THE FUTURE OF BIG OIL IN THE HYDROGEN ECONOMY

by

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Executive Summary

As investors, policymakers, and the public prioritize the urgency of addressing climate change, oil and gas companies are forced to grapple with how to reduce and eventually eliminate carbon emissions. Recently, hydrogen has gained interest from governments, companies, and investors as one solution for replacing direct fossil fuel consumption in a new energy economy. Globally, oil and gas companies have approached hydrogen fuel with varying levels of interest and investment. In Europe, where policymakers have earmarked large sums of investment for hydrogen technologies, oil majors have been generally more proactive about incorporating hydrogen into their corporate strategies. US policymakers and oil majors have overall been less focused on hydrogen, but the US has some unique conditions that may be favorable to an expanded hydrogen industry. In addition to outlining the current policy contexts around hydrogen in Europe and the US, this paper highlights the strategies of six oil majors; ExxonMobil (Exxon), Chevron Corporation (Chevron), British Petroleum (BP), Equinor, Royal Dutch Shell (Shell) and Total, as they relate to hydrogen. It also explores the unique challenges and opportunities that exist for traditional oil and gas companies related to hydrogen, and how oil majors might adapt their infrastructure and workforce to embrace a hydrogen future.

Hydrogen produced with natural gas and coal emits carbon dioxide during production and is categorized as “gray hydrogen”. Hydrogen is considered “green” when it is produced via electrolysis, the splitting of water into hydrogen and oxygen, powered by carbon-free electricity resources like solar and wind power. Only about 0.1% of hydrogen produced today is made via water electrolysis. “Blue” hydrogen, by contrast, is produced via the traditional fossil fuel methods but is paired with carbon capture and sequestration/storage (CCS) technology, capturing carbon dioxide and storing it so that it is not emitted into the atmosphere. Other possible production methods of hydrogen include nuclear-powered electrolysis, nuclear heat, and biomass gasification.

In Europe, oil and gas companies have responded to the aggressive decarbonization goal-setting from governments with their own ambitious carbon reduction goals. BP, Equinor, Shell, and Total have all adopted net-zero emissions goals by the year 2050. All four companies have begun to make major strategic shifts and invest in renewable energy technologies. In the US, where climate policies have been less consistent, emissions reduction goals made by Chevron and Exxon have been relatively less ambitious. The companies’ long-term strategies have remained focused on oil and gas production, and reductions in emissions are expected primarily via investments in CCS technologies rather than renewable energy.

The EU, Norway, and UK (home to the European majors covered by this project) have ambitious policies in place incentivizing hydrogen production, with a specific focus on green hydrogen. European oil majors are taking advantage of a favorable policy environment and high likelihood of public investment and pursuing large-scale green hydrogen projects. The expertise these companies are developing in renewable energy are serving them well as they plan to pair solar and wind resources with electrolyzed hydrogen. European majors are also advancing projects focused on blue hydrogen and CCS, diversifying their role in Europe's planned hydrogen landscape. In the US, policymakers have highlighted clean hydrogen as an important component of decarbonization. However, aside from limited R&D investments in emerging hydrogen technologies, broadscale hydrogen policies or incentives have not been implemented. Perhaps not surprisingly in this context, Chevron and Exxon have trailed behind their European peers when it comes to announced hydrogen projects. Still, Chevron and Exxon have increasingly mentioned hydrogen as part of a long-term plan and both have made commitments to increase investment in CCS technologies, which may give them an advantage in blue hydrogen production down the line.

Finally, when it comes to oil majors participating in the hydrogen economy, this paper outlines three major risks and three opportunities. Risks include competition from other technologies, a potential overreliance on CCS, and overdependence on large-scale policy incentives. Major opportunities include existing infrastructure transferability, relevant experience and human capital, and hydrogen's potential as a point of evolution in the energy transition. With hydrogen, oil majors may have a unique opening to remain relevant in a decarbonized economy. Still, the success of the technology is highly dependent on a confluence of policy support, development of an infrastructure backbone, and advancements and cost-reductions across the supply chain.

The Issue

The success of renewable energy technologies in recent decades has led governments and businesses to set ambitious carbon emission reduction targets. Challenges remain for broad decarbonization efforts, including variability of renewable electricity and the inherent advantage held by fossil fuels in energy dense applications like aviation, long-haul shipping, industrial processes, and more. Recently, hydrogen has gained interest from governments, companies, and investors as one solution for replacing direct fossil fuel consumption in a new energy economy.

Using hydrogen as an energy carrier is not a new concept. Today hydrogen is most prominently used in oil refining, agriculture, and food production. Most of the world's more than 75 Mt of hydrogen produced in 2019 was made using natural gas via a steam methane reformation (SMR) process or via coal gasification.[1] Hydrogen produced with natural gas and coal emits carbon dioxide during production and is categorized as "gray hydrogen". Hydrogen is considered "green" when it is produced via electrolysis, the splitting of water into hydrogen and oxygen, powered by carbon-free electricity resources like solar and wind power. According to the International Energy Agency, only about 0.1% of hydrogen produced today is made via water electrolysis without direct carbon emissions. Blue hydrogen, by contrast, is produced via the traditional coal or natural gas method but is paired with carbon capture and sequestration/storage (CCS) technology, capturing carbon dioxide and storing it so that it is not emitted into the atmosphere. Other possible production methods of hydrogen include nuclear-powered electrolysis, nuclear heat, and biomass gasification.

