2

Hydrogen in context

This chapter provides the context for hydrogen risk regulation and governance. It first discusses the role of hydrogen within the energy transition and hydrogen strategies in the Netherlands and Europe. The chapter also highlights trends in the production and use of hydrogen and projections for the future. The chapter concludes with a discussion on the properties of hydrogen by putting these in comparison with other conventional fuels.

Hydrogen in the energy transition

Hydrogen (H_2) is expected to play an important role in the transition to a net zero emissions world. Countries around the world are establishing ambitious goals for the application of hydrogen within their economies, in an effort to reach environmental targets from the 2015 Paris Agreement to reduce emissions and limit the global temperature increase (IEA, 2021[1]).[1] As the impacts of climate change and the interlinked biodiversity crisis become more tangible, climate action becomes all the more pressing; 2022 saw episodes of extreme wildfires such as those in France and Spain – incidents that are expected to grow more common as global temperatures rise. As oceans warm, ecosystems are affected and tropical cyclones occur more frequently. More broadly, weather and climate adverse events, such as floods and droughts, will affect food and water security (IPCC, 2022[2]).

Recent disruptions affecting global energy markets, such as the one following Russia's large-scale aggression against Ukraine, may put ambitions regarding the deployment of clean energy (including hydrogen) in a new light and create greater urgency for ongoing transitions. Higher natural gas prices and restricted supply affect the reputation of natural gas as a reliable and affordable energy source – a factor which could lead to (accelerated) fuel switching. Accelerating clean energy transition policies and increasing the scale of low-carbon gas – including hydrogen – could, over time, help ease supply pressures and build resilient energy systems, while reducing emissions (IEA, 2022[3]).

Hydrogen is seen as a promising option to tackling emission from a number of sources. In particular, its potential is grounded in three main benefits:

- **Provide solutions for "hard-to-abate" sectors:** hydrogen and hydrogen-based fuels such as ammonia can provide a cleaner source of energy or feedstock in a number of sectors that still rely heavily on fossil fuels – such as trucking, sea and air transport, and industrial processes such as iron, steel and chemical production. In many of these sectors, electricity is not the current energy form and electricity-based solutions may be too costly or technically unfeasible to replace existing high-temperature processes that use fuels such as diesel or natural gas (IEA, 2019[4]).
- **Turn low-carbon electricity into fuel and balance supply variabilities:** hydrogen holds the potential as a medium for energy storage, by turning low-carbon electricity via water electrolysis into hydrogen. Combined with the benefit that it can be transported through existing gas infrastructure, it can strengthen system resilience by absorbing seasonal variations and intermittent production from solar and wind energy sources (European Commission, 2020[5]).
- **Provide a green transport alternative:** hydrogen-powered vehicles can complement other types of green transport, in particular for heavy-duty and long-distance transport. Hydrogen-powered vehicles require fewer rare materials (for example, in their batteries) and can be refuelled relatively quickly. Hydrogen has a high energy density per mass, and the large volumes required to store large amounts of hydrogen are typically not a problem in goods transport (be it in trucks or, even more so, in maritime transport).

While hydrogen's potential is widely acknowledged, there is still some way to go. At present, hydrogen only represents a marginal share of the total energy mix and almost 80% of hydrogen is currently produced from fossil fuels such as coal, natural gas or lignite (European Commission, 2020[5]). Much of the remainder results as a by-product from other production processes such as the reformation of naphtha into gasoline (IEA, 2021[6]). Low-emission hydrogen production comes in two main forms, both of which are yet to be applied on a large scale. The first, hydrogen production with carbon capture builds on existing production processes with fossil fuels but refers to applications where carbon emissions are reduced by using carbon capture and storage (CCS) or carbon capture and utilisation (CCU) technologies. While this option can significantly reduce greenhouse gasses, this option still requires fossil fuels and its carbon impact depends on the variable effectiveness of greenhouse gas capture (European Commission, 2020[5]).

