Role of Hydrogen in Attaining Carbon Neutrality - Reality check and rationale for considering hydrogen technologies

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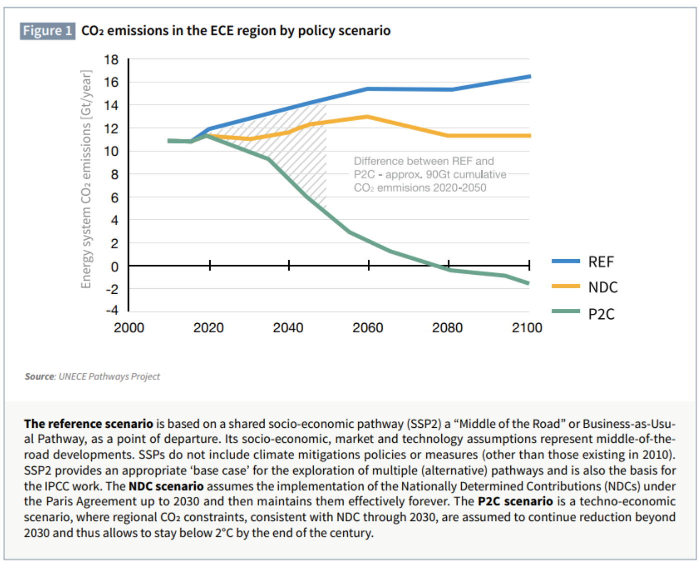
The countries from the UNECE region will need both to reduce their dependence on fossil fuels from over 80% to around 50% by 2050 and to cut or capture 90Gt of CO2 emissions by 2050 to stay on a pathway consistent with the Paris Agreement and to maintain its economic trajectory. Hydrogen can be an innovative solution for countries to achieve carbon neutrality and other climate targets.

Hydrogen (H2) is a bulk chemical that is used primarily today in petroleum refining and in the production of ammonia (for fertilisers) and methanol. When used as a fuel, it does not generate direct emissions of pollutants or greenhouse gases.

Figure 1. CO_2 emissions in the ECE region by policy scenario



Source: UNECE Pathways Project

Because of its potential as a feedstock, energy carrier and storage medium, hydrogen offers the prospect to decarbonize the energy sector and large sectors of the economy, such as transport, industry, power generation

Hydrogen can help achieve a clean, secure and affordable energy future and decarbonize a range of sectors. Hydrogen as energy carrier can be used as fuel in transport sector or for power generation. It can also be used for heating in residential and commercial sector or in high-temperature heat processes in production of steel, aluminium, paper or food. Today, hydrogen applications are most common as a feedstock in and municipal heating. It also opens interesting perspectives in hard-to-abate sectors, such as energy intensive industries or long-haul trans-port, where electrification is only partially possible.

Most hydrogen production is currently carbon-intensive. About 6% of global natural gas and 2% of global coal consumption is used to make hydrogen with the carbon in the feedstock emitted as CO2 to the atmosphere. Natural gas is the primary feedstock for hydrogen production (almost 80% of global hydrogen production), followed by coal. Today, less than 5% of hydrogen is produced from renewable and low-carbon energy sources via electrolysis. If generated through electrolysis only, the current hydrogen demand would require an additional 400 GW of baseload electricity supply. Satisfying expected clean hydrogen demand in 2050 through electricity only, would require an increase in baseload electricity in the amount of 3700GW. For hydrogen technologies to contribute to carbon neutrality, the current production of hydrogen needs to shift from fossil-fuel methods to fossil fuels with CCUS, renewable electricity, nuclear power or grid-connected electricity through electrolysis using low-carbon electricity.

To be transported hydrogen needs to be compressed, liquefied or chemically combined. Safe and cost-efficient transport and distribution of hydrogen is critical for its large-scale deployment. Hydrogen's low energy density, high diffusivity, and high flammability imply important technological and infrastructural challenges associated with the transport of hydrogen and large-scale adoption in end-markets, such as heating or transport. It is likely that the initial adoption and use will be locally concentrated in so-called hydrogen hubs or hydrogen valleys, while for global large-scale integrated value chains it will take longer to happen.

chemical industry for production of fertilizers, plastics and fuel refining.

To unlock the full potential of hydrogen to decarbonize energy system sustained policy commitment will be required. Following actions will need to be adopted by policymakers and regulators for a hydrogen economy to materialize:

[1] Note: The views expressed in this brief are those of the author and do not necessarily reflect those of the United Nations or its senior management.

