THE FUTURE OF CLEAN HYDROGEN

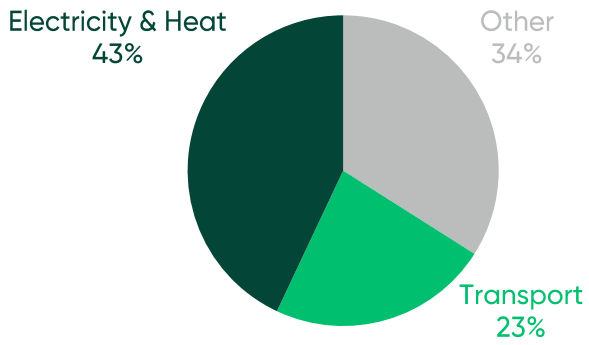
KEY POINTS

- Investor interest in hydrogen-related investments has increased significantly in recent years driven by the opportunity to reduce emissions using clean hydrogen.
- Examining the various ways hydrogen is produced (via traditional and new technological methods) and assessing its potential uses at a macro level helps our understanding of the future of hydrogen.
- Fisher Investments is cognisant of and monitors this long-term ESG-related theme for potential opportunities and associated risks. In our view, more rapid hydrogen scaling progress, technological innovation and regulatory support are needed to broaden the investment landscape over time.

INTRODUCTION

Global hydrogen demand reached 95 metric tons (MT) in 2022, almost 3% more than in 2021.[1] While fossil fuels dominate areas such as electricity production, heating, and transportation today, hydrogen has the potential to replace these sectors' extensive use of natural gas and gasoline/diesel. Hydrogen advocates claim this replacement can act as a solution to the world's climate challenges given those industries are responsible for approximately two-thirds of global CO2 emissions. (Exhibit 1)

Exhibit 1: Global CO2 Emissions by Sector



Source: International Energy Agency (IEA), as of March 2023.

There is also a growing number of countries with policies that directly support investment in clean hydrogen technologies. Governments around the world have passed legislation aimed at increasing investment in hydrogen and renewable energy projects by providing financial incentives. For example, in the United States, the Inflation Reduction Act (passed in 2022) includes the Clean Hydrogen Production Tax Credit, and the Infrastructure, Investment and Jobs Act (passed in 2021) contains funding allocated towards hydrogen research and development. These incentive programmes aim to reduce the price disparity between clean hydrogen and carbon-intensive alternatives (see Exhibit 2 for the breakdown of cost) and spur new technological advancements within the industry. Hydrogen is also gaining support overseas—more than 20 countries globally have committed to developing hydrogen strategies encouraging higher levels of hydrogen application across multiple industries. Most of these efforts are led by European countries, especially in terms of adopting important policies. Meanwhile, China is the leader in electrolyser capacity additions (a pivotal technology for generating hydrogen from water through the electrolysis of water), with 220 megawatts (MW) in operation in 2022 and 750 MW to be online in 2023, accounting for 40% of global capacity.[2]

As with any emerging industry or technology, we continuously monitor developments within the hydrogen and renewable energy space. As a top-down macro investor, we consider the risks and opportunities relative to climate change over the next 12 – 18 months, and technological solutions such as hydrogen are a part of that assessment. This paper aims to explore the viability of utilising hydrogen as a carbon-free energy alternative from a top-down, global perspective.

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[1] *Source: IEA, as of July 2023.*
[2] *Ibid.*

NOT ALL TYPES OF HYDROGEN ARE CREATED EQUAL

Hydrogen is a versatile energy source that can be produced in a variety of ways and from a range of resources—each with special qualities and uses. As such, there are many types or 'colours' of hydrogen based on what is used and how it is produced. (Exhibit 2) Traditional hydrogen production uses one of two methods: hydrogen extraction from hydrocarbons in fossil fuels (most commonly known as steam-methane reforming) and electrolysis, where electricity splits water molecules into oxygen and hydrogen. Since steam-methane reformation produces significant carbon emissions in the process it is classified as grey hydrogen. On the other hand, electrolysis produces hydrogen in a carbon-neutral manner, so it is classified as green hydrogen. Additionally, there is ongoing research and development into pairing hydrogen production with other technologies such as carbon capture utilisation and storage (CCUS) or simply using renewable-based electricity to reduce total production carbon emissions. While these newer production methods are technically green hydrogen, other shades of hydrogen are assigned accordingly by scientists to distinguish between various energy inputs. For example, yellow hydrogen lets us know that the energy input is from solar.

