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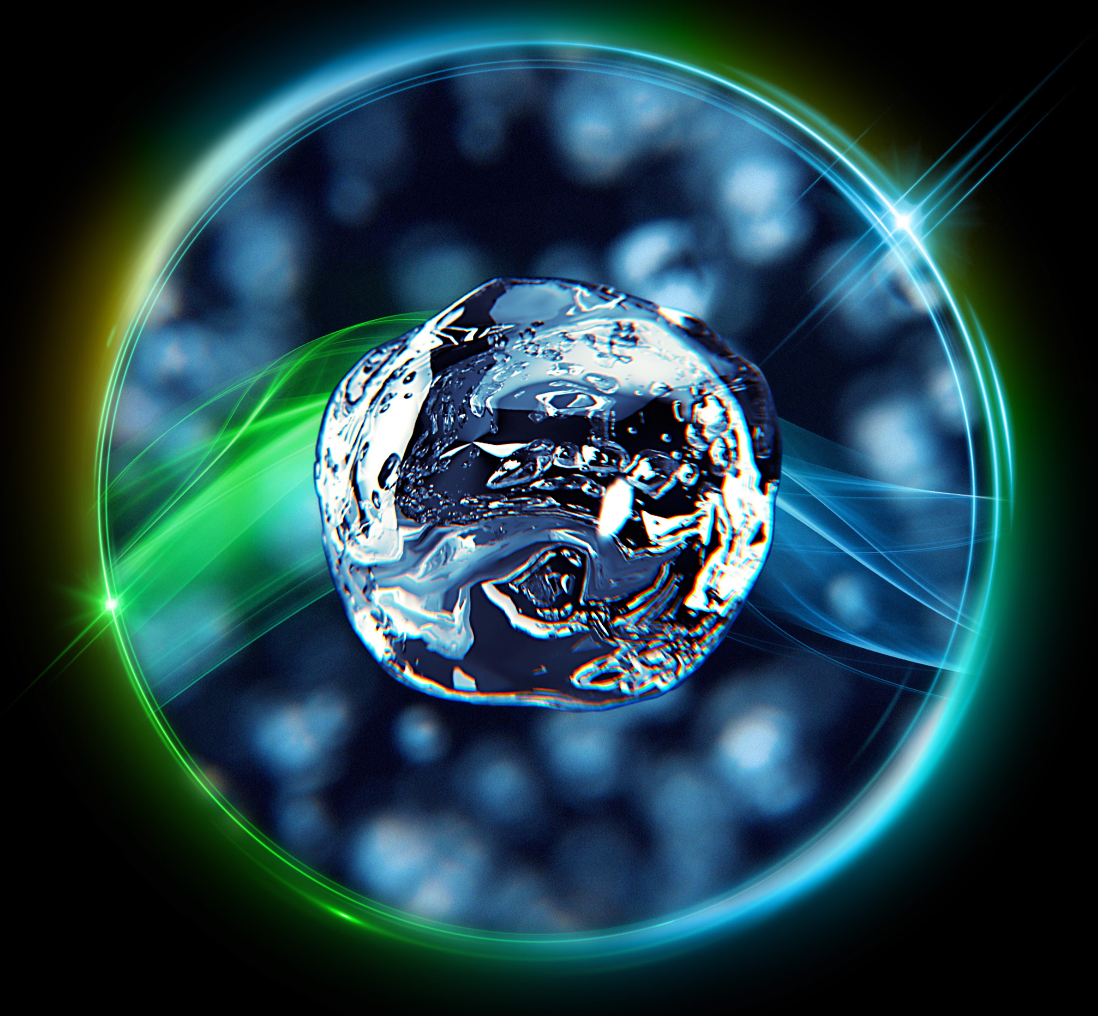


Hydrogen
Making it happen

Executive summary

Decarbonization has become a global imperative. The 27th Conference of the Parties (COP27) of the United Nations Framework Convention on Climate Change (UNFCCC) sought to push the Paris Agreement targets further, and move from pledges to practical action, with the drive to implement decarbonization solutions and lower emissions now a priority.

Clean hydrogen will most likely play an important role in the future energy system – particularly in decarbonizing sectors that cannot be realistically electrified; the so-called "hard-to-abate" sectors. By 2030, clean hydrogen is expected to be used in sectors such as methanol, refining, aviation and road freight, and expand into other sectors such as shipping thereafter[1]. According to Deloitte analysis, announcements of clean hydrogen supply projects are accelerating, but it is uncertain whether many projects will materialize, and they are not sufficient to meet the expected demand outlined in the IEA 'Net-Zero Emissions by 2050' Scenario (NZE). Indeed, three times the capacity announced so far will be needed by 2030 to stay on track for the NZE Scenario by 2050.

This report sets out the **practical solutions** needed today to help drive the large-scale deployment of clean hydrogen and meet imminent emission-reduction targets:

- **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 is important to send clear signals to the market, to stimulate regulated demand, and accelerate investment in supply.

- **Regulation:** Adopting simple and synchronized regulations across supply and demand – based on a new nomenclature and certification around the emission intensity of hydrogen (for example, a Hydrogen Emission Intensity Index) – with fast release of permits can accelerate hydrogen deployment and emission reduction.

- **Technology:** Aligning on the decarbonization technologies to adopt within each sector, and maturing them quickly, will dictate the speed of demand pick-up for clean hydrogen. On the supply side, a 'think big, start small, and scale fast' approach to production development is needed, to quickly balance large-scale needs and short-term supply chain constraints.

- **Assets, infrastructure and supply:** Faster asset cycle changes are needed on the demand side, coupled with infrastructure re-use where possible, with large-scale investment in renewable capacity, grids, and infrastructure.

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

These proposed solutions (***Figure 1***) can be brought together by forming hubs: geographic areas that combine sufficient, 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 hydrogen costs, through both economies of scale and reduced infrastructure requirements. These hubs will help to kick-start the hydrogen economy, and reduce the fragilities of existing global energy markets.

Introduction

The drive to implement solutions and lower emissions is now a priority. As one of the few options for decarbonization, aside from direct electrification, hydrogen will play an important role in lowering emissions, and demand will be high. It will also stimulate activity and employment, with the European Union (EU) estimating that, by 2030, it will create approximately 10,000 jobs (direct and indirect) for every billion euros invested[2]. However, what is less clear is how to fast-track hydrogen's development.

In the past two years, there has been significant focus on the topic of clean hydrogen (hydrogen that is produced in a way that creates little to no CO_2 emissions by using renewable electricity plus electrolysis, fossil fuels plus carbon capture and storage, etc.), with several industry events, studies, experiments, and pilots taking place. Recently, there has been more focus on tangible, bankable investments in hydrogen development; the increased awareness on the topic has helped to attract the interest of investors, and is now stimulating a growing number of hydrogen project announcements.

"COP27 theme was: 'Together for Implementation' – this is what we need for hydrogen as well; we need work together to drive its deployment and use"
– Executive, aviation

Clean hydrogen projects often require substantial governmental support to make them economically viable, and have rarely reached a final investment decision (FID). There is still an urgent need to find ways to start practical, large-scale, and rapid implementation of hydrogen if the world's climate targets are to be met.

"We can't just wait for regulation to create the hydrogen market; other conditions are as important: demand, infra, innovation, new business models, and much more" –
Executive, port

The report assesses the current clean hydrogen landscape, its market potential, and supply momentum, before diving deeper into a framework of five key factor conditions – natural demand; regulations; technology; assets, infrastructure and supply; and collaboration – as well as the solutions that could activate hydrogen production and demand at scale (***Figure 1***).

Finally, the report outlines how the five key factor conditions can be brought together, in low-carbon hubs, to accelerate implementation.

Figure 1: Factor conditions and solutions to help 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

Notes: Through interviews with over 350 CEOs, executives, and leaders across the private and public sectors, Deloitte captured insights on how the market could accelerate, by linking the demand, production, and distribution of clean hydrogen. This report sets out to identify what is needed today to help drive large-scale deployment of hydrogen in the near term. NB In this report, 'Deloitte' refers to Deloitte Netherlands, Deloitte Global or Deloitte Consulting LLP, unless indicated otherwise.

Source: Deloitte analysis

1.1 Clean hydrogen potential

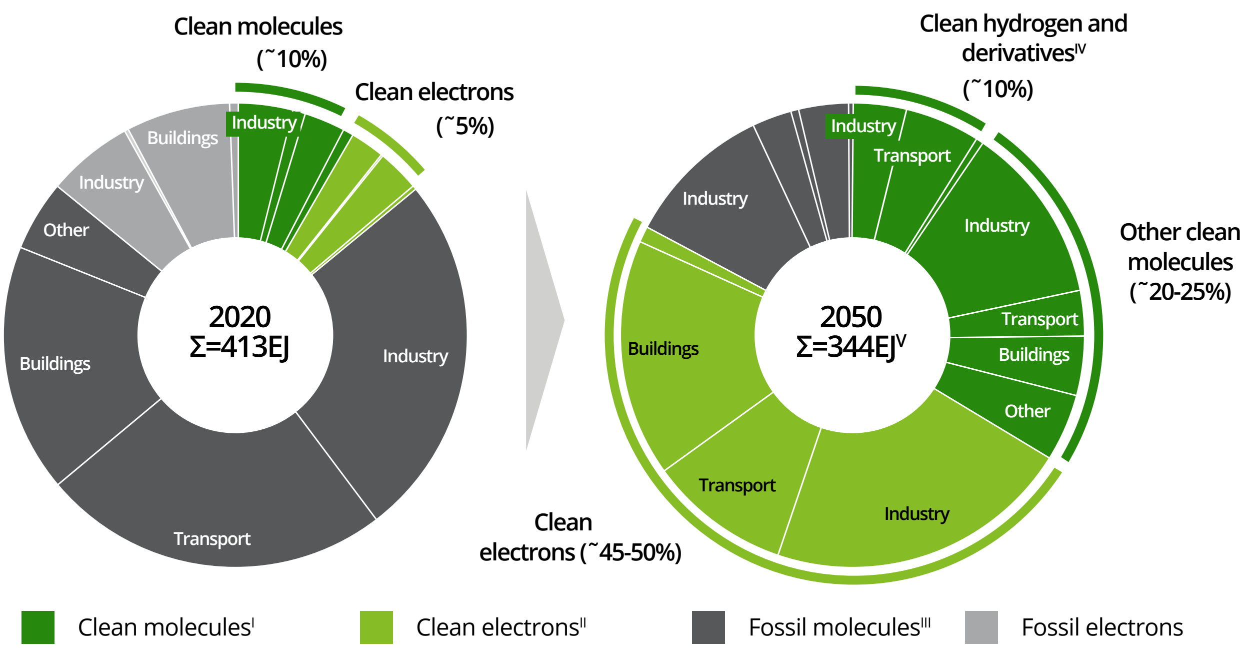
Clean hydrogen will likely play a key role in the future energy system – particularly in decarbonizing hard-to-abate sectors. By 2030, clean hydrogen is expected to be used in sectors such as methanol, refining, aviation, and road freight, and expand into other sectors such as shipping thereafter.

