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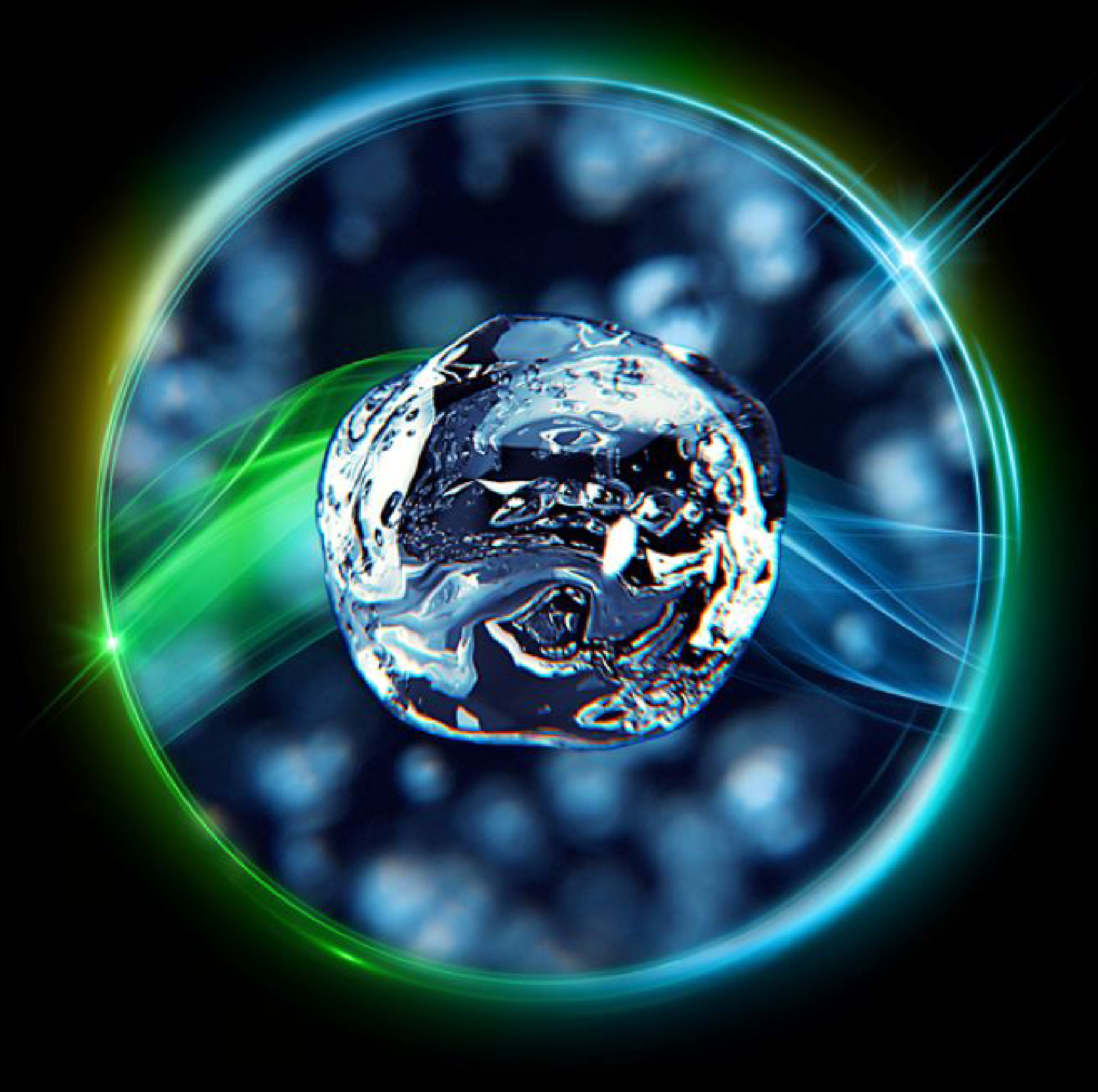


Hydrogen: From discussion to action

Introduction

Presenting practical solutions

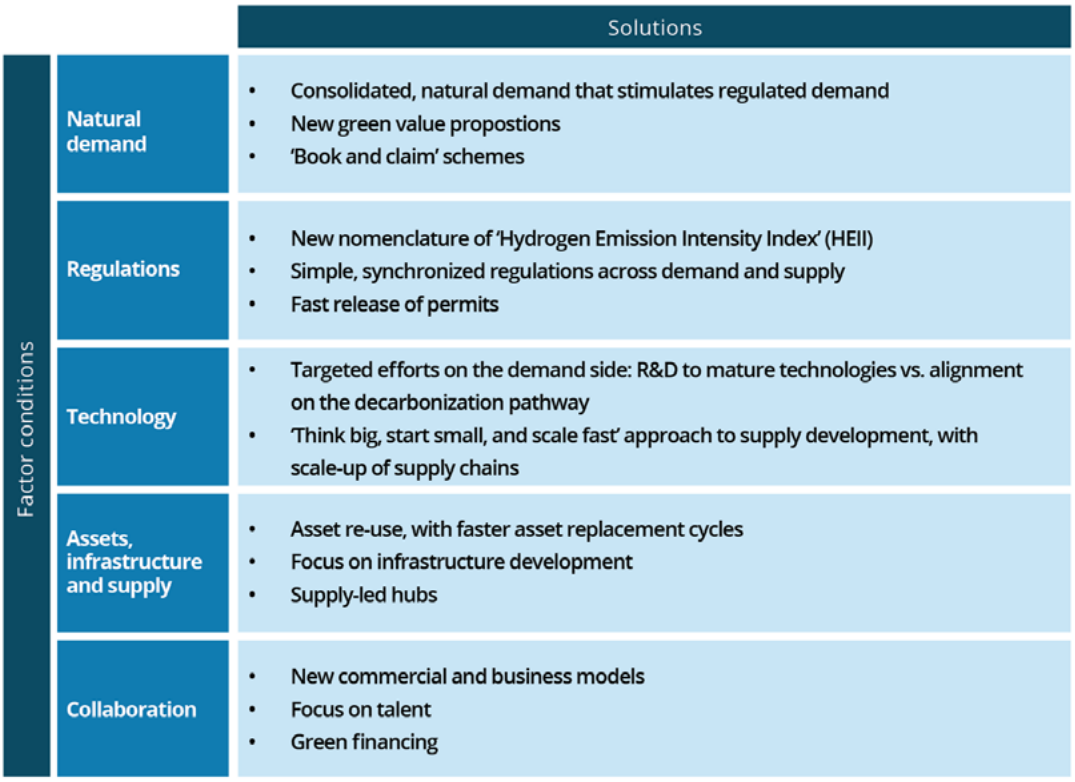
Clean hydrogen can play an important role in the future energy system—particularly in decarbonizing "hard to abate" sectors such as steel, fertilizers, aviation and refining. But how will the development be kick-started?

