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# JERA and Japan seek costly and dirty alternative to RE: Lengthening the lifeline of coal power in Japan

## Executive Summary

- Japan's Green Growth Strategy released December 2020 set the pathway for Japan to test co-firing ammonia in coal power plants in 2021 and increase its use from 2030. Jera, a joint venture between Chubu electric and TEPCO, plans to start a pilot programme to use ammonia as a fuel with coal in mixed combustion at its Hekinan thermal power station in central Japan by 2030 and hopes to achieve 20% use of ammonia at all its coal-fired power plants by 2035.

- Ammonia co-firing is in its infancy currently with 20% fuel mix (calorific value) only recently reached. Several issues regarding ammonia combustion exist, including its low flammability, high NOx emission, and low radiation intensity. 100% ammonia-firing is currently unproven on commercial scale.

- This analysis suggests green ammonia will not be able to compete on cost with fossil based ammonia by 2050 without significant policy and regulatory changes. Fossil based ammonia with CCS/CCU, marketed as "blue"ammonia cannot be considered carbon neutral as EOR technology only furthers the use of fossil fuels and the life-cycle of carbon used via utilisation can not be adequately assessed.

- We find that mid-level fuel costs will increase Jera's thermal coal power plants fuel bill to $2,680 billion per year without CCS (brown ammonia) and $3,034 billion per year with CCS (blue ammonia). An absolute increase of $1,207 billion and $1,561 billion per year respectively.

- We calculate that the introduction of ammonia into the fuel increases the LCOE to $98/MWh without CCS and $106/MWh with CCS, up from a Japan mid level average LCOE of $73 in USC coal power plants. This is in contrast to the latest solar auction producing a winning bid low under

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$100/MWh and set to decrease further and the government targeted offshore wind price of $62-74/MWh by 2030-2035.

- Our analysis suggests that a likely average carbon tax on thermal coal of $99/tCO2 would be needed for brown ammonia co-firing and $122/tCO2 with blue ammonia to be cost competitive with a 100% coal fired power plant. Potentially condemning Jera's coal fleet plans.

- Greenpeace Japan does not consider ammonia co-firing anything but a technology and process for extending the life of coal fired power plants. It is experimental, in its technological infancy and nothing but expensive greenwash.

- In the context of Japan's hydrogen aspirations, we view fossil based ammonia as another fig leaf or delaying tactic for the fossil fuel industry. It does nothing to establish a green hydrogen supply chain that is decarbonised from upstream production through to downstream applications.

- Ammonia's introduction into Japan's energy sector though should be viewed as a bailout to thermal coal based corporations and turbine manufacturers. For cheap, decarbonised electricity in Japan and abroad the future is clear and proven; wind and solar.

1. Introduction

Japan's Green Growth Strategy released December 2020 set the pathway for Japan to test co-firing ammonia in coal power plants in 2021 and increase its use from 2030. Ammonia, made from nitrogen and hydrogen burns without releasing carbon dioxide ($CO_2$).

Japan, as one of the world's biggest proponents of coal, is making seismic waves globally with its new energy policy proposals and strategies. Whether these are implemented, translate into a new Basic Energy Plan and most importantly equip Japanese society with the tools and direction for decarbonisation is still yet to be seen.

From the government's own analysis, if Japan mixed 20% Ammonia into all its coal power plants, it would need up to 20 million tons of ammonia per year. This is equivalent to roughly one-tenth of today's global ammonia market. Japan is set to rely heavily on imports, benefitting producers in Australia, North America and the Middle East.[1] In late 2020, a 40 ton shipment of "blue" ($CO_2$ captured and stored or utilised) ammonia was shipped by Saudi Aramco. Importing vast quantities of energy into Japan is not novel as the country has no fossil fuel reserves. Japan has specific interests in developing new energy strategies as they seek to become carbon neutral by 2050.

