

Chemical Engineering and Society: Mastery Check

Learning target: I can show that I understand where synthetic materials come from, how their structure gives them useful properties, what they cost and give to society, and how engineers revise criteria when a solution causes new problems.

Retrieval and mastery check

About 40 min

Individual

MS-PS1-3 · assesses

MS-ETS1-1 · practice

independent practice

writing

Standards connections

MS-PS1-3 (assesses, describing in words that synthetic materials come from natural resources through chemical processes and affect society): The retrieval items check the resource-to-material trace, the meaning of synthetic, the structure-property link and the benefits and costs of fuels, foods, medicines and plastics; the synthesis asks for a written explanation of a synthetic material's origin and impacts. All answers are qualitative or involve simple arithmetic, within the assessment boundary.

MS-ETS1-1 (practice): Two items check that students can tell criteria from constraints and explain why engineers revised the criteria for plastics, which supports the problem-defining practice of this PE.

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

Answers with reasoning

Part A: Retrieval (12 items)

1. Which of these is a natural resource rather than a synthetic material?

Answer: B: Crude oil pumped from underground.

Why: Pumping does not change crude oil into a new substance; nylon, PLA and sucralose are all made by chemical processes from natural resources.

Also acceptable: None.

2. Which statement gives the accurate meaning of **synthetic material**?

Answer: C: A material people produce from natural resources through chemical processes.

Why: Synthetic describes how a material was made. A is the 'fake' misconception, B is the 'out of nothing' misconception, and D is the textbook summary's loose definition, contradicted by lab-grown sapphire being the same substance as mined sapphire.

Also acceptable: None.

3. True or false: Petroleum took only a few hundred years to form underground from dead plants and animals.

Answer: False. Petroleum took millions of years to form from the buried remains of ancient organisms, mostly tiny ocean life.

Why: The textbook says 'hundreds' in one place and 'millions' in another; millions is correct.

Also acceptable: Accept 'false, millions of years' without the organism detail.

4. Corn starch is broken into glucose; then yeast carry out a chemical process called _____ that turns the glucose into ethanol and the gas _____.

Answer: fermentation; carbon dioxide.

Why: Yeast ferment glucose into ethanol and carbon dioxide ($C_6H_{12}O_6 \rightarrow 2 C_2H_5OH + 2 CO_2$).

Also acceptable: Accept 'ethanol fermentation' and 'CO₂'.

5. Sucralose and table sugar have almost the same molecular shape, but sucralose has three chlorine atoms where sugar has oxygen-hydrogen groups. Use this to explain why sucralose tastes sweet yet gives the body no energy.

Answer: Its sugar-like shape fits the sweet-taste sensors on the tongue, so it is detected as sweet. But the three chlorine atoms change the molecule enough that the body's digestive chemistry cannot break it down for energy, so it passes through unused and contributes no calories.

Why: Structure determines both properties: the overall shape matches sugar (taste), the small change blocks digestion (no energy).

Also acceptable: Accept 'the body does not recognize it as food' for the second part.

- Shape fits taste sensors, so sweet
- Chlorine atoms prevent digestion, so no energy

6. In the original method, treating one cancer patient with paclitaxel took the bark of about 6 mature Pacific yew trees (a historical estimate), and the trees take roughly a century to mature. How many trees would it have taken to treat 250 patients? Then explain in one sentence why the bark was being used as a nonrenewable resource even though trees are living things.

Answer: 250 patients × 6 trees per patient = 1,500 trees. The bark was being used faster than new trees could grow to replace them (about a century per tree), and stripping the bark killed the tree, so for practical purposes the supply could not be renewed.

Why: Simple multiplication, then the renewable-but-not-unlimited idea: renewable depends on use rate versus regrowth rate.

Also acceptable: Accept 1,500 trees with an explanation that names the century-long regrowth or the death of the tree.

7. A material is described as **biodegradable**. Which statement is accurate?

Answer: B: Living things can break it down, but how fast depends on heat, moisture and oxygen.

Why: Biodegradability describes what microbes can do under suitable conditions. A is the 'disappears anywhere' misconception, C confuses plant origin with breakdown, and D is unrelated.

Also acceptable: None.

8. Label each statement as a **criterion** or a **constraint**: (a) 'The bag must hold 2 kg of apples for 10 minutes without tearing.' (b) 'The team may spend no more than \$4 on materials.'

Answer: (a) criterion: it states what the bag must do to succeed. (b) constraint: it is a limit on money the design must stay within.

Why: Criteria describe required performance; constraints describe limits such as cost, time or materials.

Also acceptable: None.

9. Why did engineers add 'breaks down quickly after use' to the criteria for plastic containers?

Answer: B: Evidence showed that single-use plastics were filling landfills for years and harming wildlife.

Why: Criteria were revised because the original solution created a new problem, which is the lesson's engineering idea.

Also acceptable: None.

10. A reusable cup takes 12 MJ of energy to make and 0.1 MJ per wash. A single-use cup takes 0.5 MJ to make. After how many uses has the reusable cup used the same total energy as that many single-use cups? Show your work.

Answer: Each use saves $0.5 \text{ MJ} - 0.1 \text{ MJ} = 0.4 \text{ MJ}$ compared with a single-use cup. $12 \text{ MJ} \div 0.4 \text{ MJ per use} = 30$ uses. Check: 30 single-use cups = 15 MJ; reusable after 30 uses = $12 + 30 \times 0.1 = 15 \text{ MJ}$.

