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مركز الملك عبدالله للدراسات والبحوث البترولية
King Abdullah Petroleum Studies and Research Center

Accelerating the Demand for and International Trade in Low-Carbon Hydrogen

In this document, low-carbon hydrogen refers to both the renewable hydrogen produced from the electrolysis of water with electricity coming from renewable sources and the hydrogen derived from a production process in which carbon dioxide (CO_2) emissions are captured.

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About KAPSARC

KAPSARC is an advisory think tank within global energy economics and sustainability providing advisory services to entities and authorities in the Saudi energy sector to advance Saudi Arabia's energy sector and inform global policies through evidence-based advice and applied research.

This publication is also available in Arabic.

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Key Points

Low-carbon hydrogen is seen as a contender to complement electrification in replacing fossil fuels to help countries achieve their net-zero emission goals. The cost of low-carbon hydrogen projects and subsequent delivery prices have been among the major barriers to accelerating associated projects and increasing demand. Other challenges include formulating regulation, scaling up, and developing the required infrastructure. KAPSARC hosted a virtual roundtable on May 23, 2022, in partnership with Columbia's Center on Global Energy Policy, to discuss the policies, business models, and international standards of hydrogen that must be in place to support and drive hydrogen market development. We arrived at the following findings:

- Maintaining a technology-agnostic approach to supporting the hydrogen production process is desirable to fully unlock the potential of prospective hydrogen production technologies.

- Given the large investment required and long useful life of key assets, hydrogen project developers are likely to require revenue assurances. Price and off-take models are two crucial aspects that require attention during the early stage of hydrogen development.

- Long-term contracts in hydrogen are likely to mimic the energy contracts seen in the development of liquefied natural gas and electricity markets, including take-or-pay agreements, price adjustment clauses, and other fixed and variable premiums.

- International standards for low-carbon hydrogen are important for investors but are still under development. The more universal the criteria for certification purposes, the faster hydrogen projects will be built to reduce prices and increase demand. It is challenging to harmonize emerging certification schemes because of the different regulations in each jurisdiction.

Summary

Hydrogen is projected to play an important role in meeting decarbonization targets. Hydrocarbon-rich countries perceive this as an opportunity to decarbonize existing assets and monetize undeveloped hydrocarbon reserves. Meanwhile, non-traditional energy exporters rich in renewable energy resources view hydrogen as an opportunity to improve grid stability and a means to export surplus electricity. However, for the global trade of low-carbon hydrogen, demand must increase beyond that needed for current conventional uses. This includes increasing its use in transportation, power, and industrial heat applications. This will require regulations, demand-side incentives, innovative business models, and a reduction in the cost of the hydrogen delivered to the end user.

The workshop highlighted three main points for accelerating the development of a low-carbon hydrogen market. The first is to have the appropriate regulatory and financial framework in place to create a conducive environment for low-carbon hydrogen investment. While decarbonization targets and international cooperation are essential first steps to provide investors with clarity, they must be followed by incentives such as a carbon pricing mechanism to close the cost gap between low-carbon technologies and unabated processes. The second is to have sound business models in which producers' risks are appropriately addressed. Many lessons can be drawn from the development of other energy markets, particularly liquefied natural gas and renewable electricity, on which parties could rely. In addition, parties can build on existing contracts for ammonia and other hydrogen derivatives. Third, certification plays an important role in building consumer trust, stimulating demand, and paving the way for cross-border trade. The development of global standards and certification goes hand in hand. A universal methodology for calculating greenhouse gas emissions for hydrogen production and transport is an important and necessary first step for quantifying the carbon content of the hydrogen produced globally. Convergence in the sustainability criteria of certification schemes would also benefit from creating a liquid market for hydrogen, allowing the certificates to become more fungible.

