CANDRIAM
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Green innovations series: Hydrogen

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Marketing communication

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Tom joined Candriam in 2022 as Senior Equity Analyst in the Thematic Global Equity Team focusing on climate action.

He started his career in 2013 at BNP Paribas Fortis, initially as a Management Trainee and then in Private Banking. In 2017 he joined Degroof Petercam Asset Management, becoming a portfolio manager for institutional mandates and later a buy-side equity analyst covering the chemicals and ingredients space.

Tom holds a MSc in Business Administration from the University of Antwerp and a post graduate MSc in Banking and Finance from Ghent University. He has been a CFA Charterholder since 2018.

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Marouane joined Candriam in 2022 as Senior Fund Manager in the Thematic Global Equity Team, focusing on climate action and the effort to limit global warming.

He began his career in 2015 at Edmond de Rothschild AM in Paris as an Equity Analyst on environment-related themes. From 2018 to 2022 he co-managed a climate solutions-focused global mandate and an energy evolution fund which focused on the ongoing climate related energy transition. Beginning in 2020 he also became lead manager of the EdR Green New Deal fund, a global equity climate fund.

Marouane holds a Masters in Financial Markets and Risk Evaluation from the Toulouse School of Economics, where he is an external lecturer on Sustainable Finance and ESG analysis. He became a CFA Charterholder in 2018.

Table of contents.

The states of hydrogen: from a fluid situation to more solid progress.

Hydrogen, first documented back in 1766, is the simplest, lightest and most abundant chemical element in our universe, the first element in the periodic table, and yet it made it possible for humans to explore space. For right and wrong reasons, hydrogen has also often been cited as the number one solution to decarbonization.

At the peak of the hydrogen hope and hype in 2020-2021, it was making countless headlines (*"Could the hydrogen revolution save the planet?"*, *"Could green hydrogen save the world?"*).

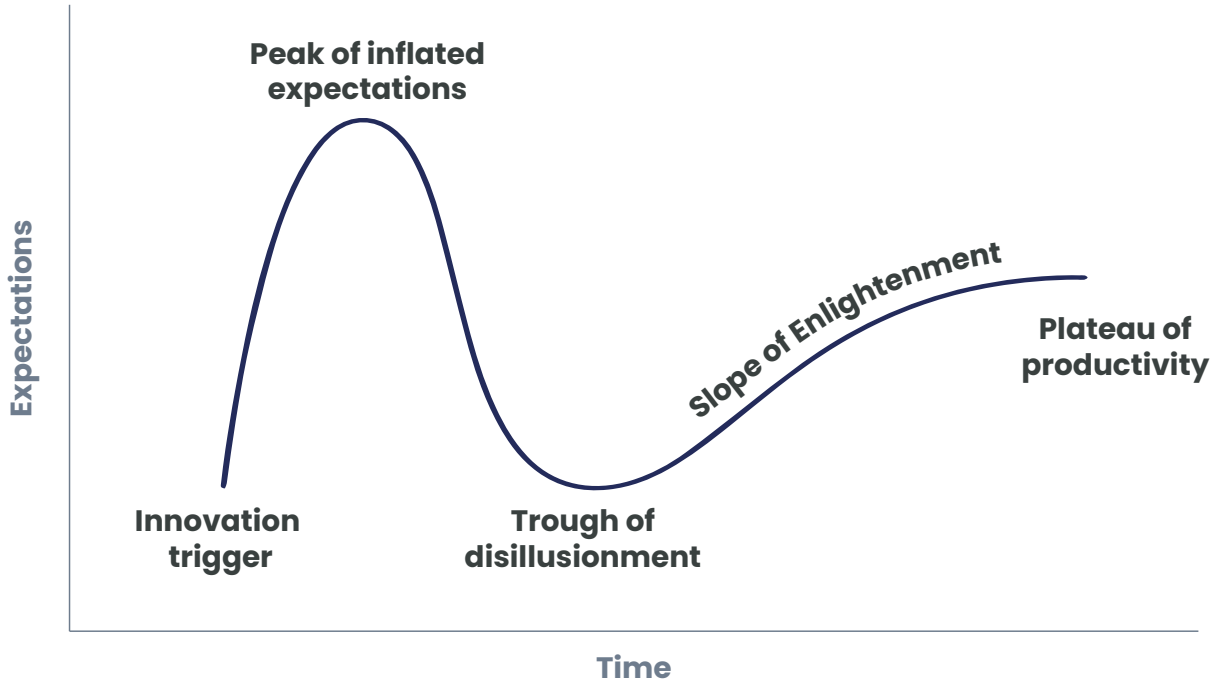
Around that time, we published a paper looking at hydrogen technologies from the environmental standpoint, and studying the factors supporting its future development. The European Commission was working on the proposals to increase hydrogen-based energy generation, with ambitious targets, as hydrogen had been identified as a key tool for achieving the EU Green Deal's targets and other objectives relating to Europe's climate-neutrality and strategic autonomy.

