# Power in Abundance

## The Economics & Applications of Hydrogen


Analysts

Alex Meile
alex.meile@mail.utoronto.ca

Jonathan Rincon Lopez
jonathan.rinconlopez@mail.utoronto.ca

Jun Park
kjun.park@mail.utoronto.ca

Yazen Abed
yazen.abed@mail.utoronto.ca

Lab Director
Professor Mark Manger
mark.manger@utoronto.ca

Global Economic Policy Lab

munk school
OF GLOBAL AFFAIRS & PUBLIC POLICY

UNIVERSITY OF TORONTO

# Hydrogen Summary

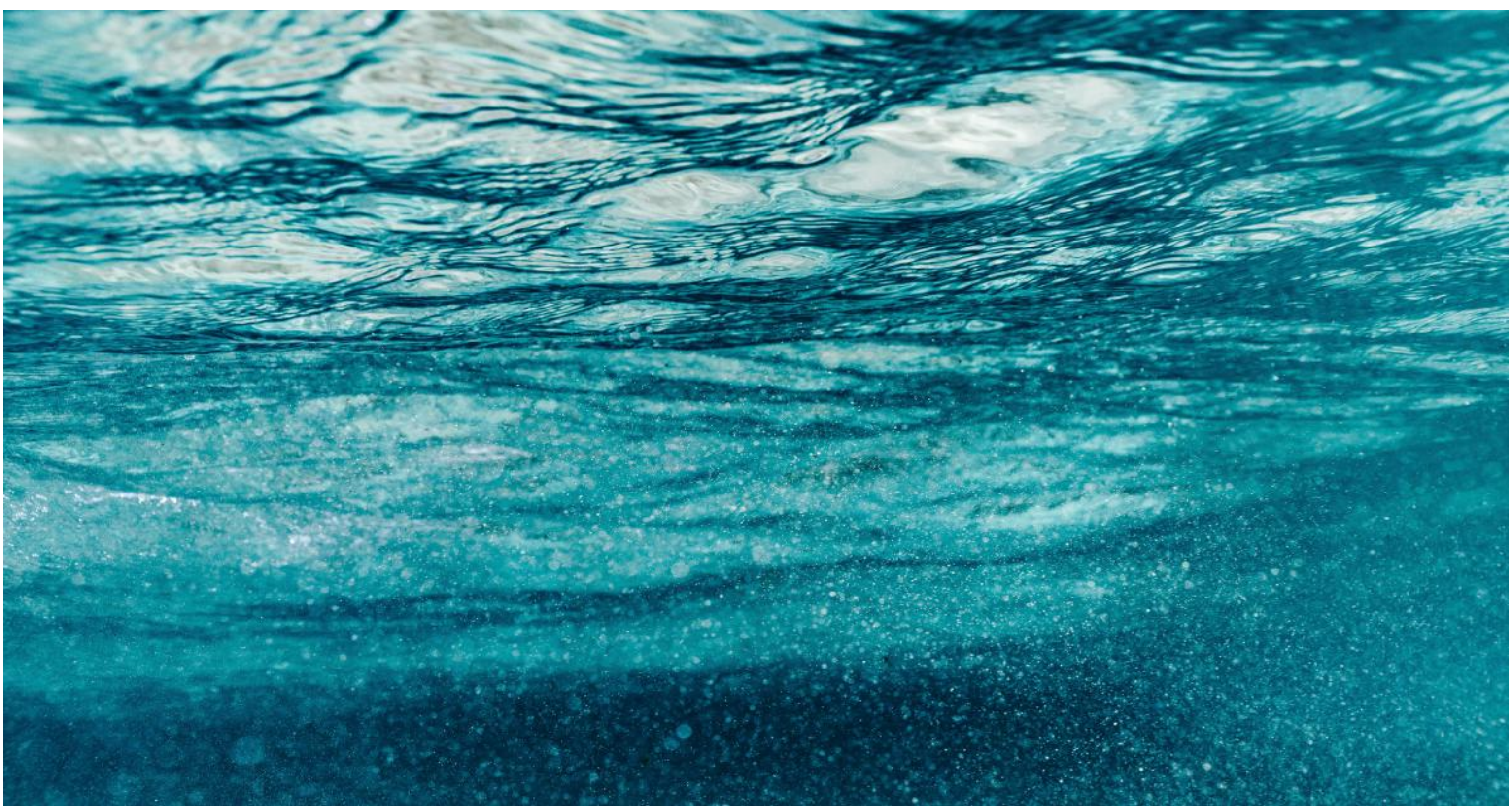
- Hydrogen is poised to take up many roles through the low-carbon transition - mainly in transportation, aviation, energy storage, and industry.

- The area where it's use is virtually guaranteed is in replacing natural gas within hard-to- decarbonize industries like steelmaking, chemicals, and cement.

- The recent surge in natural gas prices (currently at around €70/MWh [Dutch TTF] - as of Feb 15 2022) - an input for both blue and grey hydrogen - has made green hydrogen produced with cheap renewable energy cost competitive as a replacement for natural gas and blue hydrogen.

