

Atoms in Chemical Reactions

Chapter 13 of 29 • Chemical Reactions

Lesson 13: What happens to atoms when new substances form, and why does a sealed system never change mass?



PHENOMENON

Two balances, two surprises

Balance 1: a cup of vinegar and a scoop of baking soda, 142.6 g together. Tip the soda in; it fizzes for two minutes and the reading settles at 141.5 g. Balance 2: a tuft of fine steel wool, 2.00 g. Burned on a tray (teacher only), cooled and put back with every crumb: 2.14 g. One reaction seems to lose matter; the other seems to gain it.

- Notice: which reading went down, which went up, and by how much?
- Wonder: what could leave a cup, and what could join a steel pad?
- Predict: run both inside sealed bags on the balance. What happens to each reading?



What you will be able to do

1

Explain that a reaction breaks and forms bonds so the same atoms regroup into new substances.

2

Read a chemical equation: tell a coefficient from a subscript and count atoms on each side.

3

Sort a reaction by how its atoms regroup: break apart, join, swap, or a mix.

4

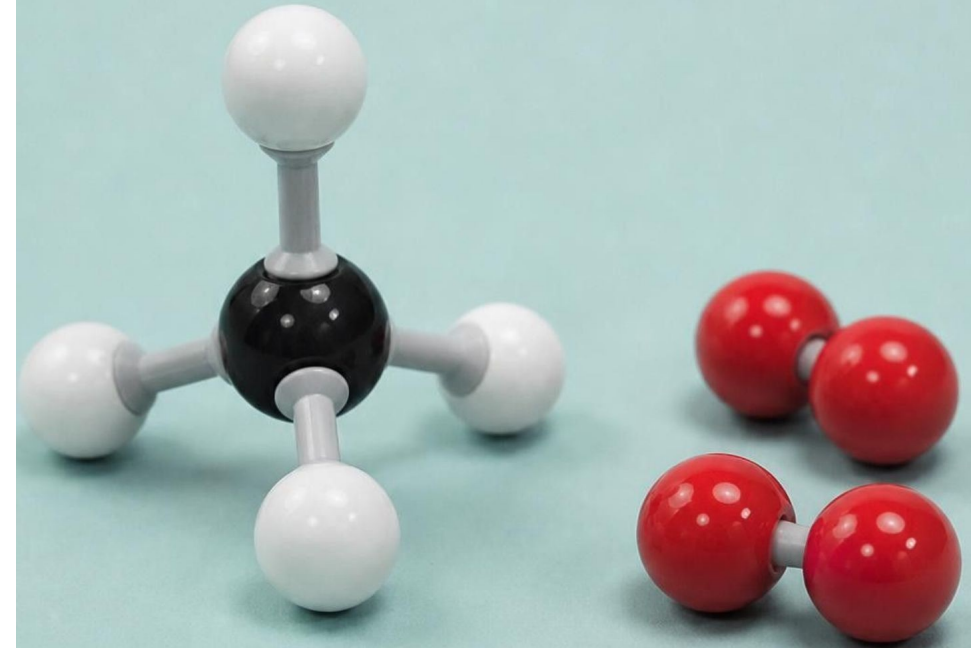
Use an atom model to explain why a closed system keeps its mass and an open one can seem not to.

5

Compare data from several process designs and combine their best features.

Zooming in: what a reaction actually does

- 1 Reactants are the substances you start with; products are the new substances that form.
- 2 A reaction breaks some bonds between atoms and forms new bonds. The atoms themselves stay whole.
- 3 The same atoms end up grouped differently, so the products have different properties.
- 4 No atom is created, destroyed or turned into a different element.