Three years have passed and it is time to run a reality check on hydrogen's potential for decarbonization, all the more as many issues have put it into question: alternative and more economical ways to decarbonize, technical issues, difficulties scaling up the value chain, insufficient on-the-ground policy support and unclear legal frameworks.

Referring to Figure 1 related to the stages of tech evolution (called the Gartner hype cycle), we believe we are past the peak of inflated expectations. The question is **at which stage we are now. Has hydrogen lost its mojo?** Are we through with H2?

> **We believe hydrogen's role will be key for the so-called hard-to-abate industries, which have few alternative solutions to decarbonize.**

Figure 1:
The Gartner hype cycle



Source: Gartner Hype Cycle Research Methodology, https://www.gartner.com/en/research/methodologies/gartner-hype-cycle

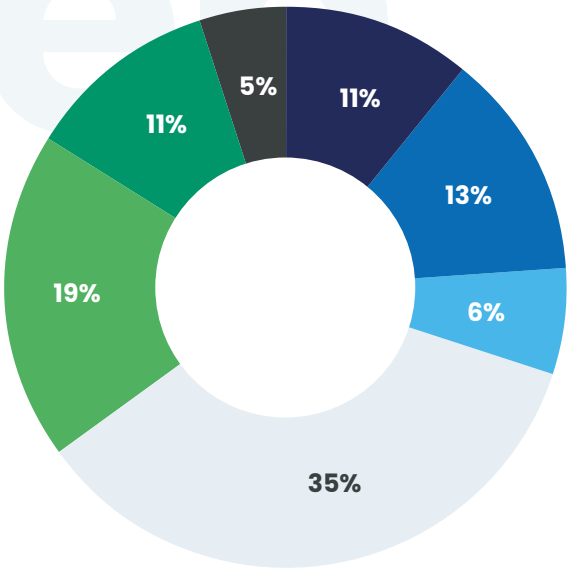
Three years after our initial paper, we review the role that H2 may have in decarbonizing certain applications over the medium-term. We also elaborate on why we expect clean hydrogen to (finally) accelerate, we evaluate the attractiveness of its investment opportunities and give our view on where investors can position their portfolios to potentially benefit from those.

Sizing up the clean hydrogen opportunity.

At face value, the role of hydrogen in decarbonization may seem modest: the International Energy Agency (IEA) estimates **hydrogen would only mitigate 6% of the cumulative emissions reductions needed under its Net Zero Emissions scenario** (Figure 2).

This narrow application scope does not mean hydrogen's role in decarbonization is negligible, however. On the contrary, we believe its role will be key for the so-called hard-to-abate industries - these industries such as steel, chemicals, heavy-duty transportation and shipping have few alternative solutions to decarbonize, notably because hydrogen is used as a (low-carbon) feedstock, because they require thermal heat, because batteries are not an option due to physical constraints, etc

Figure 2:
Cumulative emissions reduction by mitigation measure in the Net Zero scenario, 2021-2050



Behaviour and avoided demand	11%
Technology performance	13%
Hydrogen	6%
Renewables	35%
Electrification	19%
CCUS (Carbon Capture, Utilisation and Storage)	11%
Other fuel shifts	5%

