

Fuel for Flight: Which Biomass Should Become Jet Fuel?

Investigation question: A regional airline wants 30 million litres of jet fuel a year to come from biomass within five years. Which of five sources of biomass should it choose, judged by a systematic process against stated criteria and constraints?

Data-driven decision

Groups of 4

1 session

Setup 5 · Activity 40 · Cleanup 5 min

MS-ETS1-2 · assesses

MS-ETS1-1 · practice

MS-LS1-6 · supports

Scientific purpose

Students act as the airline's evaluation team. They sort requirements into criteria and constraints, compute two numbers for each candidate feedstock (how much fuel it could supply per year and what the feedstock costs per litre of fuel), screen out candidates that break a constraint, score the survivors in a weighted decision matrix, test whether changing a weight changes the winner, and write a recommendation with its trade-off. The data are a labeled teaching dataset; the skill being built is the process engineers use to compare competing solutions fairly, and the science underneath is that every one of these fuels is stored sunlight captured by producers.

Why this helps students with this chapter

Students tend to pick the option with the biggest number in the first column and defend it afterward. A decision matrix forces the opposite order: decide what matters, screen with the hard limits, then score, and only then look at who won. Seeing that a different but reasonable weighting can flip the result teaches that engineering decisions are judgments made visible, not answers looked up. The feedstock problem also closes the loop on the lesson: biomass is stored sunlight, and a biofuel is a way of borrowing that stored energy.

Standards connections

MS-ETS1-2 (assesses, evaluating competing design solutions with a systematic process against criteria and constraints): Students screen five candidates against explicit constraints, then score the survivors in a weighted matrix and justify the result with the data. The matrix, the screening table and q4 are direct evidence of a systematic evaluation, which is the PE as written.

MS-ETS1-1 (practice, stating criteria and constraints precisely before evaluating): Students sort the airline's requirements into criteria and constraints and rewrite each as something measurable, which builds the defining practice; the problem itself is supplied, so this is practice rather than assessment of the PE.

MS-LS1-6 (supports, the origin of the energy in biomass): Questions 6 and 7 make students trace the energy in every candidate fuel back to sunlight captured by photosynthesis and the carbon back to carbon dioxide, and explain why burning a biofuel still releases carbon dioxide. This is the lesson's science applied, not new evidence toward the PE.

Roles (rotate each session)

- **Facilitator:** Reads the brief aloud, keeps the group on the step order (define, screen, score, test, recommend), and makes sure every weight is agreed before scoring begins.
- **Data checker:** Reads values from the dataset to the calculator, checks every number copied onto the sheet, and flags any candidate whose data break a constraint.
- **Calculator:** Computes fuel per year and feedstock cost per litre for each candidate, fills the matrix totals, and reruns the totals for the sensitivity test.
- **Reporter:** Writes the group's criteria and constraints, drafts the recommendation and trade-off, and presents the decision to another group.

Materials

Item	Quantity	Per	Note
Printed problem brief (the airline's request and requirement list)	1	group	
Feedstock dataset sheet (the simulated teaching data)	1	group	
Recording sheet with the screening table and decision matrix	1	student	
Calculator	1	group	
Sticky notes in two colors (criteria and constraints)	10	group	
Highlighter	1	group	

Estimated cost: 2 to 4 per class (an estimate; Printing only: one brief and one dataset per group, one recording sheet per student. Calculators and sticky notes are classroom stock.)

Safety

- No physical hazards; this is a paper-and-calculator investigation.
- If students look up real sustainable-aviation-fuel figures to compare, have them record the source and date; real values change yearly and differ from the teaching dataset by design.

Teacher preparation and setup

1. Print the brief, dataset and recording sheets. Check that the dataset sheet carries the 'teaching dataset' label; the numbers are rounded and invented to make the trade-offs clear and must not be presented as real market figures.
2. Work the calculations yourself once (fuel per year = litres per tonne × tonnes per year; cost per litre = dollars per tonne ÷ litres per tonne) so you can spot a group that multiplied the wrong columns.
3. Decide whether all groups use the same weights (easier to compare) or set their own (richer debrief); the procedure assumes groups set their own and then test one change.
4. Post the five step names on the board: Define, Screen, Score, Test, Recommend.

