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# Green hydrogen:
# Energizing the path to net zero

## Summary of Deloitte's 2023 global green hydrogen outlook

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**The green energy transition is gathering momentum, with government and industry worldwide looking to address climate change while bolstering global energy security. Private companies, research institutions, regulators, financiers, and governments are working to decarbonize organizations, supply chains, sectors, and indeed, economies.**

While the greatest energy mix switch will be toward electricity from renewable sources, a portion of sectors cannot electrify easily (hard-to-abate sectors). In the context of the timeframe for the world to achieve net-zero, hydrogen, and in particular green hydrogen, gains significant currency and could redraw the global energy and resource map as early as 2030.

The introduction and growth of green hydrogen—produced from renewable electricity via electrolysis—can change the global energy mix, helping transform economies' very production systems. Indeed, it can unlock new sources of value and lay out a growth path for sustainable economic development.

Leveraging a data-driven and model-based quantitative analysis, Deloitte's Green hydrogen: Energizing the path to net zero report lays out a comprehensive analysis of the development of clean hydrogen to energize the global economy toward net-zero. This outlook relies on Deloitte's Hydrogen Pathway Explorer (HyPE) model and proposes a vision for a fast-tracked development of the clean hydrogen economy, highlighting the associated challenges and bottlenecks.

This report is not a prediction—rather, it is a plausible scenario of how this new energy transition could unfold based on the latest credible data, assessments, and regulatory and policy developments.

And with the window for meaningful climate action narrowing, it is critical that governments, executives, researchers, and others take a close look at the role of hydrogen in the energy transition—and to the all-important effort to reach climate neutrality.

# The critical role of clean hydrogen on the way to climate neutrality

While leaders worldwide are moving to shift supply chains and economies toward net-zero, with a growing understanding of the energy transition as a necessary condition for growth and sustainable development, debate continues around the pace and scale of change across industries and nation-states. But few dispute that aligning economies with the targets laid out in the Paris Agreement—limiting global warming to well below 2°C, while pursuing efforts to limit the increase to 1.5°C[1]—requires replacing legacy systems powered by fossil fuels with low-carbon energy sources such as renewables.

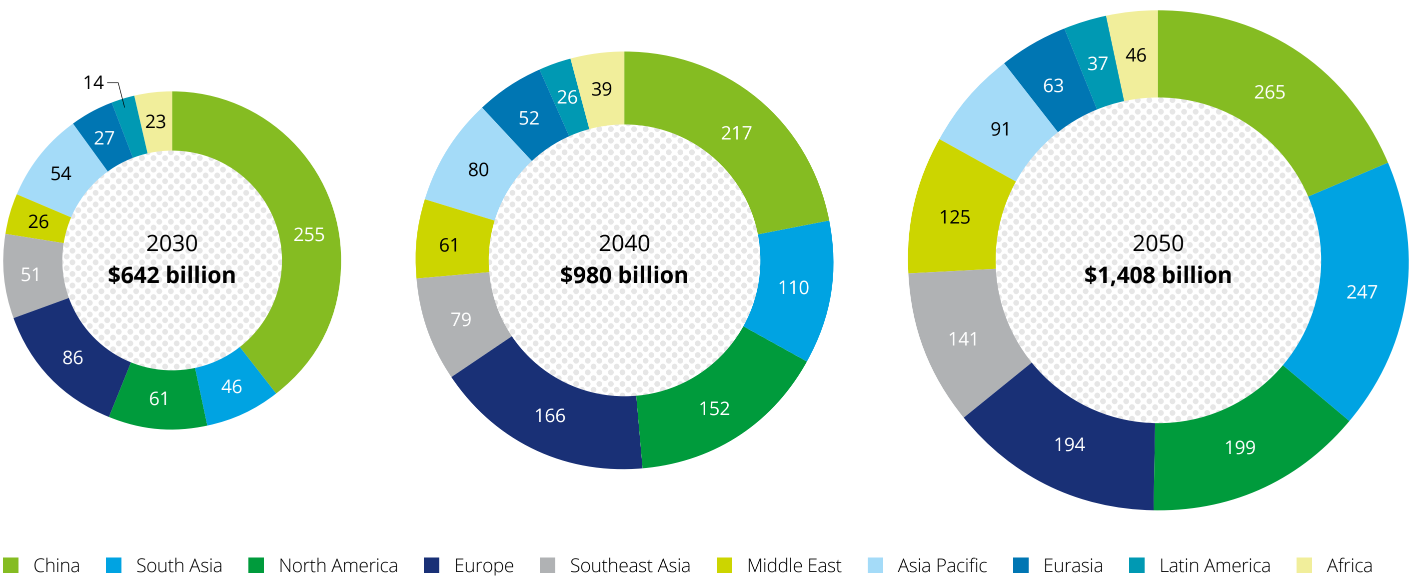
Again, while electrification, leveraging low-carbon technology solutions, appears as an essential solution, it faces real barriers, particularly when it comes to decarbonizing hard-to-abate sectors such as heavy industry and transport. Activities such as high-temperature heating, feedstock supply for chemicals, or heavy-duty freight are indeed hard to fully electrify. Besides, if wind and solar power continue to expand as prices fall, network stabilization issues can arise, with power grids needing to take into account their variability.

