

Fuel for the Island Ferry: Choosing a Biomass Source

Learning target: I can define criteria and constraints for a renewable ferry fuel, score four biomass sources against them with data, recommend a solution or a combination, and justify it by tracing the fuel's matter and energy back to photosynthesis.

Transfer and design

About 50 min

Pairs

MS-ETS1-1 · assesses

MS-ETS1-2 · assesses

MS-LS1-6 · supports

engineering design

data analysis

writing

Name

Date

Period

Directions

Work in pairs. Read the brief from the island council, then study the two tables. The first table gives typical real values; the second is a teaching dataset invented for this island. Part A turns the brief into criteria and constraints. Part B scores the candidates. Part C is your recommendation; it must be justified with numbers, and it must explain where the fuel's energy originally came from.

You will need: This worksheet, Pencil, Calculator, Ruler for the sketch

The brief from the Isla Verde council — 'Our ferry is the only link to the mainland. It burns 40,000 liters of diesel a year, all shipped in. We want to replace as much of that as we can with a fuel made here, from the island's own plants or plant waste. Rules: the fuel must be made on the island; any plant material we use must grow back at least as fast as we use it; no farmland now growing food may be switched to fuel crops; and the setup cost must not exceed \$350,000. We would like the fuel to pack as much energy as possible into each kilogram so the ferry can carry less, to cost as little as possible per liter, and to need as few changes to the ferry's engine as possible.'

Energy stored per kilogram of fuel (typical rounded values)

Fuel	Energy per kilogram (megajoules)	Works in the ferry's diesel engine?
Diesel (fossil, shipped in)	43	yes
Biodiesel (made from plant or waste oils)	37	yes, blended, with minor changes
Ethanol (made from plant sugars)	27	no; engine must be converted
Dry wood chips (burned directly)	17	no; not a liquid fuel

Reference values rounded from standard fuel tables. A megajoule (MJ) is a unit of energy; a liter of diesel holds about 36 MJ.

Four candidate biomass sources on Isla Verde (teaching dataset)

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

Candidate	Source and process	Fuel type made	Diesel-equivalent liters per year	Land used	How fast the source regrows	Takes farmland from food?	Setup cost (\$)	Cost per diesel-equivalent liter (\$)
A	Used cooking oil collected from the island's restaurants and homes	Biodiesel	12000	none	continuous (it is waste)	no	60000	1.2
B	Fast-growing energy grass planted on 20 hectares of vegetable farmland, cellulose broken into sugar, sugar made into alcohol	Ethanol	50000	20 ha of farmland	every year	yes	250000	1.6
C	Thinnings from the island's 300-hectare forest, cellulose broken into sugar, sugar made into alcohol; harvest 7.5 ha per year, forest regrows in 40 years	Ethanol	11000	7.5 ha of forest per year	each patch in 40 years; whole forest replaces 7.5 ha per year	no	180000	2.0

Candidate	Source and process	Fuel type made	Diesel-equivalent liters per year	Land used	How fast the source regrows	Takes farmland from food?	Setup cost (\$)	Cost per diesel-equivalent liter (\$)
D	Algae grown in shallow ponds on 2 hectares of bare rocky ground, oil pressed from the algae	Biodiesel	20000	2 ha of rocky ground	continuous (harvested weekly)	no	280000	3.5

Simulated data for teaching, invented to be realistic for a small island. 'Diesel-equivalent liters' means the fuel has already been converted into the number of liters of diesel it could replace, so the candidates can be compared directly.

Part A: Define the problem precisely

1. Write three **criteria** from the brief (things a good solution does as well as possible). Each must include a number or a clear way to measure it, for example 'covers the largest possible share of the 40,000 L need.'

2. Write the four **constraints** from the brief (limits a solution must not break), each with its limit. Then add one constraint of your own that the council forgot and explain why it matters.

3. Explain the difference between a criterion and a constraint using 'regrows at least as fast as it is used' and 'costs as little as possible per liter' as your two examples.

Part B: Score the candidates

4. Complete the table. For the percent column, divide the candidate's liters by 40,000 and multiply by 100; show one calculation below the table. For the last column, check each candidate against every constraint from q2.

Diesel-equivalent liters per year	Percent of the 40,000 L need	Energy per kg of its fuel type (MJ)	Breaks a constraint? (which one)
A: used cooking oil			
B: energy grass			
C: forest thinnings			
D: algae ponds			

5. Score each candidate on each criterion using the scales given, total the scores, and record whether the candidate passes every constraint. A high score does not rescue a candidate that breaks a constraint.

