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Hydrogen: opportunities, uses and risks in the energy transition

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Foreword

Hydrogen is set to play a central role in the energy transition. Innovative technologies are paving the way for green hydrogen to provide much needed solutions, especially for renewables, hard to abate industries and transport.

Promoted by government programs worldwide, hydrogen is predicted to play a leading role in the energy transition towards a low-carbon economy. As an alternative to fossil fuels, hydrogen solutions can help tackle climate change in future, helping many industries towards reducing their emissions.

While hydrogen offers clear benefits, the potential size and scope of the hydrogen economy will depend on a wide range of factors, including geopolitics, infrastructure development, policy and regulation, and, of course, the cost, relative to other sustainable alternatives. Hydrogen's unique properties also bring challenging risks and hazards – notably fire, explosion and embrittlement – that will require stringent adherence to risk management and loss prevention to ensure safe operation.

Insurers have a key role to play in the development of the hydrogen economy, enabling investment and innovation, and providing risk management advice and guidance. The industry will need to develop tailored products to cover the construction, operational phases, and business interruption risks associated with hydrogen projects. As the hydrogen economy expands, insurers will need to scale up their operations and offer risk management expertise and services.

Investment in hydrogen projects requires careful financial risk assessment and de-risking strategies. Collaboration and knowledge sharing within the industry are essential for developing best practices and building expertise. By addressing these multifaceted challenges, the insurance sector can support the growth of the hydrogen economy and facilitate the global transition to net-zero emissions.

Anthony Vassallo
Global Head of Natural Resources
Allianz Commercial

> “Insurers have a key role to play in the development of the hydrogen economy, enabling investment and innovation, providing risk management advice and guidance.

Overview

Demand surge expected: Hydrogen demand could increase fivefold by 2050, with clean production expected to rise to 60% by 2035, driven by significant investments and planned projects globally. Some 60 governments have now adopted hydrogen strategies with the number of projects increasing sevenfold to more than 1,500 in 2024 compared with 200+ projects three years earlier. Europe has the largest number (617), followed by North America (280). Europe also has the highest total investment (around US$200bn).

Future challenges and headwinds: While it holds much promise, the potential size and scope of the hydrogen economy will depend on a wide range of factors, including the evolving political, trade and economic environment, policy and regulation, demand, the development of safe infrastructure, and the cost, relative to both oil and gas and other sustainable alternatives. Technology and infrastructure will take time to develop, requiring significant government policy support and incentives. Production will need to be scaled up and made more competitive.

Risks and hazards: Hydrogen has been used in the chemical and refinery sectors for many decades, so the hazards of risks such as fire, explosion, and embrittlement – which can lead to cracks and leakages in pipelines and equipment for example – are well understood. Analysis of hydrogen-related incidents shows undetected leaks can lead to explosions.

Integrating hydrogen into sectors such as energy and construction brings a range of challenges. Energy production facilities will involve hydrogen storage and high-temperature combustion, which can lead to leaks and explosions. In transport, applications like hydrogen fuel cell vehicles will also face risks of hydrogen embrittlement and leaks. In chemical feedstock and fertilizer production, safe storage and transportation are crucial to prevent contamination and explosions. In shipping, adapting engines for hydrogen is accompanied by the risk of machinery breakdown and the potential for safety issues, again from embrittlement, gas leaks, and explosions. Port operators, bunkering facilities and fuel handlers will need to manage highly flammable and cryogenic hydrogen fuels, bringing accident and contamination risks.

Evolving technology also poses challenges such as raising the risk of serial losses, where a common fault requires the replacement of equipment across a project or multiple projects. For example, a large hydrogen production facility could involve hundreds of electrolyzers, with the same design replicated at multiple plants. Serial defect claims have already been seen with wind turbines. As the hydrogen industry scales up, supply chains may come under increasing pressure, with the risk of capacity constraints, delays and longer lead-in times for replacement parts. At the same time, new start-ups, suppliers and contractors entering the market also pose challenges for companies and their insurers who have to assess their experience and capabilities.

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Risk mitigation and loss prevention: Across all industries, stringent safety measures will be vital to manage hydrogen's inherent risks. Equipment design, maintenance and training can help prevent the escape of flammable hydrogen gas, while the risks of ignition can also be reduced by locating hydrogen facilities in the open, or within well ventilated enclosed spaces with reliable ventilation, and through the design of electrical installations and surfaces to avoid sparks and the buildup of static electricity.

Embrittlement risks can be managed through material selection and the use of hydrogen-compatible materials and coatings that have been specifically designed to resist hydrogen embrittlement. Repurposed equipment will need to be assessed for embrittlement and may require modifications.

In addition to preventing incidents, organizations can take steps to limit the extent of property damage, business interruption and third-party liability. Buildings and facilities should be designed and constructed to withstand natural hazards, fire and explosion, and limit damage to adjacent property and equipment. Robust hydrogen leak detection and isolation systems are also paramount. Sensors are essential to detect leaks promptly, while the ability to shut off the supply of escaping hydrogen is crucial to mitigating the impact of fire and explosion.