Currently, the end-uses for hydrogen are limited. Today, the vast majority hydrogen produced is used for oil refining and industrial ammonia and methanol production in the chemical and agricultural sectors. However, as advanced decarbonization efforts get underway over the next decades, hydrogen may have vastly expanded use cases. According to the IEA's Sustainable Development Scenario, which models a world where aggressive climate policies are implemented, by 2050 hydrogen production will be vastly increased and demand will be more evenly spread across fuel cells for cars, trucks, and ships, synthetic fuels and ammonia for aviation and shipping, flexible electricity generation in the power sector, space and water heating for buildings, as well as heat sources for industrial processes.[2]

Big inroads will need to be made for the hydrogen industry to ramp up enough to meet these projections. Today, both blue and green hydrogen production are costly when compared to traditional gray hydrogen production. As displayed in Table 1 in the appendix, the costs of hydrogen vary significantly depending on the production source. For example, the future viability of hydrogen produced from natural gas with CCS or with renewable energy is very dependent on natural gas prices. According to the IEA, "At low gas prices, renewable electricity must reach a cost range below USD $10/MWh for electrolysis to become cost-competitive with

[1] "IEA Energy Technology Perspectives 2020." IEA Webstore, 2020, webstore.iea.org/download/direct/4165.
[2] Ibid.

natural gas with CCUS. Higher gas prices would make higher-cost renewable electricity cost-competitive: at a gas price of USD $11/MBtu, renewable electricity would be competitive at up to around $USD 30–45/MWh."[3]

There is some reason for hope that green hydrogen could become competitive quickly, particularly as solar and wind costs continue to drop rapidly. According to a Bloomberg New Energy Finance study, the cost of alkaline electrolyzers made in North America and Europe fell by 40% between 2014 and 2019, and Chinese-made systems are already up to 80% cheaper than those made in the West. [4] The same study concluded that if costs continue to fall and electrolyzer technology scales up, hydrogen made with renewable energy could be produced for $0.7 to $1.6/kg in most parts of the world before 2050. According to the report, "This would make it cheaper than producing hydrogen with fossil fuels and CCS at current costs, and equivalent to gas priced at $6-12/MMBtu, making it competitive with current natural gas prices in Brazil, China, India, Germany and Scandinavia."

Comparing Policy Contexts

The European Landscape

In general, European governments have sought to lead the global transition from fossil fuels to renewable energy. In 2018, the European Union announced its goal to be "an economy with net-zero greenhouse gas emissions" by 2050.[5] The 27-member bloc has already made unprecedented gains in renewable energy deployment. In 2020, renewables overtook fossil fuels for the first time to become the largest source of power in the EU electricity mix. According to a report from think tanks Ember and Agora Energiewende, renewable energy sources like wind and solar generated 38% of the EU's electricity in 2020, while fossil fuels contributed 37%.[6] Still, for the EU to meet its 2050 net-zero target and intermediate goal of reducing GHG emissions by 55% by 2030, more clean energy technologies need to be deployed not only in the electricity sector but across transportation, industrialized processes, heating, and other sectors. Given the gross scale of decarbonization required, hydrogen has received significant consideration as an essential piece of the European climate strategy.

The EU plans to spend $558B to hit ambitious targets of 6 GW of green hydrogen via electrolysis by 2024, 40 GW by 2030, and 500 GWs by 2050. The EU has also set a goal of importing 40 GW of green hydrogen from neighboring non-EU countries. On a country level,

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[3] Ibid.

[4] Hydrogen Economy Outlook, Key Messages, Bloomberg New Energy Finance, March 30, 2020

[5] "Communication from the Commission: A Clean Planet for All A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy." EUR, 28 Nov. 2018, eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0773.

[6] Graichen, Patrick, and Dave Jones. "EU Power Sector in 2020." Ember Climate, 15 Feb. 2021, https://ember-climate.org/project/eu-power-sector-2020/.

most member states have plans for clean hydrogen in their National Energy and Climate Plans and have joined a region-wide "Hydrogen Initiative".[7] Central to the EU's plan is a "backbone" hydrogen pipeline system that would allow countries to transport hydrogen produced at lower costs to areas with highest demand. Under this scenario, hydrogen would be blended with natural gas for distribution across Europe, and pipelines eventually may be retro-fitted to support solely hydrogen. Plans for a pipeline system are still in their early stages, but related infrastructure investments could make hydrogen a critical component of Europe's future energy system.