Despite a lot of talk, there has been little action to date to help accelerate the implementation of hydrogen at scale—and certainly not enough to meet the world's climate ambitions. Deloitte Global seeks to help address this situation by setting out a number of practical solutions that can help activate hydrogen production and demand at scale. Through interviews with over 350 CEOs, executives, and leaders across the private and public sectors, Deloitte Global captured insights on how the market for clean hydrogen could accelerate, by linking demand, production, and distribution. This report first assesses the clean hydrogen landscape, its market potential, and supply momentum before diving deeper into five key factor conditions and associated solutions:

- **Natural demand:** Demand emerging without regulatory support, which in turn could stimulate regulated demand, and help accelerate investment in supply.
- **Regulation:** Access to permits, and simple and synchronized regulation across supply and demand—based on a new emission-intensity certification, such as a Hydrogen Emission Intensity Index (HEII).
- **Technology:** Aligning on the decarbonization technologies to adopt within each sector and maturing them quickly.
- **Assets, infrastructure and supply:** Faster asset cycle changes on the demand side, coupled with infrastructure reuse where possible, plus large-scale investment in renewable capacity, grids, and infrastructure.
- **Collaboration:** Cooperation between parties can be essential for clean hydrogen production, with new business models to help address the systemic challenges that can delay investments.

These proposed solutions (Figure 1) can help kick-start the hydrogen economy, if they are brought together in hubs: geographic areas that can combine low-cost resources for hydrogen production and/or a large enough cluster of industry off-takers; supportive regulations; and a willingness to collaborate on reducing costs, through both economies of scale and reduced infrastructure requirements.

Figure 1: Factor conditions and solutions to activate hydrogen production and demand at scale



Factor conditions	Solutions
Natural demand	• Consolidated, natural demand that stimulates regulated demand • New green value propostions • 'Book and claim' schemes
Regulations	• New nomenclature of 'Hydrogen Emission Intensity Index' (HEII) • Simple, synchronized regulations across demand and supply • Fast release of permits
Technology	• Targeted efforts on the demand side: R&D to mature technologies vs. alignment on the decarbonization pathway • 'Think big, start small, and scale fast' approach to supply development, with scale-up of supply chains
Assets, infrastructure and supply	• Asset re-use, with faster asset replacement cycles • Focus on infrastructure development • Supply-led hubs
Collaboration	• New commercial and business models • Focus on talent • Green financing

Source: Deloitte Global analysis

The current landscape

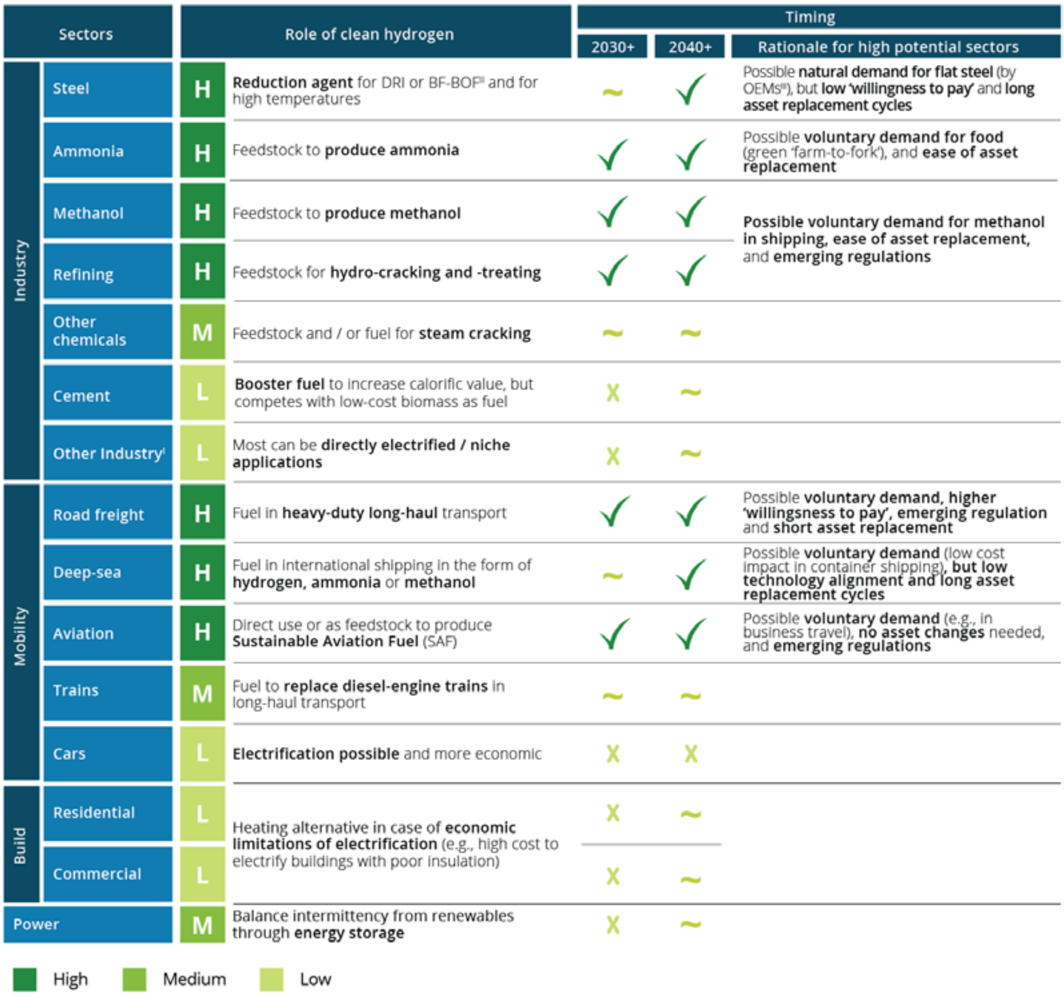
Clean hydrogen potential

By 2030, clean hydrogen is expected to be used in sectors such as methanol, refining, aviation, and road freight, expanding into others such as shipping thereafter.[1]

Molecule-based energy carriers are likely to deliver around 35% of total energy consumption by 2050 in a net-zero scenario.[2] Hydrogen is expected to constitute about one-third of this, equating to about 10% of global energy consumption.[3] Molecular energy carriers can be particularly valuable for decarbonizing hard-to-abate sectors, because they can be used in high-temperature processes, provide a feedstock or reduction agent in industrial processes, offer higher energy density than batteries, and can store the electricity generated from renewables over long periods of time.

The specific potential and timing of clean hydrogen varies by sector (Figure 2). In fertilizer production, for instance, grey hydrogen is already used, so few asset changes may be needed to produce ammonia and methanol using clean hydrogen. Similarly, relatively few process changes will likely be needed in refining, which also uses grey hydrogen currently. Other drivers may include emerging regulations in regions such as the European Union (EU) promoting take-up by 2030 in these sectors, as well as in aviation and road freight. In shipping, although new regulations are being developed, technologies remain immature and the decarbonization pathway unclear, so demand isn't likely to pick up until after 2030.