Clean hydrogen is now clearly recognized as a potential breakthrough technology to overcome these limits,[2] and can play a major role across the full scope of the global energy transition. It is a versatile molecule[3] which can be used directly via fuel cells or for electricity generation, and as feedstock to produce more suitable derivatives—such as ammonia, methanol, or sustainable aviation fuels (SAF)—to specific industrial and transport applications.

Hydrogen supply currently relies almost entirely on natural gas reforming and coal gasification, which are highly carbon-intensive (more than 1 Gt of annual $CO_2$ emissions). The real breakthrough is the potential of clean hydrogen to decarbonize current supply and develop new end uses at scale.[4] Green hydrogen, produced from renewable electricity via electrolysis, is the most promising and truly sustainable technology. Blue hydrogen, produced via natural gas coupled with carbon capture and storage, can also be labeled "clean" provided it meets stringent methane emissions and carbon capture standards.

The significance of this analysis—which showcases a steady market growth, from US$642 billion in annual revenue in 2030 to US$1.4 trillion per year in 2050, in which green hydrogen comprises some 85% of the hydrogen market, with 20% traded around the world—is twofold: First, this trade is critical to the lowest-cost decarbonization of the world economy; second, the production and export of green hydrogen offers a global sustainable development realignment for developing and emerging economies across Africa, Latin America, and the Pacific, alongside countries such as Australia and the United States and regions such as the Gulf States.  Inclusive trade can spur economic development by supporting local activity, improving trade balance, and facilitating the global energy transition. Deloitte's analysis suggests that the clean hydrogen economy could support up to one million new jobs per year by 2030, and double that pace over the following two decades (out of which 1.5 million jobs per year could be supported in developing countries).

**Figure 1. Clean hydrogen market size (US$ billion per year), 2030 to 2050.**




Source: Deloitte analysis based on the HyPE model.

