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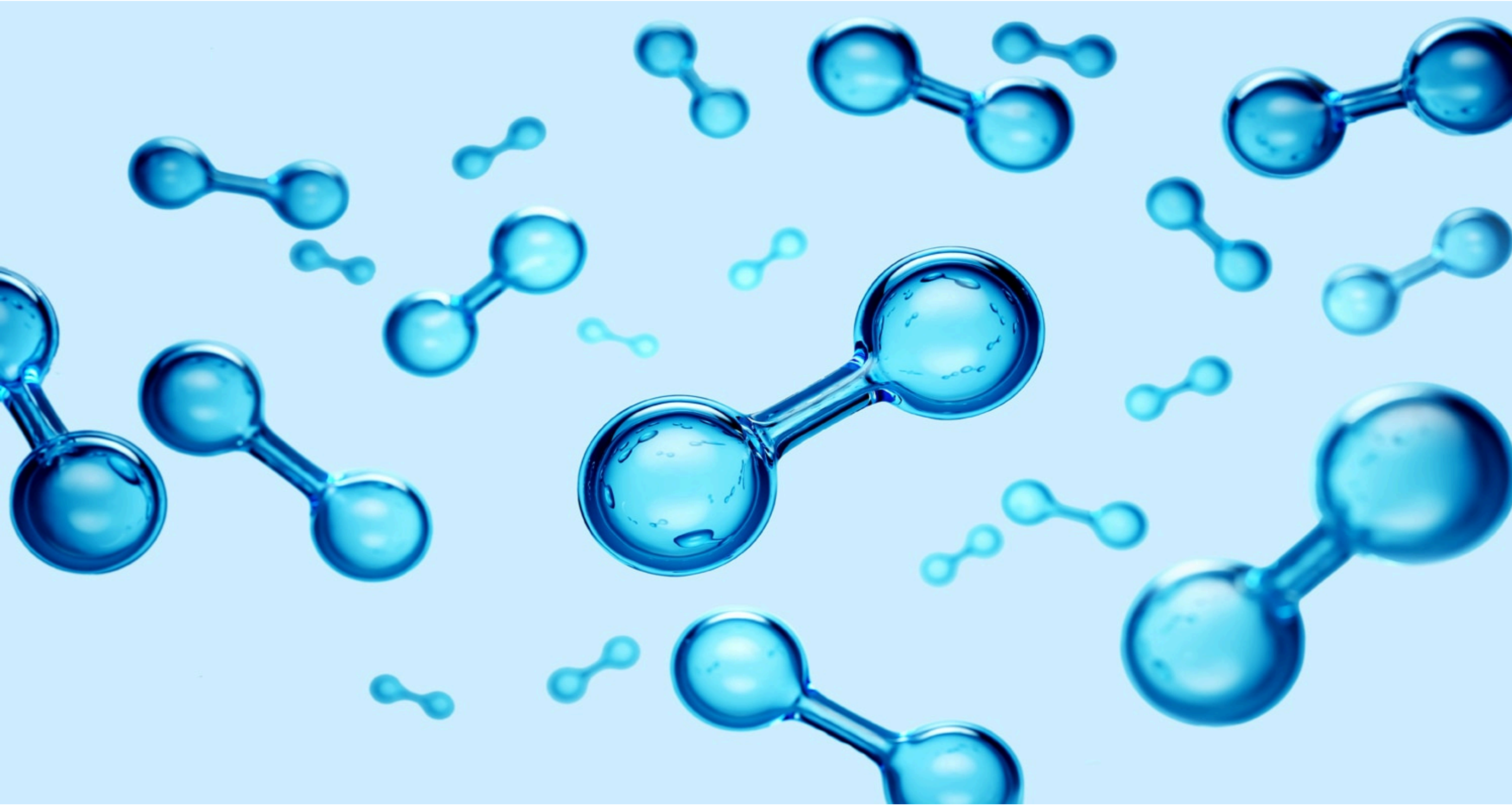
McKinsey Explainers

What is hydrogen energy?

