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The clean hydrogen opportunity for hydrocarbon-rich countries

Hydrogen could play an important role in helping hard-to-abate sectors meet climate targets. Countries with hydrocarbon resources and industry expertise can help build and scale the needed technology.

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Industry leaders are under pressure as the global climate change debate has amplified the call to limit global warming to 1.5 degrees Celsius.[1] Hydrocarbon-rich countries (HRCs) could turn this challenge into an opportunity by taking advantage of their hydrocarbon resources, geographic locations, access to abundant renewable energy (in certain cases), and highly developed infrastructure to develop and export clean hydrogen, defined as hydrogen produced with very low or zero carbon emissions, and its derivatives, including clean fuels.

Clean hydrogen is expected to play a critical role in decarbonizing typically hard-to-abate sectors such as heavy industries and long-haul transport. However, significant challenges must be resolved. The hydrogen value chain is both complex and capital intensive, many segments are not yet developing at the same rate, and staying abreast of constantly evolving technologies and regulations can be daunting.

Numerous recent publications illustrate the increasing attention around this topic. Our analysis builds on current value-chain trends to illustrate how key players in HRCs can leverage their advantaged positions and deep industry experience to become leaders in clean hydrogen. Doing so requires identifying key sources of value and choosing the right roles in the value chain.

According to McKinsey research, total hydrogen demand can reach 600 to 660 million tons by 2050, abating more than 20 percent of global emissions.[2] That said, realizing this opportunity will require all relevant stakeholders to come together to develop clean-hydrogen value chains—often across geographies. Those that take decisive action in these areas will be uniquely positioned to create new sources of value and play a leading role in future global energy markets.

Materializing the hydrogen promise

Today, most hydrogen is "gray," which means it comes from hydrocarbons, typically natural gas. This requires a process known as steam reforming, which releases carbon emissions. "Blue" hydrogen also relies on hydrocarbons but is coupled with carbon capture, utilization, and storage (CCUS) technology, which helps mitigate the environmental impact but can require incremental investments. Finally, "green" hydrogen is created using renewable energy, typically through the electrolysis of water, and results in no emissions.

For the hydrogen promise to materialize for HRCs and for the market to scale, four areas will need to be addressed: scaling competitive supply; stimulating local demand; developing transportation technology; and facilitating corporations across value chains, customers, and countries.

1. *Scaling competitive supply.* This requires HRCs to scale up both blue and green hydrogen. Blue hydrogen will play a key role in the short to medium term, together with green in the medium to long term, as it becomes increasingly economically viable. Access to cost-competitive and abundant natural gas or other hydrocarbons coupled with technological disruption in CCUS can allow for the required decline in the cost for blue hydrogen production by 2030. Complementary wind and solar resources and the continued decline in electrolyzer capital costs can also help. According to a report published by the Hydrogen Council in 2021, the cost of hydrogen for end users could drop by 60 percent from 2020 to 2030.[3] This outlook of continuous cost decline is underpinned by International Renewable Energy Agency (IRENA) scenarios by 2030 and 2050.[4]

2. *Stimulating local demand.* To create the foundations of a hydrogen ecosystem, there

[1] For more, see "The 1.5-degree challenge" on McKinsey.com.
[2] Global demand of 600 million tons in 2050 assumes net-zero commitments are achieved by leading countries while followers transition at a slower pace, as per McKinsey's Global Energy Perspective Achieved Commitments (AC) scenario. The demand of 660 million tons by 2050 assumes that the 1.5° pathway is adopted globally, driving rapid decarbonization. Emission savings are calculated by comparing total emissions in the AC scenario to emissions in the Current Trajectory scenario.
[3] *Hydrogen Insights: A perspective on hydrogen investment, market development and cost competitiveness*, Hydrogen Council and McKinsey, February 2021, hydrogencouncil.com.
[4] Herib Blanco, Marcelo Carmo, Raul Miranda, and Emanuele Taibi, Green hydrogen cost reduction, International Renewable Energy Agency (IRENA), 2020, irena.org.