Ammonia is the second most produced chemical on the planet with the majority of production going to the global agricultural industry. Approximately 88% of ammonia made annually is consumed in the manufacturing of fertilizer. Most of the remainder goes into the production of formaldehyde.[2] The production of ammonia currently consumes about 1.8-3.0% of all global energy (most of which is fossil fuel based).[3] Ammonia production requires hydrogen as a feedstock, usually provided in the form of fossil gas and produced via a steam methane reforming process or coal via a gasification process. In 2019, ammonia represented nearly 43% of global hydrogen production with China the largest producer followed by India and Russia.[4]

2. Ammonia production

   a. SMR (Steam methane reforming)

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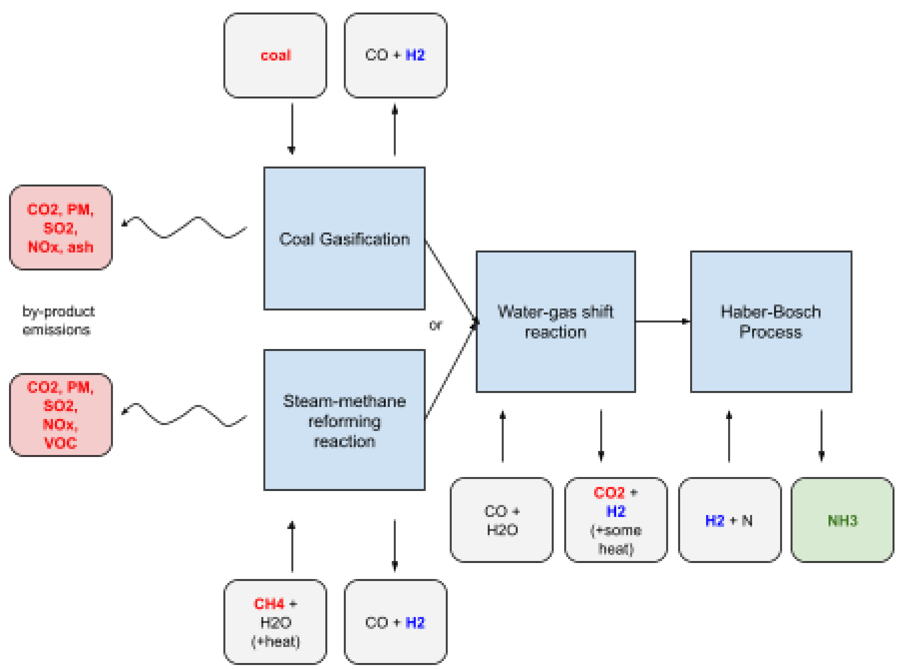
[1] https://www.spglobal.com/platts/en/market-insights/latest-news/coal/010821-interview-japan-eyes-middle-east-australia-and-n-america-for-ammonia-supply-chain

[2] https://www.aiche.org/resources/publications/cep/2016/september/introduction-ammonia-production

[3] Valera-Medina, A., Xiao, H., Owen-Jones, M., David, W. and Bowen, P., 2018. Ammonia for power. *Progress in Energy and Combustion Science*, 69, pp.63-102.

[4] https://www.iea.org/reports/the-future-of-hydrogen

Production of ammonia is almost entirely reliant on fossil fuels which are used for their high concentrations of hydrogen atoms. Steam methane reforming (SMR) is a method used in industry to produce hydrogen and is also commonly used in the production of ammonia. The SMR process can be explained in 2 steps. The first step is the steam-methane reforming reaction. This reaction requires methane ($CH_4$), which is typically sourced from natural gas, and high temperature steam (700-1000 degrees C). The methane and steam react to form hydrogen ($H_2$) and carbon monoxide (CO). The second step, or the water-gas shift reaction, then allows carbon monoxide to react further with steam to produce carbon dioxide ($CO_2$) and more pure hydrogen.[5] The carbon dioxide is either used for urea production and is exported as a co-product, captured, or is vented into the atmosphere.[6] In the case of ammonia production, the hydrogen can then react with nitrogen. The Haber-Bosch process is most commonly used to produce ammonia. It uses hydrogen from steam-methane reforming and nitrogen from the air. The Haber-Bosch process utilizes a mostly iron catalyst and an extremely high pressure and moderately high temperature environment to synthesize ammonia. The Haber-Bosch process consumes 3% to 5% of all natural gas produced in the world as well as 1% to 2% of the world's energy supply.[7]