Hydrogen energy is an alternative to fossil fuels that may represent a cleaner way to power our world.



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Fuel has always powered human technologies, from the wood fires that let us first cook our food to the fossil fuels that fed the Industrial Revolution and has made our modern way of life possible. But the burning of fossil fuels has been under scrutiny in light of climate change.

Some scientists believe hydrogen energy may be a cleaner, more efficient way to power our world. Hydrogen is a naturally occurring gas, and it is the most abundant substance in the universe. (The word in Greek means "water former" because hydrogen creates water when burned.) Clean hydrogen is hydrogen produced with very low or zero carbon emissions. The term also refers to derivative products of hydrogen, including clean fuels.

When used alongside other technologies, such as renewable power and biofuels, hydrogen has the potential to decarbonize a whole host of industries, including some of the worst emitters of greenhouse gases. According to McKinsey analysis, hydrogen could contribute to more than 20 percent of annual global emissions reductions by 2050.

Hydrogen's potential contribution to achieving net zero is not lost on organizations and governments. As of May 2023, more than 1,000 large-scale hydrogen projects have been announced globally, amounting to $320 billion in direct investments. In Europe, where $117 billion has been invested in hydrogen projects to date, McKinsey expects hydrogen to play a significant role in meeting decarbonization targets.

How exactly might hydrogen play a role in decarbonizing industries? What are the types of hydrogen energy, and what's standing in the way of widespread adoption? Read on to find out.

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What is net zero?

Net zero refers to an ideal state where the amount of greenhouse-gas emissions released into the atmosphere is equal to the amount removed. To prevent a permanent—and catastrophic—warming of the planet, all industries must achieve net zero. Decarbonization, a reduction of carbon in the atmosphere, can be achieved by switching to energy sources that emit less carbon and by counteracting any carbon that is emitted. Many organizations and governments have pledged to decarbonize, or make the transition to net zero, in coming years.

What is green hydrogen?

Green hydrogen is hydrogen derived from water. It's created using a process called electrolysis, wherein electricity from renewable sources is used to split the hydrogen molecules from the oxygen molecules in water. Because the electricity used here comes from renewable sources, there are no greenhouse-gas emissions.

Green hydrogen is a relatively new technological development. Traditionally, most hydrogen harvested globally is derived from fossil fuels like coal or natural gas. Traditional harvesting methods, such as steam reforming (whereby natural gas is treated with steam in the presence of a catalyst such as nickel), produce greenhouse gases that in the future will need to be captured or offset. Steam reforming produces what's known as gray hydrogen. (If the carbon produced by gray hydrogen is captured and stored, the result is called blue hydrogen.)

Green hydrogen production costs are expected to fall by approximately 50 percent by 2030. By 2050, gray hydrogen, including carbon costs, is projected to be significantly more expensive than blue or green.

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How can hydrogen help various high-emissions sectors meet climate targets?

Industries that rely heavily on fossil fuels, such as heavy industries and long-haul transport, stand to benefit the most from hydrogen energy. The steel industry, which accounts for 8 percent of global annual emissions, represents a particular opportunity. McKinsey has studied how players in the European steel industry could decarbonize by converting plants to run on green hydrogen (when it becomes available in sufficient volumes and at competitive cost). By 2030, hydrogen-based steelmaking could account for nearly 20 percent of emissions avoided via hydrogen.

Long-haul transport is also facing some big changes in coming years. Regulators globally are tightening emissions standards: in Europe, starting in 2030, regulators will require manufacturers to cut CO_2 emissions for new on-highway trucks by 30 percent compared with 2019 levels. It's a similar story in the United States: the nationwide emissions-reduction target by 2027 is nearly 50 percent lower than 2010 levels. Fifteen US states have additional mandates in place requiring 30 percent of trucks sold by 2030 to be zero-emission.

