Financing a Hydrogen Future

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Introduction

Countries across the globe are looking to gain a greater understanding of the potential for hydrogen's critical role in both decarbonizing the energy economy and increasing global energy security. Anticipating a growing role for hydrogen as an energy commodity is directly related to the development of a global hydrogen market.

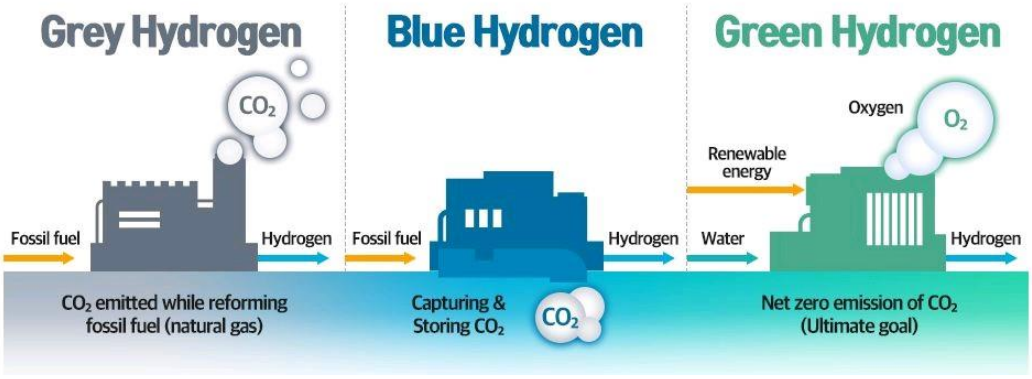
Saudi Arabia, like many countries, has immense potential for hydrogen development.[i] Under the Saudi Green Initiative, the Kingdom reaffirmed its commitment to reduce carbon emissions, and as one of its main goals is to become the world's leading hydrogen producer and exporter with the target of capturing more than 27 million tons of CO_2 by 2030 .[ii] Other countries in the Middle East and North Africa (MENA) region have ambitious plans to diversify their economies and explore hydrogen development as well.[iii,iv] Fully leveraging hydrogen to sustainably power the global economy would give the Kingdom and other MENA nations a competitive edge in an increasingly carbon-constrained world in which, according to the UN, more than 70 countries, including the biggest polluters – China, the United States, and the European Union – have set a net-zero target, covering about 76% of global emissions.[v,vi]

This paper is a summary of current reporting on the opportunities and challenges faced by the development of hydrogen as an energy commodity. Additionally, this paper is meant to be a stage-setter for discussion on the many question areas facing traditional energy-producing nations as they aim to become frontrunners in the nascent global hydrogen market.[vii] Subsequently, investment in the full value chain will play a significant role in shaping national, regional, and global strategies.

Figure 1.

Key Terms

Clean Hydrogen: As defined by the U.S. Department of Energy, is hydrogen produced with a carbon intensity of 2 kg or less of carbon-dioxide equivalent produced at the site of production per kg of hydrogen produced. (https://afdc.energy.gov/fuels/laws/HY?state=US) However, the Inflation Reduction Act (IRA) and other countries have different definitions for low-carbon hydrogen, which account for lifecycle emissions.



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1. Hydrogen Economy and Investment Opportunities

Jump-Starting the Global Hydrogen Market – Infrastructure Investments Needed

Hydrogen will likely play a key role in decarbonizing the energy mix, but significant investment and development along the supply chain is needed. Estimates vary, however, about the potential market value of hydrogen as a fuel and feedstock in a decarbonized energy system. Many observers estimate that the value of the hydrogen market is expected double by 2030, from $125 to $130 billion(B) today to $250B by 2030,[viii] and potentially $1 trillion(T) by 2050.[ix,x] Initial market development will entail the retrofit of current hydrogen facilities with carbon capture and repurposing of existing infrastructure. New projects and different types of hydrogen, e.g., blue, green, turquoise, will be deployed as widespread decarbonization tools and drive hydrogen market development. Large-scale hydrogen deployment, and production scalability (i.e., sizing up of projects),[xi] will need to be underpinned by an effective and cost-efficient system for storage and transport, strategically designed to connect supply sources to demand centers and thereby establish a deep, highly liquid market.[xii]