Neighboring European countries that are home to oil majors covered by this project have made similarly ambitious decarbonization goals and have highlighted hydrogen as an important solution. Norway's government has a goal of reducing emissions by between 90 and 95 percent before 2050, and has introduced a carbon tax that is due to increase 5% per year until 2025, incentivizing green investments across the board. In addition, Norway has introduced tax breaks for electricity supplied for hydrogen production via electrolysis as well as for consumers purchasing hydrogen-based vehicles.[8] The UK announced in 2019 its goal for net-zero GHG emissions by 2050 and is also centering hydrogen as one means of achieving decarbonization. Hydrogen is a key component of the government's "Ten Point Plan for a Green Industrial Revolution." By 2030, the UK is aiming for 5 GW of green and blue hydrogen, with plans to create hubs around existing facilities with natural gas infrastructure.[9] Similar to the EU, the UK plans to create a hydrogen "backbone" from pipelines within the country through National Grid's Project Union initiative. This will build off of the government's 10-point plan to invest more than £1B in hydrogen and will support the establishment of carbon capture, utilization and storage (CCUS) in four industrial clusters across the UK.[10] This is still in an initial scoping and assessment phase, but the plan already has monetary backing from the government and the grid operator, who hope to use this to decarbonize and learn more about hydrogen.

United States Landscape

In comparison to the European Union, Norway, and Great Britain, the US government has been less resolute when it comes to long-term GHG emissions reduction goals. The Trump

[7] "A Hydrogen Strategy for a Climate-Neutral Europe." European Commission, 7 Aug. 2020, https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf
[8] Norway, Norwegian Ministry of Petroleum and Energy and Norwegian Ministry of Climate and Environment, Tina Bru and Sveinung Rotevatn. The Norwegian Government's Hydrogen Strategy – towards a Low Emission Society, 2020.
[9] Reilly, Thomas. "Hydrogen Policy Development in the UK." Inside Energy & Environment, 29 Mar. 2021, https://www.insideenergyandenvironment.com/2021/03/hydrogen-policy-development-in-the-uk/.
[10] Making Plans for a Hydrogen 'Backbone' across Britain, 18 Mar. 2021, https://www.nationalgrid.com/stories/journey-to-net-zero-stories/making-plans-hydrogen-backbone-across-britain.

administration's withdrawal from the Paris Climate Accords and rollback of many environmental regulations set the US back when it came to ambitious climate policies. Today, the Biden administration has displayed a renewed interest in climate policy and has announced goals to create a carbon-free power grid by 2035 and a net zero emissions economy by 2050. Members of the Biden administration have mentioned hydrogen's potential role in achieving net-zero GHG emissions, but have so far been less specific about targeted goals and policies related to the technology.

Today, traditional "gray" hydrogen resources are already extensively integrated into many of the US's industrial processes. Hydrogen is used across the refining and petrochemical industries, and the U.S. has a broad hydrogen pipeline system with 1600 miles clustered primarily in refining-focused states like Texas and Louisiana.[11] The US government has also made some investments in advancing new hydrogen technologies, though not on the same scale as European governments. Over the past two decades, the U.S. Department of Energy (DOE) has spent $4 billion on R&D efforts related to hydrogen technologies. According to a DOE hydrogen report, over this time 1,100 U.S. hydrogen-related patents have been issued and over 30 commercial technologies have been brought to market.[12] In the US, previously experimental technologies like fuel cells have become more prevalent in forklifts, modular power units, and commercial vehicles across the country.

In November 2020, the US DOE released a Hydrogen Program Plan, a report that outlined the applications of hydrogen and research focuses. The Biden administration has displayed a new interest in hydrogen and announced in March the awarding of $2 million for the development of "clean hydrogen technologies."[13] Despite this announcement and some mentions of hydrogen's role in decarbonization, as of April 2021, hydrogen-related policy initiatives from the Biden administration have been limited. Critics say that limited R&D funding is a start, but that much more needs to be done to match the long-term visions and funding levels present in other countries. Some possible policy levers include larger scale government-funded R&D investment, targeted tax credits like those offered to solar and wind resources, emissions standards for transport and power, and an economy-wide carbon pricing system.[14]

Given its current cost advantages, some oil and gas leaders and industry analysts consider blue hydrogen to be the most viable type of hydrogen in the short and medium

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[11] "Hydrogen Pipelines." Energy.gov, www.energy.gov/eere/fuelcells/hydrogen-pipelines#:~:text=Approximately%201%2C600%20miles%20of%20hydrogen,operating%20in%20the%20United%20States.
[12] United States, Office of Energy Efficiency and Renewable Energy. Department of Energy Hydrogen Program Plan, November 2020.
[13] "U.S. Department Of Energy Awards $2 Million To Develop Clean Hydrogen Technologies." Energy.gov, 15 Mar. 2021, www.energy.gov/articles/us-department-energy-awards-2-million-develop-clean-hydrogen-technologies.
[14] Melvin, Jasmin. "US Seen Lagging in Hydrogen Investment, Deployment as Long-Term Vision Lacking." US Seen Lagging in Hydrogen Investment, Deployment as Long-Term Vision Lacking | S&P Global Platts, 9 Mar. 2021, www.spglobal.com/platts/en/market-insights/latest-news/electric-power/030921-us-seen-lagging-in-hydrogen-investment-deployment-as-long-term-vision-lacking.