The global energy system consumed approximately 410 exajoule (EJ) of energy in 2020[3], mainly from fossil molecules, across the industrial (e.g., chemicals, steel), transport (e.g., cars, shipping, aviation, road freight) and buildings sectors.

Although electrification solutions will play an important part in decarbonization, molecule-based energy carriers are likely to deliver approximately 30%–35% of total energy consumption by 2050[4]. Within this, hydrogen is expected to constitute 35% of the molecular energy carriers, which translates to approximately 10%, or around 35 EJ, of the total energy consumption[5] (***Figure 2***).

Molecular energy carriers are 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 compared to batteries to fuel heavy-duty vehicles, and can store the electricity generated from renewables.

Figure 2: Global final energy consumption 2020 vs. 2050 (IEA 'Net-Zero Emissions by 2050' Scenario)



Notes: Includes energy carriers used as fuel, as well as feedstock in industry (e.g., naphtha in petrochemicals, natural gas in ammonia production); I) Incl. hydrogen, biofuels, heat and fossil fuels with CCUS; II) Incl. electricity production from renewables, and natural gas with CCUS / coal with CCUS; III) Fossil molecules that remain in 2050 are used where carbon is embodied in the product such as plastics and in sectors where low-carbon technology options are scarce (i.e., primarily oil in industrial applications); IV) Incl. hydrogen derivatives such as ammonia, methanol, and Sustainable Aviation Fuel (SAF); V) Energy efficiency measures and electrification are the two main contributing factors to the decline in total final energy consumption, with behavioral changes and materials efficiency also playing a role. Without these improvements, final energy consumption in 2050 would be expected to be around 640 EJ.

Source: IEA World Energy Outlook 2022; IEA 'Net Zero by 2050'; Deloitte analysis

The specific potential and timing of clean hydrogen varies by sector, due to particular factors in each (***Figure 3***). In the chemicals sector, for instance, gray hydrogen is already used, so few asset changes and therefore limited investments are needed to produce ammonia and methanol using clean hydrogen. Similarly, refining also uses gray hydrogen already, so relatively few process changes will be required for it to switch too. In addition, emerging regulations are promoting take-up by 2030 in these sectors, as well as in aviation and road freight.

Natural demand – driven by pressure from customers demanding green products, rather than by regulation – can also play a role in early take-up in sectors such as steel (specifically flat steel[6]), although large-scale adoption will likely come after 2030.

In shipping, technologies remain immature, and decarbonization pathways unclear (***see*** ***Chapter 2.3, Technology***), so demand is likely to pick up post-2030. Finally, the economics of sectors such as cars and buildings (space heating) mean they're unlikely to use hydrogen extensively and, if they do, it will likely be post-2030.

Figure 3: 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**
Industry	Ammonia	H	Feedstock to **produce ammonia**	✓	✓	Possible **voluntary demand for food** (green 'farm-to-fork'), and **ease of asset replacement**
Industry	Methanol	H	Feedstock to **produce methanol**	✓	✓	**Possible voluntary demand for methanol in shipping, ease of asset replacement,** and **emerging regulations**
Industry	Refining	H	Feedstock for **hydro-cracking and -treating**	✓	✓	
Industry	Other chemicals	M	Feedstock and / or fuel for **steam cracking**	~	~	
Industry	Cement	L	**Booster fuel** to increase calorific value, but competes with low-cost biomass as fuel	X	~	
Industry	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**
Mobility	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**
Mobility	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**
Mobility	Trains	M	Fuel to **replace diesel-engine trains** in long-haul transport	~	~	
Mobility	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	~	
Build	Commercial	L		X	~	
Power		M	Balance intermittency from renewables through **energy storage**	X	~	

High | Medium | Low

Notes: I) Incl. non-ferrous metals, food, paper, pulp, glass, ceramics, wood, machinery, agriculture, textiles and manufacturing II) Direct Reduced Iron or Blast Furnace + Basic Oxygen Furnace III) Original Equipment Manufacturer

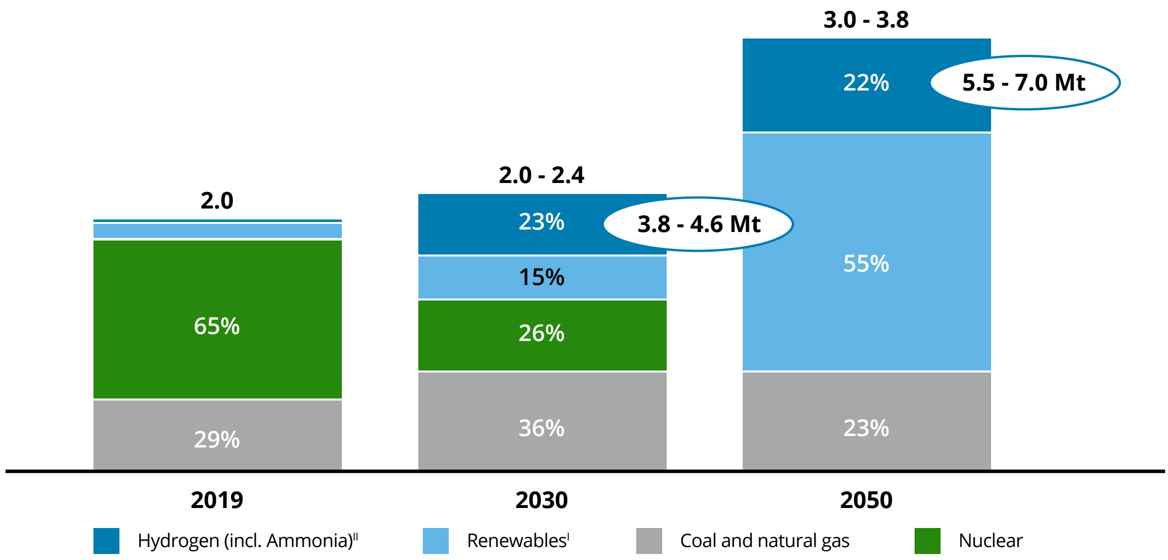
Source: IEA 'Net-Zero Emissions by 2050'; Deloitte analysis

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 (***Figure 4***), 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).

Figure 4: Clean hydrogen in the South Korean power sector (EJ) – INDICATIVE



Notes: I) 60% solar, 25% offshore wind and 15% onshore wind in 2050; incl. grid imports; II) Including dedicated and blending turbines and fuel cells

Source: South Korean Ministry of Trade, Industry and Energy ('1st Basic Plan for the Implementation of Hydrogen Economy', '9th Basic Plan for Electricity', '2050 Carbon Neutrality Roadmap'), Deloitte Energy System Model

1.2 Clean hydrogen supply momentum

Although announcements of clean hydrogen supply projects are accelerating, three times the capacity announced so far will need to come onstream by 2030, to meet expected demand

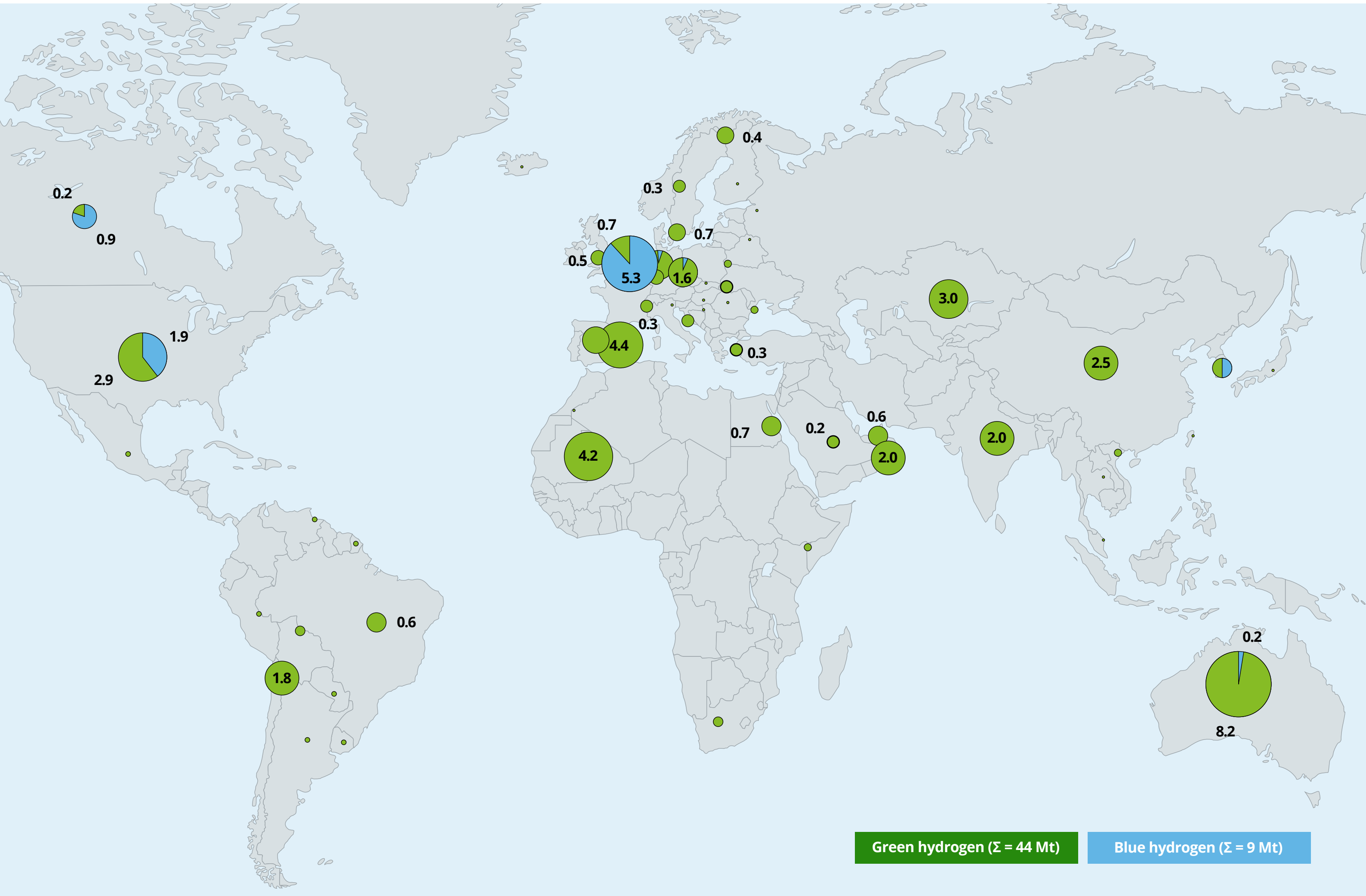
Using 2021 figures, global hydrogen supply stands at approximately 90 Megaton (Mt), of which approximately 99% is gray. Gray hydrogen is produced using unabated fossil fuels, and used mainly to produce ammonia (37%) and methanol (15%), and in refining (42%).