Investigation design

Independent variable	The candidate biomass source (city yard and food waste, used cooking oil, corn grain, fast-growing grass on marginal land, forest timber)
Dependent variable	Pass or fail on each constraint, the weighted matrix total, and the final recommendation
Controlled	Same dataset for every group; Same constraint thresholds from the brief; Same scoring scale (1 to 4 among survivors); Weights fixed before scoring and changed only one at a time in the test step
Trials	One full matrix per group plus one sensitivity rerun; the class compares winners and weights on the board.
Comparison	Each candidate against each constraint, then survivors against each other on the criteria; original weights against the changed weight.

Student procedure

1. Define: read the brief. The airline needs 30 million litres of jet fuel a year from biomass within five years. Its requirement list says: as much fuel per tonne of feedstock as possible; feedstock cost under \$0.40 per litre of fuel; the source must regrow within 5 years; it must not take food or farmland from food; it must be able to supply at least the 30 million litres; and it should cause as little other harm as possible. Write each requirement on a sticky note and sort it as a criterion (a goal to do as well as possible) or a constraint (a line that cannot be crossed). Record the sort and how each one will be measured.
2. Compute: for each of the five candidates, calculate the fuel it could supply per year (litres per tonne × tonnes available per year) and its feedstock cost per litre of fuel (dollars per tonne ÷ litres per tonne). Record both in the calculation table.
3. Screen: for each candidate, check every constraint and write pass or fail with the number that decides it. A candidate that fails any constraint is out, no matter how well it scores elsewhere. Highlight the survivors.
4. Weight: as a group, give each criterion a weight of 1, 2 or 3 (3 = matters most). Write a one-line reason for each weight. Do this before scoring any candidate.
5. Score: for each survivor, score each criterion from 1 (worst of the survivors) to 4 (best), using the data. Multiply each score by its weight and add the weighted scores to get a total. Record the matrix.
6. Test: change one weight (for example, raise 'fuel per tonne' from 1 to 3) and recompute the totals. Record whether the winner changed. This is a sensitivity test: a decision that flips with a small change in weights is a close call and should be reported as one.
7. Recommend: write the group's recommendation in three sentences: the choice, the strongest reason from the data, and the main weakness or trade-off the airline should plan for.
8. Compare: present your decision and your weights to another group. If they chose differently, find the weight or score that explains the difference and record it.
9. Answer the analysis questions individually.

Expected observations

- Fuel per year: city waste 48,000,000 L; cooking oil 18,000,000 L; corn 120,000,000 L; grass 37,500,000 L; timber 115,000,000 L. Cooking oil is the only candidate that cannot meet 30 million litres alone.
- Cost per litre: city waste about \$0.17; cooking oil about \$0.67; corn \$0.50; grass \$0.32; timber about \$0.26. Cooking oil and corn fail the \$0.40 constraint.
- Survivors after screening: city yard and food waste, and fast-growing grass on marginal land.
- With roughly equal weights, city waste wins (cheaper, larger margin, steadier supply); with a heavy weight on fuel per tonne, grass can win. Most groups' sensitivity test shows the decision is a close call.

Likely difficulties

- Multiplying cost by litres instead of dividing: check that cost per litre for city waste comes out near \$0.17, not a huge number.
- Scoring candidates before agreeing on weights, then adjusting weights to make a favorite win; the facilitator's job is to lock weights first.
- Treating 'takes food from food' as a criterion to score rather than a constraint that removes corn outright.
- Giving grass a 'fail' on food competition; the dataset says it passes if kept off farmland, which is a condition the airline can write into its contract. Accept pass with the condition noted.
- Forgetting the supply constraint and keeping used cooking oil because its fuel per tonne is highest.