[5] https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming
[6] http://www.iipinetwork.org/wp-content/Ietd/content/steam-reforming.html
[7] https://www.u-tokyo.ac.jp/focus/en/press/z0508_00041.html

b. Coal gasification

Coal gasification (CG)[8] is a process that can also be used to produce hydrogen and carbon monoxide (syn-gas). Gasification occurs in an enclosed vessel with high pressure and temperature. Within the "gasifier", the oxygen in air and steam are in direct contact with the coal allowing the conversion of the material to syn-gas. From this point, similar to SMR, the hydrogen and carbon monoxide can be converted to carbon dioxide and pure hydrogen via the water-gas shift reaction. When comparing CG and SMR processes for the goal of hydrogen production, CG is more costly and less efficient with production concentrated in China. Thus, SMR is the more commonly used process for ammonia production.[9]

c. The emissions of SMR

The SMR process emits a considerable amount of greenhouse gases. On average, there are 9 kg of $CO_2$ emissions per kg of $H_2$ produced via SMR.[10] Additionally, SMR also contributes to the emissions of several criteria air pollutants, such as VOCs (Volatile Organic Compounds), CO, NOx, $SO_2$, $PM_{10}$, and $PM_{2.5}$.[11] VOCs include a wide range of chemicals that can cause mild to severe health problems such as respiratory problems. NOx includes another group of pollutants that increases risk of respiratory problems. Additionally, NOx contributes to the formation of particulate matter and ground level ozone, which both cause adverse health effects. Similarly $SO_2$ is a pollutant that causes respiratory problems, specifically with the elderly. Particulate matter, $PM_{10}$ and $PM_{2.5}$, are liquid and solid particles that are suspended in the air. PM causes adverse health effects, specifically, $PM_{2.5}$ can get permanently deposited into the deep lung causing severe health complications.

d. Green ammonia?

Green ammonia refers to ammonia that is synthesized without any $CO_2$ emissions. For example, green ammonia could be produced if the Haber-Bosch process relied on renewable energies instead of from natural gas or coal. While there are not currently any large-scale green ammonia plants today, there are several pilot models being developed.[12] Current "low-carbon" ammonia production is considered "blue ammonia", as it generates carbon dioxide but

[8] The coal gasification process of ammonia production is mainly centralised in China for domestic consumption.

[9] https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/technologies-hydrogen

[10] https://greet.es.anl.gov/publication-smr_h2_2019#:~:text=The%20median%20CO2%20emission%20normalized,Rutkowski%20et%20al%20(2012).

[11] Sun, P., Young, B., Elgowainy, A., Lu, Z., Wang, M., Morelli, B. and Hawkins, T., 2019. Criteria Air Pollutants and Greenhouse Gas Emissions from Hydrogen Production in U.S. Steam Methane Reforming Facilities. *Environmental Science & Technology*, 53(12), pp.7103-7113.

[12] https://www.argusmedia.com/en/blog/2020/may/28/green-ammonia-opportunity-knocks

carbon capture technology can be used so it does not get released into the atmosphere.

e. Key drivers on ammonia price

Scale is the biggest determinant on capital costs with larger ammonia ammonia plants being more cost competitive than smaller ones. Any further development of ammonia plants will thus likely be large centralised plants, a continuation of the mature and developed supply chain and logistical infrastructure for ammonia trade. Pricing is most obviously impacted by the underlying energy price change, coal and gas. A mature technology, price volatility is driven by feedstock, the bulk of operating costs.