In summary, not all types of hydrogen are created equal. While green hydrogen tends to be the preferred climate change solution, production via electrolysis comes with two major drawbacks. Firstly, the hydrogen it produces contains less electrical energy potential than the electricity used to make it. Secondly, the electricity used in the process usually comes from an electricity grid with power plants burning fossil fuels therefore it is not completely carbon-free.

Exhibit 2: Types of Hydrogen Based on Production Method

Types	Production Method	Carbon Free?	Primary Beneficiaries	Production Costs (USD per kg)
Grey Hydrogen	Under high temperatures and pressure, methane (CH_4) reacts with steam and a catalyst to produce hydrogen, carbon monoxide and a relatively small amount of carbon dioxide, also known as "steam-methane reformation."	No	Traditional commercial-scale gas producers	$0.7-$1.6
Blue Hydrogen	Typically refers to the same steam-methane reformation process as grey hydrogen but is then paired with carbon capture utilisation and storage (CCUS) technologies.	Yes*	Traditional commercial-scale gas producers + emerging CCUS players	$1.50-$2.40
Green Hydrogen	Typically refers to electrolysis using electricity sourced exclusively from carbon-free renewables, most commonly wind.	Yes	Renewable electricity producers + electrolysis infrastructure players	$6-$12
Yellow Hydrogen	Typically generated using electrolysis powered by solar energy.	Yes	Renewable electricity producers + electrolysis infrastructure players	$3.0-$7.5
Pink Hydrogen	Typically generated through electrolysis powered by nuclear energy (also referred to as purple or red hydrogen).	Yes	Could be used in other hydrogen projects by producing steam for more efficient electrolysis or fossil gas-based steam methane reforming	$2.75-$4.08

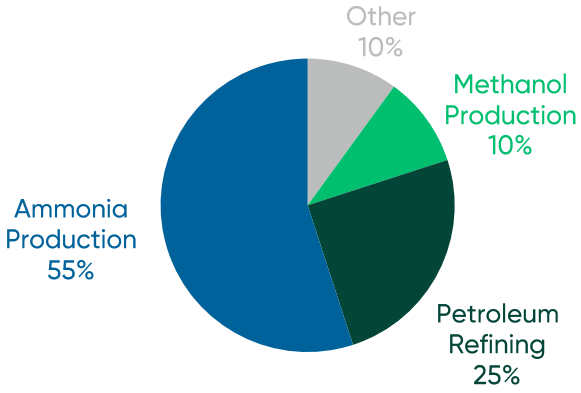
**Production creates carbon emissions, but they capture or use it without release into the atmosphere.*

Source: Resource for the Future, as of November 2022.

HYDROGEN'S POTENTIAL

With the rise of cleaner hydrogen production methods, hydrogen has the potential to be adopted in carbon-intensive sectors. For example, hydrogen is a primary ingredient in the production of ammonia (heavily used in agriculture), methanol and other industrial chemicals. (Exhibit 3) Hydrogen is also used in the refining process of oil and has the potential to be incorporated into the production of carbon-intensive materials, including aluminium, iron, steel and cement. Virtually all this hydrogen is supplied using fossil fuels, so there is significant potential for emissions reductions from clean hydrogen.

Exhibit 3: Global Hydrogen Consumption by Industry



Source: Wendell Hull & Associates International, as of September 2023.

