The Role of Low-Carbon Fuels in the Clean Energy Transitions of the Power Sector

International Energy Agency

The Role of Low-Carbon Fuels in the Clean Energy Transitions of the Power Sector

International
Energy Agency

INTERNATIONAL ENERGY AGENCY

The IEA examines the full spectrum of energy issues including oil, gas and coal supply and demand, renewable energy technologies, electricity markets, energy efficiency, access to energy, demand side management and much more. Through its work, the IEA advocates policies that will enhance the reliability, affordability and sustainability of energy in its 30 member countries, 8 association countries and beyond.

IEA member countries:

Australia
Austria
Belgium
Canada
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Japan
Korea
Luxembourg
Mexico
Netherlands
New Zealand
Norway
Poland
Portugal
Slovak Republic
Spain
Sweden
Switzerland
Turkey
United Kingdom
United States

The European Commission also participates in the work of the IEA

IEA association countries:

Brazil
China
India
Indonesia
Morocco
Singapore
South Africa
Thailand

Abstract

Governments around the world are faced with the challenge of ensuring electricity security and meeting growing electricity uses while simultaneously cutting emissions. The significant increase in renewables and electrification of end-uses plays a central role in clean energy transitions. However, due to the variable nature of solar PV and wind, a secure and decarbonised power sector requires other flexible resources on a much larger scale than currently exists today. These include low-carbon dispatchable power plants, energy storage, demand response and transmission expansion. The availability and cost of these technologies depends on local conditions, social acceptance and policies.

The possibility to combust high shares of low-carbon hydrogen and ammonia in fossil fuel power plants provides countries with an additional tool for decarbonising the power sector, while simultaneously maintaining all services of the existing fleet. The relevant technologies are progressing rapidly. Co-firing up to 20% of ammonia and over 90% of hydrogen has taken place successfully at small power plants, and larger-scale test projects with higher co-firing rates are under development.

Ultimately, using large volumes of low-carbon hydrogen and ammonia in the power sector will help establish supply chains and drive down costs through economies of scale and technological improvements, thereby complementing and mutually reinforcing the use of low-carbon in fuels in other hard-to-abate sectors such as long-haul transport and industry.

Acknowledgements, contributors and credits

This study was prepared by a cross-agency working group drawn from several directorates of the IEA. The study was designed and directed by Paolo Frankl (Head of the Renewable Energy Division). The analysis and production of the report were led and co-ordinated by Ilkka Hannula.

The work benefitted from strategic guidance by Keisuke Sadamori (Director of Energy, Markets and Security). The main contributors were: Ilkka Hannula, Paolo Frankl, Niels Berghout, Keith Everhart, Peerapat Vithayasrichareon, Luis Lopez and Sara Budinis.

Other IEA colleagues who made contributions to this work include (in alphabetical order): Julien Armijo, Elisa Asmelash, Jose Bermudez Menendez, Carlos Fernandez Alvarez, Alexandre Gouy, Astha Gupta, Taku Hasegawa, Cesar Alejandro Hernandez, Zoe Hungerford, Javier Jorquera, Randi Kristiansen, Peter Levi, Raimund Malischek, Samantha McCulloch, Gergely Molnar, Tomas de Oliveira Bredariol, Uwe Remme, Nicole Thomas and Brent Wanner.

The report benefitted also from contributions from following external consultants: Alfonso Chinnici (University of Adelaide), Graham J. Nathan (University of Adelaide), and Cédric Philibert (IFRI)

Valuable comments, feedback and guidance were provided by other senior management, including Keisuke Sadamori, Peter Fraser, Aad van Bohemen and Timur Gül.

This publication was produced with the support of the Japanese Ministry of Economy, Trade and Industry (METI).

We appreciate the contributions of speakers at the IEA online workhop the “Role of low-carbon hydrogen and ammonia in decarbonising the power sector” held in April 2021 (in alphabetical order):

Mohit Bhargava	NTPC Renewable Energy
Tobias Birwe	Thyssen Krupp
Paola Brunetto	Enel
Andrew Dickson	CWP Global
Toshiro Fujimori	IHI

Jitendra Gupta	Shell
Ahmad Al Khowaiter	Saudi Aramco
Thierry Lepercq	HyDeal
Torben Nørgaard	Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping
Akihiko Taniguchi	JERA
Sammy Van Den Broeck	Yara Clean Ammonia
Stephanie Queen	GE Power

The IEA would also like to thank the following experts who provided essential inputs to the underlying analytical work and reviewed the report:

