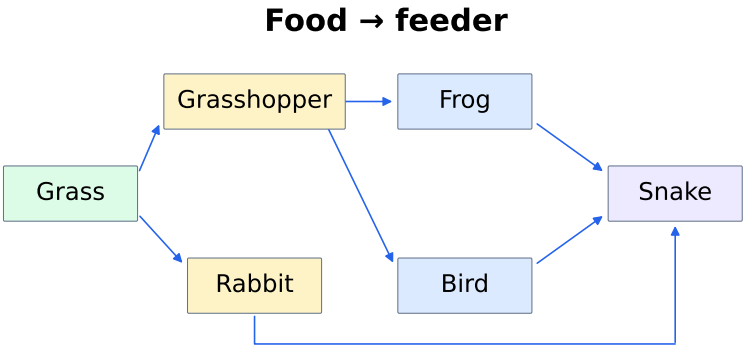
Name the carbon source and the energy source separately

Group	Sources and mechanism
Photoautotroph	Inorganic carbon; light supplies energy for fixation and anabolism
Chemoautotroph	Inorganic carbon; chemical oxidation supplies energy
Iron oxidizer	Oxidation of Fe(II) to Fe(III) can supply energy; iron does not supply the sugar carbon
Heterotroph	Organic carbon compounds obtained from other organisms; internal or external digestion

Explain assimilation without treating food as unchanged tissue

1. **Digestion.** Proteins and other complex food compounds are broken down into smaller absorbable products.
2. **Assimilation.** Absorbed amino acids can be used to build the organism's own proteins; fungal digestion can occur outside its body.
3. **Respiration.** Both autotrophs and heterotrophs oxidize organic compounds, transferring energy to ATP and releasing heat.

Read every arrow from food toward feeder



Feeding transfers organic material and its chemical energy to the consumer.

A trophic position belongs to a feeding route

1. **Chain.** Grass → grasshopper → frog → snake: producer, primary, secondary, tertiary consumer.
2. **Varied diet.** A bird eating seeds is primary on that route; eating a herbivorous insect makes it secondary on that route.
3. **Evidence.** A local web needs reliable diet evidence. Shared habitat alone does not prove feeding, and a link alone gives no transfer rate.

A decomposer is not simply the last predator in the chain

Dead matter supplies carbon compounds and chemical energy

Faeces, shed parts and whole dead organisms come from producers and all consumer levels; some production enters detritus without herbivore feeding.

A detritus feeder ingests material; many fungi digest externally and absorb products. Decomposers also grow, reproduce and respire.

Breakdown and mineralization return matter to usable nutrient forms. Respiratory heat does not become another round of sunlight.

Subtract producer respiration to obtain net primary production

1. **Define.** GPP is total fixation into organic compounds; NPP remains after producers' own respiration.
2. **Invented rates.** $\mathrm{NPP} = \mathrm{GPP} - R_{\mathrm{producers}} = 18000 - 8000 = 10000$ kJ per square metre per year.
3. **Use.** NPP can support new biomass supplied to consumers and detrital routes. Subtracting consumer respiration instead would answer a different question.

Distinguish stock, production and the material measured

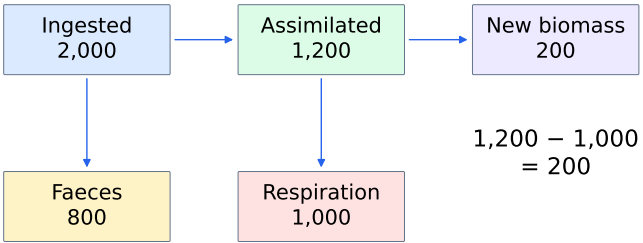
Quantity	**Meaning and units**
Standing biomass	Amount per area on a date; grams per square metre
Carbon production	New organic carbon accumulated through growth/reproduction; grams C per square metre per year
Energy production	Energy equivalent of new biomass; kJ per square metre per year
Secondary production	New heterotroph biomass; neither total ingestion nor all **assimilation**

A small stock can turn over rapidly

1. **Invented algae.** Stock 20 g C per square metre; annual production 400 g C per square metre per year.
2. **Ratio.** Production / stock $= 400/20 = 20$ per year.
3. **Interpretation.** Rapid replacement supports high flow through a small stock. Start-to-end biomass change alone can miss tissue already consumed, exported or dead.

Follow the same energy budget through successive stages

Invented consumer energy budget / kJ



Same area and period; other organic losses = 0

Assimilation supplies respiration and new biomass.