The Deloitte Energy Transition Monitor maps and analyzes all global announcements on clean hydrogen supply projects (including derivatives). Recent announcements to produce clean hydrogen have increased in the past year: as of August 2022, newly announced projects would create production capacity for 44 Mt green hydrogen, produced using renewable electricity plus electrolysis, and 9 Mt of blue hydrogen, produced using non-renewable fossil fuels plus carbon capture and storage (CCUS) of CO_2.

However, at least half of these projects are yet to announce specific plans, and only 10 (< 1% of announced capacity) have passed FID – the largest of which are China's 'Xinjiang Kuqa' project (300 megawatts (MW)) and Holland Hydrogen 1 (200 MW).[7]

In recent months, there have also been increasing discussions – although no significant announcements – around pink hydrogen, which is produced from nuclear energy plus electrolysis. Interest is picking up because pink hydrogen can enable diversification of the electricity system (vs. a system of only intermittent renewables plus hydrogen storage); it can boost the load factor of the electrolyzer and decrease the levelized cost of hydrogen (LCOH); and because developments in small modular nuclear reactors (SMRs) could also lower capital costs and development times.

Figure 5: Operational and announced clean hydrogen supply capacity by country[I] (Mt / year, August '22)



Note: I) Incl. projects in operational, planned (pre- and post-FID) and ambition (early projects without specific plans) stages. Projects have not been ranked on likelihood to materialize

Source: Deloitte Energy Transition Monitor

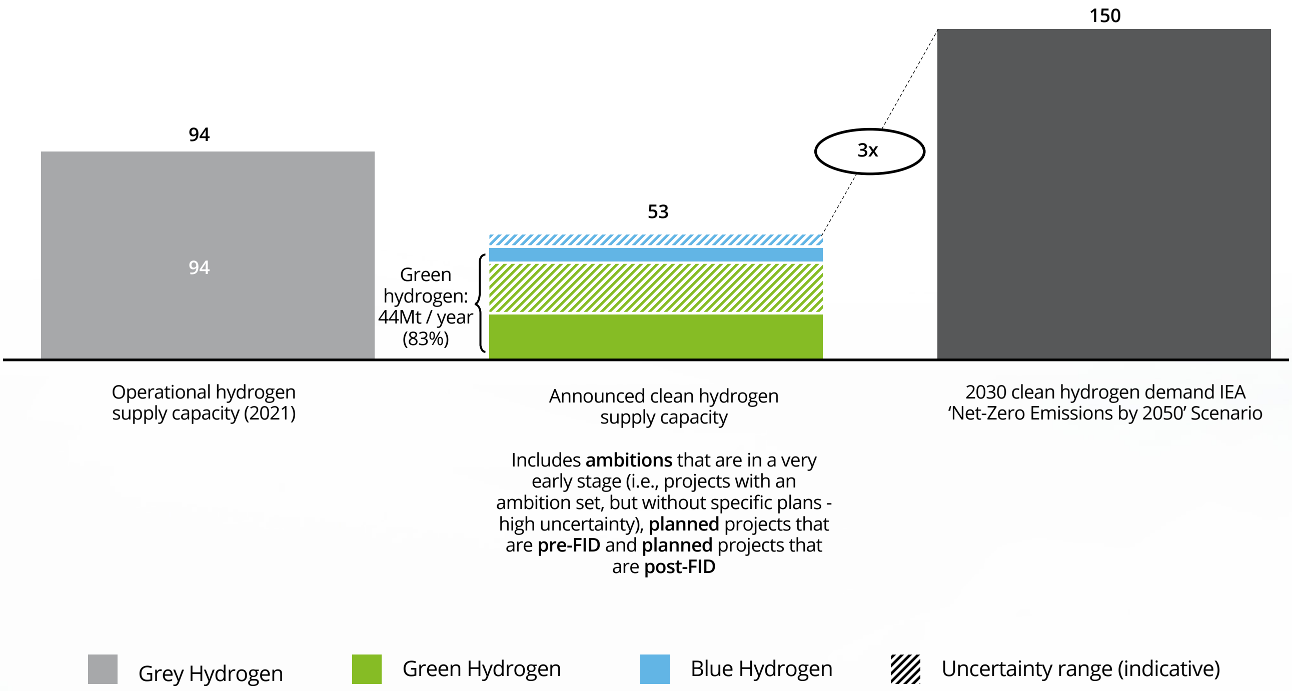
"There will not be enough hydrogen in the next years to meet all needs, and it will be expensive, so we need to be selective and start where it makes sense" – EVP Hydrogen, chemicals company

Most hydrogen project announcements have stemmed from Europe, the Middle East, the United States, and Australia (***Figure 5***). So far, there have been announcements for blue hydrogen projects from the UK (5.3 Mt, 60% of blue hydrogen capacity), US (1.9 Mt, 20%), and Canada (0.9 Mt, 10%) – mostly located near existing plants and/or reservoirs. We expect to see more blue 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., Inflation Reduction Act in the US).

Overall, even if all announced supply capacity projects were to materialize, it would still be insufficient (***Figure 6***). The IEA 'Net Zero by 2050' Scenario estimates that three times the capacity announced to date is needed by 2030.

Figure 6: Global operational and announced clean hydrogen supply capacity (August '22) vs. expected demand (Mt / year)



Projects have not been evaluated or ranked on likelihood to materialize

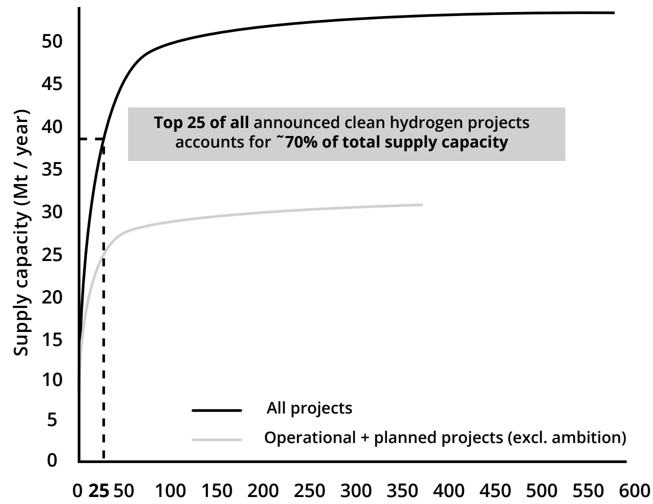
Source: Deloitte Energy Transition Monitor, IEA World Energy Outlook 2022, IEA 'Net-Zero Emissions by 2050' Scenario

Of the approximately 600 projects currently announced or operational, the 25 largest represent about 70% of total capacity (***Figure 7***), so there will be a broad range of scale that includes many small and a few large projects. Together, these can serve the variety of demand for hydrogen, from supplying single local plants, to creating scale and stimulated infrastructure changes. These are detailed further in Chapter 2.4.

Alongside hydrogen production capacity, the Deloitte Energy Transition Monitor has also recorded a number of announcements for hydrogen derivatives (***Figure 8***). This includes 80 Mt low-carbon ammonia production (44% of current global consumption) – mainly in Australia and the Middle East. For aviation, 12 Mt sustainable aviation fuel (SAF) capacity (4% of current kerosene demand) has been announced, mainly in Europe, the US, and Singapore, where many supply agreements for SAF are also being created with airlines and airports.

Announced low-carbon methanol production capacity is only ~2 Mt capacity (2% of current consumption) – mainly in Europe and the US. In shipping, a large share of this capacity is to be used to create blended shipping fuel while dual-fuel ships are being ordered. However, most of the announced hydrogen derivative capacity is at an early pre-FID stage, and will be dependent on sufficient hydrogen supply if it is to progress.

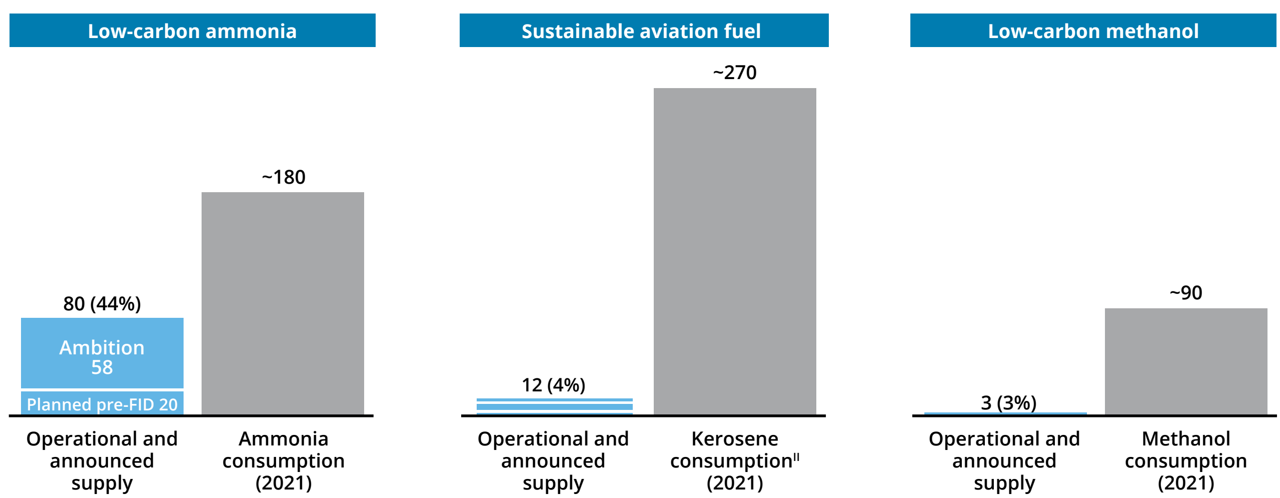
Figure 7: Global operational and announced clean hydrogen supply projects (August '22)



Note: Projects have not been assessed on likelihood to materialize.

Source: Deloitte Energy Transition Monitor

Figure 8: Global operational and announced clean hydrogen derivatives supply capacity[I] (Mt/Year, August '22)



Note: I) Incl. projects in operational, planned (pre- and post-FID) and ambition (early projects without specific plans) stages. Projects have not been ranked on likelihood to materialize; II) IEA estimates 2021 jet fuel consumption at approximately 5.5 million barrels per day (mb / d)

Source: Deloitte Energy Transition Monitor, IEA 'Oil 2021: Analysis and forecast to 2026' report, IEA 'Ammonia Technology Roadmap', Company reports

2.1 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 is important to send clear signals to the market, and to stimulate regulated demand

Demand-side factors are critical for the creation of the clean hydrogen market. Within this, natural demand (demand emerging irrespective of regulatory support) is important: although unlikely to play a big role in scaling the market, it can help to stimulate regulations for wider adoption.

Deloitte has identified three factors that we believe characterize sectors likely to experience natural demand (***Figure 9***):

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 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.