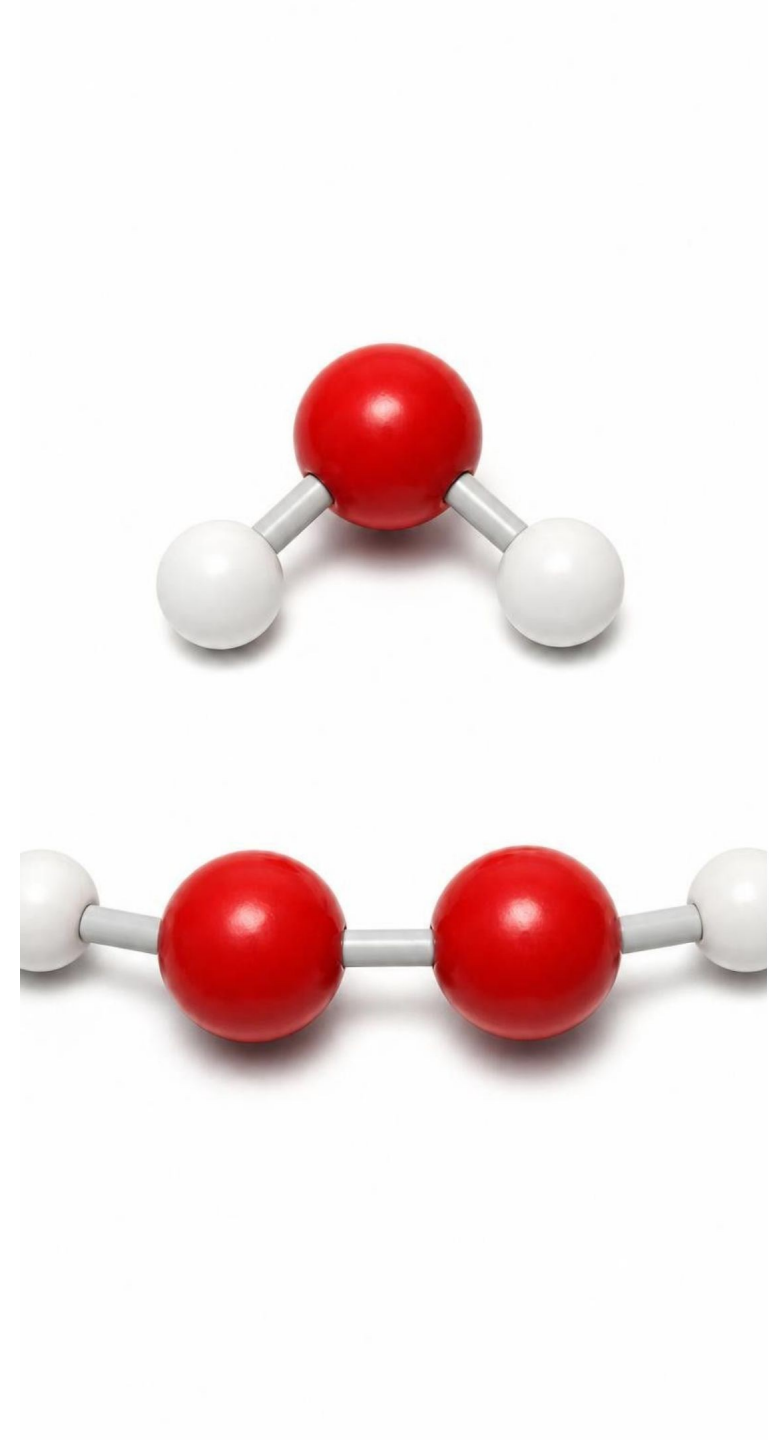
MODEL

What changes in a reaction, and what never does

Model: Before and after any chemical reaction

A reaction is a regrouping. The guest list is fixed; only the seating changes.

Changes	Stays exactly the same
Which atoms are bonded to which	The kind of each atom: an iron atom stays iron
The substances present and their properties	The number of atoms of each element
How many molecules or formula units there are	The total number of atoms
The energy stored in the bonds (Lesson 14)	The total mass of everything, if nothing leaves or enters





VOCABULARY IN CONTEXT

Three words for talking about a reaction



reactant: A substance you start with. Its atoms are the only atoms the products can be made from. *Iron and oxygen are the reactants when steel wool burns.*



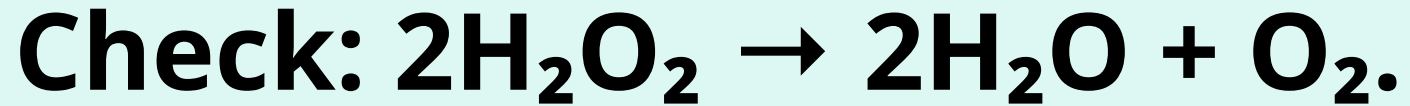
product: A new substance formed from the regrouped atoms of the reactants. *Carbon dioxide is the product that bubbles out of the vinegar cup.*



chemical equation: A one-line record of a reaction: reactants, an arrow, products, with plus signs between substances. $2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2$ records *hydrogen peroxide breaking down into water and oxygen gas.*

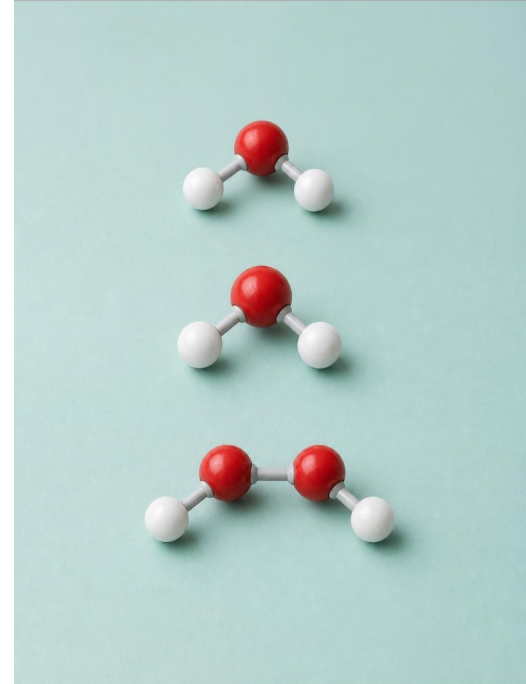
Reading an equation as an atom inventory