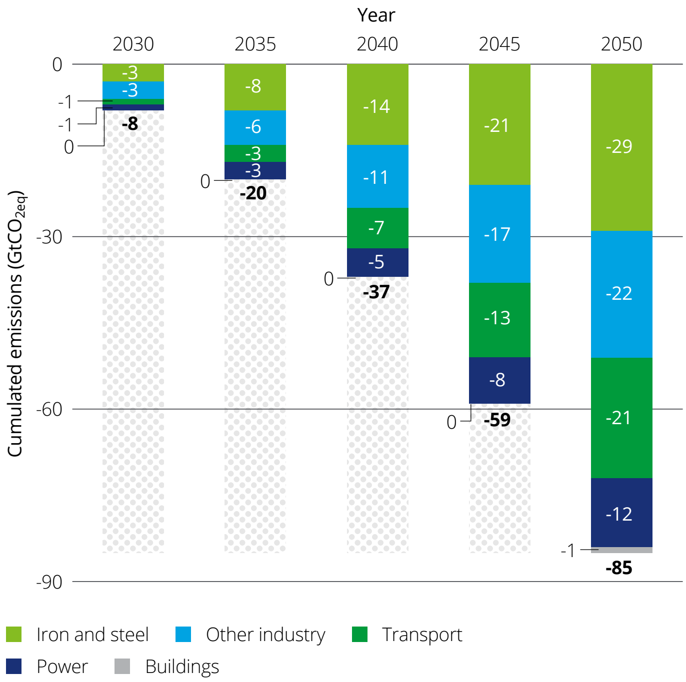
# The emerging green hydrogen economy: Deloitte's outlook

To achieve climate neutrality by 2050, the clean hydrogen market capacity can grow to 170 million tons ($MtH_{2eq}$) in 2030 and to 600 $MtH_{2eq}$ in 2050. Demand is expected to initially build on the decarbonization of existing industrial uses of hydrogen (95 $MtH_{2eq}$), most notably for fertilizer production.[5] The net-zero transition then underpins rapid demand growth, cementing hydrogen's role as a versatile solution for decarbonization. By 2050, industry (iron and steel, chemicals, cement, and high-temperature heating) and transport (aviation, shipping, and heavy road transport) respectively can account for 42% and 36% of total clean hydrogen demand. Overall, this outlook shows clean hydrogen delivering crucial carbon emission reductions. Decarbonizing current and developing new end-uses, it can abate up to 85 $GtCO_{2eq}$ in cumulative emissions by 2050, more than twice global $CO_2$ emissions in 2021.

While demand is expected to quickly ramp up in industrialized economies, clean hydrogen can also represent a major sustainable growth opportunity for developing countries, leading to the progressive structuring of a truly global market. Yet, materializing a new major industry within less than three decades presents an unprecedented challenge along the still-nascent value chain.

Projects initially depend on public support to break even, as illustrated by the first major government programs such as the United States Inflation Reduction Act, the Australian Clean Energy Finance Corp., the European Union Fit-for-55 package and Important Projects of Common European Interest (IPCEI) a funding program, and Japanese demand-side research and development (R&D) support programs. Indeed, the production cost of conventional carbon-intensive hydrogen does not sufficiently reflect its impact on climate. Government's support may be needed until clean, and especially green hydrogen catches up in terms of costs, leveraging on economies of scale and tightening $CO_2$ pricing. The breakeven point can be reached by 2030 for ammonia, 2035 for gaseous hydrogen, 2045 for methanol, and 2050 for SAF. Therefore, with time, green hydrogen can stand on its own feet. By 2050, the global hydrogen market can reach maturity as supply capacities massively scale up to meet the demand, underpinned by new end uses in industry and transport. The market growth is expected to allow spot markets to dominate price formation, improving resilience and channeling investments to the most competitive geographical areas.

**Figure 2. Greenhouse gas emissions abatement unlocked by clean hydrogen, 2030 to 2050.**




Source: Deloitte analysis

Deloitte's modeling results show that green hydrogen can dominate the supply mix from the beginning, reaching 85% of market share in 2050 (above 500 $MtH_{2eq}$). Blue hydrogen can help to build up demand in the early stages, facilitating the emergence of the hydrogen economy in regions that can leverage natural gas reserves such as the Middle East, North Africa, North America, and Australia. Production peaks in 2040 at almost 125 $MtH_{2eq}$ (30% of supply), after which blue hydrogen is set to gradually be crowded out by more competitive green hydrogen and tightening environmental constraints on unabated methane and $CO_2$ emissions.