"Demand factors are sometimes forgotten when we talk hydrogen; the focus is usually on production. We really need to involve the demand side in conversation, understand their needs, and work with them to transform"
– Director Hydrogen, energy company

Figure 9: 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[I] (~15% of market)	✓		~	★ ⯪ ☆
Industry	Ammonia	Food	~			⯪ ☆ ☆
Industry	Methanol	Container shipping (~25% of market)	~		✓	★ ⯪ ☆
Industry	Refining			✓		★ ☆ ☆
Industry	Other chemicals	Packaging, cosmetics	✓	✓	~	★ ★ ⯪
Industry	Cement	Government	*Limited clean hydrogen potential*			☆ ☆ ☆
Industry	Other industry		*Limited clean hydrogen potential*			☆ ☆ ☆
Mobility	Road freight	Branded fleet owners	✓	✓		★ ★ ☆
Mobility	Deep-sea	Container shipping (~25% of market)	~		✓	★ ⯪ ☆
Mobility	Aviation	Business travel and select cargo	✓	✓	~	★ ★ ⯪
Mobility	Trains	Diesel long-haul trains	✓		✓	★ ★ ☆
Mobility	Cars		*Limited clean hydrogen potential*			☆ ☆ ☆
Buildings	Residential		*Limited clean hydrogen potential*			☆ ☆ ☆
Buildings	Commercial		*Limited clean hydrogen potential*			☆ ☆ ☆
Power	Power			✓		★ ☆ ☆

clean hydrogen potential

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 analysis, Interviews with executives and leaders across sectors

Engagements with CEOs and executives reinforced the need for companies to develop **new value propositions [solution]** that encourage the adoption of low-carbon products. There are a number of different mechanisms, as described below.

- **Steel:** offering green flat steel could help original equipment manufacturers (OEMs) to differentiate, by creating a green vehicle (for example a full green EV) that goes beyond battery electric vs. internal combustion engine. This can provide new benefits to consumers who are aiming to reduce their carbon footprint and looking for green products. Additionally, the increase in cost will not be significant, as the cost of steel is a small part of the total car costs. A Deloitte analysis has indicated that cost would increase by approximately $200 for a standard sedan passenger car. Several OEMs, mainly in Europe, are already making commitments to adopt green steel.

- **Aviation:** using SAF increases the cost of the airline ticket (fuel makes up about 30% of the ticket price), but airlines can consider providing additional benefits to users to offset this increase: for example, airlines can offer 'green' priority security, preferential seats, meal upgrades, loyalty points, green headrests for passengers who offset the most. Cargo would 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.

- **Shipping:** the marginal cost increase of consumer products is low (approximately 1%) in container shipping when switching to use green fuels, so that can be a starting point to create green value propositions. Another segment where this could apply is cruise shipping.

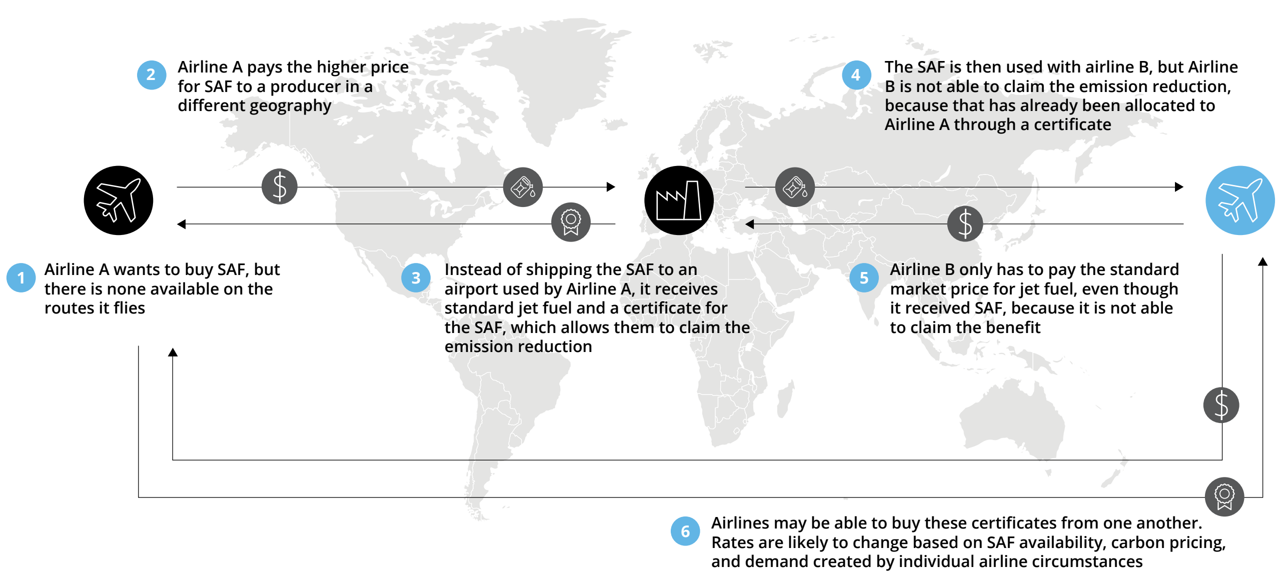
In addition, as demand tends to be fragmented across many players, another potential stimulus is to **aggregate demand and commit to long-term contracts [solution].** For example, aviation companies are already helping to reduce their corporate customers' third-party emissions, through procurement coalitions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

"By aggregating demand, we create certainty in a market that is in desperate need for it; customers need to collaborate together on green procurement and move faster than regulation"
– VP, corporate with frequent flying

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 fuels around the world to where they are needed partially negates the effect of decarbonization. Instead, **a global 'book and claim' certification scheme [solution]** can alleviate this issue, and allow regional pockets of demand to stimulate greater global supply of hydrogen. In aviation, for example, book and claim is helping airlines decarbonize by buying SAF even if local supply is limited (***Figure 10***).

As natural demand is highly dependent on sector characteristics and specific end-markets, it will unlikely be enough to activate hydrogen production and demand at scale. *Regulated* demand is expected to drive scale in this market – initially in areas with 'captive' demand (i.e., where hydrogen is already being used, such as in refineries) and in fuels for mobility sectors, given the emerging regulations. Regulation is covered in more depth in the next chapter.

Figure 10: 'Book and claim' mechanism in aviation – ILLUSTRATIVE



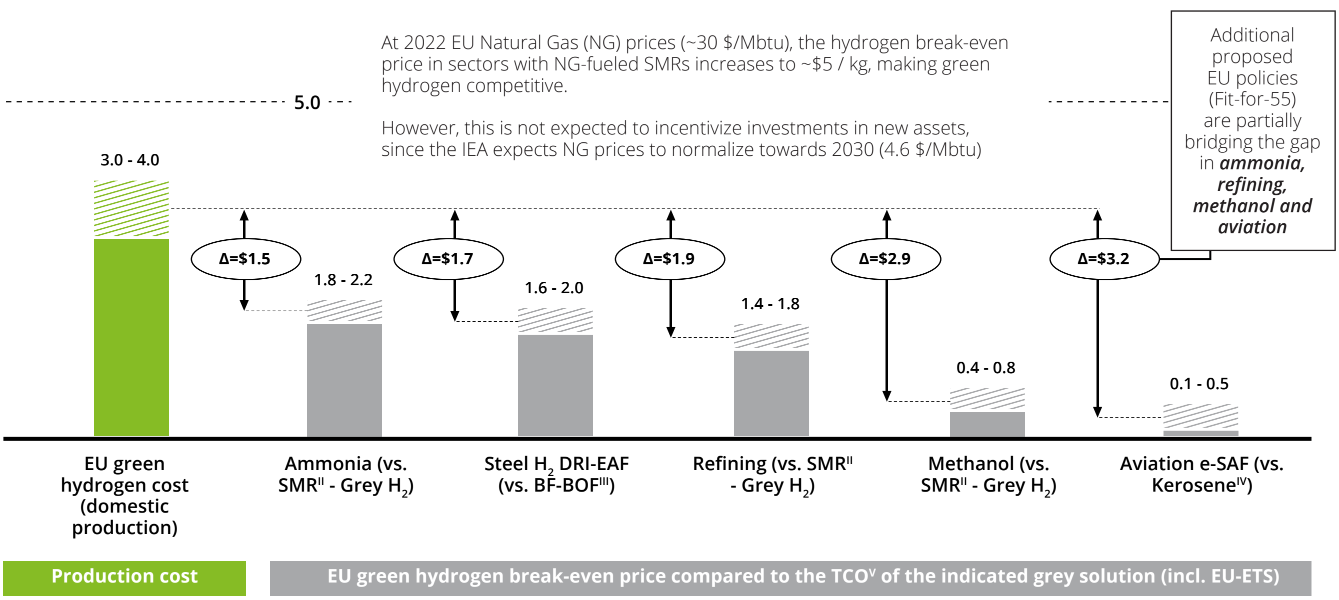
Source: Interviews with aviation executives and leaders, Deloitte analysis

2.2 Regulation

Adopting simple and synchronized regulations across supply and demand – based on a new nomenclature and certification around the emission intensity of hydrogen (for example, a Hydrogen Carbon Intensity Index) – and fast release of permits can accelerate hydrogen deployment and emission reduction

At present, the cost disadvantages of clean hydrogen, compared to gray 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[8], and no regulatory initiatives have been created (***Figure 11***). Current regulatory initiatives vary by region or country, to reflect local factors such as economic situation, local resources, industry maturity, and political position on how to stimulate the market. Across this regional variety, Deloitte has identified four emerging archetypes (***Figure 12***): a *joint focus* on demand and supply sides; *sole focus* on supply; *export* as a driver; and *testing*.

Figure 11: EU value gap between green hydrogen cost and break-even price in selected sectors (2030, $ / kg hydrogen)[I] – INDICATIVE



Note: I) All figures are in real terms excl. free allowances; commodity prices are based on IEA 'World Energy Outlook 2022: Net Zero Emission Scenario for 2030' (Natural gas $4.6 / Mbtu, Coal $52 / tonne, CO_2 price $140 / tonne, Crude oil $35 / barrel) II) Steam Methane Reforming; III) Blast Furnace – Basic Oxygen Furnace; IV) Incl. CO_2 emission cost; V) Total Cost of Ownership.

Source: IEA 'World Energy Outlook 2022', Deloitte Energy System Model

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 Scheme (EU ETS) carbon pricing with supply-side measures such as subsidies for Important Projects of Common European Interest (IPCEI).

While the demand-side measures try to make green hydrogen competitive against gray alternatives, the supply-side initiatives 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 making hydrogen solutions more competitive. This may have significant implications for the acceleration of hydrogen development in the EU in upcoming years, if longer-term uncertainty around natural gas prices remains.