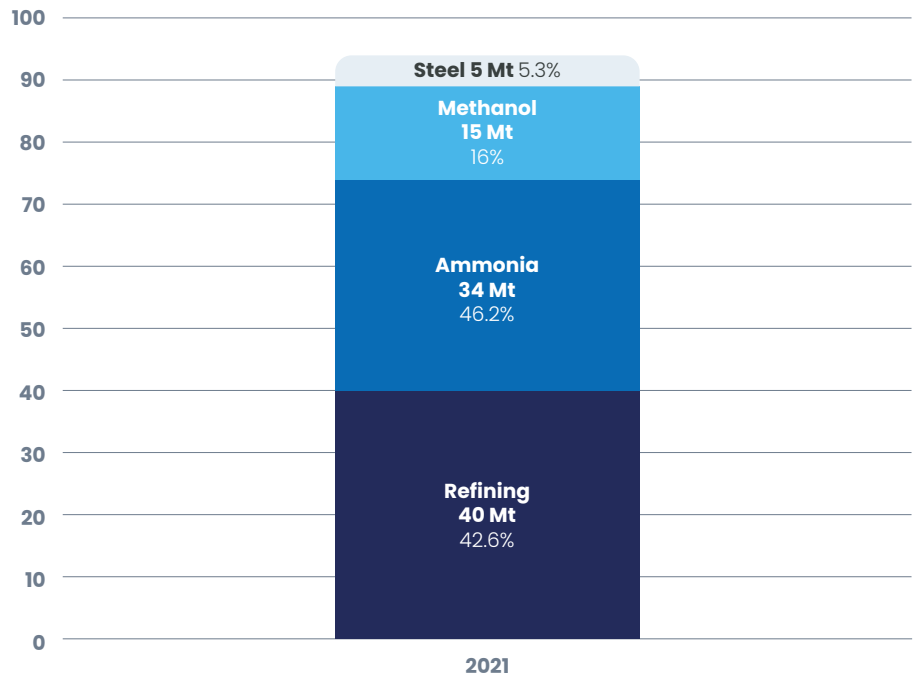
Source: IEA, Cumulative emissions reduction by mitigation measure in the Net Zero Scenario, 2021-2050, IEA, Paris https://www.iea.org/data-and-statistics/Figures/cumulative-emissions-reduction-by-mitigation-measure-in-the-net-zero-scenario-2021-2050, IEA. Last updated 22 October 2021. Licence: CC BY 4.0

The near-term outlook looks brighter on the industrial demand side

Our 2020 paper on hydrogen already divulged on hydrogen's limited short-term potential in heavy-duty transportation and shipping. Clearly, some applications will reach technological and commercial maturity sooner than others.

While most mobility applications would likely only really ramp up post-2030, the near-term outlook looks brighter on the industrial demand side. To us, the shorter term potential for clean hydrogen lies in the decarbonization of its existing users. After all, the use of hydrogen in itself is nothing new. **Global hydrogen demand was estimated to be 94 million tons (Mt) in 2021**[1], driven by applications where it plays a critical role as a feedstock or a processing aid. Its most prevalent use-case today is in refining for the desulphurization of fuels (representing almost 43% of demand), closely followed by ammonia (NH3) production (36% of estimated demand) and, to a smaller degrees, in methanol (CH4O) production (16%) and as a reduction agent in the steel industry (5% of demand). To reach Net Zero, existing users should not only switch from carbon intensive to clean hydrogen over time – but also embrace its new applications: to replace coking coal as a reduction agent in the steel industry, for industrial heating, etc. It is in this context that for example TotalEnergies has launched a call for tenders for the supply of 500 kilo tons per year of green hydrogen in an effort to decarbonize the hydrogen used in its European operations[2].