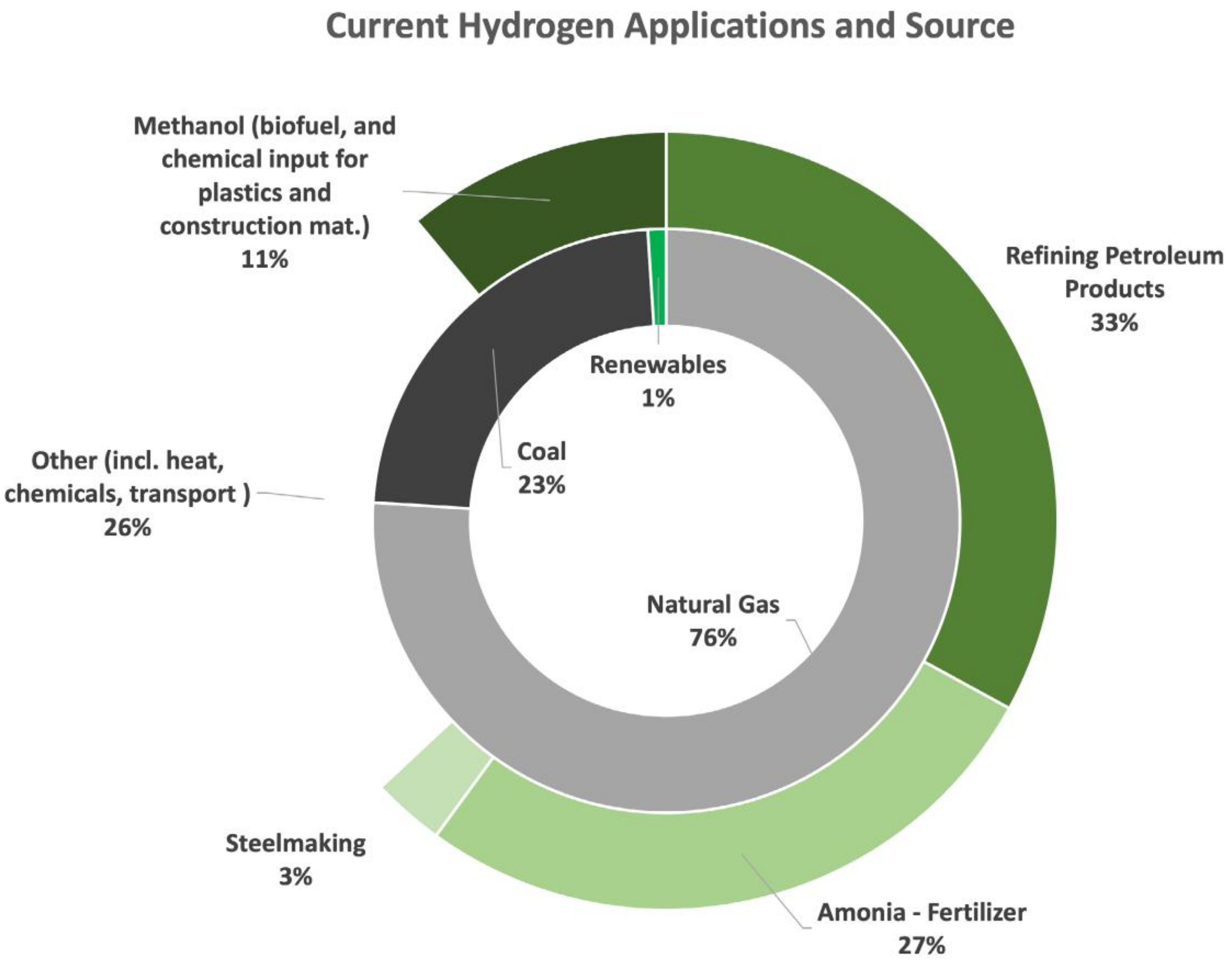
- The Hague's ruling vs. Shell plc in May of 2021 - mandating them to lower all scope emissions by 45% by 2030 - set the tone for the European energy sector's transition towards a zero-carbon future around hydrogen.

- Shell and BP are becoming leaders in hydrogen while US oil giants lag behind and hedge their bets on traditional sectors.

