Fossil fuels: from fuel to electricity

Coal, petroleum and natural gas store chemical energy from ancient organic matter. Their formation is much slower than human consumption, so these fuels are nonrenewable.

1. COMBUSTION RELEASES CHEMICAL ENERGY

Complete combustion of a hydrocarbon reacts the fuel with oxygen to form carbon dioxide and water, releasing energy. Methane, the main component of natural gas, provides a simple balanced example:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{energy}$$

The atoms are rearranged, not destroyed. The carbon in the fuel becomes CO_2.

2. FOLLOW A STEAM-ELECTRIC POWER PLANT

Burn fuel
Heat water

→

Steam
Turns turbine

→

Generator
Makes electricity

Heat in the boiler produces steam. Moving steam spins turbine blades; the turbine shaft drives the generator. A condenser cools the steam back into liquid water for reuse. Cooling transfers unused heat to the surroundings.

Energy pathway: chemical → thermal → mechanical → electrical.

3. KEEP THE MACHINES AND ENERGY FORMS DISTINCT

The turbine supplies rotation; the generator converts mechanical energy into electrical energy. Electricity is an energy carrier, not a fuel mined from Earth. Not every fossil-fuel plant follows only the steam route: a gas turbine is driven by hot combustion gases. In a combined-cycle plant, hot exhaust also helps produce steam for an additional turbine. No plant converts all fuel energy into electricity; some energy becomes less useful heat.

Core generation and combustion sequence: College Board, ENG-3.E.1-E.3.
Turbines, generators and combined cycles: US EIA, How Electricity Is Generated.
Fuel and emissions context: US EIA, Natural Gas and the Environment.

Scope: College Board AP Environmental Science CED, Topic 6.5, p. 124.

Extract the fuel before burning it

Extraction removes the resource from the ground; transport and processing prepare it for use. Environmental effects can occur before any electricity is generated.

1. COAL: SURFACE OR UNDERGROUND MINING

Surface mining removes soil and rock above shallow coal seams. Underground mining reaches deeper seams through shafts and tunnels. Surface disturbance removes habitat and increases erosion; underground workings can cause subsidence. Exposed sulfur-bearing mine materials can generate acidic drainage that carries pollutants into streams.

2. PETROLEUM: WELLS, TRANSPORT AND REFINING

Wells recover crude oil from rock reservoirs on land or offshore. Refineries turn crude oil into products such as gasoline, diesel and fuel oils. Drilling sites and access routes disturb habitat. Leaks or spills from wells, pipelines or vessels can contaminate water and soil and harm wildlife. These are not smokestack emissions.

3. HYDRAULIC FRACTURING OPENS FLOW PATHS

Inject fluid
High pressure

→

Fracture rock
Create pathways

→

Recover fuel
Flow toward well

Fluid is pumped into a well to fracture low-permeability rock. Sand or other proppant helps hold fractures open so oil or gas can flow. Fracking is often combined with horizontal drilling, but the two techniques are not the same.

4. NATURAL GAS IS NOT ALWAYS EXTRACTED THE SAME WAY

Gas can flow from conventional reservoirs or be recovered from tight formations such as shale. Fracking increases access to some deposits; it does not create new fuel or make the resource renewable.

Coal mining and associated effects: US EIA, Coal and the Environment.
Oil extraction and transport impacts: US EIA, Oil and the Environment.
Fracturing process and water cycle: US EPA, Hydraulic Fracturing Executive Summary.

Scope: College Board AP Environmental Science CED, Topic 6.5, p. 124.

Identify the pathway to the impact

Fossil fuels supply concentrated energy that can be used when fuel and facilities are available. Evaluate this benefit alongside extraction damage, air pollution and greenhouse-gas emissions.

1. FRACKING: WATER AND AIR ARE DIFFERENT PATHWAYS

Water contamination

Spilled fluids or wastewater can reach surface water or groundwater. Faulty casing or cement can let gases or liquids escape along a well. Contamination depends on an actual exposure pathway; it is not inevitable at every well.

Air emissions

Fracking-related oil and gas operations can release volatile organic compounds (VOCs) and methane. VOCs can contribute to ground-level ozone formation in sunlight with nitrogen oxides; some are toxic. Methane is a greenhouse gas.

2. COMBUSTION CHANGES AIR QUALITY AND CLIMATE

Carbon dioxide contributes to warming. Coal combustion can also release sulfur dioxide, nitrogen oxides, particulates and mercury; these are not interchangeable with CO_2. Sulfur dioxide and nitrogen oxides contribute to acid deposition. Particulates can damage respiratory health. Pollutant amounts depend on the fuel, plant and emission controls.

3. LOWER EMISSIONS DOES NOT MEAN ZERO IMPACT

Natural gas releases less CO_2 than coal per unit of fuel energy burned, but still emits CO_2. Methane leaks during supply add climate impacts. Compare the same quantity of energy and consider both fuel production and combustion.

EXTENSION: USE AN EMISSION FACTOR

Hypothetical: 1,000 kg of fuel × 2.5 kg CO_2/kg fuel = 2,500 kg CO_2.

Water-contamination pathways: US EPA, Hydraulic Fracturing Executive Summary.
Combustion pollutants: US EIA, Coal and the Environment.
Methane leakage and fuel comparison: US EIA, Natural Gas and the Environment.

Scope: College Board AP Environmental Science CED, Topic 6.5, p. 124.