Figure 3:
Global hydrogen demand estimates in 2021: 94Mt

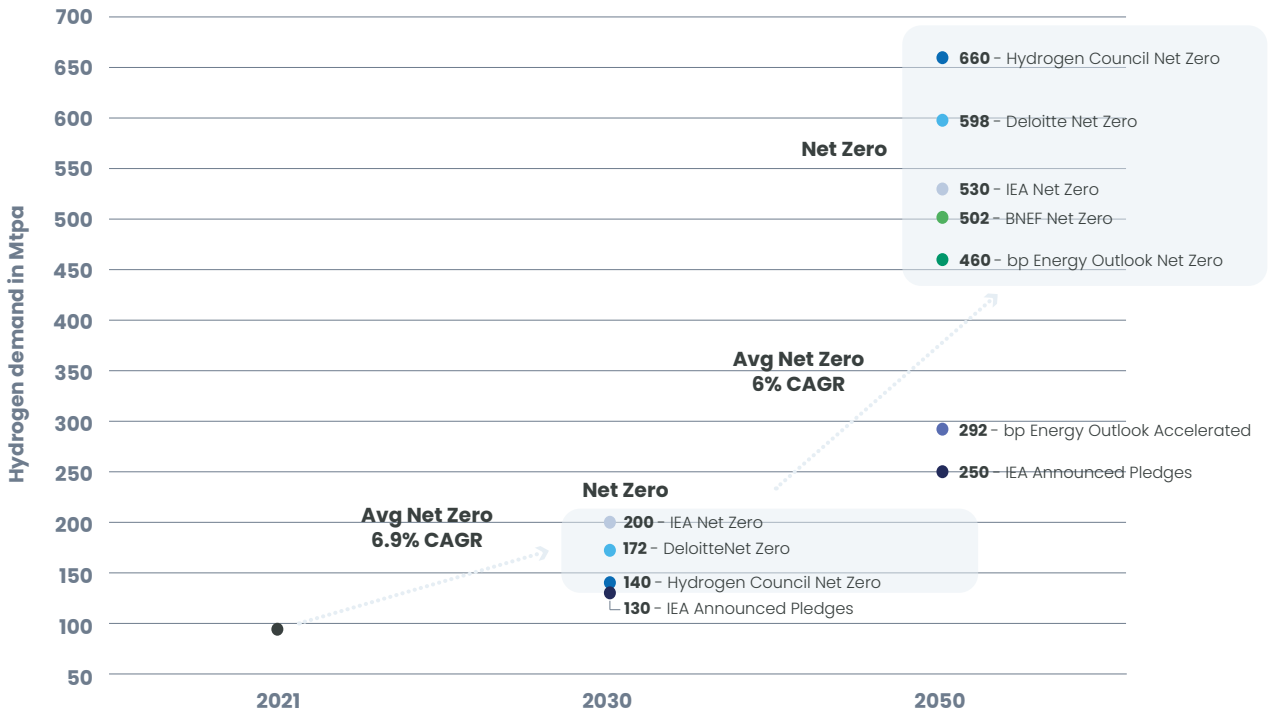


Source: IEA Global Hydrogen Review 2022, published September 2022, https://www.iea.org/reports/global-hydrogen-review-2022

Long-term demand could be 5 to 7 times higher than in 2021

What about long-term demand? Scenarios vary as shown in Figure 4. According to estimates, **to reach Net Zero by 2050, hydrogen demand should stand between 460Mt/year and 660Mt/year – implying a demand between 5 and 7 times higher than that in 2021.** And let us remember that only 0.8Mt/year of clean hydrogen supply is operational today[3].

Figure 4:
Hydrogen demand scenarios



Source: Candriam, IEA, Hydrogen Council, bp, Deloitte, 2023

The IEA Announced Pledges Scenario (APS) assumes that all climate commitments made by governments around the world, including Nationally Determined Contributions and longer-term net zero targets, will be met in full and on time. bp's Accelerated scenario is built on a 75% reduction in overall carbon emissions in the energy system by 75%.

The hydrogen rainbow

Hydrogen can be produced using various technologies and energy sources – after all, hydrogen is a carrier or vector for energy. Each type of hydrogen is typically referenced by a specific colour depending on its production methods and energy sources, from brown/black (the most emissions-heavy) to green (which is virtually carbon-free as it is powered by renewable energy sources). Note that there are however no firm definitions.

Figure 5:
The hydrogen rainbow

Technology: Electrolysis
Energy Source: Wind, Solar, Hydro, Geothermal
GHG emissions: Minimal

Technology: Electrolysis
Energy Source: Nuclear
GHG emissions: Minimal

Technology: Electrolysis
Energy Source: Mixed-origin grid energy
GHG emissions: Medium

Technology: Pyrolysis
Energy Source: Natural gas
GHG emissions: Solid carbon (by-product)

Technology: Natural gas reforming + CCUS gasification + CCUS
Energy Source: Natural gas, coal
GHG emissions: Low

Technology: Natural gas reforming
Energy Source: Natural gas
GHG emissions: Medium

Technology: Gasification
Energy Source: Black/brown caol (lignite)
GHG emissions: High

Source: Tecnicas Reunidas February 2022, https://www.tecnicasreunidas.es/articulo/hydrogen-present-and-future-part-2/

Today, nearly all hydrogen produced is grey or brown -produced from fossil-fuel sources and through processes that are highly carbon-intensive. Global hydrogen production in 2021 had associated emissions of more than 900Mt of CO_2e.[1] For hydrogen to play a real role in decarbonization, it should be produced via methods that entail low or minimal emissions.

High ambitions but little tangible progress.