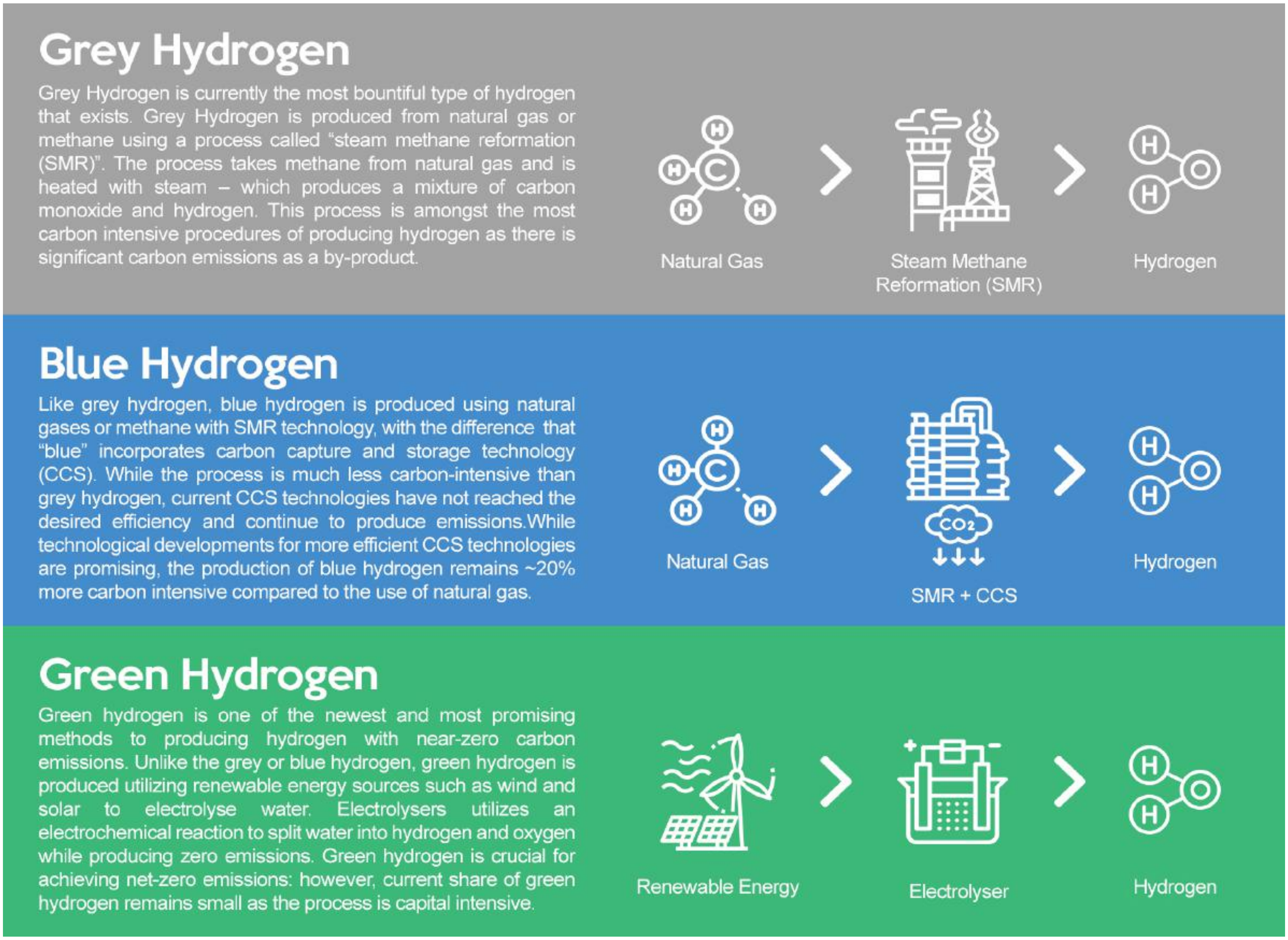


# Hydrogen Overview

A common misconception surrounding hydrogen is that it is often seen as a "clean" energy source; however, as it currently stands, this is not entirely accurate as ~90% of hydrogen is produced from non- renewable sources such as natural gas and coal, while only ~2% of global hydrogen is produced from renewable sources. There are numerous ways that hydrogen can be produced, however covering all the different methodologies of hydrogen production is beyond the scope of this brief, which and will focus on three different types: grey, blue, and green hydrogen. Before covering the three main types of hydrogen, the graph below demonstrates the breakdown of current hydrogen usage.



The illustration below provides a breakdown of the three main types of hydrogen and how each one is created




As it currently stands, the average cost of producing green hydrogen is over 50% higher than the cost for producing grey or blue hydrogen. Grey hydrogen could be as low as $1/kg in regions where natural gas is abundant, and blue hydrogen is unsurprisingly more expensive as it factors the cost of the CCS technology. The cost range for green hydrogen is significantly larger than the ranges for blue or grey, as it varies depending on renewable energy costs in different regions, and the cost for the electrolyser technology. The costs for grey and blue presented here and later in this section, are based on gas prices of around $3.4/kg which have now increased by over 30 times in Europe. This has in turn pushed the cost of grey and blue hydrogen to hover around $10/kg - making green hydrogen more attractive as a substitute for both gas-derived hydrogen and natural gas itself. If the current trend in gas prices continue, green hydrogen is poised to become cheaper than grey and blue hydrogen sooner than 2050.

# Hydrogen Applications

In recent years hydrogen has become a rising star in potential candidates to replace conventional energy sources such as coal and natural gas to achieve a true net zero economy. The application for Hydrogen is bountiful, as it is significantly more energy dense as compared to fossil fuels; hydrogen has an energy density of 120MJ/kg which is three times more that of diesel or gasoline. Moreover, a kilogram of hydrogen has the same amount of energy as 2.8kg of gasoline, this can be particularly useful for electricity production as a kilogram of hydrogen equates to 33.6kWh of energy where a kilogram of diesel produces 12-14kWh of energy. Currently, hydrogen has been deployed in various applications, namely transport and energy production. New Zealand is among the first countries to announce the complete phasing out of natural gas in favour of hydrogen by 2050. Japan, in a similar trend, is on track to achieving 1 GW of power capacity based on hydrogen by 2030. While currently hydrogen makes up only 0.2% of electricity generation globally, rapid development and maturity of hydrogen production technologies in tandem with government policies and investment into hydrogen technology has been a catalyst for the rapid growth and interest in hydrogen-based energy production in recent years.

Another notable application for hydrogen in achieving a net-zero economy is hydrogen fuel cell vehicles (FCEVs). Like hydrogen-based energy production, FCEVs represent a very small fraction of vehicles on the road, only 0.01%. However, the share of FCEVs has been rapidly growing in recent years as more than 40,000 FCEVs were on the road by the end of June 2021, with more than 8,000 vehicles being sold in the first half of 2021. Currently, South Korea occupies the largest FCEV market, with more than ~1/3 of global FCEV sales residing in the country, largely due to the government's aggressive policies for FCEV adoption with national and local governments offering up to $30,000 in subsidies. It is expected that countries with ambitious climate policies will adopt similar policies to Korea to boost FCEV sales. Government policies in tandem with hydrogen technologies reaching economies of scale, more than six million FCEVs could be on the road globally by 2050.