To produce green ammonia steady supply of renewable electricity is a crucial step in providing electrolysers with the energy requirements to operate. Large scale plants are more cost competitive thus large scale renewable energy supplies are needed. The reality is that renewable energy facilities rarely reach the capacity required to support a standard Haber-Bosch ammonia plant, although the increasing development of large scale RE “mega-projects” could change this. Additionally, drastic decreases in the cost of electricity would be required to reduce the costs of green ammonia.
The harsh reality is that most of the recent ammonia plants were built on the back of extremely competitive gas prices, which in most cases were lower than $3/mmBtu, which implies an ammonia cash cost (t) far lower than even $1/kg hydrogen can achieve.[13] This is perhaps best reflected in the government's own expectation that only 14% of hydrogen Japan uses in 2030 would be made without emitting $CO_2$.

3. Storage and Freight

Ammonia is usually transported in one of two forms, anhydrous ammonia or diluted ammonia. Anhydrous ammonia is pure ammonia and contains no water. Due to the low boiling point of ammonia, in this form, it must be stored at high pressure or low temperatures. The diluted form of ammonia, which typically ranges from 5 to 30 weight percent ammonia in water (depending on its use), is slightly safer and easier to transport. As ammonia is toxic, transportation in its diluted form is a safer approach, however, currently, both forms are being traded on the market depending on the use (anhydrous ammonia is often required for fertilizers and dilute ammonia or ammonium hydroxide is used in commercial household products).[14] Excitement around ammonia as an alternative to direct use of hydrogen is based on it not containing carbon and production from any energy resource. Additionally, ammonia storage for

[13] https://view.argusmedia.com/rs/584-BUW-606/images/Argus%20White%20Paper%20-%20Green%20Ammonia.pdf
[14] https://cargohandbook.com/Ammonia_(anhydrous)

hydrogen energy has an incredibly low cost per unit of stored energy, relative to the current competition. The volumetric energy density of liquid ammonia is higher than that of liquid hydrogen, making it more financially attractive to store. The NH3 fuel association found that 182 days of ammonia storage would cost 0,54US$/kg-$H_2$ compared with the 14,95US$/kg-$H_2$ that is required to store pure hydrogen.[15] Relative to hydrogen, ammonia is safer to store as it has a smaller flammable range.[16] Lastly, as much of the infrastructure for ammonia storage has already been developed, there would not be as much cost to scaling up ammonia production. In addition, ammonia storage is very similar to that of propane, another widely produced and transported chemical, thus, the capital requirements of ammonia storage is not a huge barrier.

Ammonia is already transported worldwide. It is the second most widely produced commodity chemical in the world with already more than 180 million tons being transported in 2018[17]. The distribution system for ammonia is well established. Ammonia is typically shipped from its production plant to other industry locations where it can be further processed. There are over 150 maritime ammonia terminals throughout the world and, additional to that, there are many domestic terminals reached by inland waterways, pipelines, or by rail.[18] In 2019, the biggest exporters of ammonia were Saudi Arabia (36%), Russia (24%), and Indonesia (9,84%) and the biggest importers of ammonia were India (14,4%), USA (13,7%), and Korea (7,44%).[19]

4. Creating electricity from ammonia

    a. Current usage of ammonia in CFPPs

Co-firing coal power plants has been long established with the use of biomass and in its simplest terms merely refers to the burning of two or more fuels to generate electricity. The government based new energy and industrial technology organization (NEDO) has been developing a feasibility study on the co-firing of ammonia in commercial coal power plants in cooperation with JERA, IHI and Marubeni Corp with the aim of popularising 20% ammonia co-firing in thermal power plants. [20] [21] Additional achievements include Chugoku energy's 1% ammonia mix (LHV) in a 120MW coal power plant.

