Equilibrium | CARBON TRANSITION INFRASTRUCTURE

Hydrogen: Equilibrium's Perspective on Investment Opportunities

April 2023

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Overview

- Hydrogen’s clean burning properties have long driven attempts to make it a viable low carbon fuel; when combined with oxygen in a fuel cell, it produces only water, electricity, and heat
- Significant energy inputs are needed to produce hydrogen, most of which has historically come from fossil fuels
- End uses are numerous, from transportation to industrial processes, to fuels, and feedstocks; it is particularly suited to hard-to-electrify sectors, e.g., metals, chemicals, and long-haul transportation
- Proponents believe low carbon hydrogen could allow for a high energy-low emission future without compromising demand from traditionally high-emitting industries
- **Drivers** of the current surge of interest in low carbon hydrogen include:
    - A proliferation of climate change policies, net zero commitments, and incentives
    - Improved technologies that are closing the low-carbon hydrogen cost gap
    - Energy security concerns
    - The prospect of large-scale industry demand
    - Storage potential, including use as an alternative to batteries for transportation
- **Challenges** that have historically prevented scale and commercialization include:
    - Energy requirements for extraction
    - Failure of low-carbon hydrogen to achieve cost parity with fossil fuel-derived
    - Complex and costly storage and transport requirements
    - Inefficiencies and hazards resulting from hydrogen’s low density and volatility
    - A lack of supporting infrastructure, e.g., fueling stations and pipelines

Hydrogen Value Chain

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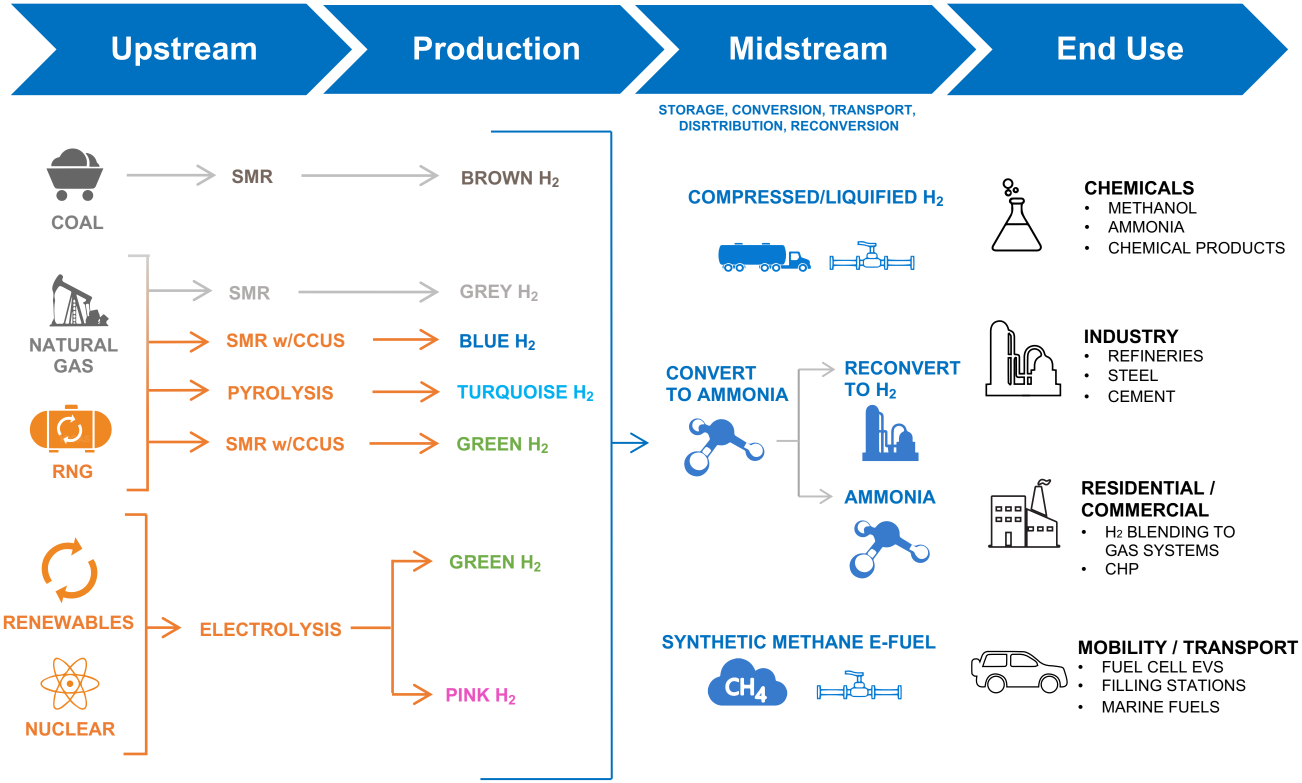

