# Hydrogen fuel cells: chemical power

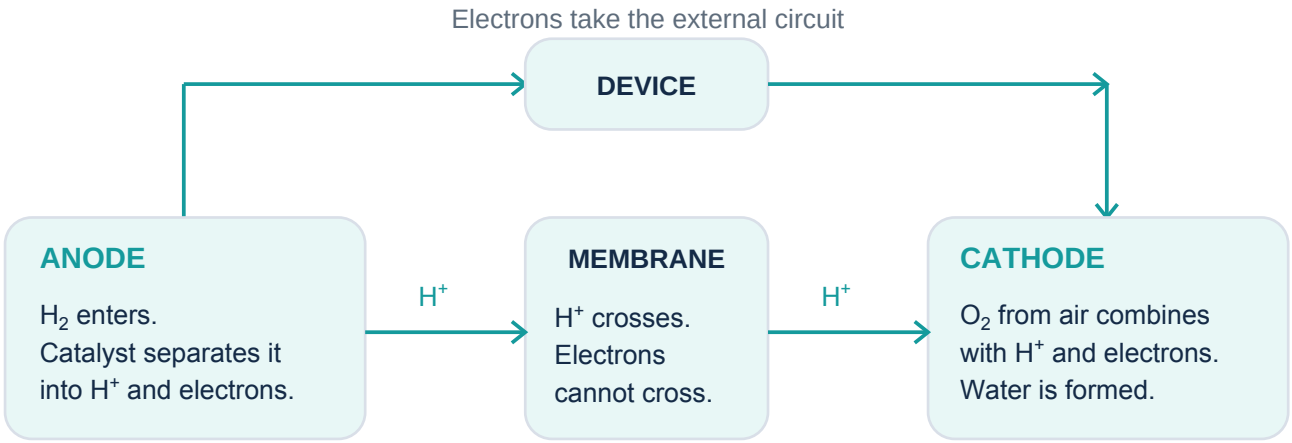
A fuel cell converts chemical energy directly into electricity. Hydrogen reacts with oxygen from air; the products are water and heat, with no fuel-burning turbine needed.

## OVERALL REACTION

$$2H_2 + O_2 \rightarrow 2H_2O + \text{electricity} + \text{heat}$$

Atoms are conserved: four H atoms and two O atoms on each side.

## EXTENSION: TWO PATHS THROUGH A PEM FUEL CELL




PEM = proton exchange membrane. The two routes reunite at the cathode; electron flow through the device supplies electrical power.

## 1. ELECTROCHEMISTRY, NOT COMBUSTION

A catalyst enables the reactions. The cell does not burn hydrogen in a flame; electrons move through an external circuit to power a load.

## 2. FUEL AND OXYGEN MUST KEEP ARRIVING

A fuel cell can run while reactants are supplied. It is not a free-energy device: the hydrogen carries chemical energy that is consumed during operation.

Operation, water and heat: US DOE, Fuel Cells.
Membrane, catalyst and electron paths: US DOE, Parts of a Fuel Cell.
Hydrogen as an energy carrier: US EIA, Hydrogen Explained.

Scope: College Board AP Environmental Science CED, Topic 6.11, p. 131.

# Where did the hydrogen come from?

Water-only exhaust describes the fuel cell, not necessarily the full supply chain. Producing hydrogen requires energy; the production route strongly affects its environmental footprint.

## 1. ELECTROLYSIS: USE ELECTRICITY TO SPLIT WATER

An electrolyzer uses electrical energy to separate water into hydrogen and oxygen:
$2H_2O$ + electrical energy → $2H_2 + O_2$.
Low-carbon electricity can reduce production emissions. Electricity from fossil fuels can cause upstream $CO_2$ emissions even though the feedstock is water.

## 2. NATURAL GAS REFORMING: A DIFFERENT PATHWAY

Steam-methane reforming uses methane and steam, with heat supplied to the process. It first produces hydrogen and carbon monoxide; a further reaction produces more hydrogen and $CO_2$. Separating hydrogen from the gas mixture does not mean the carbon dioxide has been prevented from reaching the atmosphere.

## 3. ENERGY CARRIER, NOT AUTOMATICALLY RENEWABLE

Hydrogen can store and deliver energy from other sources. It is not made renewable simply by putting it into a fuel cell. Ask which feedstock and energy source were used, and where emissions occur: production, processing, transport and final use.

## WORKED EXAMPLE: LOSSES MULTIPLY ALONG THE CHAIN

Illustrative assumptions: electrolysis is 70% efficient and the fuel cell converts 50% of the hydrogen's chemical energy into electricity, using a consistent energy basis.

100 kWh × 0.70 = 70 kWh stored in hydrogen.
70 kWh × 0.50 = 35 kWh of electricity returned.
Overall: 0.70 × 0.50 × 100% = 35%. Storage and delivery losses are excluded; these are not universal equipment ratings.

Water splitting and electricity-source emissions: US DOE, Hydrogen Production: Electrolysis.
Methane, steam and carbon dioxide: US DOE, Hydrogen Production: Natural Gas Reforming.
Energy-carrier distinction: US EIA, Hydrogen Explained. Calculation is illustrative.

Scope: College Board AP Environmental Science CED, Topic 6.11, p. 131.

# Clean at the device, assess the system

Hydrogen fuel cells can support transport, stationary electricity and backup power. Judge the benefits alongside hydrogen supply, storage, cost and safe handling.

## 1. BENEFIT: ELECTRICITY WITHOUT COMBUSTION EXHAUST

With pure hydrogen, a fuel cell produces water and heat rather than carbon dioxide or combustion air pollutants at the device. Operation is quiet and can be efficient. These point-of-use benefits are valuable, but they do not establish that hydrogen production was low-carbon.

## 2. STORAGE AND DELIVERY TAKE EQUIPMENT AND ENERGY

Hydrogen has high energy per unit mass but low energy per unit volume as a gas at ordinary conditions. Compressed-gas tanks or very cold liquid storage increase storage density. Compression, liquefaction and delivery require energy and specialized equipment, so they add costs and system losses.

## 3. COSTS AND SAFETY ARE PART OF THE DESIGN

Fuel-cell systems, catalysts, hydrogen production and fueling infrastructure can be expensive. Hydrogen is flammable and can ignite easily. Appropriate tanks and materials, leak detection, ventilation and trained handling help manage the risk. Do not confuse safe engineered use with an absence of hazards.

## 4. FOLLOW THE FULL CHAIN BEFORE COMPARING OPTIONS

Trace energy source → hydrogen production → storage and delivery → fuel cell. Identify the useful electricity output and the energy lost at each stage. Compare systems serving the same task, and distinguish direct emissions from upstream emissions. A water-only tailpipe cannot answer every environmental question.

Point-of-use benefits: US DOE, Fuel Cells.
Storage density and equipment: US DOE, Hydrogen Storage.
Flammability, leak detection and ventilation: US DOE, Safe Use of Hydrogen.

Scope: College Board AP Environmental Science CED, Topic 6.11, p. 131.