Background to the Workshop

On May 23, KAPSARC hosted a virtual roundtable in partnership with the Columbia Center on Global Energy Policy to explore the enablers for accelerating hydrogen demand and international trade. Hydrogen is becoming increasingly important for addressing decarbonization and energy security. Europe and parts of Asia-Pacific have identified that imports of low-carbon hydrogen are crucial for meeting their emission targets. Potential exporters of hydrogen from Australia and the Middle East, including Saudi Arabia, Africa, and Latin America have started to provide opportunities for resource monetization during the energy transition. However, hydrogen is not a liquid commodity and its pricing reflects its production costs. Further, most green and blue hydrogen projects are in the pilot or pre-commercial stage and the markets for both green and blue hydrogen are small. Pushing hydrogen beyond the tipping point of market adoption would therefore require support through various regulatory and market interventions.

Accelerating Hydrogen Energy Demand

The transition toward a sustainable and low-carbon energy system is an ongoing but challenging process. Since renewable energy sources increased in developing countries, hydrogen has emerged as the energy sector's star commodity and a future energy vector. Its role in mitigating climate change impacts has resulted in a rapidly developing interest in transitioning toward a hydrogen-based economy. Several countries have announced or formulated strategies to promote green or low-carbon hydrogen energy. However, scaling up the production and use of hydrogen will require both short- and long-term actions by the government, regulators, and industry as well as support from the financial community.

As hydrogen is more expensive than diesel, gasoline, and natural gas, creating demand through clearly articulated policy and regulatory interventions is important. New clean hydrogen businesses should learn from the growth story of renewables in the power sector. At the start of its journey, renewable energy was also more expensive than other conventional sources of electricity production. However, despite its unfavorable economics, renewable energy uptake was greatly influenced by many national renewable portfolio standards. For example, approximately 45% of renewable energy growth in the United States since 2000 has been attributed to renewable portfolio standards (Barbose 2021). Such policies have also been instrumental in creating demand for renewable energy in India and Australia. Similarly, governments can encourage the use of hydrogen energy by formulating decarbonization policies with clear hydrogen energy use targets aimed at the transport, industrial, and other sectors, depending on the local context and priority end-use segments.

It can be expensive and challenging for power generation companies to decarbonize coal- and natural gas-based electricity production using ammonia- and hydrogen-blended fuels. However, with further technological advancements in hydrogen production methods and reductions in production costs, power companies could fulfill their net-zero goals. Nonetheless, importing hydrogen energy, transporting it and its derivatives to power plants, and storing it are likely to pose critical scale-up challenges. Furthermore, the necessary codes and standards must be established for hydrogen energy blending. The use of ammonia to co-fire coal-fired plants is still in the trial stage and plants using 100% ammonia may not be commercially ready for another decade.

Price remains the major challenge to creating demand for hydrogen energy. Scaling up hydrogen production to benefit from economies of scale and receiving government support to make hydrogen affordable are necessary to reduce prices. Maintaining a technology-agnostic approach to support the hydrogen production process is also desirable to unlock the potential of prospective hydrogen production technologies. Further, implementing carbon pricing could improve the economics of clean hydrogen relative to alternative fuels, thereby accelerating hydrogen demand. Without waiting for demand-stimulating policies, ramping up renewable energy capacity to produce green hydrogen in the short to medium term will also benefit large-scale hydrogen production. However, producers must ensure that this capacity is not diverted from what is needed to decarbonize the power sector. Securing a stable supply of renewables is crucial for producing green hydrogen, which is interpreted differently by interested parties. Thus, a clear and unanimous definition of what constitutes green hydrogen is needed to help address some of the issues that might arise when monitoring and verifying green (or clean) hydrogen.

Pricing and Business Model

The deployment of low-carbon hydrogen infrastructure is likely to face a number of market barriers, including the high cost of low-carbon hydrogen, technology risks, demand uncertainty, the lack of market structure, and the absence of long-term policy and regulatory frameworks. These risks are amplified by the lack of hydrogen transportation, distribution, and storage infrastructure. Therefore, securing financing for investment in early-stage low-carbon hydrogen projects requires a business model that ensures revenue predictability. Given the large investment required, hydrogen project developers are likely to need revenue assurances that they can cover their capital costs throughout the assets' useful lives. Price and off-take models are two crucial aspects that require attention during the early stage of hydrogen development.