There is no shortage of ambitions from policymakers to support hydrogen growth: already 52 markets have a hydrogen strategy as of October 2023, with an additional 29 working on one[4]. Europe significantly stepped up its ambitions in 2022 under the RePowerEU plan[5], targeting 10Mt of renewable hydrogen by 2030 - half of which would be imported. Meanwhile, on the other side of the Atlantic, the Inflation Reduction Act (or IRA) is a real game-changer for the US hydrogen industry as it grants significant production and investment tax credits that are expected to make both green and blue hydrogen cost-competitive with their carbon intensive counterparts. According to the IEA, national targets for green hydrogen production capacity had reached 160 to 210GW – 30-40% of the required capacity by 2030 in their Net Zero scenario[6].

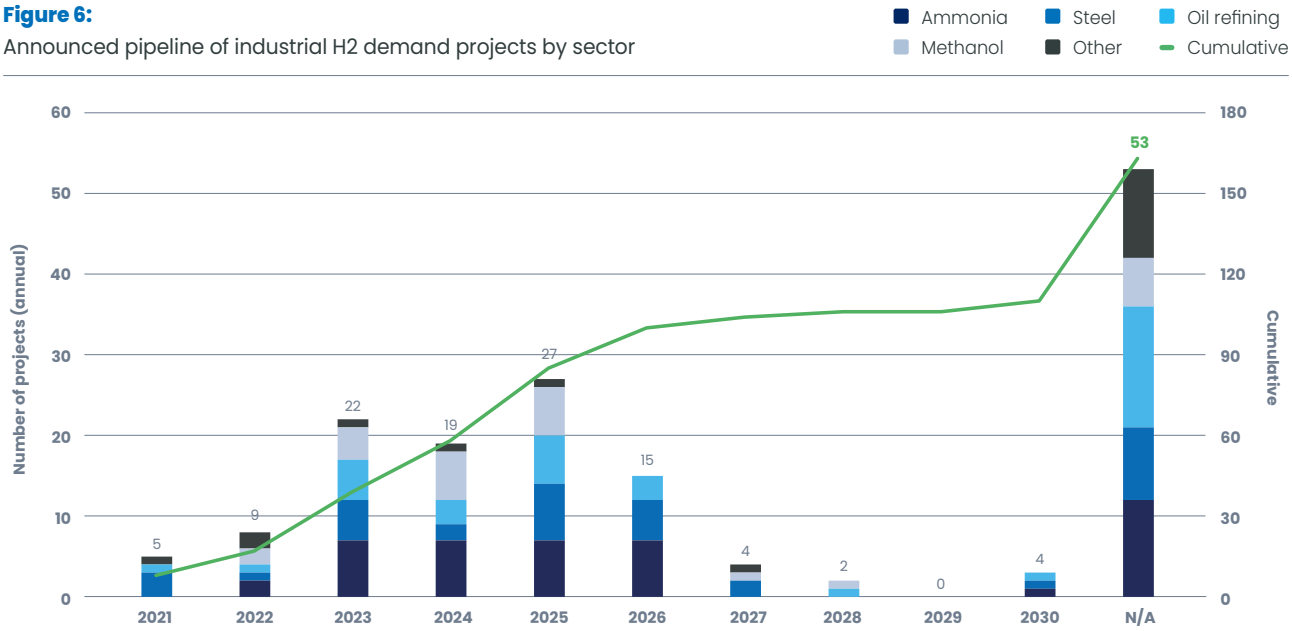
Yet despite these strong aspirations, little has effectively happened on the ground thus far, and few of the projects announced up to now have materialized into a final investment decision. Several bottlenecks have held back the pace of developments, including a lack of clarity on the rules and conditions to be eligible for governmental financial support, delays in policy implementation or insufficient policies to stimulate demand. In Europe, a very slow permitting process for renewable energy has further complicated matters. After all, scaling up of green hydrogen also requires a commensurate increase in renewables capacity.

Stars are finally starting to align for a potential growth acceleration.

Despite some stumbles right after leaving the starting blocks, **we see good prospects for clean hydrogen to resume its growth momentum over the coming years,** as support from existing policies will start to flow and new policies and targets are being introduced. BloombergNEF estimates that clean hydrogen subsidies have more than quadrupled over the past two years to cross $300bn, a 46% increase from early 2023 levels[7]. We believe these support measures should unlock actual funding and accelerate investment decisions on the ground over the next few years.