Figure 2: Clean hydrogen potential and timing per sector



Sectors			Role of clean hydrogen	Timing		
				2030+	2040+	Rationale for high potential sectors
Industry	Steel	H	**Reduction agent** for DRI or BF-BOF[ii] and for high temperatures	~	✓	Possible **natural demand for flat steel** (by OEMs[iii]), but **low 'willingness to pay'** and **long asset replacement cycles**
	Ammonia	H	Feedstock to **produce ammonia**	✓	✓	Possible **voluntary demand for food** (green 'farm-to-fork'), and **ease of asset replacement**
	Methanol	H	Feedstock to **produce methanol**	✓	✓	**Possible voluntary demand for methanol in shipping, ease of asset replacement,** and **emerging regulations**
	Refining	H	Feedstock for **hydro-cracking and -treating**	✓	✓	
	Other chemicals	M	Feedstock and / or fuel for **steam cracking**	~	~	
	Cement	L	**Booster fuel** to increase calorific value, but competes with low-cost biomass as fuel	X	~	
	Other Industry[i]	L	Most can be **directly electrified / niche applications**	X	~	
Mobility	Road freight	H	Fuel in **heavy-duty long-haul** transport	✓	✓	Possible **voluntary demand, higher 'willingsness to pay', emerging regulation** and **short asset replacement**
	Deep-sea	H	Fuel in international shipping in the form of **hydrogen, ammonia** or **methanol**	~	✓	Possible **voluntary demand** (low cost impact in container shipping), **but low technology alignment and long asset replacement cycles**
	Aviation	H	Direct use or as feedstock to produce **Sustainable Aviation Fuel** (SAF)	✓	✓	Possible **voluntary demand** (e.g., in business travel), **no asset changes** needed, and **emerging regulations**
	Trains	M	Fuel to **replace diesel-engine trains** in long-haul transport	~	~	
	Cars	L	**Electrification possible** and more economic	X	X	
Build	Residential	L	Heating alternative in case of **economic limitations of electrification** (e.g., high cost to electrify buildings with poor insulation)	X	~	
	Commercial	L		X	~	
Power		M	Balance intermittency from renewables through **energy storage**	X	~	

■ High ■ Medium ■ Low

Source: IEA 'Net Zero Emissions by 2050' Scenario; Deloitte Global analysis

Other factors that could affect the adoption of clean hydrogen in particular sectors or regions remain uncertain. For example, although hydrogen currently seems attractive for long-haul, heavy-duty road freight, developments in electric battery technology could reduce demand for hydrogen in this sector.

Moreover, while some countries (e.g., Japan and South Korea) are considering the use of hydrogen, including ammonia, for power generation, many others expect to use hydrogen in power primarily to store electricity from intermittent renewables.

Conversely, new developments in direct air capture (DAC) to extract CO_2 directly from the atmosphere could accelerate the take-up of hydrogen, as both CO_2 and hydrogen are needed in the production of synthetic fuels (e.g., green methanol).

Supply momentum

Although announcements of low-carbon hydrogen supply projects are accelerating, three times the capacity announced so far will need to come onstream by 2030, to meet expected demand.[4]

Using 2021 figures, global hydrogen supply stands at approximately 94 Megaton (Mt), of which approximately 99% is grey.[5] Grey hydrogen is produced using unabated fossil fuels and used mainly to produce ammonia (34%) and methanol (15%), and in refining (40%).[6]

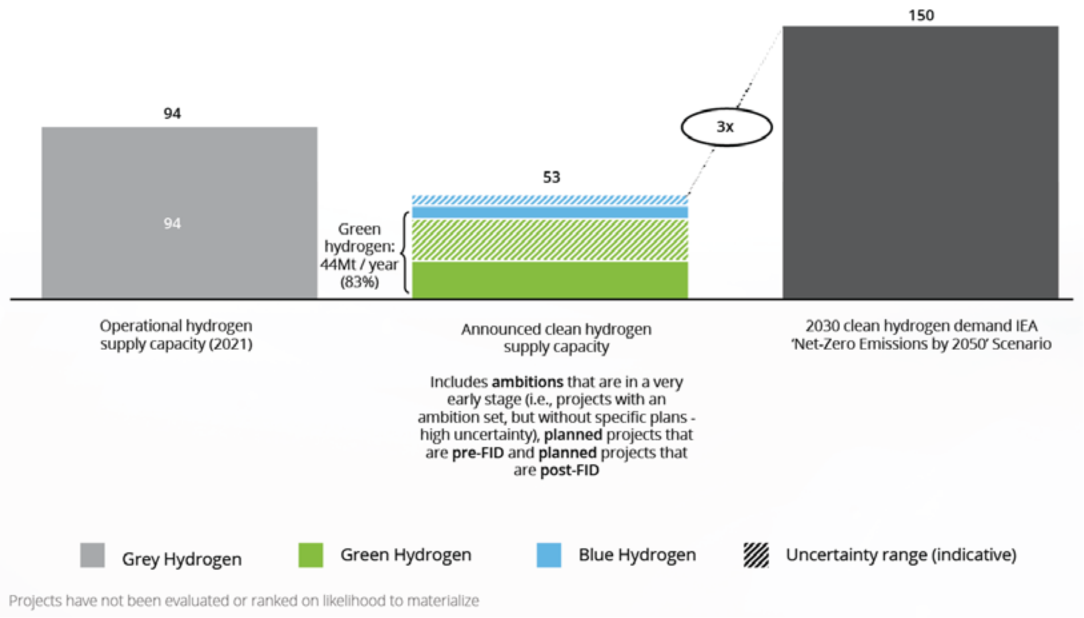
As of August 2022, newly announced clean hydrogen projects could create production capacity for 44 Mt of green hydrogen and 9 Mt of blue hydrogen.[7] However, at least half of these projects are yet to announce specific plans, and only ten—representing less than 1% of announced capacity – have passed final investment decision (FID).[8]

Most hydrogen project announcements have stemmed from Europe, the Middle East, the US, and Australia. So far, there have been announcements for blue hydrogen projects from the United Kingdom (UK) (5.3 Mt, 60% of blue hydrogen capacity), United States (US) (1.9 Mt, 20%), and Canada (0.9 Mt, 10%) – mostly located near existing plants and/or reservoirs. Deloitte expects to see more blue hydrogen announcements coming from the Middle East and Norway, for example. Most green hydrogen projects are in Europe (13 Mt, 30% of green hydrogen capacity), the Middle East (9 Mt, 20%), and Australia (8 Mt, 19%), which have ample, low-cost renewables capacity.

Regional variations in the nature and scale of capacity should evolve in response to both physical features (e.g., Middle East activity on renewables) and local regulations (e.g., US Inflation Reduction Act).

Overall, even if all announced supply capacity projects were to materialize, it would likely still be insufficient (Figure 3). The International Energy Agency (IEA) "Net Zero by 2050" scenario estimates that three times the capacity announced to date is needed by 2030. This projection is in the same order of magnitude as Deloitte's projection on what would be needed to reach net-zero by 2050 as published in Deloitte's Global Green Hydrogen Market Outlook.[9]

Figure 3: Global operational and announced clean hydrogen supply capacity (August '22) vs. expected demand (Mt / year)



Includes **ambitions** that are in a very early stage (i.e., projects with an ambition set, but without specific plans - high uncertainty), **planned** projects that are **pre-FID** and **planned** projects that are **post-FID**

Projects have not been evaluated or ranked on likelihood to materialize

Source: Deloitte Energy Transition Monitor, IEA World Energy Outlook 2022, IEA 'Net Zero Emissions by 2050' Scenario

Factor conditions and solutions

Natural demand

Addressing natural demand (i.e., demand emerging without regulatory support in specific sectors) through new green value propositions and aggregation of off-takers can be important to help send clear signals to the market, and to help stimulate regulated demand.

