# WHITE PAPER

# THE DECARBONIZATION POTENTIAL OF AMMONIA AS FUEL FOR CO-FIRING

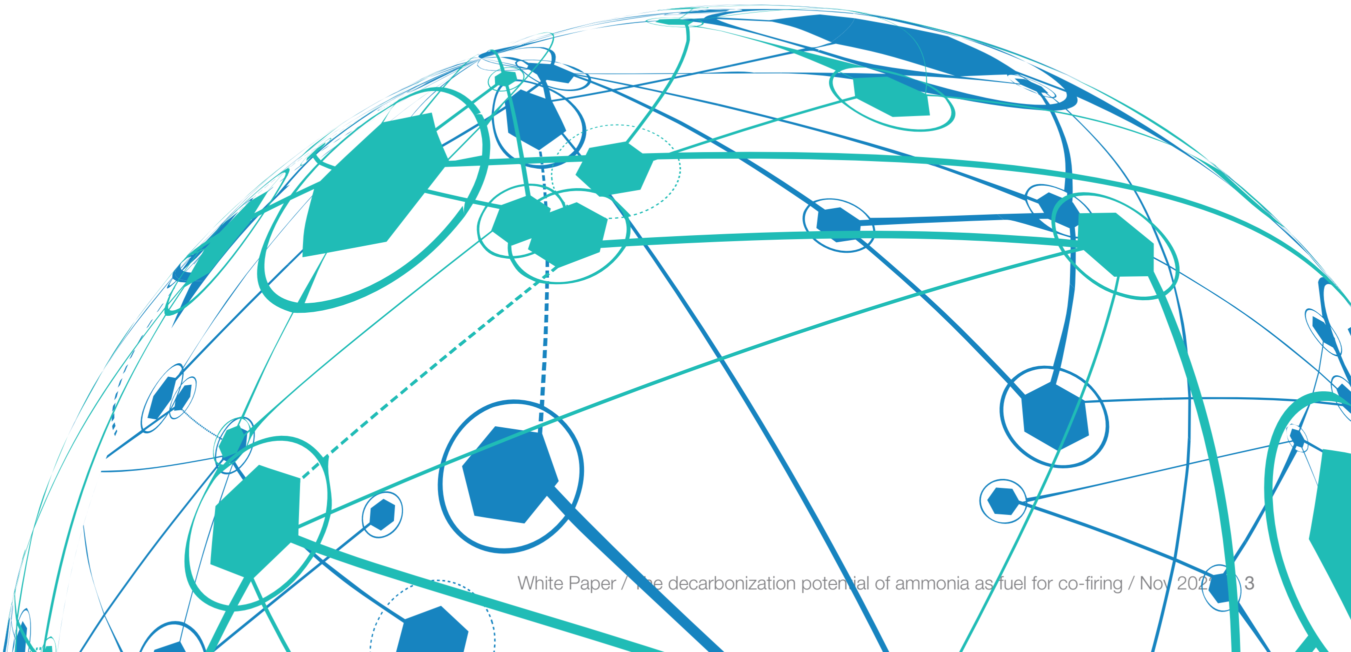
## Decarbonizing thermal power plants across Europe

Version 1. 02 November 2022

# CONTENTS

# ACRONYMS

| | |
|---|---|
| **LNG** | Liquified Natural Gas |
| **GHG** | Greenhouse Gas |
| **CFP** | Carbon Footprint |
| **FP** | Footprint |
| **RED** | Renewable Energy Directive |
| **CCS** | Carbon Capture and Storage |
| **CCUS** | Carbon Capture Utilization and Storage |
| **RES** | Renewable Energy Sources |
| **SDGs** | Sustainable Development Goals |



# 1 Introduction

As climate change is accelerating, technologies are maturing to help reach the Greenhouse Gas (GHG) emission reduction objectives set by the Paris Agreement and the Sustainable Development Goals (SDGs) set out in the UN 2030 Agenda for Sustainable Development. On the other hand, governments around the globe are faced with the challenge of ensuring energy security and meeting growing energy demand, while simultaneously cutting emissions. In addition to that, Russia's invasion of Ukraine and the ongoing energy crisis have forced the countries to take measures to reduce import dependency on Russia.