Hydrocarbon-rich countries … have a track record of building and scaling up global energy supply by leveraging their unique access to competitive natural resources.

will need to be a local market for hydrogen in parallel to the development of export corridors. Governments can help by implementing the right regulatory frameworks around decarbonization and clean air to ensure these local demand sectors start. McKinsey analysis shows that with local demand stimulated, steel and ammonia produced using clean hydrogen could be competitive with traditional production pathways by 2030 at carbon prices of around $50 to $100 per ton, depending on local conditions.

3. *Developing transportation technology.* Hydrogen must be in liquid form or transformed into ammonia before it can be transported. However, liquefying hydrogen is both costly and technically challenging because it needs to be cooled down to –252 degrees Celsius, which is the lowest boiling point of any element. Our analysis shows that converting hydrogen to ammonia for transport to Europe from the Middle East then converting it back into hydrogen could result in an additional cost of $2.50 to $3.00 per kilogram (kg) of hydrogen in 2030, which is significant, given that green hydrogen production costs could be less than $2.00 per kg by 2030 in the region.

4. *Facilitating cooperation across value chains, customers, and countries.* The clean-hydrogen value chain is nascent and will require players across the stages to work together to ensure the value chain develops consistently. For example, long-term offtake agreements between customers such as steel or green fertilizer producers and hydrogen producers could derisk investments in clean-hydrogen projects. Partnerships could enable equipment and infrastructure developers to make investments with some minimum utilization guarantee. Meanwhile, creating government-to-government partnerships could facilitate hydrogen flow between countries, further supporting demand uptake in target markets, and could lock in supply agreements.

The role of hydrocarbon-rich countries in the scale-up of clean hydrogen

HRCs are a group across geographies and include countries such as Saudi Arabia and the United Arab Emirates as well as the United States and Canada. Most of these countries have a track record of building and scaling up global energy supply by leveraging their unique access to competitive natural resources. In the case of hydrogen, HRCs could also leverage their know-how and competitive reserves to scale up clean hydrogen.

Several factors are expected to drive a competitive supply of hydrogen from HRCs, including access to hydrocarbon resources, cheap renewable energy, strong domestic demand, advantaged location, and a proven track record in establishing global energy markets. HRCs could develop and become leading suppliers of clean hydrogen by leveraging these factors, but their competitive positions may vary depending on the applicability of these factors.

To begin, HRCs are likely to supply blue hydrogen because it provides an outlet for their hydrocarbon reserves, an opportunity to (re)use hydrocarbon reservoirs and midstream infrastructure, as well as an opportunity to maintain positions of leadership in the global energy market. Doing so requires investing in technologies such as CCUS to help ensure blue hydrogen remains competitive after 2030. Because green hydrogen is expected to become competitive after 2030, those with access to competitive, low-cost zero-carbon energy could also build on the green-hydrogen momentum and leverage any favorable renewable-energy sources to hedge the risk of blue hydrogen's cost competitiveness versus green hydrogen in the decades to come (Exhibit 1).

Building a robust supply of hydrogen could allow HRCs to leverage clean hydrogen to decarbonize downstream industries, such as downstream oil and gas and chemical- and energy-intensive industries, as well as long-distance aviation and marine. HRCs could also repurpose existing gas pipelines for clean hydrogen as demand for additional infrastructure grows, helping spur investment in port infrastructure and national carriers or transport ships.

Taking the lead: Identifying sources of value and choosing the right roles in the value chain