Conventional grey and brown hydrogen relies on coal-fired power or steam reforming of natural gas (SMR); SMR accounts for 95 percent of US hydrogen production

Blue hydrogen includes the addition of carbon capture, utilization, and storage (CCUS) to conventionally-fueled processes

Green hydrogen is produced via electrolysis powered by renewable energy

Pink hydrogen is produced via electrolysis powered by nuclear energy

Turquoise hydrogen is produced via methane pyrolysis; this process is still in the R&D stage and not yet commercialized

Source: Wood Mackenzie

Hydrogen Production

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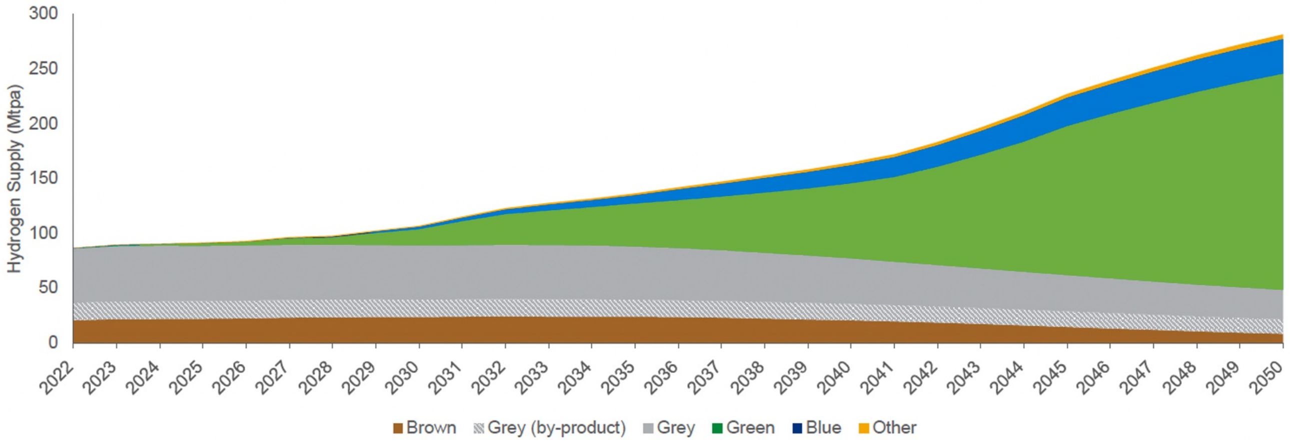
Is renewable natural gas (RNG) a viable source of energy for green hydrogen production?

- RNG producers are exploring its use as a means of producing green hydrogen, which will also diversity traditional RNG offtake
- RNG offers a pathway to produce high value, negative carbon intensity (CI) hydrogen via replacement of the conventional natural gas used in SMR facilities with CCUS

- Existing RNG volumes are minimal compared to natural gas requirements for planned, large scale, centralized hydrogen production facilities
- Using RNG to power electrolyzers would improve hydrogen CI and could provide a higher capacity factor vs. intermittent wind and solar resources; however, the latter are far easier to scale and will remain the focus for powering electrolytic green hydrogen production

- New technology may soon enable RNG-fueled hydrogen production outside of an SMR replacement; SoCalGas is constructing a combustion-free demonstration project, H2 SilverSTARS, that will power SunLine Transit Agency's fuel cell electric buses
- Skepticism regarding the use of RNG in fuel cell electric vehicles (FCEVs) stems from the inefficiency of converting one fuel into another, only to put it back into a fuel cell for a transport end use