The hydrogen combustion engine could potentially help the long-haul transport industry meet these regulatory challenges. While still a long way from widespread adoption, hydrogen combustion engines could represent a relatively easy switch from internal combustion engines, as opposed to engines that run on batteries and fuel-cell technology. What's more, they could make use of current know-how and jobs and draw on existing supply chains and production capacities in the automotive industry.

What are some challenges preventing wide-scale adoption of hydrogen energy?

The hydrogen value chain is both complex and capital-intensive. What's more, many of the industry's segments are not yet developing at the same rate—and those technologies and regulations that are developing fast are moving so quickly that staying up to date can be a challenge.

What's more, hydrogen energy does produce emissions, but the amount varies widely and is easier to control than other energy production methods. For example, green hydrogen can be produced from 100 percent solar and wind power in renewables-rich regions and delivered to any refueling station.

That said, the primary roadblock preventing hydrogen from meaningfully contributing to decarbonization is investment cost. Committing to a pathway to net zero will require additional direct investments in hydrogen of $460 billion by 2030. This investment gap breaks down into three categories:

— *Production.* Clean hydrogen production needs roughly $150 billion more in investments through 2030.

— *Transmission, distribution, and storage.* Investments here are critical to enabling access to cost-competitive hydrogen supplies. These might include developing refueling infrastructure for vehicles or building pipelines to supply industrial plants. The investment gap here is currently more than $165 billion.

— *End-use applications.* Meeting projected demand in hydrogen's various end-use applications, including steel production and transportation, will require additional investments of $145 billion.

For hydrogen to contribute to the energy transition, a scale-up over the next decade is critical.

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What is needed for the hydrogen energy market to scale?

To fulfill the vast potential of hydrogen energy, hydrocarbon-rich countries will need to address the following four areas:

1. *Scaling competitive supply:* To realize the potential of hydrogen energy, hydrocarbon-rich countries will need to scale up both blue and green hydrogen. Blue hydrogen will play a key role in the short to medium term; green hydrogen will take a larger market share in the medium to long term, as it becomes increasingly economically viable.

2. *Stimulating local demand:* To create a healthy hydrogen ecosystem, there will need to be a local market for hydrogen in addition to major exports. Regulations concerning decarbonization and clean air could help stimulate demand.

3. *Developing transportation technology:* Hydrogen is difficult to transport. It must either be in liquid form or transformed into ammonia. Both are expensive, and liquefying hydrogen is technically challenging as well: it needs to be cooled down to −252°C, one of the lowest boiling points of all the elements.

4. *Facilitating cooperation across value chains, customers, and countries:* For the nascent clean-hydrogen value chain to develop consistently, players across all stages must work together. This might include long-term offtake agreements between customers and producers or intergovernmental partnerships.

What role can actors in the hydrogen space play to speed global adoption?

All stakeholders in hydrogen-rich countries have key roles to play.

Governments can play a leading role in the initial development of the hydrogen economy both locally and internationally. Doing so would require developing hydrogen road maps, including setting ambitions for national hydrogen production, implementing regulations for decarbonizing different sectors to spur local demand for hydrogen, setting up intergovernmental partnerships to secure demand for local hydrogen exports, developing a perspective on the localization of hydrogen production across the value chain, and supporting hydrogen deployment through regulatory support.

Stakeholders in hydrogen value chains, including *utility companies*, *chemical companies*, *energy-intensive industries*, and *shipping companies* can develop hydrogen strategies to take advantage of the opportunity. Stakeholders should focus on areas such as talent development, partnerships, expanding the supply market, and long-term demand partnerships or offtake agreements.

Learn more about McKinsey's Oil & Gas Practice, and check out hydrogen energy-related job opportunities if you're interested in working for McKinsey.

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Get to know and directly engage with senior McKinsey experts on hydrogen energy

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