# Hydrogen's Future

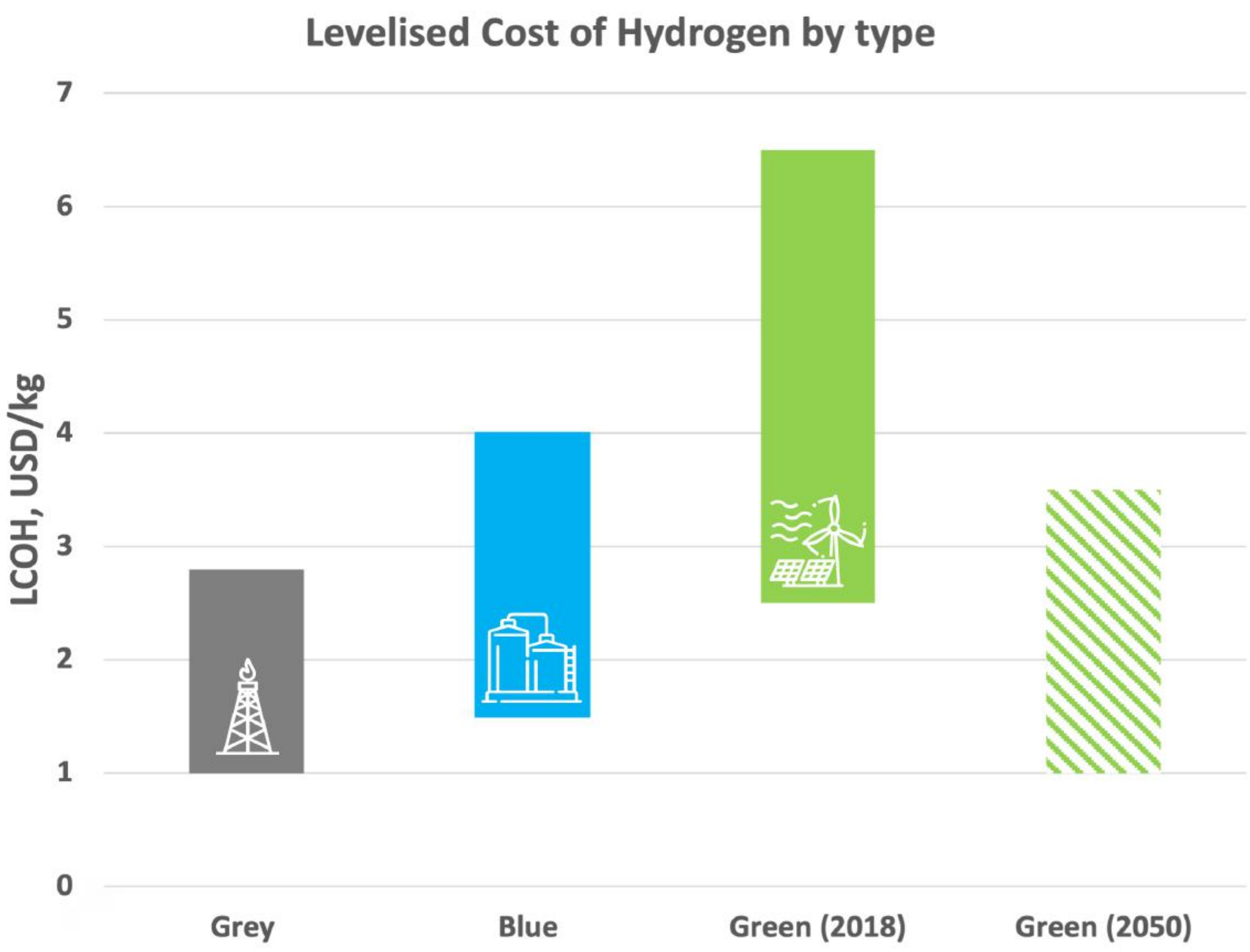
Clean Hydrogen can be guaranteed to play multiple roles as we transition towards a lower-carbon economy. Hydrogen will have the highest impact within the hardest to decarbonize industries such as steelmaking, cement, and chemicals as it replaces natural gas. These industries are hard to decarbonize due to their need for very high heat through their processes. The prospects for hydrogen towards the decarbonization and electrification of transport are also high, as it can act as a bridge to extend renewable energy over longer distances within the transportation sector. It can also step into power aviation in the long-term (net-zero 2050 future) through combustion or hydrogen fuel cells instead of regular electric batteries, as a 6.6 million pound electric battery would be required to power the average flight with electricity. Similarly, hydrogen is poised to serve as a clean source of stabilizing energy to mitigate the intermittency of renewable energy sources.

The biggest challenge for clean hydrogen (mainly green and blue) has often been quoted as the cost of carbon capture when referring to blue hydrogen, and the cost of clean fuel or the electrolyser, depending on whether you are in North America or Europe, with regards to green hydrogen.