GLOBAL HYDROGEN PRODUCTION FORECAST BY COLOR

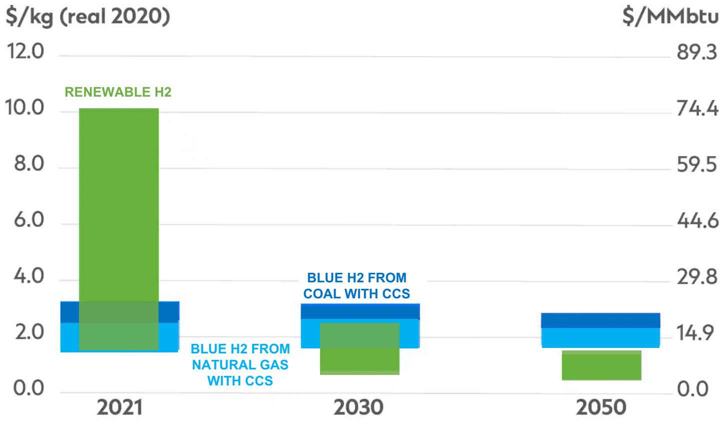


Green hydrogen will push conventional production to less than 20 percent of forecasted 2050 total

Source: Wood Mackenzie; "Fueling the Hydrogen Revolution with RNG", Biomass Magazine; "SoCalGas begins construction of RNG-to-hydrogen system in California", Canadian Biomass; "Hydrogen Production from RNG", CNG Delivery

Hydrogen Costs

PRODUCTION COSTS: GREEN VS BLUE HYDROGEN



Source: BloombergNEF. Assumes our optimistic electrolyzer cost scenario.

Green hydrogen will out-compete grey on cost in most markets by 2050

Source: Wood Mackenzie; BNEF; Independent Commodity Intelligence Services (ICIS); US DOE; McKinsey

- Cost competitiveness is dependent on natural gas pricing; countries with plentiful supplies have to-date leaned to blue hydrogen, e.g., the US and Canada
- **In North America, it costs 40 percent more to produce blue hydrogen than grey hydrogen, but this process becomes attractive where there are revenue-generating CO2 sequestration opportunities**
- The U.S. Department of Energy (DOE) reports green hydrogen production costs of about $5.00 per kg vs. $1.50 per kg for the grey variety; it aims to reduce the cost of green hydrogen to $2.00 per kg by 2025 and $1.00 per kg by 2030
- In Europe, green hydrogen is already cheaper to produce than grey because of high fossil gas prices
- Markets with abundant, cheap bases of solar and wind will see the cost of green hydrogen decrease most rapidly, e.g., France, the UK, Brazil, and Chile
- Forecasted 35 to 65 percent decreases in electrolyzer capex will make **sub-$2.00 per kg green hydrogen achievable in most markets by 2040**
- Lower cost production is driving project plans; the global low-carbon hydrogen pipeline has grown seven-fold since 2020, the majority of which targets green production in Europe, South America, and Asia
- **In North America, blue hydrogen projects have the most committed capital; however, U.S. Inflation Reduction Act (IRA) incentives are expected to shift the domestic focus to green**
- **It remains to be seen how much of the pipeline will materialize** as only seven percent of announced projects are at the final investment decision stage, under construction, or operational

Hydrogen Storage & Distribution

- Hydrogen storage and distribution presents significant scale-limiting challenges
- Production hubs should be centered around offtake because transportation is expensive; even considering price reductions and credits, transport costs could render hydrogen too expensive for distant offtake

"There's a big focus on driving down the price of hydrogen, but it can cost $4-6/kg just to transport. Hydrogen could be free, and it would still be too expensive" Matthew Blieske, CEO, Lifte H2

- **Liquid hydrogen** must be stored at extremely low temperature but offers the lowest cost of reconversion to its gaseous form as well as the highest purity
- **Compressed gaseous hydrogen** is highly explosive and has a very low energy density
- **Ammonia** is highly toxic but offers an easier means of transport and can utilize existing storage and conversion technologies, and shipping infrastructure, plus the option exists to use ammonia directly, without reconversion to hydrogen
- **Methanol** can be handled at atmospheric temperature and pressure and also allows for the use of mature technologies and distribution networks, though natural gas pipelines are only capable of carrying up to a 15 percent blend of hydrogen without leakage
- Research into **solid-state storage and liquid organic hydrogen carriers (LOHC)** is still in its infancy