- A subscript (small, after a symbol) counts atoms inside one molecule: H_2O has 2 H and 1 O.
- A coefficient (big, in front) counts whole molecules or formula units: $2\text{H}_2\text{O}$ means two water molecules.
- Atoms of one element = coefficient $\times$ subscript. In 3O_2 there are $3 \times 2 = 6$ oxygen atoms.



Left: 4 H, 4 O. Right: 4 H, $2 + 2 = 4$ O. Same inventory.

Changing a subscript changes the substance. H_2O_2 is not 'water with extra oxygen'; it is hydrogen peroxide.





CHECK FOR UNDERSTANDING

Quick check: count the oxygen

Water can be split by electricity: $2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2$. How many oxygen atoms are on each side, and how many hydrogen atoms?

A. Left: 1 O, 2 H. Right: 2 O, 2 H. The equation makes oxygen.

B. Left: 2 O, 4 H. Right: 2 O, 4 H. Same on both sides.

C. Left: 2 O, 2 H. Right: 2 O, 4 H. The equation makes hydrogen.

D. Left: 2 O, 4 H. Right: 1 O, 2 H. Atoms were lost.

Three ways atoms regroup

Model: Patterns of regrouping, with an example of each

Break apart: one substance becomes two or more: $2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2$. Hydrogen peroxide's atoms regroup into water and oxygen gas.

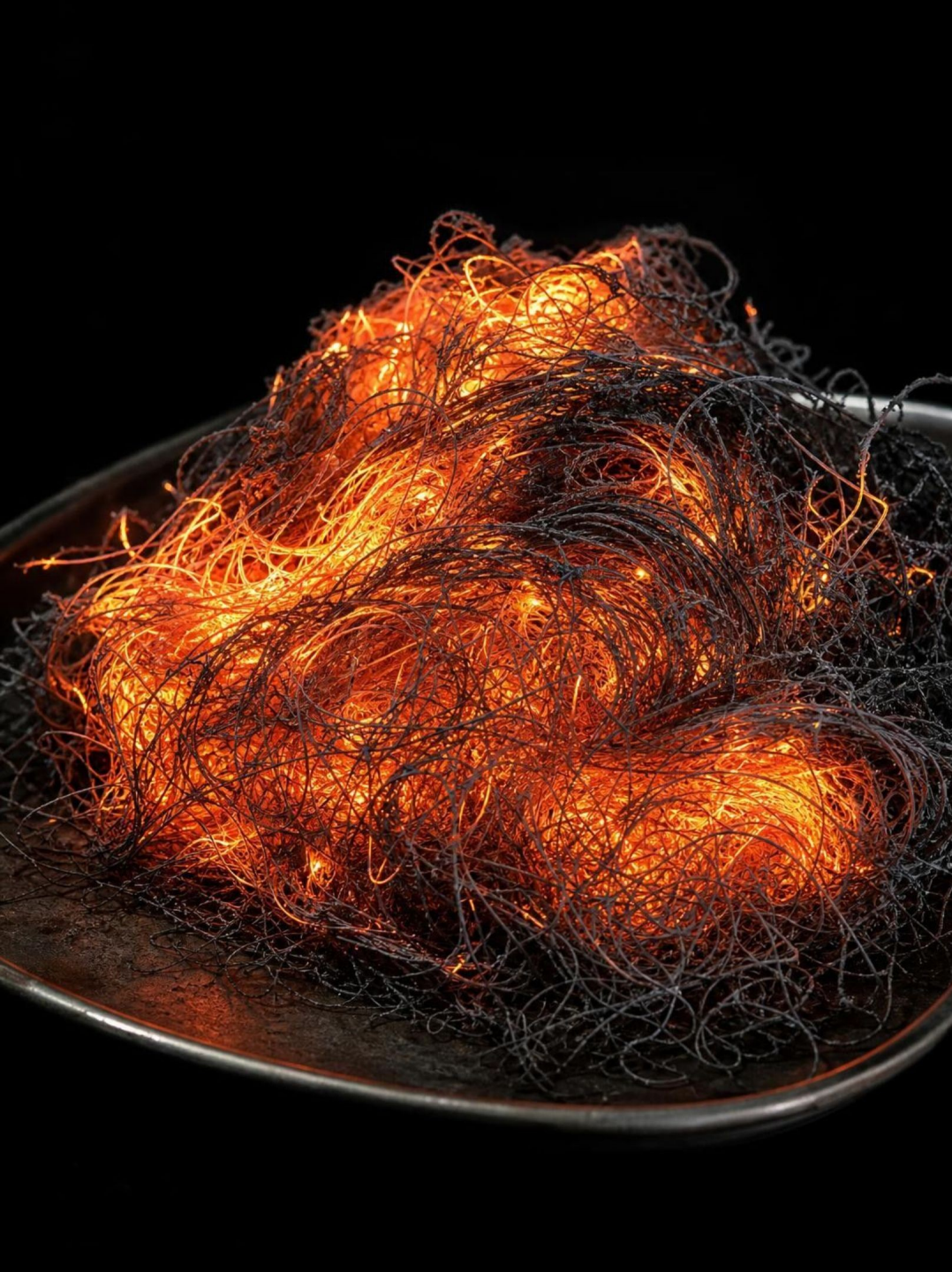
Join together: two or more substances become one: $4\text{Fe} + 3\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3$. Iron atoms and oxygen atoms bond into one extended structure, iron oxide.

