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Emissions Reductions From Co-burning Ammonia With Coal In Japan: The Need For Green Ammonia

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Introduction

Along with other 189 countries, Japan has ratified the Paris agreement. Japan's first nationally determined contribution (NDS) post 2020 committed to reduce greenhouse gas (GHG) emissions by 26% in financial year 2030 relative to 2013 (Japan, 2015).

Japan has significant challenges to decarbonize its electricity supply. Historically, the largest source of low emissions power was nuclear energy, producing 288 TWh (26%) in 2010 (IEA, 2015) however the Fukashima Daiichi power plant has led to significant reductions in nuclear output. Japan has heavy dependence on coal for electricity production. Coal comprised 320TWh of Japan's total electricity generation of 1036TWh in 2019. Current emissions from coal are approximately 280MT pa. Our analysis of recent Japanese government announcements of replacement of low efficiency coal generators with high efficiency plant would only reduce emissions by around 8%.

It is unsurprising that there is significant interest in Japan in the import of low emissions energy sources, particularly hydrogen. Ammonia is emerging as an attractive energy vector due to its established international trade, its low liquification pressures and high energy densities. Ammonia retains about 90% of the lower heating value of the hydrogen input. There are existing synergies for the coal generation industry as ammonia is already established in existing generation units, injected into the exhaust gas stream as a means for controlling NOx pollution.

Ammonia is not an ideal combustion fuel with high ignition temperatures and low heat of combustion and flame velocities. However, these problems are overcome by co-burning with another fuel. Two significant trials have established the potential for ammonia to substitute for coal as a fuel. Chugoku Electric Power (Chugoku Electric Power) tested adding sufficient ammonia in the combustion stream to generate the equivalent of 1MW of power in an operating coal plant with commensurate reduction in emissions (0.8% at 120MW). IHI has demonstrated much larger fractions with 20% ammonia (LHV basis) combusted with pulverised coal in a large scale (10MW) combustion test facility (IHI, 2018). Based on this successful outcome, IHI intend to design a cofiring system for a 1000MW coal fired plant.

Displacing 20% of the coal in Japan would require 29 million tonnes of ammonia per annum based on the likely makeup of the 2030 fleet and would deliver significant emissions reductions of 51 MT per annum in Japan.

Fossil fuel based ammonia manufacturing emissions

The standard manufacturing approach for ammonia is the Haber-Bosch process where nitrogen and hydrogen are reacted under pressure in the presence of a catalyst. The majority of the world's ammonia production uses methane both as the fuel and the source of the hydrogen. Most of the emissions result from the steam methane reforming and water shift reactions to produce hydrogen. Best available technology for ammonia production from methane results in direct emissions of 1.6 tonnes of CO_2 per tonne of ammonia produced while average intensities are greater than 2.0 kg for the average manufacturing fleet of ammonia producing regions.

Fugitive emissions from the extraction of methane indirectly add to this intensity. These emissions are in the form of methane leakage which has a global warming potential around 30 (25 in Australia) and carbon dioxide in the gas. The fugitive quantities vary depending on the source of the gas but typically add 10-20% to emissions intensity relative to the combustion of natural gas. Australia's fugitive emissions resulting from natural gas was approximately 12%. Consequently, if Japan sourced its ammonia from standard ammonia production this would result in 64 to 70 MT of emissions. This is significantly more than the savings from the reduced coal combustion in Japan.

Carbon capture and storage

As mentioned earlier, the production of hydrogen for ammonia is via the steam methane reforming/water shift processed. Carbon dioxide is a by-product of the process and has to be stripped from the hydrogen. This carbon dioxide is controlled throughout the process and is effectively captured as part of the standard process. This equates to 1.22kg of CO2 per kg of ammonia. Approximately 36% of carbon emissions from ammonia production are already captured and used for other purposes including urea manufacture and enhanced oil recovery (IFA, 2009). 60% emissions reductions are therefore relatively straightforward if low cost storage is located close by (e.g. depleted gas reserves). Despite this, the gains in emissions would still be modest with net savings only 33 to 44% of the original coal emission reductions.