LIQUID H_2

GASEOUS H_2

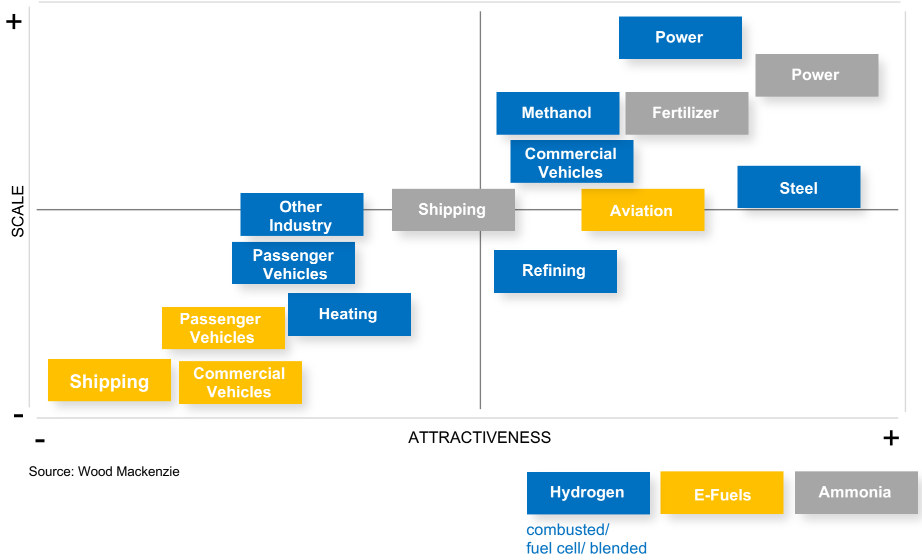
AMMONIA

LOHC

Source: Argus Media; RBC Wealth Management

Hydrogen Demand & End Uses

Hydrogen Demand Matrix



Source: Wood Mackenzie

- Government policy will play an outsized role in the development of low-carbon hydrogen markets
- **The most material, near-term uses of low-carbon hydrogen will be in sectors that already use grey hydrogen**, i.e., refining, petrochemicals and ammonia-based fertilizer production
- Transportation receives considerable attention but ultimately its strongest prospects are hydrogen use in green ammonia-fueled marine shipping and long-haul commercial fuel cell electric vehicles (FCEVs)
- Hydrogen's use in other forms of land transportation will remain limited by poor efficiency and continuous improvements in EV battery performance
- While synthetic liquid fuels will remain too costly for vehicles, the use of hydrogen in the production of synthetic sustainable aviation fuel (SAF) is being actively explored, particularly for medium- and long-haul flights that will be impossible to electrify
- **The greatest future opportunity for hydrogen lies in decarbonizing heavy industrial sectors, including power and steel**
- Blending low carbon hydrogen and green ammonia into natural gas pipelines and power plants can allow for the decarbonization of existing assets without significant reconfiguration requirements
  - Japan and Korea are aggressively pushing hydrogen-derived ammonia as feedstock for thermal power generation, heavily subsidizing demonstration projects aiming to achieve 50 percent ammonia co-firing
  - This process has been criticized for its production of nitrous oxide (NOx) emissions, high cost, inefficiency, and questionable derivation of ammonia, i.e., whether it is grey, blue, or green
  - Fortress New Energy's Long Ridge OH project is the only purpose-built hydrogen burning power plant in the U.S.; it started injecting 10 to 15 percent blue hydrogen (produced by an adjacent facility) in April 2022

