

RISING TO THE CHALLENGE OF A HYDROGEN ECONOMY

The outlook for emerging hydrogen value chains, from production to consumption

REPORT



The world is heading for hydrogen

For many, it is essential to a net-zero future

As recently as three years ago, clean hydrogen energy was on the fringes of the energy-transition conversation – an outlier solution, at least for the short or medium term. Today, it is rapidly moving into the mainstream and, for many, it is essential to a net-zero energy future.

In short, the world is heading for hydrogen, but the route is uncertain and many questions remain. How quickly can hydrogen supply scale-up to support high-demand industries? What is new about hydrogen in 2021? What are the most urgent challenges and the required enablers? Which areas of uncertainty could impact hydrogen the most in the next few years?

This report explores the outlook for the emerging hydrogen economy, drawing on DNV's survey of more than 1,100 senior professionals involved in the emerging hydrogen economy, as well as on in-depth interviews with several industry leaders.

The report explores the outlook for the hydrogen economy in three areas:

- Great expectations
- Expected challenges and enablers
- Challenging questions.

1,124

Survey respondents from across the hydrogen economy

80

Countries represented

7

In-depth interviews with industry leaders

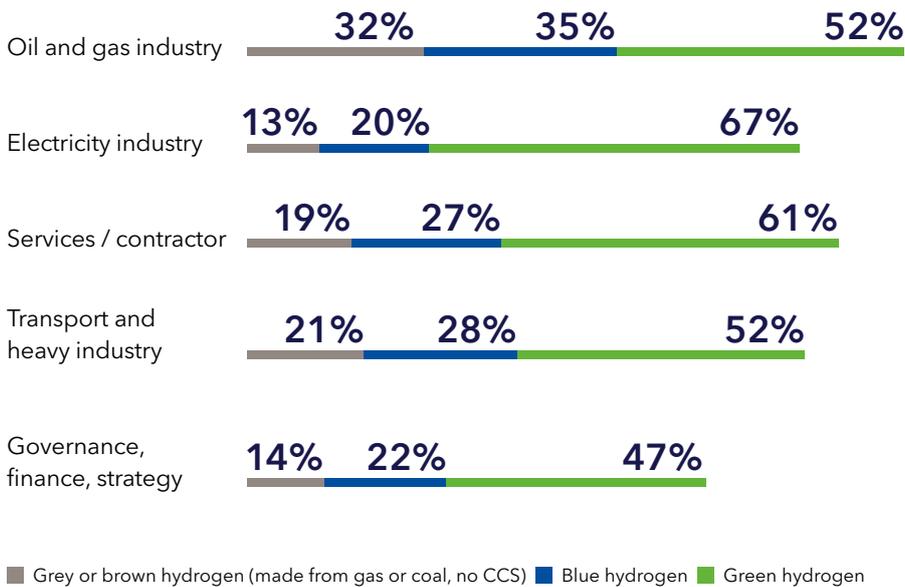
27%

Respondents from organizations with revenues in excess of US\$1bn

We would like to thank the following leaders for the time and insights they provided to this research through in-depth interviews:

- **Sebastian Koks Andreassen**, CEO at Green Hydrogen Systems
- **Antony Green**, project director – hydrogen, National Grid
- **Dr Sanjay C Kuttan**, executive director, Singapore Maritime Institute
- **Tim Peeters**, department manager, iron and steel R&D, Tata Steel Europe; and **Mustapha Bsibsi**, R&D knowledge group leader, thermal processes, Tata Steel Europe
- **Rachel Ruffle**, CEO Northern Europe at RES (Renewable Energy Systems Ltd)
- **Kristina Wittmeyer**, business opportunity manager – Hydrogen, Shell Norway
- **Yuan Zhengang**, director of New Energy Research Center of CPPEI (a think tank of CNPC)

Involvement in types of hydrogen, by broad industry groups



In this survey, among respondents that produce, distribute, store, or consume hydrogen, 56% use green hydrogen, 26% blue hydrogen, and 20% grey or brown hydrogen.

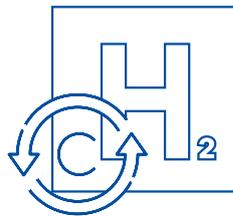
Hydrogen terminology

In this report, the term 'hydrogen' refers to low-carbon hydrogen, unless otherwise specified. 'Low-carbon hydrogen', in turn, refers to blue and/or green hydrogen. These are defined individually below.



Green hydrogen

- Green hydrogen is produced by the electrolysis of water
- The process is powered by zero-carbon electricity (e.g., wind and solar power)
- It is clean, but is currently too expensive for widespread use¹
- The cost of electrolyzers and renewable energy is expected to fall over the next decade, making green hydrogen more viable
- Green hydrogen is the ideal long-term, zero-carbon way to produce hydrogen



Blue hydrogen

- Blue hydrogen is produced from fossil fuels (typically natural gas), but emissions are dealt with using carbon capture and storage (CCS) technology
- With abundant natural gas and coal available, blue hydrogen could help to scale the hydrogen economy²
- However, this is dependent on wider adoption of CCS
- Blue hydrogen could act as a stepping stone from grey/brown to green hydrogen



Grey hydrogen

- Grey hydrogen is typically produced from natural gas in a process called steam methane reformation
- Brown hydrogen is produced from the gasification of coal (or lignite)
- These are the strongly dominant methods in use today
- They are relatively cheap, but emit large amounts of CO₂

1. Path to Hydrogen Competitiveness: A Cost Perspective, Hydrogen Council: <https://bit.ly/3gZqLDw>

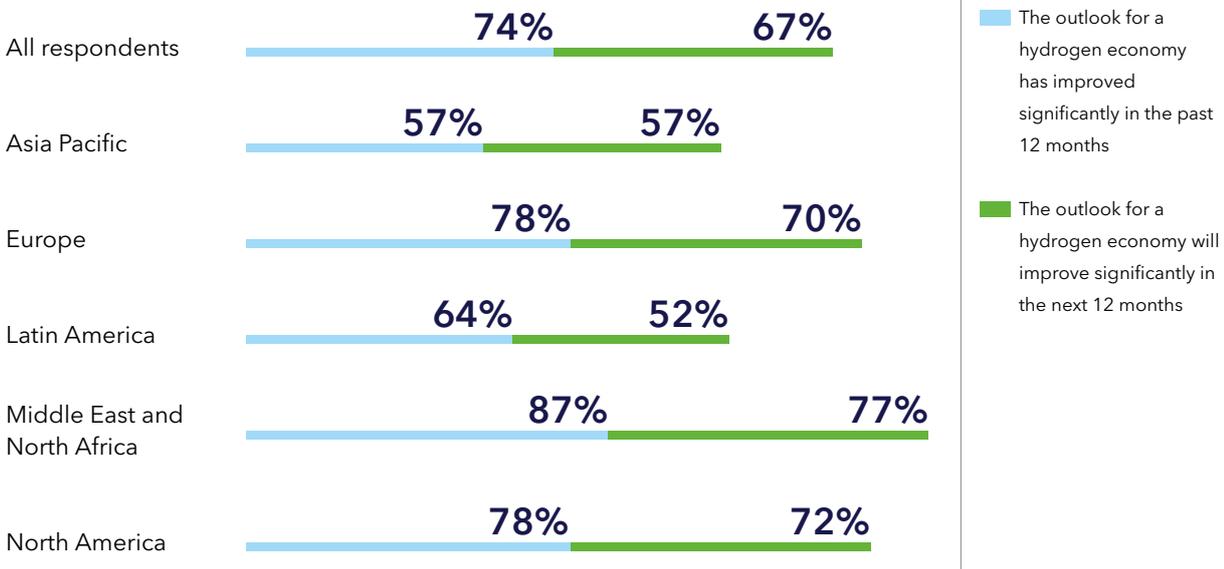
2. Unlocking the green hydrogen revolution, Recharge: <https://bit.ly/35UTAuz>