term.[15] The US has several advantages when it comes to blue hydrogen. Firstly, the US's abundant domestic natural gas resources and existing gas pipeline infrastructure could be channeled to fuel blue hydrogen production. The US has the fourth largest natural gas reserve and in recent years has led the world in natural gas production.[16] Additionally, according to a study from Resources for the Future, there are at least 2.7 million inactive gas and oil wells in the US.[17] Research conducted by Sandia National Laboratories has concluded that depleted oil and gas wells could be repurposed for hydrogen storage, though potential for leakage and contamination of fuel with impurities poses challenges.[18] Secondly, the US is a leader in carbon capture and storage, a technology necessary for the large-scale production of blue hydrogen. According to the Global Carbon Capture and Storage Institute, the US is home to over 38 commercial CCS facilities in different stages of development, representing over half of the total projects around the world. Further, 12 of the 17 large-scale CCS facilities initiated in 2020 are based in the US.[19] This recent burst in CCS development in the US can likely be attributed to the 45Q tax credit which was doubled in 2018.[20] The credit provides $50 for every metric ton of CO2 that's sequestered, or $35 a ton for producing oil with the captured carbon. In May 2020, the IRS issued guidance to help developers take advantage of these incentives.[21]

Critics say that even with these incentives, it remains to be seen whether CCS can be truly cost-effective and environmentally sound. Some point to the large percentage of CCS plants that have ended in failure for financial, technological, or other reasons.[22] Others argue that today's CCS technology rarely prevents 100% of emissions and may have residual environmental impacts such as carbon leakage, and money used for CCS may be better invested directly into renewable energy technologies. Still, technological advancements and newly defined incentives may make it more viable, and CCS makes up large portions of future carbon reductions in models prepared by IEA and others. Oil and gas companies continue to make significant investments in the technology, as described in more detail in the following sections. The US's dominance in CCS technology could produce a competitive edge when it comes to blue

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[15] Hornyak, Tim. "An $11 Trillion Global Hydrogen Energy Boom Is Coming. Here's What Could Trigger It." CNBC, CNBC, 4 Dec. 2020, www.cnbc.com/2020/11/01/how-salt-caverns-may-trigger-11-trillion-hydrogen-energy-boom.

[16] "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *International - U.S. Energy Information Administration (EIA)*, www.eia.gov/international/overview/world.

[17] Ho, Jacqueline, et al. Resources for the Future, 2016, *Plugging the Gaps in Inactive Well Policy*, media.rff.org/archive/files/document/file/RFF-Rpt-PluggingInactiveWells.pdf.

[18] "Storing Hydrogen Underground Could Boost Transportation, Energy Security." Sandia National Laboratories: News Releases : Storing Hydrogen Underground Could Boost Transportation, Energy Security, 9 Dec. 2014, share-ng.sandia.gov/news/resources/news_releases/underground_hydrogen/#.Wsp9GIjwY2w.

[19] Page, Brad, et al. "Global Status of CCS." *Global CCS Institute* , Dec. 2020, www.globalccsinstitute.com/wp-content/uploads/2020/12/Global-Status-of-CCS-Report-2020_FINAL_December11.pdf.

[20] Wade, Will, and Brian Eckhouse. "Fossil Fuel's Answer to Climate Change Just Got Less Expensive." Bloomberg.com, Bloomberg, 11 June 2020, 7am, www.bloomberg.com/news/features/2020-06-11/carbon-capture-tool-against-climate-change-just-got-cheaper?sref=mPmNm70H.

[21] "Treasury, IRS Provide Regulations to Help Businesses Claim Credits for Carbon Capture." *Internal Revenue Service*, 28 May 2020, www.irs.gov/newsroom/treasury-irs-provide-regulations-to-help-businesses-claim-credits-for-carbon-capture.

[22] Abdulla, Ahmed, et al. 2020, *Explaining Successful and Failed Investments in U.S. Carbon Capture and Storage Using Empirical and Expert Assessments*, iopscience.iop.org/article/10.1088/1748-9326/abd19e.

hydrogen, especially if CCS becomes more cost-effective and technologically advanced in the meantime. Alternatively, if green hydrogen is prioritized by investors and policymakers, a focus on carbon capture and blue hydrogen development may leave the US at a disadvantage.