Thermal generation is the largest source of power and heat in the world today, providing key flexibility to the grid. In addition, due to the current energy crisis, coal-fired production limits have been relaxed in countries such as France and the Netherlands. Also, the temporary reopening of mothballed plants is discussed and/or have been approved in Greece, Italy, the United Kingdom, Germany and Austria. According to the IEA [7], thermal power plants are also long-lasting: by 2030, 79% of the coal and gas-fired plants in advanced economies will still have a useful technical life, before declining to 43% in 2040. Countries that strongly rely on fossil fuel-based power generation will be required to make significant efforts to achieve decarbonization objectives to comply with the Paris Agreement or Net Zero targets, where applicable.

In 2021, the share of thermal generation was 70% in Asia Pacific, and 50% in Europe and Americas combined. Amid rising power demand and a strong focus on decarbonization globally, there is an urgent need to replace thermal power generation plants with renewables and battery storage or pair with new technologies such as carbon capture, utilisation and storage (CCUS) to abate emissions. A quick replacement of these thermal power plants is costly in those cases where thermal fleets still have many years of useful operation.

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 power 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.

Co-firing sustainable bioenergy can allow coal-fired and natural gas facilities to continue contributing to flexibility and capacity adequacy while reducing $CO_2$ emissions. However, the biomass feedstocks used must be considered sustainable to ensure a net $CO_2$ emissions reduction from co-firing. 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.

# 2 Addressing the problem: co-firing low-carbon energy sources in thermal power plants

**Ammonia** is increasingly recognised as a clean fuel and potential energy carrier. It has a high hydrogen content per unit volume, allows utilization of existing infrastructure, and can be combusted without reconversion to hydrogen.

Ammonia is utilized today as a basis for fertilizers, chemical raw material and more recently is successfully used in industrial applications as a fuel. In addition, when used as a carrier for hydrogen, ammonia enables an efficient, lower-cost transport and storage of a carbon-free fuel which can be used directly in natural gas power generation. Since ammonia contains no carbon, **it does not emit carbon dioxide when combusted. It may therefore enhance the power sector's efforts in reducing carbon emissions.**

To abate emissions in thermal power plants, ammonia is one available option to be used as fuel directly or by co-firing – without any reconversion. In fact, ammonia co-firing delivers over 10% reduction in carbon emissions, associated with a strategic benefit in markets, considering the high costs and physical limitations to develop Renewable Energy Sources (RES) and additional CCUS capacity.

Combusting low-carbon energy sources, such as ammonia, allows for optimisation of power plants, while maintaining grid resilience and lower carbon intensity of power generation. Furthermore, the possibility to combust high shares of low-carbon ammonia in fossil fuel power plants may provide countries with an additional option for decarbonizing the power sector, while simultaneously maintaining all services of the existing fleet.

The relevant technologies are progressing rapidly and co-firing up to 20% of ammonia and over 90% of hydrogen has been demonstrated successfully in small power plants. Larger-scale test projects with higher co-firing rates are under development.

To get on track with the Net Zero Scenario, the private sector could evaluate co-firing opportunities and conduct small-scale ammonia co-firing tests, with an eye towards commercial plant application in the coming years.

# 3 The potential use of ammonia as an energy carrier

Low levels of ammonia co-firing with coal and natural gas have demonstrated stable combustion in Poland and Japan, while companies such as IHI have announced initial trials to supply power up to 2MW in one of their coal-converted units, with a goal to replace more than 20% of coal to produce cleaner power. Similarly, the chemical company, Ube Industries Ltd. has successfully replaced coal with ammonia in initial tests for clinker production and found that the quality and strength of the final product remained the same. Research is also underway which demonstrates the feasibility of ammonia/hydrogen blends for gas turbines. This indicates ammonia has the potential for use in combined cycle gas turbines (CCGT), providing a high degree of flexibility in meeting electricity demand and compensating for the variability in renewable electricity from wind and solar sources.