Human error is also a common factor in large losses. Operational, safety, emergency procedures and training should be frequently updated and documented, while equipment should be clearly labeled. In addition, organizations should establish an incident/emergency response plan for accidental releases, establish specialist response teams, and ensure adequate fire protection resources are available. Organizations should also track and review hydrogen incidents and standards globally and update safety measures accordingly.

The crucial role of insurance: The insurance sector will play an important role in the hydrogen economy, addressing risks across the supply chain, from construction and production through to the end user. In addition, insurers such as Allianz also support the hydrogen industry through direct investments in tangible infrastructure projects, such as green hydrogen production plants.

As hydrogen becomes integrated into the global economy, the demand for comprehensive insurance coverage will increase and broaden, and the market could reach $3bn+ globally by 2030, although there are many factors which could impact this valuation. The construction of new hydrogen facilities and the repurposing of existing infrastructure will require specialized solutions, while existing property, liability and specialty coverages will need to be adapted for end-users with hydrogen exposures. Underwriters can provide a range of coverages including physical damage to assets and equipment, third party liability, machinery breakdown, business interruption, construction and marine insurance.

Given the wide reach of the hydrogen value chain and its potential uses, the implications for insurance could be far-reaching, touching on multiple sectors and lines of business over the next decade. From an exposure and potential claims perspective, however, energy/natural resources and liability are likely to see the biggest impact from hydrogen risks over the next five to 10 years, followed by property and marine.

1. Hydrogen: a sustainable fuel of the future?

As a chemical product, hydrogen has many uses, but it also has huge potential as a carrier and storer of energy. Crucially, hydrogen does not emit CO_2 when used and is widely considered a key building block of the global energy transition.

Currently, around 90% of hydrogen is used as a raw material in the chemical, refining and agricultural sectors. Notably, it is used to produce ammonia, a key component of fertilizer, but it is also used in a wide range of industrial processes, including plastics, steel and aluminum manufacturing, as well as in the food production, medical and pharmaceutical sectors.

There are many ways of producing hydrogen. The most common method is through a chemical process known as steam methane reforming, where natural gas reacts with high-temperature steam. Another method of making hydrogen is electrolysis, where electricity is used to separate water into hydrogen and oxygen.

Depending on how it is produced, hydrogen is classified by color. Gray/black/brown hydrogen is produced using fossil fuels, while the addition of carbon capture results in blue hydrogen. Green hydrogen, which is typically produced by electrolysis powered by renewable electricity, is the cleanest form.

The vast majority of hydrogen today is produced using fossil fuels such as coal and natural gas and used in the chemical and refinery sectors. The need for clean energy, however, is set to transform the hydrogen industry. In addition to providing a clean alternative to existing demand, green hydrogen is emerging as a potentially important energy solution, especially for hard to abate sectors and for electrical power generation.

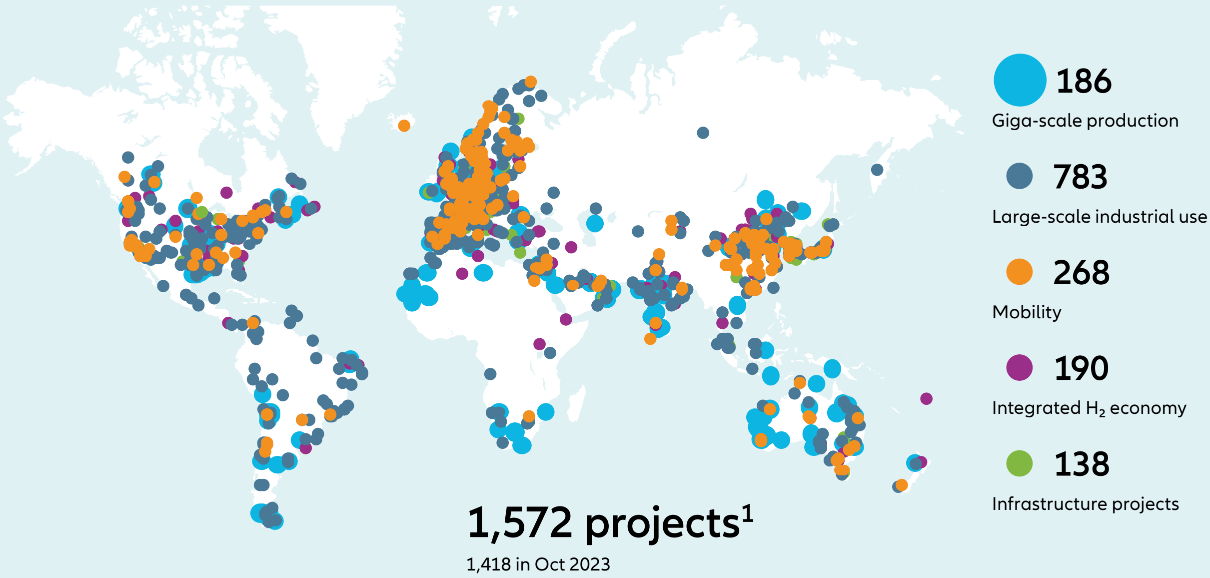
The energy transition is predicted to see hydrogen demand grow fivefold by 2050, while supply is expected to shift to 60% clean production by 2035 from nearly 100% gray hydrogen currently[1]. The number of planned clean hydrogen projects increased to 1,572 in 2024 from just 228 projects in 2021, according to the Hydrogen Council[2].