Figure 12: Regulatory archetypes by region[I]

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 analysis

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

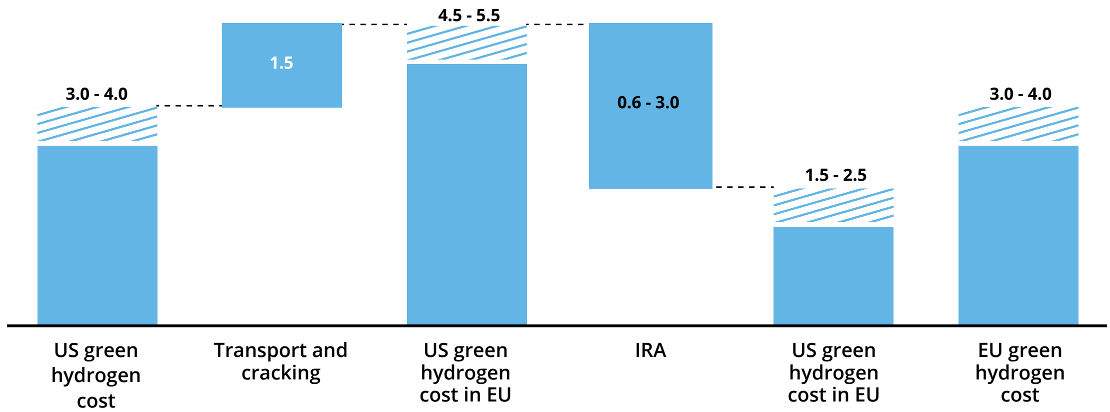
"The IRA can really disrupt, in a positive way, the export market of hydrogen and its derivatives" – Energy expert

The scale of this incentive – which can compensate most or all the production cost – is causing market disruption, such as attracting investments into the US from other regions, and creating the possibility for green hydrogen to be exported to Europe at a more competitive price (including transport and cracking) than local EU production (***Figure 13***). As a result, other regions are feeling motivated to create more competitive regulations and support for their own local production.

Australia is adopting an export-driven, supply-side approach to incentivize production and hub development for blue and green hydrogen. This includes $200 million (approximately AU$300 million) national and $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.

While the initial focus was on driving exports by harnessing Australia's low-cost renewable resources, local demand is now emerging, with some delays in the export projects. Meanwhile, several countries in the Middle East, Africa and South America are also pursuing an export-driven approach, given the abundance of low-cost natural gas and/or sources of renewable energy, as well as established capabilities and relationships in exporting fuels and products.

Figure 13: IRA impact on green hydrogen import cost in EU ($ / kg hydrogen) – ILLUSTRATIVE



Source: Deloitte analysis, Deloitte Energy System Model

Other regions are testing initiatives, such as China granting demand-side subsidies for some transport segments, and India supporting green hydrogen production by waiving its renewable electricity costs (for transmission and distribution), providing supply-side fiscal incentives and drafting demand obligations for some sectors. These approaches should become clearer as they evolve over the coming years.

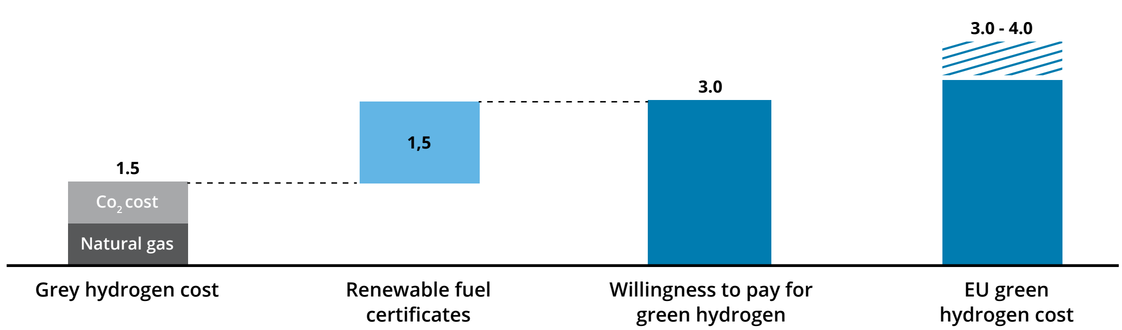
Deloitte analysis suggests large-scale change towards a net-zero energy system will require regulatory support beyond what has been announced, but some current policies can motivate investment and change.

Existing EU regulations are already changing the economics and merit order of hydrogen initiatives across sectors: for instance, RED III contains mandates that require industry and mobility to use hydrogen, and the Dutch implementation of the directive allows refineries to obtain 'Renewable fuel certificates' when using hydrogen, which helps to reduce the value gap (***Figure 14***).

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

"***To use clean hydrogen in ammonia production is not as simple as just shutting down an SMR – we need to make changes to our assets and operations"*** – CEO, low-cabon products company

Figure 14: RED III impact on Dutch refineries ($ / kg hydrogen) – ILLUSTRATIVE



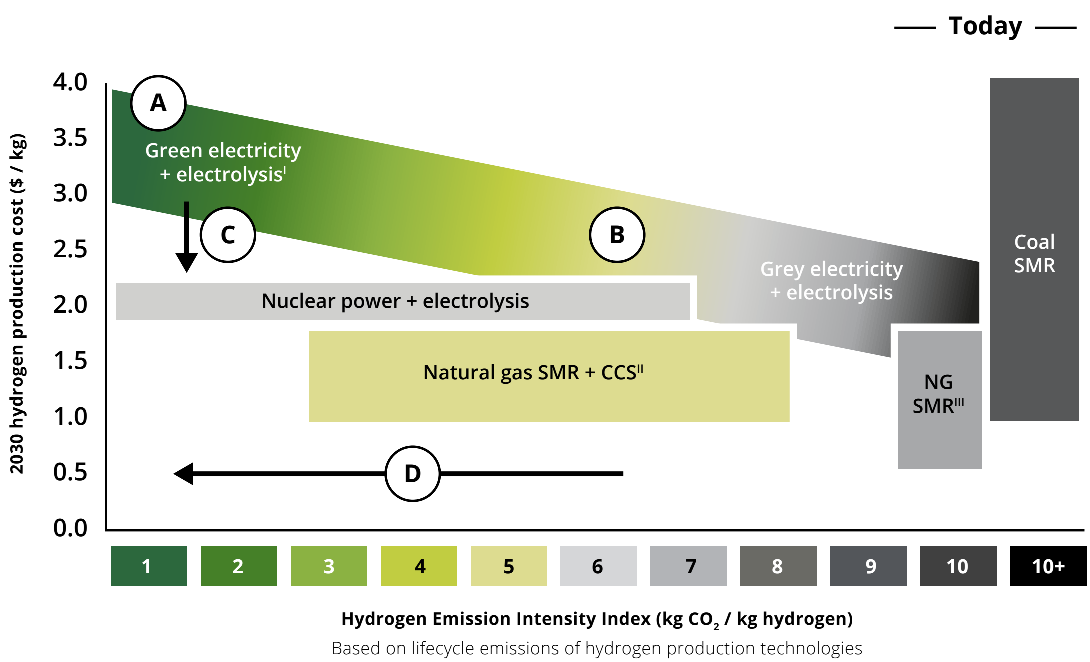
Source: Deloitte analysis, Deloitte Energy System Model

In addition, to avoid the price differential created by the gray/blue/green hydrogen classification, and thus encourage investment and reduce emissions, the industry executives Deloitte spoke to identified a more nuanced approach: to adopt a **Hydrogen Emission Intensity Index (HEII) [solution].** Such an index would 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 toward lower emissions (***Figure 15***).

"Adopting color schemes for hydrogen is not effective, and is delaying our investments" – VP, energy company

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 15: Hydrogen Emission Intensity Index (HEII)



A 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.

B 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).

C 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.

D 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 will reduce, and thus reduce production costs for low-HEII hydrogen projects. The more fine-grained HEII metric can then enable policies that encourage progressive shifts toward lower HEII levels.

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

Another consideration is that permit application timelines tend to take a long time, and can hinder hydrogen projects from moving post-FID. For example, according to Deloitte 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 [solution]** – and the administrative capacity to support them. For instance, Portugal recently decided to scrap mandatory environmental assessments for green hydrogen projects from March 2023.[9]

"Faster release of permits can remove a big burden and help investors move into implementation faster" – Project General Manager, energy company

2.3 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, and scale fast' approach to production development is needed, to quickly balance large-scale needs and short-term supply chain constraints

Sectors that have clear decarbonization pathways and mature technology should be faster to adopt clean hydrogen, but those not yet at the adoption stage should develop **targeted plans to address their specific challenges and create demand [solution]** (***Figure 16***). Depending on the positioning of the sector along the two dimensions, the solutions could be:

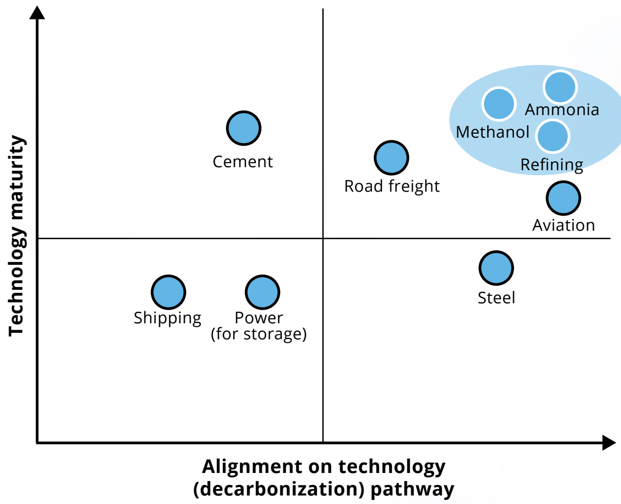
- targeted research and development (R&D) and piloting – increase investments and pilots to mature and deploy the technology; and/or

- industry collaboration and alignment – the sector should collaborate to drive alignment, and agree short-term wins to drive investment.

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 is aligned on this clear decarbonization pathway. Meanwhile, road freight shows some alignment on pathways, and hydrogen fuel cell technology is fairly mature, but there is a possibility that improvements in electric batteries will turn out to be more competitive.

However, in some sectors, technological maturity is deemed low. In steel, for example, the pathways are known – whether direct reduced iron (DRI), or CCS, but the technological maturity of both 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 also requires improvement. In shipping, progress has stalled, which Deloitte's research suggests is 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 require different ship designs, crews with different capabilities, different operations, and different port infrastructure compared to today.

Figure 16: Technology maturity vs. alignment per sector[I]



Note: I) Only showing industries previously defined as have a medium or high role for clean hydrogen in the future

Source: IEA 'Net-Zero Emissions by 2050' Scenario, Deloitte analysis

The supply side may well need to think differently about development options to both deliver sufficient capacity, and start quickly. Around 80% of announced projects are small (< 100 kt), as illustrated in Chapter 1.2, and provide the capacity to decarbonize, at most, a few local plants, but not create economies of scale. Only large-scale projects can reduce production costs, drive infrastructure developments, decrease the societal cost, and decarbonize the largest industrial plants.