Many energy experts and industry players agree that the US is uniquely positioned to take advantage of the environmental and economic benefits of hydrogen. Twenty leading industry stakeholders released the *Roadmap to U.S Hydrogen Economy*, outlining the potential for hydrogen in the United States. Chevron and Shell were listed as collaborators on the report, as well as utilities like Xcel Energy, Southern Power, and Southern California Edison, auto manufacturers like Hyundai, Honda, and Nikola, and prominent hydrogen value chain participants like Plug Power and Air Liquide. According to the report, by 2050, "the U.S. hydrogen economy could lead to an estimated $750 billion per year in revenue and a cumulative 3.4 million jobs."[23]

Comparing Oil Major Strategies

European Oil Majors: Shell, BP, Equinor, Total, and Eni

In Europe, where the EU and country-level governments have more aggressively pursued decarbonization policies and goals, oil majors have responded with their own emissions reduction commitments and business strategy shifts. Some, like Danish oil and gas company Ørsted (formerly DONG Energy), have transitioned out of their oil and gas holdings altogether[24]. The four European oil majors examined in this paper, BP, Equinor, Total and Shell, have all committed to net zero targets by 2050 or sooner. In addition, each of these firms have invested in renewable energy firms via strategic acquisitions and business shifts. In 2018, European majors spent about 6.2% of their capex on renewables compared to 0.8% spent on average by oil majors in the rest of the world, including in the US.[25]

Equinor announced aims to grow their renewable energy capacity 10-fold before 2026 and become an "offshore wind major." Among other projects, Equinor has won contracts to develop offshore wind projects totaling 3.3 GW of power for New York state. Last year, Equinor

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[23] 2020, *ROAD MAP TO A US HYDROGEN ECONOMY*, static1.squarespace.com/static/53ab1feee4b0bef0179a1563/t/5e7ca9d6c8fb3629d399fe0c/1585228263363/Road+Map+to+a+US+Hydrogen+Economy+Full+Report.pdf.

[24] "Could Our Green Transformation Inspire Yours?" Our Green Energy Transformation | Ørsted, us.orsted.com/about-orsted/our-green-energy-transformation.

[25] Elliott, Stuart. "UK Oil, Gas Industry Sees Role in Hydrogen, CCS Developments." Edited by Jonathan Dart, *UK Oil, Gas Industry Sees Role in Hydrogen, CCS Developments | S&P Global Platts*, 29 Jan. 2020, www.spglobal.com/platts/en/market-insights/latest-news/coal/012920-uk-oil-gas-industry-sees-role-in-hydrogen-ccs-developments?utm_campaign=corporatepro&utm_medium=contentdigest&utm_source=oilmajors_shifting_landscape.

brought in BP as a strategic partner in their New York offshore wind development plans. [26] BP's 50% stake in Equinor's New York wind project adds to BP's other renewable energy investments, such as their 50% stake in LightSource BP (formerly Lightsource Renewable Energy), one of the largest solar developers in Europe. Total has set an ambitious target for 100 GW of installed renewable energy capacity by 2050.[27] In 2019, Shell acquired floating wind developer Eolfi, and last year announced plans to invest between $2-3B in renewables annually.

Given the overall favorable regulatory environment for green hydrogen in Europe and the investments already made by European oil majors in renewable energy, green hydrogen has been a somewhat natural fit for the European majors. Shell, Equinor, BP, and Total have all announced projects producing hydrogen via renewable electrolysis. In depicting plans, most majors express the anticipated reliance on some level of government investment in projects. In some cases, government subsidies may make up between 40%-50% of capital costs for pilot projects.[28] Shell, Equinor, and a group of investors are developing NorthH2, the largest green hydrogen production project announced to date. [29] The project is to begin production by 2027 and by 2040 is expected to produce 800,000 tons of green hydrogen using 10GW of offshore wind in the North Sea. Another of Shell's projects, the REFHYNE project, began construction in 2018 and is a polymer electrolyte membrane (PEM) electrolysis project with a peak capacity of 10 MW, producing ~13,000 tons of hydrogen per year. [30] Meanwhile, Total announced early this year a cooperation agreement with French electricity giant Engie to build and operate the Masshlyia project, expected to be France's largest renewable hydrogen production site to date. The project will produce hydrogen for a Total refinery and will be powered by over 100 MW of solar energy.[31] BP has announced several green hydrogen production plans, including via two separate partnerships with European renewable energy giants Iberdola and Ørsted. BP is also exploring green hydrogen production in Australia to produce exportable ammonia for the South East Asia region.[32]

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[26] Equinor. "Equinor Partners with BP in US Offshore Wind to Capture Value and Create Platform for Growth." *Equinor.com*, Equinor, 10 Sept. 2020, www.equinor.com/en/news/2020-09-offshore-wind.html.
[27] "Solar and Wind: Our Ambition in Renewable Energies." *Total.com*, Total, www.total.com/energy-expertise/exploration-production/renewable-energies/solar-energy-and-wind-energy.
[28] Redmond, Simon, et al. "The Hydrogen Economy: Can Natural Gas And H2 Have A Symbiotic Relationship?" The Hydrogen Economy: Can Natural Gas And H2 Have A Symbiotic Relationship? | S&P Global Ratings, 19 Nov. 2020, www.spglobal.com/ratings/en/research/articles/210422-the-hydrogen-economy-can-natural-gas-and-h2-have-a-symbiotic-relationship-11911512.
[29] "Kickstarting the Green Hydrogen Economy." NorthH2, 12 Apr. 2021, www.north2.eu/en/.
[30] "REFHYNE Clean Refinery Hydrogen for Europe", 7 July 2020, accessed April 2021, https://refhyne.eu/
[31] "TOTAL AND ENGIE PARTNER TO DEVELOP FRANCE'S LARGEST SITE FOR THE PRODUCTION OF GREEN HYDROGEN FROM 100% RENEWABLE ELECTRICITY." Total.com, Total, 13 Jan. 2021, www.total.com/media/news/press-releases/total-and-engie-to-develop-france-s-largest-site-of-green-hydrogen.
[32] "BP Australia announces feasibility study into hydrogen energy production facility", May 8, 2020, https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-australia-announces-feasibility-study-into-hydrogen-energy-production-facility.html