Use the balance before calculating the efficiency

1. **Ingestion and faeces.** $A = I - F = 2000 - 800 = 1200$ kJ assimilated.
2. **Respiration and production.** $P = A - R = 1200 - 1000 = 200$ kJ new biomass.
3. **Conditions.** Same area and period; other organic losses set to zero. Include energy-containing excretory losses when the real budget requires them.

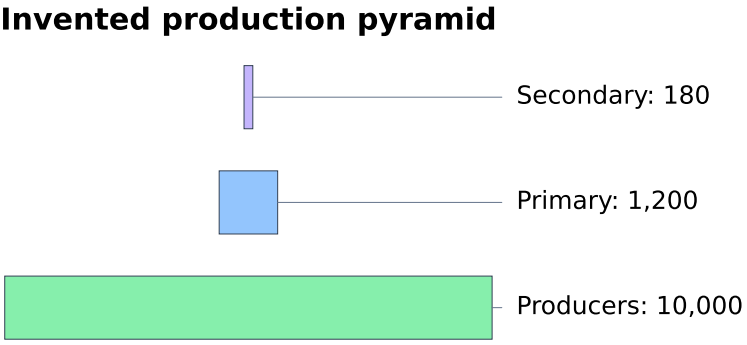
Three correct percentages can describe different stages

1. **Assimilation / ingestion.** $1200/2000 \times 100 = 60\%$.
2. **Production / assimilation.** $200/1200 \times 100 \approx 16.7\%$.
3. **Production / ingestion.** $200/2000 \times 100 = 10\%$. Name the denominator; these are different efficiencies.

Do not replace producer-to-consumer transfer with intake efficiency

1. **Supporting producer NPP.** 10,000 kJ in the same area and year; this consumer produces 200 kJ.
2. **Trophic production transfer.** $200/10000 \times 100 = 2\%$, although production / ingestion was 10%.
3. **Other routes.** Uneaten producer material can remain, die, be exported or support other consumers. It was not all respired by this herbivore.

Keep one linear width scale for all trophic bars



Rectangle widths compare production for the same area and interval.

Calculate each step with its own preceding production

1. **Separate invented chain.** Producers 10,000; primary consumers 1,200; secondary consumers 180 kJ per square metre per year.
2. **Step efficiencies.** $1200/10000 \times 100 = 12\%$; $180/1200 \times 100 = 15\%$.
3. **Across both steps.** $180/10000 \times 100 = 1.8\%$; equivalently $0.12 \times 0.15 = 0.018$. Do not add the step percentages.

Construct an energy pyramid that preserves its quantitative meaning

Label the groups, values, units and measuring interval

Place producers below successively higher consumers. Use equal-height rectangles whose widths are proportional to matched production.

Use the same linear scale for all bars; external labels keep small upper values readable without widening the bars.

A stock pyramid and a production-energy pyramid are different quantities. Imports and unmatched periods require a wider or corrected comparison.

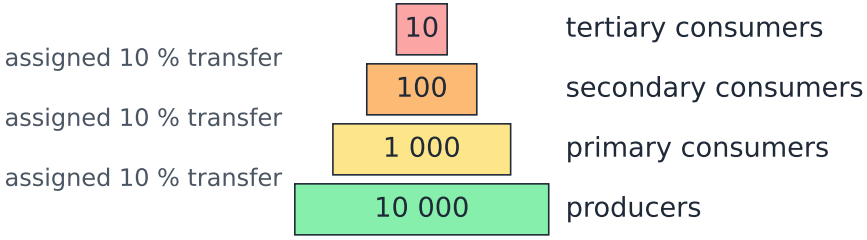
Read original research definitions before plotting the data

Silver Springs group	Historical production estimate
Herbivores	1,478 kcal per square metre per year
Carnivores	67 in the same units
Top carnivores	6 in the same units
Interpretation	Odum's rough open-web estimates; consumer intake is a different, larger quantity

Research estimates are not exact universal efficiencies

1. **Read the study.** Odum's 1957 Figure 7 and notes distinguish production from intake and describe substantial estimation limits.
2. **Two production ratios.** $67/1478 \times 100 \approx 4.53\%$; $6/67 \times 100 \approx 8.96\%$.
3. **Limit.** These concern a complex open community, not an isolated three-species chain. Plot the labelled groups with a common scale and retain the original units.