Source: Wood Mackenzie; S&P Global; International Energy Agency (IEA); KPMG

Featured Use: Green Ammonia

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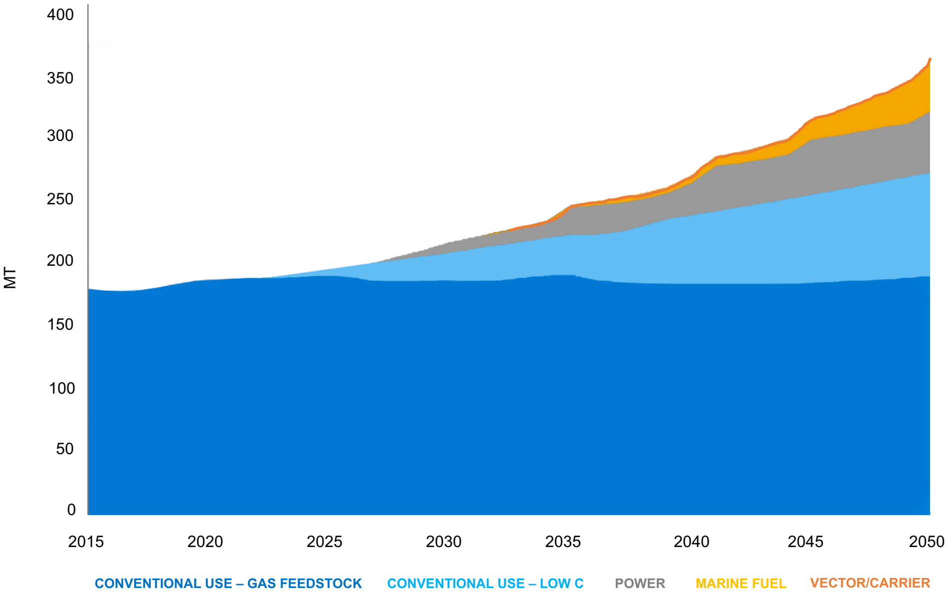
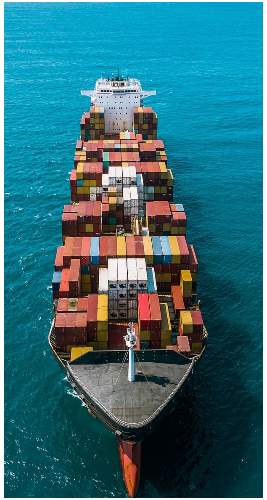
Ammonia Demand Outlook



- A large market for conventional grey ammonia already exists; global production currently stands at 200 million tonnes per year, three-quarters of which is used in fertilizer production
- The production of ammonia - combining hydrogen molecules with nitrogen molecules using the efficient, scalable Haber-Bosch process - can be decarbonized via the use of low-carbon hydrogen; this requires less energy and is lower cost than the synthesis of e-fuels
- Green ammonia has a higher energy density and requires less cooling than hydrogen; however, a dangerous safety profile means it is unlikely to be used outside of controlled industrial settings
- **Green ammonia presents a significant opportunity to broaden low-carbon hydrogen markets; it is an attractive end product, as well as a relatively easy, economical transportation solution for low-carbon hydrogen**
- Grey ammonia infrastructure already exists; it is a globally traded commodity with a price-sensitive user base, e.g., the agriculture sector

Source: Wood Mackenzie; "Green Ammonia as Fuel of the Future", Frontiers; Alfa Laval

Featured Use: Green Ammonia (cont'd)



- **Production costs for green ammonia are expected to be higher than grey for at least five years** so policy frameworks and incentives will be required to make existing markets, such as fertilizer feedstock, viable in the near-term
- With the International Maritime Organization (IMO) targeting a 50 percent reduction in the sector's emissions by 2050, to hit this target, it is estimated that between 25 to 50 percent of today's marine fuel consumption needs to be replaced by ammonia
- Blending green ammonia for power, as previously mentioned, is a controversial end use; it offers an opportunity to decarbonize existing infrastructure but not without limits and concerns that the replacement of grey ammonia should be prioritized
- Japan, South Korea, and the EU are all targeting full decarbonization of the ammonia sector by 2030; however, as with green hydrogen, demand for green ammonia has yet to mature and will need policy support to develop

Source: Wood Mackenzie; "Green Ammonia as Fuel of the Future", Frontiers; Alfa Laval