The companies are also investing in blue hydrogen opportunities. Equinor, Total and Shell all have blue hydrogen production projects either live or in the development process. These companies have all generally been active in the CCS space, developing experience that may prove useful for more blue hydrogen production down the line. For example, Equinor, Shell, and Total are collaborating on the largest carbon transportation and storage project announced to date near Oslo, with an initial capacity of 1.5 million tons of CO_2 per year. As mentioned later in this paper, risks exist with CCS technologies. In Europe specifically, public opposition and regulatory restriction could pose unique challenges. Some environmental groups and Green Party politicians in Europe argue that a focus on blue hydrogen will not make a significant enough dent into decarbonization and is a way for oil and gas companies to maintain their grip on the energy industry.33

European oil majors are taking advantage of the favorable policy environment and high likelihood of public investment and pursuing large-scale green hydrogen projects. The expertise these companies are developing in renewable energy are serving them well as they plan to pair solar and wind resources with electrolyzed hydrogen. European majors are also advancing projects focused on blue hydrogen and CCS, diversifying their role in Europe's planned hydrogen landscape.

US Oil Majors: Chevron and Exxon

In comparison to European oil and gas majors, Chevron and Exxon have taken a different approach when it comes to emissions reduction goals and renewable energy investment. Both companies released climate reports, but unlike most of the European majors, neither company has a net-zero by 2050 goal or a public carbon price. In investor reports, both companies cite risks related to investing in new business strategies and have preferred to focus on continued oil and gas development into the future. Climate goals from both companies have focused on emissions reductions related to oil and gas operations and on CCS technologies rather than substantial transitions in business strategy. This has led to increased pressure from investors to better prepare for business risks related to decarbonization. In February 2021, S&P Global Ratings downgraded Chevron and Exxon by one level, partially due to risks related to the energy transition and climate change. S&P noted that despite their published sustainability plans, Chevron and Exxon's climate efforts did not provide "material credit differentiation."[33]

In recent investor calls and reports, Chevron and Exxon have increasingly cited hydrogen as an important part of the companies' futures, but both companies have historically lagged their European peers when it comes to hydrogen-related projects. However, recent pressure from investors and new announcements may signal shifting strategies around the technology. This month, Chevron announced a memorandum of understanding with Toyota Motor North

[33] "S&P Downgrades Exxon and Chevron on Climate Risk, Dour Earnings." *Reuters*, Thomson Reuters, 12 Feb. 2021, www.reuters.com/article/us-usa-oil-credit/sp-downgrades-exxon-and-chevron-on-climate-risk-dour-earnings-idUSKBN2AC29C.

America "to explore a strategic alliance to catalyze and lead the development of commercially viable, large-scale businesses in hydrogen, with the goal to advance a functional, thriving global hydrogen economy." According to the company's statement the alliance will focus on supporting hydrogen-related policy measures, researching market demand related to hydrogen-fueled transportation, and pursuing opportunities for research and development in the hydrogen space. Specific details remain sparse on the potential outcomes of the partnership.[34] Neither Exxon nor Chevron have operating or planned blue or green hydrogen production projects.

Despite their lack of investment in current hydrogen projects when compared to European peers, US majors have made investments in carbon capture and storage technologies that may play an important role in blue hydrogen development.[35] Exxon and Chevron have both invested in carbon capture technologies for years. Exxon has prioritized carbon capture in its carbon reduction goals, announcing 20 carbon capture projects around the world and a $3 billion investment in CCS and related technologies.[36] This month, Exxon shared a proposal for a $100 billion public-private carbon storage hub along the U.S. Gulf Coast, which if pursued would be the world's largest carbon capture and storage project. The company emphasized the need for government investment and support to make the project possible. Chevron operates one of the world's largest projects to bury carbon dioxide in Australia, but the project was recently found to be faulty due to sand blockage.[37]

Continued investment, advancements, and policy support for CCS may give US oil majors a useful advantage when it comes to blue hydrogen production. Still, many uncertainties around CCS technologies exist. Firstly, CCS will likely remain too costly to be competitive without meaningful policies enacted to price carbon in the U.S. Secondly, carbon capture technologies have environmental risk factors including liability ownership for long-term carbon storage. Finally, CCS facilities require a system of monitoring and tracking to ensure proper capture and storage of carbon.