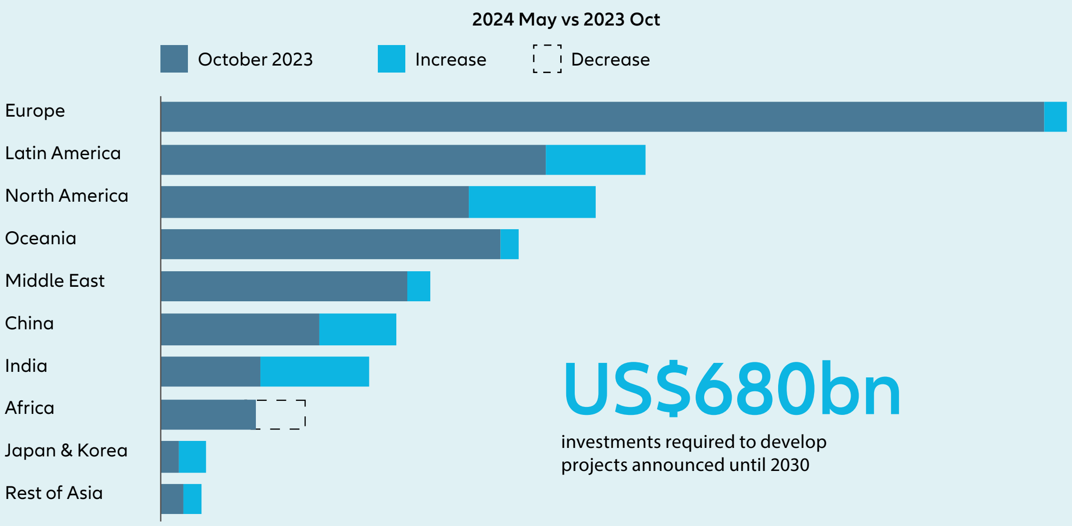
The hydrogen color spectrum

Hydrogen is classified by color based on the originating source of the hydrogen

- **Green:** Generated using electrolysis powered by renewable electricity
- **Blue:** Production is based on fossil fuels but with CO_2 emissions captured
- **Gray:** Made using fossil fuels with no emissions captured
- **Black:** Made using coal
- **Brown:** Made using lignite
- **Turquoise:** Heat is used to split fossil fuels in a process known as "pyrolysis", resulting in hydrogen and solid carbon
- **Purple, pink or yellow:** Electricity and heat from nuclear reactors could both be used to produce hydrogen, but there is no widely agreed color for such methods
- **White:** Naturally occurring hydrogen

Global project overview





1. Project announcements below 1 MW are excluded. Seven projects have not announced project type

Source: The Hydrogen Council, Hydrogen Insights 2024, Project & Investment tracker, as of May 2024

Hydrogen momentum continues: 1,572 projects have been announced globally – US$680bn investments required to develop projects announced until 2030 (as of May 2024). Growth is apparent across most regions in terms of investments and the number of projects, although growth is slower than in previous years. Europe continues to have the largest number of projects (617), followed by North America (280). Europe also has the highest total investments announced ($199bn).

The NEOM[3] Green Hydrogen project in Saudi Arabia has attracted $8.4bn of investment to build the world's largest green hydrogen plant, expected to begin production next year. India recently announced a $21bn investment in the NTPC[4] hydrogen project at Pudimadaka, which will produce green hydrogen, methanol and sustainable aviation fuel.

One of the key emerging areas for demand in the near term is the power sector, which is exploring ways to use blue and green hydrogen to generate clean electricity. A growing number of power plants are being built or retrofitted (from coal or gas) to burn 100% hydrogen or a blend of hydrogen and natural gas. In April 2025, German utility company EnBW[5] commissioned one of the country's first hydrogen-ready gas turbine power plants and has plans to convert two coal-fired plants to hydrogen-ready gas-fired power plants.

The energy transition could also see hydrogen play an important role in facilitating the growth and integration of the renewable energy sector. It can be used to store energy generated by weather-dependent renewable sources, such as wind and solar, helping to balance power supply and provide grid stability during periods of high demand and low supply. Hydrogen is also proposed as a potential solution for heating domestic and commercial buildings (either 100% hydrogen or blended with natural gas).