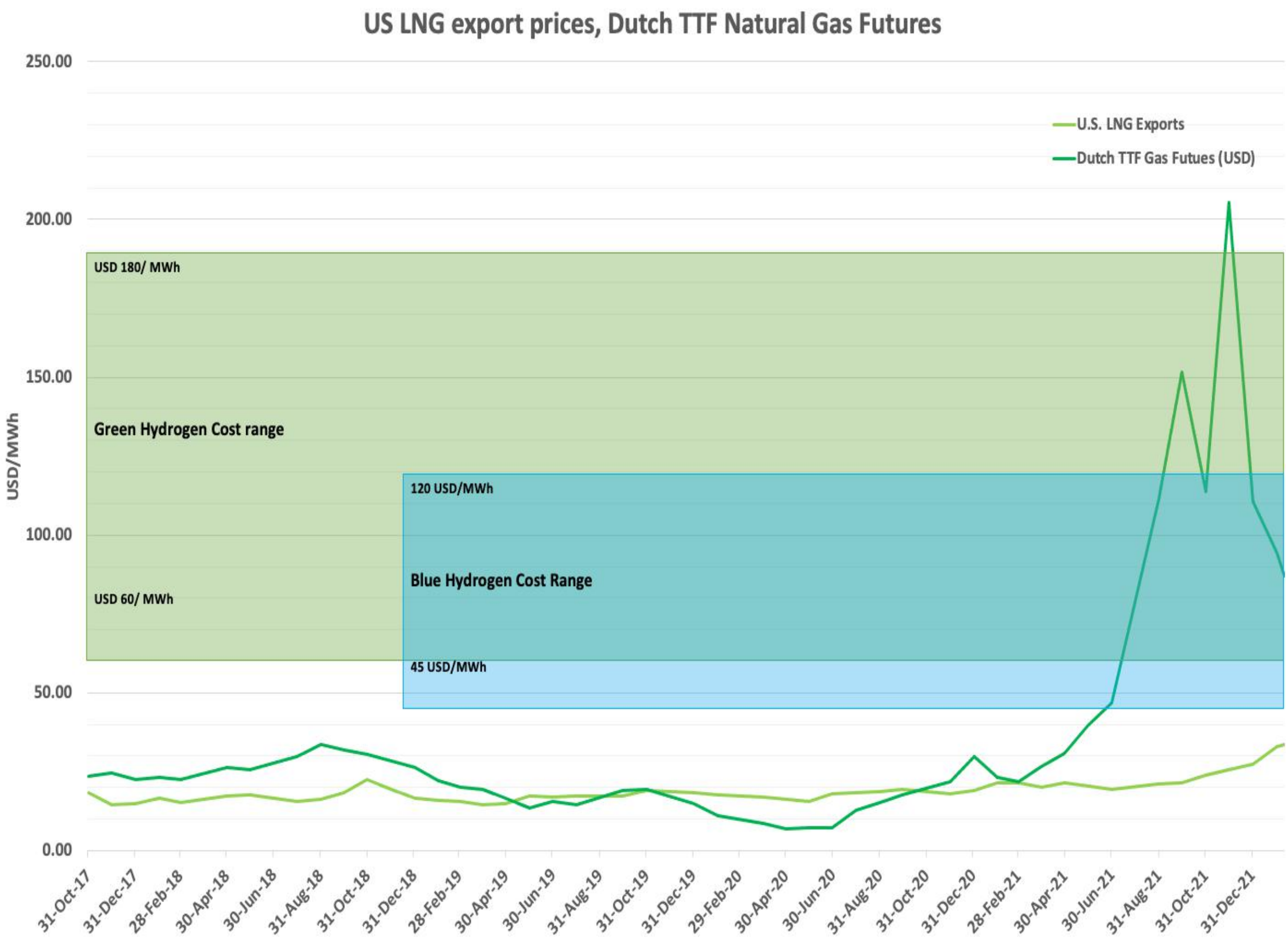
Concerning the potential for replacing natural gas, the biggest issue is that the infrastructure in place for natural gas is not suitable to manage a higher volatility gas like hydrogen at concentrations exceeding 17% by volume. Some replacement or refurbishment will be inevitable, as is currently underway in the Netherlands. Replacing infrastructure is necessary due to hydrogen's energy dense and light nature. It contains more than 2x the energy per mass of the substance when compared to natural gas (~120 Mj/kg vs. 55 MJ/kg), but it also requires more pressure to contain and compress.

Crucially, recent research shows that blue hydrogen (from fossil fuels, with CCS) potentially includes more emissions through its entire supply chain than simply burning natural gas, mostly due to leakage. If this is true, it means that the only real viable type of hydrogen for the low-carbon transition would be green hydrogen, which up until recently was in no way cost-competitive with natural gas.

As we mentioned earlier in this report, green hydrogen is estimated to cost between 3 USD/kg - 6.5 USD/kg as of Q2 of 2021. This is the levelized cost which accounts for the upfront investment, and subsequent generation costs of using hydrogen into an average net present value number. At 33.6 KWh/kg in terms of electrical energy, this translates to roughly 60 USD/MWh - 180 USD/MWh. In our first brief within this series of commodities through the low-carbon transition, we analyzed the volatile natural gas prices of Q1/2022 within the context of Europe. As of February 2022, these prices have begun to settle at around 85 €/MWh or ~96 USD/MWh. At these unprecedented rates, green hydrogen produced with the cheapest renewables (mainly utility-scale wind and solar) has a cost competitive angle when compared to natural gas.