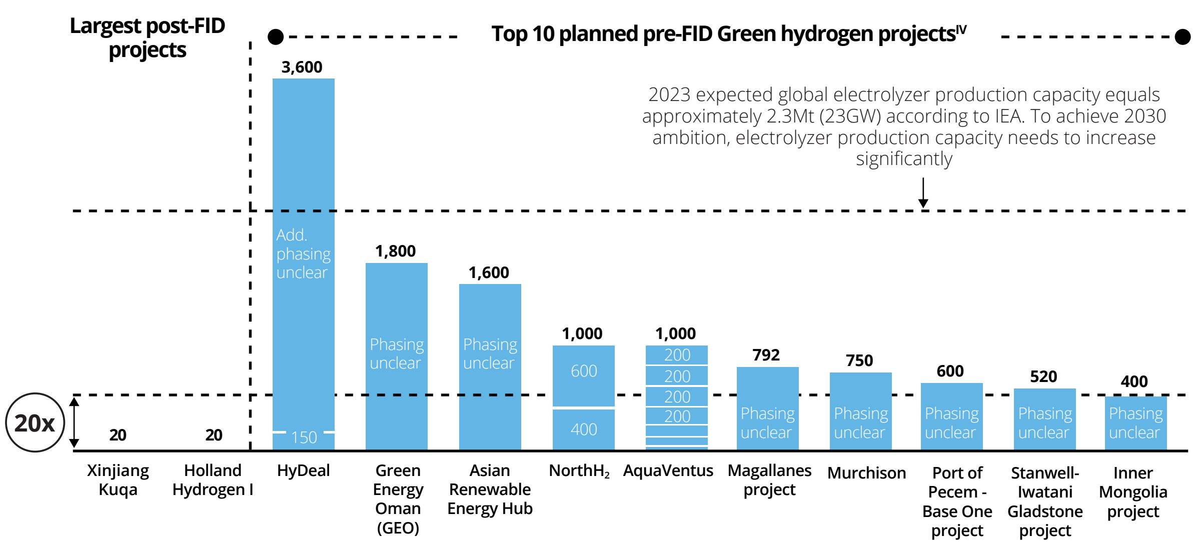
To illustrate this, according to Deloitte analysis, one of the world's 10 largest green hydrogen projects could decarbonize only one steel plant (requiring ~700 kt hydrogen) and one fertilizer plant (~300 kt).

"It is very hard to comprehend how much hydrogen we need. We need many, many large-scale projects, and that is not simple"
– Vice President Hydrogen, steel company

Despite the clear ambition for large-scale projects, the reality is that today's two largest post-FID projects may each deliver capacity of only approximately 20 kt, due in 2023 (China), and 2025 (Europe).[10] If we consider the tenth-largest project, we would need a 20-fold increase in capacity, compared to the two largest projects, to make it happen – and this needs to happen before 2030, which poses quite a big technological, operational, and supply chain challenge (***Figure 17***).

Given these challenges, a more pragmatic approach would be to set big goals – because this is needed, and will have the desired impact – but aim to start small, to create volume while addressing current technical and supply chain constraints – i.e., **'think big, start small, scale fast' [solution].** In parallel, technological development must be accelerated through R&D and digitization (e.g., to mature offshore electrolysis and increase asset efficiencies), and supply chains must be scaled up.

Figure 17: Top 10 planned pre-FID green hydrogen supply projects vs. largest post-FID projects (kt / year, August '22)



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

2.4 Assets, infrastructure and supply

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

Standard replacement cycles and low asset replacement momentum, across sectors not already using hydrogen, inhibit the take-up of hydrogen, which will likely require an immediate shift to **faster asset cycles [solution].** In particular, Deloitte analysis indicates that less than 1% of global asset bases in hard-to-abate sectors are undergoing operational decarbonization. Asset replacement cycles are typically long, and replacement rates low: in steel making, 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.

Although asset replacement can be accelerated, the approach and potential varies by sector (***Figure 18***). For example, aviation can use SAF as a drop-in replacement for legacy fuel. In steel, a partial short-term shift is possible by blending up to 20% clean hydrogen into the fuel for existing assets, but the switch from blast furnaces to direct reduced iron (DRI) and electric arc furnace (EAF) assets will take many years. Although road freight has much shorter asset lifespans than steel, the asset base is significantly larger, with approximately 30 million trucks globally, compared to around 500 steel plants.

Rather than delay progress by waiting for full asset replacement for green hydrogen, a gradual move from gray to green hydrogen (lowering the HEII discussed in Chapter 2.2) could initiate a reduction of emissions, help develop large-scale capacity rapidly, and incentivize demand-side investment in new assets, such as fuel cell vehicles (FCVs).

Large-scale clean hydrogen capacity would also need significant investment to transport it, in modes of transport and infrastructure, and to produce it, in renewable energy supply and distribution.

Figure 18: Asset replacement momentum and ease to accelerate – ILLUSTRATIVE

Sectors	Asset replacement momentum (July '22)		Ease to accelerate asset replacement	
	Operational decarbonization projects	Global asset base		
Ammonia	7 plants ~1.20%	580 plants 100%	H	Hydrogen is already used as a **feedstock** in the current production process
Aviation	No aircraft change needed 100%	30k aircrafts 100%	H	**E-SAF** and **Bio-SAF** can be used as **drop-in fuel** in operational airplanes
Cement	35+[I] plants ~1.00%	3.6k plants 100%	H	Hydrogen is suited as **booster fuel** in current production process
Steel	4 plants ~0.70%	550 plants 100%	M	Hydrogen **can be blended** into a **blast furnace** (max. 20%) without major asset changes; full asset changes (i.e., to Direct Reduced Iron furnace) required for full hydrogen adoption
Road freight[II]	4k trucks ~0.01%	30M trucks 100%	L	Use of hydrogen requires **full asset changes** (i.e., new FCV trucks)
Shipping[III]	5 vessels ~0.01%	73k vessels 100%	L	Use of hydrogen (liquified or in ammonia/methanol form) requires **full asset changes** (i.e., new ships) and uncertainty about decarbonization pathway

Notes: I) Mainly plants that have tackled some of their emissions by using bio-fuel for heating or partial clinker substitutes. Additional measures are required to further bring down process emissions; II) Only projects related to heavy-duty road freight; III) Only projects related to international shipping (bulk carriers, tankers, container shipping), excluding operational LNG projects

Source: Deloitte Energy Transition Monitor, Deloitte analysis

Where supply and demand centers are in close proximity, **maximizing asset re-use can play a big role [solution].** Local hydrogen transport and CO_2 storage can use existing natural gas grids and disused reservoirs, respectively. However, for long-distance or high-volume seaborne transportation, hydrogen should be liquified or converted to ammonia, which could require new vessels, terminals, and cracking facilities (***Figure 19***). Similarly, new infrastructure would be needed to transport CO_2 to synthetic fuel producers, such as e-methanol producers, and provide reservoirs for its storage.

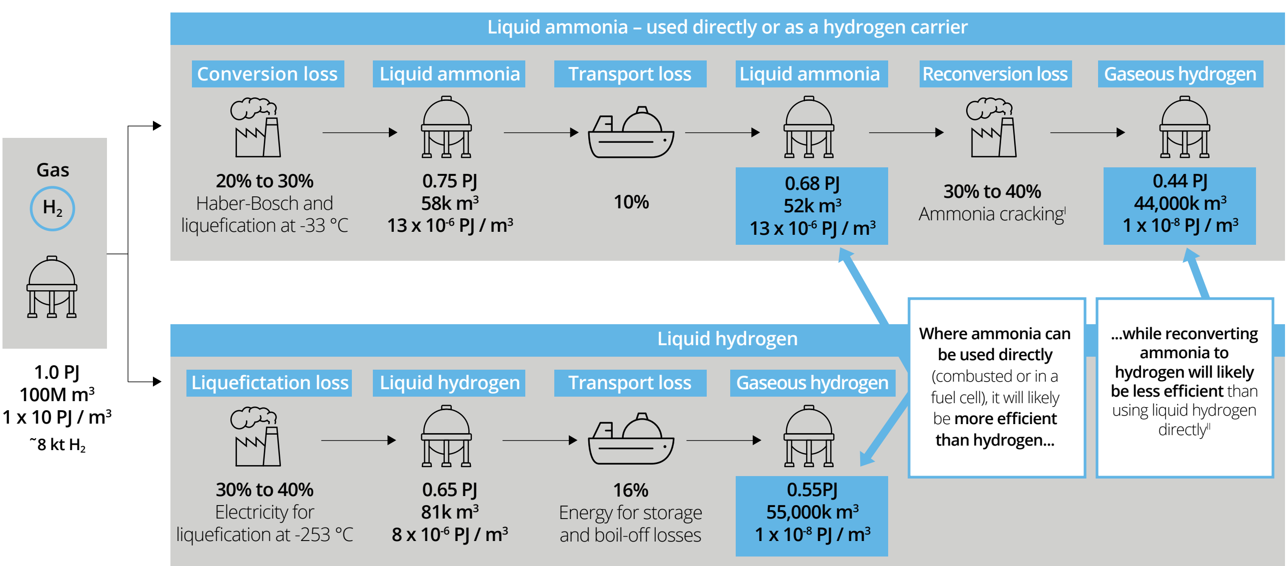
Infrastructure also plays a big role in the mobility sectors, where investments would be required to develop hydrogen fuel stations, charging stations, and bunker terminals for shipping fuels and SAF. For instance, there are currently approximately 200 hydrogen fuel stations operational globally for heavy-duty road transport (350 bar).

Despite its importance, little attention is currently being given to **infrastructure development [solution].** Conversations about grid upgrades and new pipelines have been ongoing for a while, but there has not been much action. This adds risk, and stalls progress, for both suppliers and off-takers – for example, suppliers in the Middle East who don't know how to transport the hydrogen to potential off-takers.

Some private companies have shown interest in investing in infrastructure, so collaboration – for instance, through Public Private Partnerships (PPP) – could help to accelerate development, as discussed in Chapter 2.5.

Meanwhile, supply-side investments are needed to increase the supply of renewable electricity and the grid capacity to distribute it. For instance, the expected green hydrogen demand in 2030[11] will 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. Deloitte analysis suggests one global solution to this shortfall may come though **supply-led hubs [solution]**, such as the Middle East and Australia, where solar and wind power are abundant and very low-cost. More discussion on hubs in Chapter 3.

Figure 19: Ammonia vs. hydrogen transportation efficiencies to ship 1 PJ of hydrogen – ILLUSTRATIVE



Notes: I) Ammonia cracking is energy intensive, requiring temperatures of >500 °C; II) Hydrogen use after reconversion also has downsides, as PEM fuel cells (e.g., in trucks) are vulnerable to trace amounts of NH3, requiring additional separation and purification

Source: 'Limitations of Ammonia as a Hydrogen Energy Carrier for the Transportation Sector' (Chatterjee et,. al. ACS Energy Letters 2021), Deloitte analysis

2.5 Collaboration

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

Collaboration, between energy suppliers and off-takers, and with government, finance, and technology organizations, can help overcome the barriers of capital, knowledge, and risk, to shift the market from its current, illiquid state, and instigate the large-scale projects that are needed.

Of the announced clean hydrogen projects, 80% are being developed by a small number of companies working together, while energy suppliers are collaborating across the value chain (e.g., with off-takers) and in the broader ecosystem (e.g., technology and investment businesses) to share capital, risk, and capability (***Figure 20***). At present, the Deloitte Energy Transition Monitor indicates that only around 10% of partnership project capacity is being developed with off-takers, and most of this is being developed between multiple suppliers (***Figure 21***).

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.