Kenji Akiyoshi	Inpex Corporation
Henrik Bach Mortensen	Siemens Gamesa
Herib Blanco	IRENA
John Bøgild Hansen	Haldor Topsøe
Paola Brunetto	Enel
Jose Chaves	Comillas Pontifical University
Cosmas Chiteme	Department Science and Technology, South Africa
Fernando de Sisternes	World Bank
Gniewomir Flis	Agora Energiewende
Toshiro Fujimori	IHI
Timo Gerres	Universidad Pontificia Comillas
Walburga Hemetsberger	Solar Power Europe
Marina Holgado	IEA Hydrogen TCP
Ayaka Jones	USDOE
Emmanouil Kakaras	Mitsubishi Heavy Industries EMEA
John Lau	Independent expert
Pharoah Le Feuvre	Enagas
Franz Lehner	NOW
Thierry Lepercq	HyDeal
Paul Lucchese	CEA & IEA Hydrogen TCP
Laura Martin	Natural Resources Canada
Giuseppe Montesano	Enel Foundation
Sam Muraki	Tokyo Gas
Manabu Nabeshima	Ministry of Foreign Affairs, Japan
Carlo Napoli	Enel Foundation
Yasushi Ninomiya	Institute of Energy Economics, Japan
Daria Nochevnik	Hydrogen Council

Torben Norgaard	Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping
Luc Pelkmans	IEA Bioenergy TCP
Cédric Philibert	IFRI
Attilio Pigneri	H2U - The Hydrogen Utility
Tobias Rehnholm	Vattenfall
Hisahide Okuda	JERA
David Reiner	University of Cambridge Judge Business School
Xavier L. Rousseau	Snam
Nicolo' Sartori	Enel Foundation
Robert Steele	EPRI
Toshiyuki Suda	IHI
Emanuele Taibi	IRENA
Heino von Meyer	International PtX Hub
Masashi Watanabe	Ministry of Economy, Trade and Industry, Japan
Akira Yabumoto	J-Power
Deepak Yadav	CEEW – Council on energy, environment and water
Mads Zacho	Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping

Thanks also to the IEA Communications and Digital Office (CDO) for their help in producing the publication, especially to Jad Mouawad, Head of CDO, Astrid Dumond, Mariam Aliabadi and Therese Walsh. We thank Elspeth Thomson for copy-editing the manuscript.

Executive summary

Using low-carbon hydrogen and ammonia in fossil fuel power plants can play an important role to help ensure electricity security in clean energy transitions

Governments around the world are faced with the challenge of ensuring electricity security and meeting growing electricity uses while simultaneously cutting emissions. The significant increase in renewables and electrification of end-uses plays a central role in clean energy transitions. However, due to the variable nature of solar PV and wind, a secure and decarbonised power sector requires other flexible resources on a much larger scale than currently exists today. These include low-carbon dispatchable power plants, energy storage, demand response and transmission expansion. The availability and cost of these technologies depends on local conditions, social acceptance and policies.

Thermal generation is the largest source of power and heat in the world today, also providing key flexibility and other system services that contribute to the security of electricity supply. These plants are also long-lasting: By 2030, 79% of the coal and gas-fired plants in advanced economies will still have useful technical life, before declining to 43% in 2040. In emerging economies, due to recent investments, these figures are 83% in 2030 and 61% in 2040. Countries that rely strongly on fossil fuel-based power generation will be required to make very significant efforts to achieve decarbonisation objectives to comply with the Paris Agreement or Net Zero targets, where applicable.

The possibility to combust high shares of low-carbon hydrogen and ammonia in fossil fuel power plants provides countries with an additional tool for decarbonising the power sector, while simultaneously maintaining all services of the existing fleet. The relevant technologies are progressing rapidly. Co-firing up to 20% of ammonia and over 90% of hydrogen has taken place successfully at small power plants, and larger-scale test projects with higher co-firing rates are under development.

The value of low-carbon fuels in the power sector depends on system contexts and regional conditions

The value of low-carbon dispatchable power capacity depends on several variables, such as market design, availability of other flexibility options, energy mix and the price of carbon, which can vary greatly across regions.

By 2030, thermal power plants using low-carbon fuels could play a growing role as a dispatchable resource for covering peak demand periods when the value of the produced electricity is high, and for providing a range of system services to ensure energy security and capacity adequacy to avoid costly disruptions in the energy supply. For example, dispatchable thermal power plants in India are expected to provide 40% of energy, 50% of system inertia, almost 60% of peak capacity and over 70% of ramping flexibility services in the IEA Sustainable Development Scenario (SDS) by 2030.

Low-carbon fuels can play an especially important role in countries or regions where the thermal fleet is young, or when the availability of low-carbon dispatchable resources is constrained. In these settings, they can allow existing assets to continue operating even when climate regulations are tightened, thereby diminishing the risk of creating stranded assets. This is particularly the case in the East and Southeast Asia.

This report provides a detailed assessment of three supply chain categories for using low-carbon hydrogen and ammonia in the power sector in 2030: importing low-carbon fuels to an advanced economy (Japan); importing low-carbon ammonia to an emerging economy (Indonesia); and using domestically produced low-carbon hydrogen in an emerging economy (India).

Production costs of low-carbon fuels must decrease further

Natural gas with carbon capture, utilisation and storage (CCUS) is currently the lowest-cost production route for low-carbon fuels. Cost estimates for 2030 are generally in the range of USD 8-16/GJ (USD 0.9-1.9/kg) for hydrogen and USD 12-24/GJ (USD 230-440/t) for ammonia in regions with access to low-cost natural gas and availability of CO_2 storage.