Adopting a fixed price (i.e., using feed-in tariffs), a fixed premium, and a variable premium were the three notable price support options that encouraged the successful deployment of renewable energy. Each has its advantages and differing levels of complexity. However, these price support options can be adapted to reimburse early-entry low-carbon hydrogen producers. To encourage investment in hydrogen energy production, the offered price should allow for full cost recovery or support the long-term commitment to fund capital expenditure (capex). This is an approach found in power purchase and liquefied natural gas tolling agreements. Therefore, it would be prudent to design an economic model of hydrogen supply that is fundamentally a cost-plus model, similar to that of electric power.

In the absence of hydrogen spot benchmark pricing, clean hydrogen producers could be reimbursed based on their fixed and variable costs. If hydrogen producers were initially offered a guaranteed off-take price linked to the prevailing benchmark technology costs, the capex forbearance price would need to be set and reviewed periodically to avoid windfall profits from changing circumstances. However, as the hydrogen market evolves, adopting a competitive auction of hydrogen projects could lower hydrogen purchase costs and reduce the need for future government support.

Liquefied natural gas prices are generally indexed to other commodities, usually the market prices for oil and gas. This creates a volatile and risky price dramatically affected by geopolitics and market imperfections. Therefore, linking the hydrogen price support mechanism to the reference natural gas price could create further complexities.

In the wake of demand uncertainties, likely due to the absence of strong demand-stimulating policies and regulations, market players may adopt an off-take business model similar to the take-or-pay contracts offered to early renewable energy projects. Long-term contracts are preferred to secure financing. Early hydrogen supply contracts were mainly characterized by low volume and short duration, as most hydrogen was consumed on site. However, as the international trade in low-carbon hydrogen accelerates, parties must consider new contract structures. Key contact terms include contract duration, price, off-take volume, quality specifications, transportation, and delivery terms. More importantly, besides covering dispute resolution and contract termination-related clauses, hydrogen supply contacts should offer the flexibility to review prices and other terms after a specified duration; similar price review clauses are found in some gas and liquefied natural gas contracts. As green and blue hydrogen production carries different market risks, hydrogen sale and purchase agreements are unlikely to be standardized, but may prove to be similar. Further research is required to develop new low-carbon business and contracting models.

The Role of Certification to Enable Cross-Border Trade

Having harmonized standards and certification schemes is important for bringing liquidity to the nascent hydrogen market. Certification allows end users to verify the origin of hydrogen molecules and provides information on the production pathway and associated greenhouse gas emissions. Thus, certification could serve as a risk management tool for off-take contracts.

Certificates are not a new concept in the field of energy procurement. Renewable electricity certificates were first introduced approximately two decades ago to evidence the production of electrons from renewable electricity. However, they were introduced into a mature electricity market with developed transmission, distribution, and end uses, which is not the case for hydrogen today. A common international standard for low-carbon hydrogen is important to foster a level playing field and give investors confidence in the industry (Climate Bond Initiative 2022). However, a variety of hydrogen standards have emerged with diverging criteria and requirements. This is proving to be a challenge for exporting countries, as a specific plant design for hydrogen production could be accepted in one market but rejected in another. Thus, any divergence in low-carbon standards could result in a fragmented market for hydrogen, leading to a less liquid market and a slow ramp-up in production.

Certification schemes attempt to reflect the regulatory framework of a national market and show compliance with the eligibility requirements for these markets. The German Energy Agency assessed 11 emerging hydrogen certification schemes globally to explore whether these standards could be harmonized. The results showed that it would be challenging to harmonize these standards because one region with ambitious criteria for its standards would have to moderate such criteria for the sake of a globally harmonized system (Dena 2022). The differences in many sustainability criteria include differences in the tracking model (book and claim vs. mass balance)[1], greenhouse gas emissions boundaries (well-to-gate vs. well-to-wheel)[2], and eligible carbon sources for manufacturing hydrogen derivatives. Some certification schemes also consider land and water use, whereas others do not. Taking the common denominator from these sustainability criteria results in strict requirements for designing a plant, thus making the manufactured low-carbon hydrogen costly.