Hydrogen Commercialization Timeline

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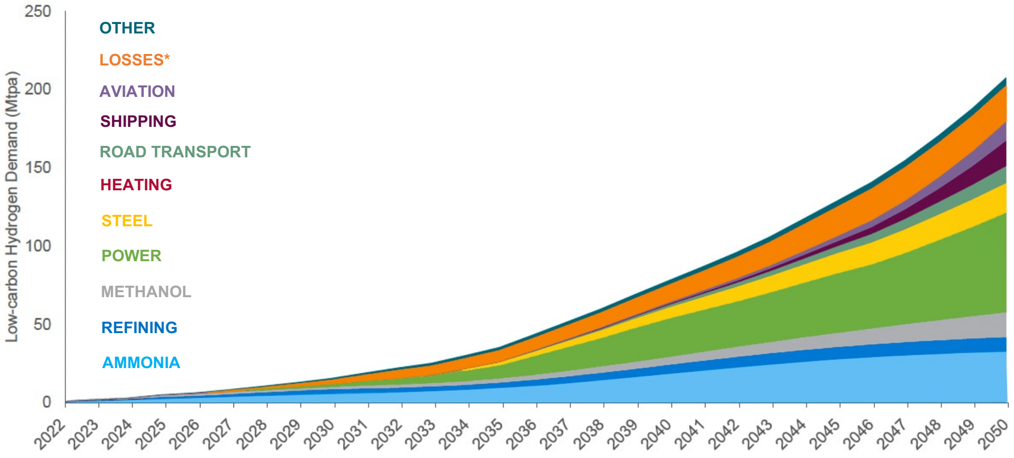
GLOBAL LOW CARBON HYDROGEN DEMAND BY SECTOR (2022 TO 2050)



Source: Wood Mackenzie
*Losses that result from converting and transporting hydrogen

Demand share will shift from ammonia to power and heavy industry

- Global demand is expected to increase from below 1 Mtpa in 2022 to 223 Mtpa by 2050, or from 1 percent of current hydrogen usage to 36 percent; more aggressive forecasts assume requirements of 500+ Mtpa of low-carbon hydrogen to meet global net zero commitments
- In addition to policy, time to commercialization will depend on:
  - Technology viability and lifecycle
  - Upfront capex requirements, operating costs, and scalability
  - Advantages vs. alternative solutions in terms of efficiency, density, footprint, maintenance, and lifespan
- Growth constraints include access to capital, competition from electrification and CCUS, natural gas blending limits, incumbent infrastructure, and a still-nascent regulatory framework
- **Commercialization will begin with the displacement of grey ammonia, including the use of green ammonia in shipping**
- Hydrogen will be an option for heavy duty vehicles that operate in off-the-grid environments
- Power will be the largest demand sector by the mid-2030s as a result of strong policy support in the Asia Pacific region
- Large-scale use in heavy industrial sectors and aviation remains a longer-term prospect and unlikely before 2040

Source: Wood Mackenzie; Hydrogen Council; LEK Consulting; Argus Media; Fortress New Energy

Policy & Legislative Implications (U.S.)

- The **Inflation Reduction Act of 2022** (IRA) hydrogen incentives have sparked a flurry of activity in the U.S. market and include:
  - A production tax credit (PTC), the maximum $3 per kg of which is larger than the current cost spread between green and grey hydrogen
  - An investment tax credit (ITC) of up to 30 percent of equipment costs
  - Carbon capture provisions that will allow blue hydrogen to benefit from carbon capture, utilization, and storage tax credits
  - Economic boosts for co-locating with renewable energy, nuclear, storage, and carbon capture, as well as downstream investments in alternative fuel infrastructure and clean vehicles
- The IRA is not a silver bullet for hydrogen; uncertainty remains around measurement and reporting, as well as the ease with which tax credits can be monetized
  - The ITC is less profitable on a per kilogram basis; however, the PTC comes with operational and offtake risk; these incentives are mutually exclusive
  - Project structuring and financing will be challenging; traditional tax equity has shied away even from more mature clean energy segments
- The 2021 **U.S. Infrastructure Investment and Jobs Act** includes more than $62 billion for the DOE to deliver a more equitable clean energy future, including the allocation of $8 billion to establish regional clean H2Hubs
- Applications represent more than $150B of private capital with funding being led by consortiums of large corporates and governments
- Selection of the hubs is set for Fall 2023, following which the challenge will be to remove roadblocks to permitting what are likely to be large, complex projects