Swap partners: two substances trade and make two new ones: $\text{Pb}(\text{NO}_3)_2 + 2\text{KI} \rightarrow \text{PbI}_2 + 2\text{KNO}_3$. Lead ends up with iodine; potassium ends up with the nitrate group.

A mix of patterns: $\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$. Methane and oxygen both come apart and the atoms rejoin in two new ways.

Sort by counting substances on each side of the arrow: one to many, many to one, two to two.





Why burning steel wool gets heavier

Steel wool is mostly iron. When it burns, iron atoms bond with oxygen atoms from the air: $4\text{Fe} + 3\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3$. Every oxygen atom that joins brings its mass along, so the dark, crumbly product has more mass than the shiny pad. Nothing was created. Atoms moved from the air, where the balance could not count them, onto the pad, where it could.

THINK, PAIR, SHARE

Discuss: did the steel wool make new matter?

- Where could 0.14 g of atoms come from if not from nowhere?
- What would you have to include on the balance to catch those atoms before and after?
- What reading would prove the classmate wrong? What reading would prove you wrong?

A classmate says, 'The steel wool gained 0.14 g, so burning created matter.' Argue against this using atoms, then design one test that would settle it.





VOCABULARY IN CONTEXT

Numbers in a formula and what they count



coefficient: The whole number in front of a formula; how many molecules or formula units take part. It multiplies every atom in the formula. *3O_2 is three oxygen molecules, six oxygen atoms.*



subscript: The small number after a symbol inside a formula; how many atoms of that element are in one unit. Part of the substance's identity. *The 3 in Fe_2O_3 means three oxygen atoms for every two iron atoms.*



formula unit: The smallest repeating group of atoms in an extended structure that has no separate molecules. *Fe_2O_3 is a formula unit of iron oxide; the real solid is one huge network.*

Check for understanding

Quick check: coefficient or subscript?