Interest and momentum surrounding hydrogen is growing, but the idea of using hydrogen as an energy carrier has come in and out of fashion since the 1970s. Despite decades of interest and research, however, obstacles remain to scaling up a hydrogen market beyond its use as a specialty chemical. Currently, hydrogen accounts for only about one percent of the energy mix, is predominately produced using unabated fossil fuels, and is used mainly at or near where it is produced.[xiii,xiv]

While hydrogen has attributes that make it attractive as a flexible option for many energy uses, challenges remain to it becoming a globally traded commodity. As noted, past waves of interest have not translated into sustained investment or policy support for hydrogen, and in fact, from 2008 to 2018 global spending on hydrogen declined by 35 percent.[xv]

The evolving nature of the investments is accelerating at the same time - the advent of Environmental Social and Governance (ESG)[1] activism and the social justice[2] movement magnified during the COVID pandemic. Governments around the world as seen in the United States. and European Union are taking stock of ESG as exhibited by the Biden administration's (SEC and FTC) examination of the challenges of mitigating climate change. The National Association of Corporate Directors, among many investors and board rooms, expect the ESG movement to continue to expand at a rapid pace as must the reporting and engagement frameworks for companies.[xvi]

For hydrogen to be a widely adopted energy option, costs must continue to fall, and infrastructure must be expanded. Currently, most reporting is focused on production, however, significant investment in transportation, storage, and distribution also needs study. Investment in projects, and the availability of only a small volume of hydrogen, indicates how nascent the development is of a hydrogen market; this creates significant near-term investment risks. There are many investment approaches ranging from ancillary business (e.g. natural and other gas business) to producers of hydrogen and fuel cells.[xvii] The conundrum of whether initial investments should be made in, for example, production or in off-take markets - creates a chicken-and-egg type obstacle to investment that must be solved, by both innovative technology solutions, policy support, and application of existing technologies to upstream, middle, and end stream challenges. ***While there is significant uncertainty, there is also tremendous opportunity for investment in hydrogen infrastructure, technologies, transportation options -- and in the development of a global market for hydrogen.***

The many challenges and opportunities highlighted in the section above require further exploration. Below are some key questions for discussion:

- **What is the Hydrogen Economy and What are the investment opportunities and Risks?**

[1] Individuals and organizations that advocate for Environmental, Social, and Corporate Governance (ESG) criteria as part of evaluating business operations.
[2] The idea of a fair and equitable division of resources, opportunities, and privileges in society.

- **How will ESG or other types of new analytical factors shape investments in hydrogen?**
- **How will the Inflation Reduction Act in the U.S. and the Carbon Border Adjustment Mechanism in the EU shape future financing for hydrogen?**

2. Views on Investing in Hydrogen

The hydrogen option offers many opportunities to decarbonize major sectors of the economy (e.g., power generation, steel, chemicals, or heavy transport); this will, however, require an ample and reliable supply of hydrogen. Lack of cost-competitive renewable and low-carbon hydrogen supply in the short term and lack of infrastructure could delay investment decisions downstream.[xviii]

A combination of decarbonization technologies could bring industry emissions close to zero: demand-side measures, energy efficiency improvements, electrification of heat, using hydrogen as feedstock or fuel, using biomass as feedstock or fuel, methane pyrolysis,[3] and other innovations.[xix] Important to this suite of options; falling renewable energy prices—coupled with the reduced cost of electrolyzers and increased efficiency due to technology improvements—have increased the commercial viability of green hydrogen production.[xx] Additionally, retrofitting existing hydrogen production facilities with CCS could be a low cost option to decrease the emissions intensity of hydrogen already in production. However, the creation of a market around the competitiveness of hydrogen as a new fuel must be taken with the understanding that significant investment into bankable projects is a necessity.