The EU (finally) adopted two delegated acts in February 2023 detailing the rules to define renewable hydrogen. The European Hydrogen Bank has launched a first subsidy auction for clean hydrogen in November 2023. Furthermore, while most measures have focused on hydrogen supply up to now, incentives are now also ramping up to promote hydrogen demand: EU lawmakers have agreed to put in place **binding quotas for industrial hydrogen users to replace at least 42% of their demand with renewable hydrogen by 2030, rising to 65% by 2035[8].** They also set minimum targets on H2 or advanced biofuel adoption for transportation. BNEF estimates these mandates would create 2.1-4.2Mt/ year of renewable hydrogen demand by 2030 – requiring 22-43GW electrolyzer capacity – and 2.8-4.9Mt/ year by 2035[8]. Germany is the frontrunner in Europe when it comes to supporting hydrogen adoption: not only is it planning

Figure 6:
Announced pipeline of industrial H2 demand projects by sector



Source: BloombergNEF, 2 Mar 23 BNEF 1H23 Hydrogen Market Outlook

the buildout of a significant hydrogen pipeline network, it has set itself a 10GW electrolyzer installation target and a lofty 2.4-3.3Mt/ year clean hydrogen demand target by 2030. Note that these projects typically have a lead time of a couple of years, meaning that the timeline for project announcements to reach the 2030 targets in time is shortening.

The Internal Revenue Service (IRS - the U.S. federal agency that oversees the collection of taxes - primarily income taxes - and the enforcement of tax laws) in the United States has finally provided clarity on the eligibility rules for hydrogen production and investment tax credits. While the guidance contains strict requirements to be eligible for the full production tax credit[9] and may require a rethink of some projects, we believe this clarity should still enable companies to finally pull the trigger and make final investment decisions. Supplementing the IRA, on October 13 2023 President Biden announced the winners of the 7 US hydrogen hubs[10] that will receive $7bn funding with a target to produce 3Mtpa of clean hydrogen. Another $1bn of funding is allocated to support clean H2 demand.

Navigating the hydrogen value chain.

Despite its attractive prospects, the clean hydrogen industry remains nascent, and its value chain is complex. From an investor point of view, deciding on where to position oneself in the value chain is thus no easy task as situations can greatly differ from one segment to another.

Scaling up clean hydrogen production will require significantly more renewable energy and carbon capture capacity…

Upstream, **renewable energy developers as well as companies active in carbon capture (usage) and sequestration** will see significant demand coming from green and blue hydrogen production respectively. BloombergNEF estimates that a whopping 21 000TWh of electricity is needed for green hydrogen production in 2050 under its Net Zero scenario – equivalent to three quarters of the world's current power demand[11].

…as well as a significant step-up in electrolyzer capacity

Besides, producing the required quantities of green hydrogen will require vast amounts of installed electrolyzer capacity. The IEA estimates global electrolysis capacity could reach 3GW by the end of 2023, ramping up to 170-365GW by 2030 would all projects that are currently in the pipeline be realized. This implies a 78-99% CAGR in electrolyzer capacity, but remains far from the required 550GW of capacity needed to be on track with its Net Zero Emissions scenario[12].

Awaiting take-off, **electrolyzer manufacturers** have announced aggressive capacity expansion plans. BNEF counts 42GW of announced annual electrolyzer production capacity by the end of 2023, risking large manufacturing overcapacity especially in China[13]. These expansion plans need to be taken with a pinch of salt however: the difference between theoretical capacity and actual operational capacity is getting clearer with some manufacturers in the developed world experiencing difficulties to ramp up to a commercial

scale. Should Chinese capacity be unable to fill the gap due to funding restrictions or trade rules, this could result in a tighter electrolyzer market in developed markets.

How can investors identify the winners? **Short-term, the winners that will see outsized order growth are those with demonstrated operational manufacturing capacity and a reliable operating track record.** In contrast, determining the medium-to-long term winners amongst electrolyzer manufacturers is more difficult: electrolyzer technology is still immature with several variants whose pros and cons are still widely debated amongst manufacturers and hydrogen producers, and it is highly uncertain which one of these technologies will ultimately prevail. Finally, many of the electrolyzer manufacturers are not profitable yet and will need to see a ramp-up in demand to reach it, let alone become cash generative.

Significant fuel cell take-up is likely to take longer

Further down the value chain, ***fuel cell manufacturers*** have only seen limited uptake thus far. Although we do see a future for fuel cell technology in stationary power and heavy-duty transportation applications where batteries are less competitive, developments in the mobility market have been especially disappointing. Today, fuel cell electric vehicles represent less than 1% of global vehicle sales and stem mostly from China[14]. Hydrogen mobility still seems plagued by the chicken-and-egg problem for now: a lack of refueling infrastructure intertwines with a lack of hydrogen mobility solutions. Indeed, twelve times more battery-powered than fuel-cell heavy-duty truck models have been announced for this decade[15].