Deloitte has identified three factors that characterize sectors likely to experience natural demand (Figure 4):

1. The ability to capture benefits for companies (e.g., increasing market share) and consumers (e.g., providing new functional or emotional benefits);
2. A high level of public scrutiny from society and government, and accordingly, a high level of reputational risk; and
3. A marginal increase in cost to the consumer, where the switch to hydrogen would mean a minimal price increase.

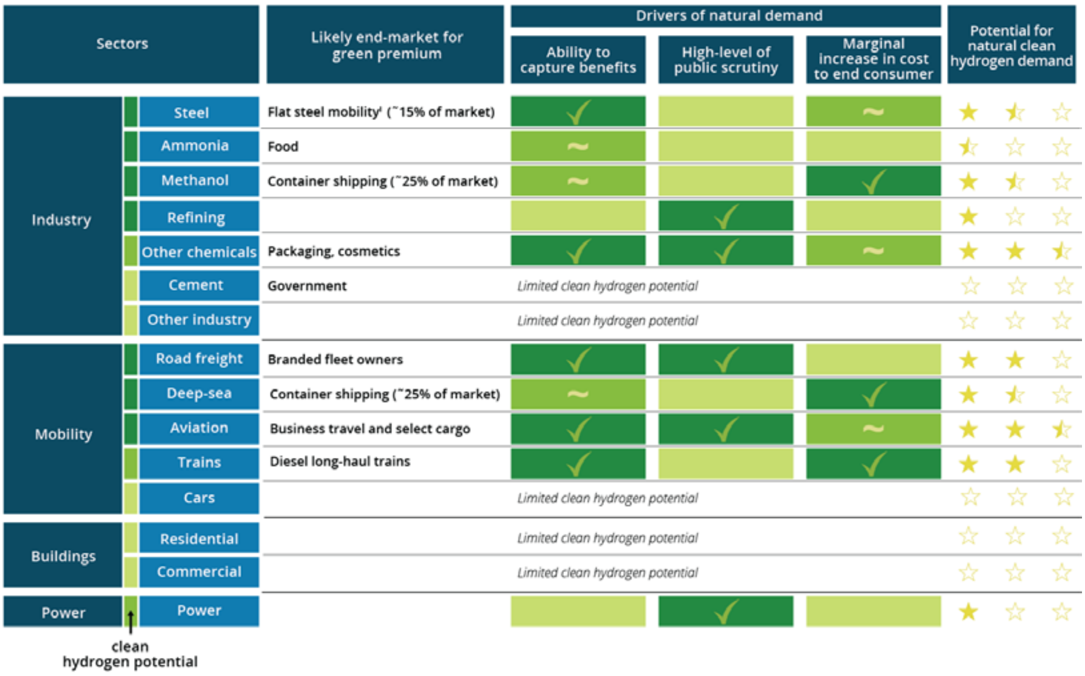
Companies in sectors likely to experience natural demand could develop new value propositions that may encourage the adoption of low-carbon products, such as original equipment manufacturers (OEMs) using green flat steel to help create a full-green electric vehicle (EV). Aviation offers another example. Using sustainable aviation fuel (SAF) can increase the cost of the airline ticket—where fuel makes up about 30% of the ticket price—but airlines can consider providing additional benefits to passengers to help offset this increase. For instance, airlines can offer "green" priority security, preferential seats, meal upgrades and / or loyalty points for passengers who offset the most. Similar schemes could be applied to cruise ships.

Cargo could be another likely end-market. When goods are shipped in high volumes, costs can be spread across each item, lowering the additional cost per unit. In container shipping, for instance, the marginal cost increase for consumer products can be low (approximately 1%) when switching to green fuels, so that could be a starting point for creating clean-hydrogen value propositions.

Another potential stimulus may be to aggregate natural demand and commit to long-term contracts. For example, aviation companies are already helping to reduce their corporate customers' third-party emissions through procurement coalitions such as the Sustainable Aviation Buyers Alliance (SABA). Long-term contracts (more than one year) can help build a reliable and lasting increase in demand, which can also lower risk and help enable knock-on benefits, such as motivating supply chain improvements and financing decisions.

Furthermore, matching the supply and local demand of hydrogen across geographies could be difficult in the short- to medium-term as the market grows. Transporting clean fuels around the world to where they may be needed partially negates the positive effects they may have upon decarbonization. A global "book and claim" certification scheme can help alleviate this matter and allow regional pockets of demand to stimulate greater global supply of hydrogen. In aviation, for example, book and claim can help airlines decarbonize by buying SAF even if local supply may be limited.

Figure 4: Natural clean hydrogen demand potential by sector



Sectors		Likely end-market for green premium	Drivers of natural demand			Potential for natural clean hydrogen demand
			Ability to capture benefits	High-level of public scrutiny	Marginal increase in cost to end consumer	
Industry	Steel	Flat steel mobility[1] (˜15% of market)	✓		~	★ ⯨ ☆
	Ammonia	Food	~			⯨ ☆ ☆
	Methanol	Container shipping (˜25% of market)	~		✓	★ ⯨ ☆
	Refining			✓		★ ☆ ☆
	Other chemicals	Packaging, cosmetics	✓	✓	~	★ ★ ⯨
	Cement	Government	*Limited clean hydrogen potential*			☆ ☆ ☆
	Other industry		*Limited clean hydrogen potential*			☆ ☆ ☆
Mobility	Road freight	Branded fleet owners	✓	✓		★ ★ ☆
	Deep-sea	Container shipping (˜25% of market)	~		✓	★ ⯨ ☆
	Aviation	Business travel and select cargo	✓	✓	~	★ ★ ⯨
	Trains	Diesel long-haul trains	✓		✓	★ ★ ☆
	Cars		*Limited clean hydrogen potential*			☆ ☆ ☆
Buildings	Residential		*Limited clean hydrogen potential*			☆ ☆ ☆
	Commercial		*Limited clean hydrogen potential*			☆ ☆ ☆
Power	Power			✓		★ ☆ ☆

Note: I) Flat steel refers to steel sheets and plates used in a wide range of applications (for example, automotive, machinery and domestic appliances)

Source: Deloitte Global analysis, Interviews with executives and leaders across sectors

Regulation

Adopting simple and synchronized regulations across supply and demand based on a new nomenclature and certification around the emission intensity of hydrogen, along with fast release of permits, could help accelerate hydrogen deployment and emissions reduction.

At present, the cost disadvantages of clean hydrogen compared to grey alternatives are likely to inhibit the development of solutions. For instance, the use of green hydrogen for ammonia production and aviation in the EU is unlikely to be competitive by 2030, if natural gas prices return from their current heights to 2020 levels, and no regulatory initiatives have been created.[10]

Current regulatory initiatives could vary by region or country, reflecting local factors such as economic situation, resources, industry maturity, and the political position on how to help stimulate the market. Across this regional variety, Deloitte has identified four emerging archetypes across supply, demand, exports, and testing, as illustrated in Figure 5.