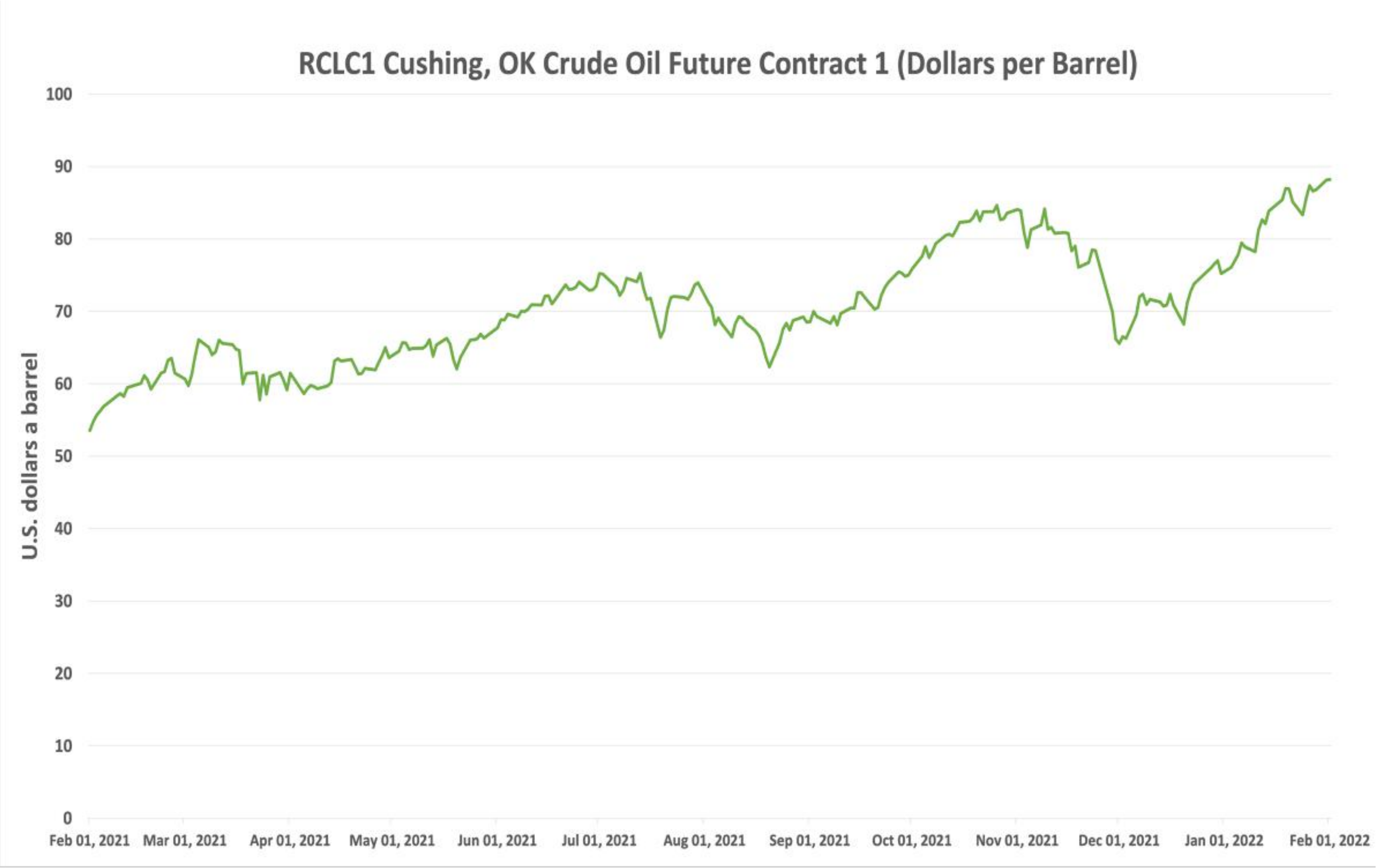
This will likely continue to be the case, but because there is an infrastructure limitation to the replacement of natural gas with hydrogen, the first projects to take hold will be those that can stomach a large capital investment to upgrade infrastructure for longer term cost savings and are relatively isolated. This means cash-rich, hard-to-decarbonize industries. As the cost of renewable energy keeps decreasing, making green hydrogen cheaper, while simultaneously the cost of natural gas continues to go up, we will be able to justify large- scale overhauls of natural gas infrastructure throughout cities and buildings. This will likely only occur in themedium-to-long term, and at the same time, we will likely never see natural gas replaced entirely (10-20%) of end uses likely to remain) as these networks of pipes and infrastructure are highly interconnected, complex, and widespread.