Greater capture fractions require capture of the emissions in the flue gases. While there are proposals for 90% of emissions to be captured from hydrogen production, these are yet to be demonstrated.

Renewable hydrogen and ammonia

The energy input for ammonia production can be partially or totally met with renewable energy.

Electrolysis of water from renewable electricity can replace the steam methane reforming process for hydrogen production. This can be the used as the partial or total hydrogen source for the standard methane driven Haber Bosch process. The full benefit of the emissions reduction in the steam methane reform process are not met due to the transfer of waste heat and steam to the Haber Bosch plant. Based on the analysis of Smith et al (Smith, Hill and Torrente-Murciano, 2020), the residual emissions will be of the order of 0.22 tonnes per tonne of ammonia with the loss of energy transfer offset by reduced purges with higher purity hydrogen and the increased delivery pressure from PEM electrolysers.

The input energy for the Haber Bosch process can also be delivered by electricity. Thyssenkrupp has developed 100% electric ammonia plants resulting in near zero direct emissions if operated with renewable electricity(Thyssenkrupp, 2019). Electricity use is 9.6MWh per tonne based on the largest capacity 300 tonne per day facility with 120MW input power. This design is the basis for the Port Lincoln Ammonia Supply Chain Demonstrator in South Australia.

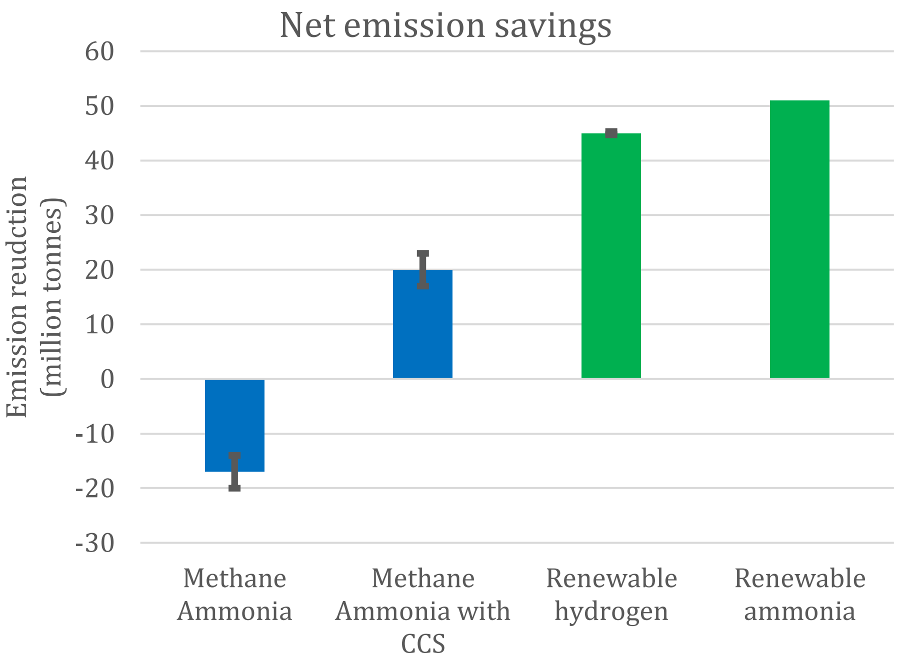

Figure 1. Net emissions savings from 20% co-combustion of ammonia in Japanese coal fleet with different sources of ammonia. Error bars represent the variation due to the 10-20% range for natural gas fugitive emissions.

Policy implications

The completed work will present the policy implications for the choice of ammonia source. Standard greenhouse accounting practices provides no incentives for Japan to choose to use “green” ammonia rather than “blue” despite the significant difference in net global emissions as shown in Figure 1.

In theory, efficient global market mechanisms for carbon pricing and reduction targets should make this question unimportant as production countries should price the cost of emission reductions into the ammonia production. However, the lack of carbon pricing in most regions of the world and other regional incentives could result in choices that results in increased emissions.

We will explore

- Incentives in Japan to use low emission ammonia
- Potential for bilateral arrangements
- Direct Japanese investment in production facilities
- Ammonia certification

and the likely effects on the supply choice

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