[15] https://nh3fuelassociation.org/2018/12/07/ammonia-hydrogen-power-for-combustion-engines/
[16] Kobayashi, H., Hayakawa, A., Somarathne, K. and Okafor, E., 2019. Science and technology of ammonia combustion. *Proceedings of the Combustion Institute*, 37(1), pp.109-133.
[17] Valera-Medina, A., Xiao, H., Owen-Jones, M., David, W.I.F. and Bowen, P.J., 2018. Ammonia for power. *Progress in Energy and combustion science*, *69*, pp.63-102.
[18] Hignett T.P. (1985) Transportation and Storage of Ammonia. In: Hignett T.P. (eds) Fertilizer Manual. Developments in Plant and Soil Sciences, vol 15. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-1538-6_7
[19] https://trendeconomy.com/data/commodity_h2/281410#:~:text=In%202019%2C%20the%20world%20imports,trade%20statistics%20of%20126%20countries).
[20] https://www.ihi.co.jp/en/all_news/2019/resources_energy_environment/2020-3-27/index.html
[21] http://energy.mit.edu/wp-content/uploads/2019/06/2019-MIT-Energy-Initiative-Spring-Symposium-Presentation-Takamasa-Ito.pdf

b. Ammonia combustion & emissions

As mentioned earlier, ammonia combustion is a carbon-free process, which is the main reason why it is such a desirable energy source. However, there are still several issues regarding ammonia combustion, including its low flammability, high NOx emission, and low radiation intensity. The flammability range is quite narrow and the ignition temperature is high causing the low flammability of ammonia. This is an issue as it will be more energy intensive to ignite ammonia combustion. However, current solutions utilizing catalysts are being investigated. In regard to the concern about NOx emissions, it is important to note that NOx is not a part of the final products of ammonia combustion, instead it is only $N_2$ and $H_2$. Additionally, the Central Research Institute of Electric Power Industry investigated the impact on potential NOx emissions when ammonia was added to a co-fired coal combustion furnace. CRIEPI reports that the NOx emissions were comparable from the values recorded for coal combustion without the addition of ammonia.[22]

5. JERA Case Study

a. What is JERA's aim?

In 2020, Japanese utility giant JERA[23] announced the phasing out of its inefficient[24] thermal coal power plants whilst seeking to gradually switch existing and planned ultra super critical (USC) thermal coal power plants to ammonia and hydrogen fired power plants. Key dates for this analysis include aims for a 20% ammonia mix by 2035.

JERA's ammonia plans stem from a collaboration with fellow Japanese giants IHI Corp. and Marubeni Corp. It plans to start a pilot programme to use ammonia as a fuel with coal in mixed combustion at its Hekinan thermal power station in central Japan by 2030 and hopes to achieve 20% use of ammonia at all its coal-fired power plants by 2035. The companies launched a feasibility study with Japan's New Energy and Industrial Technology Development Organization (NEDO) launched in March 2020.

b. Ammonia requirements 2030-2035

Although Jera has pledged to phase out their inefficient thermal coal units we estimate an overall minor decrease of thermal coal capacity by 2035 due to planned and under construction power plants. Currently, Jera has 7,95GW of thermal coal power plant (CFPP) capacity and will likely have 7,7GW by 2035.

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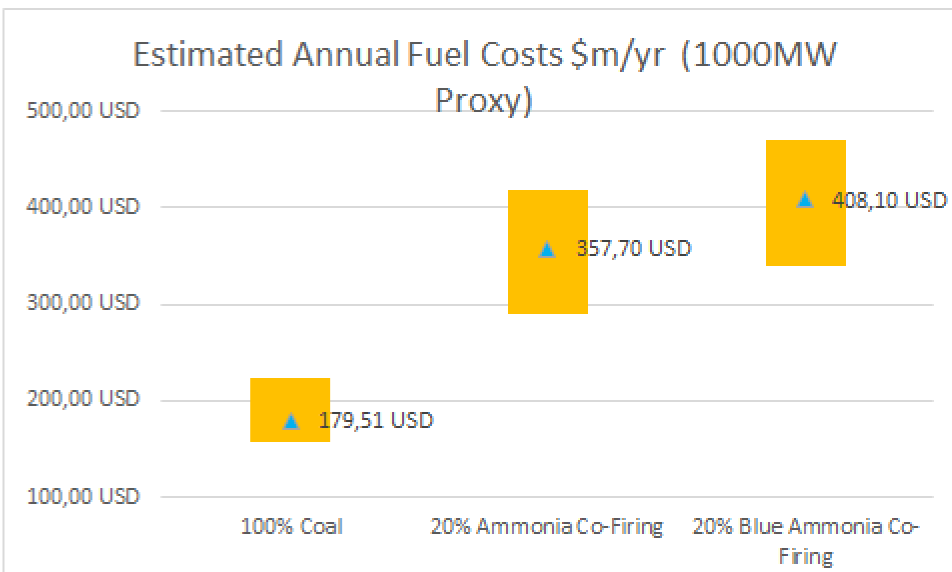
[22] Kobayashi, H., Hayakawa, A., Somarathne, K. and Okafor, E., 2019. Science and technology of ammonia combustion. *Proceedings of the Combustion Institute*, 37(1), pp.109-133.
[23] Jera is the thermal energy based joint venture between TEPCO and Chubu Electric
[24] Super-Critical