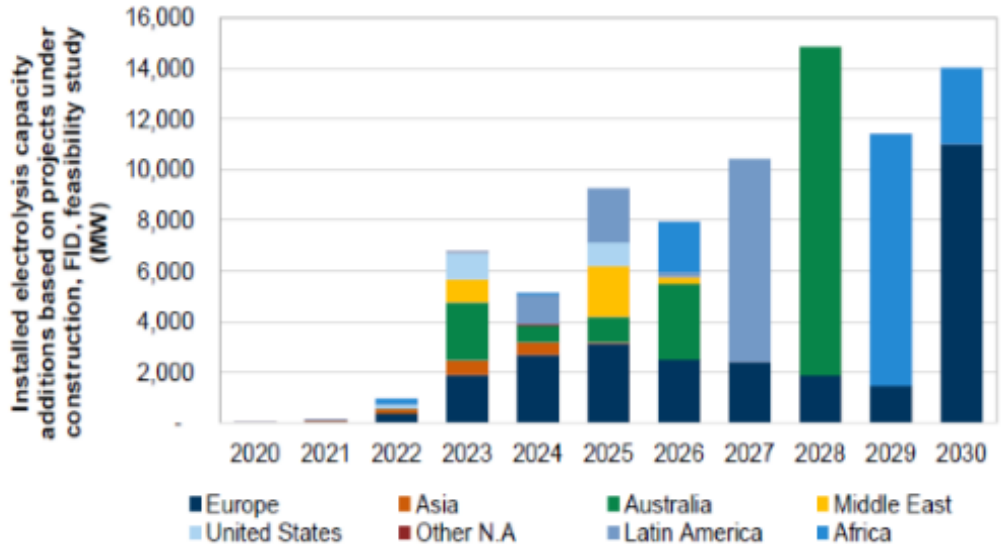
[3] Methane pyrolysis is an industrial process for "turquoise" hydrogen production from methane by removing solid carbon from natural gas.

To date, few hydrogen power generation projects have been brought to market and those under construction and operation remain small (less than 50 MW), in comparison to fossil fuel alternatives.[xxi] However, investments in the hydrogen industry are increasing, particularly in production technology deployment.[xxii] Goldman Sachs estimates that significant investment is needed to set the world on a path consistent with net zero (CO_2 emissions) by 2050. In aggregate, it estimates that "significant investment" necessary for full hydrogen supply chain development - from deploying capital into any of the several types of production, storage, distribution, transmission, and global trade for net zero is $5T.[xxiii] However, as hydrogen technology is developing are financial products for the industry. On August 22, Broker Marsh with AIG and others launched the first insurance products specifically for hydrogen energy government projects.[xxiv] As addressed in the other workshops, new policy and regulatory frameworks are needed, but action is also critical for incentivizing investment in hydrogen.

Government action is gaining momentum. More than 25 national hydrogen strategies have been developed over the past two years, which Goldman Sachs believes will spur the strong pace needed for investments. For instance, as part of its national hydrogen strategy, Germany announced a €9B package, which, according to the German government, will likely lead to an additional €33B of private investments. Goldman Sachs expects that, as seen in the solar and wind industries, public investments may lead to ever higher private investments fueling the hydrogen industry's acceleration.

With a focus on the direct supply chain of clean hydrogen, encompassing investments required for its production (electrolyzers and CCUS for green and blue hydrogen, respectively), storage, distribution, transmission, and global trade, Goldman Sachs estimates that reaching a net-zero by 2050 scenario will require $0.6 T to 2030 and $5.0 trillion of cumulative investments in the direct clean hydrogen supply chain through 2050. According to Goldmans Sachs analysis, these totals are exclusively CAPEX investment needs and do not include OPEX or other costs needed for the supply chain of clean hydrogen. It also does not include the CAPEX associated with end use markets (industry, transport, buildings) or upstream CAPEX associated with the powerplants needed for generating electricity with hydrogen.[xxv]

Figure 2: Europe, Australia, Latin America, and the Middle East – green hydrogen projects (Installed electrolyzer additions based on projects under construction)