# Global trade connects the dots

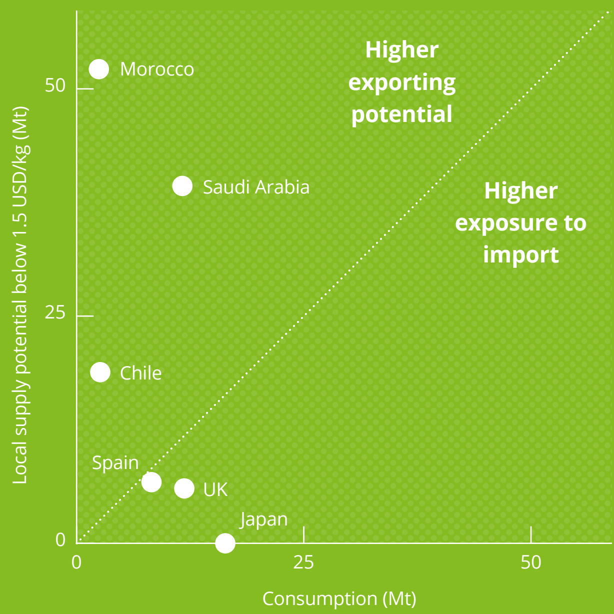
Throughout this outlook, global trade between major regions can represent almost one-fifth of total volume, reaching about 110 $MtH_{2eq}$ in 2050. The most common products are hydrogen derivatives—ammonia, methanol, and SAF—which are easier to transport over long distances. Ammonia also can become a medium for transporting hydrogen, implying conversion and re-conversion steps. By 2050, four regions collectively account for about 45% of global hydrogen production and 90% of trade: North Africa and Australia have the highest export potential (44 $MtH_{2eq}$ and 16 $MtH_{2eq}$ respectively) compared to their domestic demand. They are followed by North America (24 $MtH_{2eq}$) and the Middle East (13 $MtH_{2eq}$). South America and sub-Saharan Africa can also actively take part in global trade, with some 10% of traded volumes. On the import side, Japan and Korea facing resource and land availability constraints, can heavily depend on global trade, importing 90% of their demand between 2030 and 2050. Europe, China, and India can produce substantial amounts of hydrogen but also are like to rely on imports throughout the transition.

In 2050, global trade between major regions can generate more than US$280 billion in annual export revenues in 2050. The main recipients include North Africa (US$110 billion per year), North America (US$63 billion), Australia (US$39 billion), and the Middle East (US$20 billion). Free and diversified trade can significantly reduce costs, improve energy security, and foster economic development in developing and emerging markets. Export revenues from clean hydrogen can help today's fossil fuel exporters offset declining revenue from oil, natural gas, and coal.

Interregional trade can help reduce the geographic mismatch between demand and low-cost supply. Some of the largest demand centers (primarily European countries, Japan, and South Korea) may not be in a position to produce low-cost hydrogen in sufficient quantities to fully meet demand. By contrast, regions with high renewable endowment and ample land availability—such as Australia and parts of Africa and Latin America—could likely produce cost-competitive green hydrogen in quantities that exceed domestic needs. Trade opportunities and associated cost savings naturally arise from such discrepancies, and several countries (including, Australia, Chile, Germany, and Japan) could position themselves as future hydrogen importers or exporters. Several partnerships or memorandums of understanding have already been signed to harness the Global South's renewable energy potential.[6] A diversified transport infrastructure can be key to help facilitate global trade.

## Identifying potential green hydrogen importers and exporters

The diversity of renewable energy endowments and land availability across countries can create significant differences in achievable green hydrogen production costs and quantities. A country's consumption profile depends on population size, industrial structure, and economic development, with international trade shaped by divergences in consumption profiles and production potentials. Supply-constrained countries can attempt to lower their procurement cost by procuring all or part of their needs from international markets; countries with ample low-cost production potential may seek to maximize revenues through exports.