Structured debrief

1. Post every group's screen on the board. All groups should have removed used cooking oil (cost \$0.67 per litre and only 18 million litres), corn grain (takes food; also \$0.50 per litre) and forest timber (30 to 40 years to regrow). If a group kept one of these, find the constraint they skipped and ask what happens to the airline in year two.
2. Post the winners and the weights. Most groups will pick city waste; some that weighted fuel per tonne heavily will pick grass. Ask the class to find the weight that explains each difference, and make the point that both are defensible decisions made with the same data and a different judgment about what matters.
3. Ask what the sensitivity test showed. A winner that flips when one weight changes is a close call, and an honest report says so. Engineers report the decision and its sensitivity, not just the winner.
4. Close on the science: every candidate is stored sunlight. The grass captured light last summer; the timber captured it over decades; the cooking oil came from seeds that captured it last year. Burning any of them releases the carbon dioxide the producer took in, which is why 'renewable' is not the same as 'carbon-free,' and why the city-waste option is attractive mainly because that carbon was going to be released in a landfill anyway. Note that real aviation biofuel is still a small, expensive fraction of jet fuel as of 2026; the dataset is for practicing the method.

Recording sheet: what students fill in

Lab 3 recording sheet: Fuel for flight

Work in the order Define, Screen, Score, Test, Recommend. Do not look at the totals until the weights are agreed. Every number you write must come from the dataset or from a calculation you show.

Define: the airline's requirements

Requirement from the brief	Criterion or constraint?	How we will measure it (number and unit)
As much fuel per tonne of feedstock as possible		
Feedstock cost under \$0.40 per litre of fuel		
Source regrows within 5 years		
Does not take food or farmland from food		
Can supply at least 30 million litres per year		
As little other harm as possible		

Candidate biomass sources (teaching dataset: rounded, invented values chosen to show the trade-offs; not real market data)

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

Candidate	Litres of jet fuel per tonne of feedstock	Feedstock available within 200 km (tonnes per year)	Feedstock cost (\$ per tonne)	Years for the source to regrow	Takes food or farmland from food?	Other impacts
City yard and food waste	120	400000	20	0 (continuous supply)	No	Mixed and messy; needs sorting; otherwise goes to landfill
Used cooking oil	900	20000	600	0 (continuous supply)	No	Small supply already wanted by other buyers
Corn grain	400	300000	200	1	Yes	Fertilizer and irrigation water; raises food prices
Fast-growing grass on marginal land	250	150000	80	1	No, if kept off farmland	Needs land and water; some habitat lost; harvest is seasonal
Forest timber (pine)	230	500000	60	30 to 40	No	Forest habitat lost; soil erosion after cutting

All five finished fuels have about the same energy per litre (roughly 35 MJ) and release about the same carbon dioxide per litre when burned, because they are refined into nearly the same hydrocarbons. The differences are in the source.

Compute: two numbers for each candidate

Candidate	Fuel per year (litres per tonne × tonnes per year)	Enough for 30,000,000 L? (yes/no)	Feedstock cost per litre (\$ per tonne ÷ litres per tonne)
City yard and food waste			
Used cooking oil			
Corn grain			
Fast-growing grass			
Forest timber			

Screen: pass or fail on each constraint

Candidate	Cost under \$0.40/L?	Regrows within 5 years?	No food competition?	Supplies 30 million L?	Survivor?
City yard and food waste					
Used cooking oil					
Corn grain					
Fast-growing grass					
Forest timber					

Score: weighted decision matrix for the survivors (score 1 to 4, times weight)

Criterion	Weight (1-3) and reason	Survivor 1: score × weight	Survivor 2: score × weight	Survivor 3 (if any): score × weight
Fuel per tonne of feedstock				
Lowest cost per litre				
Supply margin above 30 million L				
Least other harm				
Reliability of supply through the year				
TOTAL				

Test: change one weight and recompute

Weight changed (criterion, old → new)	New total, survivor 1	New total, survivor 2	Did the winner change?

1. Show the calculation of fuel per year for the fast-growing grass and for the used cooking oil. Which one could supply the airline's 30 million litres on its own?

Answer: Grass: $250 \text{ L/t} \times 150,000 \text{ t/yr} = 37,500,000 \text{ L per year}$. Cooking oil: $900 \text{ L/t} \times 20,000 \text{ t/yr} = 18,000,000 \text{ L per year}$. Grass could supply the 30 million litres on its own; cooking oil could not.

Why: Fuel per year is the product of yield and available feedstock; the comparison with 30,000,000 L is the supply constraint.

Also acceptable: Accept 37.5 million and 18 million with units.

2. Show the calculation of feedstock cost per litre for corn grain and for city waste. Which passes the \$0.40 constraint?

