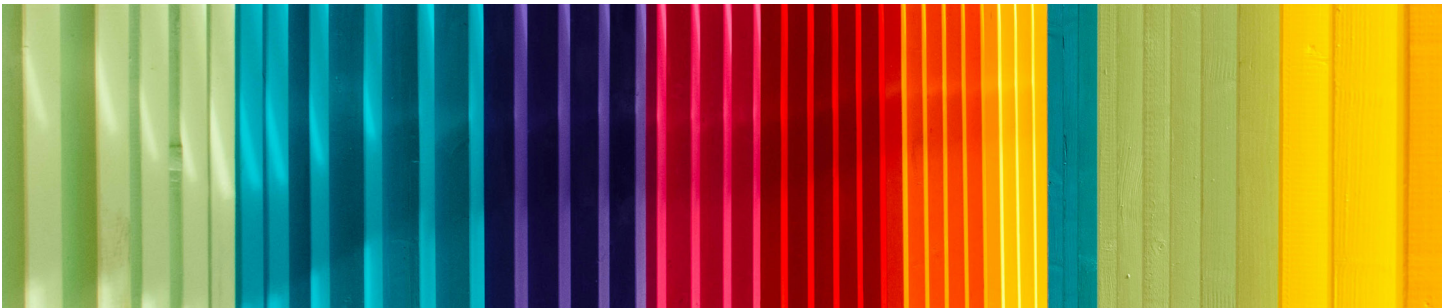




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The Colors of Hydrogen

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A rainbow of colors dominates almost every conversation on the transition to a low-carbon economy: green, grey, blue, turquoise, pink, yellow, orange – an ever-increasing palette to describe the same colorless, odorless, and highly combustible molecule, hydrogen. The only difference is the chemical process used to produce it.

Hydrogen is the most abundant element in the solar system, but it naturally occurs only in its compound form on Earth. Therefore, it must be produced from molecules that contain it, such as water or hydrocarbons, through specific processes, including thermo-chemical conversion, biochemical conversion, or water electrolysis.

The colors of hydrogen are crucial for the energy transition because each production pathway generates different amounts of greenhouse gas emissions and results in different production costs. Today, renewable (or green) hydrogen is 2 to 3 times more expensive than hydrogen produced from fossil fuels. However, these costs will decrease over time thanks to innovation, economies of scale, and carbon pricing policies.

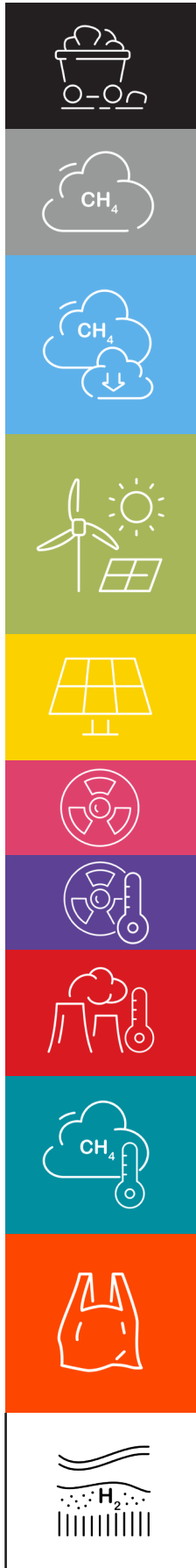
Furthermore, the world's dependence on grey hydrogen has a high carbon cost. A shift to blue hydrogen would halve carbon emissions. Although fossil fuel plants utilizing Carbon Capture and Storage (CCS) are well-suited to mitigate emissions, only adopting renewable hydrogen at scale, with its zero-carbon impact, would fully address emissions concerns associated with the production and consumption of hydrogen.

General Definitions

Low-carbon hydrogen refers to hydrogen produced from energy sources of nonrenewable origin with a carbon footprint below a defined threshold, such as blue hydrogen.

Clean hydrogen refers to renewable and low-carbon hydrogen. It is important to note that while hydrogen burns cleanly as fuel at its point of use, hydrogen produced from fossil fuels simply relocates emissions from one site to another.

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Black or brown hydrogen refers to hydrogen produced by coal gasification. The black and brown colors sometimes indicate the coal type: bituminous (black) and lignite (brown). This process generates significant CO₂ emissions (19 tCO₂/tH₂).

Grey hydrogen refers to hydrogen produced from fossil fuels, mainly by steam gas reforming or coal gasification. It generates significant CO₂ emissions, between 10-19 tons of CO₂ tCO₂/tH₂. Over 95% of the world's hydrogen consumption is grey hydrogen.

Blue hydrogen is produced mainly from natural gas by steam gas reforming, paired with carbon capture and storage (CCS). Blue hydrogen has a much lower carbon intensity than grey hydrogen, with estimates ranging from 1-4 tCO₂/tH₂. Although using CCS increases costs, blue hydrogen remains the cheapest "clean" alternative to grey hydrogen.

Green or renewable hydrogen is produced from renewable energy sources like wind and solar through a process known as water electrolysis, where an electrolyzer splits water molecules into oxygen and hydrogen. No CO₂ emissions are generated during the production process. Today, green hydrogen costs are significantly more than those of grey hydrogen. It accounts for less than 0.1% of the world's hydrogen production.

Yellow hydrogen refers to green hydrogen produced from solar energy. It does not generate CO₂ emissions. Estimates suggest that yellow hydrogen may become the cheapest form of renewable hydrogen in the medium term.

Pink hydrogen is produced by water electrolysis powered by nuclear power, a clean but non-renewable energy source that does not generate CO₂ emissions.

Purple hydrogen is produced by water electrolysis using nuclear power and heat.

Red hydrogen is produced by the high-temperature catalytic splitting of water using the heat and steam generated from nuclear plants. This process requires much less electricity than traditional electrolysis.

Turquoise hydrogen is hydrogen produced from natural gas under a process known as methane pyrolysis. In this process, natural gas is decomposed into hydrogen and solid carbon at high temperatures. Currently, turquoise hydrogen is still in the early development stage.

Orange hydrogen refers to emerging processes that produce hydrogen using plastic waste as a feedstock. It may offer a solution to both the clean energy problem and issues surrounding plastic waste disposal. Orange hydrogen remains in the early development stages, with various technologies and production processes, including pyrolysis, microwave catalysis, and photo-reforming, under evaluation.

White hydrogen, also known as natural hydrogen, is naturally generated within the Earth's crust through interactions between water molecules and iron-rich minerals at high temperatures and pressures. As water reacts with these minerals, it releases hydrogen gas. There are no strategies to exploit this hydrogen at present.