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Great expectations

The hydrogen pledges, plans, and pilots of recent years have now evolved into concrete commitments, investments and full-scale projects.

Short-term outlook for the hydrogen economy, by region



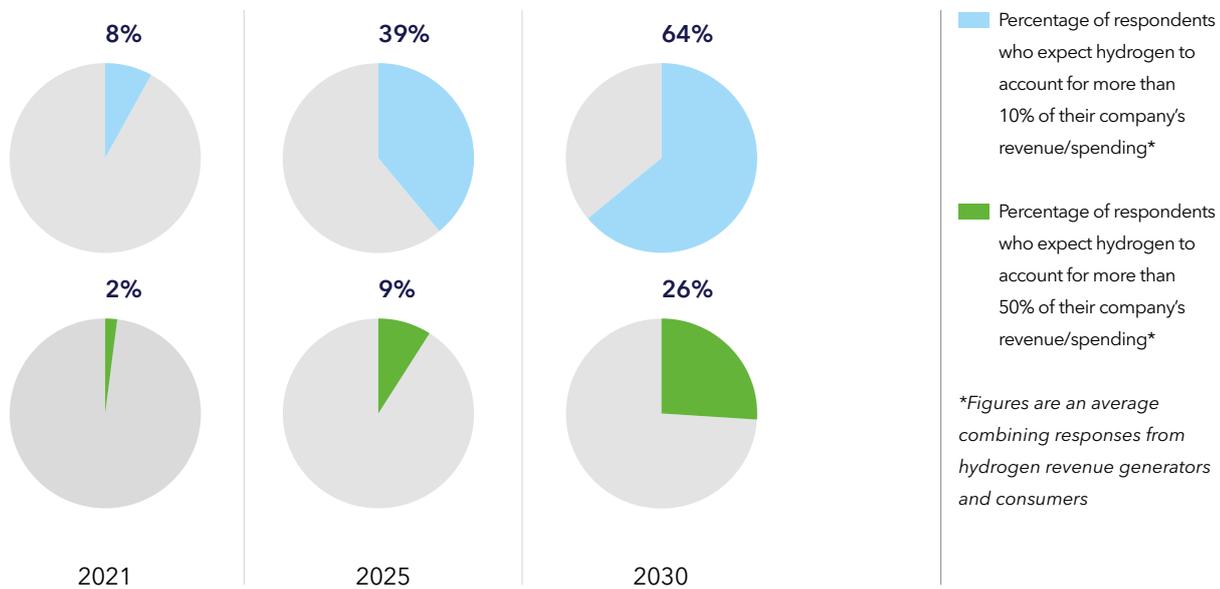
In 2021, hydrogen holds the status of a viable and rapidly developing pillar of the energy transition. Three-quarters (74%) of energy professionals say that the outlook for a hydrogen economy has improved significantly in the past 12 months, while two-thirds (67%) expect this to continue in the next 12 months.

Today, just 8% of hydrogen revenue earners in our survey (i.e., those involved in hydrogen production, distribution, technology, engineering, infrastructure/facility development or financing/investing in hydrogen projects) derive more than one-tenth of their total revenue from their hydrogen operations. By 2025, this is expected to rise fivefold, to 44%. By 2030, this number will rise to 73%.

At the other end of this new energy value chain, the growth of spending on hydrogen consumption for energy and/or feedstock is expected to grow at only a slightly slower rate. By 2025, 33% of hydrogen consumers expect hydrogen to represent more than one-tenth of their organizations' energy (and/or feedstock) spending, up from just 9% today. This is projected to rise to 57% by 2030.

Taken together, these numbers are impressive considering how new hydrogen is to most organizations. A strong majority of those we surveyed (71%) have only begun their involvement with hydrogen within the past five years, while 55% have only commenced within the past three years.

Expectations for hydrogen to account for 10% and 50% of revenue/spending, by 2025 and 2030



From small base to major role

For many in our survey (45%), hydrogen accounts for less than 1% of their organization's revenue. Indeed, most organizations with hydrogen interests are not pure plays - rather, hydrogen is a new, but increasingly important, venture within an established business.

"Green hydrogen, for me, is the final piece of the jigsaw."

Rachel Ruffle, CEO Northern Europe at RES

"We always talk about the trilemma of energy security, sustainability, and cost, and the trade-offs that have historically been needed between them, says Rachel Ruffle, CEO Northern Europe at RES, a global renewable-energy business. "We have essentially resolved the sustainability-cost equation because renewable energy is now the cheapest form of new electricity generation. But the variability of renewables has not been resolved. That is what sparked our initial interest in hydrogen. It could support long-term energy storage, helping to make use of surplus supply, and also meet peak demand."

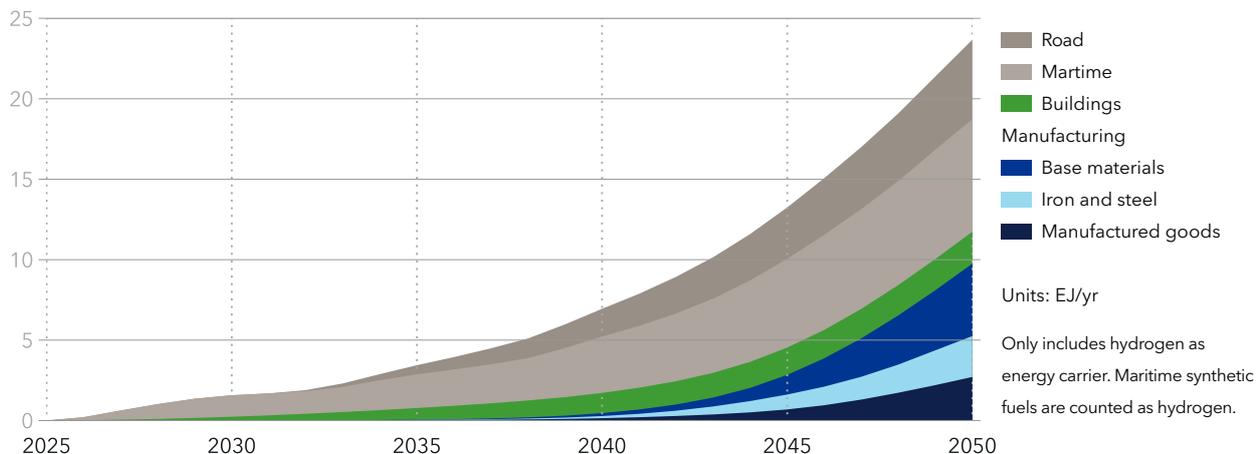
But as Rachel Ruffle adds, over the past few years, hydrogen's role in the future of energy has grown much more fundamental. "It is now not just about decarbonizing the electricity sector," she says, "but the whole of the energy sector, including in heavy industry where grey hydrogen is being used."