Source: Deloitte analysis

As illustrated in this figure, Chile, Morocco, Saudi Arabia, Spain, the United Kingdom, and Japan occupy different positions on the importer-exporter spectrum.

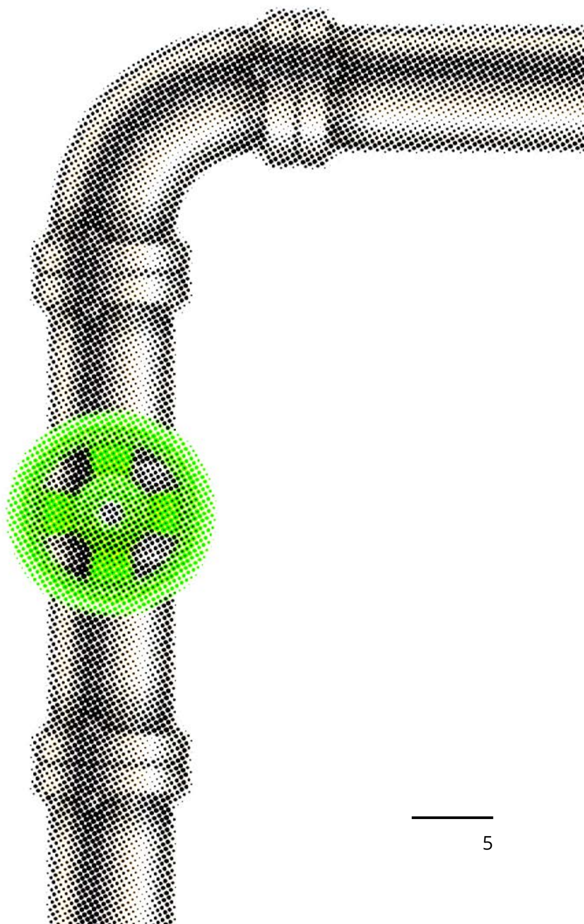
- Northern **Chile** has some of the world's highest solar irradiation levels, boosting the country's export potential for renewable energy.
- **Morocco** has access to outstanding solar and wind resources, which is compatible with a highly competitive large-scale production industry leveraging its proximity to the European Union.

- **Saudi Arabia** benefits from high solar irradiation and abundant available land. Deloitte's outlook shows the country producing 39 Mt of low-cost green hydrogen in 2050, four times its domestic demand. The country is already involved in several international trade agreements to export green hydrogen, which could be one of the building blocks of its strategy to diversify its economy away from petroleum.[7]
- **Spain's** high level of solar exposure makes it one of the best European candidates for green hydrogen production; the country could be close to self-sufficiency in 2050. Yet, Spain can expect significant volumes of imports due to its geographical position as a gateway to proximate demand clusters—notably Germany—minimizing transport costs by leveraging its pipeline connection to Morocco and the pan-European transport infrastructure, including a $2.6 billion Barcelona-Marseille hydrogen pipeline announced in December 2022.[8]
- The **United Kingdom** can count on significant wind power endowment and can mobilize its full competitive potential, producing some 7.5 Mt of green hydrogen based on Deloitte's outlook. Yet, as updates to the UK Hydrogen Strategy suggest, the forecasted strong increase in demand[9] in the 2030s (reaching up to 12 Mt by 2050 in Deloitte's outlook) is likely to prompt imports.
- **Japan** may be constrained by a combination of limited renewable energy potentials and high population density along its coastlines, with high economic industrialization boosting domestic demand levels. In Deloitte's outlook, Japan is one of the primary importing countries.

It is worth mentioning that additional constraints apply for large countries such as the United States and China. Notably, the remoteness of some available land suited for production (for example, desert areas) from consumption or export hubs could entail a high transport cost—and a technical challenge to deploy internal transport infrastructure over long distances—therefore limiting the potential for competitive supply.