Answer: Corn: $\$200 \text{ per tonne} \div 400 \text{ L per tonne} = \$0.50 \text{ per litre}$. City waste: $\$20 \text{ per tonne} \div 120 \text{ L per tonne} = \$0.17 \text{ per litre (0.1667)}$. City waste passes the \$0.40 constraint; corn fails.

Why: Cost per litre is cost per tonne divided by litres per tonne. Corn fails on cost before the food constraint is even applied.

Also acceptable: Accept \$0.16 or \$0.17 for city waste.

Analysis questions: answer key

3. List each candidate that failed the screen and the single constraint (with its number) that removed it. Why is it fair to remove forest timber even though it could make the second-largest amount of fuel per year and has the largest supply?

Answer: Used cooking oil failed the cost constraint (\$0.67 per litre, over \$0.40) and the supply constraint (18 million litres, under 30 million). Corn grain failed the food constraint (takes food and farmland) and also the cost constraint (\$0.50 per litre). Forest timber failed the regrowth constraint (30 to 40 years, over 5).

Removing timber is fair because a constraint is a limit the solution must stay inside: a source that cannot be regrown in time stops being renewable after the first cutting, so its high yield and large supply would last only once.

Why: Constraints screen before criteria score; the timber case shows why a strong criterion score cannot rescue a constraint failure.

- Names all three removed candidates with the deciding number
- Explains that a constraint failure cannot be offset by criterion scores
- Explains the renewability logic for timber

4. State your group's recommendation, the strongest piece of data behind it, and the main trade-off the airline should plan for.

Answer: Example (city waste): We recommend city yard and food waste. It passes every constraint, costs about \$0.17 per litre (the lowest), and can supply about 48 million litres a year, well above the 30 million needed, from a supply that arrives every week. Its main trade-off is that the waste is mixed and must be sorted, and its fuel per tonne is the lowest of all five, so the airline needs a large sorting operation. Example (grass): We recommend fast-growing grass on marginal land. It gives about twice the fuel per tonne of city waste, costs \$0.32 per litre, and can supply 37.5 million litres; its trade-offs are land and water use, a seasonal harvest, and the need to keep it off farmland by contract.

Why: Either survivor is defensible; grade the use of data and the honesty of the trade-off, not the choice.

- Recommends a survivor, not a screened-out candidate
- Cites at least two specific numbers from the calculations
- Names a real weakness from the dataset

5. In your sensitivity test, did changing one weight change the winner? What does that tell the airline about how confident it should be in the decision?

Answer: Group-specific. In most groups, raising the weight on fuel per tonne to 3 brings grass level with or ahead of city waste, so the winner changes or the totals become close. That tells the airline the decision is a close call that depends on how much it values fuel per tonne versus cost and reliability; it should report both options and the weighting, and perhaps plan to use both sources.

Why: Sensitivity testing converts a single answer into a statement about confidence.

Also acceptable: If a group's weights made city waste win by a wide margin even after the change, accept 'the decision is robust to that weight' with the totals shown.

- Reports whether the winner changed
- Interprets a flip (or a near-flip) as low confidence and a close call

6. Every candidate on the list is biomass. Trace the energy in a litre of grass-based jet fuel back to its original source, naming each step.

Answer: Sunlight → absorbed by chlorophyll in the grass's chloroplasts → stored as chemical energy in sugar made from carbon dioxide and water → built into the grass's cellulose and other biomass → broken down and converted into fuel hydrocarbons at the plant → released as heat and motion when the fuel burns in the jet engine.

Why: Every biofuel is captured sunlight; the chain should start with light and pass through photosynthesis and biomass.

- Starts with sunlight
- Includes photosynthesis storing energy in sugar
- Includes biomass (cellulose) and the fuel conversion
- Ends with energy released in the engine

7. A classmate says, 'Biofuel is carbon-free, so the airline can stop worrying about carbon dioxide.' Use the dataset note and what you know about photosynthesis to correct the claim.