DNV's *Energy Transition Outlook* (ETO) finds that only around 20% of final energy demand today is for electricity.

Electricity as a share of overall energy demand is set to double to around 40% by 2050, but this leaves significant demand in our forecast for fossil fuels, which will need to be replaced by greater electrification or by decarbonized/green gases such as hydrogen, if the world is to meet the targets of the Paris Agreement.

³ Energy Transition Outlook 2020, DNV: <https://eto.dnv.com/2020>

World hydrogen demand by sector



DNV Energy Transition Outlook 2020

Hydrogen consumers expect a rapid increase in their usage

Our research shows that hydrogen producers are investing and upscaling to generate vast amounts of green and blue hydrogen in the coming years. They are confident enough to do so because several industries are simultaneously building the demand-side of the hydrogen economy.

These industries need to reinvent many of their plants, machines, models, and practices to switch to hydrogen. Most have a pressing need to replace a carbon-intensive part of their business - the top driver of hydrogen adoption among consumer-businesses in our survey.

Hydrogen can be a substitute for either fossil-fuel-based energy or feedstock needs in these industries. For example, long-haul trucking fleets can replace diesel with hydrogen fuel cells; power companies can exchange natural gas turbines for hydrogen-burning alternatives; and chemical companies that produce ammonia can swap grey/brown hydrogen feedstock for blue/green equivalents.

The steel industry is one that could ultimately create enormous demand for hydrogen. Globally, over six million tonnes of iron ore is mined every day, adding up to over two billion tonnes a year. This giant industry is still growing, with iron ore production forecast to rise by 5.1% between 2021 and 2025⁴.

Targeting high-impact applications

Almost all of the world's iron ore is converted into pig iron - the primary ingredient in all types of steel. This process is the

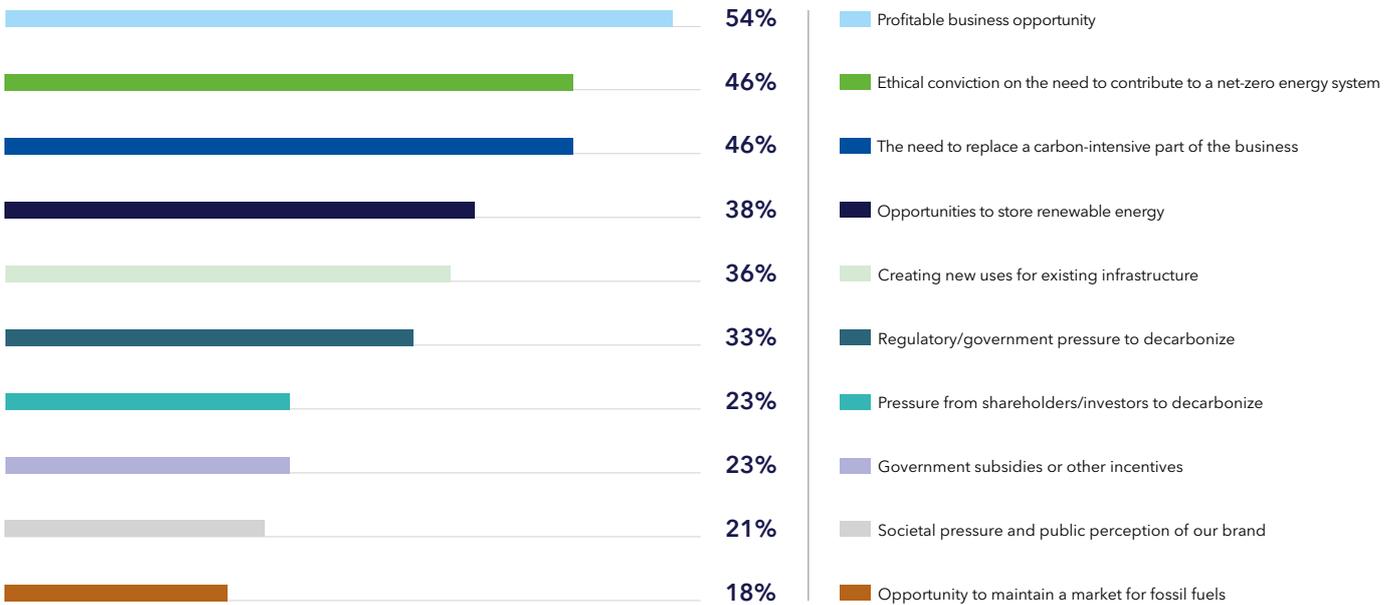
most carbon intensive part of the industry, and also an area where hydrogen could help the most. This is because it has the potential to serve as both a primary feedstock (replacing carbon, in the form of coke, as a reducing agent in the process that frees iron from iron oxide) and as an energy source (replacing fossil fuels in various heat-intensive stages of the iron- and steelmaking process).

Evolving the steelmaking industry towards net zero targets is the biggest challenge - and the biggest transformation - the sector has faced over the course of over two centuries. Many technical barriers exist, many of which are not well-understood outside the industry. "The outside world expects the industry to change very quickly," says Tim Peeters, department manager, iron and steel R&D, Tata Steel Europe, part of a major multinational steelmaking business, "but the kind of plant we need to build only exists on paper. It has never been done in practice, at full scale. People overlook the technical challenges that are still ahead of us, and so we need to communicate the transition path we are on and the steps that need to be taken."

However, even if these technical challenges were solved, it will take several years before there is enough green or blue hydrogen to serve the steelmaking industry. "Going full hydrogen means you need a huge amount of hydrogen. Just for our business in the Netherlands, we would need approximately 1.5 million tonnes of hydrogen annually to transform completely from coal to hydrogen. That is a major bottleneck when you consider how small green hydrogen production is at the moment," says Mustapha Bsibsi, R&D knowledge group leader, thermal processes at Tata Steel Europe.

⁴ World iron ore output to rise 5.1% by 2025 - report, Mining.com: <https://bit.ly/3h0tmgr>

Top drivers of involvement in the hydrogen economy



Aligning roadmaps

Like many prospective hydrogen-consuming industries, the steel industry needs a clear roadmap from the supply-side, showing the availability of specific amounts of hydrogen over the coming years. "If you really need to replace, for example, a single blast furnace with a hydrogen-based ironmaking technology, that in itself is a huge step," says Peeters, "It's not a gradual change from one to the other. So by when do we need that to be ready? By when will the hydrogen be available?"