For the hydrogen transition to succeed in contributing to climate action, it must be generated from clean energy sources (LucidCatalyst, 2020[7]). In this effort, many countries therefore have an ambition to shift further towards the second main form of low-carbon hydrogen production. This second form of hydrogen is produced with renewable energy sources or other cleaner energy sources, usually using water electrolysis to split water into oxygen and hydrogen gas (IEA, 2021[1]).

To achieve hydrogen's potential, countries are looking to stimulate hydrogen demand and promote investment and research. Boosting hydrogen demand could support a more widespread adoption of hydrogen technologies along the full hydrogen value chain[2] and scaling up of applications. This, in turn, could lower the costs of hydrogen and make it more competitive.[3] Investment incentives could help mitigate investment risks and push pioneer companies to develop new applications and start new low-emission hydrogen projects. In combination with research and development, this could support innovation, bring in new technologies and increase efficiency. Eventually, this could allow low-emission hydrogen to become more competitive when compared with other existing energy sources (IEA, 2021[1]).

Crucially, for hydrogen to fulfil its promise, regulations, standards and oversight mechanisms need to be developed, tailored and reviewed to support its deployment. Hydrogen technologies continue to advance and safer systems are being built. But, given the novelty of many of these applications and their increasing role in future energy systems, regulatory and oversight frameworks need to keep pace. Some countries have already developed guidelines on the safe use of hydrogen and there exist international codes and standards for some types of hydrogen application. However, in many cases, countries have not developed regulatory frameworks specifically for hydrogen and generic rules are applied to the sector instead. It should be assessed whether the use of more general rules is the most efficient option to address the actual risks of hydrogen in all scenarios, and whether there are any regulatory gaps. Safety strategies during the hydrogen life cycle will be required to ensure safe production, transport, usage and the building of public confidence and awareness. On the other hand, unnecessarily complex or outdated legal barriers and excessively precautionary rules, procedures and requirements need adjustment to ensure a smooth development of the hydrogen sector.

These regulations can provide a suitable solution to manage risks until assessments of regulatory requirements have been concluded, but may not necessarily be the most efficient option to address the actual risks of hydrogen in all scenarios.

Hydrogen strategies: ambitious and urgent goals for the Netherlands and the EU

In 2020, the Dutch government published its hydrogen strategy, part of a wider wave of strategies being developed and deployed around the world (Rijksoverheid, 2020[8]). This trend exemplifies the current momentum for the deployment of hydrogen throughout energy systems. While, at the time of the 2019 *Future of Hydrogen* report by the International Energy Agency (IEA), only three governments[4] had strategies in place for hydrogen, this had increased to 17 governments by 2021[5] And to 26 governments by 2022.[6] Moreover, more are expected to join this list, with many having announced, preparing or currently consulting their strategies (IEA, 2022[9]).

The Netherlands identifies low-emission hydrogen as an essential element to ensuring a sustainable energy system that is reliable, clean, affordable, safe and spatially compatible (Rijksoverheid, 2020[8]). To reach 2030 climate targets[7] and support a net zero 2050 target, the 2019 Climate Agreement ("the Agreement") for the Netherlands foresees that hydrogen could be used in a number of areas. These include the chemical industry and other energy-intensive sectors, for the storage of wind and solar energy, for transport and the heating of buildings. The Agreement also envisages the creation of a global hydrogen market in which the Netherlands could take a leading role, building on the current energy hub function of the Rotterdam harbour and the development of a hydrogen pipeline infrastructure (Klimaatakkoord, 2019[10]).

The Dutch government foresees a wide application of hydrogen technologies across different sectors. This will contribute to its actions to accelerate climate change measures as required by the "Urgenda court ruling".[8] To meet future hydrogen demand, production in the Netherlands is expected to include large electrolysers and production installations, with CCS close to existing industrial clusters, as well as smaller production locations. The Netherlands aims to have an electrolyser production capacity of 600MW by 2025 and 80 petajoule (PJ) hydrogen production from renewable sources by 2030 (NWP, 2022[11]). This would also require facilities for hydrogen storage and the development of a basic national hydrogen infrastructure to connect clusters. For the transport sector, the Netherlands also foresees an important role for hydrogen in the achievement of a 100% emission-free mobility sector by 2050 (NWP, 2022[11]). To support these ambitions, the Netherlands will make available a number of financial mechanisms to provide financial support to investors (Rijksoverheid, 2020[8]).[9]