A pyramid of energy



About 10% passes on at each step

Account for energy missing from the next grazing level

Route	Where it can go
Uneaten material	Remains, is exported or enters detrital pathways
Unassimilated faeces	Chemical energy remains available to appropriate detrital organisms
Respiratory use	Energy transformations during ATP production and use release heat
Conservation	Energy is transformed and dispersed; it is not destroyed

Repeated fractional transfers limit support for higher levels

1. **Hypothetical model.** Start with 10,000 producer energy units; assume 10% production transfer at each step.
2. **Successive levels.** $1{,}000 \rightarrow 100 \rightarrow 10 \rightarrow 1$ units. This illustrates compounding, not a universal measurement.
3. **Biological meaning.** Lower total support does not require every predator to be smaller than prey or tissue to contain less energy per gram. A few large predators can depend on many small prey.

An inverted biomass snapshot does not reverse the production flow

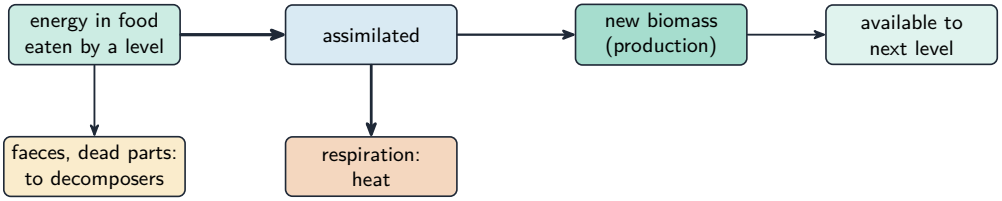
Rapid replacement changes the relation between stock and rate

Phytoplankton can produce new biomass rapidly while grazing keeps their standing stock small.

A larger zooplankton stock on one date does not demonstrate creation of extra energy; compare production over matched intervals.

Imported food and different time windows can make a local comparison misleading. Define the supporting pathway and its boundary.

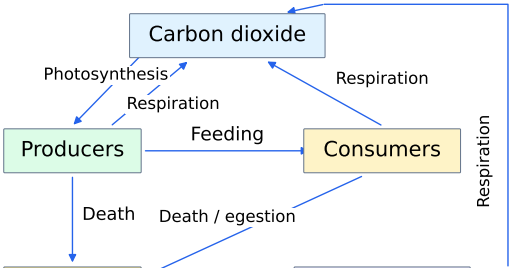
Where a consumer's energy goes



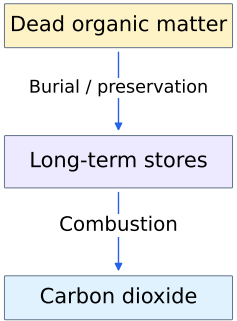
model chain at 10% per step: $10\,000 \to 1\,000 \to 100 \to 10 \to 1$ units; energy is conserved, not destroyed

> Only the new biomass reaches the next level

Follow carbon stores through labelled transformations



Carbon moves; energy transforms



A slower storage pathway

Respiration returns carbon dioxide from every living group.

Explain the biological carbon loop in order

1. **Entry and feeding.** Carbon dioxide $\rightarrow$ producer organic compounds by photosynthesis; feeding transfers organic carbon to consumers.
2. **Detritus.** Death/egestion supply organic matter; decomposer uptake builds biomass while respiration returns carbon dioxide.
3. **Gas interdependence.** Oxygenic photosynthesis releases oxygen from water for aerobic respiration. Respiration supplies carbon dioxide for fixation.

A long-lived store and rapid combustion operate on different timescales

Name the store and the process releasing its carbon

Peat can accumulate where waterlogging and oxygen limitation restrict decomposition. Fossil carbon stores formed over geological times under varied conditions.

Combustion of biomass, peat, coal, oil or natural gas releases carbon dioxide and transfers energy. Lightning can cause fires; human activities greatly increase combustion.

Burning recent biomass releases carbon dioxide now. Any later balance requires actual regrowth over a stated boundary and interval; it is not an instant exemption.

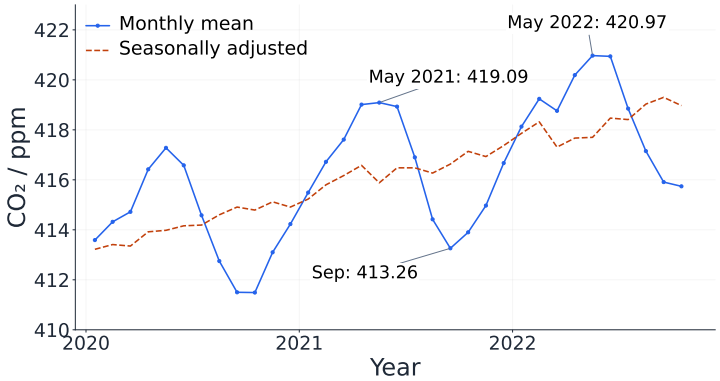
Whole-community respiration changes the sink calculation

1. **Invented annual carbon fluxes.** Fixation 900; producer respiration 350; heterotroph respiration 400 g C per square metre per year.
2. **Two balances.** NPP $= 900 - 350 = 550$; net ecosystem uptake $= 900 - 350 - 400 = 150$ in the same rate units.
3. **Alternative.** If total respiration is 980, fixation minus respiration is -80: a net source of 80 under the restricted budget.