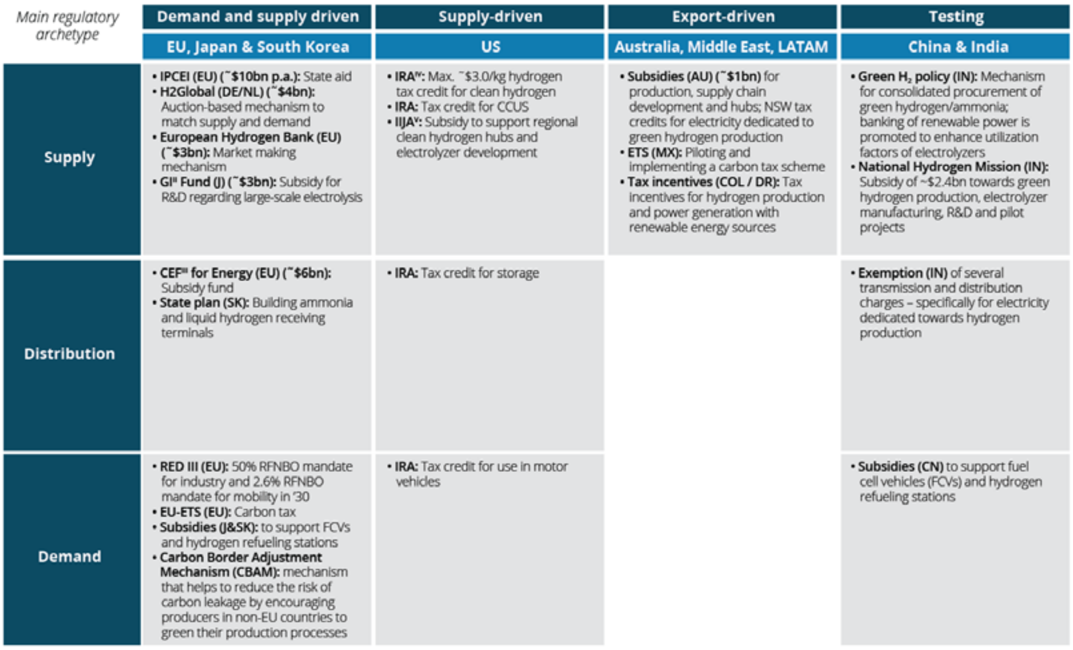
The EU, for instance, is combining demand-side mandates such as the Renewable Energy Directive (RED) III, Carbon Border Adjustment Mechanism (CBAM), and Emission Trading System (EU ETS) carbon pricing with supply-side measures such as subsidies for Important Projects of Common European Interest (IPCEI).

While the demand-side measures may try to make green hydrogen competitive against grey alternatives, the supply-side initiatives help to address security of supply by keeping production local, with further measures, such as the European Hydrogen Bank, currently being defined. A consideration related to the EU is the significant increase in natural gas prices in 2022, which is helping to make hydrogen solutions more competitive. This may have significant implications for the acceleration of hydrogen development in the EU in the coming years, if longer-term uncertainty around natural gas prices remains.

The US has more of a supply-side focus, with its Infrastructure Investment and Jobs Act (IIJA) and Inflation Reduction Act (IRA). These acts help to incentivize producers of low-carbon molecules (including hydrogen) - for instance, the IRA offers a tax credit of US$0.6–US$3.0 per kilogram of hydrogen produced, as a push to get projects past FID.[11]

Australia is adopting an export-driven, supply-side approach to help incentivize production and hub development for blue and green hydrogen. This includes US$200 million (approximately AU$300 million) national and US$335 million (approximately AU$500 million) regional funds, plus further local incentives, such as a 90% exemption from water costs for green hydrogen production, announced by New South Wales.

Figure 5: Regulatory archetypes by region



Main regulatory archetype	Demand and supply driven	Supply-driven	Export-driven	Testing
	EU, Japan & South Korea	US	Australia, Middle East, LATAM	China & India
Supply	• **IPCEI (EU) (˜$10bn p.a.):** State aid • **H2Global (DE/NL) (˜$4bn):** Auction-based mechanism to match supply and demand • **European Hydrogen Bank (EU) (˜$3bn):** Market making mechanism • **GI[II] Fund (J) (˜$3bn):** Subsidy for R&D regarding large-scale electrolysis	• **IRA[IV]:** Max. ˜$3.0/kg hydrogen tax credit for clean hydrogen • **IRA:** Tax credit for CCUS • **IIJA[V]:** Subsidy to support regional clean hydrogen hubs and electrolyzer development	• **Subsidies (AU) (˜$1bn)** for production, supply chain development and hubs; NSW tax credits for electricity dedicated to green hydrogen production • **ETS (MX):** Piloting and implementing a carbon tax scheme • **Tax incentives (COL / DR):** Tax incentives for hydrogen production and power generation with renewable energy sources	• **Green H_2 policy (IN):** Mechanism for consolidated procurement of green hydrogen/ammonia; banking of renewable power is promoted to enhance utilization factors of electrolyzers • **National Hydrogen Mission (IN):** Subsidy of ~$2.4bn towards green hydrogen production, electrolyzer manufacturing, R&D and pilot projects
Distribution	• **CEF[III] for Energy (EU) (˜$6bn):** Subsidy fund • **State plan (SK):** Building ammonia and liquid hydrogen receiving terminals	• **IRA:** Tax credit for storage		• **Exemption (IN)** of several transmission and distribution charges – specifically for electricity dedicated towards hydrogen production
Demand	• **RED III (EU):** 50% RFNBO mandate for industry and 2.6% RFNBO mandate for mobility in '30 • **EU-ETS (EU):** Carbon tax • **Subsidies (J&SK):** to support FCVs and hydrogen refueling stations • **Carbon Border Adjustment Mechanism (CBAM):** mechanism that helps to reduce the risk of carbon leakage by encouraging producers in non-EU countries to green their production processes	• **IRA:** Tax credit for use in motor vehicles		• **Subsidies (CN)** to support fuel cell vehicles (FCVs) and hydrogen refueling stations

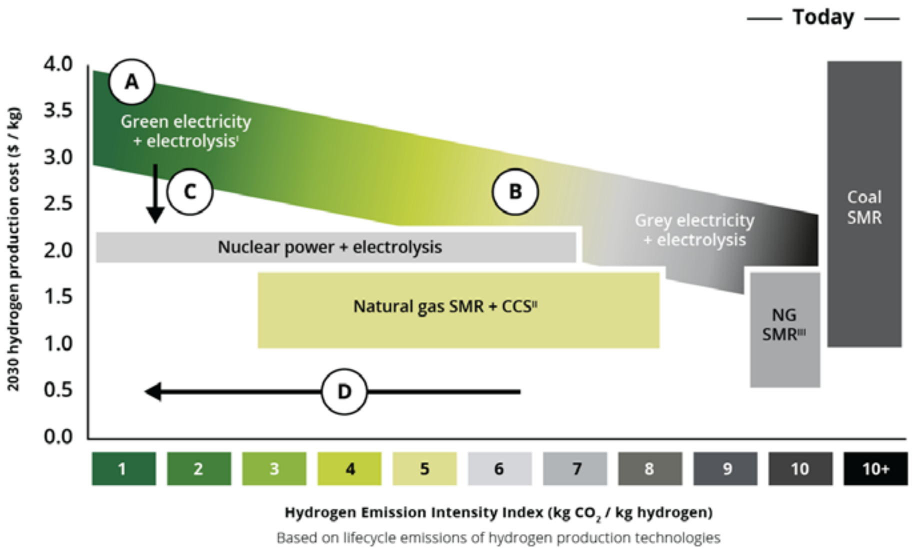
Note: I) Overview of regulatory initiatives is not exhaustive; only includes selected highlights; II) Green innovation; III) Connecting Europe Facility; IV) Inflation Reduction Act; size of tax credit depends on total lifecycle CO_2 emissions; V) Infrastructure and Investment Jobs Act.