To grow a hydrogen market, some experts argue that a carbon intensity certification scheme is viable as it would provide flexibility for producers and consumers. Organizations are developing a universal methodology for analyzing the lifecycle of greenhouse gas emissions throughout the hydrogen value chain for different production pathways. Once a global lifecycle analysis methodology is adopted, regions and countries can determine whether their carbon content meets their thresholds and can then price them accordingly.

[1] In the book and claim model, the physical delivery of the energy carrier and the issuance of the certificate can be traded apart from one another. In the mass balance model, the energy carrier and the certificate are linked along the chain of custody.

[2] "Well-to-gate" measures the emissions up to and including the hydrogen production facility (including electricity production for electrolysis and hydrocarbon extraction for steam reforming/gasification). "Well-to-wheel" extends the boundary to hydrogen storage, conversion, and transport.

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About the Workshop

KAPSARC co-hosted a virtual roundtable with Columbia's Center on Global Energy Policy on May 23, 2022. It brought together over 40 experts from government, industry, and non-governmental organizations to discuss the enablers of hydrogen demand and international trade.

List of participants

Radwan Abdallah – Senior Manager, SABIC

Saad Alhatem – General Manager of Standards Department, SASO

Saad Al-Khaldi – Certification Lead, Saudi Aramco

Fahad Almalki – Public Relations Analyst, KAPSARC

Wael Almazeedi – Managing Director, Avance Labs

Majed AlSuwailem – Fellow and Acting Director, Oil & Gas, KAPSARC

Jiyoung An – Associate Research Fellow, Korea Energy Economics Institute

Agnieszka Ason – Visiting Research Fellow, Oxford Institute for Energy Studies

Marthad BaAbbad – Head of Industry & Policy Development, Saudi Aramco

Tim Bertels – Senior Partner, DAREL Group

Abdullah Bokhari – Advisor, Saudi Arabia Ministry of Energy

Thomas Bosse – Manager, NEOM

Marcello Contestabile – Director of Economics & Policy, HBKU QEERI

Anne-Sophie Corbeau – Global Research Scholar, Center on Global Energy Policy

Allyson Cutright – Senior Energy Markets & Data Division Analyst, International Energy Forum

Bassam Dally – Professor, KAUST

Stavroula Evangelopoulou – Energy Technology Analyst Hydrogen, IEA

Frank Felder – Director Utilities and Renewables, KAPSARC

Doris Fujii – Head of Hydrogen and CCUS Analysis, BP

Hendrik Gordenker – Senior Advisor, JERA Co.

Shahid Hasan – Fellow, Utilities and Renewables, KAPSARC

Juan Carlos Jobet – Distinguished Visiting Fellow, Center on Global Energy Policy

Shigeto Kondo – Senior Researcher, JIME Center of the Institute of Energy Economics, Japan

Megumi Kotani – Analyst, Hydrogen Unit, IEA

Kim Malin Lakeit – Expert, International Market Development Hydrogen

Martin Lambert – Head of Hydrogen Research, Oxford Institute for Energy Studies

Melissa Lott – Director of Research, Center on Global Energy Policy

Yushan Lou – Research Associate, Center on Global Energy Policy

Robin Mills – CEO, Qamar Energy

Amin Nasser – Department Manager for Chemical Business Strategy and Low-Carbon Hydrogen, Saudi Aramco

Daria Nochevnik – Director, Policy & Partnerships, Hydrogen Council

Erik Rakhou – Associate Director, Boston Consulting Group

Jitendra Roychoudhury – Fellow, Transport & Infrastructure

Saumitra Saxena – Research Scientist, KAUST

Maxime Schenckery – Director, IFP School

Rami Shabaneh – Fellow, Oil & Gas, KAPSARC

Hadia Sheerazi – Program Manager, Carbon Management Research Initiative, Oxford University