Production costs for the electrolytic route are decreasing rapidly due to continuing reductions in the cost of renewable electricity and economies of scale in electrolyser manufacturing. By 2030, costs are estimated to be in the range of USD 13-19/GJ (USD 1.5-2.2/kg) for hydrogen and 22-33/GJ (USD 400-620/tNH3) for ammonia in regions with excellent wind and solar resources.

By 2030 the cost of low-carbon hydrogen and ammonia for use as chemical feedstock becomes comparable to those of unabated production from fossil fuels. However, for use as a fuel, they are expected to remain significantly more expensive than projected prices of coal and natural gas in 2030 in the SDS.

Full value chains, including transport and storage, must be considered when comparing the cost of using low-carbon fuels from different sources

An extensive transport and storage infrastructure is a prerequisite for establishing global value chains, and connecting low-cost production regions with users of low-carbon fuels.

Transmission of hydrogen and ammonia via pipelines is a mature technology and represents a relatively small proportion of the overall supply cost. Intercontinental ammonia transport is also well developed, relying on chemical and semi-refrigerated liquefied petroleum gas (LPG) tankers.

For marine transport, hydrogen can be liquefied in a manner similar to what is done for natural gas. However, liquefaction is a very energy- and capital- intensive process. Transporting fuels via shipping over a distance of 10 000 km is estimated to cost USD 14-19/GJ for liquid hydrogen, while it is only USD 2-3/GJ for ammonia. The resulting total supply projected costs in 2030, including production and marine transport, are respectively USD 22-35/GJ (USD 2.6-4.2/kg) for hydrogen and USD 14-27/GJ (USD 260-500/t) for ammonia.

The use of low-carbon fuels in fossil fuel power plants must lead to significant and measurable life-cycle emission reductions

Substantial greenhouse gas (GHG) life-cycle emissions reductions can be achieved by substituting fossil fuels with low-carbon hydrogen and ammonia in thermal power plants. Indicatively, switching from natural gas-based power generation to hydrogen derived from fossil fuels with 95% CO_2 capture delivers about 70% GHG reduction, while electrolytic hydrogen from renewables reduces emissions by 85-95%. Similarly, switching from coal-based power generation to low-carbon ammonia delivers about 80% reduction in emissions when ammonia is produced from fossil fuels with 95% CO_2 capture, and 90-95% when ammonia is produced from wind and solar.

There are currently no internationally agreed rules or standards on the maximum allowable GHG emissions associated with the production of hydrogen and/or hydrogen-derived fuels. In the case of the CCUS route, such standards would dictate minimum eligible CO_2 capture rates and place limits on the maximum allowable upstream emissions. At the same time, such rules and standards are also relevant for electrolysers if grid electricity is used, as the power mix will significantly influence life-cycle emissions.

Going forward, standards are needed to create end-user confidence towards fuels that are carbon-free at the point of consumption, but might produce significant

GHG emissions during production, transport and final distribution. For example, switching from coal to unabated fossil ammonia can double life-cycle GHG emissions, and even triple them in the case of switching from natural gas to unabated fossil hydrogen.

A versatile mix of supply routes for low-carbon fuels will enhance diversification and security of supply while contributing to cost predictability

A diverse mix of supply locations and technologies can help ensure secure supplies should producers struggle to meet rapidly growing demand. Costs for renewables and the electrolytic route are more predictable and can help to balance possible disruptions in the supply and price swings of natural gas and coal, which affect the production costs of the fossil fuel with CCUS route.

Low-carbon hydrogen and ammonia production can be kick started in places where production can build on existing infrastructure and demand. There are also possibilities to integrate the electrolytic and fossil fuel with CCUS processes into a hybrid plant that can offer increased efficiency and potentially lower capital investment requirements.

If the biomass feedstock is sustainably produced, carbon-negative hydrogen and ammonia can be produced by capturing by-product CO_2 from a biomass conversion plant, a particularly interesting option in high-price carbon jurisdictions.

The overall strategies and policies to incentive low-carbon fuels should be kept open for different technology options as long as basic sustainability criteria are met. This is likely to increase competition and accelerate cost reductions, while increasing diversification and security of supply.

A portfolio of policies is required to compensate for cost gaps and foster uses that maximise system value

By 2030, low-carbon hydrogen and ammonia are likely to remain expensive energy carriers for power generation. However, in Japan the gap between the generation cost and the value of the produced electricity is moderated by the wholesale electricity market that allows higher prices during peak demand periods, and by the high carbon price assumed in the SDS for advanced economies by 2030. Our analysis suggests that co-firing 60% of low-carbon ammonia in a Japanese coal power plant in 2030 would lead to a generation cost that is 30% higher than energy market value in baseload, but just 15% higher in peak load conditions. In addition, these generators will be able to compete on Japan’s capacity market, striving for an additional source of revenue. By contrast, using the same low-carbon ammonia in Indonesia would lead to a four-fold increase in