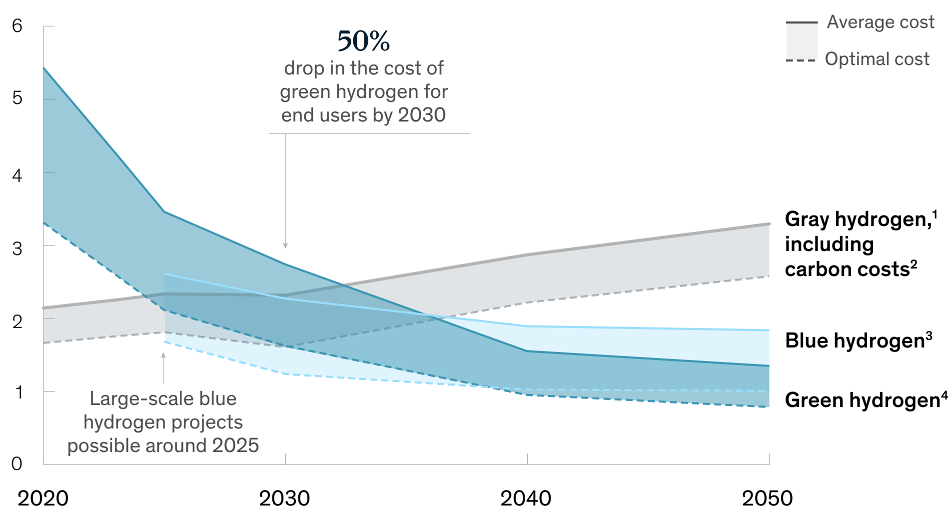
HRCs could gain leadership positions in the future hydrogen market by identifying the sources of value creation and using a number of distinct business models (Exhibit 2). For instance, NEOM, ACWA Power, and Air Products have committed to invest $5 billion into an integrated power hydrogen, and ammonia production plant—including export

Exhibit 1

Green hydrogen production costs are expected to fall by approximately 50 percent by 2030.

Forecast as of September 2022

Projected global production cost of hydrogen, $/kilogram



[1]Steam methane reforming (SMR) without carbon capture, utilization, and storage (CCUS).
[2]Based on projected average global CO_2 costs of $57/ton (2030), $94/ton (2040), and $131/ton (2050). For Saudi Arabia, CO_2 costs are assumed to be $33/ton in 2030, $69/ton in 2040, and $105/ton in 2050.
[3]Gas prices of $2.60 to $6.80/MMBtu (approximately $3/MMBtu in Saudi Arabia).
[4]Refers to the cheapest green hydrogen, which is provided by solar energy.
Source: McKinsey Hydrogen & Derivatives Flows Model, October 2022

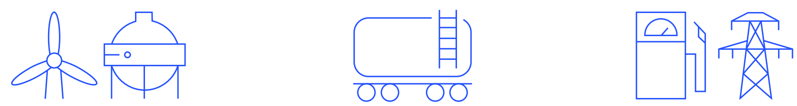
facilities—by 2025.[5] At the time of publication, more than 680 large-scale projects have been announced globally, representing more than $240 billion in mature investments.

Identifying key sources of value

Many players have focused on the entire value chain by developing integrated projects to derisk what could potentially be limited or slow development of certain segments of the value chain. Other players, mainly original-equipment manufacturers, have focused on specific value-chain verticals.

Exhibit 2

The full hydrogen value chain has a variety of sources of value—and challenges—at each stage.



Value chain[1]	Upstream	Midstream	Downstream
	$45–$55 billion	$11–$14 billion	$11–$14 billion
What it includes	• Energy generation and resources (eg, hydrocarbons, renewable energy) • Production of hydrogen (eg, electrolyzers, reformers, and CCUS[2] projects) • Equipment	• Equipment (compression/ liquefaction and reconversion) • Shipping (services) • Infrastructure (eg, ports, ships, and pipelines)	• Conversion to end products (eg, blue and green steel, synthetic fuel, ammonia) • Fuel cells and tanks • Vehicles, vessels, aircraft, and generators • Last-mile delivery
Sources of value	• Advantaged access to conventional energy resources • Advantaged access to renewable energy • Technology	• Technology and innovation • Existing infrastructure that may be repurposed	• Captive demand • Advantaged location • Government to government relations to lock in demand
Challenges	• Uncertainty regarding evolution of demand and how it will impact the scaling of production of electrolyzers or CCUS[2]	• Technological unlock required for liquefied hydrogen transport	• Significant investments required to redesign technologies in certain sectors such as in long-haul vehicle transport

[1]Estimated earnings before interest and taxes by 2030.
[2]Carbon capture, utilization, and storage.

[5]"Air Products, ACWA Power and NEOM sign agreement for $5 billion production facility in NEOM powered by renewable energy for production and export of green hydrogen to global markets," July 7, 2020, airproducts.com.

Developing the right plays in the hydrogen value chain

There are six plays ideally suited for building on the competitive advantages of players in HRCs: 1) hydrogen equipment manufacturing, 2) hydrogen production, 3) carbon capture, utilization, and storage, 4) hydrogen transportation, 5) clean-hydrogen downstream production (such as blue or green steel or synthetic fuels) and 6) integrated project developers (Exhibit 3).