1. **Promote all clean hydrogen technologies →** Research and innovation in all clean hydrogen technologies is required to unlock all sustainable production pathways and to move away from fossil-fuel production.
2. **Build on existing gas infrastructure →** The natural gas transmission network can be used to integrate hydrogen in a cost-efficient way at 10-15% of the cost of a newly built hydrogen pipeline.
3. **Accelerate deployment of electrolysers →** The development of electrolysers cannot wait until 100% of electricity is from renewable sources. Support is needed for the deployment of electrolysers connected to the electricity grid and low carbon generation plants.
4. **Scale up hydrogen projects by 2030 →** Long-term offtake commitments for clean hydrogen produced for industrial, transportation, heating and synfuels projects are necessary. A clear regulatory framework and supportive mechanisms that promote, scale and de-risk investments are required.
5. **Promote projects of common regional interest →** By 2030, investments in electrolysers in Europe could range between €24-42bn and around €11bn in retrofitting half of the existing coal and gas-powered plants with CCUS. Investments of €65bn will be needed for hydrogen transport, distribution and storage and hydrogen refueling stations, manufacturing and intellectual property.

Figure 2. Hydrogen value chain

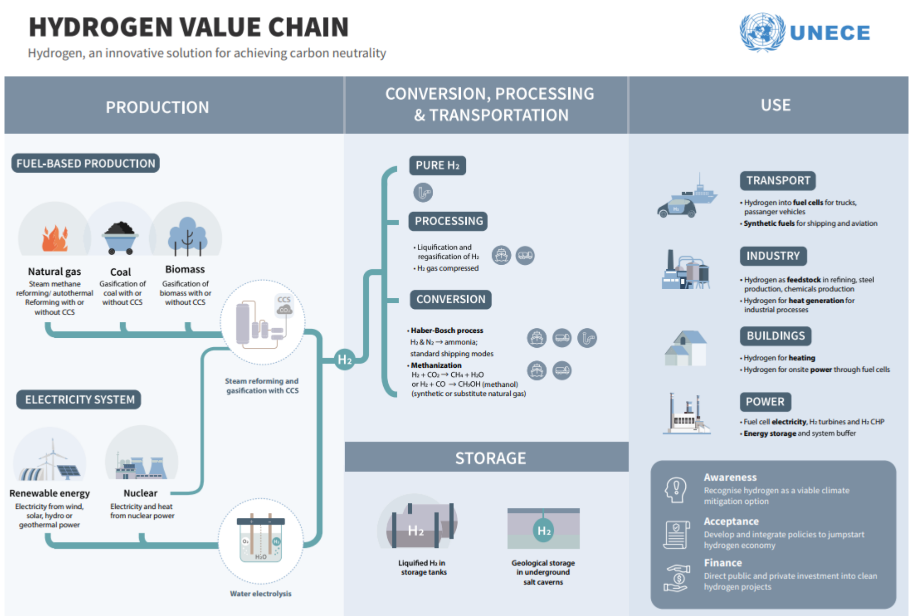


Figure 3. Transportation of hydrogen

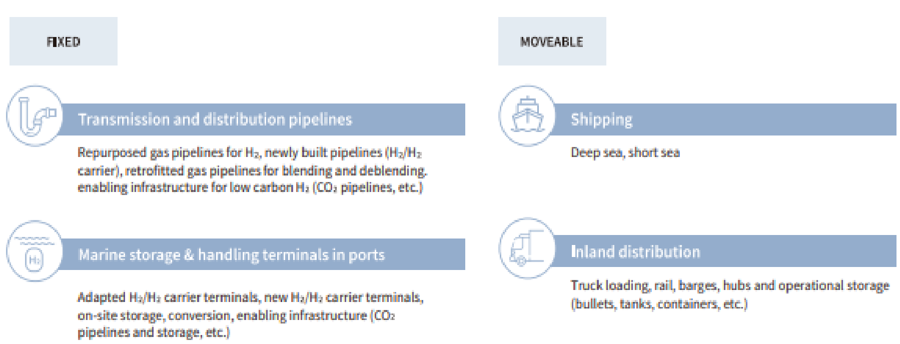


Figure 4. Hydrogen applications across sectors

Table 1. Overview of hydrogen production routes

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		INPUT	PROCESS	OUTPUT	LIFE CYCLE EMISSIONS [kg CO_2 eq/ kg H_2]	COST [$/kg]	TECHNOLOGY MATURITY	COMMERCIAL READINESS	MAJOR ADVANTAGE	MAIN CONCERN	SOCIAL READINESS
FOSSIL-FUEL BASED HYDROGEN	Natural gas & steam reforming	H_2O	Steam reforming hydrocarbons into hydrogen and carbon monoxide	H_2, CO_2	9.0-11.0	0.7 - 2.1	●●●●●●●●●	●●●●●●	Low cost, proven reliability	CO_2 emissions; methane is non-renewable	●●●●●
	Natural gas & partial oxidation	O_2	Methane reacts with limited amount of oxygen	H_2, CO	9.0-11.0	0.7 - 2.1	●●●●●●●●●	●●●●●●	Low cost, proven reliability	CO emissions; methane is non-renewable; produces less hydrogen per unit of input fuel compared to SMR	●●●●●
	Natural gas & steam reforming with CCS	H_2O, CCS	Steam reforming hydrocarbons into hydrogen and carbon monoxide	H_2, CO_2 (stored)	3.0-7.0	1.2 - 2.3	●●●●●●●●○	●●●●●○	Low cost, proven reliability, low CO_2 emissions	Methane is none-renewable; needs access to carbon storage	●●●●○
	Natural gas & partial oxidation with CCS	O_2, CCS	High temperature reaction between coal and oxygen	H_2, CO_2 (stored), Other species	3.0-7.0	1.2 - 2.3	●●●●●●●●○	●●●●●○	Low cost, proven reliability, low CO_2 emissions	Methane is none-renewable; needs access to carbon storage	●●●●○