Source: Deloitte Global analysis

Another area that should be important to consider is the synchronization of regulatory initiatives between supply and demand, since significant investments are likely required from both sides to help alter or develop assets. This even plays a role in some of the simpler applications where hydrogen may already be used.

In addition, to help avoid the price differential created by the grey/blue/green hydrogen classification, the industry executives Deloitte Global spoke to identified a more nuanced approach: to adopt an HEII. Such an index could take into account both emission and economic measures of different hydrogen production technologies, allowing economically viable solutions to be better identified and adopted in the short-term, as part of an incremental shift towards lower emissions (Figure 6). For instance, electrolysis-based hydrogen production that initially blends renewable and non-renewable electricity can increase the load factor of electrolyzers and operate more cost-effectively than renewable-electricity-based (green) hydrogen production, while also addressing demand and reducing emissions intensity.

Figure 6: Hydrogen Emission Intensity Index (HEII)



Ⓐ Producing green hydrogen expected to be ˜2–3x more expensive than grey hydrogen (2030), which means some sectors cannot afford it, and governments need to provide large amounts of subsidies to address the large gap.

Ⓑ Depending on regional specifics, a more economically viable solution could be selected that still provides a significant reduction in carbon intensity in the short term (e.g., electrolyzers with blending to increase the load factor).

Ⓒ Over time, while capacity is being built, assets, infrastructure and supply will move down the cost curve (e.g., electrolysis), which also reduces the production cost the hydrogen projects with a lower HEII.

Ⓓ Policies can be implemented that strongly encourage increased adoption of lower-emission-intensity technologies (i.e., moving to a lower acceptable HEII).

Notes: I) Assuming lifetime emissions of offshore wind at 12 g / kWh and 70% efficiency for the electrolyzer; II) There is significant uncertainty regarding the emission intensity of blue hydrogen, and depends on methane leakage reduction and carbon capture potential of the equipment; III) ~5 kg from conversion of methane to CO_2, ~4 kg to create energy to drive the SMR, ~1 kg upstream emissions in NG production

Source: Intergovernmental Panel on Climate Change (IPCC), IEA, Deloitte analysis

As capacity builds over time, costs for greener assets and infrastructure should decrease, thus reducing production costs for low-HEII hydrogen projects. A more fine-grained HEII metric could then help enable policies that encourage progressive shifts toward lower HEII levels.[12]

Although Figure 6 offers an illustrative example, it can help to explain some of the benefits of an index-based approach. For it to be effective, industry leaders and governments should work together to help develop and refine the details, achieve widespread alignment, and establish assurance mechanisms. Once in place, such an approach could also help blend clean hydrogen into existing processes (e.g., ammonia production). However, the motivation to do this in practice may rely on having a clear, HEII-based certification system for overall output, or mass balancing rules that can certify part of the production output.

Of course, an HEII-based approach should align with net-zero ambitions and national targets. These can be secured by adopting sustainability thresholds that projects would need to adhere to. Deloitte's Global Green Hydrogen Outlook helps to give guidance on what some of these sustainability thresholds should be to help achieve the objectives of the Paris Agreement.

Another consideration may be that permit application timelines tend to take a long time and can hinder hydrogen projects from moving past the final investment decision (FID) stage. For example, according to Deloitte's analysis, it can take up to four years for an offshore wind permit to be granted in the Netherlands. To get hydrogen projects past the FID stage, policy initiatives can be supported by transparent, short-term permissions—and the administrative capacity to help enable them. For instance, Portugal recently decided to scrap mandatory environmental assessments for green hydrogen projects from March 2023.[13]

Technology

Aligning on the decarbonization technologies to adopt within each sector—and maturing them fast—helps to dictate the speed of demand pick-up for clean hydrogen. On the supply side, a "think big, start small, scale fast" approach could help to balance large-scale needs and short-term supply chain constraints more quickly.

Sectors that may have a clearer decarbonization pathway and mature technology should be faster with adopting clean hydrogen, but those not yet at the adoption stage will likely need to develop targeted plans to help address their specific challenges and create demand.

For example, methanol and ammonia production and refining already use hydrogen in their processes and can adopt clean hydrogen with limited asset changes. That is, the technology is relatively mature, and the sector should be aligned on this decarbonization pathway. Meanwhile, road freight shows some alignment on pathways, and hydrogen fuel-cell technology is fairly mature, but there may be a possibility that improvements in electric batteries could turn out to be more competitive.

However, in some sectors, technological maturity can be deemed low. In steel, for example, the pathways are known—whether direct reduced iron (DRI) or carbon capture and sequestration (CCS), but the technological maturity of either is not high. For example, there aren't yet any plants running on full hydrogen DRI; the existing DRI plants run on natural gas. Similarly, the CCS efficiency and ability to capture CO_2 may also require improvement. In shipping, progress has stalled, which Deloitte's research suggests is likely due to low maturity and uncertainty about pathways: methanol, ammonia, and (synthetic) liquefied natural gas (LNG) are all possibilities, but the lack of alignment could risk creating complex supply chains with high costs, as different fuels may require different ship designs, crew capabilities, operations, and port infrastructures compared to today.

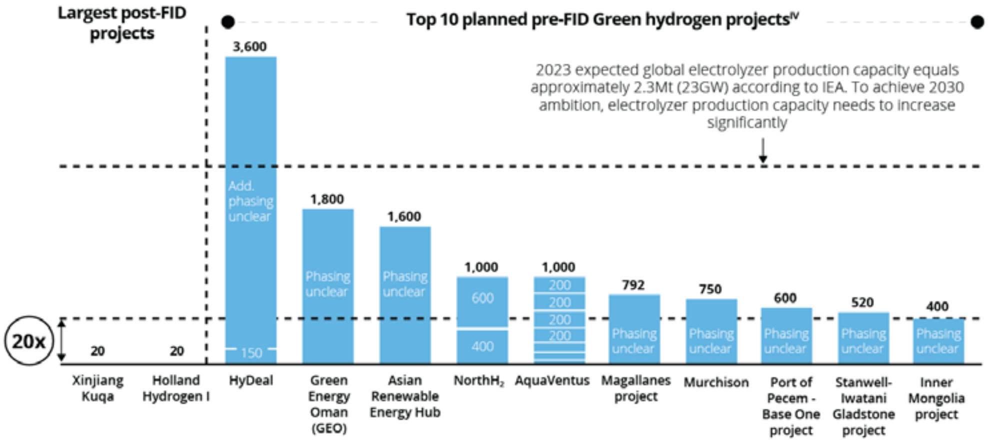
Such solutions could be developed and refined through research and development (R&D) and running pilots to help mature and deploy the technology, or the sector could collaborate to help accelerate alignment and agree on short-term wins to help attract investment.