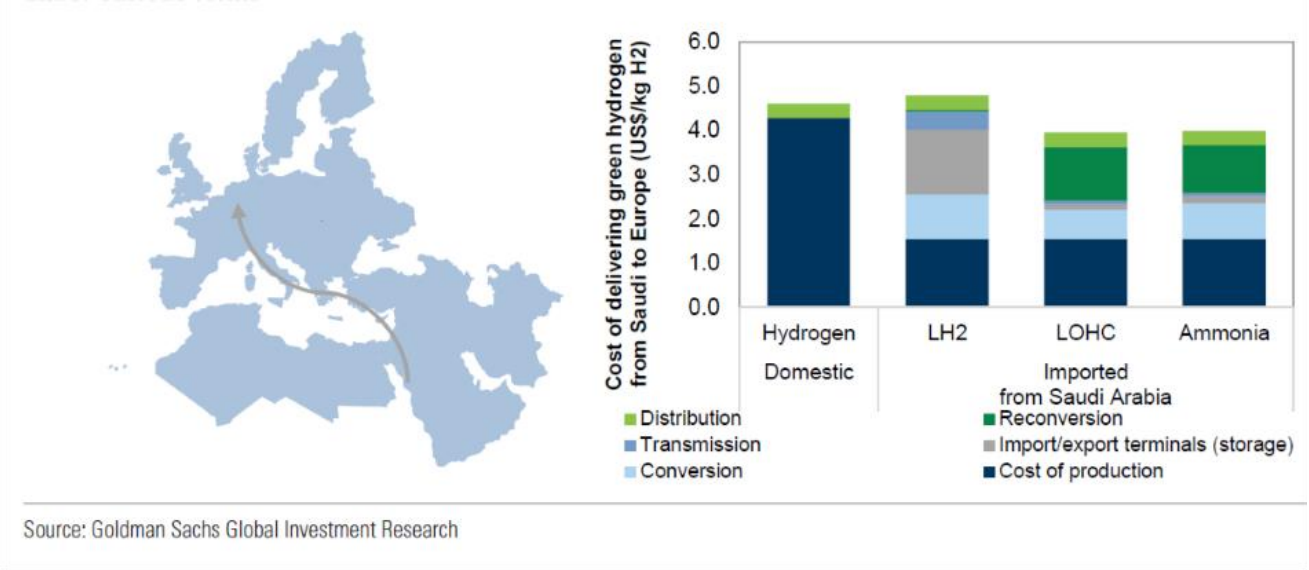


Source: Goldman Sachs Global Investment Research

Figure 3 depicts the all-in costs for exporting green hydrogen from the Middle East to Europe. Goldman Sachs performed a similar analysis for exporting hydrogen (in various forms) from Saudi Arabia to the port of Rotterdam via the Suez Canal, to North-West and Central Europe (and particularly the Port of Rotterdam); its analysis noted that the cost of renewable power and therefore the cost of production of green (i.e., low carbon hydrogen) hydrogen can be higher or lower than shown depending on the region being supplied. ***This analysis concluded that North-West Europe would indeed benefit from importing green hydrogen from the Middle East or North Africa, even when the cost of transportation and conversion/reconversion are included.*** This is consistent with analysis in other parts of the Goldman Sachs report and with the EU's strategy for developing 40GW of installed electrolyzer capacity by 2030, which could produce 6.84 Mt of hydrogen,[4] and to source an additional 6.84 Mt of hydrogen from nearby regions.[xxvi]

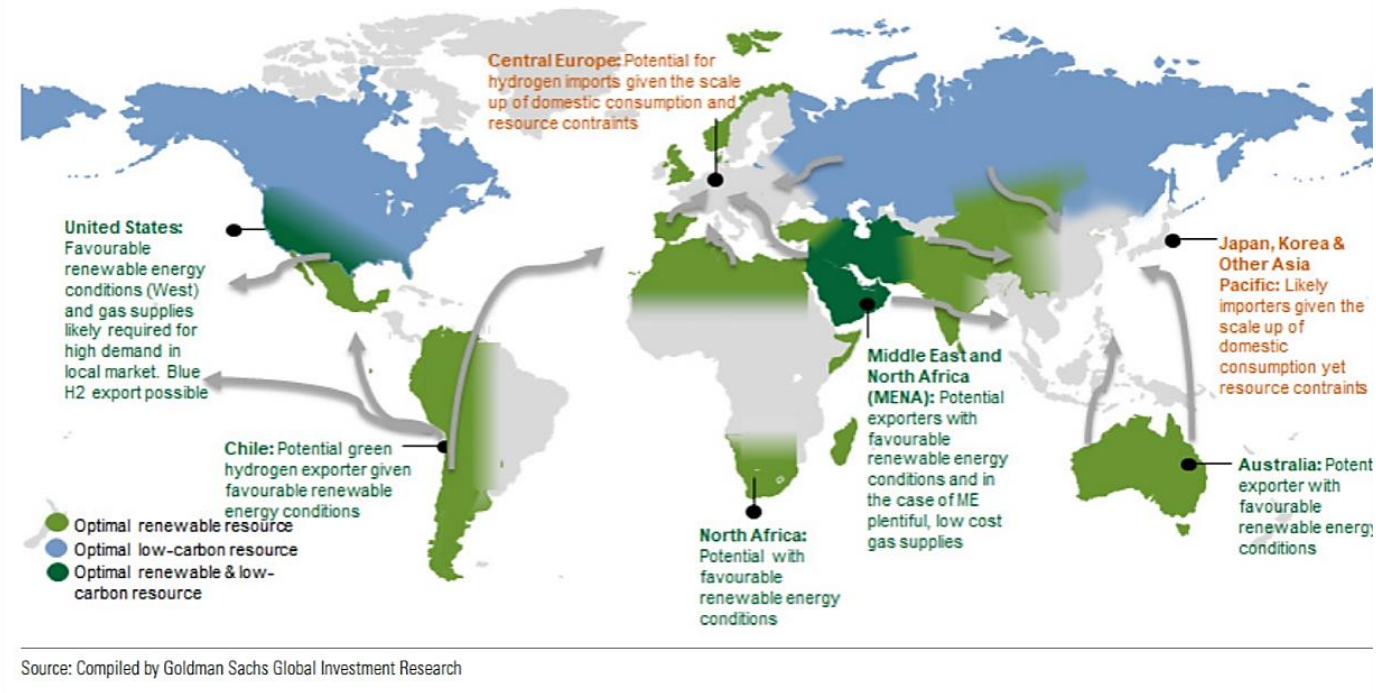
Figure 3: A summary of all-in costs for NW Europe importing green hydrogen from Saudi Arabia under various forms