Do not substitute a large store for a measured sink

Term or condition	Interpretation
Store	Amount present; a large forest stock need not be a large present-day sink
Sink/source	Net uptake/net release over the stated interval
Full open budget	Include fire, harvest, dissolved carbon, imports and other important fluxes
Other elements	Decomposers help recycle needed nutrients; local exports mean recycling need not be complete

Read within-year change and corresponding-month change separately



A seasonal decline can coexist with a rising atmospheric concentration over years.

Quantify three historical NOAA monthly measurements

1. **May to September 2021.** $419.09 - 413.26 = 5.83$ ppm fall.
2. **May 2021 to May 2022.** $420.97 - 419.09 = 1.88$ ppm rise.
3. **Concentration units.** $419.09/1000000 \times 100 = 0.041909\%$ of dry air. The record is concentration, not factory counts or one forest's fixation rate.

Explain the seasonal pattern without switching off plant respiration

Northern Hemisphere vegetation changes the uptake–release balance

Strong spring/summer land-plant growth increases photosynthetic uptake. Plants continue respiring during that season.

Later reduced photosynthesis plus continuing plant/decomposer respiration contributes to the seasonal return; Northern Hemisphere land vegetation has a strong influence.

Net atmospheric additions, with fossil-fuel combustion a major driver and land-use change also important, underlie the longer rise. Seasonal decline does not cancel that trend.

Combine a useful pattern with mechanisms and independent evidence

A theory does not become a law through approval

Laws and useful generalizations describe reproducible patterns and support predictions. Explanatory theories account for mechanisms and evidence.

Energy conservation is robust; a simple 10% trophic rule is an approximate model requiring scope and assumptions.

Compare equivalent months or adjusted values. Use emissions, isotope evidence and land/ocean exchanges alongside the concentration curve to investigate causes.

Attempt the complete handout practice before checking

Draw the boundary before calculating the percentage

Construct the web and carbon cycle; explain nutrition, detrital pathways, respiration, production and proportional pyramids.

Calculate system and consumer budgets, turnover, step/overall efficiencies and ecosystem carbon balance.

Interpret the published NOAA comparison and evaluate recycling, dark-habitat, biomass-combustion and scientific-law claims.

Check system, production and turnover practice

1. **Pond storage.** $180 - 145 = 35$ kg C gained; an internal 60 kg algae-to-grazer transfer is not another external input.
2. **Producer NPP.** $24000 - 9000 = 15000$ kJ per square metre per year.
3. **Production / stock.** $450/30 = 15$ per year; production is a rate, whereas stock has no time denominator.

Check every denominator in the consumer practice

1. **Balance.** $A = 3000 - 1200 = 1800$ kJ; $P = 1800 - 1500 = 300$ kJ.
2. **Stage efficiencies.** $A/I = 60\%$; $P/A \approx 16.7\%$; $P/I = 10\%$.
3. **Trophic production.** $300/15000 \times 100 = 2\%$ from the supporting producer NPP. Same area/interval; no additional organic loss in this model.

Check proportional widths and compounded transfers

1. **Three-level practice.** Widths $1 : 0.15 : 0.015$; step efficiencies 15% and 10%; overall 1.5%.
2. **Four-step model.** 50,000 $\to$ 5,000 $\to$ 500 $\to$ 50 $\to$ 5 units.
3. **Interpretation.** Multiply fractions, do not add percentages. Stocks, production rates, individual body size and energy per gram are different quantities.

Check the full carbon budget before calling the ecosystem a sink

1. **Producer balance.** NPP $= 1200 - 450 = 750$ g C per square metre per year.
2. **Community balance.** $1200 - 450 - 600 = 150$ net uptake in the same units, ignoring other fluxes.
3. **Add fire.** $150 - 220 = -70$: net source of 70 under the complete stated budget. A large store does not determine its net change.

Check yourself

Follow the atoms, the energy and the denominator

Food-web arrows go toward the feeder. Carbon-cycle arrows require named processes; every living group can respire.

New biomass production is not ingestion or standing stock. Some energy enters detritus; heat dispersal does not destroy energy.

State the boundary, date/interval and units. Carbon sinks depend on net transfers; seasonal and long-term atmospheric changes can coexist.