We believe that high-capacity refueling stations will only be built in about 2 years from now and hence that **hydrogen for mobility applications will likely only take-off beyond 2025.** Nevertheless, power generation for stationary applications, for example to replace back-up diesel generators in datacenters and hospitals, provides a – albeit much smaller – short-term growth market for fuel cells.

The industrial gas industry is at the center of today's hydrogen economy

At the center of today's hydrogen economy is the ***industrial gas industry***, dominated by three global companies. Although the majority of hydrogen supply today is still captively produced by the industrial end-users themselves, the latter have increasingly been outsourcing hydrogen production to the industrial gases players over the latest decades and years. Industrial gas companies build and operate hydrogen production plants and sell the molecule to the off takers, often with defensive take-or-pay contract structures. While industrial gases companies today produce mostly carbon-intensive hydrogen, they have plans to both invest in new green and blue hydrogen capacity and to decarbonize their current grey hydrogen production via carbon capture. As they already have the critical distribution infrastructure (including pipelines) in place that connect industrial customers in key basins, **industrial gas companies should be well placed to capture some of the growth of the hydrogen economy** – no matter its colour. This is also echoed by the companies themselves, that all see attractive growth prospects stemming from the energy transition.

Conclusion: From up in the air to on-the-ground progress, hydrogen's time is getting closer.

All segments of the clean hydrogen value chain come with their own set of risks and opportunities, which are not static but will evolve through time. Navigating this nascent investment landscape is technically complex and requires knowledge and experience. What is becoming clearer is that, although progress over the past year(s) has been disappointing, **there are reasons to be more optimistic on the future of hydrogen and the investment opportunities that it presents.**

Hydrogen's real potential has been a bit up in the air until now – we also mean this *literally*, as hydrogen is used as fuel by the sun and other stars, and has powered numerous vessels into space including the Apollo missions. However, we believe progress on the ground will accelerate, earning hydrogen its rightful space in the energy transition.

> **Although progress over the past year(s) has been disappointing, there are reasons to be more optimistic on the future of hydrogen and the investment opportunities that it presents.**

Notes & References.

1 IEA Global Hydrogen Review, published September 2022, https://www.iea.org/reports/global-hydrogen-review-2022

2 Decarbonizing Refining: TotalEnergies Launches a Call for Tenders for the Supply of 500,000 tons per year of Green Hydrogen, https://totalenergies.com/media/news/press-releases/decarbonizing-refining-totalenergies-launches-call-tenders-supply-500000

3 Hydrogen Insights 2023, Hydrogen Council, https://hydrogencouncil.com/en/hydrogen-insights-2023/

4 BNEF Global Hydrogen Strategy Tracker, BloombergNEF, Oct 18 2023, https://www.bnef.com/insights/28035

5 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

6 Hydrogen - IEA Tracking Clean Energy Progress July 23

7 Hydrogen Subsidies Skyrocket to $280 Billion Led by US, Full Report, BloombergNEF, 16 Aug 23, https://www.bnef.com/insights/32031/

8 EU Hydrogen Quotas Raise Global Demand for Green Molecules, BloombergNEF, 19 Jul 23, https://www.bnef.com/insights/31243

9 Hydrogen Industry Signals Alarm Over Proposed US Tax Credits - Bloomberg, December 6 2023, https://www.bloomberg.com/news/articles/2023-12-05/hydrogen-industry-raises-alarm-over-leaked-us-tax-credit-rules?leadSource=uverify%20wall

10 Biden-Harris Administration Announces Regional Clean Hydrogen Hubs to Drive Clean Manufacturing and Jobs, The White House, https://www.whitehouse.gov/briefing-room/statements-releases/2023/10/13/biden-harris-administration-announces-regional-clean-hydrogen-hubs-to-drive-clean-manufacturing-and-jobs/