Current global ammonia is about 180 million tons[25] with Japanese government calculations assuming imports of over 10% of global ammonia production to reach 20% ammonia fuel mix in coal power plants. The government is also keen to import ammonia produced using CSS and CCU technologies (blue ammonia) in a bid to boost environmental credentials. Greenpeace Japan estimates that if Jera and the Japanese government is to achieve its aim of 20%(LHV) ammonia co-firing then approximately 512,000 tons/GW will be required annually. For JERA's thermal coal fleet this amounts to 3,9 million tons annually.

i. Fuel Cost

We expect that adding 20% ammonia into the calorific base (LHV) of a coal power plant will increase mid-level fuel costs by 99% or $178 million per year without the added costs of CCS (brown ammonia) and by 127% or $229 million per year with CCS (blue ammonia). Incorporated into Jera's thermal coal power plants portfolio, this equates to $2,75 billion per year with brown ammonia and $3.12 billion per year with blue ammonia with an absolute increase of $1,37 billion and $1,74 billion per year respectively compared to a 100% coal power plant.

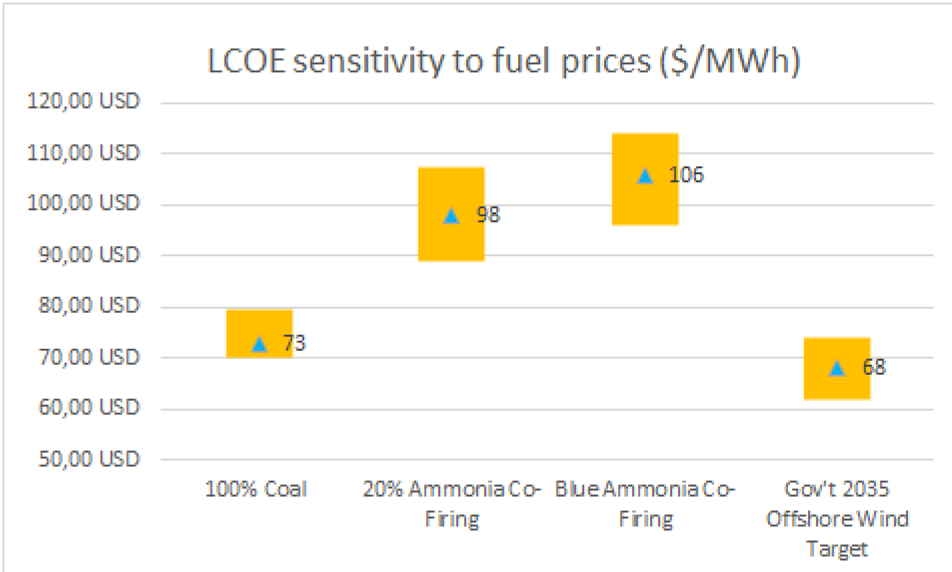



ii. LCOE

At the bottom line, the levelized cost of electricity is dramatically affected through the increase in fuel cost. Greenpeace estimates that a USC coal power plant in Japan has an mid level LCOE of $73/MWh. The introduction of ammonia

[25] Kobayashi, H., Hayakawa, A., Somarathne, K.K.A. and Okafor, E.C., 2019. Science and technology of ammonia combustion. *Proceedings of the Combustion Institute*, *37*(1), pp.109-133.

into the fuel increases this to $98/MWh with brown ammonia and $106/MWh with blue ammonia.