Last year, GE and IHI Corporation (IHI), signed a Memorandum of understanding (MOU) for the collaborative development of a gas turbine roadmap. The roadmap will support the use of ammonia as a carbon-free fuel to lower carbon emissions in both existing and new gas turbines in Japan. IHI is one of the leading companies of ammonia co-firing technology and has successfully run co-firing tests in gas turbines with 70% of liquid ammonia ratio.

In 2022, IHI and JERA are conducting projects to achieve a 20% ammonia co-firing rate at Unit 4 of JERA's Hekinan Thermal Power Station with the aim to raise that rate above 50%. The project will help Malaysia to cut greenhouse gas emissions by 45% from 2005 levels by 2030 and make the nation carbon neutral by 2050. Moving forward, Malaysian state-owned utility Tenaga Nasional Bhd (TNB) have carried out the country's first test of co-firing ammonia for a coal-fired power generation system, aimed at decarbonizing the country's power sector. TNB said the experiment, conducted at TNBR's test rig facility in Kajang, Selangor, was successful with $CO_2$ and $SO_2$ emissions "reduced in accordance with the co-firing rate. They reported that no generic ammonia sources were detected at the exit of the furnace during the experiment.

In South Korea, The Ministry of Trade, Industry and Energy is promoting ammonia and hydrogen power generation. The commercialization of ammonia co-fired at 20% rate for power generation is estimated to be ready by 2030 and hydrogen co-firing (30% or more) by 2035. These technologies will replace coal and liquefied natural gas (LNG) power generation to dramatically reduce greenhouse gas emissions. Ammonia power generation also plans to complete 20% co-fired demonstration by 2027, and to apply and commercialize 20% co-fired power generation to 24 units of all coal power plants (43 units in total) by 2030.

# 4 Results carbon intensity of fuels

To quantify the potential GHG emission reduction of ammonia as fuel for co-firing, this section compares the carbon footprint (CFP) of low-carbon and renewable ammonia to liquefied natural gas (LNG). The CFP methodology used, is the one prescribed by the (EU) RED II for fuels, which is a well-to-grave lifecycle analysis.

The end-use of the ammonia and LNG is fuel for co-firing process in EU power plants. Therefore, to quantify the total GHG impact, combustion emissions are included in the scope.

Assumptions were made to calculate the CFP of the three fuels. In the case of low-carbon ammonia, it is assumed that the (low-carbon) hydrogen stems from a Autothermal Reforming process with CCS. Renewable ammonia on the other hand is assumed to be produced with a zero CFP hydrogen using RES.

To quantify the CFP of Liquified Natural Gas, the supply chain is modelled considering Cheniere's Sabine Pass facility specific GHG emission data for production, gathering, and boosting, transmission, processing, liquefaction, regasification, and transportation of LNG to the Netherlands.

A well-to-gate analysis was conducted to show the different emissions and granularity along the production pathway of ammonia and LNG, and a well-to-grave approach to account downstream and combustion emissions and total GHG emissions of the three products.

Figures 1 and 2 show a well-to-gate and well-to-grave Carbon Footprint Results analysis and comparison of the three fuels LNG, low-carbon and renewable ammonia on an energy content basis.

The results of this study show that LNG has a much higher CFP than ammonia when used as fuel for co-firing in the EU. The combustion of LNG is the most important contributor to the CFP of this product. The analysis also concluded that in terms of percentage change, **LNG has a 39.4% higher CFP than low-carbon ammonia on an energy content basis ($gCO_2$/MJ). Finally, when comparing the relative change of LNG with respect to renewable ammonia, it results in a 75.2% higher CFP.**

The preceding analysis demonstrates the potential for significant GHG emissions reductions in Europe using ammonia co-combustion in thermal power generation facilities. Furthermore, ammonia co-firing is presented as a cost-effective alternative to decarbonize the electricity sector and a secondary energy source to replace the more pollutant fossil fuels for thermal power generation.