The supply side may also need to think differently about development options to help deliver sufficient capacity and start quickly. Around 80% of announced projects are small [< 100 kiloton (kt)], and provide the capacity to help decarbonize, at most, a few local plants, but not create economies of scale.[14] Large-scale projects can reduce production costs, drive infrastructure developments, decrease the societal cost, and decarbonize the largest industrial plants.

To help illustrate this, according to Deloitte Global's analysis, one of the world's 10 largest green hydrogen projects could decarbonize only one steel plant (requiring ~700 kt hydrogen) and one fertilizer plant (~300 kt).

Despite the world's ambition for large-scale clean hydrogen projects, the reality is that today's two largest post-FID projects may only deliver capacity of approximately 20 kt each.[15] Thus, increases in capacity are likely needed before 2030, which can pose quite a large technological, operational, and supply chain challenge (Figure 7). A pragmatic approach could be to set big goals but aim to start small and create volume while addressing some of the current technical and supply chain constraints (i.e., "think big, start small, scale fast"). In parallel, technological development will likely need to be accelerated through R&D and digitization, and supply chains will likely need to be scaled up.

Figure 7: Top 10 planned pre-FID green hydrogen supply projects vs. largest post-FID projects (kt/year, August '22)



	Xinjiang Kuqa	Holland Hydrogen I	HyDeal	Green Energy Oman (GEO)	Asian Renewable Energy Hub	$NorthH_2$	AquaVentus	Magallanes project	Murchison	Port of Pecem - Base One project	Stanwell-Iwatani Gladstone project	Inner Mongolia project
First production	2023	2025	2026	>2030[III]	2025	2030	2025	2024	2027	>2030	>2030	2025
Implied CAPEX ($B)[I]	0.2	0.2	43.2	21.6	19.2	12.0	12.0	9.5	9.0	7.2	6.2	4.8
Renewable capacity (GW)[II]	0.2	0.2	36	18	16	10	10	8	8	6	5	4

Note: I) Assuming 12 $m/kt production capacity for green hydrogen; II) Assuming on average 1 GW offshore wind capacity is needed for 100 kt of hydrogen output from the electrolyzer (kt/y); III) Post 2026 - FID target; IV) All projects have announced a phased approach, but the majority do not specify capacity per phase

Source: IEA 'Global Hydrogen Review 2022', Deloitte Energy Transition Monitor

Assets, infrastructure and supply

Faster asset cycle changes are likely needed on the demand side, coupled with infrastructure reuse where possible, and complementing large-scale investment in renewable capacity, grids, and infrastructure.

Standard asset replacement cycles inhibit the take-up of hydrogen, which will likely require an immediate shift to faster asset cycles. In steelmaking, for example, assuming a 40-year lifetime and a 5% annual replacement rate for blast furnaces, it would take until 2065 to replace all assets, if started in 2025. Rather than delay progress by waiting for full asset replacement for green hydrogen, a gradual move from grey to green hydrogen could initiate a reduction of emissions, help develop large-scale capacity rapidly, and help incentivize demand-side investment in new assets, such as fuel cell vehicles (FCVs).

Where supply and demand centers may be in close proximity, maximizing asset reuse can play a big role. For example, local hydrogen transport and CO_2 storage can use existing natural gas grids and disused reservoirs, respectively. Indeed, with an extensive network of natural gas transmission pipelines already in existence in many regions, the quickest and most efficient means of incorporating hydrogen into the energy mix would likely be to repurpose lines to carry varying amounts of hydrogen gas.

As it is the smallest element, hydrogen's molecular size permits it to penetrate pipelines in ways that methane cannot. This process of "absorption" can result in the embrittlement of the pipe. A German study found that incorporating hydrogen into methane pipelines can help speed up embrittlement by 20% to 50%, but only in the case that there are existing fractures and the line is subjected to fluctuating pressures.[16] A similar study, the HyBlend Project, is being conducted in the United States by the National Renewable Energy Laboratory (NREL) and five other Department of Energy (DOE) labs.[17] The goal of this project is to examine the long-term effects of hydrogen on multiple pipeline materials at different blend ratios.

Since potential embrittlement may be a roadblock with transporting hydrogen, pipes could conceivably be coated to better handle the gas. Due to its small molecular size, hydrogen also has a higher potential for leakage than methane. To help repurpose existing infrastructure, valves and fittings should be monitored closely and potentially replaced to help make existing natural gas transmission lines more suitable for hydrogen.

At present, using blended gas is one of the least technically daunting solutions. The US Department of Energy estimates that existing natural gas flows can be combined with up to 15% hydrogen and require only minor modifications.[18] This percentage may vary based on pipeline conditions but provides a valuable frame of reference for what could be implemented today. However, additional safety measures should be considered when using any amount of hydrogen in the stream. Since hydrogen can ignite with almost any air-to-fuel ratio, equipment should be "spark-proofed" to an even higher degree than when using only methane.

Assuming hurdles to repurposing transmission lines are overcome, blended gas still has its pros and cons in the marketplace. In the pro column, it could create demand. In the con column, it could decrease value. For instance, blending of hydrogen into a gas pipeline might not be an attractive option for any of the parties involved if the line in question is already at full capacity because any hydrogen added would displace natural gas. Another extremely important consideration for the blending of hydrogen with methane is whether customers can accept a blended stream.

Elsewhere, despite its importance, little attention appears to be currently being given to infrastructure development, adding risk and potentially stalling progress for both suppliers and off-takers. Conversations about grid upgrades and new pipelines have been ongoing for a while, but there has not been much action. This can add risk and may stall progress for both suppliers and off-takers. For example, there may be suppliers in the Middle East who don't have a way to transport the hydrogen to potential off-takers. Collaboration—for instance, through public-private partnerships—could help to accelerate development.

Meanwhile, supply-side investments may be needed to help increase the supply of renewable electricity and the grid capacity to distribute it. For instance, the expected green hydrogen demand in 2030 will likely require up to 8.0 terawatts (TW) of wind and solar power, which is eight times the capacity currently in operation, and four times the combined operational and announced capacity.[19] Deloitte analysis suggests one global solution to this shortfall may come though supply-led hubs, such as the Middle East and Australia, where solar and wind power are abundant and low-cost.

Collaboration

Collaboration can be essential for clean hydrogen production, with new commercial and business models to help address the systemic challenges and inertia that can delay investments.