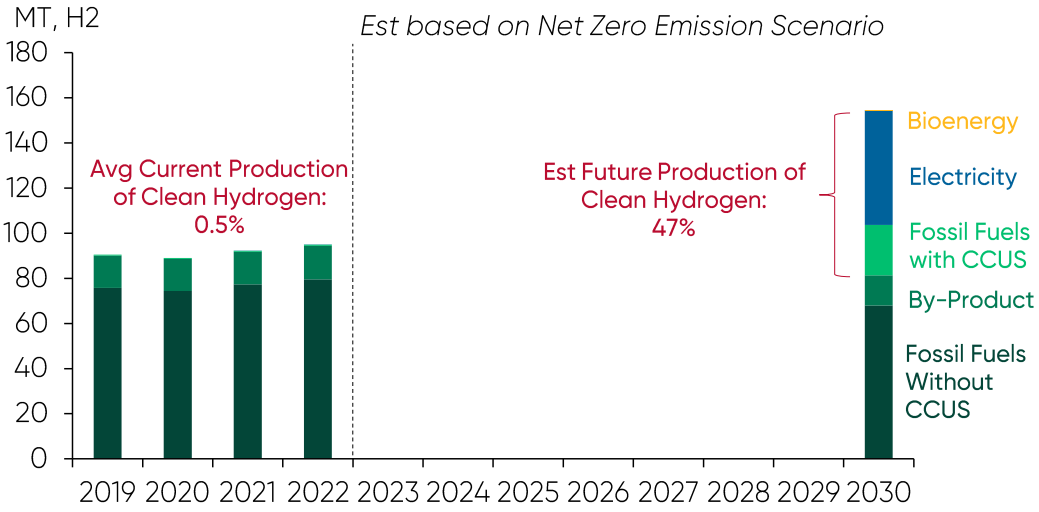
Hydrogen can also play an important role in grid electricity production, potentially solving the long-standing renewable energy storage problem of intermittency. What do you do when the sun stops shining or the wind stops blowing? Battery-based electricity storage solutions are currently too expensive to generate widespread utility-scale adoption. Hydrogen, however, could act as this energy storage medium. Sunshine and wind permitting, excess renewable electricity would create hydrogen through electrolysis. Stored hydrogen could then generate electricity as needed through fuel cells or, more conventionally, powering an electric generator through direct combustion.

In transportation, hydrogen can power road transportation/rail/marine/aviation vehicles. For instance, fuel cell electric vehicles (FCEVs) use hydrogen to create electricity acting as a replacement for heavy and expensive lithium-ion batteries EVs use today. Fuel cells use hydrogen, oxygen and a catalyst to create electricity, driving an electric motor. Stored hydrogen could allow long-range and quick-refuelling FCEVs. In heating, hydrogen combustion can play a role in heating businesses and homes, either exclusively (replacing natural gas heating) or blended into existing natural gas systems to reduce a system's carbon footprint.

CHALLENGES OF DECARBONISING HYDROGEN

While there has been recent momentum in policies, new technology and infrastructure underway, producing carbon-neutral or clean hydrogen remains challenging. Exhibit 4 demonstrates how IEA future production assumptions for cleaner hydrogen may be too optimistic based on the Net Zero by 2050 Scenario. As of 2022, steam-methane reformation (i.e. grey hydrogen) is responsible for the majority of commercial hydrogen production today (47% natural gas, 27% coal and 22% oil byproducts). Meeting 2030 estimates for cleaner hydrogen production (47% of hydrogen production) requires a dramatic scaling up of technologies which today make up less than 1% of total hydrogen production. Cleaner hydrogen production methods such as carbon capture utilisation and storage (CCUS) are available today but require significant technological advances and capital to meet implied 2030 production estimates. Also, the pipeline of announced projects to produce hydrogen via electricity or water electrolysis could be operational by 2030, but more than half of these are still in the early stages of development. Further, cleaner hydrogen production isn't economically viable for most applications, with the cleanest form of hydrogen costing roughly three times as much as the same amount of fossil fuels.

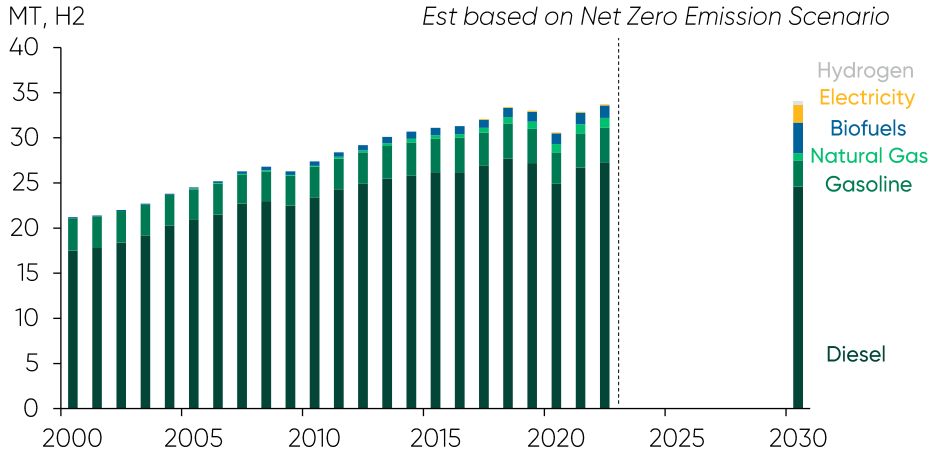
Exhibit 4: Global Hydrogen Production by Technology



Source: International Energy Agency, as of July 2023. Clean hydrogen comprises of hydrogen produced by bioenergy, electricity, fossil fuels with CCUS.