Figure 1: Well-to-gate carbon footprint comparison

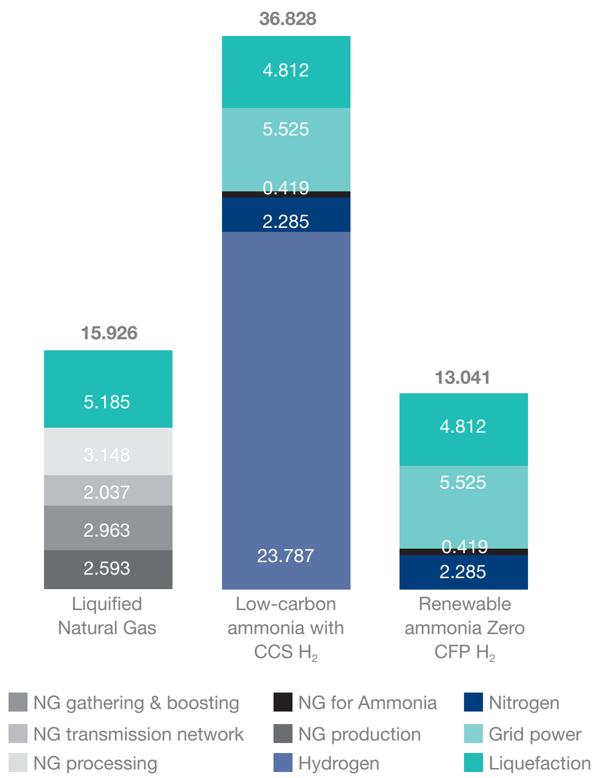
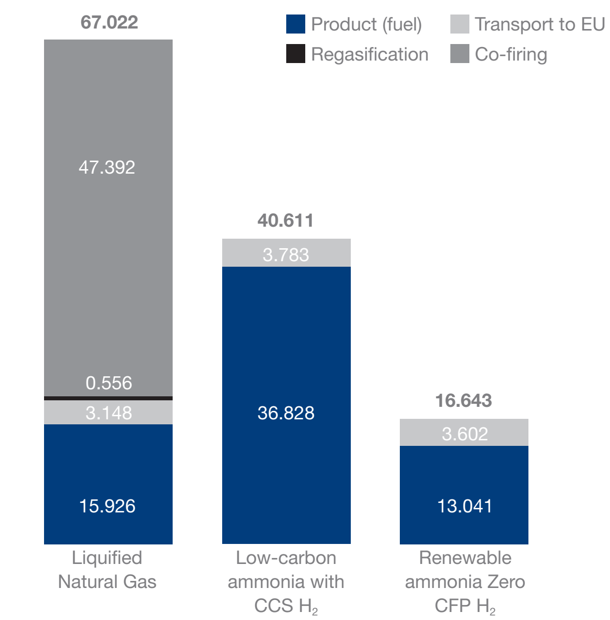



Figure 1: Well-to-grave carbon footprint comparison



# 5 Co-firing as an alternative to decarbonize power in the short term

Around 20% percent of European electricity is generated from coal and 17% from natural gas. Here, too, the differences between countries are large. Coal-fired power plants account for a particularly high share of electricity generation in Germany, Russia, Poland and Ukraine, whereas gas-fired power plants in Belgium, Greece, Ireland, Italy, Latvia, Lithuania, Portugal and the Netherlands – i.e. primarily in countries that do not have a high level of nuclear power generation.

According to the European Energy Agency, the EU's GHG emission intensity of electricity generation is on average 275 $gCO_2e$/kWh. From a regulatory perspective, the delegated regulation (EU) 2022/1214 complementing the EU Taxonomy Regulation includes specific GHG reduction targets and requirements to drastically cut emissions by implementing combustion of gas, mixed with low-carbon energy sources.