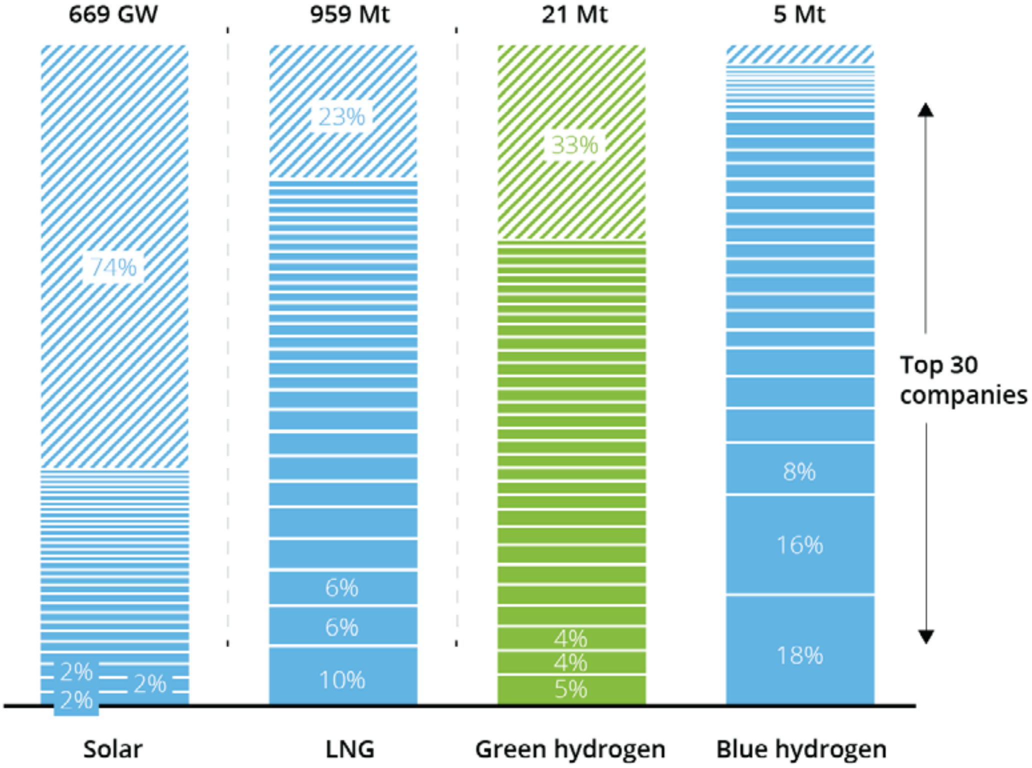
Cooperation between energy suppliers and off-takers and government, finance, and technology organizations can help move the market forward from its current, illiquid state by overcoming some of the barriers of capital, knowledge, and risk. Surmounting these barriers could be essential for instigating some of the large-scale projects that the world may need. Of the announced clean hydrogen projects, 80% are being developed by a small number of companies working together (Figure 8), while energy suppliers are collaborating across the value chain (e.g., with off-takers) and in the broader ecosystem (e.g., with technology and investment businesses) to share capital, risk, and capability.

Current clean hydrogen supply capacity is dominated by incumbents, such as utility and international or national oil companies (IOCs and NOCs). They represent around 50% of all operational and announced projects, and have experience of developing large-scale energy projects, with capital, a network of off-takers, and capabilities such as the subsurface knowledge needed for carbon capture and storage.[20]

Just as important as collaboration, though, is the need for new commercial, business, and risk models that can help address the systemic issues that at times may delay investment. Current bilateral models may not be efficiently addressing the value gap, or making projects happen, as evidenced by the scarcity of projects that have reached FID. Instead, new business models should be considered that are, for instance, more integrated or coordinated along the hydrogen value chain. This can help to share value and risk and help encourage investment.

Capability development may also demand closer attention—partly because the hydrogen economy can create new employment opportunities, but mainly because the scarcity of such talent can be one of the major obstacles to getting hydrogen projects developed and operational. Effective measures to help build capability, and to help attract and retain talent, should focus on education; reskilling to build on existing capabilities; automation to free up staff for new challenges; and extending the ***retirement age***.

Figure 8: Company concentration across selected energy carriers (% of global operational and planned supply capacity)



Source: Deloitte Energy Transition Monitor

Implementation

Forming cooperative hubs

The conditions needed to help accelerate hydrogen deployment at scale will likely converge in specific geographies. These "hubs" could kick-start the hydrogen economy and help reduce the fragilities of existing global energy markets.

The factor conditions and proposed solutions in this report—natural demand; regulation; technology; assets, infrastructure and supply; and collaboration—can be brought together by forming hubs. Three types of hubs could help create a foundation for global trading markets by satisfying enough demand to help reduce local energy market needs, and exporting any surplus production to regions that may require economically viable clean hydrogen.

Demand-led hubs will likely arise in regions with low structural domestic supply, whether from insufficient renewables, natural gas or storage capacity for CO_2. For instance, Japan and South Korea are switching from a dependence on LNG toward clean hydrogen, with some capacity for small-scale local production. In the early stages of these moves, bilateral trade is expected to emerge first, alongside the potential for demand centers and off-takers to invest in developing supply capacity.

Supply-led hubs are most likely to exist in geographies where production capacity exceeds local demand, such as the Middle East or the US Gulf Coast, or where economic circumstances may create lucrative export markets, whether to supply regions that lack alternatives, or through an overall shortage of supply. For instance, the Gulf Cooperation Council (GCC), which is committed to hydrogen-related R&D, could spur the hydrogen economy by helping to create a geographically localized ecosystem capable of attracting foreign talents and investments. Moreover, this could allow both leading and newly established hydrogen companies to be located close to one another so they could leverage their synergies for a future hydrogen hub. The GCC could also capitalize on its existing attributes, such as the availability of different renewable energy sources, advanced infrastructure, and proven shipping routes representing a strategic asset, to export hydrogen to high-demand energy countries such as some of those within Europe and Asia-Pacific. Combined, these factors could give the region a significant competitive advantage in both the short- and longer-term as both a local supplier and an international exporter of hydrogen. However, such export potential, in the GCC or elsewhere, should be considered in the broader context of social license, and the expectation that hydrogen can be used to help improve local social welfare. Governments are therefore considering how to achieve a suitable balance of the societal and economic benefits from clean hydrogen.

Some hubs may be driven by both supply and demand. Such **balanced hubs** could be key to helping stimulate clean hydrogen deployment at a local scale, both by creating supply chains and reducing costs. These hubs are most likely in regions that can develop enough hydrogen supply to meet the demand from large, local industries; have a density of demand that requires only simple, low-cost transportation to customers; and have governments willing to help support the development of both supply and demand through transparent regulations, standards and frameworks, and subsidies. For example, the Netherlands is particularly well-positioned to become a balanced hub, with ample local demand, a well-educated workforce, supportive EU hydrogen policies, optimal locations for storage, and existing infrastructure that can easily be repurposed to transport hydrogen. But, the main advantage is the North Sea: an excellent clean energy resource, since it is shallow enough to supply renewable wind power for electrolysis.

Hubs may require a new way to collaborate and possibly share infrastructure in the ecosystem—sometimes with former competitors—to develop a sense of “coopetition” between hub members, which can help accelerate innovation, and scale up the mutual benefits. Indeed, the Deloitte US’ recent study of the business case for hubs found that participation as part of a hub could help reduce a company’s infrastructure costs by up to 95% compared with investing alone to achieve the same production volumes and emissions reduction.[21]

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End Notes

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