Even if cleaner global hydrogen production increases, there is currently no significant source of demand within the transportation sector for hydrogen to be used as a fuel source, and that is not expected to noticeably change for many years, as shown in Exhibit 5. A switch to hydrogen requires a complete reinvention of the transportation infrastructure: from the production of hydrogen, transportation to refuelling sites, and finally the end-use vehicle technology that transforms the energy to power a hydrogen fuel cell vehicle.

Exhibit 5: Global final energy demand for trucks and buses by fuel, 2000-2030



Source: IMF, 2023 estimates based on April 2023 report. FactSet, as of September 2023.

In contrast, demand for electricity as a transportation fuel source is estimated to increase. Within sectors where direct electrification is readily available and more feasible, such as road transportation and heating, it is harder for cleaner hydrogen to compete with demand. Direct electrification uses less energy to power cars and heat homes when compared to clean hydrogen—making it more efficient as a low-carbon alternative.[3] Additionally, direct electrification does not require conversions into different states for transmission, distribution, and end-use. Overall, as a clean energy alternative, direct electrification has more benefits compared to hydrogen.

[3] *Source: Environmental Defence Fund, as of January 2023.*

FISHER INVESTMENT'S HYDROGEN OUTLOOK

FI believes any hydrogen adoption likely plays out over many years (potentially decades). This likely creates investment risks including: 1) the likelihood of early hydrogen pioneers' failure and 2) more promising unforeseen technological advancements usurping hydrogen's potential. In our view, if hydrogen trends play out as boosters promise, there will be plenty of time for investors to participate. Consider late-1990s Tech investors: They may have correctly identified internet services growth, but many hyped companies failed. A study of nearly 2,000 business-to-business (B2B) e-marketplaces launched during the tech bubble found that only 55% stayed in business at least two years after September 2002, when the Nasdaq hit its lowest point.[4]

Currently, many of these hydrogen pure-play companies are smaller in size and don't fit with our current style preference for larger-cap names with healthy balance sheets. While hydrogen is not a meaningful portfolio theme today due to its size and the technology's early-stage status, FI portfolios may have some indirect exposure. There are large public companies that invest in hydrogen developments. The top 3 companies by market share can be found mostly in the Energy and Industrials sectors (Exhibit 6) and even then, hydrogen tends to be a smaller end market for these companies and not part of their core business models. For example, we own Shell (a multinational oil & gas company) in several portfolios. However, it has been transitioning to clean energy since 2015 via a pipeline of newly activated projects. One of the projects is to construct Europe's largest green hydrogen plant in the Netherlands (~10x larger than the current biggest plant in Europe). We also own BP in select portfolios. As the hydrogen market expands, we believe these larger companies can adapt to changing global energy demands.

Exhibit 6: Top 3 MSCI ACWI Companies by Market Share with Exposure to Hydrogen Development

Companies	Product Line	Sector
Shell	Specialises in producing oil, natural gas, and green hydrogen	Energy
Linde	Specialises in producing and distributing atmospheric and process gases, including green hydrogen	Industrials
BP	Has diverse global base of low-cost oil productions has become a leader in the energy transition	Energy

Source: FactSet, as of November 2023.

CONCLUSION

With any nascent and growing industry, it is hard to predict who the long-term winners are going to be as competition and applications change rapidly. Typically, we wait to invest until an industry has time to mature and we can more accurately assess potential long-term winners and losers. Of course, more rapid hydrogen scaling progress and regulatory shifts may broaden the investment landscape over time. However, conversely, the opposite may be true. Lack of progress in hydrogen adoption and tightening regulations may narrow the investment landscape. As we look forward, the future of clean hydrogen will likely continue to evolve on social, political and economic fronts. We know that the world is slowly transitioning away from fossil fuels and FI's dynamic and flexible investment process allows our research group to broadly study and monitor this ESG-related topic. We believe maintaining a top-down, global perspective of long-term trends will help identify future growth opportunities.

[4] *"Through the Service Operations Looking Glass: An Empirical Model of B2B eMarketplace Failures," by T. Laseter, E. Rosenzweig, and A. Roth, Darden School.*

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