Green hydrogen could also help decarbonize hard to abate industries where other renewable alternatives might be unfeasible or more expensive. There are potential uses for green hydrogen in long-distance transport, including trucks, trains, aircraft and shipping. It can also help decarbonize heavy industry and industrial processes such as the manufacturing of steel, aluminum and cement. Hydrogen technology is also being explored to decarbonize plant and machinery in sectors like construction and mining.

"Hydrogen is becoming more and more important due to significant investments in production and manufacturing. In Germany, for example, we are seeing growing investment in combined power plants that are designed to run with green hydrogen, as well as development of hydrogen technology by German manufacturers," says **Harald Dimpflmaier, a Regional Head of Natural Resources Underwriting at Allianz Commercial.**

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Emerging uses

Decarbonizing heavy industry: In Sweden, Stegra[6] is constructing the world's first large-scale 100% hydrogen-based Direct Reduced Iron (DRI) plant, which aims to produce five million tons of green steel annually by 2030. In 2023, the Hyflexpower consortium led by German engineering company Siemens successfully demonstrated the use of a 100% renewable hydrogen gas turbine at the Smurfit Kappa Saillat[7] paper mill in France, the world's first industrial-scale green hydrogen turbine.

Power generation/renewables: In 2024, a hydrogen test project[8] in Denmark successfully linked a wind turbine with two electrolyzers. Energy companies Lhyfe and Centrica are to pilot green hydrogen production in the North Sea[9], powered by offshore wind turbines. Sparc Hydrogen[10] is to pilot a first-of-its-kind green hydrogen plant in South Australia that produces green hydrogen directly from water using solar energy without an electrolyzer.

Heating: The UK[11] is evaluating the feasibility of using hydrogen as an alternative to natural gas for heating residential buildings, trialing the supply of green hydrogen powered by an offshore wind turbine to around 300 homes through a new network laid parallel with the existing natural gas network.

Trains: In 2016, Alstom unveiled The Coradia iLint[12], the world's first passenger train powered by a hydrogen fuel cell. Last year, the EU's FCH2RAIL[13] project tested a hydrogen train in Spain and Portugal. Hydrogen trains have also been trialed in the US, UK and India, while French train companies[14] have ordered a fleet of hydrogen trains.

Automotive: Volvo[15] has developed hydrogen-powered trucks that are due to hit the test track next year, with a view to commercial production by the end of this decade. CaetanoBus and Solaris have provided hydrogen-powered fleets to a number of European cities, including Paris, London and Barcelona[16]. Toyota and Hyundai[17] have launched passenger hydrogen fuel cell vehicles (FCEVS) in selected markets, while hydrogen internal combustion engine vehicles are also in development.

Aviation: Hydrogen propulsion technology in aviation is in the early stages of development. Under its ZEROe project[18], Airbus is developing hydrogen fuel cell technology to power a prototype aircraft. Boeing and Lockheed Martin are also working to develop new prototypes.

Marine: Hydrogen-fueled vessels are not yet widely available, but the industry has made progress in testing these. Norwegian ferry company Torghatten Nord[19] has ordered two hydrogen-powered vessels due to be delivered in 2026. Last year, Holland Shipyards completed its second hydrogen-powered container vessel, H2 Barge 2[20], which will operate on the Rhine between Rotterdam, the Netherlands, and Duisberg, Germany. Another hydrogen-powered inland vessel, Zulu 06[21], was trialed by French shipping company Sogestran Group in 2024.

Green hydrogen for industry: As part of the GET H2 Nukleus project, RWE[22] is planning to build an electrolysis capacity of 300 megawatts (MW) on the site of the Emsland gas-fired power plant in Germany in three expansion stages by 2027. The first 100 MW of electrolysis capacity is scheduled to go into operation in 2025. The aim of the Nukleus project is the large-scale commercial production of green hydrogen, which will be supplied to industrial customers. Allianz Commercial is involved as a lead insurer.

2. Energy policies drive investment but headwinds and uncertainties remain

Momentum behind hydrogen is building. As of 2024, around US$75bn of investments were committed to clean hydrogen projects, a seven-fold increase since 2020, according to the Hydrogen Council[23] and McKinsey. Some 60[24] governments (including the European Union) have now adopted hydrogen strategies, according to the International Energy Agency (IEA). The US and the EU have been particularly active, although China leads when it comes to deployment. China is home to 60% of global electrolyzer manufacturing capacity and accounted for 40% of global investment decision in capacity in 2023. India is also emerging as a key player.

Hydrogen is a key plank of the EU's energy transition, but it has also taken on additional urgency since Russia's invasion of Ukraine: In 2022, the EU launched its REPowerEU plan, which aims to accelerate investments in green energy and reduce reliance on fossil fuels, in particular imports of Russian natural gas. Under the EU's hydrogen strategy, the EU expects that green hydrogen could cover around 10% of the EU's energy needs, up from 2% in 2022[25].