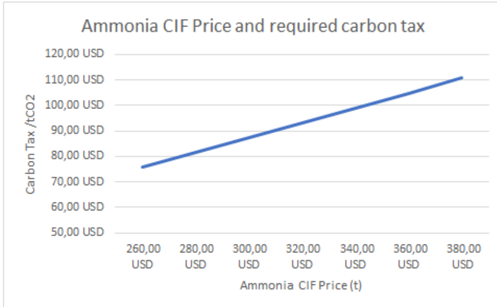

With the government's targeted offshore wind price of $62-74/MWh by 2030-2035 it is impossible to ignore the assumed outlook where considerably cheaper forms of electricity are available in 2030-2035. The cost of RE in Japan has been dropping substantially in recent years with the latest solar auction producing a minimum winning bid below $100/MWh. [26,27]

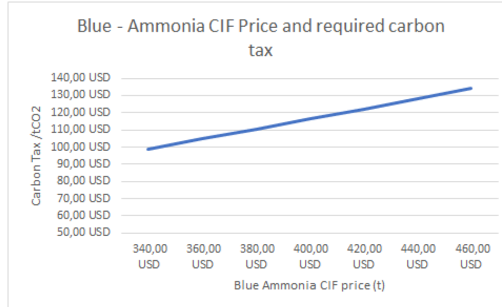
iii. Carbon Tax

Our analysis suggests that a likely average carbon tax on thermal coal of $99/tCO2 would be needed for brown ammonia co-firing and $122/tCO2 with blue ammonia to be cost competitive with a 100% coal fired power plant. Potentially leaving JERA's plans in the balance.

Our analysis on the price of ammonia and the corresponding carbon tax reflects the volatility large importers are likely to face in the future.

[26] https://nyusatsu.teitanso.or.jp/servlet/servlet.FileDownload?file=00P7F00000SWPgr
[27] $1 = Y105.23






It is highly unlikely such a tax would be introduced and there seems to be little appetite outside of the Ministry of Environment[28]. Indeed taxes levied on coal whilst importing blue ammonia would rival the world's highest in Sweden.
It is thus more likely operational expenses are simply subsidised in the form of a feed-in-tariff, introduced on co-firing as was historically available with biomass / coal co-firing. This attractive FiT for coal + biomass generators saw utilities take advantage, recently removed as officials seek to drive down biomass co-firing LCOE. It is not inconceivable that utilities are gearing up to take advantage of a similarly subsidised fuel.

c. What are the emissions reductions?

A beneficial decrease of 20% GHG emissions is the result of co-firing with ammonia as noted by the government.[29] This however ignores the lengthened lifetime toxic coal-fired power plants will enjoy and the polluting process of ammonia production.

The recent 40 ton shipment of blue ammonia from Aramco used CCS and CCU techniques. Approximately 20 tons of CO2 was used for EOR (enhanced oil recovery) and 30 tons used in the manufacture of methanol.[30] EOR or tertiary recovery is the process by which gas or steam are pumped into an oil reservoir to retrieve oil that cannot be recovered using conventional techniques. $CO_2$ captured from the SMR process can be utilised in this process and are marketed as a carbon capture storage technique. However, such activities do not lower overall $CO_2$ emissions and contradict the need to keep the majority of remaining fossil fuel reserves in the ground. Furthermore, enhanced oil recovery can have retention rates of below 30%.[31] For these reasons we do not and cannot consider this process as a viable climate mitigation technology or strategy.