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[34] "Chevron (CVX) to Develop Major Hydrogen Businesses With Toyota", April 26, 2021, https://finance.yahoo.com/news/chevron-cvx-develop-major-hydrogen-160604541.html

[35] "Hydrogen and the decarbonization puzzle (United States)", Fueling the Future, Deloitte, https://podcasts.apple.com/fi/podcast/hydrogen-and-the-decarbonization-puzzle-united-states/id1482227899?i=1000516144548

[36] Exxon Mobil to Invest $3 Billion in Carbon Capture and Other Project to Lower Emissions" The New York Times, The New York Times, 1 Feb. 2021, Cox, Lisa. www.nytimes.com/2021/02/01/business/energy-environment/exxon-mobil-carbon-capture.html

[37] "Western Australia LNG Plant Faces Calls to Shut down until Faulty Carbon Capture System Is Fixed." *The Guardian*, Guardian News and Media, 14 Jan. 2021, www.theguardian.com/environment/2021/jan/15/western-australia-lng-plant-faces-calls-to-shut-down-until-faulty-carbon-capture-system-is-fixed.

Business Risks & Opportunities

Risks for Oil Majors Pursuing Hydrogen:

Competition from Other Technologies

Many experts predict hydrogen will play a "gap-filling" role in the new energy economy, finding niche roles in the transportation, heating, and industrial sectors. Still, within all potential applications, the industry faces competition. For example, electric vehicles have gained significant momentum in different transportation applications. Heat pumps and biogas may become more competitive as heat and power sources for buildings and industry. Fossil fuels with CCS, though seen as a production source for blue hydrogen, could also compete with hydrogen in applications such as industrial heating and steel production. The competitiveness of green hydrogen is also highly dependent on the costs of natural gas. For the foreseeable future, natural gas prices are expected to remain relatively low, challenging the ability of green hydrogen to compete with traditional fossil sources. A price on carbon might improve competitiveness, but in the US, the policy remains untenable politically.

Blue Hydrogen's Dependence on Carbon Capture and Sequestration

Blue hydrogen is seen by many oil majors and energy experts as the more realistic avenue for hydrogen production in the near and medium term. According to a Goldman Sachs analysis, the cost of green hydrogen production can be 1.3-5.5X that of blue hydrogen depending on the price of natural gas and the LCOE of related technologies.[38] Still, blue hydrogen is highly dependent on advancements in CCS technology, an industry with its own unique challenges. In the US, CCS technology has become cheaper with the onset of new tax incentives but remains costly without significant public investment. A study from UC San Diego found that of the CCS projects proposed in the US, most (>80%) end in failure.[39] CCS faces unique challenges including long-term storage liability and potential environmental risks. Finally, many CCS technologies are not inherently carbon free and require monitoring and verification to ensure CO2 is properly captured and retained. Still, technologies are improving and many experts consider CCS to be a crucial component of a decarbonized economy. For example, in the IEA Sustainable Development Scenario, CCS makes up 15% of the reduction in emissions by 2070 compared to business as usual.[40]

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[38] Vigna, Michele Della, et al. Goldman Sachs, 2020, *Carbonomics The Rise of Clean Hydrogen*, www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-rise-of-clean-hydrogen/report.pdf.

[39] "Explaining successful and failed investments in U.S. carbon capture and storage using empirical and expert assessments", Ahmed Abdulla et al 2021 Environ. Res. Lett. 16 014036, https://iopscience.iop.org/article/10.1088/1748-9326/abd19e/pdf

[40] Ibid.

Dependence on Supportive Policies

Finally, a carbon price or other supportive incentives are necessary to allow both green and blue hydrogen to compete in hard to abate sectors. Contrary to fossil fuels which are extracted, hydrogen must be manufactured, making it inherently more expensive. To reap the decarbonization benefits of hydrogen, governments will have to enact a price on carbon or similar incentive.[41] In the US, a flurry of investment into CCS followed the 45Q budget law that provided tax incentives for CCS. Continued support for CCS will likely be needed if this proves a viable method for broad scale blue hydrogen production. Other policy incentives advocated for by industry groups include larger scale government-funded R&D investment and support for pilot projects, targeted tax credits like those offered to solar and wind resources, and emissions standards for transport and power.

Opportunities for Oil Majors Pursuing Hydrogen:

Transferrable Experience and Human Capital

Oil majors have a foundation of experience and human capital in segments of business that will be directly applicable to hydrogen production. Through experiences with gray hydrogen production and use in refining, CCS technologies, and pipeline and storage infrastructure, oil majors have access to experts that will prove useful in a hydrogen economy. Professionals who have worked in oil and gas for years on pipelines, gas storage, hydrogen production, refining, carbon capture and more have transferable skills that the majors can maneuver into a hydrogen-based economy. According to DNV GL's Heading to Hydrogen report, based on a survey of over 1,000 senior oil and gas professionals, oil and gas professionals are preparing for new business related to hydrogen. When asked if they expected significant increases in hydrogen use to decarbonize gas consumption, 41% of oil and gas professionals expected an increase across the operational value chain, and 50% expected hydrogen to grow in the downstream segment.[42]

Infrastructure Advantages

Oil majors have a unique opportunity to use existing infrastructure to participate in the hydrogen economy. Transporting and storing hydrogen will require large investments, presenting oil majors with an opportunity to build on existing fuel transport and storage infrastructure like pipelines, salt cavern storage, and depleted oil and gas field storage. According to Bloomberg New Energy Finance, "If hydrogen were to replace natural gas in the global economy today, 3-4 times more storage infrastructure would need to be built, at a cost

[41] Ibid.