LEVELIZED GREEN HYDROGEN PRODUCTION COST

IRA tax credits can reduce the cost of green hydrogen production by half for a project starting in 2023; the impacts fade steadily until expiration in 2032

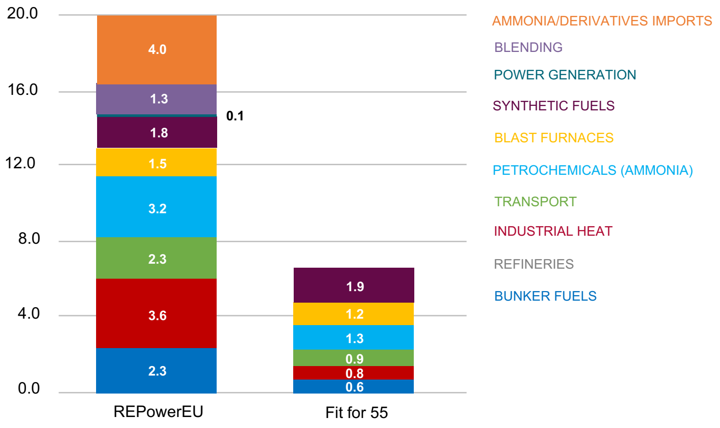
Source: Hydrogen Council; LEK Consulting; Argus Media; International Council on Clean Transportation (ICCT) ; Fortress New Energy

Policy & Legislative Implications (Non-U.S.)

- Public sector support has ramped up considerably, with at least 25 governments outside of the U.S. committing to adopt hydrogen as a clean energy component of their energy systems and setting targets for the deployment of production technologies and infrastructure development
- In 2023, government subsidies are due to begin in the EU, UK, and likely Canada, India, and Portugal, making profitable green hydrogen projects a reality
- **Canada** is implementing hydrogen tax credit in 2023 as part of clean fuels credit program; it has strong provincial and federal government support and will be competitive with IRA incentives
- **Europe's** ambitious hydrogen goals are outlined in the 2022 REPowerEU strategy, which aims to produce 10 million tonnes and import 10 million tonnes of renewable hydrogen by 2030, a substantial increase from the 5.6 million tonnes foreseen within the previous Renewable Energy Fit for 55 Directive
- The US IRA has shifted production dynamics from what previously looked to be an EU lead (based on strict regulation and high energy costs) to a focus on the US; with stronger demand incentives in Europe, US-produced hydrogen may end up used overseas
- **The UK's** strategy also sets goals for low carbon hydrogen production capacity by 2030, via near-term production funding and medium-term policy development, as well as an increased focus on private sector investment
- **Japan** was the first country to adopt a national hydrogen framework, one that leverages robust public-private collaboration, builds on its leadership in hydrogen FCEVs, develops supply chains, and targets ambitious cost and supply goals (including co-firing power plants with ammonia)

EUROPE'S EVOLVING HYDROGEN TARGETS

Hydrogen use by sector in 2030 (Mt H2)



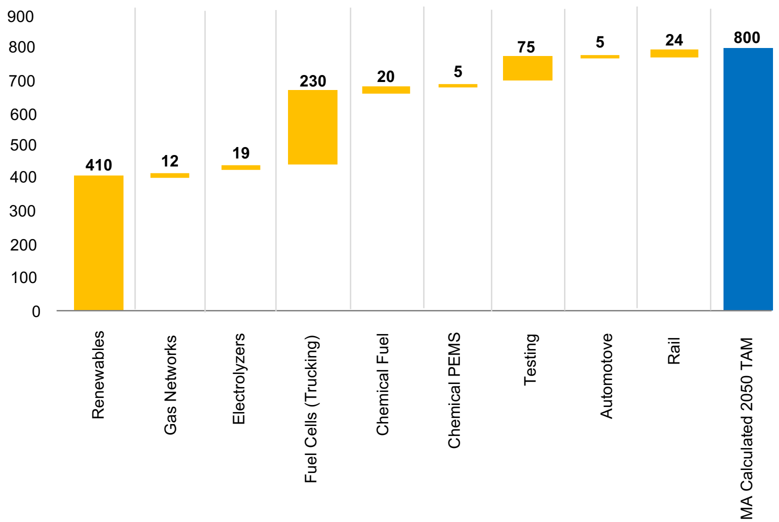
Source: Hydrogen Council; LEK Research and Analysis; "Hydrogen update to the Market: December 2022", UK Department for Business, Energy, and Industrial Strategy; Government of Canada; "Japan's Hydrogen Industrial Strategy", Center for Strategic and International Studies; Argus Media,
Source: European Commission (2022)