Answer: The claim is wrong. The dataset note says every finished fuel releases about the same carbon dioxide per litre when burned, because burning fuel rearranges its carbon atoms into carbon dioxide. A biofuel's advantage is different: its carbon was pulled out of the air by producers recently (last year's grass, not ancient fossil carbon), and the source can be regrown to pull carbon out again. So the carbon cycles on a short loop instead of being added from underground, but the airline still releases carbon dioxide every time it flies and still has to count it.

Why: Renewable is not carbon-free; the conservation of atoms from Lab 2 applies to burning as much as to building.

- States that burning any fuel releases carbon dioxide
- Explains the actual advantage: recently captured carbon and a regrowable source
- Does not claim biofuel is carbon-free

8. A sixth candidate is proposed: algae grown in open ponds on desert land. Name the three numbers from the dataset columns you would need before you could screen and score it, and predict which constraint it is most likely to fail.

Answer: You would need litres of fuel per tonne of algae, tonnes of algae available per year within reach, and cost per tonne (plus the regrow time, which for algae is days). The constraint most likely to fail is cost per litre: growing, harvesting and drying algae from ponds is expensive, so the feedstock cost per litre is likely to exceed \$0.40. Supply could also fall short if the ponds are small.

Why: The point is that a new candidate is evaluated with the same columns and the same screen; a prediction of the cost failure matches the real history of algal fuels.

Also acceptable: Accept 'other harm' (water use in a desert) as the predicted failure if justified.

- Names yield, supply and cost (any three dataset columns)
- Predicts a specific constraint with a reason

Individual evidence of learning

Each student submits a completed define table, calculation table, screening table, decision matrix, sensitivity test and written answers to q1 through q8. The screening table and q3 show the constraint reasoning; the matrix and q4 show the systematic evaluation; q6 and q7 connect the decision to photosynthesis.

Assessment criteria

Criterion	Proficient looks like
Criteria and constraints	Sorts all six requirements correctly, with each constraint given a threshold number and each criterion a measurable quantity.
Calculations	Fuel per year and cost per litre correct for all five candidates with the operation shown; the cooking-oil supply shortfall and the two cost failures identified.
Systematic evaluation	Screens before scoring, removes the three failing candidates with the deciding number, fixes weights before scoring, and computes matrix totals correctly.

Recommendation and trade-off	Recommends a survivor, cites specific data, names a real weakness, and reports what the sensitivity test showed.
Science connection	Traces the fuel's energy to sunlight captured by producers and explains that burning a biofuel still releases carbon dioxide.

Accessibility adaptations

- Provide the calculation table with the first row worked as an example and a calculator with large keys; allow the data checker to read values aloud.
- Offer the define step as a card sort with the six requirements pre-printed, and a two-column mat labeled 'goal to maximize' and 'line not to cross.'
- Allow the recommendation to be presented orally and recorded; provide a sentence frame: 'We recommend ___ because ___. Its main weakness is ___.'
- Give a glossary strip for feedstock, tonne, litre, criterion, constraint, renewable and trade-off, with translations where helpful.

Low-cost alternative

Project the dataset instead of printing it, and have groups draw the tables on notebook paper. The whole lab then costs nothing beyond one recording sheet per student, or none if answers are written on lined paper with the table headings copied.

Model limitations

The dataset is simulated: the values are rounded and invented to make the trade-offs visible, and they are not real prices, yields or supplies. Real feedstock-to-fuel yields depend on the conversion pathway, real costs change yearly, and a real airline would also weigh conversion-plant cost, fuel certification, blending limits and the full life-cycle carbon of each source. As of 2026, sustainable aviation fuel is well under 1 percent of jet fuel used and costs several times more than conventional fuel; the lab teaches the evaluation process, not the state of the industry. The activity has not been run with students by the authors; the calculations have been checked.

Teacher notes

Grade the process, not the pick: a group that chose grass with a locked, reasoned weighting and an honest trade-off meets the standard; a group that chose city waste by skipping the screen does not. The calculations have been checked: fuel per year 48 M, 18 M, 120 M, 37.5 M and 115 M litres; cost per litre \$0.17, \$0.67, \$0.50, \$0.32 and \$0.26. If a group asks about real figures, tell them the teaching dataset is invented and that real sustainable aviation fuel in 2026 is under 1 percent of jet fuel and several times the price of conventional fuel; the Department of Energy's Alternative Fuels Data Center lists real feedstocks and pathways.