[42] DNV-GL Heading to Hydrogen Whitepaper, 2020 Sept. https://www.dnv.com/oilgas/hydrogen/heading-for-hydrogen.html

of $637 billion by 2050 to provide the same level of energy security."[43] As the world decarbonizes, oil majors may be able to take advantage of an emerging appetite for investment in hydrogen-related infrastructure. For example, in Europe, policymakers are making long-term strategies related to hydrogen transport and storage hubs. In the US, the multitude of depleted gas reserves could play an important role in underground hydrogen storage.

Hydrogen's Role in the Evolution of the Oil and Gas Sector

Investors have increasingly prioritized environmental, social, and governance (ESG) factors and sought to reduce exposure to climate change related risks.[44] Oil and gas companies have experienced targeted pressure to accelerate the transition to low-carbon solutions. The poor financial performance of oil and gas companies during the COVID-19 pandemic seemingly accelerated these climate-related pressure campaigns. As mentioned previously, many oil majors are responding with unprecedented emissions reduction goals. As shown in Table 2 in the Appendix, the European oil majors have all set net zero targets by 2050. Chevron and Exxon are experiencing consistent investor pressure to set similarly ambitious targets.[45] Hydrogen presents a unique opportunity for oil and gas companies to build on a foundation of infrastructure and expertise advantages to pursue decarbonization. In the medium and long term, hydrogen may represent a lifeline for oil companies in a net-zero world.

Looking Ahead

Hydrogen is a unique opportunity for oil majors to maintain relevance as policymakers and investors prioritize decarbonization. As oil majors increasingly make emissions reduction goals in response to policy and investor pressure, hydrogen may be a key part of long-term company strategies. The landscape is constantly changing and every day new hydrogen-related announcements are made. However, the future success of the technology is dependent on the level of policy support, the development of an infrastructure backbone, as well as advancements and cost-reductions across the supply chain.

[43] Ibid.
[44] "About Climate Action 100+." Climate Action 100+, www.climateaction100.org/about/.
[45] Govind, Hari. "Exxon Investors Warned By Activist Fund on Climate Risks: FT." *Bloomberg.com*, Bloomberg, 25 Apr. 2021, www.bloomberg.com/news/articles/2021-04-25/exxon-investors-warned-of-risk-from-emissions-goals-ft-reports?sref=mPmNm70H.

Appendix

Table 1: Costs of Hydrogen Production

		Costs ($/kg H2)			
Colors of H2	**Power Source of H2**	IEA, 2018	BNEF, 2020	Goldman Sachs, 2020	World Nuclear Association (via International Atomic Energy Agency '19 & Lucid Catalyst '20)
Green	Renewable Energy	3.0 - 7.5	2.5 - 4.52	3.0 - 8.0	
Blue	Natural Gas or Coal with CCS	1.5 - 2.9	1.4 - 3.4	1.4 - 2.6	
Gray	Natural Gas	0.9 - 3.2		0.9 - 2.0	
Brown /Black	Coal	1.2 - 2.2		0.97 - 1.3	
Pink / Purple / Red	Nuclear Electrolysis				2.0 - 4.15

Table 2: Comparing Oil Major Net Zero and Renewable Energy Targets

Oil Major	Commitment to Net Zero Emissions	Internal Carbon Price (Per Ton of CO2)	Renewables Investment
BP	Net Zero by 2050	$40 today, $100 in 2030[46]	10x increase in low-carbon energy to $5B / year over the decade
Equinor	Net Zero by 2050	Countries w/out Carbon price: $55/ton CO_2. Countries w carbon price, min. $55/ton or country carbon price Exploring USD $100/ton[47]	Expecting capacity of 4-6 GW by 2026 and 12-16 GW by 2035
Total	Net Zero by 2050	$40 today, $100 in 2030	100 GWs gross renewable capacity by 2030
Shell	Net Zero by 2050	Not public	$2-3 B in renewables annually
Exxon	None	Not public	N/A
Chevron	None	Not public	$750M through 2028 on renewables projects and offsets

[46] Parnell, John. "BP Adopts $100 Carbon Price Assumption for 2030, With Big Implications for Clean Energy." *Greentech Media*, Greentech Media, 16 June 2020, www.greentechmedia.com/articles/read/european-oil-majors-ready-to-scale-up-energy-transition-investment.

[47] Equinor CDP Climate Change Questionnaire 2020, September 3, 2020

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