# Redirecting investments from fossil fuels to clean hydrogen

Creating the pathway to net-zero compliance in 2050 as it is materialized in this outlook is estimated to require over US$9 trillion of cumulative investments in the global hydrogen supply chain, including US$3.1 trillion in developing economies. The figures may sound daunting, but average annual investments over this 25-year period, are actually less than the US$417 billion spent on oil and gas production in 2022. If governments and companies can redirect spending on oil and gas to clean hydrogen, this seems to be a manageable endeavor. Deloitte's outlook suggests that China, Europe, and North America—the main consuming regions, also accounting for more than half of production—invest US$2 trillion, US$1.2 trillion, and US$1 trillion, respectively. Significant funding should also be raised in developing and emerging economies, including about US$900 billion in North Africa, US$400 billion in South America, and US$300 billion each in Sub-Saharan Africa and Central America. In these regions, the development of the green hydrogen economy can be a unique opportunity to attract foreign investment.



# Future-focused policy action

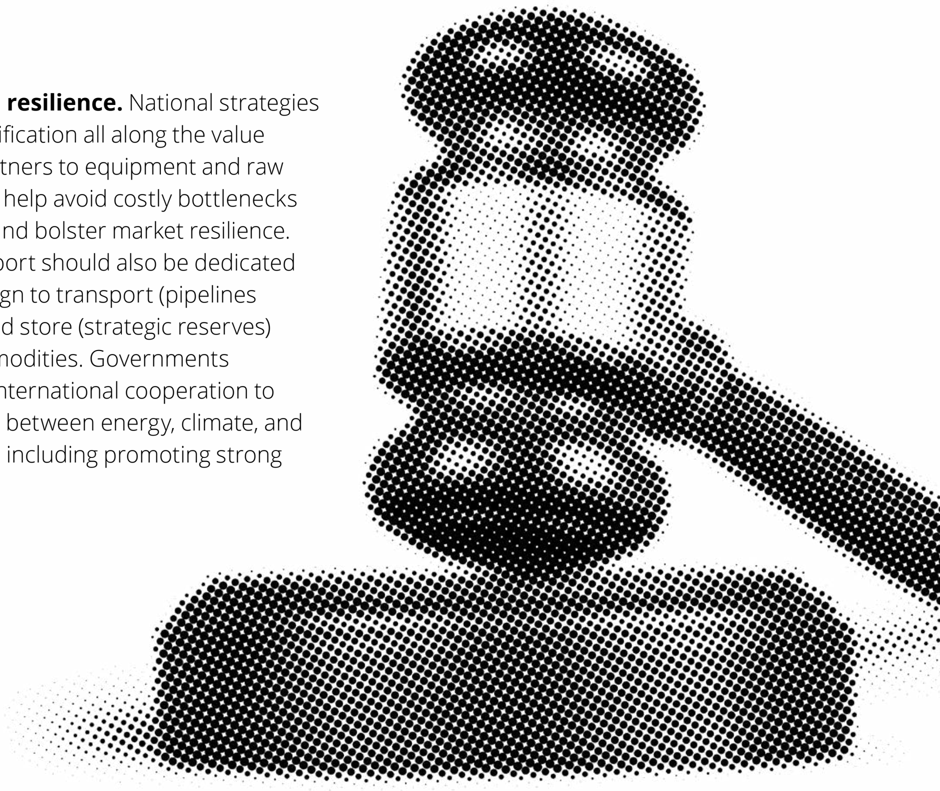
**Decisive policy support can help to scale up the clean hydrogen economy and ensure that, especially, green hydrogen plays its needed role on the path to climate neutrality. To date, more than 140 countries (collectively responsible for 88% of global $CO_2$ emissions[10]) have adopted net-zero targets. However, clean hydrogen projects announced worldwide would provide a collective production capacity of only 44 $MtH_{2eq}$ by 2030, one-quarter of this demand scenario. Targeted policy support for clean hydrogen may be crucial to help ensure that early projects, such as pilot and head of series, can compete on a level playing field, enter the market, and trigger economies of scale.**

**Policymakers should focus attention on three components:**

**Laying the foundations for a climate-oriented market.** Policymakers can lay out national and regional strategies to boost the visibility and credibility of development prospects. A robust and shared certification process for clean hydrogen can ensure transparency and avoid technological lock-ins. International cooperation is a critical piece to help mitigate political friction and ensure a level playing field.