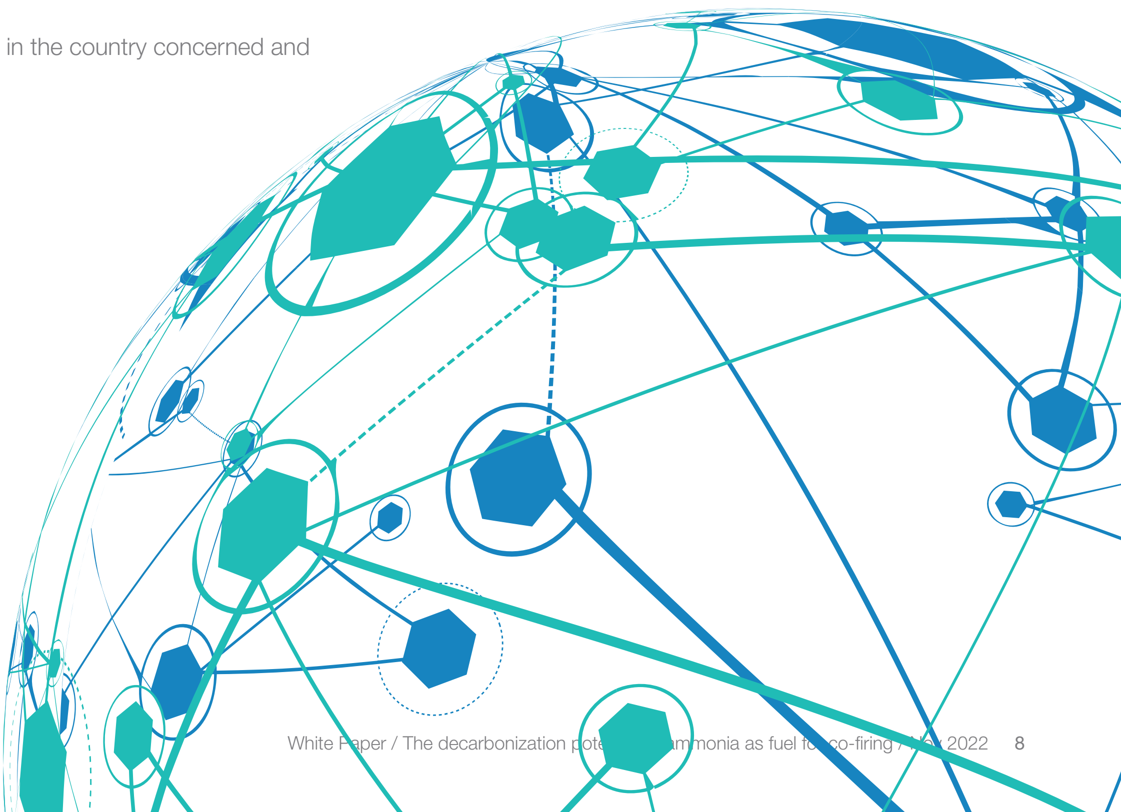
In general, gas-fired power plants must have greenhouse gas emissions of less than 100 g $CO_2$/kWh. New gas-fired power plants that receive a permit by the end of December 2030 must demonstrate that:

- The electricity generated cannot yet be efficiently produced by renewables.
- Gas-fired power plant replaces an existing plant with higher emissions and the emissions reduction per kWh is at least 55 per cent.
- The facility is designed and constructed to use renewable and/or low-carbon gaseous fuels and the switch to full use of renewable and/or low-carbon gaseous fuels takes place by 31 December 2035.
- A coal phase-out is planned in the country concerned and laid down in an official plan.

The aforementioned cuts in GHG emissions from thermal power generation would probably only be achievable with CCS or CCUS, which at this stage may be inefficient and costly in those cases where thermal power plants still have many years of useful life. Blending fossil fuel with low-carbon fuels, allows utilization of existing production, transportation, and storage infrastructure, making it a cost-effective solution and easy to implement in the short term.

The Taxonomy classification will likely stimulate private-sector investment. Due to the high construction costs and time delays of nuclear power plants and the currently high gas prices, low-carbon fuels could be cheaper and more cost-effective compared to fossil fuel alternatives.

Finally, co-firing experiments done in demonstration facilities have shown that using a 10 MWth-class combustion test furnace coupled with 20% ammonia co-firing rates, $N_2O$ emissions are under detection limits (>100ppm), whereas NOx emissions stay within the same range as usual emissions in coal power plants.