[4] This is assuming a capacity factor of 98%.



EU and Asia – potential importers of MENA hydrogen: Japan, Korea, and potentially central Europe (among other nations) could emerge as clean hydrogen importing regions, depending on the pace of hydrogen penetration in their local economies. Japan and Korea are two potential hydrogen demand hubs, with strong policy support (both regions have pledged net zero by mid-century) and an appetite for the development of clean hydrogen as a key pillar of their domestic energy ecosystem and energy transition. Depending on the pace of hydrogen penetration in these regions, GS sees both countries becoming clean hydrogen importers in the long term.[xxvii] Japanese companies have a history of investment in LNG off-take hubs, such as those in the Texas Gulf Coast Region.[xxviii] Central Europe could also become a clean hydrogen importer, with the EU's Hydrogen Strategy aiming for 40 GW of domestically installed green hydrogen capacity by 2030, and another 40 GW from neighboring countries.[xxix]

Figure 4. Potential evolution of an international clean hydrogen market



With its Public Investment Fund (PIF), Saudi Arabia can take a long-term view on investments; this fund invests with a higher tolerance for risk for projects that are deemed to advance the Kingdom's national interests. The PIF has a diversified strategy with global dimensions that are in line with Vision 2030. Vision 2030 has a mission to diversify the Kingdom's economy through investment in global sectors and markets.[xxx] PIF's investments in the MENA region include investments in companies in the Kingdom and throughout the region. [Interactive Map: https://www.pif.gov.sa/en/Pages/OurInvestments-Map.aspx]

Case Study of Natural Gas in Qatar: Qatargas was established in 1984 as a joint venture with *QatarEnergy* and foreign partners to market and export LNG. Qatar and the Qatar Investment Authority have a top-down strategy[xxxi] designed to take a long view on investing; it often focuses its natural gas investments in integrated, large-scale projects linked to LNG exports or downstream industries that use natural gas as a feedstock. These projects tend to include investment from international oil companies including ExxonMobil, Shell, and Total, that have the technology and expertise for integrated megaprojects. In this investment structure, each venture has an individual ownership structure, although state-owned Qatar Petroleum (QP) owns at least 65 percent of each. The Qatargas consortium includes QP, Total, ExxonMobil, Mitsui, Marubeni, ConocoPhillips, and Shell.[xxxii] Thirty-eight years later Qatargas is an innovative leader and fully integrated LNG company, with an eye on

becoming the World's Premier LNG Company[xxxiii], that runs from the wellhead, off-shore Qatar, to customers around the world.[xxxiv]

In October 2021, Saudi Energy Minister HRH Prince Abdulaziz bin Salman al-Saud said that the country wants to become the top supplier of hydrogen in the world, with the aim of producing four million tons of hydrogen by 2030.[xxxv,xxxvi] Clean hydrogen could generate a new stream of export revenue that allows Saudi Arabia to become less reliant on oil as the key source of government and business revenue, consistent with Vision 2030. This is particularly relevant in the carbon-constrained modern world characterized by the previously noted wave of net-zero targets from governments and industries, including Saudi Arabia's own. In 2020, oil exports accounted for about 70 percent of the country's total exports in terms of value and about 53 percent of Saudi government revenues.