Why: Setting $0.5n = 12 + 0.1n$ gives $0.4n = 12$, $n = 30$.

Also acceptable: Accept 30 uses with either the division or the equation shown.

11. Give one benefit and one cost of using corn ethanol instead of gasoline. Your cost may not be 'it is a chemical.'

Answer: Benefit: corn can be grown again every year, while petroleum cannot be replaced (or: it reduces the amount of petroleum used). Cost: growing corn for fuel uses farmland and water, competes with corn for food and feed, takes energy to grow and distill, or gives a car slightly fewer kilometers per tank because ethanol carries less energy per liter.

Why: Any accurate benefit and any accurate, specific cost. Do not accept 'it takes more energy than it gives' stated as a fact; accept 'it takes a lot of energy to produce.'

Also acceptable: Accept 'ethanol can be made from waste plants or algae' as a benefit if phrased as a possibility.

- One accurate benefit
- One specific, accurate cost

12. Draw a four-box flow for any synthetic material from this chapter other than ethanol: natural resource → chemical process (name what happens) → synthetic material → one effect on people or the environment. Label every box.

Answer: Examples: crude oil → refinery separation, cracking and polymerization join small molecules into long chains → polyester (or nylon, or polyethylene plastic) → effect: cheap, durable clothing or packaging that comes from a nonrenewable resource and lasts for decades in a landfill. Or: corn starch → glucose fermented to lactic acid, joined into chains → PLA → effect: cups from a renewable crop that break down only in an industrial composter. Or: sugar → chemical process swapping three oxygen-hydrogen groups for chlorine → sucralose → effect: sweet taste without calories for people limiting sugar. Or: yew needle compound → chemical conversion steps → paclitaxel → effect: a cancer treatment that no longer requires killing slow-growing trees.

Why: Four labeled boxes in the correct order with an accurate chain and a real effect (benefit or cost) earn full credit.

Also acceptable: Accept copper and tin ores → melted together → bronze → harder tools.

- Four boxes in order: resource, process, material, effect
- The process box names what happens
- The chain is accurate for the chosen material

Part B: Synthesis

13. Return to the two jackets from the start of the chapter: one leather, one faux leather made of polyurethane on polyester. Rewrite your first explanation of why a company would make the faux jacket. Your new explanation must (1) trace the faux jacket to its natural resource and name the kind of process that made it, (2) give one benefit and one cost of each jacket for people or the environment, (3) use at least four of these terms correctly: natural resource, synthetic material, polymer, nonrenewable, renewable, biodegradable, trade-off, and (4) end with one sentence about what information you would still need before calling either jacket the better choice.

Answer: Sample: The faux jacket starts as crude oil, a nonrenewable natural resource; at a refinery and chemical plant, reactions turn small molecules from the oil into the polymers polyurethane and polyester, so the jacket is a synthetic material. The leather jacket starts as a cowhide, a renewable natural resource, that was tanned. Faux jacket benefit: it is cheaper, needs no animal, and can be made in any amount and color; cost: it uses a nonrenewable resource, its coating cracks within a few years, and it is not biodegradable, so worn-out jackets sit in landfills for decades. Leather benefit: it can last twenty years and will eventually break down; cost: raising cattle uses land and water and tanning uses chemicals that must be handled carefully. Choosing either is a trade-off. Before calling one better I would need to know how much water, energy and land each takes to make and how long the average owner actually keeps each one.

Why: Full credit requires the trace with the kind of process named, a benefit and a cost for each jacket, four terms used correctly, and a specific information need. Compare with the student's W1 response; growth in the trace and in the fairness of the costs is the point.

Also acceptable: A student who argues strongly for one jacket is fine if both jackets receive a real benefit and a real cost and the information need is specific.

- Faux jacket traced to petroleum with a chemical process named
- Benefit and cost for each jacket
- At least four listed terms used correctly
- A specific piece of information still needed

Teacher notes

Items 1, 2, 3, 6 and 7 target the chapter's documented misconceptions and the textbook's own slips (synthetic defined as 'not found in nature', petroleum over 'hundreds of years', unconditional 'biodegradable'); the key gives the accurate version for each. The six-trees-per-patient and century-to-mature figures in q6 are the textbook's historical estimates and are labeled as such. For q11, the energy balance of corn ethanol is measured and debated; do not mark 'takes more energy than it gives' as correct or incorrect as a fact, and steer students to the specific costs that are not disputed. Score Part B with the four numbered requirements as a checklist; the most useful comparison is with the same student's W1 Part C, which is why W1 was kept.

Scaffold offered to students: If you are stuck

For any 'which is natural' question, ask whether people chemically changed it into a new substance; if they only dug it up, pumped it or harvested it, it is a natural resource. For criterion versus constraint, ask whether the sentence says what the design must do (criterion) or sets a limit it must stay inside (constraint). For the break-even calculation, each use of the reusable cup saves the cost of a single-use cup but adds a wash; divide the making energy by the saving per use. For Part B, build your paragraph in the order of the four numbered requirements.

Extension: One material, two stories

Pick one synthetic material from the chapter and write two short paragraphs about it: one as an honest advertisement that uses only true statements, and one as an honest warning that also uses only true statements. Then write two sentences on what a reader would need to add to either paragraph to get a fair picture, and why a scientist would refuse to call the material simply 'good' or 'bad.'