IOCs and NOCs are also able to create demand for hydrogen in their refineries and chemical plants. In addition, the emerging clean hydrogen sector is also attracting non-traditional players, such as new entrants and industrial gas companies that can bring capital, technical capabilities, or innovation (***Figure 22***).

Figure 20: Company concentration across selected energy carriers (% of global operational and planned supply capacity)

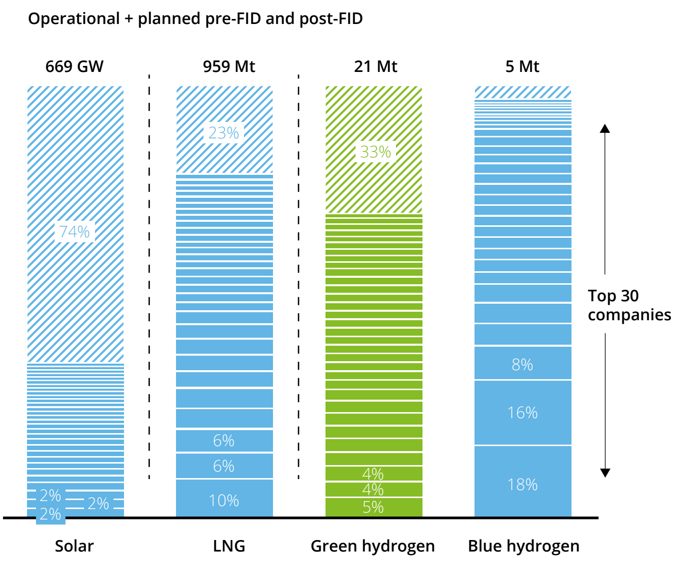
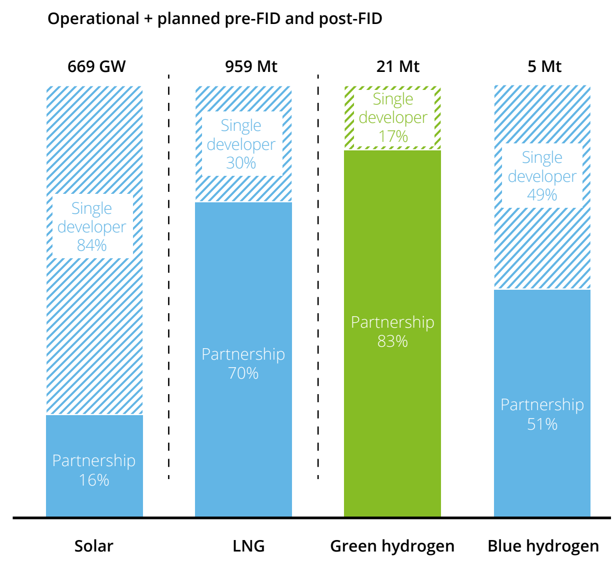
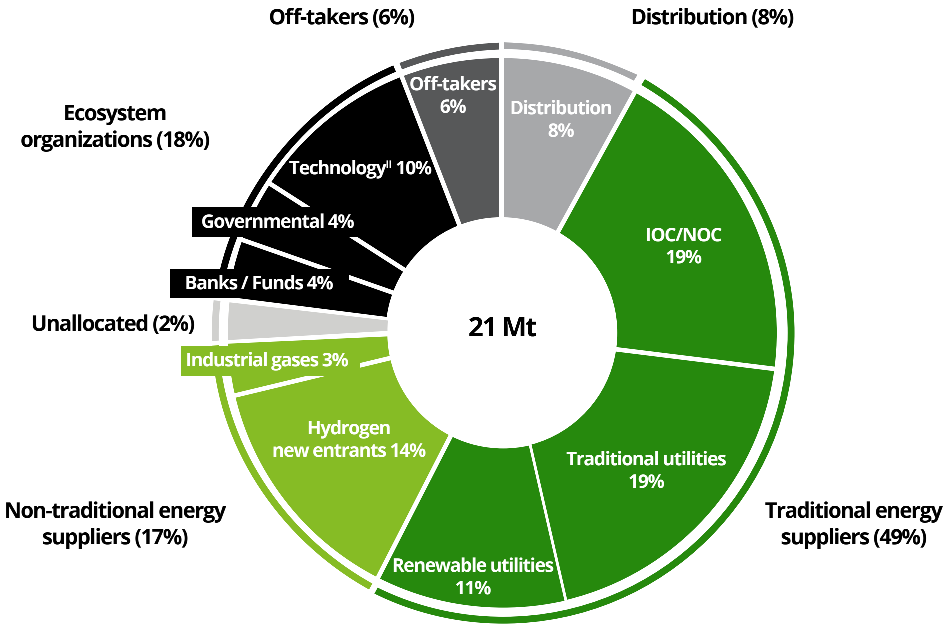


Figure 21: Partnerships vs. single developer shares across selected energy carriers (% of global operational and planned supply capacity)



Source: Deloitte Energy Transition Monitor

Figure 22: Green hydrogen operational and planned supply capacity by company type[I]



Note: I) Capacity of supply projects is allocated to companies involved based on equity shares where known and equal shares if unknown; II) Includes technology providers, original equipment manufacturers (OEMs), construction companies, engineering companies

Source: Deloitte Energy Transition Monitor

Although collaboration will remain important, its form is expected to change as the market evolves, leading to partnerships of fewer players. The current phase has seen large groups of suppliers working together, to bring learning and create option value, but the involvement of many companies means reconciling differences in priorities and decision-making approaches, which adds complexity, requires scarce project management talent, and slows down progress.

As a result, the next phase of development is expected to involve more streamlined collaborations that can act faster. Greater investment by off-takers in production projects is also expected, following similar models to LNG. Meanwhile, incumbents have the capabilities for large-scale clean hydrogen development, and are likely to continue having a major role.

Value in collaboration between suppliers and off-takers to lift barriers and synchronize on investments needed was also found during the cross-value-chain interviews conducted for the joint Shell-Deloitte study on decarbonizing the steel value chain: Decarbonizing the steel value chain: Forging new paths together.

More important than just collaboration, though, is the need for new commercial, business, and risk models that can address the systemic issues that at times delay investment. Current bilateral models are not efficiently addressing the value gap, or making projects happen, as evidenced by the scarcity of projects that have reached FID. Instead, **new business models [solution]** need to be considered that are, for instance, more integrated or coordinated along the hydrogen value chain. This can help to share value and risk, encouraging investment in this early, illiquid market (***Figure 23***).

"We need a business model solution to hydrogen deployment; technology in many cases is not the issue. How we work and collaborate is where the opportunity lies" – VP, steel company

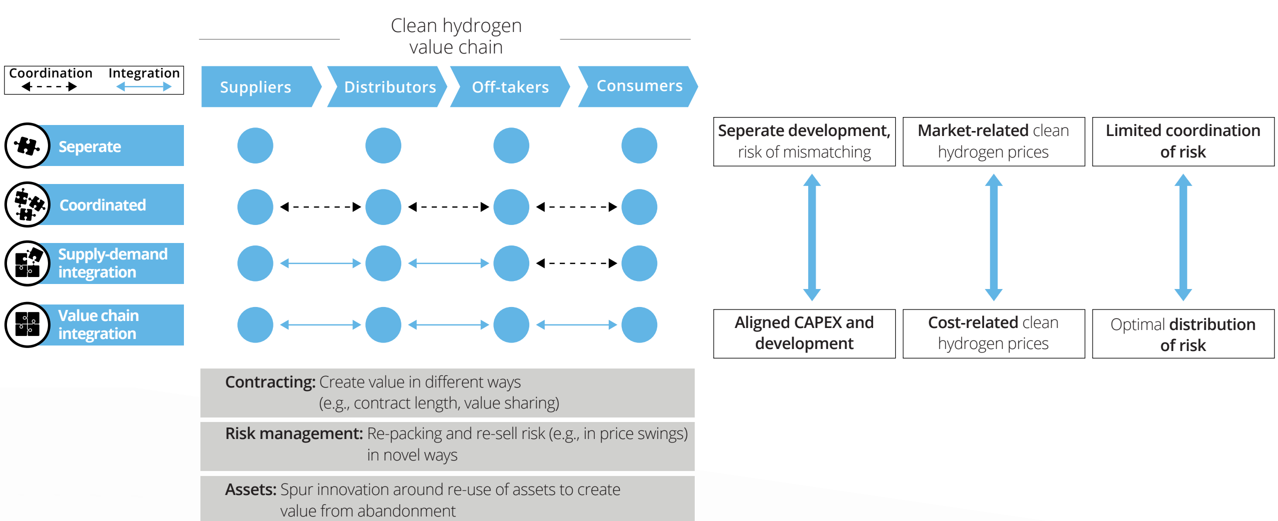
Increased integration might also entail having more transparent commercial conversations and setups, and using cost-based prices rather than market prices. This may decrease the need for subsidies, but also encourage companies to think about value-creation in different ways, by considering contracting, risk management and asset lifecycle norms. *Contracting* should account for value drivers beyond locked-in price in off-take agreements, and instead create value in different ways (e.g., length of agreement, cross-industry off-take agreements, etc). Novel *risk management* approaches may be required, to deal with excess risk through repacking and resale, with insurers playing a key role.

Finally, it seems inevitable that some existing infrastructure might need to be abandoned, or substantially retrofitted. Companies should understand how to spur innovation around the re-use and/or recycling of *assets*, to create value from abandonment, as discussed in Chapter 2.4.

Such new business models can also accelerate the deployment of innovative solutions, such as 'trucking as a service'. Because hydrogen trucks can prove expensive, and uneconomical, some companies have decided to invest in them to then lease them to road freight players. Doing so is helping to create the market for such trucks while they become less expensive to acquire. Similarly, mining companies are driving the forward integration of their supply chains, by buying low-emission ships and allowing others to operate them.

Alongside collaboration, capability development demands closer attention – partly because the hydrogen economy can create new employment opportunities, but mainly because the scarcity of such talent can be a major obstacle to getting hydrogen projects developed and operational. Effective measures to **build capability, and to attract and retain talent [solution]**, should focus on *education*; *re-skilling* to build on existing capabilities; *automation* to free up staff for new challenges; and extending the *retirement age*.

Figure 23: Business model considerations



Source: Deloitte analysis, Interviews with over 350 senior executives and experts across sectors

3.1 Hubs

The 'stars will align' in specific geographies with the conditions needed to accelerate hydrogen deployment at scale. These hubs will likely kick-start the hydrogen economy, and reduce the fragilities of existing global energy markets

The five factor conditions discussed in Chapter 2 can be brought together to accelerate large-scale hydrogen development, by forming hubs – i.e., geographic areas that combine:

- sufficient low-cost resources for hydrogen production;
- a large enough cluster of industry off-takers;
- supportive regulations; and
- a willingness to collaborate on reducing hydrogen costs, through both economies of scale and reduced infrastructure requirements.

Such hubs could create a foundation for global trading markets, by satisfying enough demand to reduce local energy market needs, and exporting any surplus production to regions that require (and will pay for) economically viable clean hydrogen.