# 6 About OCI

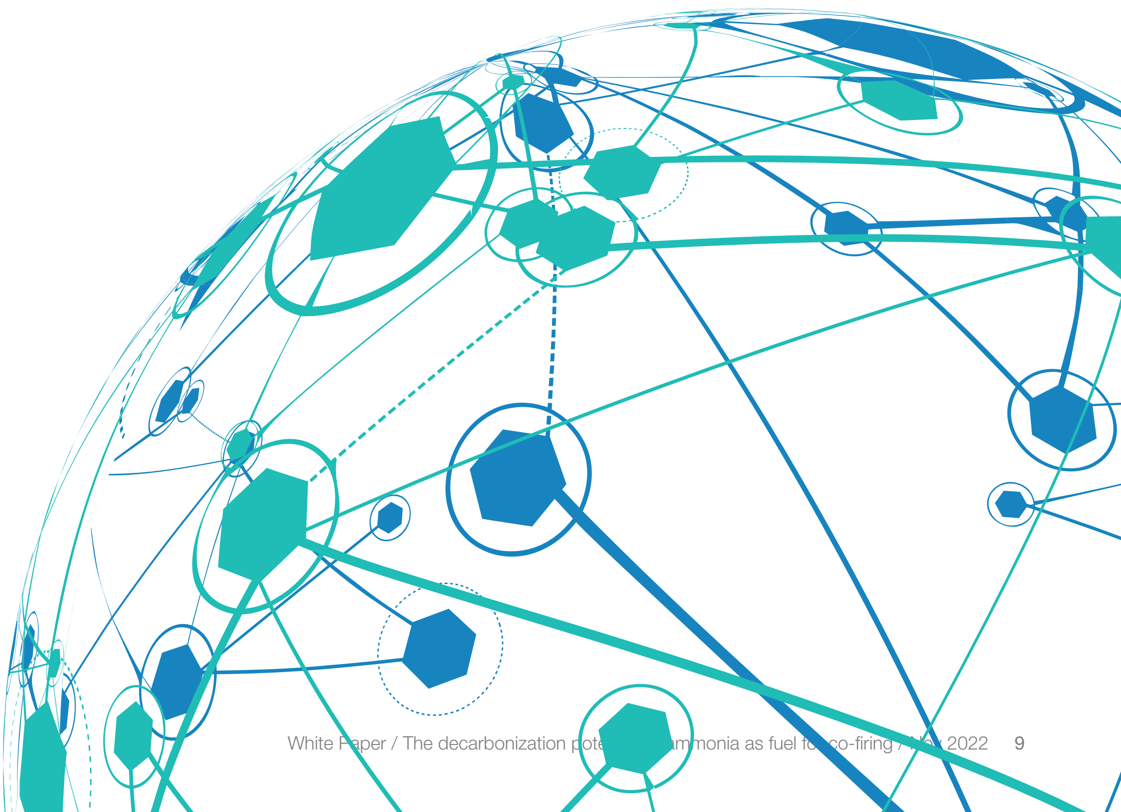
This White paper was developed by Hinicio, on behalf of OCI.

### About OCI

Founded in 1950 in Egypt, OCI N.V. has grown from a small family-run construction business into a leading global producer and distributor of nitrogen fertilizers, nitrogen products and methanol, providing sustainable solutions to agricultural and industrial customers around the world. Our production capacity spans four continents and comprises approximately 16.1 million metric tons per year of nitrogen fertilizers, methanol, diesel exhaust fluid and melamine. We employ approximately 4,200 people, are headquartered in the Netherlands, and listed on Euronext in Amsterdam.

### About Hinicio

Hinicio is a strategy consulting firm specialized in sustainable energy and mobility. Since 2006 Hinicio has been developing and consolidating a unique level competence center in hydrogen and fuel cells, which is now recognized as a leading authority in Europe and Latin America. Hinicio builds on an outstanding team of high-level experts, including chemical, electrical, mechanical, software engineers, economists, environmentalists, and policy experts. Hinicio is headquartered in Brussels, Belgium, and has offices in Paris, Rotterdam, Santiago de Chile, Bogota, Washington DC, and representation in Mexico and Beijing.