Exhibit 3

There are six plays ideally suited for building on the competitive advantages of players in HRCs.

Potential clean hydrogen plays for HRC	HRC Stakeholder archetype: National oil companies	Utilities/ RES developers	Chemical companies	Energy intensive industry	Shipping	Rationale for plays
Hydrogen equipment manufacture Electrolyzers Carbon-capture equipment	●					Secure critical equipment supply Carbon-capture equipment can be used to decarbonize other products in the portfolio Contribute to economic development of the HRC
Hydrogen production	●					Capabilities to produce and sell energy globally and execute large capital projects
		●				Experience in developing renewables and executing large capital projects
			●			Capabilities to develop and operate complex industrial processes and executing large capital projects
Carbon capture, utilization, and storage	●	●	●	●		Technology and processes can be applied to decarbonize other products in the portfolio Potential applications for carbon, such as enhanced oil recovery or synthetic oil production
Hydrogen transportation						
Hydrogen pipeline, port, or marine transport	●					Existing infrastructure and capabilities to develop and operate pipelines and shipping energy products globally
Hydrogen pipeline		●				Synergies between pipeline asset development and operations and existing transmission assets
Port and marine transport					●	Existing daily shipping fleet and port-operations capabilities
Clean-hydrogen downstream industry	●		●	●		Existing assets that consume hydrogen, such as ammonia and steel production Decarbonize products such as steel and synthetic aviation and marine fuels
Integrated project developers	●					Capability to develop value chain and demand to de-risk projects

Hydrogen is a necessary part of curbing greenhouse gas emissions across the world while ensuring sufficiently stable and affordable energy supply.

1. *Hydrogen equipment manufacturing:* HRCs with high aspirations in hydrogen and a strong manufacturing sector could set up a hydrogen equipment manufacturing champion to facilitate the national road map and to become a global equipment supplier. That said, the most logical equipment manufacturing plays are owned by original-equipment manufacturers, and the kind of equipment plays that would likely make the most sense would be in the final tier of the supply chain, such as the assembly of components in electrolyzer or CO_2-capture equipment. Localizing manufacturing could help secure access to critical electrolyzer or carbon-capture equipment in the event of potential supply-chain constrains associated with projected growth in the hydrogen economy. Furthermore, developing carbon-capture or electrolyzer assembly can also help create jobs and contribute to GDP.

2. *Hydrogen production:* National oil companies and renewable developers can ensure demand for hydrocarbons or renewable resources. According to the Achieved Commitments scenario in our 2022 Global Energy Perspective, producing 600 million tons of hydrogen will require 650 billion cubic meters (bcm) of natural gas per year and 17,400 terawatt-hours of electricity per year in 2050, which corresponds to up to 25 percent of expected global renewable generation by that time.[6] Chemical companies, particularly those with significant exposure to industrial gases, such as gray hydrogen, have a majority of the capabilities and assets required to produce clean hydrogen today. All three players have experience developing, executing, and operating capital-intensive, complex industrial projects required to develop clean-hydrogen projects.

3. *Carbon capture, utilization, and storage:* HRC players such as national oil companies, utilities, chemical companies, and energy-intensive industries are the top contributors to national greenhouse gas (GHG) emissions and subsequently could have an important role to play in developing CCUS. Not only is CCUS critical for blue hydrogen production but also it offers opportunities to decarbonize operations across companies' portfolios. In addition, captured carbon can be used in existing operations, such as enhanced oil recovery or in future products, such as synthetic fuels.