Since 2021, the EU has implemented a package of hydrogen-related policies, which included a new regulatory framework for hydrogen infrastructure[26] and binding targets[27] for the uptake of renewable hydrogen in industry and transport by 2030. It also established a dedicated financing instrument – The Hydrogen Bank – to unlock investment and accelerate the establishment of a full hydrogen value chain in Europe.

There is also the European Hydrogen Backbone (EHB)[28] initiative, a project which aims to provide Europe with a 53,000km network of hydrogen pipelines across 28 countries by 2040, with 40% of new pipelines and 60% conversion of existing natural gas pipelines.

In the US, the 2021 Infrastructure Investment and Jobs Act allocated $8bn to develop regional clean hydrogen hubs, while the 2022 Inflation Reduction Act set out a hydrogen production tax credit, with final guidance[29] published in January 2025. Last year, California[30] announced a landmark $12.6bn public-private investment in clean hydrogen production, infrastructure, power and transport projects.

While hydrogen holds much promise, the future size and scope of the hydrogen economy will depend on a number of factors, including technical and infrastructure developments, government policy, regulation and future demand.

Numerous hydrogen production technologies are, or are close to being, commercially viable. However, production will need to be scaled up if hydrogen is to fulfil its potential transition role. The sector would need to grow at an unprecedented compound annual growth rate of over 90% between 2024 and 2030, well above the growth experienced by solar PV (photovoltaic) technology during its fastest expansion phases, according to the IEA[31].

Further advances in hydrogen technology are expected to pave the way for more efficient and scalable green hydrogen production going forward. However, for large hydrogen production investments to be viable, there must also be sufficient demand beyond the traditional uses of hydrogen in chemical and industrial sectors.

While there are promising innovations in hydrogen end use technologies for heavy industry and transport these have yet to be demonstrated at scale. The cost of hydrogen relative to alternatives, and the lack of infrastructure (aviation and shipping, for example, will require hydrogen refiling and bunkering infrastructure at ports and airports) are also factors affecting uptake.

Producing green hydrogen is up to six times more costly than unabated fossil-based production, according to the IEA[32]. The cost of low-emission hydrogen production from renewable electricity would need to halve from today's levels under a net zero by 2050 scenario, yet current policies are only on track to deliver just a 30% reduction.

Delays in policy implementation and a lack of policies to stimulate demand are hampering the scale-up of clean hydrogen production and use. Several projects have faced delays and cancellations due to regulatory uncertainties, cost pressures, and a lack of incentives to accelerate demand. Regulation and certification schemes (particularly in terms of greenhouse gas emissions) are said to be underdeveloped, while infrastructure to deliver hydrogen to end users is lacking.

Aircraft manufacturer Airbus[33] recently delayed its plans to develop commercial hydrogen-powered aircraft due to infrastructure concerns. Trials of hydrogen buses have been halted or delayed due to fuel costs and supply chain issues. Studies[34] suggest only a limited role for hydrogen in domestic heating due to infrastructure challenges, safety concerns and competition from cheaper alternatives.

The evolving political, trade and economic environment is also likely to affect both production and demand. The relative cost of oil and gas would have implications for the viability of hydrogen as a fuel, while weakening of transition targets and policy could crimp demand. Under the Biden administration, the US saw a surge in investment in hydrogen, but the future of such policies is changing under the current administration[35].

"Hydrogen has great potential, but the technology and infrastructure will take time to develop, and will require significant government policy support and incentives. We are seeing some large projects, but hydrogen production will need to be scaled up and made more competitive. It's good for the planet, but hydrogen is currently expensive compared with cheaper alternatives, although these are not always as sustainable," says **Steffen Halscheidt, Global Underwriting Product Leader, Natural Resources, Allianz Commercial.**

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3. Risks and hazards

Hydrogen's unique chemical properties make it a promising candidate for generating and storing clean energy. But they also present challenging risks across the hydrogen value chain, from production, transportation and storage, through to the end user.

Chief among these is the risk of fire. Once mixed with air, hydrogen is easily ignited, highly flammable and potentially explosive (static electricity or a hot surface is enough to ignite hydrogen). Hydrogen is colorless, odorless and burns with a near-invisible flame, making it hard to detect without specialist sensors. Significantly, hydrogen molecules are the smallest of all elements, which makes it more prone to leaking.

Hydrogen is also the lightest of the elements. While its buoyancy is less likely to cause a vapor cloud explosion than hydrocarbons like methane, there are conditions in which damaging explosions can occur. The ignition of a sudden release of a large mass of pressurized liquid hydrogen can result in a fireball, while sudden detonation can cause a shockwave. Accidental releases of pressurized hydrogen, such as from a blocked or faulty valve or pipeline, can cause jet fires.