A	B	C	D
Criterion 1: share of need covered (2 = over 40%, 1 = 25 to 40%, 0 = under 25%)			
Criterion 2: energy per kg (2 = 35 MJ or more, 1 = 25 to 34, 0 = under 25)			
Criterion 3: cost per liter (2 = under \$1.50, 1 = \$1.50 to \$2.50, 0 = over \$2.50)			
Criterion 4: engine changes (2 = minor, 1 = conversion, 0 = cannot be used)			
Total score			
Passes every constraint? (yes/no)			

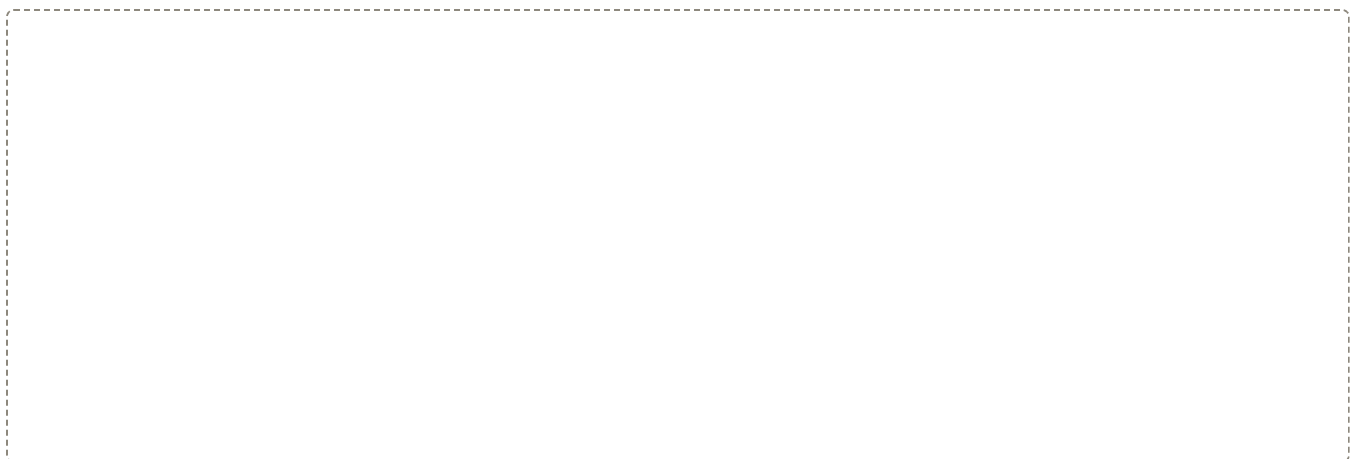
6. No single candidate that passes every constraint covers more than half the need, so consider combinations. For each of these pairs, add the liters, compute the percent of the need, and add the setup costs: A + C, A + D, C + D, and A + C + D. Which combinations stay within the \$350,000 setup limit?

Part C: Decide and justify

7. Recommend one candidate or one combination to the council. Justify it with: (1) the constraints it passes and the one candidate you rejected for breaking a constraint; (2) at least three numbers from your tables; (3) one trade-off you accepted and why; and (4) one sentence tracing where the energy in your fuel originally came from and how it got into the plant material.

8. A council member says: 'Great, biofuel means the ferry will stop putting carbon dioxide into the air.' Is that right? Explain what burning the biofuel does release and what is actually different from burning shipped-in diesel.

9. Sketch the path of matter and energy for your recommended fuel, from the sun to the ferry's propeller. Use solid arrows for matter (carbon dioxide, water, plant material, oil or sugar, fuel, exhaust) and dashed arrows for energy (light, chemical energy in the plant, chemical energy in the fuel, energy of motion). Label every arrow.



Constraints first, then scores

Engineers check constraints before they score anything, because a candidate that breaks a constraint is out no matter how well it scores. Go down the brief's four rules and ask each candidate 'does this break the rule?' before you fill in the score table. Then, for combinations, remember that liters add and setup costs add, but the percent of need must be recomputed from the new total: $(\text{total liters} \div 40,000) \times 100$.

The second ferry

Five years later the island adds a second ferry, doubling the need to 80,000 liters per year, and the council allows 10 hectares of farmland to be used for fuel after all. Reopen the problem: which constraints changed, which candidates re-enter, and does your recommendation change? Write a short memo with the new numbers. Then explain why a decision that was best under the old constraints can stop being best when the constraints move, even though none of the data about the candidates changed.