**Creating a business case.** Policymakers can use targeted instruments (for example, mandates, direct subsidies, Carbon Contracts for Difference, fiscal incentives, public guarantees, and creating targets or markets for hydrogen-based products) to reduce the cost difference between clean and fossil-based technologies. Long-term offtake mechanisms, such as Germany's H2Global project,[11] can substantially mitigate project risks, bridge the gap between price and willingness to pay, and strengthen price stability.

**Ensuring long-term resilience.** National strategies should aim for diversification all along the value chain, from trade partners to equipment and raw material suppliers, to help avoid costly bottlenecks during the ramp-up and bolster market resilience. Extensive public support should also be dedicated to infrastructure design to transport (pipelines and marine roads) and store (strategic reserves) clean hydrogen commodities. Governments should aim to strike international cooperation to strengthen synergies between energy, climate, and development policies including promoting strong regional integration.



**The emergence of a clean hydrogen market comes with opportunities and challenges at each stage of the value chain. Achieving carbon neutrality entails not only decarbonizing the current hydrogen supply but scaling it more than sixfold to help cover the new uses essential to the energy transition. This would demand an unprecedented ramping up of technological development (fuel cells, direct reduction for iron and steelmaking, and sustainable aviation fuels), manufacturing capabilities (electrolyzers, solar panels, and wind turbines), and infrastructure (production, transport, and storage facilities) while building new supply chains and establishing a global hydrogen trade.[12]**

Large uncertainties remain on which pathway the global value chain follows,[13] depending on choices of supply technologies and associated leadership, production and consumption locations and resulting energy trade routes, and hydrogen applications. These decisions could create conflicts between the various stakeholders in the hydrogen economy, such as governments (energy security and industrial policy), energy suppliers and utilities, equipment manufacturers, consumers, and transport actors (shipping companies and port facility managers).

But the target remains firm: the emergence of a carbon-neutral, inclusive clean hydrogen economy in the years leading up to 2050. Deloitte's outlook is based on the paradigm that the global economy reaches carbon neutrality by the middle of this century, with governments and companies proactively tackling financial and geopolitical matters, allowing free clean hydrogen trade to unfold in a diversified way, with the Global South playing an integral part. Such a level of ambition is likely necessary to help fight global warming without delay while creating fair development opportunities and, with a diversified hydrogen value chain, improving global energy security and reducing the risk of supply chain disruption.[14]

**Download the full report [for further insights](#).**

# Endnotes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2. Max Bearak, "Inside the global race to turn water into fuel," New York Times, March 11, 2023.
3. Tarek Helmi et al., "Hydrogen: Pathways to decarbonization," Deloitte, 2023.
4. Noam Boussidan, "Everything you need to know about hydrogen in the clean energy transition," World Economic Forum, January 12, 2023.
5. Fabio Bergamin, "Here's how fertilizer could be produced more sustainably," World Economic Forum, January 10, 2023.
6. Japan, Korea, and some European countries (Germany, Belgium, and Netherlands) have been pioneers in establishing bilateral relationships with various developing or emerging markets (e.g., Chile, Morocco, Namibia, South Africa, Tunisia, Uruguay) that were already underway at the end of 2021. This movement continues—for instance, with the signing of an EU-Egypt partnership in November 2022.
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11. H2Global, "H2Global Stiftung," accessed April 5, 2023.
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14. International Renewable Energy Agency in partnership with Ammonia Energy Association, "Innovation outlook: Renewable ammonia."

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