Manal Shehabi – Senior Research Fellow, Oxford Institute for Energy Studies

Adam Sieminski – Senior Advisor to the Board of Trustees, KAPSARC

Jos Tuinenburg – Senior Consultant, I-REC Standard Foundation

Noe van Hulst – Chair, IPHE

Ghassan Wakim – Low-Carbon Hydrogen Manager, Clean Air Task Force

Notes

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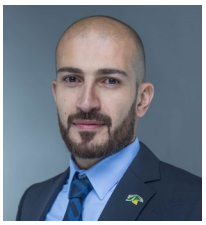
About the Team



Rami Shabaneh

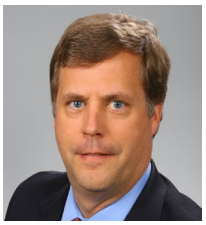
Rami Shabaneh is a fellow in the Oil and Gas program at KAPSARC, with a focus on global gas and hydrogen markets. Rami has over 15 years of research and industry experience analyzing energy markets and energy policies. Before joining KAPSARC, Rami worked at Cenovus Energy as a market fundamentals analyst, providing analytic support for specific issues affecting North American gas, natural gas liquids, and condensate markets. His work informed the company's hedging strategies. Before working at Cenovus Energy, Rami spent three years working as a research economist at the Canadian Energy Research Institute. He holds an M.Sc. in Sustainable Energy Development and a B.Sc. in Actuarial Science from the University of Calgary.

Shahid Hasan

Shahid Hasan is a research fellow at KAPSARC. His research focuses on electricity sector transitions and hydrogen economics, policy, and regulatory issues in Gulf Cooperation Council (GCC) member states. He also studies the development of regional electricity markets in the GCC, Middle East, and North Africa. He previously consulted extensively on policy, regulatory, and market design for governments, electricity regulators, public utilities, and electricity industries in India and Southeast Asia.

Anne-Sophie Corbeau

Anne-Sophie Corbeau is a global research scholar at the Center on Global Energy Policy at Columbia University's School of International and Public Affairs. Her research focuses on hydrogen and natural gas. Anne-Sophie has over 20 years of experience in the energy industry and is a recognized expert in natural gas. She is the author of many publications focusing on the gas and liquefied natural gas markets in Asia (especially China and India) and Africa, including the book *LNG Markets in Transition: The great reconfiguration* (Oxford, 2016). She is also a member of the governing body of Gastech. Before joining the Center, Anne-Sophie was a senior leader and head of gas analysis at BP, where she was responsible for advising the leadership team on gas market developments and long-term pricing assumptions. As part of BP's Economic and Energy Insights team, she led the Energy Outlook's analysis of gas, industry, nuclear energy, and hydrogen. She also served as a member of BP France's Comex board. Before joining BP, she was a Research Fellow at KAPSARC in Riyadh, where she established and expanded the natural gas program. She previously worked for the International Energy Agency, where she was responsible for managing research on global gas markets, and for IHS CERA. She began her career as an engineer working in fuel cells and hydrogen at Peugeot and Debis Systemhaus. Anne-Sophie holds an M.Sc. from Ecole Centrale Paris and an M.Sc. from the University of Stuttgart.



Frank Felder

Frank Felder is an engineer, energy policy analyst, and the program director for KAPSARC's Energy Transitions and Electric Power program. Before joining KAPSARC, he was a research professor at the School of Planning and Public Policy at Rutgers University, director of the Rutgers Energy Institute, and director of the Center for Energy, Economics, and Environmental Policy. In these roles, he conducted original and applied research in the areas of electric power system modeling, clean energy policies, and climate change for academic foundations, government agencies, and energy utilities. He has also worked as an economic consultant and a nuclear engineer.

About the Project

Hydrogen is emerging as an important energy vector that can accelerate the path toward net-zero emissions. Given its diverse applications and potential to abate carbon emissions, it is ideally suited as an enabler of the circular carbon economy. This project aims to investigate the different pathways toward a hydrogen economy and role of resource-rich countries in offering low-cost clean hydrogen solutions.

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