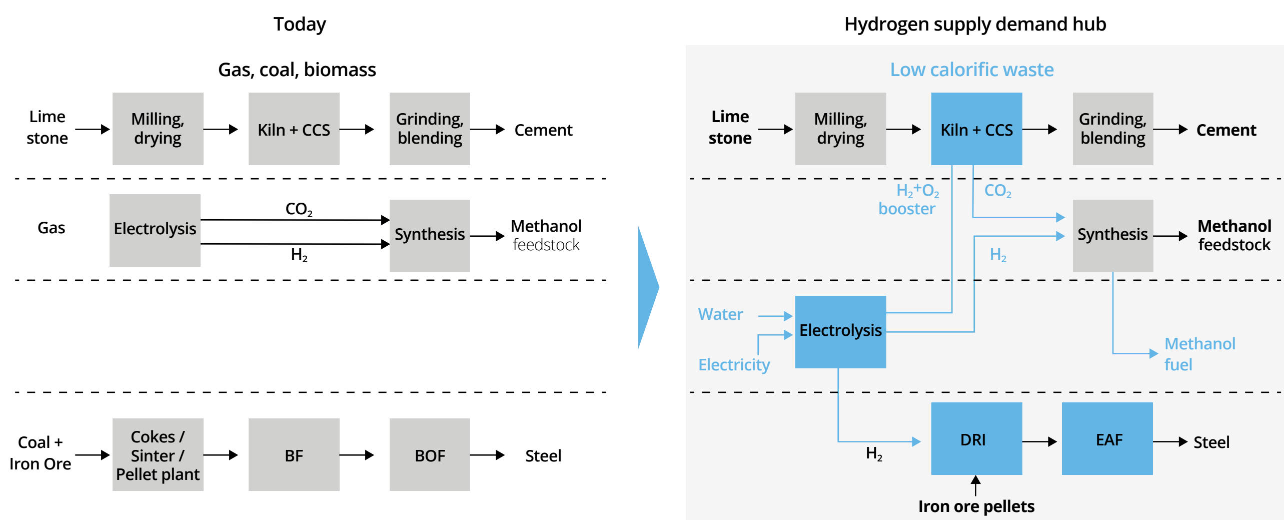
The hubs currently emerging can be categorized as supply-led, demand-led, or driven by both supply and demand. The latter will likely be key to stimulating clean hydrogen deployment at a local scale, by both creating supply chains and reducing costs. These hubs are most likely in regions that can develop 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 support the development of both supply and demand, through transparent regulations, standards and frameworks, and subsidies.

Across these factors, a willingness to collaborate is crucial in many activities, such as developing new business models, advocating for hydrogen take-up, granting market access, and sharing assets across sectors. For example, adding an electrolyzer can create synergies between the production of cement, methanol, and steel, and motivate new collaborative and commercial models (***Figure 24***).

Deloitte analysis has found that supply-led hubs are most likely to exist in geographies where production capacity exceeds local demand, such as the Middle East or US Gulf Coast, or where economic circumstances create lucrative export markets, whether to supply regions that lack alternatives, or through an overall shortage of supply. However, such export potential should be considered in the broader context of social license, and the expectation that hydrogen will be used improve local social welfare. Governments are therefore considering how to achieve a suitable balance of the societal and economic benefits from clean hydrogen.

"We want a real energy transition, not just a fuel transition – as in we don't want to end up with the same situation as the current fossil fuel export world, which doesn't really benefit local communities" – Professor of energy systems.

Figure 24: Decarbonization pathways for selected sectors – SIMPLIFIED



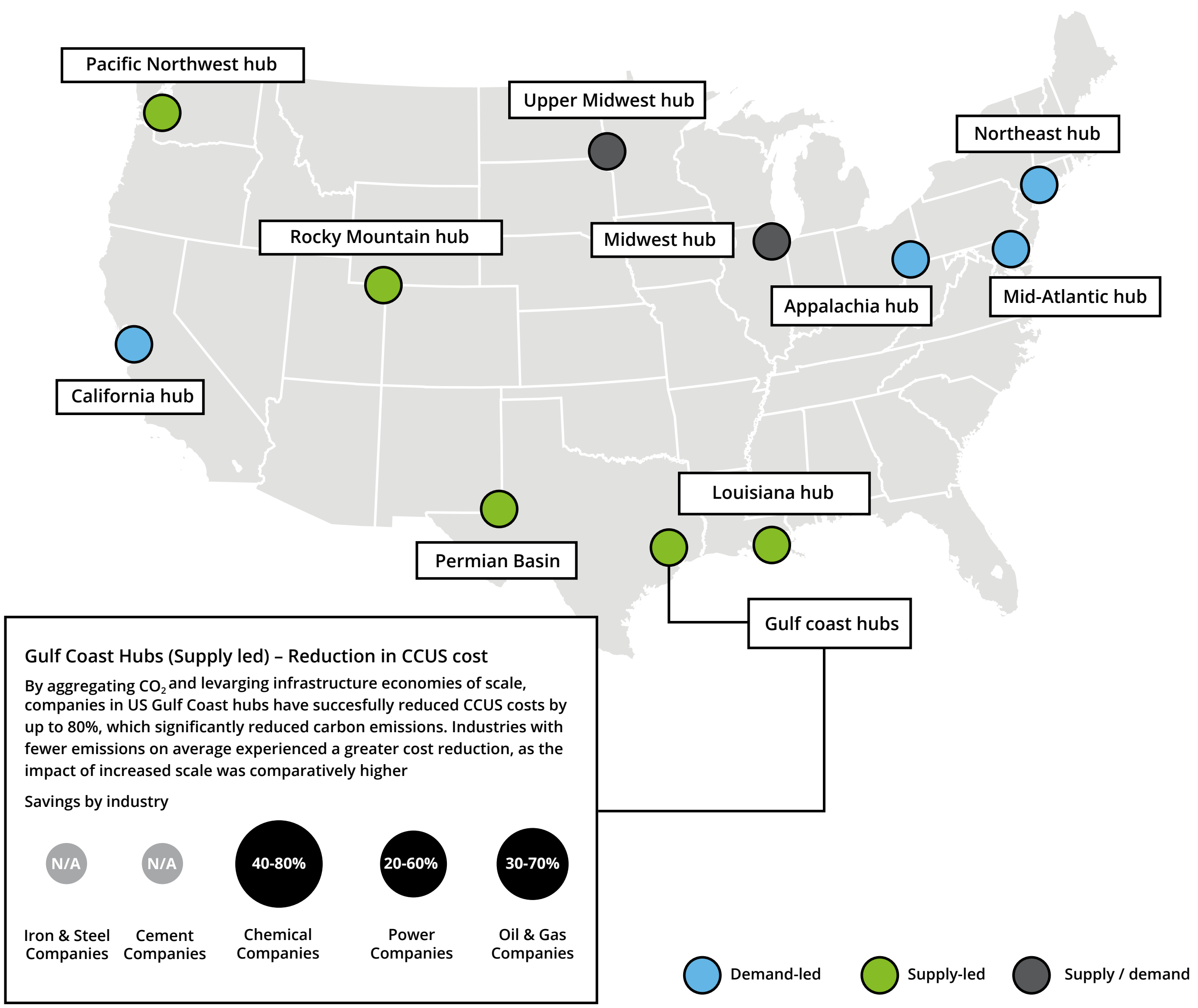
Source: Deloitte analysis, Interviews with over 350 senior executives and experts across sectors

Deloitte analysis has also found that 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.

Deloitte's recent study of the business case for hubs found that participation as part of a hub could reduce a company's infrastructure costs by up to 95% compared with investing alone to achieve the same production volumes and emissions reduction (***Figure 25***). Hubs necessarily require a new way to collaborate and possibly share infrastructure in the ecosystem – sometimes with former competitors – to develop a sense of 'co-opetition' between hub members, which can raise all their games, accelerate innovation, and scale up the mutual benefits.

"Let's not ponder about the chicken-and-egg problem of assets and infrastructure availability, but start to collaborate and enable the ecosystem to make it happen" – CEO, transportation company

Figure 25: Emerging hubs in the US – ILLUSTRATIVE



Source: Deloitte analysis, Interviews with over 350 senior executives and experts across sectors

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Our insights can help you take advantage of change. If you're looking for fresh ideas to address your challenges, we should talk.

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Acknowledgements

This piece of work would not have happened if not for the efforts of:

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Deloitte Tools

Deloitte Energy Transition Monitor

A database of 30,000+ energy transition demand and supply initiatives across sectors and energy vectors globally, including clean hydrogen, with a view on companies involved, maturity stage, timeline, capacity and location

Deloitte European Electricity Model (DEEM)

A tailor-made optimization model of the European power system that allows to assess the impact of fundamental shifts (policy change, technological breakthroughs etc.) on power prices, asset values, investments, and company strategies

Deloitte Energy System Model (ESM)

ESM forecasts energy demand scenarios by energy carrier, sector, region and company, including implications for emissions and primary energy supply. The forecast is based on company plans and techno-economic modeling of plausible decarbonization pathways.

Hydrogen Pathway Explorer Model (HyPE)

A tailor-made optimization model for assessing the green & clean hydrogen production potential, technology choice, investments, and trade for countries around the world

Deloitte Decarbonisation Solution

A suite of interactive modules tailored by sector and business that helps companies to aggregate current and future emission footprint, identify emission reduction targets, evaluate abatement projects, optimize the portfolio, assess short- and long-term risks, and report on plans

Deloitte Applied Research on Energy model (DARE)

Our in-house EU27+ energy system optimization model. It enables technoeconomic modeling of the entire energy system, delivers quantitative insights on main uncertainties along the energy transition journey, and provides energy transition pathways of key sectors, considering a wide range of economic activities for each of the member states of the EU27

Endnotes

[1] IEA. Net Zero by 2050. IEA, Paris. May 2021. Available from: https://www.iea.org/reports/net-zero-by-2050.

[2] European Commission. Directorate-General for Energy. Jan Cihlar, Ainhoa Villar Lejarreta, Anthony Wang, et al. Hydrogen generation in Europe: overview of costs and key benefits. Publications Office. July 2020. Available from: https://data.europa.eu/doi/10.2833/122757.

[3] IEA. Net Zero by 2050. IEA, Paris. May 2021. Available from: https://www.iea.org/reports/net-zero-by-2050.

[4] IEA. Net Zero by 2050. IEA, Paris. May 2021. Available from: https://www.iea.org/reports/net-zero-by-2050.

[5] IEA. Net Zero by 2050. IEA, Paris. May 2021. Available from: https://www.iea.org/reports/net-zero-by-2050.

[6] Mainly used in automotive, machinery, and domestic appliances.

[7] Announcements tracked by the Deloitte Energy Transition Monitor.

[8] EU natural gas price outlook in the IEA NZE by 2050 Scenario. Available from: https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf.

[9] Source: 'Absolutely crucial' | Portugal scrapping mandatory environmental assessments for green hydrogen projects | Hydrogen news and intelligence (hydrogeninsight.com).

[10] Deloitte Energy Transition Monitor.

[11] IEA NZE by 2050 Scenario. Available from: https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf.

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