	Coal gasification	H_2O	High temperature reaction between coal and oxygen	H_2, CO_2, Other species	18.0-20.0	1.3 - 2.5	●●●●●●●●●	●●●●●●	Low cost, proven reliability, synergy with chemicals industry	CO_2 emissions; coal is non-renewable	●●●●●
	Coal gasification with CCS	H_2O, CCS	High temperature reaction between coal and oxygen	H_2, CO_2 (stored), Other species	11.8	1.6 - 2.6	●●●●●●●●○	●●●●●○	Low cost, proven reliability, low CO_2 emissions	Coal is non-renewable; needs access to carbon storage	●●●●○
	Methane pyrolysis		Splitting natural gas into hydrogen and solid carbon	H_2, C Solid carbon/ graphite	1.9-4.8	1.6 - 3.4	●●●●●●○○○	●●○○○○	Low cost, low CO_2 emissions	Use/disposal of carbon	●●●○○
RENEWABLE ENERGY-BASED HYDROGEN	Electricity from renewable energy	H_2O	Electrolysis - splitting water into hydrogen	H_2, O_2	0.7-2.8	2.6 – 23.0	●●●●●●●●○	●●●○○○	Low carbon technology, flexible location	Seasonable intermittent supply Capacity linked renewable energy deployment. Dependent on rare earth metals for electrolysers	●●●●○
	Biomass gasification with CCS	CCS	High temperature reaction between oxygen and biomass (e.g., wood logs)	H_2, CO_2 (stored), Other species	-14.6-0.4	1.9-8.4	●●●●●●●●○	●●●●●○	Potentially negative emissions. Synergies with waste industry	Quantity of waste versus H_2 demand. Sustainability of biomass. Needs access to carbon storage	●●●●○
	Biomass & pyrolysis	(without O_2)	High temperature reaction of biomass (e.g., wood logs) with no oxygen	H_2, Other species	-14.6-0.4	1.3-2.2	●●●●●●○○○	●●○○○○	Potentially negative emissions. Synergies with waste industry	Quantity of waste versus H_2 demand. Sustainability of biomass. Use of non-hydrogen products of pyrolysis	●●●○○
NUCLEAR POWER-BASED HYDROGEN	Electricity from nuclear power		Electrolysis – splitting water into hydrogen	H_2, O_2	0.3-0.6	4.2 - 7.0	●●●●●●●●○	●●●○○○	Baseload low-carbon supply of electricity	A controversial technology that requires capacity ramp up. Dependent on rare earth metals for electrolysers	●●●○○
	Heat from nuclear power		Heat from nuclear power and water through thermochemical process. Heat for Steam reforming hydrocarbons	H_2, O_2	~0.1	2.2-2.6	●●●●●●○○○	●○○○○○	Baseload low-carbon supply of heat	A controversial technology with potentially high development investment costs	●●○○○

* More information about comparative analysis focus on technology, commercial and social readiness see Annex I page 32.
* Depending on capture rate and methane fugitive emissions. Lower range: 93% capture, 0.2% methane emission rate -> ~3kg CO_2 eq/kg H_2. Higher range: 55% capture, 1.5% emission rate -> ~7kg CO_2 eq/kg H_2.
* Life cycle emissions without additional Carbon Dioxide Removal using BECCS or DACCS to deliver net zero GHG impact.

Source: data collected from various sources and vetted by UNECE experts