The supply-side, of course, needs a similar roadmap from the industrial users, so that they can build production to match demand. "On both sides, and with regulators, policymakers, and all other stakeholders, there is a need to coordinate and collaborate," says Bsibsi.

Hydrogen makes business sense

Of course, companies would not have such high growth expectations if hydrogen did not make business sense. In fact, among survey respondents, the belief that it represents a profitable business opportunity is the biggest driver for those involved in the hydrogen economy, especially for investors, producers and distributors.

However, among the key drivers in our research, profitability is closely followed by sustainability factors. The need to replace a carbon-intensive part of the business, and an ethical conviction on the need to contribute to a net-zero energy system, tie for second place in our list of hydrogen drivers.

Indeed, most respondents believe that hydrogen is critical to the fight against climate change:

- 84% believe that hydrogen has the potential to be a major component of a global, low-carbon energy system.
- 73% say Paris Agreement targets will not be achievable without a large-scale hydrogen economy.
- 74% say that, whether economically viable or not, there is no way to achieve a zero-carbon economy by 2050 without hydrogen.

In this context, how the environmental effects of hydrogen projects are measured is crucial to assessing its real impact.

"We need to take a full life-cycle perspective as we adopt hydrogen, considering the total carbon footprint, covering all factors and not just thinking about hydrogen at the point of use."

Dr Sanjay C Kuttan, executive director of the Singapore Maritime Institute.

"That analysis is important because, in the past, there has been a tendency to use the narrowest of boundaries to justify why we do one thing or another, and I think that is part of why we have developed an unsustainable world", says Dr Sanjay C Kuttan, executive director of the Singapore Maritime Institute.

Hydrogen has had a few false dawns in the past, but there has never been anything like the current levels of investment, government support, and industry commitment. All of these will be crucial to meeting the great expectations respondents have for hydrogen - both for boosting net profit and moving towards net zero.



Hydrogen: similar yet different

Hydrogen is a fascinating prospect because of its unique features. Technically, it is not a fuel, even though it can be used as one. As with electricity, hydrogen is an energy carrier – and, like electric power, it can be used to ‘charge’ batteries (comprised of fuel cells). But it is also explosive. It produces heat when combusted. It can be held in tanks, moved through pipelines, and stored indefinitely. In these respects, it is much more like fossil fuels.

Hydrogen is at once familiar and different from anything else in the energy system. And, while much of the required hydrogen technology is proven, hydrogen value chains require a lot of development. “A lot of today’s hydrogen technology is not new – it has been around for decades,” says Kristina Wittmeyer, business opportunity manager – hydrogen, at Shell Norway. “However, to scale these technologies to meet the demand and new applications that are expected will require new ideas, processes, and models.”

“The challenge today is how we can put all the required elements together in a way that is viable, reliable, and large-scale – that’s where the innovation is.”

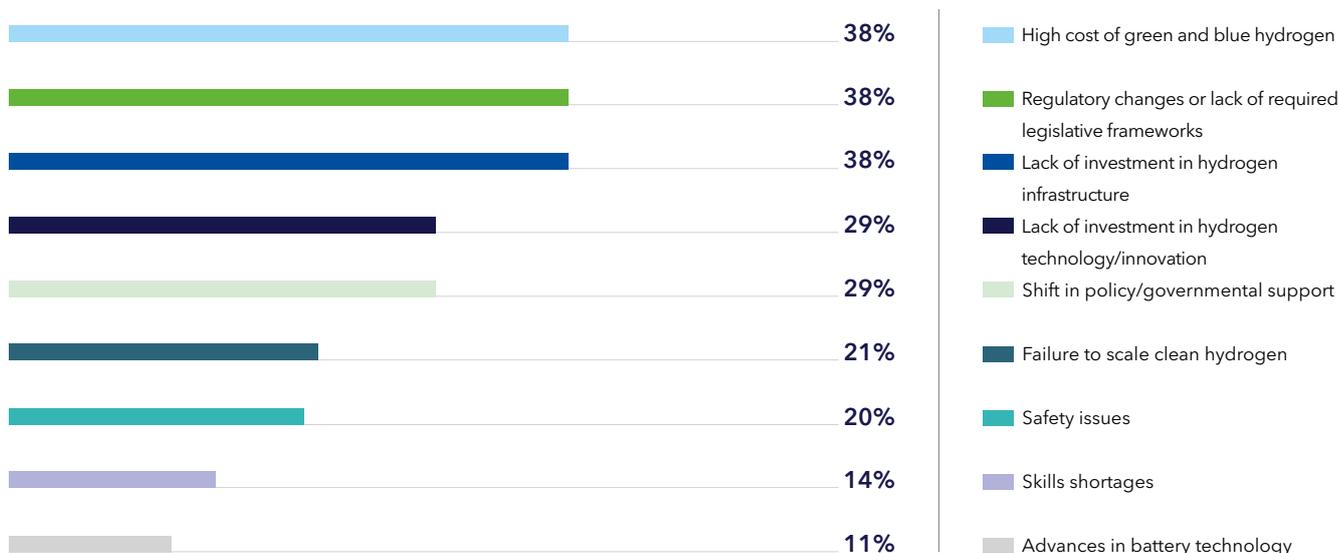
Kristina Wittmeyer, business opportunity manager – hydrogen, at Shell Norway

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Expected challenges and enablers

Respondents are not blind to the significant challenges involved in keeping the hydrogen economy on a rapid-adoption trajectory.

Greatest risks in progressing the hydrogen economy



Some 71% of respondents believe current hydrogen ambitions underestimate the practical limitations and barriers to adoption. Infrastructure and cost are two of the biggest hurdles, while the right regulations are deemed the most powerful enabler, followed by carbon pricing. Proving the safety case will also be key to scaling the hydrogen economy.

Infrastructure and investment to match ambition

Governments and industry are targeting full-scale adoption of hydrogen in many regions and in several domains, ranging from energy storage to consumption in transport, buildings, and industry. This requires the rollout of a diverse range of supporting infrastructure, so that hydrogen can be produced, moved, stored, distributed, and integrated into the wider energy system. Hydrogen infrastructure must be built at large-enough scale, low-enough cost, and fast-enough speed to ensure the hydrogen economy can play a key role in the energy transition.

Without sufficient progress on infrastructure, hydrogen economy participants will face significant barriers; based on our research, this is a major concern. Respondents selected a lack of investment in hydrogen infrastructure (38%) as the joint-highest risk their organizations face in relation to hydrogen. For those currently not invested or involved in hydrogen, a lack of infrastructure is the top reason why they focused elsewhere.

There are lessons the hydrogen industry can draw from the maturation and integration of renewable energy sources over the past ten years, particularly wind and solar power. However, there are major differences, too. “What wind turbines have done is produce electricity in a different way, but the world already runs on electricity,” says Sebastian Koks Andreassen, CEO at Green Hydrogen Systems, a manufacturer of electrolyzers for hydrogen production from renewable electricity. “Green hydrogen is different, because we not only need to find a way to produce it on an industrial scale, but we also need to develop totally new infrastructure in many cases, and that adds an additional dimension.”