4. *Hydrogen transportation:* There is ample opportunity for HRCs with strong export infrastructure, shipping sectors, and pipeline networks. To begin, national oil companies can repurpose existing gas pipeline infrastructure or develop new hydrogen networks to facilitate transportation. They can also partner with ship builders to develop hydrogen carriers. A number of carriers of liquefied hydrogen will be required to facilitate a global clean-hydrogen market by 2030. Meanwhile, utilities and developers of renewable energy sources can leverage

[6] Achieved Commitments scenario from *Global Energy Perspective* 2022, McKinsey, April 26, 2022.

existing pipelines or develop new ones to transport hydrogen locally. National oil companies and utilities can also invest in the electric grid to facilitate the transmission and distribution of green electricity. In Europe, an estimated 39,700 kilometers of hydrogen pipeline infrastructure could be installed by 2040, connecting low-cost production locations with demand hubs.[7] Finally, shipping companies could see ammonia transport opportunities, ultimately leading to the development of liquid hydrogen carriers. On this point, green and blue ammonia transport could increase shipped ammonia volumes in 2030, as compared to the scenario in which clean hydrogen is not adopted.

5. *Clean-hydrogen downstream production:* HRCs with either developed downstream industry or access to cheap hydrogen could become suppliers of clean end products, such as green ammonia. National oil companies could decarbonize products using hydrogen as feedstock. And chemical companies could see new opportunities in the production of green and blue ammonia, for which gray hydrogen is currently a feedstock. The same applies to energy-intensive industries, such as steel. The Hydrogen Council's 2021 report shows that green steel can cost as little as $515 per ton of crude steel, representing a premium of $45 per ton of CO_2e by 2030.[8] Leveraging downstream assets and industries, HRC countries have an opportunity to capitalize on growing demand for decarbonized products driven by shifting consumer preferences and regulations. For example, our analysis shows that global low-CO_2 flat-steel demand could grow to more than about 100 metric tons by 2030. This could be addressed with hydrogen direct reduced iron making (H_2-DRI), with the exception of about ten to 20 metric tons, which will come from scrap and electric arc furnaces (EAFs).

6. *Integrated project developers:* National oil companies can leverage their strong cross-value-chain positions to derisk project and downstream industries as well as their G2G relations to help secure demand. This play is a good fit for oil companies with advantaged access to energy resources, such as hydrocarbons and green energy, as well as advantaged geography, a broad set of G2G relations in energy, and substantial local demand driven by local industries over the long term.

Next steps for HRCs to play a prominent role in hydrogen

All stakeholders in HRCs, including governments as policy makers and regulators, national oil companies (NOCs), investment funds, utilities, and downstream industries, have key roles to play in setting up their respective countries on a successful path as the world adopts clean hydrogen.

Governments can play a leading role in the initial development of the hydrogen economy both locally and internationally. Doing so would require developing hydrogen road maps, including setting ambitions for national hydrogen production, implementing regulations to decarbonize different sectors to spur local demand for hydrogen, setting up G2G partnerships to secure demand for local hydrogen exports, developing a perspective on the localization of hydrogen production across the value chain, and supporting hydrogen deployment through regulatory support.

Stakeholders in hydrogen value chain in HRCs will need to develop their hydrogen strategies to identify the relevant opportunities for them along the hydrogen value chain and assess where to compete. These could include utilities playing the role of green hydrogen producers; NOCs supporting development of technologies

[7] "European hydrogen backbone grows to 40,000 km, covering 11 new countries," Gas for Climate, April 13, 2021.
[8] Premiums will vary depending on local conditions.

that are critical for hydrogen development, namely CCUS, liquefied hydrogen transport, direct air capture (DAC), and hydrogen fuel cells for trucks; NOCs investing in midstream infrastructure; and downstream players producing green products, such as green steel and green ammonia, and capturing their value pools. Last, players in HRCs will need to work on a number of enablers, including talent development, forming partnerships to ensure development of the required technology, expansion of the supply market, and long-term demand partnerships or offtake agreements.

HRCs have traditionally played an important role in supplying the world's energy needs. They also benefit from access to the resources required to produce green and blue hydrogen at competitive costs. They offer a key unlock in scaling green and blue hydrogen supply and accelerating cost reductions. Partnerships with hydrogen stakeholders in HRCs can offer companies and countries opportunities to gain exposure to the hydrogen economy and, more important, offer a path to decarbonize their respective operations and sectors.

Hydrogen is a necessary part of curbing GHG emissions across the world while ensuring sufficiently stable and affordable energy supply. HRCs are in a unique position to help develop and scale the technology. Those that take the right actions today will not only help stay ahead of the curve accessing new and growing value pools but will also help provide a cleaner, greener future.

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