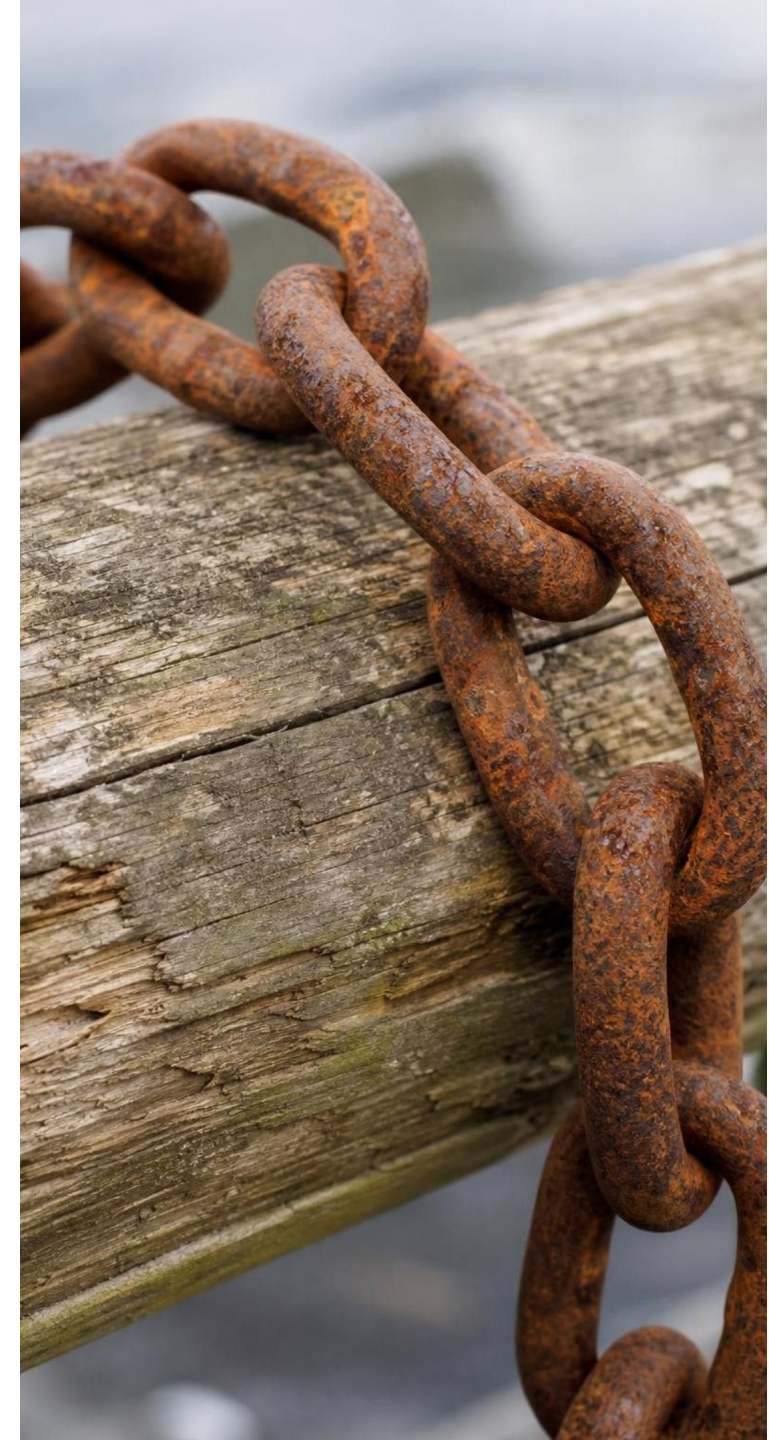
In the equation $4\text{Fe} + 3\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3$, how many oxygen atoms are on the right side, and which number told you that?

A. 3, from the subscript alone

B. 5, from $2 + 3$

C. 6, from the coefficient 2 times the subscript 3

D. 2, from the coefficient alone





The law of conservation of matter

- In every ordinary chemical or physical change, matter is neither created nor destroyed.
- Reason at the atom level: atoms are only regrouped, and each atom keeps its own mass.
- So the mass of the products equals the mass of the reactants, every time, for every reaction.
- A scientific law describes a pattern that has held in every careful test. The atom model explains why.
- The rule applies to chemical and physical changes. Nuclear changes are a separate topic.

MODEL

Open system or closed system: what does the balance see?

Model: The same reaction, two different boundaries

Define the system first. Then every change in the reading is atoms crossing the boundary.



Closed system (sealed container on the balance)

No atoms can enter or leave the container

Carbon dioxide forms and stays inside

Total mass is the same before and after

Shows the law directly

Open system (cup on the bench)

Atoms can cross the boundary: gas out, air in

Carbon dioxide forms and floats away into the room

Balance reads lower by the mass of gas that left

Seems to break the law until you count the gas



CHECK FOR UNDERSTANDING

Quick check: the cup that lost 1.1 g

The open cup of vinegar and baking soda read 142.6 g before and 141.5 g after. Which statement is correct?

A. 1.1 g of matter was destroyed by the reaction.

B. 1.1 g of carbon dioxide left the cup; the atoms still exist in the room's air.

C. The reading dropped because the cup got colder.

D. Baking soda has no mass once it dissolves.

VOCABULARY IN CONTEXT

Words for the law and for the boundary



law of conservation of matter: In any ordinary chemical or physical change, matter is neither created nor destroyed, so total mass stays the same. *A capped bottle of fizzing vinegar and baking soda has the same mass before and after.*