The Kingdom's current strategy is to gain a large market share of blue hydrogen (hydrogen produced from natural gas and supported by carbon capture and storage) with a focus on the production of blue ammonia in the coming decade. Blue hydrogen and its associated products can help the country leverage its hydrocarbon resources with existing capabilities and infrastructure, such as carbon capture and storage (CCS). In the future, green hydrogen could help the country develop a new industrial sector. Saudi Arabia's green hydrogen-related technological and economic experiments are in the incubation phases and being deployed in Neom, a city built to demonstrate a range of future technologies.[xxxvii]

An example of innovative cooperation and financing that may aid in this discussion is the hydrogen project at Kansai International Airport (KIX) in Japan. The experiment at KIX is an example of a national and local government partnership, supported by both domestic and international private sector investment.[xxxviii] Activity at KIX started in 2014, designed to be a leading example of support for the government of Japan's release of its third Strategic Roadmap for Hydrogen and Fuel Cells in March 2019.[xxxix] In June 2022 the KIX experiment added international investors, including Airbus, and Kansai Airports announced a Memorandum of Understanding to explore the use of hydrogen at three airports in Japan. Through this partnership, Airbus and Kansai Airports will jointly prepare a roadmap for hydrogen needs and study the development of infrastructure for the use of hydrogen in the aviation sector.[xl]

The many challenges and opportunities highlighted in the section above require further exploration. Below are some key questions for discussion:

- **What Policies Would Spur Investment? How is Development Financed?**
- **What are Innovative Financing Mechanisms for Spurring Investment in Hydrogen?**
- **Could instruments from International Financial Institutions such as the Global Climate Fund be useful?**
- **What are the key variables that will drive the export economics for hydrogen?**

3. Opportunities and Barriers: Energy Security and Economic Challenges

Successfully implementing and achieving the global clean energy transition requires a cohesive alignment across political, economic, and technological systems. To carry out such an alignment, critical focus is needed to: (1) clearly signal long-term commitments to foster investor confidence; (2) stimulate commercial demand for hydrogen in multiple applications; (3) help mitigate risk and other policy or regulatory hurdles that otherwise reduce the flow of capital to clean energy projects; and (4) promote investment into R&D and knowledge sharing, among challenges to be addressed in the other workshops.[xli] ***Top-down, directed financing could enable more ambitious goals and gain support down the value chain for the benefits and opportunities hydrogen has to offer to support the clean energy transition and deep decarbonization.***

While some clean energy solutions are already commercial, many innovative technologies will need to be developed, proved, and deployed to achieve net-zero targets. This will necessarily need to be supported by entirely new supply chains. For example, decarbonizing transportation will require new battery, fuel cell, and electro-fuel technologies as well as new infrastructures for charging and fueling. Widespread deployment of smart and distributed electricity generation and storage systems will also require new infrastructure investment in transactive transmission and distribution systems enabled by digital systems, and sophisticated energy management systems supported by broadband communication capabilities. The impact of climate change will require that new infrastructures to enhance system resiliency. Meeting these needs—and many more, simultaneously – ***will require substantial increases in investment*** – as well as innovation in the architecture of infrastructure systems.

The requirement to deploy existing and develop new clean energy solutions at scale and speed leads to an opportunity to promote economic growth, improve energy system resilience and reliability, and ensure greater energy security and prosperity. The growth of new industries can create skilled jobs[xlii] and contribute to building a more competitive economy. In this regard, Saudi Arabia is well-positioned to create innovations and industries in clean energy given its wealth of resources. ***However, all of this is predicated on the idea that there is sufficient capital available to fund the energy transition.***

The many challenges and opportunities highlighted in the section above require further exploration. Below are some key questions for discussion:

- **What are the challenges of the clean energy transition in relation to the investment attractiveness of hydrogen fuels?**
- **How can the carbon intensity of hydrogen production affect financing?**