Natural-gas distribution networks are, potentially, a partial exception. Although they require significant investment to be repurposed for hydrogen, there is growing confidence that this can be done successfully. DNV is analysing potential opportunities for reusing gas networks in several countries, and these projects are showing that reuse offers substantial cost savings over alternatives. The Gas for Climate consortium has made similar conclusions in its European Hydrogen Backbone research.⁵

Around 78% of respondents in our survey believe that re-purposing existing gas infrastructure will be key to developing a large-scale hydrogen economy. “Our research work is showing that the majority of our assets are indeed capable,” says Antony Green, project director – hydrogen, at National Grid, a British electricity and gas utility. “It has shown us that there are really no showstoppers to re-purposing our natural gas network for hydrogen transmission.”

⁵ The European Hydrogen Backbone vision, Gas for Climate: A Path to 2050: <https://gasforclimate2050.eu/>



HyStreet infrastructure at DNV's Spadeadam Research and Testing facility, playing a vital role in proving the safety case for hydrogen.

Safe systems for hydrogen

Safety will be key to scaling the hydrogen economy. It is the seventh-highest risk for our respondents in a list of factors that could disrupt progress in the hydrogen economy. In turn, globally accepted hydrogen standards and recommended practices - a key aspect of safety management - are the sixth-placed enabler of a successful hydrogen economy.

"Safety has to be front and centre of the hydrogen agenda. We need to demonstrate that what we plan to do is safe, and will remain safe going forwards," says Antony Green.

"A major area for us is to prove our network can carry hydrogen safely, without any additional risk. So, we are constructing a GBP12.7m project at DNV's Spadeadam test site. It will complete a beach-to-meter facility on one site, which will help us prove that the pipework, valves, and safety devices all function properly in a hydrogen world."

Antony Green, Project Director - Hydrogen, at National Grid

For hydrogen to gain broad acceptance and adoption - in domestic settings and for new applications beyond current industrial uses - industry and regulators will need to establish robust safety standards for each specific use case, just as they do for other potentially dangerous substances.

Work is already well under way, perhaps explaining why safety is on the radar of respondents but not among the top risks and enablers. For example, gas-network operators are collaborating to create guidelines for the introduction of hydrogen into natural-gas networks.⁶ Work is also under way to establish safety standards for hydrogen within homes,⁷ determine minimum purity levels,⁸ and explore small-scale, inner-city green hydrogen production.⁹ This represents impressive progress towards wider adoption of hydrogen, but more is needed to assure governments and society at large that it is a safe and viable energy solution.

⁶ 'Industry collaboration supports the integration of renewable electricity by enabling hydrogen addition to natural gas', DNV: <https://bit.ly/2WfGVgv>

⁷ 'Proving the safety case for hydrogen': DNV in Gastech Insights: <https://bit.ly/2Wf5E4j>

⁸ 'DNV delivers a minimum purity standard for the future use of hydrogen in UK homes and businesses', DNV: <https://bit.ly/3d1Yelw>

⁹ 'Heating Dutch homes with hydrogen', DNV: <https://bit.ly/2WfH1on>

Down-scaling costs

While infrastructure needs to scale up, the cost of green and blue hydrogen needs to come down. Currently, low-carbon hydrogen is expensive and failure to find a way to reduce cost is another of the top risks identified by our respondents.

“The industry must develop in order to reduce the cost of the entire chain, from production to distribution and consumption, it all depends on commercialization to decrease costs.”

Yuan Zhengang, director of New Energy Research Center of CPPEI (a think tank of CNPC)

“In the early stages when the costs are high, enterprises have to follow long-term strategies and implement plans that may lack profits. But they will gain market share in the industry, and once hydrogen supply and demand increase, costs will be reduced, and profits will improve,” says Yuan Zhengang, director of New Energy Research Center of CPPEI (a think tank of CNPC), China’s state-owned oil and gas corporation.

For costs to come down smoothly, hydrogen supply and demand need to dance to the same rhythm, expanding at similar rates, without one leading, or lagging, the steps of the other. “There is an element of demand and supply mechanisms needing to progress and develop in parallel,” says Sebastian Koks Andreassen. “In most markets, apart from regulation and policies, this is really about maturing the demand side, where a significant amount of infrastructure investment is required to allow the society to start running on green hydrogen.”

On the supply side, Andreassen points out that electricity from renewables takes up around two-thirds of the total cost of green hydrogen.

“The green hydrogen industry will need not only enough green electricity, but also electricity at lower cost, and we believe that is possible based on forecasts and our analysis.”

Sebastian Koks Andreassen, CEO at Green Hydrogen Systems

Economics by application

Hydrogen is closer to making economic sense in some applications than others. For instance, setting aside the infrastructure, safety, and practical barriers, it will be a long time until the world has the capacity to produce enough green hydrogen to power international shipping fleets.

“To produce enough green hydrogen for the maritime industry with current methods would require several times the total output from all renewable and nuclear energy generated today,” says Sanjay Kuttan. “And that is on top of all the grey/brown hydrogen that needs to be also replaced in applications such as energy, agriculture and industry, coupled with the fact that the renewable electricity cannot be deployed elsewhere across the economy. So without major technical breakthroughs, I cannot see how hydrogen is going to become the primary fuel for the international maritime sector anytime soon.”

It is therefore important that hydrogen is used in applications where it is best-suited, where it has the most potential, and where it makes business sense. But, in addition to the economics of individual applications and the dynamics of a growing market, costs can also be driven by technology innovations and standardization. “For example, one of the biggest variables from a cost perspective is hydrogen compression,” says Antony Green. “The compressors we have currently are expensive, so we need to look at what can be done to reduce that over time and take opportunities to standardize. This is one area where networks can contribute to lowering costs overall.”

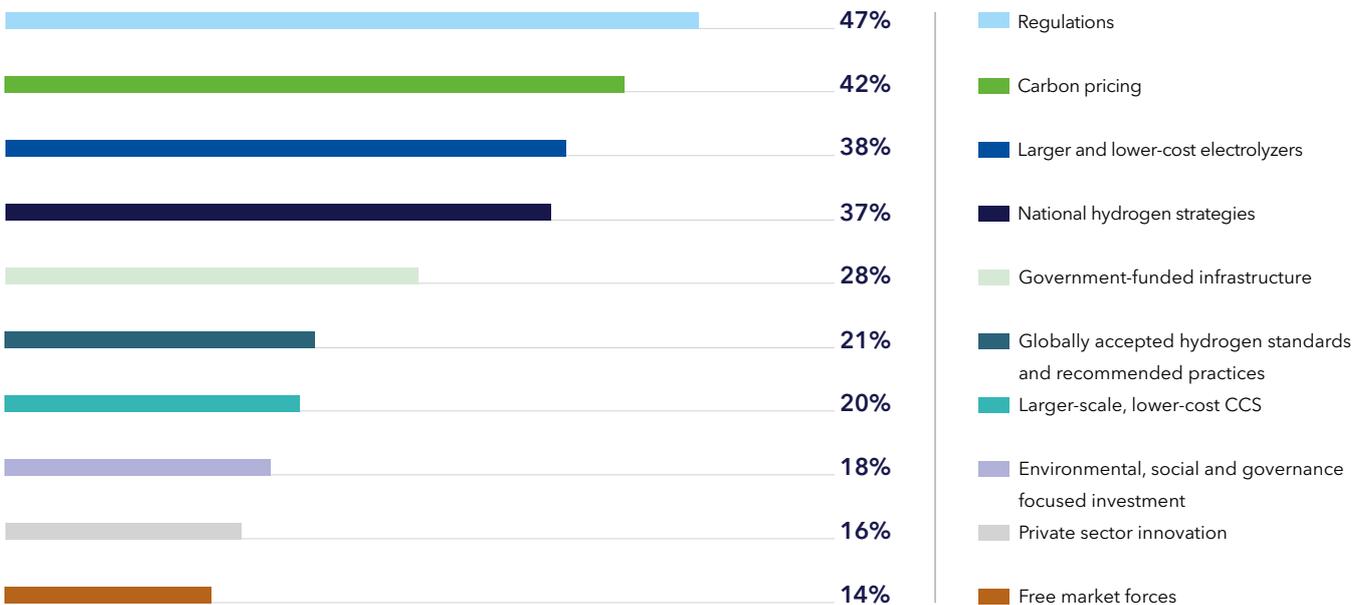
Regulations tip the scale

Regulatory changes, or a lack of required legislative frameworks, are the third of the joint-top risks organizations face in their progress through the hydrogen economy. But regulations can tip the scale in both directions, also coming in as the top choice when we asked respondents which factor would, between now and 2030, be the most important enabler of a successful hydrogen economy.

What the hydrogen economy needs is strong, stable, and supportive regulations. Currently, regulatory regimes could hold back the development of hydrogen - not only regulations that govern hydrogen directly, but also the industries where hydrogen could be used, or the industries that support hydrogen production.

A key example is the regulatory framework for renewable electricity, which can impact the viability of green hydrogen production. “We would like to see more governments evolve their permitting regimes around wind, solar, and electricity,” says Rachel Ruffle. “We are not doing much in England because of limiting planning policy whereas, in Scotland, Ireland, and Wales, height limits prevent us from building the most powerful and efficient systems. So, for example, we are currently building 2MW wind turbines in Scotland, but 6.4MW turbines in Germany and Scandinavia.”

Most important enablers of a hydrogen economy to 2030



Policies to drive the hydrogen economy forward

Regulations often flow directly from government plans and policies. Many countries – including Australia, Canada, Chile, Finland, France, Germany, Japan, Netherlands, Norway, Portugal, the US and South Korea, as well as the European Union (EU) – have plans to grow hydrogen production and/or consumption.¹⁰

“It really helps to have clear policy frameworks that are transparent on long-term goals,” says Kristina Wittmeyer. “The targets that are set, for example, by the EU, provide greater predictability, which helps in commercial decisions that drive investments in hydrogen.”

80%

Say the hydrogen economy needs effective carbon-pricing regulations before it can scale-up

China looks likely to make a major push towards hydrogen adoption in the near future, and this could significantly accelerate the hydrogen economy, given the size of China’s markets, industries, and energy needs.

“In the next one-to-two years, the introduction of hydrogen-related policies will signal the real commencement of hydrogen more broadly in China.”

Yuan Zhengang, director of New Energy Research Center of CPPEI (a think tank of CNPC)

“This could include, for example, a top-level strategy at national level, plus industrial development planning, medium- to long-term planning, and designating hydrogen as a strategic energy,” says Yuan Zhengang of CNPC.

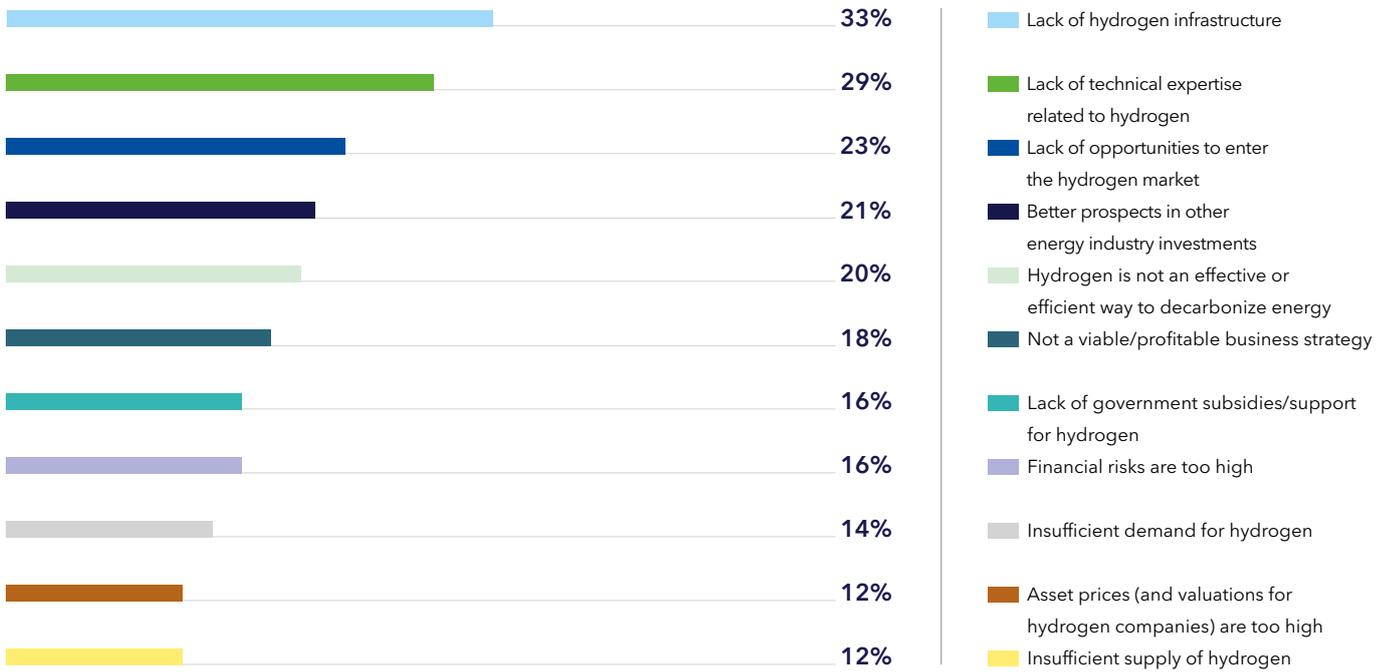
“In 2020, the Chinese government enacted new policies to incentivize hydrogen fuel cell vehicle adoption in several cities. The targets for these cities include lowering the cost of hydrogen, improving technologies, and increasing the network of hydrogen refueling stations. In terms of the public transportation sector or commercial vehicle market, China has incomparable advantages in driving the industry forward due to its large-scale population and urban agglomeration network, when compared to many other countries,” says Yuan Zhengang.

¹⁰Countries Roll Out Green Hydrogen Strategies, Electrolyzer Targets, Power Magazine: <https://bit.ly/3hbsLHM> &

US Department of Energy releases Hydrogen Program Plan, electrive.com: <https://bit.ly/3h24h4Y>

¹¹China pushes hydrogen energy to achieve carbon goals, Nikkei Asia: <https://s.nikkei.com/3A4ycRi>

Top reasons why some organizations are not investing in or getting involved in hydrogen



Why not hydrogen?

Of those who took DNV's survey who are not involved in hydrogen, 1 in 5 says it is not an effective or efficient way to decarbonize energy, while 18% of those not pursuing hydrogen say that the reason is that hydrogen is not a viable/profitable business strategy for them. However, the top reason given for not pursuing hydrogen is the lack of hydrogen infrastructure, followed by a lack of technical expertise.

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Challenging questions

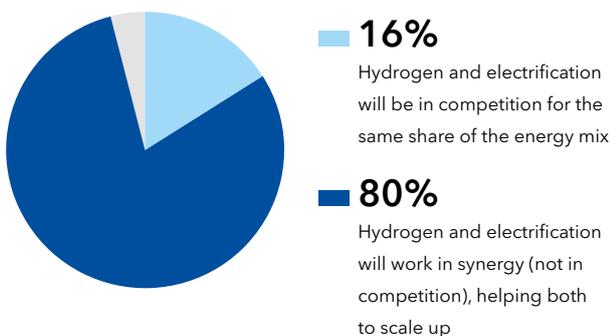
Energy transitions take decades, and there are still many open questions, uncertainties, and unresolved debates about the future hydrogen economy.

Many of these questions are critically important, but others can be counterproductive. For example, in decarbonizing transport and industry, most projections conclude that this will require both hydrogen and greater electrification, depending on the application, location, and numerous industry-specific considerations.¹²

“You have people at the opposite extremes arguing for electrifying everything or using hydrogen for everything,” says Antony Green. “Actually, both have a role and support one another in a whole systems approach. We need to stop wasting effort arguing about extremes and focus on the middle ground. Ultimately, the market will decide where electrification is best and where hydrogen is best, but both are important if we are to hit our 2050 targets.”

Our respondents agree, with 80% saying that hydrogen and electrification will work in synergy, helping both to scale up; just 16% believe hydrogen and electrification will be in competition for the same share of the energy mix.

The view on hydrogen and electrification, by 2030



*The balance of respondents selected “Don’t know” or “Not applicable”.

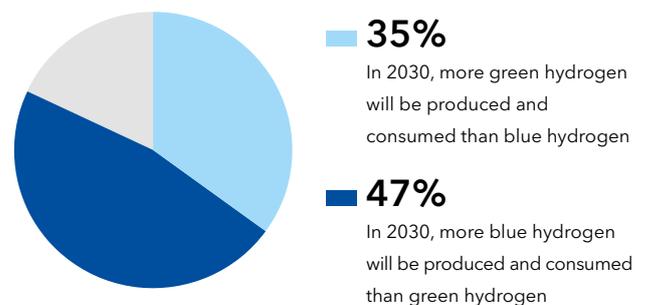
The role of blue hydrogen

The debate over the relative merits of green and blue hydrogen is similarly unproductive at times, but it is not as clear cut.

While green hydrogen production is commonly regarded as the ultimate aim, DNV’s *Energy Transition Outlook* forecasts that blue hydrogen will be key to scaling the hydrogen economy, with 85% of hydrogen used as an energy carrier in 2030 being blue. Green hydrogen production will ramp up from 2035 and grow at a faster pace than blue hydrogen in the 2040s. The cost of electrolyzers and renewable energy is expected to fall over the next decade, making green hydrogen more viable. In contrast, blue hydrogen has lower production costs and may have an equally low carbon footprint as green hydrogen, when lifecycle emissions of solar panels, wind farms, and natural-gas production are considered. We forecast a roughly 50/50 split between blue and green hydrogen in 2050.

The majority of our respondents (77%) believe that both blue and green hydrogen need to work in synergy to scale the hydrogen economy successfully, but how the market will be divided is uncertain. By 2030, just under half believe that more blue hydrogen will be produced and consumed than green hydrogen, while 35% have the opposite view. The numbers are closer in the electricity industry, leaning marginally towards green (42% to 40%). In the oil and gas industry - the primary developer of blue hydrogen - more respondents expect blue (53%) to have the greater market share in 2030 than green (29%). This is despite the fact that far more of our respondents are involved in green hydrogen (56%) than blue (26%). The reason for this is that blue hydrogen, once mature, will likely see higher volumes of production per organization (or per project) than green hydrogen.

The view on green and blue hydrogen, by 2030



*The balance of respondents selected “Don’t know” or “Not applicable”.

¹² Net Zero by 2050: A Roadmap for the Global Energy Sector, IEA: <https://www.iea.org/reports/net-zero-by-2050>

Will hydrogen globalize?

Respondents to our survey are divided on whether hydrogen trade will become a fully globalized market (42%), like liquefied natural gas (LNG) for example, or whether it will be more of a patchwork of regional markets without significant import/export trade and intercontinental transport (52%).

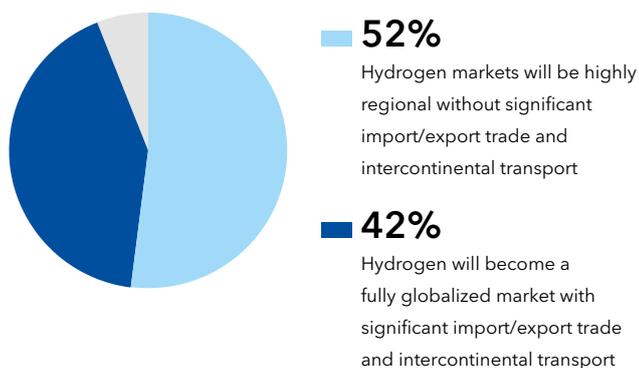
Blue hydrogen will likely be created at or near existing oil and gas refineries, which are often located close to other industrial sectors that may become blue hydrogen consumers. They are also often located near ports, and so long-distance trade could be a natural move.

Green hydrogen can be produced at or near shipping hubs, particularly when powered by offshore wind. However, renewable electricity can also be transmitted to locations of hydrogen demand, where electrolyzers could then produce hydrogen close to where it is needed.

“At some point, the electricity source and the electrolysis that makes green hydrogen, need to be coupled,” says Sebastian Koks Andreassen, “and that does create a geographical aspect. Hydrogen can become a global market with long-distance trade, but clearly transport costs are always a factor, and so often there will be good reason to produce and use hydrogen closer to the source of renewable electricity.”

The need for long-distance green hydrogen trade is driven by cases where large quantities of renewable electricity can be generated in places that are far from areas of high demand, and, conversely, areas of high demand that do not have access to sufficient renewable electricity to produce green hydrogen locally. Australia and Japan have these respective attributes, a fact that has driven the development of a large-scale hydrogen trade pilot project between the two nations.¹³

The view on regional vs global hydrogen markets, by 2030



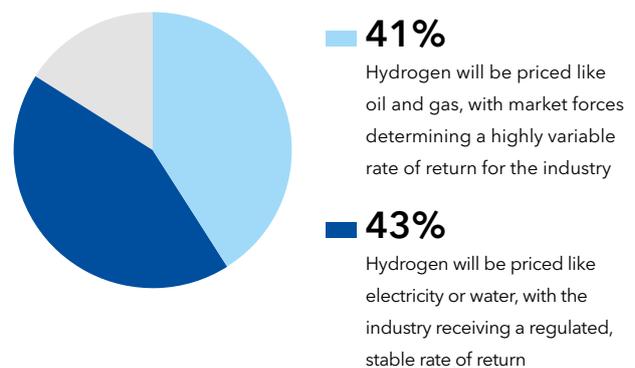
*The balance of respondents selected “Don’t know” or “Not applicable”.

Will hydrogen be priced like oil and gas?

As mentioned above, hydrogen has a unique mix of attributes that give it similarities to electricity and to a fossil fuel. Electricity prices are often governed by regulatory bodies, which serve to protect consumers and guarantee a stable rate of return for providers. Many fossil-fuel prices are driven by free-market forces, which makes them more volatile. So, how will hydrogen be priced once the market matures?

Overall, our survey respondents are neatly divided, with 41% anticipating it will be driven by market forces, and 43% expecting a regulated rate of return. In some groups, there are clearer expectations. For example, greater numbers of electricity-industry respondents expect regulated prices (50%), rather than market-driven prices (40%). The opposite is true among North American respondents, where more expect market-driven prices (57%) than regulated prices (33%), in keeping with the region’s general leaning towards free-market economics.

The view on hydrogen pricing models, by 2030



*The balance of respondents selected “Don’t know” or “Not applicable”.

¹³Hydrogen Energy Supply Chain Pilot Project, Australian Government, Department of Industry, Science, Energy and Resources: <https://bit.ly/2TdBOrt>

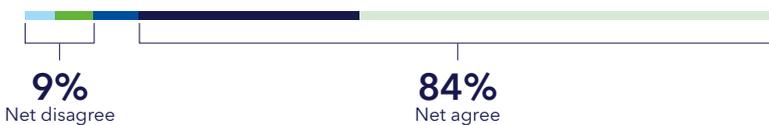


Are hydrogen targets achievable?

How confident are you that your organization and/or government will meet the hydrogen energy targets it has set? Around 43% of our respondents believe that the majority of national and organizational hydrogen goals are realistic. This might appear quite high, considering how ambitious some of those targets are, and the challenges involved in overcoming the barriers to progress.

For example, the EU hydrogen strategy targets green hydrogen production that is 10 times the level DNV forecasts in its *Energy Transition Outlook*. But just 12% had high conviction (selecting “strongly agree”) and so there is understandable uncertainty among those that lean towards the goals being realistic and achievable. Close to one-quarter (24%) are neutral or unsure, which leaves one-third (33%) who are sceptical enough to moderately (22%) or strongly (11%) disagree that targets are realistic and achievable.

Hydrogen has the potential to be a major component of a global, low-carbon, energy system



The majority of national and organizational hydrogen goals are realistic and achievable



Current hydrogen ambitions tend to underestimate the practical limitations and barriers



- Strongly disagree
- Moderately disagree
- Neither agree nor disagree
- Moderately agree
- Strongly agree
- Not applicable/don't know

Fast-tracking the hydrogen economy

Meeting the targets of the Paris Agreement

To meet the targets of the Paris Agreement, the world needs to transition to a deeply decarbonized energy system. In addition to energy efficiency gains, this will require greater renewable power generation and electrification, and the scaling of technologies to remove the carbon from fossil fuels. There's recognition that hydrogen will be needed to connect and enable these paths, but doubts remain around how quickly hydrogen can scale to enable them.

73%

Say Paris Agreement targets will not be achievable without a large-scale hydrogen economy

Ambitions and the needed rate of change in the hydrogen economy are sky-high, leading some to question whether hydrogen goals are realistic. Just a year ago, in DNV's report *Heading for Hydrogen*, we wrote that the challenge for the hydrogen economy is not in the ambition, but in changing the timeline, from hydrogen on the horizon to hydrogen in our homes, businesses, and transport systems. This remains the case, but it is a challenge to which governments and industry are increasingly rising. By 2025, almost half of the energy professionals we surveyed expect hydrogen to account for 10% of their company's revenue/spending.

That represents a significant role for hydrogen, much sooner than many anticipated. It also signals the emergence of a full-scale hydrogen economy, which governments and industry are fast-tracking to play a key role in bringing about deep decarbonization.



Survey details

Respondents from across the hydrogen economy

This survey was aimed primarily at energy professionals who have either shown interest in, or who work in sectors that are likely to play a role in, the hydrogen economy.

The focus of the research is to show the outlook from across organizations that will mature into a defined hydrogen industry, rather than to analyse hydrogen within different sectors. However, other DNV research targeted at existing industry niches (e.g., oil and gas) has tracked growing ambitions around hydrogen over recent years.¹⁴

Nature of interest, involvement or investment in hydrogen*	
Hydrogen production	37%
Hydrogen distribution	29%
Hydrogen consumption	27%
Hydrogen energy storage	33%
Technology, engineering or infrastructure/facility development	55%
Financing and/or investing in hydrogen projects	23%
Regulation, governance, or industry association	26%

*Respondents could select all applicable answers.

Around a quarter of respondents (27%) are from organizations with revenues in excess of US\$1bn, while a third (33%) are from organizations with revenues of US\$100m or less.

¹⁴Turmoil and Transformation: The Outlook for the Oil and Gas Industry in 2021: <https://industryoutlook.dnv.com/2021>



ABOUT DNV

DNV is an independent assurance and risk management provider, operating in more than 100 countries, with the purpose of safeguarding life, property, and the environment. As a trusted voice for many of the world's most successful organizations, we help seize opportunities and tackle the risks arising from global transformations. We use our broad experience and deep expertise to advance safety and sustainable performance, set industry standards, and inspire and invent solutions.

In the energy industry

We provide assurance to the entire energy value chain through our advisory, monitoring, verification, and certification services. As the world's leading resource of independent energy experts and technical advisors, we help industries and governments to navigate the many complex, interrelated transitions taking place globally and regionally, in the energy industry. We are committed to realizing the goals of the Paris Agreement, and support our customers to transition faster to a deeply decarbonized energy system.

Disclaimer

All information is correct to the best of our knowledge. Contributions by external authors do not necessarily reflect the views of the editors and DNV AS.

DNV

NO-1322 Hovik,
Norway
Tel 47 67 57 00
www.dnvgl.com