# 7 Bibliography

1 Al-Breiki, M., & Bicer, Y. (2020). Technical assessment of liquefied natural gas, ammonia and methanol for overseas energy transport based on energy and Exergy analyses. International Journal of Hydrogen Energy, 45(60), 34927–34937. https://doi.org/10.1016/j.ijhydene.2020.04.181

2 Aresi, L., & Takahashi, Y. (2021, June 21). Ge and IHI sign agreement to develop ammonia fuels roadmap across Asia. GE News. Retrieved October 27, 2022, from https://www.ge.com/news/press-releases/ge-and-ihi-sign-agreement-to-develop-ammonia-fuels-roadmap-across-asia

3 Atchison, J. (2021, November 24). South Korea sets targets for hydrogen & Ammonia Power Generation. Ammonia Energy Association. Retrieved October 28, 2022, from https://www.ammoniaenergy.org/articles/south-korea-sets-targets-for-hydrogen-ammonia-power-generation/

4 Atchison, J. (2022, September 6). Ammonia combustion for power generation: Updates from Korea, Malaysia and Singapore. Ammonia Energy Association. Retrieved October 28, 2022, from https://www.ammoniaenergy.org/articles/ammonia-combustion-for-power-generation-updates-from-korea-malaysia-and-singapore/

5 IEA (2021), Ammonia Technology Roadmap, IEA, Paris https://www.iea.org/reports/ammonia-technology-roadmap

6 IEA (2022), Coal-Fired Electricity, IEA, Paris https://www.iea.org/reports/coal-fired-electricity

7 IEA (2021), The Role of Low-Carbon Fuels in the Clean Energy Transitions of the Power Sector, IEA, Paris https://www.iea.org/reports/the-role-of-low-carbon-fuels-in-the-clean-energy-transitions-of-the-power-sector

8 IHI Corporation. (2022, October 26). IHI launches partnership with JERA Asia for ammonia utilization in Malaysian thermal power plants to expand the ammonia value chain. Retrieved October 28, 2022, from https://www.ihi.co.jp/en/all_news/2022/resources_energy_environment/1198069_3488.html

9 The Royal Society. (2020, February 19). Ammonia: zero-carbon fertiliser, fuel and energy store. Green ammonia | Royal Society. Retrieved October 27, 2022, from https://royalsociety.org/topics-policy/projects/low-carbon-energy-programme/green-ammonia/

10 GE. (2021, June 22). Ge and IHI sign agreement to develop ammonia fuels roadmap across Asia. GE News. Retrieved October 28, 2022, from https://www.ge.com/news/press-releases/ge-and-ihi-sign-agreement-to-develop-ammonia-fuels-roadmap-across-asia

11 Roman-White, S. A., Littlefield, J. A., Fleury, K. G., Allen, D. T., Balcombe, P., Konschnik, K. E., Ewing, J., Ross, G. B., & George, F. (2021). LNG Supply Chains: A supplier-specific life-cycle assessment for improved emission accounting. ACS Sustainable Chemistry & Engineering, 9(32), 10857–10867. https://doi.org/10.1021/acssuschemeng.1c03307

12 Takamasa Ito, Hiroki Ishii, Juwei Zhang, Sakiko Ishihara, Toshiyuki Suda*, IHI Corporation (2019, November 12) New Technology of the Ammonia Co-Firing with Pulverized Coal to Reduce the NOx Emission. Ammonia Energy Conference. https://aiche.confex.com/aiche/2019/meetingapp.cgi/Paper/571237

13 Wood Mackenzie (2022, May 18). Ammonia co-firing in thermal power plants could be worth US$100 billion in 2050. Wood Mackenzie. Retrieved October 27, 2022, from https://www.woodmac.com/press-releases/ammonia-co-firing-in-thermal-power-plants-could-be-worth-us$100-billion-in-2050/