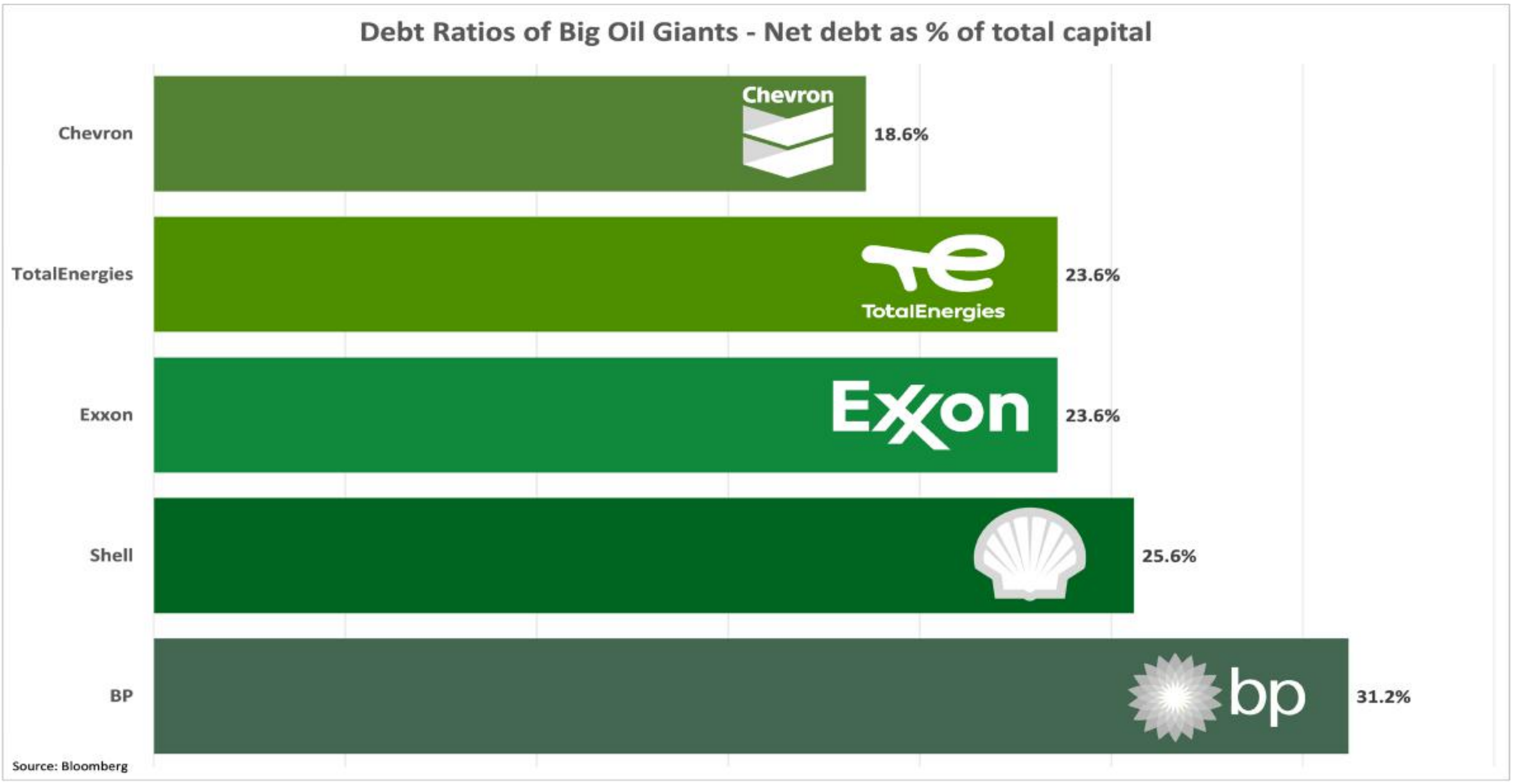


# Hydrogen & Energy Giants

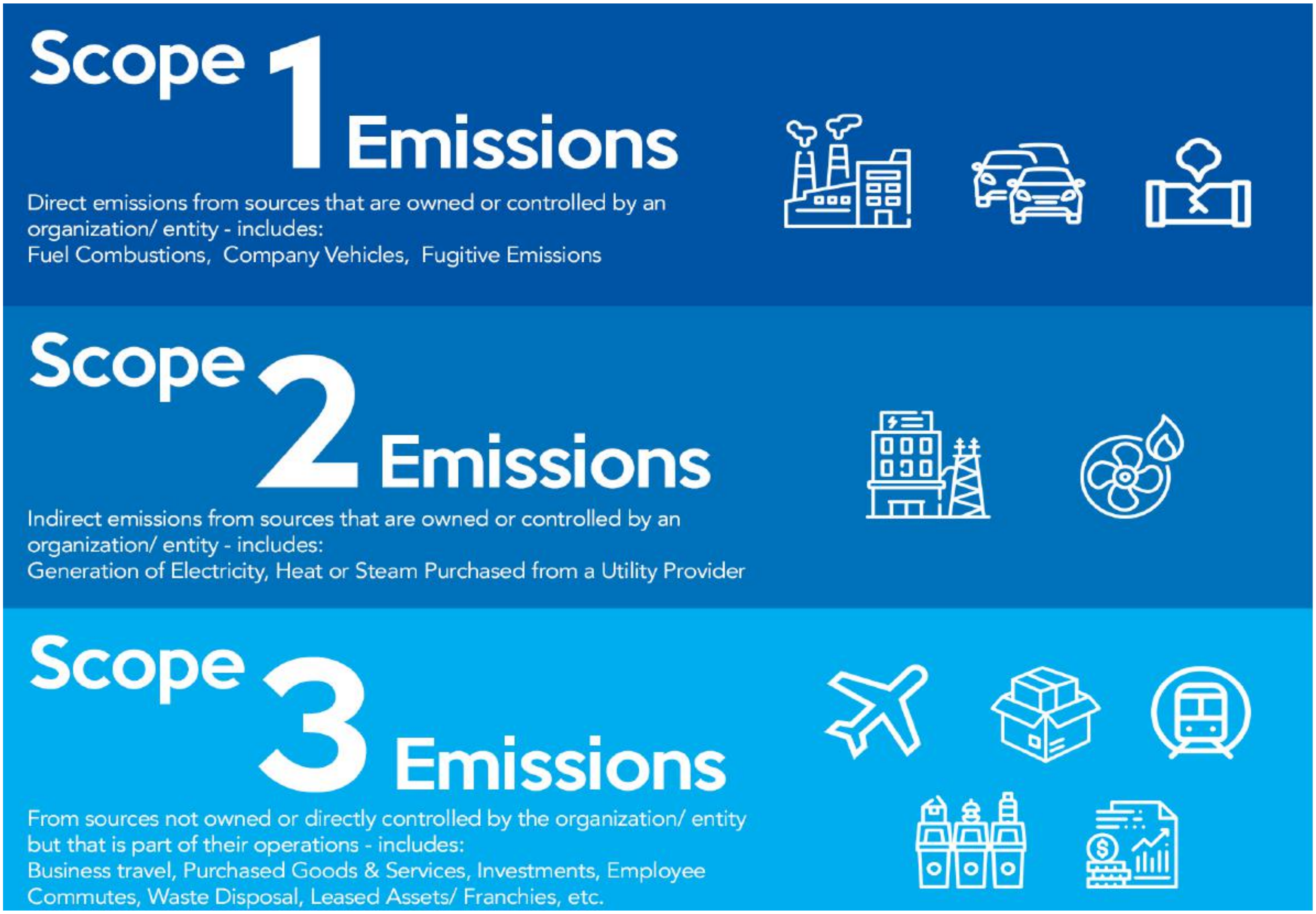
The future potential of hydrogen as an alternative fuel and strong source of revenue has become clear to even the largest global energy firms, some of which have begun to take significant steps in their quest to become a zero-emission industry. Currently, however, robust aggregate demand for oil products continues to outpace supply in economies throughout the world, with global futures benchmarks listing the commodity at ~$92/barrel. Supply shortages are exacerbated by external factors such as weather, damaged infrastructure, and falling inventories on tankers. European energy firms are simultaneously faced with high uncertainties around the Ukraine conflict. European oil giants, including BP plc and Shell plc hold large stakes in Russian energy giant Rosneft PJSC and a Gazprom PJSC-led LNG project respectively.