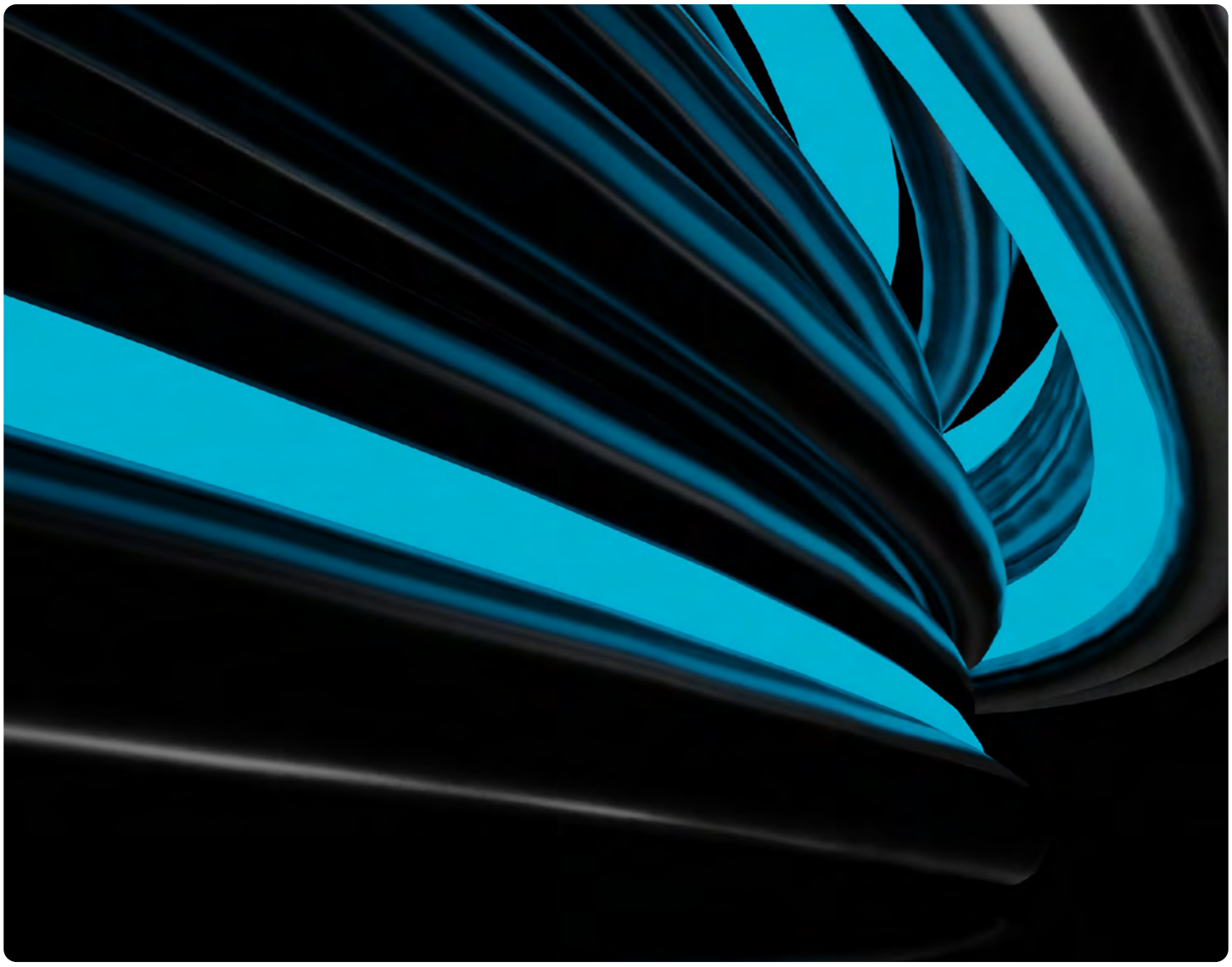
11 New Energy Outlook 2022: A Pathway to Net Zero, BloombergNEF, https://www.bnef.com/insights/30197

12 Electrolysers - Energy System - IEA, https://www.iea.org/energy-system/low-emission-fuels/electrolysers

13 Hydrogen Electrolyzer Shortage Hits EU: BNEF Roundtable, BloombergNEF, 22 Mar 23, https://www.bnef.com/insights/31055 & Overcapacity of China's Electrolyzer Makers Spells Trouble, BloombergNEF, 30 Mar 23, https://www.bnef.com/insights/31105

14 Hydrogen Insights 2023, Hydrogen Council, McKinsey & Company, May 2023, https://hydrogencouncil.com/wp-content/uploads/2023/05/Hydrogen-Insights-2023.pdf

15 Hydrogen Won't Dominate in Heavy-Duty Trucking, BloombergNEF, https://www.bnef.com/insights/30239



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