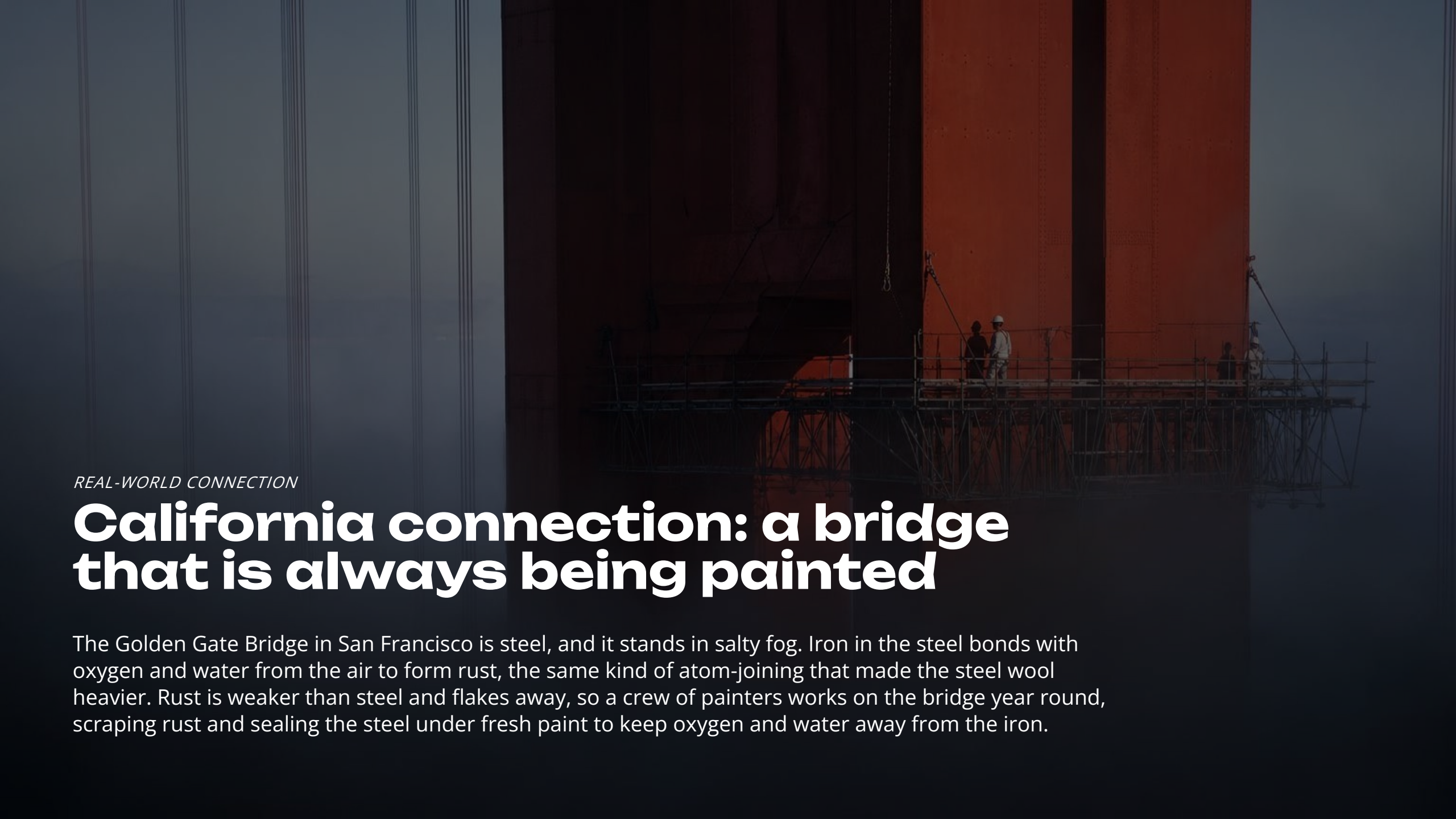


closed system: A region that matter cannot enter or leave during the change you study. Energy can still cross. *A zip bag sealed before the reaction starts.*



open system: A region whose boundary matter can cross, so readings can rise or fall as atoms come and go. *A cup on a bench loses gas to the room; a damp steel pad gains oxygen from it.*





REAL-WORLD CONNECTION

California connection: a bridge that is always being painted

The Golden Gate Bridge in San Francisco is steel, and it stands in salty fog. Iron in the steel bonds with oxygen and water from the air to form rust, the same kind of atom-joining that made the steel wool heavier. Rust is weaker than steel and flakes away, so a crew of painters works on the bridge year round, scraping rust and sealing the steel under fresh paint to keep oxygen and water away from the iron.

Atom accounting in a factory: where does every atom go?

1. Every reactant atom ends up in a product. Some products are wanted; the rest are waste.
2. Chemists measure a process by its atom economy: the share of reactant mass that lands in wanted products.

Making ibuprofen in the 1960s took six reaction steps and sent

about **60** percent of the reactant mass to waste.

1990s: a reusable catalyst cut it to

three steps; about **77** percent of the mass became ibuprofen.