Rosneft accounts for 30% of BP's oil and gas productions and thus generates a large portion of BP's free cash flow. The current uncertainty around the recent escalation in Ukraine poses a certain risk for the two European oil giants, as they seek progress with their commitments towards zero-carbon with the help of their cash flow generated from their traditional sectors.





Debt Ratios of Big Oil Giants - Net debt as % of total capital
Chevron
18.6%
TotalEnergies
23.6%
Exxon
23.6%
Shell
25.6%
BP
31.2%
Source: Bloomberg

Scope 1 Emissions
Direct emissions from sources that are owned or controlled by an organization/ entity - includes:
Fuel Combustions, Company Vehicles, Fugitive Emissions
Scope 2 Emissions
Indirect emissions from sources that are owned or controlled by an organization/ entity - includes:
Generation of Electricity, Heat or Steam Purchased from a Utility Provider
Scope 3 Emissions
From sources not owned or directly controlled by the organization/ entity but that is part of their operations - includes:
Business travel, Purchased Goods & Services, Investments, Employee Commutes, Waste Disposal, Leased Assets/ Franchies, etc.

As such, the European competitors appear to be the first to make net-zero commitments backed by action. Notable here has been the Hague's ruling on Shell's carbon emissions in May 2021, in which the oil giant was ordered to reduce the carbon emissions of its suppliers, customers, and its own production by 45% in 2030, setting a new tone on the continent. While the ruling is limited to Dutch law and subject to appeal, it nonetheless will require Shell to accelerate its energy transition plans by spending an annual $3 billion USD on renewables and low-carbon technologies, i.e. ~30% of the firms budgeting for its upstream business of exploration and production. Analysts speculate that energy firms with subsidiaries in the Netherlands could be facing similar litigation in the near future, possibly across Europe, as the European Union (EU) commission commits to a greener future.

In response to EU policies and mounting legal pressure in key markets, the European oil giants BP and Shell, have begun to reshuffle both their strategies and senior roles as they strive to implement their low carbon plans. BP is planning to construct a green and blue hydrogen base in Teesside, United Kingdom (UK), which will be producing 60 megawatts (MW) by 2025 and 1 gigawatt (GW) by 2030 respectively. The firm is pouring funds into the hydrogen business with the expectation that the alternative fuel will begin to displace fossil fuels across sectors by the end of the decade, thus putting BP on track to meet its UK strategy for net zero emissions by 2050. Meanwhile, BP is considering similar projects in Germany, Spain, and the Netherlands.

Shell plc, formerly known as Royal Dutch Shell prior to its relocation to the UK from the Netherlands following the Hague ruling, is taking steps to push for greater hydrogen production capacities in both the Netherlands and China. In the latter, Shell has taken a 20MW electrolyzer - producing green hydrogen by electrolysis - into operation for the 2022 Beijing Winter Olympics. In the Netherlands, Shell and Thyssenkrupp are supporting the nation's effort towards a hydrogen future through a supply contract for a 200MW producing green hydrogen project dubbed 'Hydrogen Holland I', which is going operational in 2024. The Dutch are taking central stage in the continent's shift towards Hydrogen. Both through their strong commitment towards a zero carbon future - as reflected in the Hague's ruling vs. Shell - and due to the need to diversify their energy supplies and reduce their foreign dependence. The current energy and gas crisis has exacerbated Dutch worries over local capital assets in Groeningen - formerly Europe's largest gas field - becoming stranded infrastructure. It's operation had been halted prior in response to production problems and political policy pressing for emission cuts. As such, existing infrastructure is being repurposed for the transportation, production, and storage of hydrogen in the coming years, including in Groeningen. This is congruent with the construction of new hydrogen infrastructure projects from Shell, which together are to contribute to the EU's goal of producing 40GW of green hydrogen by 2030.

Additionally, Shell has continued to expand its global reach on hydrogen and diversified its projects in an effort to become a global leader. Shell has taken the steps to integrate hydrogen into their global strategy. They have done so by developing hydrogen hubs and innovating new ways to produce and supply hydrogen to its own refineries. Shell has also paid particularly close attention to heavy duty transport in efforts to extend its network of hydrogen retail stations. In December 2021, Shell launched two projects in the Illawarra region of Australia with BlueScope, in an effort to develop novel ways to leverage hydrogen in a country with an abundance of natural resources and the potential to become a major producer of hydrogen for the purpose of renewable energy. The first project, similar to the electrolyser in Beijing, harnesses green hydrogen to lower emissions in steelmaking, which is of particular interest to Shell in the wake of the Quest Plant being found to emit more carbon than it captures. The other project, a "hydrogen hub" will be a collaborative effort to explore innovative ways to manage the hydrogen supply, including an examination of the logistics infrastructure required to maintain and expand hydrogen flows in Australia.

While the BlueScope collaboration focused on Australia, Shell took part in a recent $18 million Series A investment round in Ionomr Innovations, a Vancouver based tech company, to take a more holistic approach to harness hydrogen for clean tech. Ionomr develops ion-exchange membranes and polymers that reduce the cost and increase the efficiency of hydrogen production and storage, contributing to a clean energy economy. These polymers are particularly useful in eliminating the need for metal requirements in hydrogen production and electrolysis, the two projects Shell has recently launched. By investing in natural resource countries and in technology that will streamline hydrogen production and transport, Shell has exhibited a commitment to achieve double digit market share in clean hydrogen by 2030, focusing on the industry and the transportation sector.

Shell's long-term low-carbon strategy revolves around increasing hydrogen production towards transportation uses and within industry. The latter seems to be a sure shot as hard to decarbonize industries (steelmaking, chemicals, cement) that require high amounts of heat cannot electrify completely. Cheaper green hydrogen is poised to be a good replacement for natural gas in the short-to-medium term for these industries, although at an initial premium with the need to replace natural gas infrastructure.