4. Endnotes

[i] https://www.kapsarc.org/news/saudi-arabia-bets-big-on-blue-hydrogen/#:~:text=The%20researchers%20also%20see%20significant,imposed%20on%20carbon%20emissions%20worldwide
[ii] https://www.saudigreeninitiative.org/targets/reducing-emissions/
[iii] https://dii-desertenergy.org/mena-hydrogen-alliance/
[iv] https://www.iea.org/reports/hydrogen
[v] https://www.kapsarc.org/ Policy Pathways to Meet Saudi Arabia's Contributions to the Paris Agreement, D. Wogan, E. Carey and D.Cooke, February 2019
[vi] https://wedocs.unep.org/bitstream/handle/20.500.11822/37350/AddEGR21.pdf
[vii] https://www.kapsarc.org/research/publications/saudi-arabias-clean-hydrogen-ambitions-opportunities-and-challenges/
[viii] https://www.kapsarc.org/research/publications/saudi-arabias-clean-hydrogen-ambitions-opportunities-and-challenges/
[ix] https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf
[x] https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-clean-hydrogen-revolution/carbonomics-the-clean-hydrogen-revolution.pdf p. 7-8
[xi] https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-clean-hydrogen-revolution/carbonomics-the-clean-hydrogen-revolution.pdf p.8
[xii] https://www.iea.org/reports/hydrogen
[xiii] https://www.iea.org/reports/hydrogen
[xiv] https://www.ief.org/programs/hydrogen-market-pathways#:~:text=The%20IEF%20is%20leading%20a,strive%20to%20reduce%20carbon%20emissions p.8
[xv] https://www.iea.org/reports/the-future-of-hydrogen
[xvi] https://blog.nacdonline.org/posts/esg-audit-fortune-500
[xvii] https://www.kiplinger.com/investing/esg/604876/hydrogen-stocks-unstable-potentially-explosive
[xviii]https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/how%20industry%20can%20move%20toward%20a%20low%20carbon%20future/decarbonization-of-industrial-sectors-the-next-frontier.pdf
[xix]https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/how%20industry%20can%20move%20toward%20a%20low%20carbon%20future/decarbonization-of-industrial-sectors-the-next-frontier.pdf p.6
[xx] https://blogs.worldbank.org/ppps/green-hydrogen-key-investment-energy-transition
[xxi] https://www.pwc.com/gx/en/industries/energy-utilities-resources/future-energy/green-hydrogen-cost.html
[xxii] https://www.iea.org/reports/the-future-of-hydrogen
[xxiii] https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-clean-hydrogen-revolution/carbonomics-the-clean-hydrogen-revolution.pdf p.7
[xxiv] https://www.marsh.com/us/about/media/worlds-first-insurance-facility-for-green-and-blue-hydrogen-project.html
[xxv] https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-clean-hydrogen-revolution/carbonomics-the-clean-hydrogen-revolution.pdf p.34
[xxvi] https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-clean-hydrogen-revolution/carbonomics-the-clean-hydrogen-revolution.pdf p.65
[xxvii] https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-clean-hydrogen-revolution/carbonomics-the-clean-hydrogen-revolution.pdf p.63

[xxviii] https://www.naturalgasintel.com/sempra-taps-totalenergies-mitsui-and-japan-lng-for-cameron-expansion/
[xxix] https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-clean-hydrogen-revolution/carbonomics-the-clean-hydrogen-revolution.pdf p.63
[xxx] https://www.vision2030.gov.sa/
[xxxi] https://www.qia.qa/en/how-we-invest/Pages/default.aspx
[xxxii] U.S. IEA, Qatar International energy data and analysis, October 20, 2015, P.3
[xxxiii] https://www.qatargas.com/english/aboutus/direction-statement
[xxxiv] https://www.qatargas.com/english/aboutus/Documents/Qatargas%20Value%20Chain_Final.pdf
[xxxv] https://www.reuters.com/business/energy/saudi-arabia-wants-be-top-supplier-hydrogen-energy-minister-2021-10-24/
[xxxvi] https://www.arabnews.com/node/1954046/business-economy
[xxxvii] https://www.csis.org/analysis/geopolitics-hydrogen-indo-pacific-region p.18
[xxxviii] https://www.gov-online.go.jp/eng/publicity/book/hlj/html/201502/201502_05_en.html
[xxxix] https://www.meti.go.jp/english/press/2019/0918_001.html
[xl] https://www.airbus.com/en/newsroom/press-releases/2022-06-airbus-and-kansai-airports-partner-to-study-the-use-of-hydrogen-in
[xli] https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf p.172
[xlii] https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf