

A large industrial chemical plant at dusk. The sky is a deep orange and red from the setting sun. Several tall, dark smokestacks and distillation columns are visible, some with lights on them. A large, complex network of pipes and structural steel forms the main body of the plant. A plume of white smoke or steam rises from one of the stacks on the left side of the image.

# Chemical Engineering and Society

## Chapter 15 of 29 • Chemical Reactions

*Lesson 15: Where do synthetic materials come from, and what do our choices cost?*

Angela's Wand • Bring Science Alive! 7th Grade Integrated



*PHENOMENON*

## **Two black jackets, same price, same look**

One tag says 'genuine leather'. The other says 'vegan leather, 100% polyurethane'. They bend the same way and both shed water. One began as a cow's hide. The other began as crude oil pumped from deep underground; chemists broke its molecules apart and joined the pieces into long chains that can be spread into a sheet that acts like skin. Why make a material the hard way when nature already makes one?

- Notice: what could you test to tell them apart without the tags?
- Wonder: how far back can you trace each jacket's raw material?
- Predict: which one will still be around in a landfill in fifty years?

LEARNING TARGETS

# What you will be able to do

- 1 Tell a natural resource from a synthetic material and trace the synthetic one back to its source.
- 2 Explain how a material's molecular structure gives it the properties people want.
- 3 Describe benefits and costs of a synthetic material for people and the environment.
- 4 Judge whether a source of information about a material is credible.
- 5 Write criteria and constraints precise enough to compare designs fairly.





# Natural resources: what people take from Earth and living things

- Dug or pumped from the ground: iron ore, gold, salt, crude oil, natural gas, coal.
- Collected from the air: nitrogen, which is most of what you breathe.
- Grown or harvested from living things: cotton, wood, wool, hides, corn, fish oil.
- Taking a resource does not change its molecules. Refining or reacting it does.
- Coal is a rock formed from ancient plants, not a mineral like gold or salt.

# Synthetic means made by chemical processes, not fake

A synthetic material is one that people produce from natural resources through chemical reactions. The word describes how it was made, nothing more.

Some synthetic materials are brand new, like nylon, which no living thing makes. Others copy nature: a sapphire grown in a lab has the same atoms in the same arrangement as a mined one, and synthetic vanillin is the same molecule that gives vanilla beans their smell.



An oil pumpjack is visible on the left side of the slide, set against a sunset background. The pumpjack is a mechanical device used for extracting oil from a well.

# From an oil well to a plastic bag

MODEL

## Model: How petroleum becomes polyethylene

1

Crude oil pumped from underground: a mixture of many carbon-hydrogen compounds

2

### **(separate)**

Refinery heats the oil and separates it into fractions by boiling point

3

### **(crack)**

Some fractions are cracked: large molecules split into small ones, including ethylene

4

### **(polymerize)**

Ethylene molecules are joined end to end into chains thousands of units long

5

### **(shape)**

Polyethylene pellets are melted and formed into film, bottles and bags

*Two of the five steps are chemical reactions: cracking breaks molecules, and polymerizing joins them. The product has properties crude oil never had.*



VOCABULARY IN CONTEXT

## Three words to keep straight

**natural resource:** A useful material people take from Earth or living things without chemically changing it. *Crude oil, cotton, iron ore and nitrogen from the air.*

**synthetic material:** A material made from natural resources by chemical processes. *Nylon, polyester, PLA, sucralose, a lab-grown sapphire.*

**polymer:** A substance whose molecules are long chains of repeating units. *Polyethylene is a chain of ethylene units; cellulose in cotton is a chain of glucose units.*

*Check for understanding*

## Quick check: natural resource or synthetic material?

- A bar of silver dug from a mine and polished.
- A polyester jersey made from petroleum.
- A lab-grown sapphire used in a watch face.
- A pine board cut from a tree.
- A cotton T-shirt with a printed plastic logo.

**Sort each item. Hold up N for natural resource, S for synthetic material, or B for both parts.**





MODEL

# One natural resource, a whole family of products

**Model:** What comes out of a barrel of petroleum

CENTER: PETROLEUM (CRUDE OIL)

**Fuels:** Gasoline, diesel and jet fuel: fractions separated and blended at the refinery.

**Plastics:** Polyethylene bags, polypropylene cups, PET bottles: built from small molecules made from oil fractions.

**Fabrics:** Polyester, nylon and acrylic fibers: polymer chains drawn into threads.

**Rubber:** Synthetic rubber for tires (blended with natural rubber) and many gloves, from styrene and butadiene.

**Dyes and flavors:** Food coloring such as Blue No. 1 and synthetic vanillin, made by reaction steps.

**Medicines:** Many drugs are built from small petroleum molecules such as toluene through long chains of reactions.

**Asphalt and wax:** The heaviest fractions pave roads and coat paper.

*Each branch needs different reactions, so each product has properties the oil never had.*

# A short history of making materials nature did not

MODEL

## Model: Milestones in synthetic materials

**1879: saccharin:** A sweetener about 300 times sweeter than sugar, discovered by accident in a Baltimore lab.

**1907: Bakelite:** Leo Baekeland's hard, heat-resistant plastic from phenol and formaldehyde, the first fully synthetic plastic.

**1935: nylon:** Wallace Carothers' DuPont team makes the first nylon; toothbrush bristles 1938, stockings 1940.

**1941: polyester:** Whinfield and Dickson in England make PET, now the fiber in fleece and the plastic in soda bottles.

**1942-45: synthetic rubber:** Cut off from Asian rubber plantations, the U.S. builds plants making rubber from petroleum and grain alcohol.

**1976: sucralose:** Chemists in London modify sugar with chlorine atoms; approved for U.S. foods in 1998.

**Early 2000s: PLA at scale:** The first large plant making plastic from fermented corn sugar opens in Nebraska.

*Each new material solved a problem of its time, and several of them later created a new one.*





*THINK, PAIR, SHARE*

## **Discuss: when does a whole society switch materials?**

- What pushed each switch: price, supply, a new property, a law?
- What would make people go back to the natural material?
- Who benefits and who pays when a society changes materials?

**In World War I sugar ran short and many people switched to saccharin, then switched back. In World War II the U.S. built a synthetic rubber industry in three years, and it stayed. Why the difference?**

# Structure decides the job: chains and shapes

- Plastics, nylon and polyester are long tangled chains; chains give strength and let thin pieces flex.
- How far a plastic bends before cracking depends on which plastic: PET bottles flex, PLA cups are stiffer.
- Sucralose is shaped like sugar: two rings joined by an oxygen atom, so it fits the tongue's sweet sensors.
- Three chlorine atoms replace three OH groups, so the body cannot use it for energy: sweet, but zero calories.
- Engineers choose or build a molecular structure to get the property they want.





*CHECK FOR UNDERSTANDING*

## Quick check: why does the bag stretch?

A polyethylene grocery bag stretches a little and resists tearing. Which explanation fits best?

A. Its molecules are small and round, so they roll past each other

B. Its molecules are long tangled chains that can slide and straighten without separating

C. It contains oil that keeps it soft

D. It was heated, and heated things are always flexible

# Fuels: gasoline from oil versus ethanol from corn

- Gasoline is refined from petroleum: separated, cracked and blended, then burned for energy.
  - Petroleum took millions of years to form; we use it far faster than Earth makes more.
- Ethanol is made when enzymes turn corn starch into glucose and yeast ferment the glucose.
  - Corn regrows every year, but it uses farmland and water and competes with food and feed.
  - Growing, harvesting and distilling take energy; how much comes back is measured and debated.



*REAL-WORLD CONNECTION*

# California connection: what is in the pump and the bag

Almost every gallon of gasoline sold in California is E10: about one tenth ethanol, mostly fermented from Midwest corn and blended in before it reaches the station. And since January 2026, under a 2024 state law, California grocery checkouts can no longer hand out plastic carryout bags of any thickness; recycled-content paper bags are allowed. Both are society-level material choices made with trade-offs in mind.





# **Foods: additives, natural and synthetic**

- A food additive is anything added to change flavor, color, texture, shelf life, nutrition or safety.
- Natural additives: salt, sugar, vitamin C, beet juice for color.
- Synthetic additives: sucralose, saccharin, Blue No. 1, synthetic vanillin.
- Zero-calorie sweeteners let people enjoy sweet tastes while limiting sugar and calories.
- Regulators review safety evidence before an additive is allowed; evidence, not origin, is the test.

# Words for fuels, foods and endings

**biofuel:** A fuel made from recently living material, such as corn or algae, instead of from fossil fuels. *The ethanol in E10 gasoline was fermented from last year's corn crop.*

**food additive:** Any substance added to food to change its flavor, color, texture, freshness, nutrition or safety. *Salt in crackers and Blue No. 1 in a sports drink are both additives; one is natural, one is synthetic.*

**biodegradable:** Able to be broken apart into simpler substances by living things such as bacteria and fungi, under the right conditions. *A PLA cup is biodegradable in a hot industrial compost pile but lasts for years in a landfill.*





# Medicines: start in nature, then make it last

- 1 Many medicines began as natural substances: penicillin from a mold, paclitaxel from a tree.
- 2 In **1962 bark** from the Pacific yew entered a U.S. cancer-drug screening program.
- 3 The **bark** worked, but stripping it kills a slow-growing tree; one patient could need several trees' worth.
- 4 Chemists found a related compound in European yew **needles** and convert it into paclitaxel by reaction steps.
- 5 **Needles** regrow, so the supply became renewable; later the compound was made by yew cells grown in tanks.



*Think, pair, share*

## **Discuss: can a renewable resource run out?**

- Compare how fast it is taken with how fast it regrows.
- Does taking it kill the organism or just trim it?
- Would the answer change for corn, for wood, for fish, for groundwater?

**Pacific yew trees grow back, so bark should be renewable. Yet scientists worried the species would be wiped out. What makes a resource truly renewable, and what would you measure to decide?**

# Plastics: a solution that created a new problem

- First criteria: sturdy, flexible, light, long-lasting. Constraint: cheap to make. Plastics met them all.
- Then evidence arrived: single-use items, little actually recycled, landfills filling, wildlife eating pieces.
- In the U.S. only about 9 percent of plastic waste was recycled in 2018; most went to landfills.
- New criterion: still sturdy in use, but breaks down within months after use.
- PLA from corn meets it only in an industrial composter kept hot and moist for weeks.





*Model*

# The design cycle in the plastics story

Model: How a working solution leads to a revised problem

- Define criteria and constraints → (plastics: sturdy, light, cheap)
- Design and produce a solution → (containers everywhere)
- Use it widely and gather evidence → (landfills, wildlife, low recycling)
- Discover new problems → (add: breaks down after use)
- Revise the criteria → (test PLA and others) (back to the start)

*The loop does not end: PLA's limits are the evidence for the next revision.*

APPLY IT SIMULATED DATA FOR PRACTICE.

# Task: which cup should the spring fair buy?

The fair needs 600 cold-drink cups and has \$75. Score each option 0-2 on sturdiness, renewable origin and fate after use here, check the budget, pick one, and name the trade-off you accepted.



| Option                        | Natural resource and process                          | Sturdy for a cold drink?     | What happens after use at this school                     | Cost per cup (teaching values) |
|-------------------------------|-------------------------------------------------------|------------------------------|-----------------------------------------------------------|--------------------------------|
| PET plastic cup               | Petroleum; cracked, reacted into polyester, molded    | Yes                          | Recycling bin accepts PET; many are still thrown in trash | 7 cents                        |
| Paper cup with plastic lining | Trees pulped; thin polyethylene lining from petroleum | Yes, goes soft after an hour | Lining blocks paper recycling; goes to landfill           | 9 cents                        |
| PLA cup                       | Corn starch; fermented to lactic acid, polymerized    | Yes, cracks if squeezed hard | No industrial composter within 100 km; goes to landfill   | 11 cents                       |
| Reusable polypropylene cup    | Petroleum; polymerized, molded thick                  | Yes, for hundreds of uses    | Washed and reused; needs water, soap and volunteers       | 60 cents, reused <sub>22</sub> |

*CHECK FOR UNDERSTANDING*

## Quick check: criterion, constraint or neither?

- It must hold hot soup for 30 minutes without leaking.
- The company can spend at most 12 cents per container.
- It must break down within 180 days in an industrial composter.
- The design team likes the color green.
- Only materials already approved for food contact may be used.

**For a new compostable food container, sort each statement: C for criterion, K for constraint, N for neither.**





# Reading claims about materials like a scientist

- Who wrote it, and do they gain if you believe it? A seller, an agency, a researcher, a stranger online?
- Is the claim specific and testable? 'Eco-friendly' is vague; 'composts in 180 days at 58 °C' is testable.
- Does it cite evidence you could check, or just repeat a label?
- Do two independent sources agree? If they disagree, what would settle it?
- 'Natural' and 'chemical-free' on a label are marketing words, not measurements.

MISCONCEPTION CHECK

# True or false? Natural is safe, synthetic is harmful

"If a material came straight from nature it is safe to use, and if it was made by chemical reactions in a factory it is harmful to people or the environment."

True or false? Explain your reasoning.





*PUTTING IT TOGETHER*

## Putting it together

- Every synthetic material starts as a natural resource changed by chemical reactions.
- Petroleum feeds fuels, plastics, fabrics, rubber, dyes and medicines; corn feeds ethanol and PLA.
- Structure decides properties: tangled chains flex; three swapped atoms keep sucralose sweet but calorie-free.
- Every material choice is a trade-off for people and the environment; natural is not a safety rating.
- When a solution causes a new problem, engineers revise the criteria and test again.

*EXIT TICKET*

# Exit ticket

- Pick one product from today and write its natural resource, the chemical process and the synthetic material.
- Name one benefit and one cost of that product for people or the environment.
- Write one criterion and one constraint from your produce-bag design and label which is which.
- A website says a cup is 'all natural, so it is safe.' Write one question you would ask before believing it.