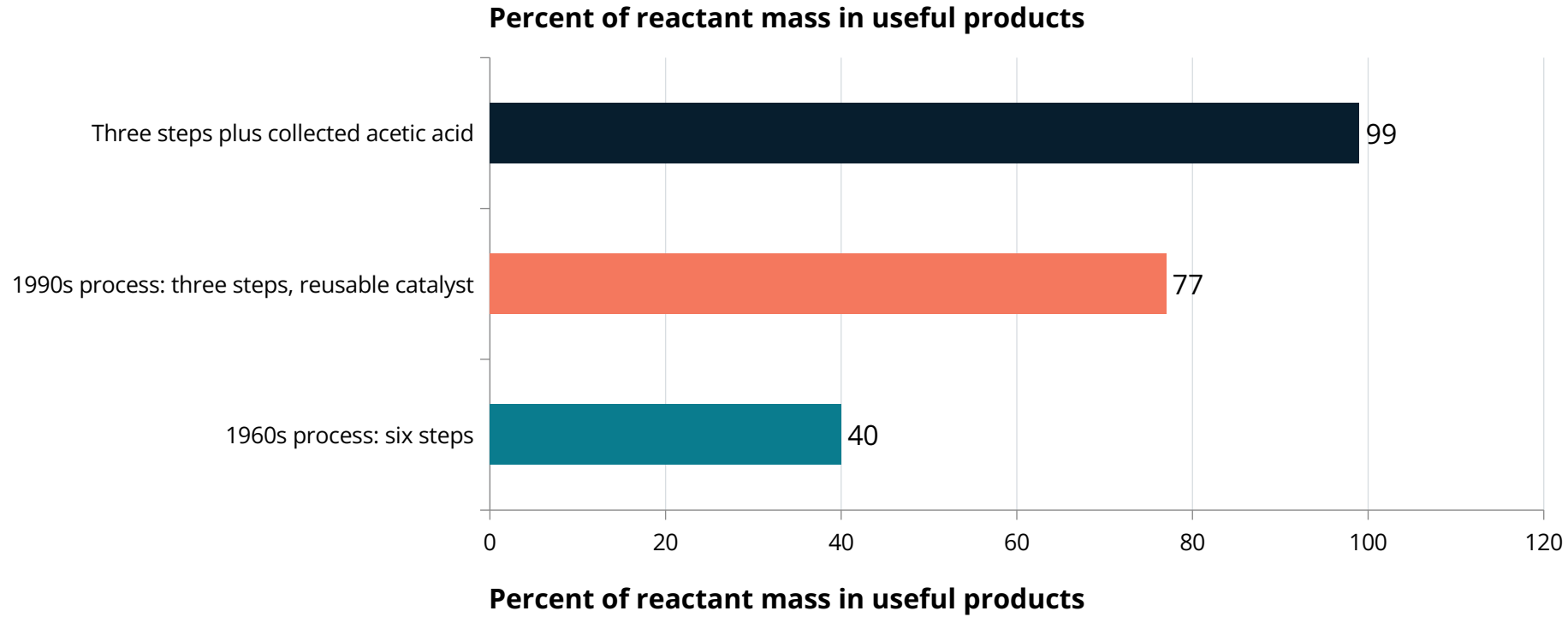
A by-product, acetic acid, was collected and used elsewhere instead of discarded: about

99 percent useful.



Three designs for the same medicine

Model: Share of reactant mass that ends up in useful products (atom economy)



Rounded values for the ibuprofen processes. The last improvement kept the three-step catalytic route and added by-product recovery.