The Netherlands' hydrogen ambitions complement broader EU ambitions as defined in the European Commission's hydrogen strategy and the ambitions put forward in the Commission's RePowerEU Plan (European Commission, 2020[5]) (European Commission, 2022[12]). These two plans together "put forward a comprehensive framework to support the uptake of renewable and low-carbon hydrogen to help decarbonise the EU in a cost-effective way and reduce its dependence on imported fossil fuels". Since the adoption of the strategy, the Fit-for-55 package put forward legislative proposals to translate the strategy into legislation (European Commission, 2023[13]).The EU hydrogen strategy defines ambitions across three different time horizons:

- **2020-2024**: installation of 6 GW of renewable hydrogen electrolyser capacity to decarbonise existing hydrogen production such as that found in the chemical sector, and to facilitate the uptake of hydrogen consumption in new applications such as industrial processes and heavy-duty transport. The RePowerEU Plan aims for ten million tonnes of domestic renewable hydrogen production and 10 million tonnes of renewable hydrogen imports by 2030.
- **2025-2030**: installation of 40 GW of renewable hydrogen electrolyser capacity, gradually allowing hydrogen produced through electrolysis with renewable electricity to become more cost-effective by comparison with other forms of hydrogen and with applied uses in steel making, road haulage, rail and maritime transport, and for daily or seasonable storage of renewable electricity. This could be complemented by increased use of CCS technologies in existing hydrogen production, planning towards a pan-European hydrogen grid, a refuelling station network, and local hydrogen clusters that could extend the use of hydrogen towards the heating of buildings.
- **2030-2050**: renewable hydrogen technologies reach maturity and could be deployed at a larger scale to reach all hard-to-decarbonise sectors, including aviation, shipping and to decarbonise certain industrial and commercial buildings. A strong increase in renewable electricity will be required to fulfil demand for low-emission hydrogen production through electrolysis, while biogas may have a role to play in replacing natural gas in hydrogen production.

Given these significant ambitions for the development of hydrogen applications in the EU and the Netherlands, there will be a need for a regulatory framework for hydrogen that can support a smooth hydrogen transition, while removing any unnecessary obstacles for innovation and development.

Box 2.1. An overview of some key benefits of hydrogen as an energy vector

Because of hydrogen's specific physical and chemical behaviour, and of the considerable research efforts put into developing safer equipment, there are situations where hydrogen is safer than hydrocarbon fuels in a direct, immediate way (see Chapter 6 in Part 1- Literature Review). The main way in which hydrogen can overall reduce risks in a very important way is through its positive impact on climate change (assuming of course low-emission hydrogen is used, which this report focuses on).

Reducing climate emissions means a considerable impact in terms of reduction of risks from catastrophic climate events. Finally, hydrocarbon fuels also present other major environmental and health risks, which hydrogen use would decrease. This is crucial particularly considering applications where other low-carbon alternatives such as electric batteries are inadequate for reasons of weight and range, e.g. transport of goods, particularly maritime transports but also road freight transport.

Looking more specifically at detailed benefits of the switch from hydrocarbon fuels to low-emission hydrogen:

Climate

In the EU alone, transport is responsible for 800 Megatons of CO2 equivalent, of which close to 40% due to trucks (EEA, 2022[14]). Achieving carbon neutrality for Europe will entail a 90% reduction in transport emissions by 2050, and hydrogen is explicitly mentioned as a tool for that purpose in the EU Commission's "Sustainable and Smart Mobility Strategy" (European Commission, n.d.[15]).

Globally, 15% of greenhouse gas emissions stem from transportation, and with a high energy density and low refuelling time, low-emission hydrogen is well suited for transport decarbonation. Apart from its strong advantages for transportation of goods (trucking and shipping), it is also (if technical obstacles can be solved) an interesting alternative for aviation. Being a highly energy-dense fuel on a mass basis (120 MJ/kg, against 43.1 MJ/kg for kerosene), hydrogen has particular strengths to replace petrol-based fuels in aviation (https://www.airbus.com/en/innovation/low-carbon-aviation/hydrogen).

Shipping pollution

Large ships typically burn bunker fuel on the high sea (or indeed in the national water and harbours of those countries that do not or cannot regulate effectively). In addition to greenhouse gas emissions, bunker fuel causes large harmful emissions of sulphur dioxide and nitrogen dioxide. Shipping thus accounts for about 10% of all anthropogenic sulphur emissions (Eyring, 2005[16]) (ITF, 2016[17]). A switch to hydrogen will especially benefit developing countries, which have until now lacked the ability to effectively regulate shipping emissions (Saiful, 2010[18]).

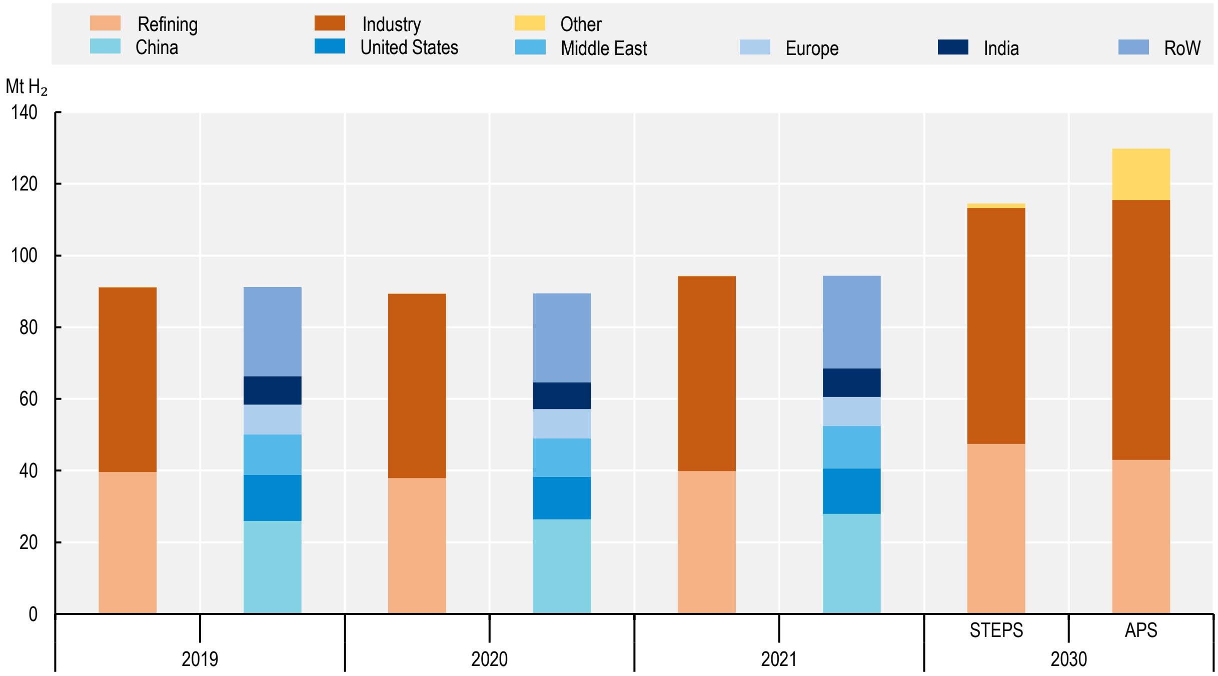
Status quo and future trends in hydrogen use worldwide

Current usage of hydrogen can be seen as modest compared with its future aspirations as an energy source. Global hydrogen demand was 94 million tonnes (Mt) in 2021, almost entirely for refining and industrial purposes. Oil refineries consumed nearly 40 Mt, with industrial processes consuming the remaining 54 Mt (Figure 2.1). Natural gas was used as the primary source for hydrogen production, accounting for roughly three-quarters of total hydrogen production (6% of global natural gas use). Twenty-three percent of hydrogen production used coal as an energy source (2% of global coal use). The remaining (small) share of production used oil and electricity.

In oil refining, hydrogen is used mainly to remove impurities (in particular sulphur) and to upgrade heavy oil into lighter oil products. Most of the supply of hydrogen for oil refining is created as a by-product from other processes in the refinery, using naphtha, natural gas and to a lesser extent coal. China, and North America together account for nearly half of global hydrogen demand in refining (IEA, 2022[9]).

Ammonia (NH_3) and methanol (CH_3OH) production consume the vast majority of hydrogen used in industrial processes. Ammonia is mainly used in the production of nitrogen fertilisers, but also for industrial applications in explosives, synthetic fibres and other materials (IEA, 2021[1]). Methanol is used mainly in the manufacturing of a number of solvents and industrial chemicals – used for the production of plastics and other materials – and in the process to produce gasoline from natural gas and coal (IEA, 2019[4]). Most of the remaining hydrogen in industrial processes is used in iron and steel manufacturing.

Figure 2.1. Hydrogen demand by sector and by region based on stated policies and announced pledges, 2019-2030



Note: Mt H2 = million tonnes of hydrogen; STEPS = Stated Policies Scenario, which reflects the scenario based on the policies currently in place as well as those that have been announced by governments; APS = Announced Pledges Scenario, which reflects the scenario in which all climate commitments by governments will be met in full and on time. Other includes transport, buildings, power generation sectors and production of hydrogen-derived fuels and hydrogen blending.
Source: (IEA, 2022[9]), Global Hydrogen Review 2022, https://www.iea.org/reports/global-hydrogen-review-2022.

In Europe, hydrogen has been applied in industrial processes in the chemical sector and oil refineries for a long time, including in the Netherlands where hydrogen production for industrial purposes is mature and well-developed. However, Europe's rollout of hydrogen-powered vehicles (in particular fuel cell electric vehicles, or FCEVs) stations is trailing developments in other countries, where China, Japan, Korea and the United States together held over 90% of the global total of FCEVs (see Chapter 5 – "Scenario 3 – Road transport"). Europe held the largest share in water electrolysis production capacity as of 2020, but China has more recently pioneered the development of larger-scale electrolysers (see Chapter 5 – "Scenario 1 – Production through water electrolysis"). In their efforts to keep pace with these global developments, the Netherlands and the EU can make use of the experiences in other countries, to design regulatory frameworks that address actual hydrogen risks while supporting the hydrogen transition.

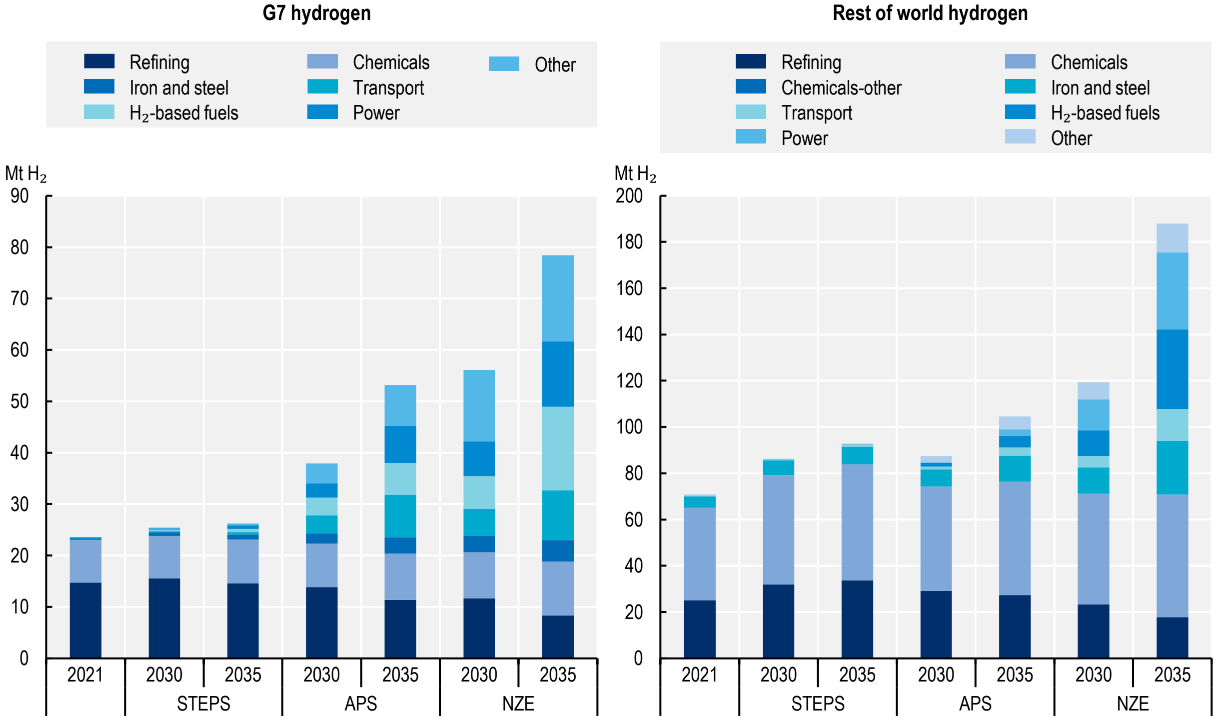
Future trends

The IEA identifies a significant gap between the announced pledges by governments regarding the use of hydrogen and the Net Zero Emissions by 2050 Scenario it developed (IEA, 2021[1]). To meet the Net Zero Emissions scenario, the IEA estimates that hydrogen usage would have to increase to 175 Mt in 2030 and 266 Mt in 2035 (Figure 2.2). To reach these net zero objectives, the IEA foresees an initial focus on converting existing hydrogen uses to low-emission hydrogen, with a subsequent expansion of hydrogen across all end-uses. Before 2030, a rapid scaling up of electrolyser manufacturing and development of transport infrastructure could bring down production costs and facilitate the use of hydrogen storage to balance demand and supply fluctuations. The scenario also requires a large increase in the number of FCEV, which the report estimated to reach 15 million vehicles by 2030. After 2030, hydrogen could expand its role across sectors and provide flexibility to electricity systems through storage and hydrogen-based electricity generation. By 2050, a significant share of total hydrogen and hydrogen-based fuels (such as ammonia, synthetic kerosene and synthetic methane) would be used in transport, requiring a strong increase in its applications across road, sea and air transport (IEA, 2021[19]).

The significant role for hydrogen envisaged in the IEA's future scenarios is also underlined in EU and Dutch energy strategies. The European Commission expects hydrogen's share in Europe's energy mix to increase from less than 2% to 13-14% by 2050 (European Commission, 2020[5]). In the Netherlands, the Cabinet's vision expects gaseous energy carriers, including hydrogen and biogas, to supply at least 30% of total energy use by 2050 (Rijksoverheid, 2020[8]).

Regulation is a key element to enable this projected growth to actually happen – both in terms of facilitation (enabling zoning, simplified licensing and permitting) and of safety (ensuring best safety practices are effectively followed). Indeed, as has often been underlined, major hydrogen-linked accidents would, beyond their direct human harm, hinder further development of hydrogen through a loss of trust. Ensuring *effective* regulation is key – which requires adequate technical requirements, taking into account the latest research and technological advances, and supported through well-targeted, risk-based inspections and enforcement. Hydrogen development requires zoning and permitting streamlining, but this does not mean "less regulation" – on the contrary, it means developing *specific regulation for new hydrogen applications* (MultHyFuel Project, 2021[20]).

Figure 2.2. Hydrogen demand in the G7 and the rest of world by sector and by scenario



Note: STEPS = Stated Policies Scenario, which reflects the scenario based on the policies currently in place as well as those that have been announced by governments; APS = Announced Pledges Scenario, which reflects the scenario in which all climate commitments by governments will be met in full and on time; NZE reflects the IEA's Net Zero Emissions by 2050 Scenario. "Other" includes generation of high temperature heat in industry, small demands in industrial applications such as electronics or glassmaking, other industries and use in buildings. "H2-based fuels" includes ammonia used as a fuel and synthetic hydrocarbons.
Source: (IEA, 2023[21]), *Towards hydrogen definitions based on their emissions intensity*, https://www.iea.org/reports/towards-hydrogen-definitions-based-on-their-emissions-intensity.

Understanding and managing hydrogen risk

There is a disconnect between the large hydrogen ambitions discussed above and the relatively limited progress in its deployment in practice. Consequently, the deployment of low-emission hydrogen solutions needs to speed up if it is to achieve its potential as a low or zero-carbon solution in the future energy mix. However, the properties of hydrogen, as well as the technologies through which hydrogen is being deployed, differ from other conventional fuels and their technologies. This could make decision makers more precautionary or risk averse in its deployment and will require public bodies to develop new expertise to manage hydrogen risks effectively. A careful assessment of its actual risks and potential risk mitigation measures will therefore be crucial for a smooth hydrogen transition.

While there is no doubt that real risks are associated with hydrogen, there are often large gaps between risk *perceptions* and actual, science-based risk assessments (Høyland, Kjestveit and Østgaard Skotnes, 2023[22]). This is in line with risk perception problems that have been well studied over the last decades (Slovic, 1987[23]) (Slovic and Peters, 2006[24]), which only underlines the need to address this perception issue through adequate engagement and communication. There is also an insufficient differentiation between high risk applications in some industrial processes (or in rocketry) and far lower risk applications e.g. in fuel-cell-powered vehicles. Indeed, records of industrial accidents involving hydrogen are typically in situations where it is combined with large amounts of oxidising substances, or where hydrogen is a by-product (but not a cause or driver) of a chemical reaction gone awry.[10]

Hydrogen is a colourless, odourless, tasteless and flammable gas. It has a high energy content by mass (per kilogram), but, due to its low density, it has a low energy content by volume (per cubic metre). Hydrogen is the lightest element. Thus, a common practice for the efficient storage, transportation and handling of hydrogen is its compression or liquefaction.

To put its properties in context, hydrogen can be compared with other conventional fuels, in particular natural gas (which consists of 87-98% methane). In comparison with methane, hydrogen has a lower density, lower energy content by volume and a lower auto-ignition temperature.[11] On the other hand, it has a higher heat capacity,[12] energy content by mass,[13] flame temperature, laminar burning velocity[14] and molecular diffusivity.[15] Moreover, hydrogen has wider flammability limits – meaning that it can ignite or explode at a wider range of concentrations of hydrogen in air – and a lower minimum ignition energy (MIE) for hydrogen volume fractions in air between 8 and 58%.[16] These are factors why – without appropriate safety measures – hydrogen may sometimes be considered more hazardous than methane under similar circumstances. In addition, the application of available safety measures have the potential to reduce these risks substantially.

Moreover, as with all flammable gases and vapours, the consequences associated with hydrogen releases are dependent on the situation and the presence of ignition sources. When hydrogen is released outside, its low density combined with moderate wind will usually cause hydrogen to rise and disperse. Indoors, hydrogen releases tend to accumulate near the ceiling, where ignition sources are less likely to be present. The exact consequences will, among other things, depend on the presence of appropriate safety measures, the total volume of hydrogen released, the total volume of the space into which hydrogen is released, the speed and direction with which it is released, and the ventilation systems that are present.

While certain properties of hydrogen differ from conventional fuels that are currently used, this does not necessarily mean that the use of hydrogen applications increases overall risk levels. Already, research and development have resulted in increased knowledge and made available a range of technical solutions that counter the more hazardous properties of hydrogen (see Chapter 5 for a discussion of safety measures for specific scenarios of hydrogen production and usage). Given this, governments should make use of smart and agile regulatory frameworks that incentivise innovation to lower climate change risks and provide the necessary protections to health and safety (see Chapter 1 – Designing regulation).

Managed properly, hydrogen is overall not riskier than hydrocarbon fuels for many applications considered in this report, even when considering only safety risk in the narrowest sense – and can sometimes, with the right technology, already be safer (Institute for Safety, 2021[25]). If one takes into account the climate impact and other adverse health and environmental impacts of hydrocarbon fuels, there is little doubt that hydrogen is not a *riskier* fuel, but quite the contrary. It is thus essential to develop an effective regulatory framework, that ensures best safety practices are followed, and allows the development of hydrogen as a fuel through in particular revisions to zoning requirements and licensing processes.

A more extensive discussion of hydrogen properties and associated risks can be found in the Part 1 – Literature review. A discussion of the risks of specific hydrogen applications can be found in Chapter 5 – Hydrogen applications in practice.

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Notes

[1] The Paris Agreement is a legally binding international treaty on climate change, adopted on 12 December 2015 at the twenty-first session of the Conference of the Parties to the United Nations Framework Convention on Climate Change signed by 194 parties (UN, 2022[27]).

[2] For a simplified overview of the hydrogen value chain, see (Cordonnier and Saygin, 2022[26]).

[3] At present, the price of hydrogen is still significantly higher than other conventional fuels (LucidCatalyst, 2020[7]).

[4] France, Korea and Japan already had a strategy in place for the use of hydrogen at the time of the IEA Future of Hydrogen report (IEA, 2019[4]).

[5] Australia adopted its hydrogen strategy in 2019; Canada, Chile, Germany, the Netherlands, Portugal, Russia, Spain and the European Union adopted hydrogen strategies in 2020, whereas France updated its strategy in 2020. The Czech Republic, Colombia, Hungary and the United Kingdom adopted their strategies in 2021 and Norway updated its strategy that same year (IEA, 2021[6]).

[6] The total of 26 governments includes 25 countries and the European Commission.

[7] The Dutch Climate Agreement is based on the objective to decrease greenhouse gasses by 49% in 2030 compared with 1990 levels.

[8] At the end of 2019, in a court case between the Urgenda Foundation and the State of the Netherlands, the Dutch Supreme Court ruled that the Dutch government must reduce emissions immediately in line with its human rights obligations. This was the first time a country was required by a court to take action on climate change (OECD, 2021[28]).

[9] These include the Demonstration Energy and Climate Innovation Scheme (Demonstratie Energie- en Klimaatinnovatieregeling, DEI+), and the Stimulating Sustainable Energy Production and Climate Transition grant (Stimulering Duurzame Energieproductie en Klimaattransitie, SDE++).

[10] The eMARS database describes 1186 accidents, of which 142 involve the phrase “hydrogen"; however, filtering out chemical compounds (such as hydrogen fluoride, chloride, sulfide, etc.) and accidents in the petrochemical industry reduces that number to 22. At least 8 of these are clearly not relevant to hydrogen as an energy vector (e.g. the Corus UK 2001 accident, involving formation of hydrogen from water having infiltrated a blast furnace).

[11] The auto-ignition temperature is the lowest temperature at which a substance spontaneously ignites.

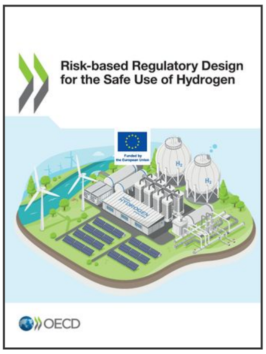
[12] The heat capacity indicates how much heat one kilogram of substance needs to absorb to increase its temperature by one degree. The heat capacity can be expressed as units of Kilo Joules per kilogram per degree Celsius.

[13] The energy content by mass is the amount energy that can be released when one kilogram of the substance is combusted. It is also called the calorific value and can be expressed in units of kJ/kg or kJ/unit volume (m^3).

[14] The speed at which a flame spreads through a substance.

[15] The molecular diffusivity shows how fast a substance is diffused in air. This is important as quicker dispersion could reduce risk levels.

[16] The minimum ignition energy is the lowest amount of energy that is required for the substance to be ignited.



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