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[28] https://mainichi.jp/articles/20210130/k00/00m/040/122000c
[29] https://www.meti.go.jp/press/2020/12/20201225012/20201225012-2.pdf
[30] https://www.ammoniaenergy.org/articles/saudi-arabia-ships-low-carbon-ammonia-to-japan/
[31] Olea, R.A., 2015. CO2 retention values in enhanced oil recovery. *Journal of Petroleum Science and Engineering*, *129*, pp.23-28.

Methanol ($CH_3OH$) is used in various industries as it can be used as a solvent, antifreeze, fuel source, etc. The largest use of methanol is for the manufacture of other chemicals, namely formaldehyde making up roughly 40% of all methanol use so that it can then be made into other products, such as plastics, plywoods, paints, etc. Methanol is also often used as a fuel source or in combination with other fuel sources. For example, the European Fuel Quality Directive allows up to 3% methanol to be blended with gasoline. Additionally, China uses more than 1 million gallons of methanol per year as a transportation fuel in low and high level blends to accommodate different vehicles.[32] It is precisely the variety and scale of different applications of methanol that make it near impossible to reliably consider the $CO_2$ utilised from the SMR process properly sequestered. Without a full, traceable life cycle analysis of CO2 utilised we cannot consider CCU a climate mitigation technique.

6. GPEA Japan position

Greenpeace Japan views the government's pursuit of ammonia based power generation as wasteful, dirty and a bailout to Japanese utilities struggling coal assets. The global ammonia supply chain is based on fossil gas and will stay that way long beyond Japan's net zero aims. Production coupled with CCS or CCU either, at a minimum does not reduce net $CO_2$ emissions, or, the life cycle of carbon utilised in methanol production cannot be sufficiently tracked to deem it a viable tool for carbon dioxide emission reductions. Furthermore, particulate emissions from ammonia production and combustion, particularly nitrous oxides are harmful to human health and it has not been adequately assessed in duel-fuel use to mitigate these issues.

It is impossible to reasonably consider ammonia co-firing anything but a technology and process for extending the life of coal. Japan has long been a global outlier with its position on coal based electricity and this does nothing but hinder net-zero aims. Perhaps even more cynically, Japanese corporations have begun to profess this dirty and expensive technology abroad including for the internationally condemned Vung Ang 2 coal-fired power plant in Vietnam. [33]

Ammonia is a chemical with wide ranging viable uses going forward into a decarbonised future. Its use in Japan's energy sector though should be viewed as nothing more than a bailout to thermal coal based corporations and turbine manufacturers. For cheap, decarbonised electricity in Japan and abroad the future is clear; wind and solar.

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[32] https://thechemco.com/chemical/methanol/#:~:text=Its%20principal%20uses%20are%20in,produce%20biodiesel%20via%20transesterification%20reaction.

[33] https://asia.nikkei.com/Spotlight/Environment/Climate-Change/Greta-Thunberg-joins-Asian-charge-against-Vietnam-coal-plant

Notes:

- *Volatility in this analysis is expressed as a year*
- *Ammonia prices are based on the Middle East Spot price*
- *Coal prices are based on the Ministry of Finance Coal Cocktail price*
- *Mid-level operational and capital expenditures are used in LCOE calculations and power plants proxies. Fuel it the only variable.*
- *All prices are $USD 2020 real*
- *Shipping and distribution costs are based on IAE's and JGC Corp Cost Evaluation Study on Low Carbon Ammonia and Coal Co-Fired Power Generation*[34]
- *CCS costs are based on $50/tCO_2$ in UAE*[27] *, we base total CCS cost on the assumption that all $CO_2$ is captured.*
- *9kg of CO2/kgH2 from SMR and 2.237/kg$CO_2$ per coal/kg is assumed.*

Lead author: Alastair Jackson
Contributing author: Elli Newman

Greenpeace Japan
8-13 11 NF Bldg, 2 F, Nishi-Shinjuku
Shinjuku, Tokyo 160-0023
Tel: 81-3-5338-9800

www.greenpeace.org/japan

[34] https://nh3fuelassociation.org/wp-content/uploads/2018/12/0830-Cost-Evaluation-Study-on-Low-Carbon-NH3_JGC-IAE.pdf