Investment Landscape

- There is a $460 billion gap between announced investments and targets through 2030; longer term, the global market for low-carbon hydrogen represents a $600 to $800 billion opportunity through 2050
- Over half of this market lies in wind and solar inputs, followed by downstream fuel cells
- To-date, investment has focused on constraints to mass adoption, i.e., electrolyzer technology and solutions to efficiency and cost issues
- Looking forward, opportunities along the value chain include renewable energy inputs, CCS products, production equipment and technologies, production facilities, storage and distribution, and end use applications, including FCEVs
- Most opportunities still sit with early-stage companies, many of which have small pilots which address fundamental technology risks, but for whom commercial traction remains three to five years into the future; investors need to be comfortable with both market risk and this timeline for scaling
- Large oil and gas corporates are investing in hydrogen, in part to decrease the carbon intensity of their refinery operations and boost their longevity
- As markets mature, industrials may look to fill a manufacturer or EPC role, allowing startups to retreat up the value chain via toll, outsourcing, and/or assembly models
- Few private equity funds are dedicated to low carbon hydrogen but an increasing number are including it in their investment mandates

- Real asset opportunities, e.g., in production facilities, are, to-date, limited as most projects are early-stage proof-of-concepts or very large-scale public-private partnerships, e.g., outside of large strategics and governments, it will be challenging for financial players to participate in the U.S. hydrogen hubs

TOTAL ADDRESSABLE MARKET ESTIMATES TO 2050 ($BN)



Source: Wood Mackenzie; Morgan Stanley; McKinsey; LEK Consulting; World Bank; BNEF

Conclusions

- Low carbon hydrogen is widely acknowledged as a critical component of the energy transition and value chain development is being supported globally by a proliferation of regulatory frameworks, policy, and incentives
- Green hydrogen will be the most cost-competitive option in much of Europe and Asia by 2030 but natural gas-rich nations are likely to see a slower transition that initially relies on blue hydrogen
- Blue hydrogen will allow for gas-fired production (with CCUS) and will play an important role in developing downstream infrastructure if it can be offered at a lower price than grey; however ongoing economic viability will require policy and subsidies
- In the U.S., policies to stimulate demand creation lag those for production and are focused on transport; more certainty around industrial applications and offtake is needed, particularly when off-takers still need to pay a premium for green hydrogen and ammonia
- Decarbonization of existing hydrogen applications with mature supply chains, e.g., fertilizer, represent the lowest-hanging fruit and should be prioritized
- Hard-to-abate sectors are at least a decade from commercialization, but net zero goals will eventually drive the use of low-carbon hydrogen in steel, ammonia, chemical, and oil refining; use in these sectors will be greater than all the world's hydrogen cars combined
- With green ammonia, too, decarbonization of traditional markets will be the most significant demand driver; it will be 2030+ before the liquidity and scale required to achieve commercial levels of ammonia-fueled energy demand are in place
- Considerable technology risk remains, as well as risks around what the commercial model and applications will look like; it is too early for performance guarantees
- For this reason, institutional capital has, to a degree, remained on the sidelines; today's existing and planned pilot projects are expected to be ready for repeatable, modular scaling by the mid-2020s
- As of April 2023, with low-carbon hydrogen production and its downstream value chain in a relatively nascent state, Equilibrium will continue to focus on applications for biofuels to play a feedstock and/or energy input role for green hydrogen, i.e., either as a replacement for conventional natural gas or as a renewable energy source for electrolysis
- While the California transportation market might remain the most lucrative end use for negative carbon intensity ("CI") RNG, i.e., RNG produced from animal waste, low CI RNG from wastewater, landfills, and food waste is, we believe, an ideal input to produce greener hydrogen
- We will continue to monitor opportunities that will arise from the maturing of low-carbon hydrogen technology, companies, infrastructure, and end uses

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