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> “Hydrogen can be a challenging medium, with a risk of fire and explosion.

Hydrogen’s low minimum ignition energy, high flammability and ability to spread vertically can make fires difficult to extinguish. Generally, the supply of fuel will need to be isolated or burned off, as hydrogen will easily reignite. Failure to cut off the supply also raises the risk of explosion if escaping hydrogen mixes with air and is allowed to accumulate, especially in a confined space.

“Hydrogen can be a challenging medium, with a risk of fire and explosion. So, location is key. Hydrogen production and storage will need to be a safe distance from buildings and equipment. Natural catastrophes also pose a risk. Plants need to be close to sources of water, but this could come with heightened risk of flooding,” explains **Steffen Halscheidt, Global Underwriting Product Leader, Natural Resources, Allianz Commercial.**

Embrittlement is another important concern. Hydrogen’s small atoms are able to permeate through some materials, including steel and certain alloys, resulting in cracking and structural weakening. Hydrogen can also accelerate fatigue and reduce stress thresholds in some materials, such as carbon and low-alloy steel, which are commonly used in pipelines. The structural integrity of carbon fiber can also be compromised when hydrogen gas causes blisters and raised areas on the surface.

Innovation and prototype technology are another consideration. While some forms of hydrogen production technology are well understood and established, research and development are ongoing. In the power sector, manufacturers are developing and testing new combined turbines for power generation, as well as electrolyzers and other technology to generate green hydrogen alongside renewables.

When it comes to end use, technology is often experimental or not proven at scale. Decarbonizing heavy industry like steelmaking will increasingly see prototypes and pilot projects to test new technology and how it integrates with existing processes. In transport, manufacturers are already developing and testing prototype hydrogen or hybrid propulsion systems for shipping, aircraft, trains and commercial vehicles like buses and trucks.

The incorporation of hydrogen into existing production processes and infrastructure, such as power, heavy industry and transport, can also pose challenges. For example, existing power plants can be retrofitted to run on hydrogen or a blend of hydrogen and natural gas. Material choice to avoid embrittlement will be critical, while turbines will require modifications to mitigate the risks of “flashback” caused by differing densities of hydrogen and natural gas.

“The production and distribution of hydrogen is an emerging area. Hydrogen has different chemical properties to natural gas – it is more prone to leaking, ignites easily, and can degrade equipment depending on its metallurgy – so you can’t just use existing infrastructure,” says **Pietro Berardinelli, Senior Risk Consultant, Natural Resources, Allianz Commercial.**

Hydrogen value chain: a work in progress

Production: Gray hydrogen is currently mostly produced using inexpensive thermal processes, such as Steam Methane Reforming, in which steam reacts with hydrocarbons at high temperatures. Hydrogen can also be produced through the process of electrolysis, using electricity and an electrolyzer to separate water into oxygen and hydrogen.

When paired with renewable power, electrolysis produces green hydrogen, although there are other less well-developed technologies that produce green hydrogen using sunlight and/or microbes such as bacteria and microalgae. There are several types of electrolyzer technologies, each with their own advantages and limitations, making them suitable for different applications and scales of hydrogen production.

- **Alkaline Electrolyzers (AEL)** are a mature and cost-effective technology that is ideal for large-scale industrial hydrogen production. However, they are less efficient and require a larger physical footprint.
- **Proton Exchange Membrane (PEM)** electrolyzers, in contrast, offer higher efficiency and a compact design, making them suitable for integration with renewable energy sources, yet they are more expensive and have a shorter operational life.
- **Solid Oxide Electrolyzers (SOE)** are very efficient at high temperatures, making them suitable for industrial applications where high-temperature heat is available. However, their high operating temperatures result in material degradation and a shorter lifespan.
- **Anion Exchange Membrane (AEM)** electrolyzers combine the benefits of alkaline and PEM electrolyzers. However, they are still in development and face challenges in durability.

In green hydrogen production, electrolysis errors can lead to gas mixing, and breakdowns may result from short circuits. Other problems include freezing water in the electrolysis stack and membrane failures.

Transport: At present, hydrogen is primarily produced and consumed at refinery and fertilizer plants, but to expand the use of hydrogen the development of safe and cost-effective infrastructure will be critical. Pipelines offer the most cost-effective method of large-scale hydrogen transport over long distances but require high capital investment and extensive safety measures. Due to hydrogen's properties, it is also often not feasible to use existing natural gas infrastructure to deliver hydrogen. Trucks and trailers with high-pressure cylinders are a common way to transport hydrogen over short distances, but capacity is limited, and this method requires specialist infrastructure and safety systems for loading and unloading. Mixing hydrogen with a liquid carrier (liquid organic hydrogen carriers) can reduce the risks associated with hydrogen transport and is suitable for longer distances. Ammonia is another option for large-scale long-distance transport of hydrogen, especially for international shipping, but requires safe handling due to the toxicity of ammonia and the potential for contamination.

Storage: Hydrogen can be stored in a compressed, liquid or solid state. A widely used and mature technology, compressed hydrogen storage is suited to portable power systems and fuel cells for hydrogen-powered transport. The main challenges of compressed hydrogen are the higher costs and the need for robust safety. Liquid and solid-state hydrogen have higher energy density and are ideal for long-term storage, large-scale industrial processes and shipping. Liquid hydrogen, however, is stored at cryogenic temperatures (-253°C), which brings some unique safety challenges and the need for specialist equipment and infrastructure. By absorbing hydrogen in a metal alloy, solid state hydrogen allows for storage at low pressures and ambient temperatures. Solid state storage is still in the research and development phase, but could revolutionize the hydrogen economy, offering an efficient safe storage solution.

4. Risk mitigation and loss prevention

Given hydrogen's unique properties and high combustibility, ensuring safety throughout the hydrogen value chain is crucial. Key to managing these exposures are the design and location of hydrogen systems, measures to address embrittlement, hydrogen gas detection solutions, training, maintenance, and emergency planning and response.

"Hydrogen has been used in the chemical and refinery sectors for many decades, so there is a good understanding of the hazards – of risks like embrittlement and fire and explosion. We know the dangers, and there is the expertise and procedures needed for handling hydrogen safely," says **Pietro Berardinelli, Senior Risk Consultant, Natural Resources, Allianz Commercial.**

Analysis of hydrogen-related incidents reveals that undetected leaks can easily lead to explosions. Relative to natural gas, hydrogen has a greater tendency to leak through valves, seals, pipes, threads and joints. Equipment design, maintenance and training can help prevent the escape of flammable hydrogen gas, while the risks of ignition can also be reduced by locating hydrogen facilities in the open, and through the design of electrical installations and surfaces to avoid sparks and the buildup of static electricity. Ventilation is also important, especially in enclosed spaces, to avoid accumulation of hydrogen gas and to mitigate the risk of explosion and asphyxiation.

"The layout of a facility plays an important role. A fire can spread to adjacent equipment, property and assets," says **Lucas Illgen, Senior Risk Consultant, Property, Allianz Commercial.**

"

Human error is a common factor in large losses.

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A common problem with hydrogen is embrittlement and fatigue of equipment and infrastructure, which can lead to cracks, leakages, fire and explosions. These risks can be managed through material selection and the use of hydrogen-compatible materials and coatings that have been specifically designed to resist hydrogen embrittlement. Repurposed equipment will need to be assessed for embrittlement and may require modifications, according to **Flor Angela Quintero, Senior Liability Risk Consultant, Allianz Commercial.**

In addition to preventing incidents, organizations can take steps to limit the extent of property damage, business interruption and third-party liability. Buildings and facilities should be designed and constructed to withstand natural hazards, fire and explosion, and limit damage to adjacent property and equipment. Robust hydrogen leak detection and isolation systems are also paramount. Sensors are essential to detect leaks promptly, while the ability to shut-off the supply of escaping hydrogen is crucial to mitigating the impact of fire and explosion.

Human error is also a common factor in large losses. Operational, safety, emergency procedures and training should be frequently updated and documented, while equipment should be clearly labeled. In addition, organizations should establish an incident/emergency response plan for accidental releases, establish specialist response teams, and ensure adequate fire protection resources are available. Organizations should also track and review hydrogen incidents and standards globally and update safety measures accordingly.

The quality and reliability of energy and water supply is critical for electrolyzers. Fluctuation or outages in power supply can cause production problems and potentially electrical damage, so backup capacity is essential where energy supply may vary, such as with wind turbines. Water feed quality should be monitored, and when commissioning electrolyzers, demineralizing, cleaning and testing of supply is a must. Random borescope inspection prior to and after commissioning is an additional risk mitigation measure to consider.

"When handling hydrogen, organizations will need a good understanding and awareness of the risks and hazards. Hydrogen can leak and ignite more easily than natural gas and is more difficult to detect. So, there will need to be appropriate risk management controls, training, detection and emergency response planning in place," says **Illgen.**

5. The critical role of insurance

The insurance sector is set to play an important role in the hydrogen economy, addressing risks across the supply chain, from construction and production through to the end user. In addition, insurers such as Allianz also support the hydrogen industry through direct investments in tangible infrastructure projects, such as green hydrogen production plants.

Underwriters can provide a range of coverages to the hydrogen sector, including physical damage to assets and equipment, third party liability, machinery breakdown, business interruption, construction and marine insurance, explains **Harald Dimpflmaier, a Regional Head of Natural Resources Underwriting at Allianz Commercial:**

"Green hydrogen is likely to play an important role in the energy transition, in particular with power generation, transport and heavy industry. We fully intend to provide insurance for the range of hydrogen risks and are actively positioning our business in this exciting emerging field."