Apply it

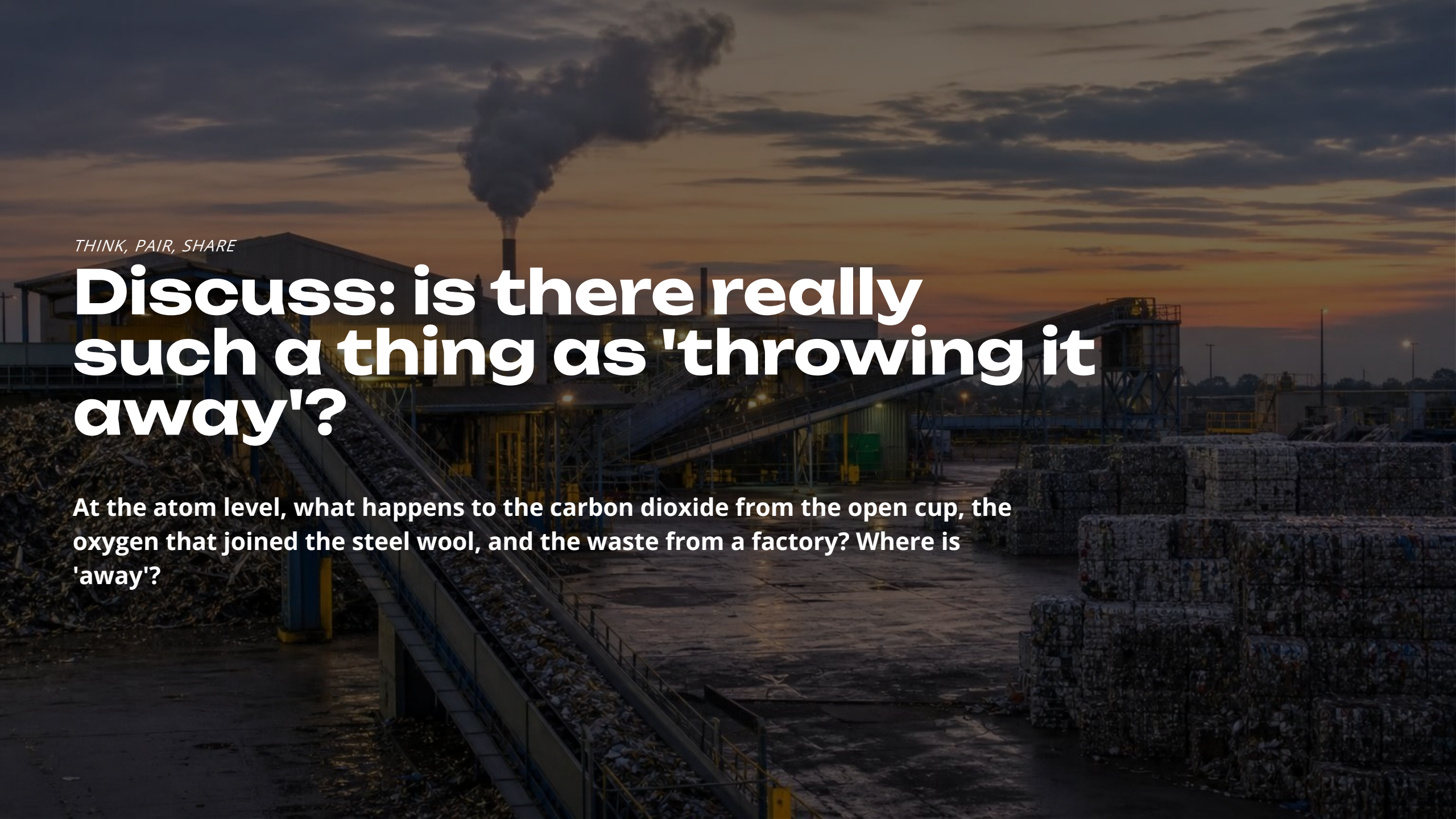
Task: which features should the engineers combine?

Simulated data for practice.

Three test runs of a new cleaning-product process gave the data below. Identify the best characteristic of each design, then propose a combined design and predict its results.



Design	Reaction steps	Catalyst recovered?	Reactant mass (kg)	Wanted product (kg)	Waste (kg)	Time per batch (h)
A	5	no	100	45	55	6
B	3	yes	100	70	30	9
C	4	no, but waste is sold as fertilizer	100	60	40 (sold)	5

A photograph of an industrial waste management facility at dusk. In the background, a smokestack emits a thick plume of dark smoke into a cloudy sky. The foreground and middle ground show various industrial structures, including conveyor belts, metal frameworks, and large stacks of compressed waste bales. The scene is dimly lit, with some artificial lights visible on the facility's structures.

THINK, PAIR, SHARE

Discuss: is there really such a thing as 'throwing it away'?

At the atom level, what happens to the carbon dioxide from the open cup, the oxygen that joined the steel wool, and the waste from a factory? Where is 'away'?



MISCONCEPTION CHECK

True or false? Burning destroys most of the wood

"When a log burns in a campfire, almost all of it is destroyed. Only a little ash is left, so this is a case where matter is not conserved."

True or false? Explain your reasoning.

PUTTING IT TOGETHER

Putting it together

- 1 A reaction breaks and forms bonds; the atoms stay whole and keep their identity.
- 2 A chemical equation is an atom inventory: coefficient $\times$ subscript, the same count on both sides.
- 3 Atoms regroup by breaking apart, joining, swapping, or a mix. Count substances to sort.
- 4 Atoms are conserved, so mass is conserved. A closed system shows it; an open one hides it.
- 5 Engineers use atom accounting to send more reactant atoms into products and fewer into waste.





EXIT TICKET

Exit ticket

- In $2\text{Fe}_2\text{O}_3$, how many iron atoms and how many oxygen atoms? Show the multiplication.
- The fizzing cup lost 1.1 g and the steel wool gained 0.14 g. Explain both with one rule.
- Name the regrouping pattern for $2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2$ and for $4\text{Fe} + 3\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3$.
- A sealed, rigid bottle of reactants reads 85.0 g before the reaction. What does it read after, and why?