As hydrogen becomes integrated into the global economy, the demand for comprehensive coverage will increase and broaden, and the market could reach $3bn+ globally by 2030, although there are many factors which could impact this valuation. The construction of new hydrogen facilities and the repurposing of existing infrastructure will require specialized insurance solutions, while existing property, liability and specialty coverages will need to be adapted for end users with hydrogen exposures, according to **Dimpflmaier:**

"We are currently working on a hydrogen insurance solution at Allianz and have set up a cross-functional climate tech team to bring together all experts and knowledge in this field and offer solutions for transition opportunities like green hydrogen risks."

> A challenge for insurers is the amount of innovation, with new technology and uses of hydrogen emerging at a fast pace.


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Given the wide reach of the hydrogen value chain and its potential uses, the implications for insurance could be far reaching, touching on multiple sectors and lines of business over the next decade. From an exposure and potential claims perspective, however, energy/natural resources and liability are likely to see the biggest impact from hydrogen risks over the next five to 10 years, followed by property and marine.

Integrating hydrogen into the energy/natural resources and construction sectors brings a range of challenges. Energy production facilities will involve hydrogen storage and high-temperature combustion, which can lead to leaks and explosions. In transport, applications like hydrogen fuel cell vehicles will face risks of hydrogen embrittlement and leaks. In chemical feedstock and fertilizer production, safe storage and transportation are crucial to prevent contamination and explosions.

The adaptation of hydrogen in shipping will introduce new exposures for marine insurers. Adapting engines for hydrogen could increase the risks of machinery breakdown or give rise to safety issues. Shipping companies will also encounter the heightened risks of hydrogen embrittlement, gas leaks, and explosions. Port operators, bunkering facilities and fuel handlers will need to manage highly flammable and cryogenic hydrogen fuels, increasing accident and contamination risks.

Across all these industries, stringent safety measures are vital to manage the inherent risks associated with hydrogen use, according to **Steffen Halscheidt, Global Underwriting Product Leader, Natural Resources, Allianz Commercial.**

"As a fast growing and emerging sector, hydrogen risks will require careful risk assessment and attention to loss prevention and loss mitigation," says **Halscheidt.**

"During construction, insurers will want to assess the quality and experience of manufacturers, contractors and project teams, as well as the readiness of new materials and technologies. Once the plant is operational, we would look at whether it is meeting its performance targets, maintenance levels and the availability of spare parts."

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The biggest challenge for insurers is the sheer amount of innovation, with new technology and uses of hydrogen emerging at a fast pace. Failure rates for new technology are typically higher but reduce as the technology matures over time. As a result, underwriters must carry out due diligence when providing coverage to prototypes, while manufacturers' warranties and service will be key considerations.

Underwriters will need to assess the quality and experience of installers, contractors and operators. They will also look at the quality training, adherence to standard operating procedures and maintenance to mitigate hazards and ensure hydrogen is handled safely, explains **Dimpflmaier:**

"Insurers need to make sure we understand the risks of new and emerging hydrogen technologies. There is very little loss data but there is a lot of innovation that can help us understand the quality of new technology, (in addition to recognized international standards and best practices that are already available)*, while we can also be involved and have dialogue at an early stage of technology development.*

"We like to get involved in technical discussions at an early stage to understand the project plans and provide support. Leveraging our specialist risk engineering team – which includes experts in hydrogen – and wider knowledge gained from insuring thousands of plants and facilities globally, we can help clients identify potential risks and make risk recommendations."

For insurers, novel risks and start-ups make for unpredictable risks, according to **Lucas Illgen, Senior Risk Consultant, Property, Allianz Commercial:**

"We need to take into consideration the maturity of the hydrogen industry. We are dealing with technologies that are untested or established at scale. Some projects are using new electrolyzers for the first time, so when assessing risks, we need to understand if the technology used is established or a prototype."

Evolving technology also raises the risk of serial losses, where a common fault requires the replacement of equipment across a project or multiple projects. For example, a large hydrogen production facility could involve hundreds of electrolyzers, while the same design could be replicated at multiple plants.

"We have already seen serial defect claims in the past with wind turbines. If one hydrogen electrolyzer develops a problem, others may then be taken out of action. And as the sector scales up, we could see concentrations of electrolyzers in a single location. If they are too close together, it would potentially increase the exposure to fire and explosion," says **Pietro Berardinelli, Senior Risk Consultant, Natural Resources, Allianz Commercial.**

Still evolving supply chains are also a driver for risks and potential losses, adds **Berardinelli:** *"There are a limited number of established and specialist suppliers and contractors, which makes it harder to diversify supply chains. And as the hydrogen industry scales up, supply chains may come under increasing pressure, with the risk of capacity constraints, delays and longer lead-in times for replacement parts. At the same time, new start-ups, suppliers and contractors entering the market also pose challenges for insurers who have to assess their experience and capabilities."*

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